National Park Service
U.S. Department of the Interior

Natural Resource Stewardship and Science

Lassen Volcanic National Park

Natural Resource Condition Assessment

Natural Resource Report NPS/NRSS/WRD/NRR—20132/725

ON THE COVER
Lassen Volcanic National Park
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Lassen Volcanic National Park

Natural Resource Condition Assessment

Natural Resource Report NPS/NRSS/WRD/NRR—20132/725

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This report was prepared under Task Agreement J8W07100032 (Cooperative Agreement H8W07060001) between the National Park Service and Southern Oregon University.

November 2013

U.S. Department of the Interior
National Park Service
Natural Resource Stewardship and Science
Fort Collins, Colorado

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Please cite this publication as:

Adamus, P. R., D. C. Odion, G. V. Jones, L. C. Groshong, and R. Reid. 2013. Lassen Volcanic National Park Natural Resource Condition Assessment. Natural Resource Report NPS/NRSS/WRD/NRR—20132/725. National Park Service, Fort Collins, Colorado.

NPS 111/122753, November 2013

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Executive Summary

We compiled existing data and information to characterize the condition and trends in priority natural resources in Lassen Volcanic National Park. 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 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 six natural resource themes considered by this park's managers and scientists to be most important. They are:

- Precipitation, Snowpack, and Water Availability
- Surface Waters and Their Resources
- Terrestrial Vegetation
- Wildlife
- Air Quality
- Natural Quality of the Park Experience

We identified 23 indicators to evaluate these six 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 23 indicators, we determined that the condition of three indicators is of "Significant Concern" in this park. Those are: the distribution of forest stand ages, deposition of airborne contaminants, and ozone damage to vegetation. There is little that park managers can do to control the latter two. 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.With regard to the distribution of forest stand ages, 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.

We assigned a rating of "Somewhat Concerning" to eight indicators:

- Recovery of human-disturbed areas
- Diversity of native aquatic species
- Distributions of major vegetation types
- Extent of invasive plant species
- Extent of exotic pathogens
- Visibility
- Timing and rate of spring snow melt and discharge in springs and streams
- Maximum annual depth and volume of snowpack by location

Park managers have limited capacity to influence the condition of the last four. 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.

The condition of a plurality of the indicators (10) was rated "Good." However, information was insufficient to rate the present condition or trends of four very important indicators:

- Maximum annual extent, depth, and volume of snowpack
- Timing and rate of spring melt and discharge in springs and streams
- Perennial stream extent, seasonal flow volume, wetted width
- Water bodies with ecologically harmful species

Information sufficient to estimate *trends* was lacking for 12 of the 23 indicators, and none were considered to have a high degree of certainty.

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 excellent input at several points during preparation of this assessment, from Lassen Volcanic National Park we thank Jennifer Carpenter (Chief of Resource Management), Louise Johnson (formerly, Chief of Resource Management), Nancy Nordensten (formerly, Resource Management Specialist), Janet Coles (Plant Ecologist), and Mike Magnuson (Wildlife Biologist). Overall guidance was provided by the NPS Project Managers—initially David Larson from Lava Beds National Monument, succeeded by Mac Brock of 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. xv) 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), focuses on these questions as they pertain to Lassen Volcanic National Park.

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] and State of the Park Report, 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]

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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

- identify or develop reference conditions/values for comparison against current conditions;[4]
- 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.

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[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").

[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.

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 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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[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.

[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

Lassen Volcanic National Park ("the park") is located in northeastern California in portions of Lassen, Plumas, Shasta, and Tehama counties and is roughly 50 miles east of both Red Bluff and Redding, California (Figures 1, 2). The park encompasses 106,372 acres and is almost completely surrounded by Lassen National Forest. The park was established by an Act of Congress on August 9, 1916, to provide recreational opportunities for the public and to preserve its natural wonders and resources. In 1972, Congress designated 75 percent of the park (78,982 acres) as the Lassen Volcanic Wilderness. The park is a high elevation island with elevations ranging from 5,250 to 10,457 feet, while only a few isolated peaks in the surrounding area rise above 6,000 feet. Topography within the park varies greatly with rugged, volcanic mountain peaks in the western section; a lava plateau in the east; deep glaciated valleys and several geothermal features in the south; and peaks and ridges of lava modified by erosion in the north.

The park is an outstanding example of a dynamic geologic landscape. Lassen Peak is the southernmost active volcano in the Cascade Mountain Range and erupted intermittently between 1914 and 1921. The park is unique in that it preserves examples of all four types of volcanoes recognized by geologists: shield, composite, plug dome, and cinder cone volcanoes. Lassen Peak is one of the largest plug dome volcanoes in the world. Also within the park is the most extensive, intact network of geothermal resources west of Yellowstone National Park, including examples of boiling springs, mudpots, and fumaroles. The numbers and variety of small ponds and wetlands are also exceptional for northern California.

Park soils are generally rocky, shallow, rapidly drained, and strongly acidic. They are almost exclusively volcanic in origin. Soil depths vary from several feet in some lower elevation meadows to thin or nonexistent on the higher elevations.

Four general vegetation types cover most of the park from lower to higher elevations: yellow pine forests, red fir forests, subalpine forests dominated by whitebark pine and mountain hemlock, and alpine fell fields. Patches of montane chaparral dominated by greenleaf manzanita (*Arctostaphylos patula*), snowbrush ceanothus (*Ceanothus cordulatus*), or pinemat manzanita (*Arctostaphylos nevadensis*) cover approximately 10% of the park. Most of these shrub fields became established after high intensity fires and are gradually being recolonized by conifers. Willow, alder, and meadow vegetation grow along many of the streams and aspen is found in several moist riparian zones and upland habitats. A large area of the park is rocky and relatively devoid of vegetation.

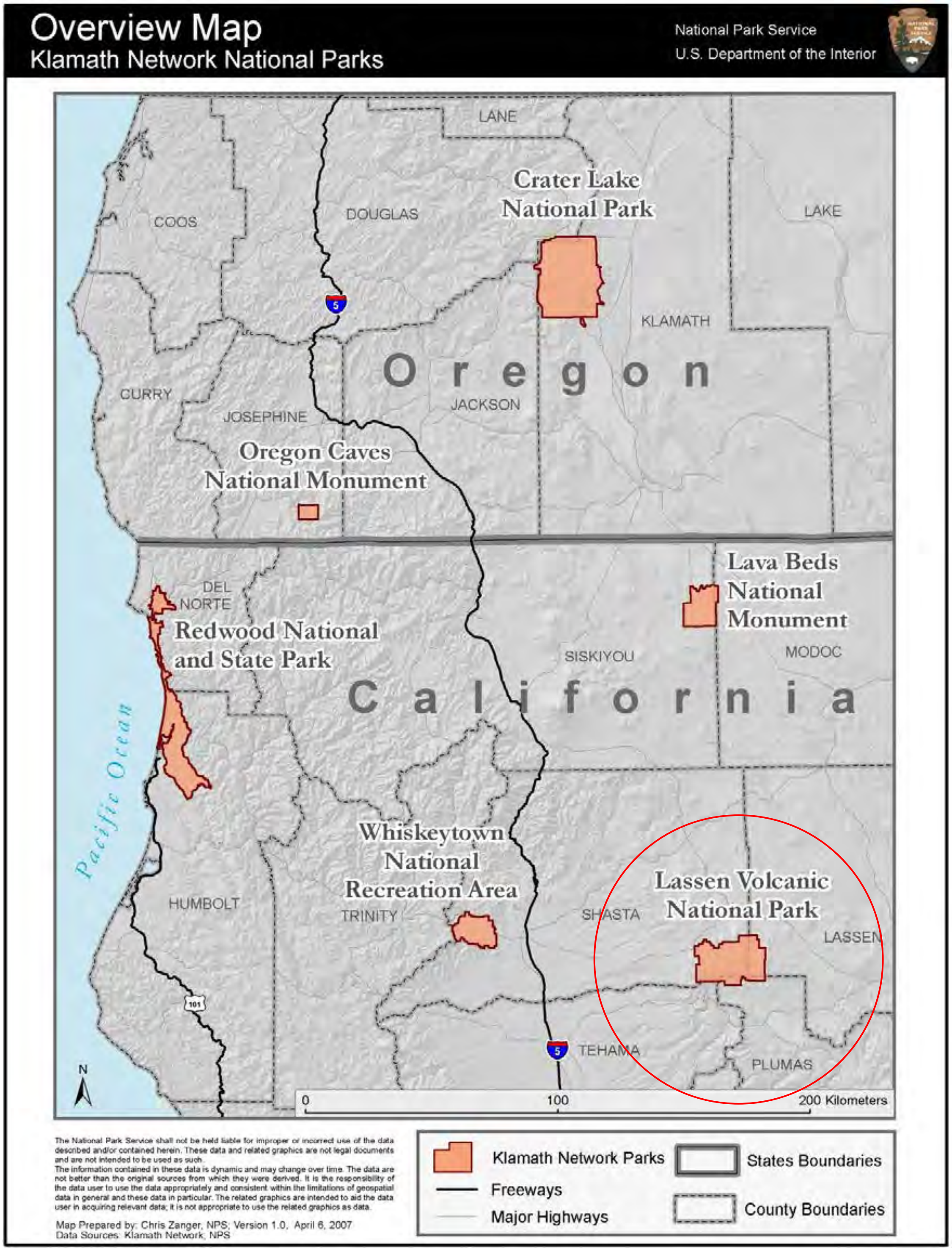

Figure 1. Location map for Lassen Volcanic National Park

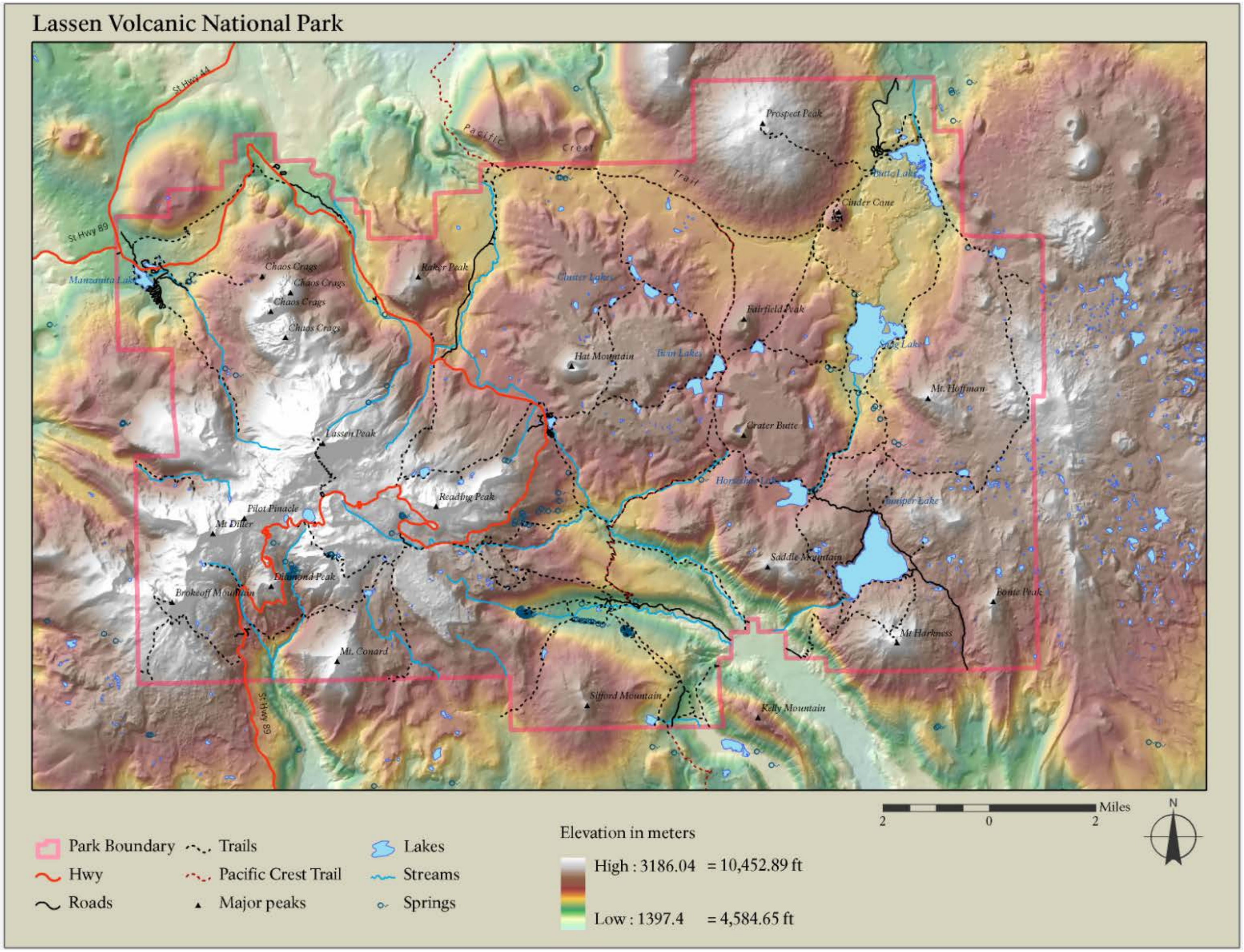

Figure 2. Base map for Lassen Volcanic National Park.

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. Dr. Adamus served as report editor as well as writing all sections except section 2.3 which addresses vegetation and fire regime. That section was prepared by Dennis Odion, vegetation ecologist, Southern Oregon University. A supporting analysis of changes in vegetation distribution based on historical maps was done by Dr. James Thorne of the University of California, Davis. 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 Framework and Information Gathering

This assessment is one of three NRCAs prepared under a single agreement with Southern Oregon University. The others pertain to Lava Beds National Monument (LABE) 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 Lava Beds 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. Then the team traveled to Lassen and sought information from several scientists there.

Natural resource issues in the park had recently been prioritized by the park's staff, using a structured input process, and that was a great help in focusing our efforts. In no particular order, the 15 "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:

- Lakes and streams
- Wetlands and riparian areas
- Groundwater flow
- Geologic and geothermal resources
- Fire regimes

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

- Fire suppression and fuels management
- Invasive species (plants)
- Phenological cycles
- Solitude and silence
- Dark night sky
- Recreation
- Wilderness
- Deposition of airborne contaminants
- Moisture and climate cycles
- Global warming

More specifically, the issues mentioned as being of greatest concern in Lassen were:

- Climate change and its impacts on high elevation ecosystems
- Changes in the timing and extent of snowpack
- Condition of primary lake areas (e.g., Summit and Manzanita)
- Overall condition of high elevation meadow and riparian systems
- Effects of atmospheric deposition on park ecosystems
- Condition of forest health and function

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. Lassen's 1999 Resource Management Plan (NPS 1999) provided useful background information, as did, to a lesser degree, the "State of the Park Report" (NPCA 2009) and the General Management Plan (NPS 2003).

The task of identifying documents important to understanding these issues 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 related to Lassen, as well as relevant documents pertaining to the regions surrounding the park, searching with phrases such as "Southern Cascades," "northern Sierra Nevada," "Lassen National Forest," "Lassen County," and "Caribou Wilderness." We obtained complete digital copies (PDFs) of all available publications that reported relevant research results from the park and the surrounding region. We then indexed the 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 and park staff.

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. 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 within the park. Watersheds (Figure 3) were used as the “analysis units.” The four major watersheds that the park intersects are:

- Battle Creek Watershed
- Lower Pit-Honey Eagle Lakes Watershed
- North Fork Feather Watershed
- Thomas Creek-Sacramento River Watershed

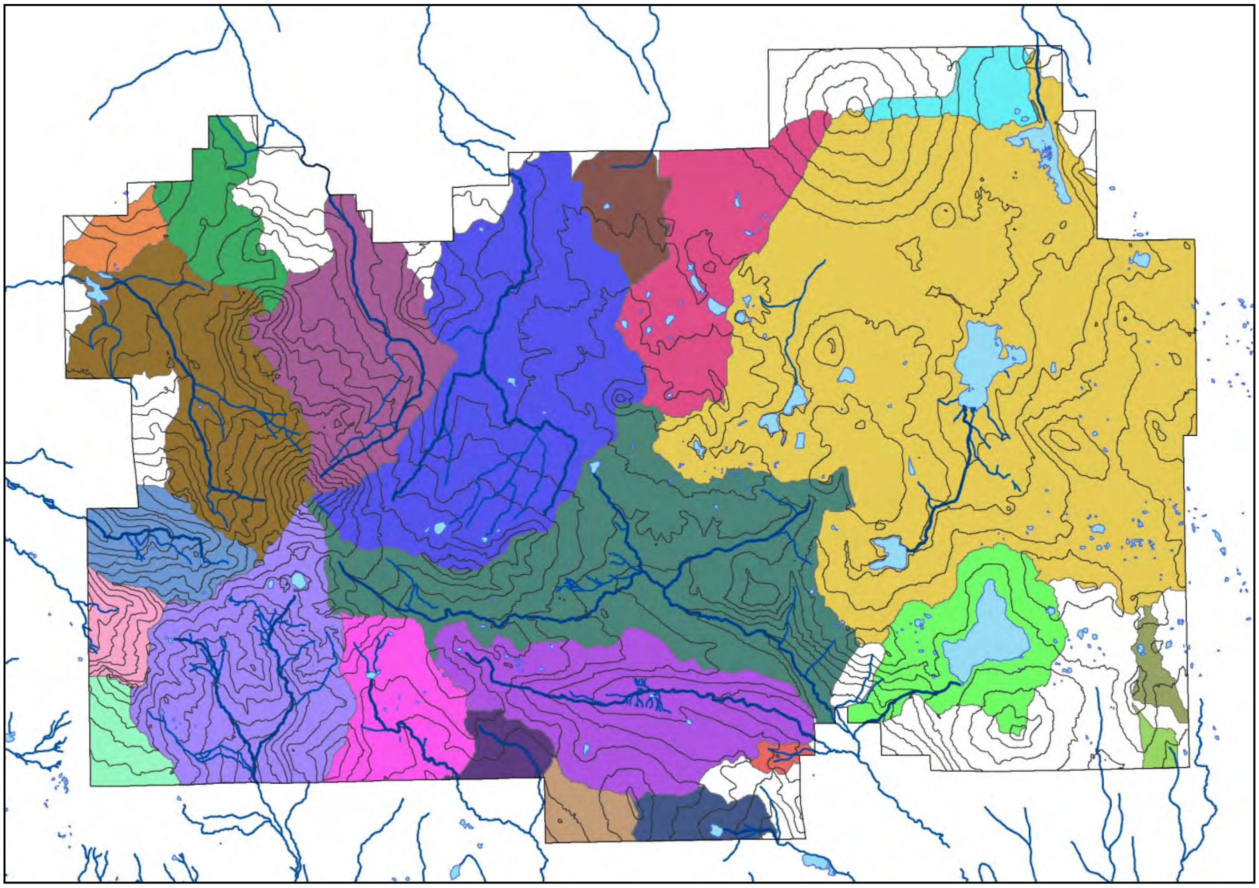

Figure 3. Watersheds of Lassen Volcanic National Park.

4.0 Natural Resource Conditions and Trends

According to park staff, the greatest concerns regarding the natural resources at Lassen, in no particular order, are currently:

1. Changes in the extent of montane snowpack and the timing of water availability, as possibly affected by global or regional climate change.

2. Changes in condition and distribution of high elevation lake, wetland, meadow, and riparian systems as a result of climate change, recreational use, invasive plants, and deposition of airborne particulates, nutrients, and contaminants.

3. Changes in the condition, distribution, diversity, and connectivity of vegetation types and their associated wildlife, as potentially affected by fire suppression, fuels management, insects, disease, climate change, air pollution, and invasive species.

4. Recovery rate of soils and vegetation on disturbed lands, such as those in Warner Valley and in places where trespassing cattle, unauthorized trails, other human activities (including those from before the park was established) may have caused impacts.

5. The overall natural quality of the park experience, as reflected by physical remoteness, quiet, and unobscured night sky.

Each of those natural resource concerns is now described 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

4.1 Changes in Precipitation, Snowpack, and Water Availability

4.1.1 Background

Precipitation and snowpack are essential for supporting forests and wildlife, sustaining stream flow and water table levels that feed ponds, lakes, and wetlands, and for reducing fire risk. Long term changes in air temperatures can affect precipitation and snowpack in several ways. First, warming winter (November – March) temperatures influence the proportion of precipitation that falls and is retained longer in the season as snow. Snow depth affects the overwinter survival and springtime germination of plants and emergence of insects, as well as wildlife movements, breeding success, and the availability of shelter. Second, the timing and speed of snowmelt are sensitive to changes in springtime temperatures (Knowles et al. 2006). Snowmelt water helps sustain public and private water supplies in drier low-elevation lands. When snowpack melts quickly, the period when side channel and floodplain habitats are inundated by water is shorter, limiting the habitat for fish and other aquatic animals. Decreased flows during late spring, summer, and early fall coupled with rising air temperatures are likely to increase water temperatures, reducing habitat suitability for native coldwater fish (Barr et al. 2010). Under normal circumstances, because water is released from melting snow more gradually than from rainfall, water infiltration into soils and groundwater is more complete. Consequently, stream flow is sustained longer into the growing season and natural processes may have longer to detoxify any pollutants present in precipitation and snow pack. However, warming trends may cause less nitrate to be exported from melting snow because soil microbial and plant uptake processes that effectively remove nitrate may be activated earlier in the season (Sickman et al. 2003).

For Lassen, long-term precipitation and temperature averages are shown in Appendix A. In general, the amount of precipitation decreases in an easterly direction from Lassen Peak due mainly to the rain shadow effect of the western Sierra Nevada and Cascade Ranges. Most precipitation occurs from November to April, and snow accumulates mainly from December to March. Below 6000 feet in elevation, a larger proportion of the annual precipitation occurs as rain.

4.1.2 Regional Context
No other areas in the immediate vicinity of Lassen support a year-round snow pack. The closest such area is Mount Shasta, located 70 miles to the northwest. 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%

4.1.3 Issues 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 between 1916 and 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).

The snowpack has declined over much of the West (Mote 2003a, 2003b) despite increases in winter precipitation in many places. The largest reductions have occurred where winter temperatures are mild, especially in the Cascade Mountains (where estimates of April 1 snow water equivalent indicate a 15–35% decline from mid-century to 2006) and in northern California. In most mountain ranges, snowpack has changed little at the highest elevations but major declines have occurred at lower elevation snow lines (Mote et al. 2005, Mote et al. 2008a). A shift in the timing of springtime snowmelt towards earlier in the year also has been observed during 1948–2000 in many western rivers. The shift has been attributed to more precipitation falling as rain rather than snow and earlier snowmelt (Knowles et al. 2006). In the Sierra Nevada, the last several decades were among the warmest of the last millennium (Graumlich 1993). In the Pacific Northwest, the snow water equivalent (i.e., the depth of water equivalent to the weight of the snowpack) decreased over the period 1950–2000, and is related to increases in temperature (Mote 2003a).

4.1.3.2 Future Climate Change

For the western U.S., predictive models 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 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 century was approximately 0.2°C per decade (Mote et al. 2008b). In the Sierra Nevada, by the years 2050 to 2100, average annual temperature could increase by as much as 3.8ºC (6.8ºF) (Snyder et al. 2002). This is the equivalent of about an 800 m upward displacement in climatic zones. Average temperatures in May could increase by 9 ºC. Even a relatively modest mean temperature increase (2.5°C) would significantly alter precipitation, snow pack, surface water dynamics (e.g., flow), and hydrologic processes in the Sierra Nevada.

The most pronounced changes would probably be a lower snowpack volume at mid-elevations (Knowles and Cayan 2001). Two climate models predict significant reductions in Sierra Nevada snowpack by the year 2100: one model predicts 30–70% reduction, the other a 73–90% reduction (Hayhoe et al. 2004). Also, the snowmelt runoff would occur earlier (Hamlet and Lettenmaier 2007, Jeton et al. 1996, Kim 2005, Kim et al. 2002, Leung et al. 2004), summer base flows and soil moisture would be reduced, and winter and spring flooding might increase. In California, a larger proportion of the streamflow volume would occur earlier in the year. In snowmelt-driven basins, late winter snowpack accumulation will decrease by 50% toward the end of this century (Miller et al. 2003). For the Klamath Network region specifically, simulations indicate future decreases in snow (e.g., Leung et al. 2004) and changes in the timing of snowmelt runoff (e.g., Stewart et al. 2004, 2005). Projections of future changes in Sierra Nevada climate related to precipitation quantity are less certain (Howat and Tulaczyk 2005), but precipitation is simulated to increase in winter, while summer-drought conditions will become more severe (Dettinger 2005, Dettinger et al. 2005, Mote et al. 2005).

4.1.4 Indicators and Criteria to Evaluate Condition and Trends

Although little or nothing can be done within the park to address changes in precipitation, snowpack, and water availability, 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, with the goal of maintaining conditions within the usual range of interannual variation:

1. Maximum annual extent, location, and depth of snow pack
2. Volume, timing, and rate of spring melt
3. Seasonal flow volumes, wetted width and length, and seasonal timing of discharge in all of the park's springs and streams
4. Number, area, depth, and seasonal persistence of the park's wetlands, ponds, and lakes

These have not been comprehensively documented, and existing data from the park are insufficient to determine past or likely future trends. Locations of various types of weather instruments in or near the park were mapped and described in Davey et al. (2007) and Daly et al. (2009). The latter report describes results of a statistical analysis whose purpose was to investigate possible long-term trends in air temperature and precipitation. No data are available that quantify snow pack extent (not just depth) or spring melt conditions, nor flow characteristics in the 12 perennial and many ephemeral streams before they exit the park. The areas of most of the park's wetlands, ponds, and lakes are known and should be re-measured with updated aerial imagery at intervals of one decade or less, depending on apparent rates of climate change. However, interannual and seasonal differences in precipitation, wind, and temperature would first need to be ruled out if detection of long-term change is the objective.

4.1.4.1 Maximum Annual Depth and Volume of Snowpack by Location

Criteria
Local and regional data on snow amounts are insufficient to quantify reference conditions appropriate for this park, so qualitative statements will define the reference conditions. "Good" condition would be represented by the amount (depth, extent, volume) of snowpack needed to sustain conditions close to the average historical condition in all parts of the park, and especially at higher elevations because of their importance in sustaining streams, ponds, and wetlands throughout lower portions of the park. "Somewhat Concerning" would be snowpack that is less than historical condition but still supports most of the park's key ecological processes and natural resources. "Significant Concern" would be snowpack that is insufficient to support those.

Condition
Indeterminate. Despite a relative abundance of snow depth measurements from in or near the park, condition is rated "Indeterminate" because the annual depth and volume of snowpack which comprise "normal" conditions for sustaining within the park has not been determined. Snow depth has been monitored at Manzanita Lake (since 1949), Lake Helen (since 1930), Lassen Chalet (since 1986), and at four sites outside but near the park: Harkness Flat (since 1930), Feather River Meadow (since 1930), Mineral (since 1948), and Chester (since 1948). The Lake Helen site has the most snow of any place in California, with an April 1 average of 178 inches, a maximum of 331 inches, and a minimum of 64 inches (Andalkar 2005b). Snow depth tends to be greater in the southern parts of the park and at higher elevations.

The El Niño/La Niña Southern Oscillation (ENSO) weather phenomena clearly influence the amount of snowfall in the park. During the years since record-keeping began in 1949, when there were strong El Niño conditions, snowfall in the northern California Cascades was 10-40% above normal. When there were strong La Niña conditions, snowfall was 5-15% above normal. When there were weak El Niño or weak La Niña conditions, snowfall was 5-15% below normal (Andalkar 2005b). Snow depths associated with these conditions are shown in Table 2.

Table 2. Average annual snowfall at Lassen associated with ENSO conditions, 1950-2005 (from Andalkar 2005b).

Condition	Annual Snowfall (inches)		
	Manzanita Lake (elevation= 5900 ft)	**Lassen Chalet (elevation= 6700 ft)**	**Mineral (elevation= 4900 ft)**
Strong El Niño	203	515	160
Weak El Niño	204	396	162
Neutral	171	387	142
Weak La Niña	179	374	145
Strong La Niña	207	451	161
Average	*189*	*429*	*152*
Maximum	328	712	309
Minimum	76	230	71

Trends
Somewhat Concerning – Low Certainty. Analysis of the climate data possibly suggests a warming trend and no clear trend in annual precipitation. Snowpack depth and volume depend on coincidence of increased precipitation with cooler temperatures. Analyses of trends in this specific pairing would not be meaningful because available data are only from lower elevations within the park. Only the data from the Manzanita Lake monitoring site are sufficiently detailed and complete to calculate trends in this indicator directly. From 1949 to 2007, a statistically significant decline occurred in the April 1 snow depth at that site (Daly et al. 2009). The winter (January-March) snow depth showed no statistically significant trend during that period. The ecological significance of a snowpack trend that is or is not statistically significant is unknown.

Assessment Confidence and Data Gaps
Although there are useful data from the Manzanita Lake site and the years it was monitored, data are too limited to draw any conclusions parkwide. Due to the large elevation differences within the park, and the fact that Manzanita Lake is in a nonrepresentative "rain shadow" location, it is unlikely that snow depth at other locations would mirror this site closely.

4.1.4.2 Timing and Rate of Spring Snow Melt and Discharge in Springs and Streams

Criteria
Local and regional data on snow melt timing and stream discharge are insufficient to quantify reference conditions appropriate for this park, so qualitative statements will define the reference conditions. “Good” condition would be represented by concordance of the current and historical seasonal timing (phenology) and rate of spring snow melt, especially at higher elevations which control water availability throughout much of the park. “Somewhat Concerning” and “Significant Concern” ratings would be assigned depending on the degree of discordance between the current and historical seasonal timing.

Condition
Indeterminate. This indicator has not been measured directly in the park. Streamflow timing might be inferred partly from by computing late-spring heating days from continuous temperature records, or from stream discharges for streams in or near the park. If data are sufficient, a fine-scale spatially explicit predictive model of snowmelt might be derived empirically by using existing snow depth data from multiple locations and elevations nearest to the park, combined with existing data on air temperature, elevation, topographic aspect, and other potentially influencing variables.

Trends
Somewhat Concerning – Low Certainty. Although no data are available that measure this indicator directly, trends in some of the following indicators suggest that the timing and rate of snowmelt might be shifting. This was not tested. Data through 2011 were analyzed for this report and the trends described below were found to be statistically significant. For this trend analysis, the Mineral data began in 1927, Manzanita Lake data began in 1949, and Chester data began in 1957.

- increase in the minimum high temperature (Min Tmax) – Manzanita Lake
- increase in the minimum observed minimum temperatures (Min Tmin) – Chester and Manzanita Lake
- decline in % of days with a cold maximum temperature (Tmax< 10th percentile) – Chester and Manzanita Lake
- decrease in % of days with extreme cold minimum temperature (Tmin < 10th percentile) – Chester
- increase in % of days with very warm nighttime temperature (> 90th Percentile Tmin) – Chester
- fewer entire days with below-freezing conditions (Tmax < 0°C) – Mineral and Manzanita Lake
- fewer partial days with at least some below-freezing conditions (Tmin < 0°C) – Mineral and Chester
- fewer cold days (Tmin < -10°C) – Chester
- shorter cold spells – Chester
- longer cold spells – Mineral

- decrease in diurnal temperature range (°C) – Chester
- increase in diurnal temperature range (°C) – Manzanita Lake
- more annual precipitation – Mineral
- shorter wet spells – Manzanita Lake
- more annual # of days of precipitation > 20 mm – Mineral
- more days with heavy precipitation (>95th percentile) – Mineral

In addition, Daly et al. (2009) computed trends in temperature and precipitation *for each month* at Mineral, Chester, and Manzanita Lake, but for a shorter time period, 1971-2007 (Appendix A). They did likewise for the park as a whole using spatially modeled values and also computed the 1895-2007 trend at that scale using modeled data. They found that August-September precipitation has decreased but that *no trend is discernible in annual precipitation. Maximum temperature in or near the park showed no long term trend*, and the 1971 -1990 period was somewhat cooler than the rest of the period.

Assessment Confidence and Data Gaps
Local and regional data on snow amounts and snowmelt timing are insufficient to quantify reference conditions, current conditions, or trends for this park. No direct measurements were available of the timing and rate of spring melt and discharge in springs and streams within the park over extended multiyear periods. A need exists to measure those and then correlate with the 27 core climate indices. Despite lack of high-elevation measurements and gaps in temporal coverage, the existing climate data are believed to be valid. Comparing trends among the three Lassen weather data sites is not valid because of their different periods of record, high variability within sites, and different incidences of missing records.

4.1.4.3 Perennial Stream Extent, Seasonal Flow Volume, Wetted Width

Criteria
Local and regional data on perennial stream extent, seasonal flow volume, and wetted width are insufficient to quantify reference conditions appropriate for this park, so qualitative statements will define the reference conditions. "Good" condition would be represented by concordance of the current and historical snowpack amounts, such that no section of a perennial stream within the park becomes ephemeral more often than it has historically, or experiences measurable reduction in its width or seasonal flow volume. Somewhat Concerning" would be some reduction in flow and extent of perennial length, affecting some of the park's key ecological processes and natural resources. "Significant Concern" would be reductions that are widespread, resulting in non-support of those processes.

Condition
Indeterminate. Very limited data are available from the USGS for stations near the park with the following codes: 11376038, 11376100, 11376200, 11381000, 11355500. There are a sufficient number of years to compute trends only at the last one (Hat Creek), which is located about nine miles north of the park, and only for the period 1927 through 1994.

Trends
Indeterminate. USGS daily flow data were obtained for Hat Creek. Dates were converted to the Julian calendar (January 1 = 1, December 31 = 365, etc.). Peak flow during most years occurred in the May-June period, primarily reflecting snowmelt from higher elevations. For each year, the dates during the spring (defined as April-July) when the five highest flows occurred were averaged. These averages were then plotted against year. No evidence was found that the date of peak runoff is occurring earlier in the spring, or that the size of peak flow is becoming larger or smaller. For this particular station during this time period, the median date of peak springtime flow was May 29 (earliest was April 15, latest was June 25). The median peak springtime flow was 205 cfs (115-372 cfs). The larger peak flows tended to occur during years when the peak occurred later in the spring.

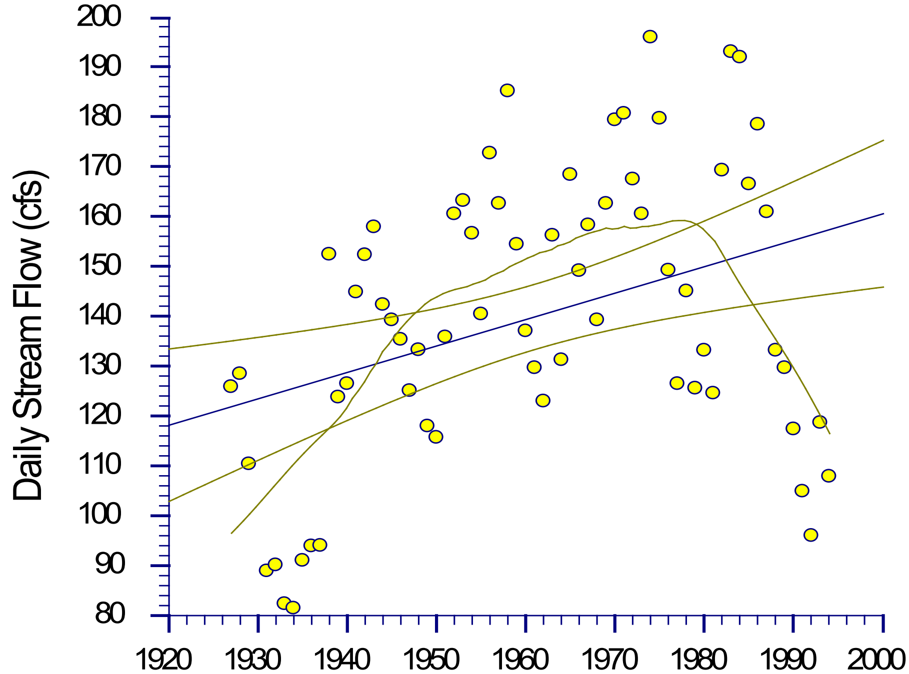

Figure 4. Average daily flow 1927 to 1994 at Hat Creek. Hat Creek originates within the park but these measurements are from a stream gauge located outside the park. The curved line is the locally weighted regression line (with 40% smoothing). The straight line is the least squares regression with confidence bands. R2=0.1316, p=0.0025, slope= 0.5310, n= 67.

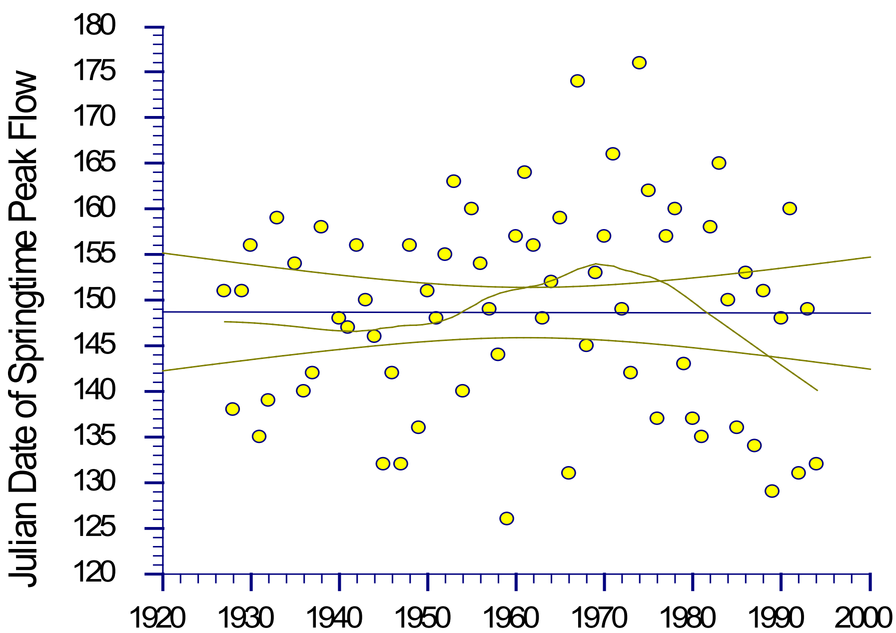

Figure 5. Dates of springtime peak flow, 1927 to 1994 at Hat Creek. Hat Creek originates within the park but these measurements are from a stream gauge located outside the park. The curved line is the locally weighted regression line (with 40% smoothing). The straight line is the least squares regression with confidence bands.

Assessment Confidence and Data Gaps

The analysis of the data from the single gauging station near the park is insufficient because of the distance between the park's snowpack and the gauging station, as well as the confounding influences of antecedent soil saturation (as separate from melting snowpack), late spring rainfall, and other factors which could not be determined. For the other indicators (e.g., location of perennial stream headwaters, a downslope movement of which could signal a shift to a drier climate), no data were available so condition or trends cannot be described.

Ideally, criteria would also specify what volume of snowpack is needed to sustain stream flow and water table levels for specified durations and channel widths under a variety of temperature conditions during the subsequent growing season. This cannot be determined without computer simulations calibrated with field measurements from specific locations in the park. Lacking such data, the assessment of the adequacy of current and future snow pack could be based on comparison with average historical discharges of snowpack-fed streams at the highest elevations where discharge was continuously measured. Additionally, the upper portions of the park's perennial streams could be walked at the driest time of an average year and their headwater (highest point of perennial flow) location pinpointed with GPS. Of predictive importance are the frequency of no-flow or low-flow conditions, the annual daily mean flow, the total annual flow, and the date of peak discharge attributable at least partly to snowmelt (i.e., late spring and summer). Without installation of continuous-flow monitoring gauges and plotting of hydrographs from the collected data, these cannot be determined.

4.1.4.4 Number, Area, and Distribution Pattern of Wetlands, Ponds, and Lakes

Criteria
"Good" condition would be represented by concordance between the current and historical number, area, distribution, and ecological condition of wetlands, ponds, and lakes as determined partly by using the variables recorded by Adamus & Bartlett (2008). "Somewhat Concerning" would be a slight but persistent reduction in the ecological condition of wetlands, ponds, and lakes, but without a large reduction in their number, area, or distribution. "Significant Concern" would be a major reduction in all of these metrics. It is recognized that wetlands are naturally dynamic and some wetlands fluctuate between years from being seasonally to persistently flooded, and those cycles are beneficial to their productivity.

Condition
Good. The park's wetlands were first mapped by the National Wetlands Inventory (NWI) in the 1980s using color infrared imagery with a scale of 1:58,000. Refinements and additions were made in 2005 by Adamus & Bartlett (2008). Permanent markers were placed in each of 68 wetlands comprising a probability sample of an estimated 990 wetlands in the park. The sample wetlands were visited once and were mapped using GPS, with the coordinates reported in a database provided to the Klamath Network. These assessments determined that *nearly all wetlands are in good condition* as defined mainly by their plant communities. A wetland assessment method (CRAM, California Rapid Assessment Method; Collins et al. 2006) was applied to the data from all the 68 surveyed wetlands, resulting in a median CRAM score of 78 on a scale of 10 to 100 (as compared with a median of 46 for riverine wetlands outside the park assessed by other people)[10]. This suggests that the park's wetlands might be in relatively good condition. However, CRAM does not use any direct measures of wetland health, such as amphibian productivity. Moreover, CRAM scores from the park's wetlands were not correlated significantly with any of the independent measures of potential risks to those wetlands (e.g., proximity to roads and trails, visual evidence of human visitation), as would be expected.

Trends
Indeterminate. No data are available for estimating trends in their quantity or quality (ecological condition). The wetlands spatial data from the Adamus & Bartlett assessment provide a reasonably complete baseline for wetland area and distribution in the park, and the data provide a partial baseline for comparing future wetland quality.

Assessment Confidence and Data Gaps
Medium. The park's wetlands were initially mapped by the National Wetlands Inventory using aerial photographs from the 1980s. The Adamus & Bartlett (2008) survey ground-truthed many of those mapped wetlands and added others, but did not involve walking all likely parts of the park to intentionally search for unmapped wetlands. Also, the Adamus & Bartlett survey did not measure contaminants, other water quality variables, groundwater levels, amphibians, underwater aquatic plants, or several other indicators of wetland ecological condition.

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[10] Calculated from data posted on the CRAM web site (http://www.cramwetlands.org/) as of 18 March 2007.

4.2 Changes in Surface Waters and Their Resources

4.2.1 Background

Surface waters include streams, ponds, lakes, geothermal springs, and wetlands. The quantity, quality, and distribution of these influence and are influenced by local climate, soils, vegetation, wildlife, and fish and other aquatic animals. They also are a major source of park visitor enjoyment. Watershed boundaries are shown in Figure 3. These were modeled from topographic data, with each watershed beginning at the park boundary and extending upslope into the park.

4.2.2 Regional Context

Geothermal springs are a major feature drawing people to the park, along with more than 200 ponds and lakes. Over the past 300,000 years, volcanism has greatly altered the park's landscape and created a wide array of thermal features such as roaring fumaroles, mudpots, boiling pools, and steaming ground. The park has several high-elevation, acid-sulfate, low-chloride springs that are characteristic of vapor-dominated hydrothermal systems (Ingebritsen and Sorey 1985). These geothermal acidic features represent some of the most extreme life-supporting environments on earth. Temperatures range from 50 to 115°C, and pH from 0 to 3. Boiling Springs Lake is the third-largest body of geothermally-warmed water anywhere in the world. Data from various sampling sites within the park indicate that geochemical composition of springs varies widely even among features in similar areas of the park with similar temperatures and pH values (Thompson 1985). The park's geothermal features provide an unusual chemical environment due to their mineral-rich underground source and the rapid evaporation associated with hot surface temperatures. In many of the springs in the Growler and Morgan Hot Springs area, chloride and arsenic occur at levels that would threaten most of the usual forms of aquatic life. However, in this park, as in the hot springs of Yellowstone National Park, there are unusual microbes (Archaea) which not only tolerate severe conditions, but can actually derive energy by processing sulfur compounds or methane, while not depending on sunlight or organic matter for food. Most geothermal features are located in the southwestern part of the park and nearly all (except for the springs at Drakesbad Meadow) are acidic and rich in hydrogen sulfide and sulfate (Thompson 1983). At a scale of a few meters, the locations of hydrothermal features such as mudpots can shift with time as the underground plumbing changes and pathways of fluid flow are sealed by mineral deposition or fractured by seismic activity. Thermal water discharging at Morgan Hot Springs and Growler Hot Spring as well as the deep thermal water at Terminal Geyser probably originates beneath the surface at Bumpass Hell (Thompson 1983).

Compared with many other areas in California, the park's water bodies are at relatively low risk from pollutants carried in via water from locations outside the park, because the park is at the top of several watersheds and no surface water enters from outside the park. Nonetheless, high-elevation aquatic ecosystems in the Sierra Nevada are particularly sensitive to additions of atmospheric nitrogen and sulfur because the waters are generally nutrient-poor and have a low capacity to buffer these additions without becoming acidified or experiencing major biological changes (Sullivan et al. 2001, Mutch et al. 2008). The capacity of the park's waters to buffer the acidifying effect of these particles is limited by very low concentrations of calcium and other base cations. The low buffering capacity is due to soils in many areas of the park being very young, thin, and poorly developed, partly as a result of the volcanic eruptions and erosion events in 1915, and partly due to the magnesium-rich granitic composition of most of the area's bedrock (Clow et al. 2003). Of the seven lakes sampled by EPA's Western Lake Survey in the park in the

1980s, five had levels of acid neutralizing capacity low enough to indicate that they are at risk of both episodic and chronic acidification (Eilers et al. 1987). Small water bodies (i.e., ponds and wetlands) are most at risk when they lack surface water outlets and are fed by relatively small high-elevation contributing areas. Phytoplankton, and epiphytic and benthic algae in these waters are likely to be most sensitive to acidification and nitrogen deposition, with unknown consequences for other components of the aquatic food web.

4.2.3 Issues Description

Several factors can potentially degrade the quality of the park's water bodies and in some cases threaten their very existence. The more notable of these include the following, which are subsequently described:

- Climate Change
- Deposition of Atmospheric Nitrogen and Sulfur
- Deposition of Other Airborne Contaminants
- Changes Resulting From Fires and Fire Control Activities
- Visitor-associated Water Contamination
- Ecologically Harmful Aquatic Plants and Animals
- Natural Sources

4.2.3.1 Impacts from Climate Change

Historical climate conditions and predicted future changes are described generally in section 4.1. Changes in the extent and duration of snowpack, ice cover, stream flow, lake and wetland water levels, temperature, and chemistry will likely occur as a result of predicted climate change, and will affect biological resources. In general, the most sensitive species tend to be boreal species near the southern edge of their range which occur at higher elevations and have limited mobility and low reproductive rates. Several of the park's aquatic plants and animals fit one or more parts of this description. 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 aquatic or wetland-associated and are likely to have formerly or currently nested in the park include Barrow's goldeneye, bufflehead, eared grebe, osprey, willow flycatcher, and Lincoln's sparrow.

4.2.3.2 Impacts from Air Pollution: Deposition of Atmospheric Nitrogen and Sulfur

At least one recent study attributed enrichment of high-elevation lakes in the Sierra Nevada to deposition of atmospheric nitrogen (Sickman et al. 2003). This is potentially a significant concern in Lassen because the park's waters are nutrient-poor, due partly to their headwater positions. Some of their aquatic flora and fauna are thus not equipped to survive significant increases in nutrients. Moreover, even slight changes in species composition of aquatic algae in response to increased nutrients can alter aquatic food chains, sometimes with results that appear to be detrimental.

4.2.3.3 Impacts from Air Pollution: Deposition of Other Contaminants

Although few pollution sources remain within the park, long-distance airborne transport of pesticides and other contaminants poses a potential threat. In other parts of the Sierras, long distance transport of airborne pesticides has been noted (Zabik and Seiber 1993, McConnell et al.

1998) with possible damage to aquatic invertebrates and amphibian populations (Davidson 2004).

4.2.3.4 Aquatic Impacts of Fires, Fire Control Activities, and Vegetation Change

The type, amount, and spatial pattern of vegetation strongly influences aquatic systems (Ball et al. 2010) and is in turn affected by fire. Thus, the magnitude and frequency of some types of disturbances in aquatic systems, such as changes in shading and sediment loads from erosion, depend on the severity and frequency of fire. Fire also can have long-term effects on aquatic systems by changing the dominant land cover along streams and other water bodies. For example, the amount of plant litter, its decay characteristics, and its potential for delivery to and through aquatic systems can profoundly influence aquatic invertebrate and fish communities. The fire regime at Lassen is described in section 4.3.

4.2.3.5 Visitor-associated Water Contamination

Soil erosion has been accelerated locally within a few heavily traveled areas of the park, due to compaction, vegetation damage, and changed runoff patterns. High levels of overnight use have been reported to have caused substantial damage adjacent to some lakes (NPS 1999). Damage included loss of vegetation, soil compaction, increased sediment loads in water bodies, and, less frequently, bacterial pollution of surface water.

4.2.3.6 Impacts from Ecologically Harmful Aquatic Plants and Animals

In other parts of California, several exotic plants and a few non-native animals have extensively invaded wetlands and some other water bodies (California Dept. of Fish & Game 2008). When this happens on a large scale, some native species are extirpated and ecosystem processes can be altered in unpredictable ways. Invasions are more likely to occur at lower-elevation aquatic sites that receive heavy recreational use, as well as those experiencing unnatural water level fluctuations as a result of human activities.

4.2.3.7 Natural Sources

The volcanic eruptions of 1915 resulted in massive deposition of sediment and nutrients in some of the park’s water bodies. Also, at a few locations the chemical concentrations in geothermal springs naturally exceed levels considered harmful to some freshwater species at other locations. Elevated arsenic levels in Mill Creek and Canyon Creek, which are fed by geothermal springs, persist more than 2 km downstream (Sorey 1986).

While fires themselves are major agents of change, fire-fighting, especially in steep terrain, potentially results in additional disturbance that affects aquatic systems including soil compaction and contamination from fire retardants. Applications of fire retarding chemicals have not been documented at Lassen, but in recent years NPS policy is to avoid the use of fire retardant as much as possible. Fire retardant agents must be on an approved list for use by the Forest Service and Bureau of Land Management, and must not be applied within 200 feet upslope of any wetland, stream, or other water body. Fire retardants used in controlling or extinguishing fires contain about 85% water, 10% fertilizer, and 5% other ingredients such as corrosion inhibitors and bactericides. Fire suppressant foams are more than 99% water. The remaining 1% contains surfactants, foaming agents, corrosion inhibitors, and dispersants.

4.2.4 Indicators, Criteria, Condition, and Trends

Indicators that might be used to monitor degradation of surface waters and their resources include the following, with the goal of maintaining conditions within the expected natural range of interannual variation:

1. Proportion of water bodies regularly experiencing exceedances of key thresholds for important water quality parameters; i.e., those that are important to human health, maintenance of aquatic ecosystem processes, and the continued survival of important species and biological communities;

2. Presence and persistence of the current diversity of native aquatic plant and animal species;

3. Proportion of the park's wetlands, ponds, lakes, and riparian segments in which invasive species have (a) colonized or (b) become dominant, and have reduced native species richness.

To develop meaningful criteria for evaluating these, it is important to understand each indicator's natural range of variation and/or its potential for harming the park's resources. Invertebrate and fish data collected from the park's lakes in 2008 and 2010, and from the park's streams in 2011, will help define the expected spatial variation. However, those data were not available for review at the time of report preparation. Therefore, criteria are based on published standards related to ecological harm, or on professional judgment of the authors. The indicators are described in the following sections.

4.2.4.1 Water Quality Threshold Exceedances

Criteria

Local and regional data on water quality are insufficient to quantify reference conditions that are appropriate for those waters of this park that are chemically atypical due to natural geothermal phenomena. However, those waters are relatively limited in extent within the park. To define reference conditions, criteria and standards for protection of aquatic life, as published by federal and state agencies, were consulted. "Good" condition would be represented by no exceedances or increases in substances harmful to aquatic life during a multiyear period of assessment, except as attributable solely to natural factors, e.g., catastrophic floods, geothermal effluent. This is consistent with the antidegradation policies of state and federal regulatory agencies. "Somewhat Concerning" condition would be a slight and/or occasional exceedance of a water quality standard. "Significant Concern" would be severe, chronic, or acute exceedances of a water quality standard at concentrations that could harm aquatic life.

Condition

Good. Water quality data prior to 1999 were compiled and summarized in a "Horizon Report" by NPS (1999), and briefly by Hoffman et al. (2005). Results from some of the more recent sampling are reported by Currens et al. 2006 and Janik & Bergfeld 2010. The Horizon Report covering this park noted at least one exceedence of EPA aquatic life protection criteria for the following: dissolved oxygen, pH, chloride, chlorine, and arsenic. Sulfate, chloride, arsenic, and barium exceeded their respective EPA criteria for drinking water standards. Fecal-indicator bacteria concentrations (fecal coliform) and turbidity occasionally exceeded screening limits for freshwater bathing and aquatic life, respectively. Dissolved oxygen problems were present at least once in Reflection Lake, Horseshoe Lake, Butte Lake, and Boiling Springs Lake. The low levels of dissolved oxygen in these lakes is likely to be a natural occurrence. Low pH (harmful acidity) was noted from far more samples than excessively high pH (harmful alkalinity). The highest pH (9.7 SU) was reported from an unnamed spring in the area of Growler and Morgan Hot Springs and the lowest pH (1.7 SU) from an unnamed spring in the northern section of Bumpass Hell.

As a supplement to the NPS Horizon Report and this report, in December 2011 we queried the USEPA STORET database. This yielded 9342 records of measurements of 61 water quality parameters from 246 sample points among the park's waters between June 1960 and September 2005 (the most recent data available online). Table 3 summarizes some comparisons with official water quality criteria.

Trend
Indeterminate. Sampling has mostly been sporadic over the past 50 years, and has been conducted with insufficient regularity and quality control to determine trends. None of the water quality characteristics in the STORET database have been monitored at the same location with sufficient frequency (seasonal and annual) to reliably examine multiyear trends. Monitoring of trends in pH, turbidity, and temperature in the park's waters (especially the smaller ponds and seasonal wetlands) is of particular interest, as these broadly influence the cycling and bioavailability of many other substances as well as habitat suitability for amphibians and crustaceans. They are most likely to be affected by climate change and the types of disturbances that are most common within the park.

Table 3. Comparison of water samples from Lassen with USEPA thresholds for potential harm to aquatic life. An unknown portion (but likely a majority) of these samples were from hydrothermal features, which commonly exceed criteria due to natural geochemistry. "Sites" are loosely defined; some may be within a few feet and in the same water body while others are miles apart. Data source is EPA's STORET database. Threshold for aluminum= 87 µg/L; arsenic= 150 µg/L; barium= 1000 µg/L; chloride= 230 mg/L; iron= 1000 µg/L; manganese= 50 µg/L; pH= 9.0. For pH, there were also 58 sites that were too acidic (pH < 6.5).

Parameter	Units	Maximum	# of Sites Sampled	# of Sites Exceeding the Criteria
Aluminum, dissolved	µg/L	28000	18	12
Arsenic, dissolved	µg/L	24300	6	5
Barium, dissolved	µg/L	3100	13	9
Chloride	mg/L	2370	72	20
Iron, dissolved	µg/L	63000	39	29
pH	SU	9.95	189	11

Assessment Confidence and Data Gaps
Low. Confidence in the existing data from the park is limited by the non-systematic temporal and spatial coverage of past water sampling efforts. However, data from a new, relatively comprehensive sampling program that measures water quality in a statistical sample of the park's lakes and streams should be available soon. As noted above, trends could not be assessed. Confidence in the applicability of the USEPA water quality criteria to conditions in most of this park is moderate to high, being limited only because it is unknown whether the tolerances of the fauna in the park's water bodies are similar enough to those of the species used by USEPA in its toxicity testing.

4.2.4.2 Diversity of Native Aquatic Species and Habitats
The park's six largest lakes—Juniper, Snag, Butte, Horseshoe, Lower Twin, and Upper Twin—are all in wilderness areas that have been either designated or proposed. Manzanita, Butte, and Blue Lake Canyon Lakes are the only natural lakes likely to have been inhabited by fish historically (Parker et al. 2008).

Floristic Quality Assessment (FQA) indices have been developed in other regions of the United States for quantifying the intactness of plant communities (including those of wetlands and lakes), but no such plant indices have been developed for this part of California. Similarly, Indices of Biotic Integrity (IBIs) are often used to evaluate the condition of aquatic invertebrate or fish communities. Although none have been developed or calibrated to the specific conditions present in this park or nearby areas, the general principles they embody are being applied by NPS to interpret data collected from the park's streams in 2011.

In national forests of the Sierra Nevada region, the USDA Forest Service (2008) has chosen and is monitoring the following aquatic or wetland-associated species or groups and their associated habitats as "management indicator species":

Pacific tree frog – wet meadow
yellow warbler – riparian woody vegetation
aquatic macroinvertebrates – riverine and lacustrine

Criteria
Condition of the park's aquatic biota could be evaluated relative to a goal of sustaining the natural turnover rates of all native aquatic species currently inhabiting the park. By "natural turnover rates," we mean the changes in abundance or presence attributable to expected natural factors, either gradual (e.g., vegetative succession) or event-focused (severe storms, fire). A more detailed goal might be to sustain the proportions and functional characteristics of species that reflect well-functioning food webs and ecological intactness. However, there are no legally-sanctioned numeric criteria for evaluating the degree of intactness of any of the park's aquatic plant or animal communities. Likewise, local and regional data on natural turnover rates, minimum viable population levels, desired productivity or species richness levels, or other attributes of native aquatic species and their habitats are insufficient to quantify reference conditions appropriate for this park. Thus, qualitative statements will define the reference conditions. "Good" condition would be represented by concordance between the current and

historical turnover rates of all native aquatic species inhabiting the park. "Somewhat Concerning" condition would be loss of one or a few native aquatic species historically present. "Significant Concern" condition would be loss of several native aquatic species historically present, in excess of natural turnover rates.

Condition

Somewhat Concerning – Low Certainty. A rating of "Good" is not assigned because of the apparent disappearance from the park of Cascades frog. Also, at least four native bird species which are known to have nested in the park historically, though with unknown regularity, have not been documented nesting for at least a decade. They are common loon (last nested in 1948), canvasback (last nested in 1951), redhead (last nested in 1976), and Barrow's goldeneye (last nested in 1920s). Whether the extirpation of these species is simply part of natural turnover rates, or is due to fine-scale human influences (such as the introduction of fish to some lakes and/or disappearance of those fish in subsequent years) or broad-scale factors (such as climate change that may have affected these essentially boreal species in unknown ways), remains uncertain.

A pond survey 35 years ago (West 1976) covered 162 wetlands, ponds, and lakes in LAVO. In 131 systems the following were measured (Hoffman et al. 2005): 1) water temperature, 2) color, 3) clarity, 4) site depth (maximum and mean), 5) site bottom and shore type, 6) watershed condition, 7) site surface area, 8) presence and location of inlets and outlets, 9) fish presence, 10) presence of fish predators, and 11) relative abundance of aquatic invertebrates and vegetation. In the mid-1980s the USEPA's Western Lake Survey analyzed physical and chemical characteristics of seven Lassen lakes (Landers et al. 1987, Eilers et al. 1987). However, until recently only wetland plants (Adamus & Bartlett 2008) and lentic fish and amphibians (Stead et al. 2005) had been the subject of publications based on park-wide biological surveys. As noted earlier, the Klamath Network implemented an extensive survey of the park's lakes and streams in 2008-2011, but data were not available for review in time for preparation of this report.

The Adamus & Bartlett wetland study in 2008 did not survey plants that live completely underwater; the survey detected 51% of the park's known wetland flora. Among the 338 plant taxa (both wetland and upland), at least two were found that are listed by the California Native Plant Society as rare or having limited distribution. In most wetlands, more than 30 plant species were found, and most of the 100 m^2 herbaceous plots in wetlands had more than 13, with a maximum of 43. The plant species composition tended to be more unique in wetlands that were dominated by emergent (herbaceous) vegetation, not on lakeshores, at lower elevations, and intercepted by streams. At least two acid geothermal fens, a relatively rare and sensitive wetland type in California (Cooper & Wolfe 2006, Weixelman et al. 2006), were identified. These are fed largely by warmed groundwater and have extensive moss cover. They are present near Forest Lake area, just east of Ridge Lakes, and next to Bumpass Hell. Just outside the park, the sphagnum moss wetland along the edge of Willow Lake is unusual for the region. Little Willow Lake just inside the park also has a floating *Sphagnum* mat and supports a similar assemblage of plants unusual for this region.

A separate survey of 365 of the park's wetlands and ponds in 2004 (Stead et al. 2005) found amphibians in 90% of the surveyed lakes, 73% of the wet meadows, 64% of the permanent ponds, and 47% of the temporary ponds. The most widespread species was Pacific treefrog (*Pseudacris regilla*) at 59% of the sites, followed by long-toed salamander (*Ambystoma* *macrodactylum*) at 10% of the sites, western toad (*Anaxyrus boreas*) at 8%, and Cascades frog (*Rana cascadae*) and rough-skinned newt (*Taricha granulosa*) at just 1% each. The Cascades frog is listed as a federal and state species of concern and was considered abundant throughout the park until the mid-1970s. It is estimated that the frog has now been extirpated from about 99 percent of its southernmost range (Lassen Peak and surroundings) and 50 percent of its total historical distribution in California. In 1974, Pacific treefrogs with extra hind legs were first discovered in the park, and a resurvey between 1999 and 2002 found hind limb deformities to be common in this species. The cause is believed to be an infection from a parasite (*Ribeiroia ondatrae*) that is hosted by aquatic flatworms (Johnson et al. 2003).

Among reptiles, western terrestrial garter snake (*Thamnophis elegans*) and the common garter snake (*T. sirtalis*) were found most often by the Stead et al. survey (2005). Either or both were found at 26% of the mainly aquatic sites. Although not listed as threatened or endangered statewide, the western pond turtle (*Actinemys marmorata*) is believed to be suffering from declines in large parts of its range. Although previously documented in the Manzanita and Reflection Lake area, there have been no recent sightings in the park.

Aquatic invertebrates were surveyed in most of the park's lakes and ponds by Parker et al. (2008). The Klamath Network also completed an invertebrate survey of the park's lakes and streams (Dinger et al. 2012) but data were not available for review during preparation of this report. Underwater visual surveys of aquatic vegetation have been done in a few places by Dr. John DeMartini of Humboldt State University, but similarly, the data have not been published and were not available for this report.

Native fish known from the park include speckled dace (*Rhinichthys osculus*), Lahontan redside (*Richardsonius egregius*), tui chub (*Siphateles bicolor*), rainbow trout (*Oncorhynchus mykiss)*, and mottled sculpin (*Cottus gulosus*) (Potts and Schultz 1953). Records from the park of the Modoc sucker (*Catostomus microps*), which is listed as endangered by both the state and federal governments, have been determined to be a misidentification. Some of the park's ponds have reverted to their historically fishless condition as a result of winterkill (naturally low levels of dissolved oxygen under prolonged ice conditions). The associated loss of mostly non-native predatory fish has been shown to be beneficial to some of the park's amphibian species (Stead et al. 2005) and to overall diversity of the park's aquatic invertebrates (Parker et al. 2008).

Physical habitat characteristics in the park's streams have not been widely quantified, and headwater origin points of perennial flow in the park's streams have not been precisely located. One of the park's streams, Mill Creek, is exceptional among regional streams in having no dams blocking anadromous fish, and appears to be relatively undegraded most of the distance from its origin in the park downstream to the Sacramento River. Mill Creek is listed in the Lassen National Forest's Land Management Plan as a candidate for inclusion in the National Wild and Scenic River System. Kings Creek supported what was apparently the world's only population of the Kings Creek caddisfly (*Parapsyche extensa*), discovered in 1948 but believed to be no longer present.

Several studies have examined microbial diversity in the park's hot springs (Whitaker et al. 2003, Brown & Wolfe 2006, Siering et al. 2006, Tin et al. 2011) and fumarole steam vents (Benson et al. 2011). These have provided evidence that geothermal features can be connected via the subsurface over long distances and that subsurface sources provide a potentially diverse source of microorganisms for downstream waters (Tin et al. 2011).

Bufflehead (a duck) has been a particular focus because the park is at the southern edge of its range, perhaps making it highly susceptible to the effects of global warming. Data collected by park biologists annually since 1997 describe number of adults (and with or without broods), number of broods, number of young, size and age of young at various times post-hatch, associated fish species, and survey effort. Maps have also been created and color-coded to represent areas surveyed and not surveyed. The surveyed areas are further divided into areas of buffleheads with broods, areas of adult buffleheads, areas of no buffleheads, and areas not officially surveyed but where buffleheads were noticed. Other waterbirds are noted, but mallard, Canada goose, and common merganser are the only others that are equally or more common, and no large wading birds nest in the park. A bird closely associated with streams—the American dipper—is a fairly common breeder.

Trends

Indeterminate. It is certain that numbers of at least one of the park's species (Cascades frog) have declined to the point of extirpation, and as described above under *Condition*, four waterbirds that historically bred in the park no longer do. On the other hand, it is also certain that non-native fish introduced into many of the park's lakes up until perhaps the 1990s have now disappeared due to natural factors (Parker et al. 2008), and this trend can be viewed as positive relative to a goal of maintaining the park's diversity of aquatic invertebrates and amphibians. An overall rating of "Indeterminate" is assigned because of the presence of both positive and negative trends (depending on aquatic group), and because quantitaive data are not sufficient to quantify trends in most of the park's aquatic plant, invertebrate, and amphibian species.

Assessment Confidence and Data Gaps

Low. Confidence in trends is limited by lack of published surveys of underwater plants and historical surveys of other forms of aquatic life.

4.2.4.3 Water Bodies with Ecologically Harmful Species

Criteria

Local and regional data on invasive aquatic animals and plants are insufficient to quantify reference conditions applicable to this park, so qualitative statements will define the reference conditions. "Good" condition would be represented by complete absence of non-native aquatic plant or aquatic animal species that threaten the long-term persistence of native species currently existing within the park. "Somewhat Concerning" and "Significant Concern" ratings would reflect increasing degree and extent to which native species are being impacted by invasive aquatic species.

Condition

Somewhat Concerning – Low Certainty. The park hosts four non-native fish species—golden shiner (*Notemigonus crysoleucas*), fathead minnow (*Pimephales promelas*), eastern brook trout (*Salvelinus fontinalis*), and brown trout (*Salmo trutta*). Their adverse effects on native aquatic life in the park's lakes, ponds, and wetlands have been demonstrated (Parker et al. 2008). Trout have been introduced in all of the park's streams, but effects on aquatic communities in the park's streams are unmeasured. For recreational purposes, non-native sport fish were introduced into at least 42 of the park's lakes and ponds until perhaps the early 1990s, sometimes repeatedly. Currently, only about 14% of surveyed lakes in the park have fish (Parker et al. 2008).

Long-toed salamander, Cascades frog, and Pacific treefrog are commonly consumed by trout. Among 728 ponds in the Klamath Mountains surveyed in 1999-2002 by Welsh et al. (2006), fishless ponds were far more likely to support these amphibian species which are normally prey for fish. Similar results were found at Lassen by Stead et al. (2005) who also found that fishless ponds were more likely to host a native fairy shrimp (*Streptocephalus sealii*) that fish consume, which was present in 15% of the 365 wetlands and ponds that were surveyed.

A survey of 365 of the park's wetlands and ponds in 2004 (Stead et al. 2005) did not report any occurrences of bullfrog (*Rana catesbiana).* A variety of pathogens, such as chytrid fungus and ranavirus, have been found elsewhere to seriously impact amphibian populations and have been found in the park.

A number of plant species found partly in wetlands and along streams are considered to be "disturbance species." Nearly all are non-natives, and some are invasive weeds. Studies elsewhere have shown they increase around areas of human or natural disturbance. A botanical survey of 68 of the park's wetlands in 2005 (Adamus & Bartlett 2008) found 19 disturbance species (6% of all species encountered) among 44 of the 68 wetlands that were surveyed. In the 100 m^2 herbaceous plots, the median number of disturbance species was zero. In the 400 m^2 shrub plots, the median number of disturbance species was seven. For entire wetlands, the median number of disturbance species among all wetlands was two. The number of disturbance species was greatest in large, sloping, relatively wet shrub and forested wetlands intersected by streams with higher conductivity and in the western part of the park. The number of disturbance species, as well as the percent of a wetland's species list that was comprised of disturbance species, increased the closer a wetland was to a road. However, the percentage decreased with proximity to *trails*. The total number of plant species also increased significantly closer to roads.

To date, there are no park records of the New Zealand mud snail (*Potamopyrgus antipodarum)* or other ecologically harmful invertebrates known to occur in northern California (personal communication, Eric Dinger, NPS Klamath Network, Ashland, Oregon).

Trends
Indeterminate. Surveys indicate a decline in the number of lakes and ponds inhabited by non-native fish. Nonetheless a rating of "Indeterminate" is assigned because data are not sufficient to determine if there are long term trends across the park in harmful aquatic plants.

Assessment Confidence and Data Gaps
Medium. Although significant occurrences of invasive plants have mostly been surveyed in a sample of wetlands, not all wetlands were surveyed. Also, there are no published surveys that describe locations of invasive underwater plants and invertebrates in the park's streams and lakes.

4.3 Changes in Terrestrial Vegetation

4.3.1 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 are therefore essential for defining the ecological integrity of park terrestrial ecosystems.

Vegetation structure, function, and composition can be altered by many park activities (e.g., fire management) or from extrinsic factors (e.g., off-site pollution, climate change, invasive species) (Figure 6). 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.

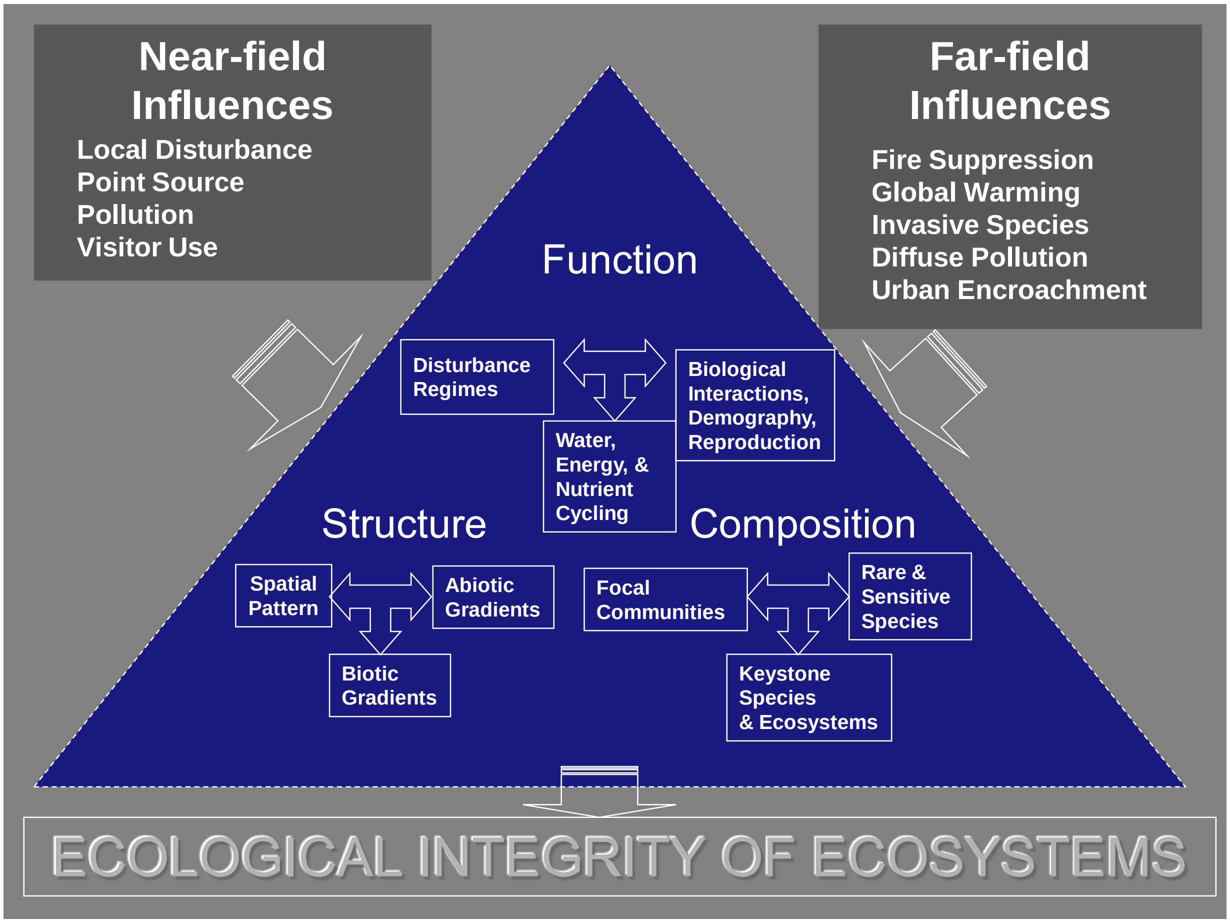

Figure 6. Human influences on the structure, function, and composition of ecosystems.

Along a hypothetical elevation gradient from low to high, Lassen's vegetation is dominated by white fir and mixed conifer forests, Jeffrey pine (*Pinus jeffreyi*) forests, lodgepole pine (*P. murraya* var. *contorta*) forests, red fir (*Abies magnifica*) forests (the most abundant type), and modest amounts of subalpine forests and woodlands of mainly mountain hemlock (*Tsuga mertensiana*), with inclusions of whitebark pine (*P. albicaulis*) (Parker 1991). The highest elevations, particularly Lassen Peak itself, are characterized by mostly rock and persistent snow with a very sparse cover of herbaceous vegetation. Within the lower elevation conifer belt, there are localized areas of montane chaparral shrub vegetation due to fire and soil conditions. There are also large expanses of barren lava fields or pyroclastic deposits with very sparse herbaceous vegetation or no vegetation. Wet meadows and perennial grasslands occupy a small area, as do specialized vegetation such as riparian forests and aspen stands. Table 4 lists the broad vegetation types and the area they occupy currently.

Table 4. Area of broad vegetation types in Lassen. The areas are based on the 2007 vegetation map prepared by James von Loh, but uses the classification of Wildlife Habitats (WHR) from the California Vegetation Map (Cal-Veg) prepared by the US Forest Service http://www.fs.fed.us/r5/rsl/projects/frdb/layers/ev_mid.html.

Vegetation	Area (ha)
Red fir forest	21,540
Lodgepole pine forest	5,569
White fir forest	4,750
Barren*	4,195
Jeffrey pine forest and woodland	2,625
Montane chaparral	2,125
Subalpine conifer woodland and forest	1,611
Alpine dwarf shrubland	381
Wetland	360
Montane riparian	181
Perennial grassland	145
Sagebrush	52
Aspen	2

* Barren areas often contain sparse herbaceous vegetation and occasional small trees or shrubs.

4.3.2 Regional Context

Lassen contains a great variety of vegetation partly because it lies at the confluence of the Cascade Range, the Sierra Nevada, the Great Basin, and Klamath regions. The importance of the Klamath Region as a floristic center of diversity for western North America has been recognized in classic papers by Whittaker (1960, 1961) and Stebbins and Major (1965). This diversity is paralleled in other life forms, leading to the area being highlighted for its global biodiversity significance (DellaSala et al. 1999). The biological wealth of the region is generally attributed to the remarkable array of geologic parent materials and climates present (Wallace 1983). The young volcanic landscapes at Lassen contribute a unique element to this geological and corresponding biological diversity. The Lassen area also contains significant subalpine and alpine habitat. These are common in the Sierra Nevada to the south and Cascades to the north, and Lassen’s subalpine habitats provide a stepping stone between these two large areas of high elevations. Disturbances such as fire have also been instrumental in promoting vegetation diversity across the region (Taylor and Skinner 1998, Odion et al. 2004).

4.3.3 Issues Description

Issues pertinent to vegetation composition, structure, and function at Lassen include: 1) fire regimes, fire suppression and fuels management, 2) vegetation succession, 3) invasive plants, and 4) invasive pathogens. These are now discussed. In addition, impacts to vegetation from atmospheric pollution are discussed briefly in section 2.5.

<u>4.3.3.1 Fire Regimes, Fire Suppression, and Fuels Management</u>

Like most other forests of western North America, fire is a keystone ecological process at Lassen and in the surrounding environs of the southern Cascades (Taylor 2000, Bekker and Taylor 2001, 2010, Beaty and Taylor 2001). Also, as with many other western North American forested landscapes, there is a very high level of concern about the long-term effects of fire suppression and fire management in Lassen. The impacts of fire suppression and fire management are key components of this condition assessment. To assess the impacts requires understanding of the historical reference conditions for fire regimes at Lassen.

At many low- to mid-elevation forests in the western USA there are very strong concerns that fire suppression has led to substantially increased susceptibility of forests to uncharacteristically severe fire. However, Lassen contains mid-to upper elevation forests, and it is uncertain how the susceptibility to fire has changed in these forests. Susceptibility to uncharacteristically severe fire is related to both changes the likelihood of fire and the likely severity of fire that occurs.

Evaluating whether forests are more susceptible or not to severe fire depends on the historic fire regime. Where a low-severity regime operated, fires were frequent (<20 year recurrence interval) and this limited fuels and fire severity. Fire suppression has greatly reduced the likelihood of low-severity fire where low-severity fire regimes occurred historically, but the probability of high severity fire may have increased, as shown in Figure 7.

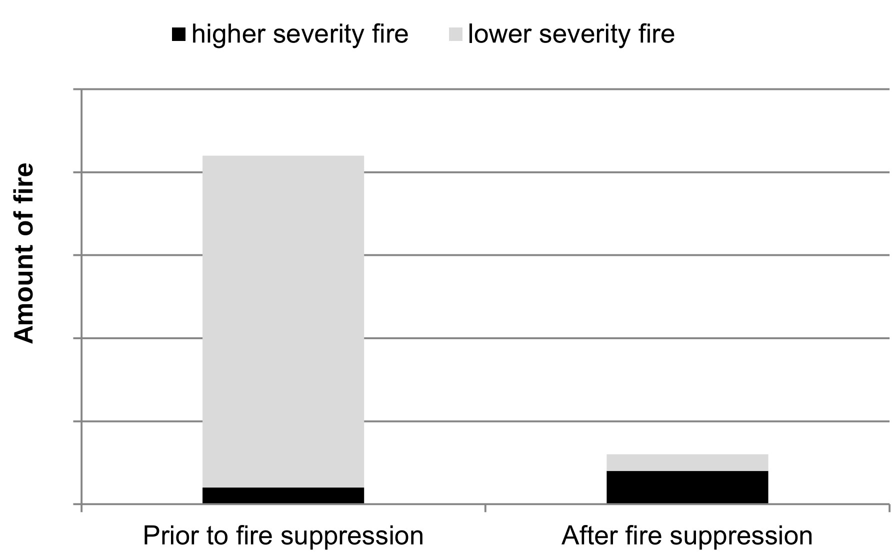

Figure 7. Hypothetical changes in the amount of higher and lower severity fire with fire suppression where a low-severity fire regime and steady-state conditions historically occurred.

In mixed-severity fire regimes (Baker et al. 2007: Table 1, Perry et al. 2011), fire operated in a patchwise and irregular fashion to cause instability of forest populations through disturbance, causing significant turnover in stands, or new stand initiation (Whittaker 1960). The effect of fire suppression in this case has been to generally reduce amounts of all fire: low-, moderate- and high-severity (Figure 8).

The transition between low- and mixed-severity fire regimes affected so differently by fire suppression may occur at elevations within Lassen National Park. We therefore evaluate the best evidence available to determine which historical fire regime occurred in different portions of the park in order to assess the changes in forest susceptibility to severe fire that have occurred with fire suppression.

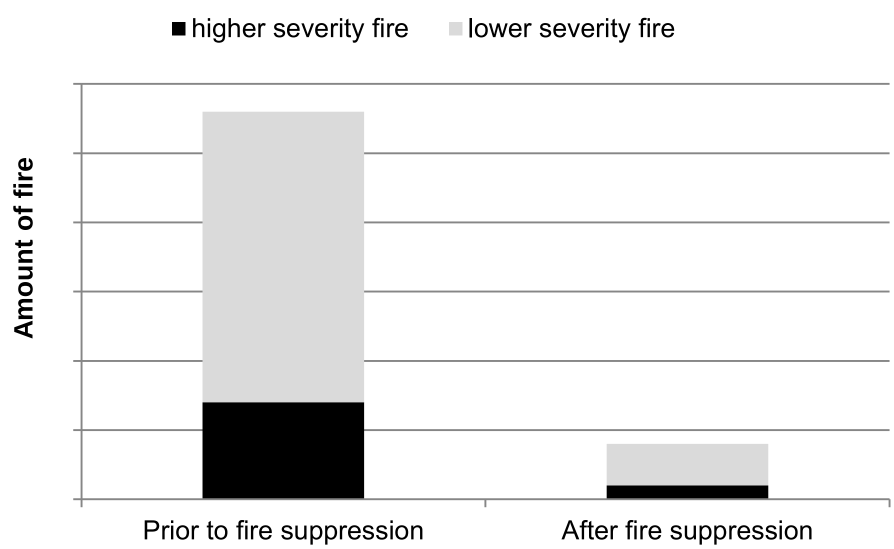

Figure 8. Changes in the amount of higher and lower severity fire with fire suppression under a historical model of mixed severity fire.

4.3.3.2 Climate Change and Fire

Changes to fire regimes that may be ongoing or occur in the future are particularly hard to predict due to ongoing climate change. Fire frequency in the Pacific Northwest has been found to track the Pacific Decadal Oscillation (PDO), at least since fire suppression became effective (Heyerdal et al. 2008, Morgan et al. 2008). PDO oscillates on a frequency of about 25 years. 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 four to five years (http://cses.washington.edu/cig/pnwc/aboutpdo.shtml). Thus, in the absence of other climate factors, fire in the Pacific Northwest should occur at lower amounts for the next couple of decades than it did in recent decades. However, the future behavior of PDO may be altered by climate change.

In terms of actual patterns in fire occurrence under changing climate, Miller et al. (2009) and Miller and Safford (2012) found that the severity of fires in the Sierra Nevada region has been increasing since 1984. Their study area included the Lassen area. However, these two studies used modern vegetation maps to identify forests that had burned. This approach will introduce a trend unrelated to fire severity that can make it appear that severity is increasing when it is not. This is because high severity fire causes forests to transition to early successional vegetation, such as chaparral. A current map may not identify areas of forest that burned at high severity in the past because such areas would currently be mapped as chaparral. This has the effect of deleting some of the conifer forest that experienced high-severity fire in the early years of the time series since 1984, but has not yet returned to conifer forest through natural succession. The result is that the amount of high-severity fire in conifer forest in the earlier years of the time series may be underestimated, creating the false appearance of an upward trend. Therefore, Miller et al. (2012) emphasize the need to use pre-burn vegetation mapping in assessing fire severity trends. Without such a trend analysis, the ongoing fire trends in the Lassen region remain uncertain. It should be noted that this region has seen some exceptionally severe fires in recent decades, such as the Moonlight Fire of 2007 and the Fountain Fire of 1993. However, large areas of dense, even-aged plantations burned in these two fires. Plantations are known to burn with much greater severity than unmanaged forests (Odion et al. 2004). This effect needs to be taken into account, along with weather, in explaining the behavior of these two extreme fires.

4.3.3.3 Vegetation Succession

Fire suppression can have a major influence on vegetation structure, composition, and function. The historic fire regime, with large amounts of moderate and high severity fire (Beaty and Taylor 2001, Bekker and Taylor 2001, 2010), would have favored the maintenance of aspen, Jeffrey pine, lodgepole pine, and chaparral. Historically, the establishment and maintenance of these vegetation types likely depended on mixed-severity fires that created patches of early successional vegetation. Aspen, pines, and chaparral species do not typically reproduce continuously under steady state conditions; they reproduce following stand-replacing events, mainly fire. Removing the regeneration niche for these vegetation types may therefore threaten their persistence on a site, although they may be resilient and come back if fire does eventually return.

There are concerns about loss of early successional vegetation at Lassen, in particular, aspen. Aspen (*Populus tremuloides*) is well-recognized as an early successional and disturbance dependent species in coniferous forest landscapes (Pierce and Taylor 2010). Growth of conifers into aspen stands in the absence of fire is a successional change that has been described in the southern Cascades by Pierce and Taylor (2010), and in Lassen by McCullough et al. (2012). Aspen may create an environment that facilitates conifer growth. For example, growth rates of conifers have been found to be faster in aspen stands than pure conifer stands (Peterson and Squiers 1995a,b). Once overtopped, the shade intolerant aspens release resources to conifers. Aspen do not maintain dormant seed banks and often reproduce by sprouting from roots. Thus, resiliency to long fire-free periods depends on the lifespan of root systems in declining stands as well as the availability of seed to disperse from surrounding areas. Reproduction from seed has been found to be common after high severity fire, even where no aspens were nearby (Romme et al. 2005). However, aspen have decreased in the area around Lassen as well. Establishment of aspen from seed is highest in the most severely burned areas. Greater fire severity not only promotes aspen seedling establishment, but helps prevent conifers from surviving in the stand to compete with the young aspens. At Yellowstone, the conifers killed by fire were also a key to survival of young aspens because downed branches and logs from these trees helped inhibit ungulate browsing (Ripple and Larson 2001, Turner et al. 2003). The ecology of aspen makes fire the best tool for restoring stands because mechanical removal of conifers could reduce the flammability of the stand, favoring conifers in the long run, and because removing the conifers will preclude their post-fire role in protecting young aspen growth.

Chaparral, like aspen groves, may be relatively quickly replaced by conifers in montane zones if not maintained by fire (Wilken 1967, Odion et al. 2004, 2010a, Nagel and Taylor 2005). Conifer succession may be facilitated by chaparral shrubs which reduce drought stress on conifer seedlings (Zavikovski and Newton 1968), and through provision of mycelia of mycorrhizal fungi shared with *Arctostaphylos* (Horton et al. 1999). Conifer succession may also be aided by the nitrogen fixing capacity of chaparral shrubs in the genus *Ceanothus* (Busse et al. 1996). However, the shrubs maintain dormant seed banks that can remain viable for centuries or millennia (Quick and Quick 1961), while manzanita seeds may be dispersed by mammals, which eat the berries. Thus, chaparral can be replaced by conifers on a site, but still be resilient following stand-replacing fire. However, the lack of chaparral over much of the landscape due to fire suppression means that species that are associated with chaparral for example birds and insects, along with the shrubs themselves will be present at much lower than characteristic amounts.

Like aspen groves and chaparral, meadow vegetation is shade intolerant and may be subject to establishment of conifers. While conifer encroachment into montane meadows is likely associated with reduced fire frequency (Taylor 1990), damage from historic grazing has also been a likely cause In fact, it may be difficult to separate historic grazing effects in meadows from effects of fire suppression because fire may not have burned nearly as frequently in meadows as adjacent forests. There are records of meadows burning from lightning fires, but they are rare (DeBenedetti and Parsons 1979). But this is related, at least in part, to fire suppression. It is not known how often historically fires burned from forests into meadows and then stopped; this cannot be determined from fire scars.

Soil compaction and erosion from livestock can cause downcutting in meadows along drainages and small streams. This can lower the water table such that the soil does not remain saturated to near the surface during the growing season, promoting conifers, as described for Sierran meadows (Wood 1975, Vankat and Major 1978, DeBenedetti and Parsons 1979, Odion et al. 1988, Sarr 1995). This can be a subtle effect; it need not require deep meadow incision. It may be exacerbated by removal of beavers. Conifers can more readily grow on the meadow margins when the water table is lowered. Conifer succession may also be facilitated by burrows of fossorial mammals (marmots, voles), which bring mineral soil to the surface. Conifer germination and initial survival may depend on these environments.

An additional concern about fire suppression impacts involves forest vegetation. There has been a shift towards increasing forest dominance by shade tolerant fir species (Taylor 2000). With periodic fires, establishment of firs and growth into the forest overstory would have been more limited than it is with fire suppression. This effect is most common in western forests where fire suppression and historical logging have both occurred (Naficy et al. 2010), but could also have been facilitated by historical grazing. Increased atmospheric CO_2 could be related to increased forest density as well; growth rates of trees in drier western coniferous forests have increased due to CO_2 (Soulé and Knapp 2011). Forests in the Pacific Northwest, particularly in upper montane zones, have increased growth rates in recent decades (Latta et al. 2010), despite warming temperatures.

4.3.3.3 Invasive Plants

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. In many regions, invasive species are second only to habitat loss as a threat to native biodiversity (Wilcove et al. 1998). Impacts from invasives that can severely degrade native ecosystems 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 alteration of disturbance regimes (Mack and D'Antonio 1998).

While not all non-native species are invaders that threaten native species, across the Klamath Network the number of non-native species declines sharply from low elevations of Whiskeytown to the higher elevations at Lassen (Figure 9). This pattern has been well-established in other studies in California (Mooney et al. 1986, Rejmanek and Randall 1994, Schwartz et al. 1996, Keeley et al. 2011). The question here is: Does this mean that Lassen may be relatively immune from invasive plants?

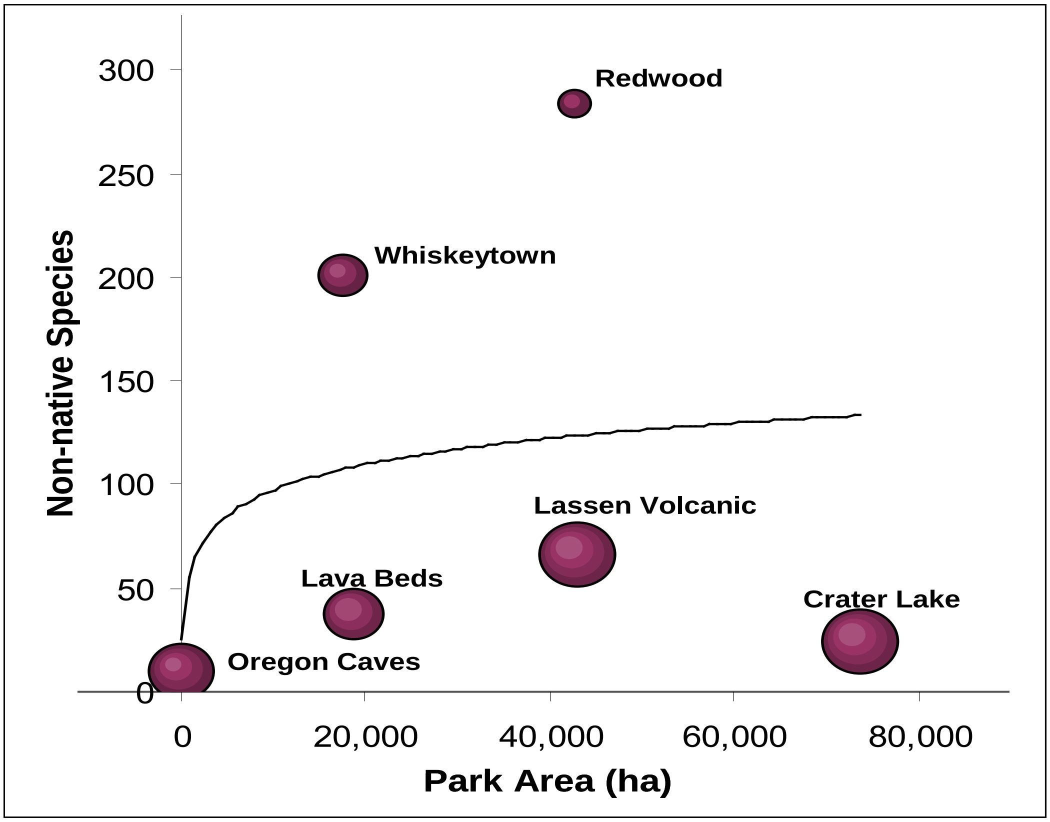

Figure 9. Non-Native Plant Species Richness as a Function of Park Area and Elevation in the Klamath Network. A logarithmic line illustrates the expected species/area relationship across park sizes, and oval size is proportional to mean park elevation. The lower elevation parks have more nonnative species than expected for their size, whereas higher elevation parks have fewer recorded species.

We reviewed the physiological tolerances of invasive plants that are present or expected in all Klamath Network Parks (Odion et al. 2011, Odion and Sarr 2012). We found that Lassen may be more vulnerable to invasive plants that are ecosystem transformers than the current low levels of invasion may suggest. The analysis appears to support concerns about invasive plants at Lassen and the use of invasive plants as an indicator of ecosystem condition in this park. The invasive species of greatest concern that are still controllable because they have not established are shown in Table 5. Equilibrium species, some of which will be subject to control efforts if found in backcountry areas, are shown in Table 5.

Table 5. Invasive plants of greatest concern at Lassen National Monument as determined by the prioritization process used by the Klamath Network and involving park resource staff (Odion et al. 2011). The ranking is based on a semi-quantitative 0-1 score. The species on this list are invaders that are considered capable of transforming ecosystems. Species in the colonization phase may have been recorded, but are not yet established in the park. Species in the establishment phase have one to a few relatively small, localized populations within Lassen Volcanic National Park.

Scientific Name	Common Name	Invasion Phase	Ranking Score
Taeniatherum caput-medusae	Medusahead	Colonization	0.920
Lythrum salicaria	Purple Loosestrife	Colonization	0.901
Genista monspessulana	French Broom	Colonization	0.895
Cytisus scoparius	Scotch Broom	Colonization	0.875
Centaurea solstitialis	Yellow Starthistle	Colonization	0.873
Euphorbia esula	Leafy Spurge	Colonization	0.866
Centaurea maculosa	Spotted Knapweed	Colonization	0.854
Onopordum acanthium	Scotch Thistle	Colonization	0.848
Bromus tectorum	Cheatgrass	Establishment	0.827
Rubus armeniacus	Himalaya Berry	Establishment	0.823
Lepidium latifolium	Broadleaved Pepperweed	Establishment	0.812
Phalaris arundinacea	Giant Reed Grass	Establishment	0.798
Halogeton glomeratus	Halogeton	Colonization	0.789
Isatis tinctoria	Dyer’s Woad	Colonization	0.770
Carduus pycnocephalus	Italian Thistle	Colonization	0.769
Hirschfeldia incana	Mediterranean Mustard	Colonization	0.755
Centaurea diffusa	Diffuse Knapweed	Colonization	0.750

Table 6. Equilibrium species in Lassen Volcanic National Monument and status of species which will or will not be monitored in the backcountry by the Klamath Network Inventory and Monitoring Program.

Scientific Name	Common Name	Ranking Score	Monitor in Backcountry?
Cirsium vulgare	Bull Thistle	0.679	Yes
Verbascum thapsus	Common Mullein	0.655	Yes
Tragopogon dubius	Goat's Beard	0.595	Yes
Vulpia myuros	Vulpia	0.550	No (control infeasible)
Poa pratensis	Kentucky Bluegrass	0.530	No (control infeasible)
Lactuca serriola	Wild Lettuce	0.496	No (control infeasible)
Taraxacum officinale	Dandelion	0.494	No (control infeasible)
Poa annua	Annual Bluegrass	0.421	No (control infeasible)
Plantago lanceolata	English Plantain	0.414	No (control infeasible)
Plantago major	Common Plantain	0.404	No (control infeasible)

4.3.3 4 Extent of Invasive Pathogens (Condition of Subalpine Vegetation

The outstanding non-native species and plant pathogen of concern at Lassen is the blister rust fungus (*Cronartium rubicola*). It is the only plant pathogen we treat in this condition assessment, although it is important to note that there may be more pathogens arriving in the future. Blister rust is the main factor impacting the condition of the park's subalpine vegetation, particularly whitebark pine, which was a top management concern raised by the park. The Klamath Network identified whitebark pine as a vital sign of ecosystem health to monitor and has initial monitoring results (Smith et al. 2011, Erik Jules, pers. comm.).

Blister rust forms rusty looking lesions, or cankers, of dead tissue that girdle tree boles or stems. The rust affects 5-needle white pines; at Lassen, these include not only whitebark pine, but sugar pine (*Pinus lambertiana*) and western white pine (*P. monticola*). Present concerns are mainly the impacts to whitebark pine. Impacts to the other species have already occurred and are no longer a major concern.

To complete its life cycle, the rust fungus must disperse from the pines to an alternate host, a shrub in the genus *Ribes* (currant and gooseberry) or the herbs *Castilleja* (Indian paintbrush) and *Pedicularis* (lousewort) (Geils et al. 2010). Removal of alternative hosts is one approach that has been taken in an attempt to manage the disease, with generally little success and with potentially adverse effects on important wildlife species.

Preliminary assessments of 2012 monitoring data suggest that blister rust infections may be more common than previously believed at Lassen. Jules et al. (2012) found that white pine blister rust infected 53% of whitebark pine at Lassen. Future monitoring by Dr. Jules and colleagues, in collaboration with the Klamath Network Inventory and Monitoring Program, should help clarify the status and trends in blister rust in whitebark pine.

Concern about blister rust in whitebark pine stems from its role as both a foundation and keystone species in high-elevation forest communities where it dominates. It can regulate ecosystem processes, community composition and dynamics, and it influence regional biodiversity (Tomback and Kendall 2001, Ellison et al. 2005). Whitebark pine plays a role in initiating community development after fire, influencing snowmelt and stream flow, and preventing soil erosion at high elevations (Farnes 1990, Tomback et al. 2001). Perhaps most importantly, the large, wingless seeds of whitebark pine are high in fat, carbohydrates, and lipids and provide an important food source for many granivorous birds and mammals (Tomback and Kendall 2001). In particular, Clark's nutcracker (*Nucifraga columbiana*) has developed a mutualistic relationship with the pine (Tomback et al. 2001). Nutcrackers decrease in whitebark stands as tree mortality increases (McKinney et al. 2009). Whitebark pine also provides important habitat structure for high-elevation vertebrates. For example, white-tailed jackrabbits (*Lepus townsendii*) have been documented using dense, low-growing whitebark pine mats for shelter in the Sierra Nevada. This once common mammal has become rare in the Sierra Nevada, the southernmost portion of its range (http://www.sibr.com/mammals/M050.html)

Smith et al. (2011) discuss possible implications of climate change for future levels of blister rust. They suggest that such implications could be quite complex because they may operate through both direct and indirect mechanisms. There are also complicating factors. In particular, warmer temperatures in recent years have allowed mountain pine beetles (*Dendroctonus ponderosae*) to shift to and persist in higher-elevation forests (Logan 2010). Murray (2010) reported that mountain pine beetle is now the primary cause of whitebark pine mortality at Crater Lake National Park, and it appears that this is the case at Lassen as well (Jules et al. 2012).

Whether the beetle affects the susceptibility of whitebark pines to blister rust, or vice versa, is not known. Bockino and Tinker (2012) found that whitebark pine trees which were selected as hosts by mountain pine beetles exhibited significantly greater blister rust severity than trees that were not selected. Other indirect effects could occur if climate increasingly favors or inhibits blister rust. For example, the rust favors moister conditions, and increased precipitation in winter is a possible trend under climate change in the Pacific Northwest. Direct effects of climate could favor the pines, as many high-elevation trees are growing more rapidly today (Bunn et al. 2010). However, more rapid growth of other high-elevation tree species could act as an indirect effect that places the pine at a competitive disadvantage, especially if whitebark pine cannot migrate quickly enough to avoid being displaced by superior competitors with more rapid growth potential, such as mountain hemlock (*Tsuga mertensiana*) and noble fir (*Abies procera*). These trees are quite dense in many whitebark pine stands.

4.3.3.5 Rare Plant Species and Species Diversity

Many plant species are rare within the park but are found rather widely outside the park boundaries. Others that occur within the park are rare throughout the region and thus are major contributors to biodiversity measured at a landscape or regional scale. Some Lassen species will be lost through natural processes that influence species turnover, while the unintentional loss of others could occur directly or indirectly as a result of climate change or management practices.

Vegetation in the park may also be sensitive to elevated levels of ozone and to deposition of atmospheric nitrogen and sulfate. These are discussed in section 2.5.

4.4 Indicators and Criteria to Evaluate Condition and Trends in Vegetation

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

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

Indicator	Conditions Tracked
Stand age distributions	Fire regimes, vegetation dynamics
Fire rotations	Fire regimes, vegetation dynamics
Abundance of major vegetation types	Broad vegetation types
Invasive plants	Vegetation/ecosystem transformation
Invasive pathogens	Vegetation/ecosystem transformation
Rare plants and diversity of native plants	Climate change, natural succession

4.3.4.1 Distribution of Stand Age Classes

The distribution of stand ages in a landscape that has not been logged can illustrate whether low- or mixed-severity fire regimes occurred historically (Figures 7, 8), and the departure from historic vegetation structure as shaped by fire. Using the stand age distributions as a measure of vegetation condition is consistent with recommendations for using a statistical distribution to describe reference conditions for an indicator rather than relying on mean or median values (Stoddard et al. 2006). A comparison on the current distribution of stand ages with a distribution unaffected by fire suppression provides an explicit illustration of how stand ages have changed with fire suppression. When coupled with an understanding of vegetation succession, the changes in vegetation age provide a model of landscape change.

Figure 10 shows the stand-age distributions that would exist where a low-severity regime historically occurred. In this distribution, most stand ages reflect the maximum lifespan of trees because stand-initiation by fire has not occurred. Therefore stands will mostly be several centuries old. However, an increase in fire severity due to fire suppression in recent decades would lead to some young stands being created, as also shown in Figure 10. Conversely, Figure 11 shows the stand-age distribution that would exist where mixed-severity fire regimes occurred historically. Prior to fire suppression, stand-initiation would have occurred continuously, creating mostly stands whose initiation occurred in the decades prior to fire suppression. The effect of younger stands in erasing older stands causes a long statistical tail, with relatively few stands as old as the ones that dominate in a low-severity regime.

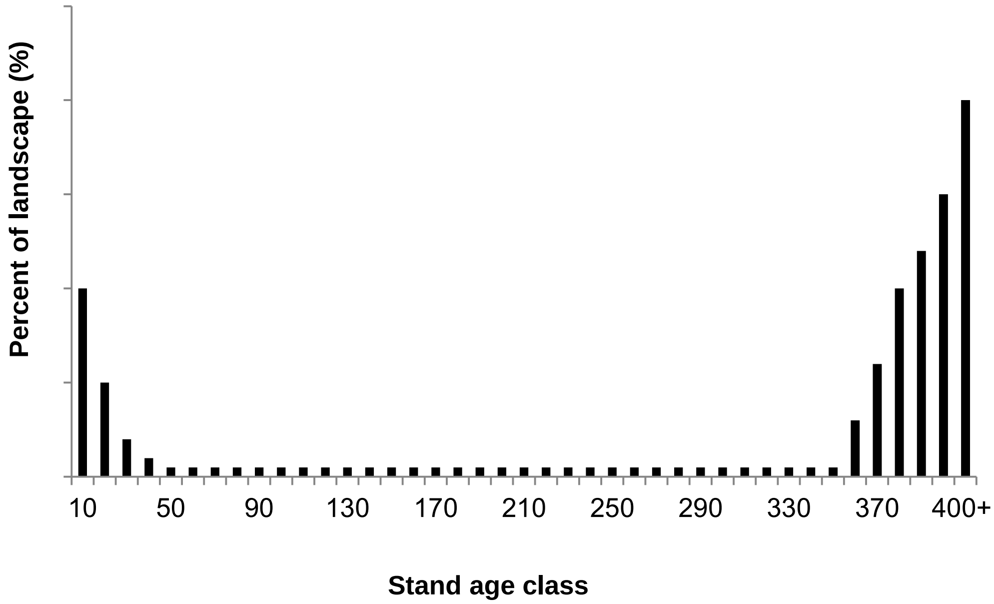

Figure 10. Theoretical stand age distribution in forests affected by a low-severity fire regime and an increase in susceptibility to more severe fire in recent decades due to fire suppression.

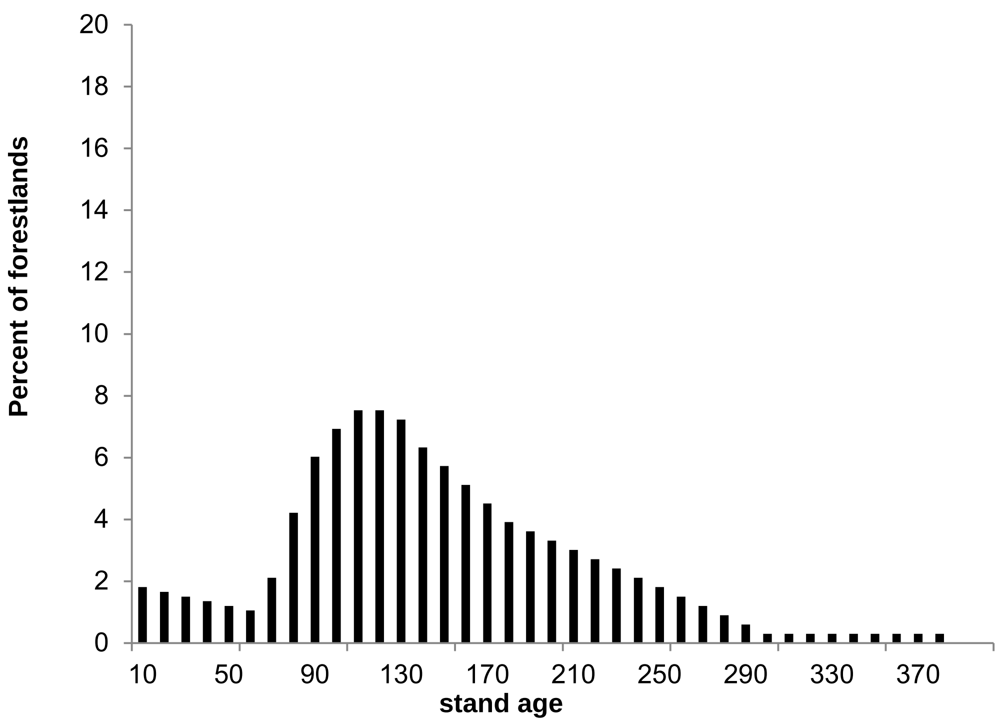

Figure 11. Hypothetical stand age distribution for forests affected by a mixed-severity fire regime and 70-90 years of reduced fire due to fire suppression.

Criteria

Good condition would be current stand ages in unlogged areas that appear to be similar to historical stand ages. Little effect of fire suppression would be apparent in the age class distribution. *Somewhat Concerning* would be stand-ages moderately altered by fire suppression. *Significant Concern* would be stand-ages substantially altered by fire suppression.

Condition and Trends

The condition and trend for the stand age indicator are rated *Significant Concern*. Stand age analyses indicate that mid-to upper elevation forests in the southern Cascades and nearby Sierra Nevada were shaped by mixed severity fire because stands were initiated continuously prior to fire suppression (Figure 12).The substantial reduction in stand-initiation with the onset of fire suppression in the early 1900s is consistent with fire being a dominant process causing stand-initiation, otherwise we would expect little impact of fire suppression on stand ages. The occurrence of a mixed-severity fire regime is also supported by literature reviewed in the next section (Beaty and Taylor 2001, Bekker and Taylor 2001, 2010, Hessburg et al. 2007, Baker 2012), and the loss of early successional vegetation as described in section (4.3.4.3).

Since the onset of fire suppression, landscape vegetation patterns have been shaped far less by fire. Figure 12 clearly shows that the probability of stand-initiation by fire is much lower with fire suppression than it was historically. As a consequence, stands younger than 80 years are currently substantially underrepresented compared to a scenario in which fire suppression never occurred (gray bars), while, stands 80-200 years are overrepresented. With no fire suppression, many of these intermediate-aged stands would have been erased by more recent stand-initiation fires. Stands over 200 years are about the same as occurred historically.

Certainty is rated as medium because we relied on regional data rather than data specific to the park. To obtain a large enough sample size of stand age data, we used data from U.S. Forest Service Inventory and Analysis (FIA) plots from lands *that have never been managed for timber production* throughout the southern Cascades and nearby Sierra Nevada (see Appendix C for methodological details).). Only plots from the same forest types were selected, and these occurred in similar proportions as the forest types occur presently in Lassen (Appendix C).Fire regimes in areas protected from timber management in this region, like those in this park, have been affected by similar disturbance regimes, as well as fire suppression management as has occurred in the park. Nonetheless, there may be important differences between the park and neighboring areas supporting the same forests. For example, the existence of barren areas (e.g., historic lava flows, etc.) at Lassen could reduce historical fire frequency and severity in some areas.

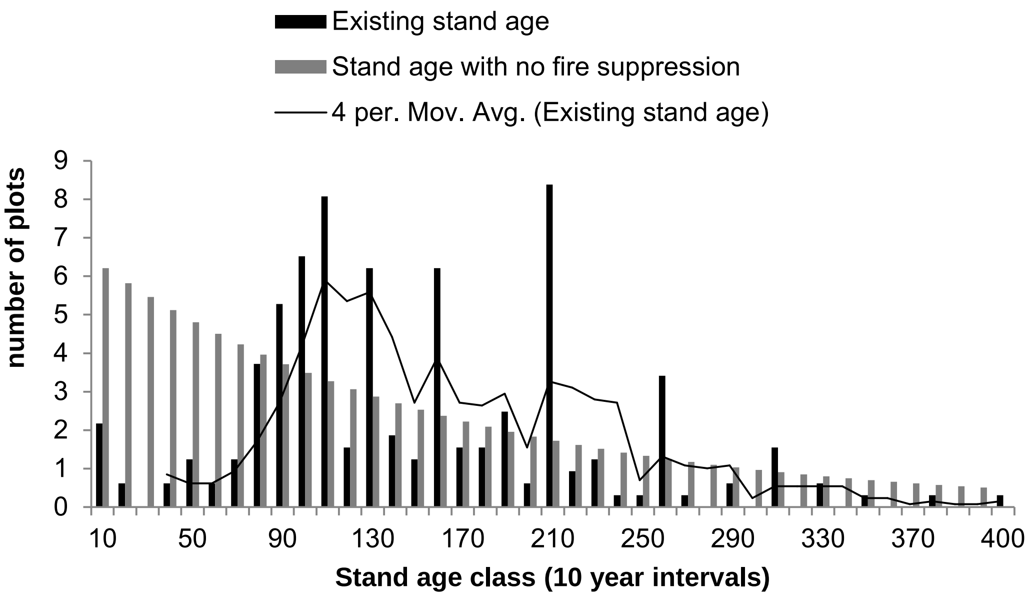

Figure 12. Never-managed forest stand age distribution in the upper montane zones of the eastern Cascades (black bars), compared with the theoretical distribution that would be present had pre-suppression fire disturbances not been interrupted by fire suppression (gray bars).

There are a variety of ecological effects caused by the suppression of mixed-severity fire. Lack of mixed-severity fire leads not only towards older age class distributions, but also greater homogeneity as younger age classes are diminished and intermediate-aged stands become overrepresented compared to historical stand age structure. Suppression of mixed-severity fire also leads to a lack of complex early successional vegetation created by fire (e.g., Swanson et al. 2011). Thus, chaparral, Aspen forests, and young conifer forests have been lost. These are major resource management concerns already identified by the park.

For fire and stand age conditions to reverse themselves and the former patterns to return, an order of magnitude more wildfire than presently occurs over a period of about 80 years would need to occur (see next section on fire rotations). About half of all forests in the park would have to burn with stand-initiating fire over that time. Planned prescribed burns are very constrained in area and are mostly limited to surface fires. Logging does not recreate complex early seral conditions, down wood to protect aspens from undulates, standing snags and down wood to promote aspen growth and wildlife, and it raises complex ethical issues in a National Park.

Wildland fire use (allowing unplanned fires to burn) is also constrained for pragmatic reasons (see discussion above in section 2.4.3.1). Thus, the trend of greatly reduced mixed-severity fire and stand-initiation will likely continue. In addition, much park fire management aims to reduce the behavior of fire, which would further move conditions away from those that occurred historically. However, the effects of fire suppression and fuels management in reducing mixed-severity fire might be reversed, at least in part, by the effects of climate change, although there is much uncertainty about how this will play out (see discussion above in section 4.4.3.1).

Assessment Confidence and Data Gaps

Medium. As mentioned above, most of the available information about past range of variation in stand ages comes from an area that is much broader than the park. In addition, as with nearly all ecological changes, there are both detrimental and beneficial effects. Suppression of fire is unnatural, but does lead to more area of dense, late-successional forest, which benefits species like northern spotted owls and fishers.

The assessment based on this indicator is also limited by the fact that stand ages are approximations. Some older stands may not have been initiated by fire disturbances and estimates of their ages may have been based on trees that germinated without disturbance. Nonetheless, the shift in age classes due to fire suppression is quite substantial and not a function of age uncertainty of old stands. The general effects of fire suppression indicated by stand age analysis are consistent with expectations from literature on historical fire regimes in the eastern Cascades and southern Cascades (Hessburg et al. 2007, Beaty and Taylor 2001, Bekker and Taylor 2001, 2010, Baker 2012).

Future amount of stand-initiating fire will be monitored under the land-use, land cover protocol of the Klamath Network Inventory and Monitoring program. Monitoring status and trends in the amounts of early successional vegetation is difficult with plot data because a large number of plots randomly located throughout the park would be required. There is no plot monitoring program in the park that accomplishes this.

Another approach to assessing the loss of mixed-severity fires is to use a species which depends on early successional habitat created by such fire, such as the black-backed woodpecker. This species is a management indicator for the National Forests of the Sierra Nevada region that surround Lassen. We describe park conditions based on this indicator in the wildlife section (2.2.4.1). In addition, the next two indicators provide information about altered fire regimes and resulting consequences to vegetation.

4.3.4.2 Fire Rotations

The fire rotation is the amount of time needed to burn an area of interest one time. It is equivalent to the mean fire frequency for the entire landscape of interest. These properties make the fire rotation the best measure for comparing rates of fire across landscapes or time periods (Baker 2009, Miller et al. 2012). The fire rotation for a landscape often differs from the mean fire interval, or frequency of fire, estimated from fire scars somewhere within that same landscape.[11]

[11] This can occur because the fire scars are rarely probabilistic samples (i.e., the target population they provide inference for is, except in a few cases, not the whole landscape ; Johnson and Gutsell 1994), and they are usually sampled from small areas. In addition, the frequency of fire measured from fire scars is a composite of fires that each differ in the amount of area burned and the area is often unknown. In such a composite measure of fire frequency, the frequency increases by increasing the area studied. For example, in studies of Jeffrey pine in Baja California, Minnich et al. (2000), found a fire rotation or mean fire interval for the landscape of 52 years. A fire scar study in the same landscape found a fire frequency of about 16 years over the same time period (Stevens and Olsen 2004). Therefore we use fire rotation here as a standard that allows comparison of the specific amount of fire affecting a landscape over time.

The rotation is estimated by summing the areas of fires observed over the specified area and period of time, then dividing the period of time by the fraction of the specified area that burned. For example, if 1000 hectares of a 3000 hectare area burns in 20 years, the fire rotation is calculated as: 20 years/(1000/3000) or 60.6 years. Typically, some of the areas that burned will have burned more than once and other areas not at all. The fire rotation can be calculated for particular kinds of fire, such as low or high severity fire (Odion and Hanson 2006) and can also be estimated from stand age data (Johnson and Gutsell 1994).

We calculated current rotations of fire since 1984, the earliest year available from the "Monitoring Trends in Burn Severity" (MTBS) program, to compare with fire rotations from prior to fire suppression. We also calculated the rotation for high severity fire. We obtained fire severity data from the federal website MTBS.gov. We used data from 13 fires that occurred in Lassen or within 30 km of Lassen. We included area outside the park because relatively little fire severity data from Lassen was available.

Criteria
"Good" condition would be current fire rotations that appear to be similar to historical fire rotations. There would be little effect of fire suppression apparent on the length of fire rotations. "Somewhat Concerning" would be rotations moderately altered by fire suppression; "Significant Concern" would be rotations substantially altered by fire suppression.

Condition and Trends
Both condition and trend for this indicator are rated *Somewhat Concerning – Medium Certainty*.

Since 1984, a total of 19,260 ha have burned in the park out of 38,847 ha of burnable vegetation (mainly forest). The rotation over this time period is therefore (28 years/19260/38,847) = 56 years. Notably, prior to the occurrence of the Reading Fire in 2012, the fire rotation was considerably longer: 85 years. The park's condition benefited from this fire and management that allowed it to cover as much area as it did.

Table 8 shows pre-suppression rotations calculated from landscapes near Lassen. A 56 year rotation is slightly longer than the ranges calculated for all fire in mid-montane forests in these nearby landscapes and within the range for upper montane forests. Moreover, expanding the time period of reference would broaden the range of variability in past fire (Whitlock et al. 2010). The current rotation may therefore be within a more expansive natural range of variation for mid-montane forests and well within the historical range for upper elevations.

There are specific locations where more frequent occurred historically as measured by fire scars (e.g., Table 8: Point Fire return intervals). There are no areas of the park, except perhaps some prescribed burn units, where such repeat surface fires have occurred. However, it is impossible to know the locations in the landscape to which the frequent surface fire locations may apply (Johnson and Gutsell 1994)[12].

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[12] These are not probabilistic samples of the whole landscape because not every tree/location has an equal probability of being sampled because certain trees must be selected (Johnson and Gutsell 1994). The samples best describe the area immediately around the point location. Statisticians for the Inventory and Monitoring Network encourage greater reliance on data collected by probabilistic sampling when making inferences especially at a landscape scale (see Stevens and Olsen 2004).

Table 8. Mean fire frequency prior to fire suppression from studies in the northern Sierra Nevada and southern Cascades.

Forest Zone	Forest Types	Fire Rotation Interval from Mapped Fires (yrs)	Point Fire Return Interval (yrs)	Source
Mid-montane	white-fir, sugar pine, Jeffrey pine	22-50	7-55	Bekker and Taylor (2001)
	white fir, ponderosa pine, red fir	17-43	5-108	Beaty and Taylor (2001)
Mid-upper montane	white-fir, Jeffrey pine, red-fir	46-147	4-91	Bekker and Taylor (2001)
	Jeffrey pine, white fir, red fir (Prospect Peak, Lassen NF)	17.1-75.9	9.5-109	Taylor 2000

We estimated a high severity rotation of 784 years since 1984. This can only be considered a rough estimate of the amount of high-severity fire presently occurring in the park. Notably, the high-severity rotation would have been 1177 years without the Reading Fire. The 784 year estimate is, however, consistent with the calculation of the rotation based on stand-initiation from the stand-age data, which was 700-800 years over the time period 1940-2009.

The high severity fire rotation is more than twice as long as the rotation for high severity in the two nearby studies by Taylor and colleagues which provide the best published information on the pre-suppression variability in fire behavior[13] (Table 9). The current high severity rotation is also more than twice as long as the 155 year historic high-severity rotation calculated from the stand age data. It is possible that wildfires have been more severe in Lassen than surrounding areas from which much of the fire severity data originate (meaning our rotation estimate is high). However, much of the fire in Lassen since 1984 (40% since 1989) has been prescribed fire, which is generally low severity. Thus, it is possible the rotation is short (i.e., there is actually less high severity fire since 1984). The rotation is consistent with the finding that stand-initiating fire in the region is much less frequent than it was historically, as illustrated by the near cessation of stand-initiation (Figure 12). This is also consistent with concerns about loss of early-successional vegetation like aspen and chaparral.

[13] The amount of moderate and high severity fire they found over a specified time period of analysis can be used to calculate the rotation of moderate and high severity fires prior to fire suppression, which can be compared with modern rates of such fire. The rotation is calculated as the number of years moderate and high severity fire were detectable divided by the percentage of the landscape burned by moderate and/or high severity fire.

Table 9. Fire rotations from studies of small landscapes in the southern Cascades adjacent to Lassen National Park.

Study Location and size (km^2)	Source	Forest Type	Type of Fire	Pre-suppression Rotation (years)
S. Cascades near Lassen	Bekker and Taylor (2001)[2]	Jeffrey pine, white fir, and red fir	Low severity‡	24-91
			High/moderate severity†	111-225
			High severity*	165-210
S. Cascades near Lassen	Beaty and Taylor (2001)[3]	Mixed conifer, white fir, red fir, Douglas-fir and ponderosa pine	Low severity‡	19-89
			High/moderate severity†	83-114
			High severity*	101-394

*"High severity" <10 emergent trees/ha remaining after fire.

†High" and "moderate" severity = <20 emergent trees/ha remaining after fire, which may be considered high severity fire according to many definitions.

‡Low severity rotation obtained by subtraction of the high and moderate severity rotations from the rotation for all fire (the percentage of the landscape affected by low severity fire does not include any low severity fire that may have occurred in areas that burned at moderate and high severity).

[2]High and moderate severity rotation based on proportion of landscape affected from 1864-1939. These fires occurred predominantly in the 1800s. The 75 year time period from 1864-1939 started and ended on large fires. This time period was therefore bracketed by ½ of an average rotation interval for all fire (33 years) to produce a 109 year time period/fraction burned to calculate rotation. The range in rotations reflects the minimum and maximum rotations from different forest types (Table 2 of Bekker and Taylor 2001).

[3]High and moderate severity rotation based on proportion of landscape affected from 1883-1926 (fires were consistent through this whole period). The 43 year time period from 1883-1926 started and ended on a large fire this time period was bracketed by ½ of an average rotation interval for all fire (28.2 years) to produce a 71 year time period/fraction burned to calculate rotation. The range in rotations reflects the minimum and maximum based on different slope/aspect categories (Table 8 of Beaty and Taylor 2001).

Both Bekker and Taylor (2001, 2010) and Beaty and Taylor (2001) found that, over only several decades to a century, most area had been affected by fires where fewer than 20 emergent trees/ha could be observed. Although 10-20 emergent trees was considered "moderate severity," this would still be consistent with stand-renewing fire in forests where up to several hundred remaining trees/ha may be the norm. Bekker and Taylor (2010) in particular emphasize the dominant role played by severe fire with high levels of tree mortality.

As discussed in the previous section, the suppression of low-, moderate-, and high- severity fire will cause a loss of earlier successional vegetation and age class diversity. In addition, older pine stands become increasingly dominated by shade-tolerant firs. These changes are evident from the comparison of the 1930s historic vegetation map and more current mapping (see section 4.3.4.3). In addition, the dead trees created by high severity fire are important disturbance legacies for biodiversity that also reduce the environmental stress and magnitude of a disturbance (Odion and Sarr 2007). In particular, the standing dead trees left by fire are critical for species such as black-backed woodpecker, an indicator used in this assessment.

For high-severity fire rotations to return to more historical levels, an order of magnitude more wildfire than presently occurs would need to occur. Planned prescribed burns are very constrained in area. For example, if only prescribed burns were occurring, the fire rotation would be 112 years. The limitations on the amount of area that can be burned by prescribed fire are often beyond the control of the park (e.g., air quality restrictions). In addition prescribed burns and are limited to mainly surface fire effects.

Assessment Confidence and Data Gaps
Medium. There are important limits to the data. Unfortunately, most existing data for reconstructing fire regimes capture only a portion of the variability in a fire regime (Whitlock et al. 2010). There would be greater variation detected in fire frequency and behavior if we could assess a longer record. In addition, published fire rotations consider only small landscapes (Beaty and Taylor 2001; Bekker and Taylor 2001, 2010; Taylor 2000) and the time period used for assessing high severity fire was far shorter than the rotation for high severity fire.

Future amount of stand-initiating fire will be monitored under the land-use, land cover protocol of the Klamath Network Inventory and Monitoring program. Monitoring status and trends in the amounts of early successional vegetation is difficult with plot data because a large number of plots randomly located throughout the park would be required. There is no plot monitoring program in the park that accomplishes this.

4.3.4.3 Changes in Abundance of Major Vegetation Types
To evaluate how major vegetation types maybe shifting in abundance during the last 75 years due to successional processes, we performed a quantitative change detection study, comparing a historic (circa 1930s) vegetation map to a modern one. Figure 13 shows the 1930s Vegetation Type Map (VTM) vegetation map and the current map. The VTM map is not as spatially detailed as the current map. Neither map has had a quantitative accuracy assessment. The VTM maps are considered very accurate due to the extensive field work done to support them. The current map was done to the standards of the National Park Service Vegetation Mapping Program, and therefore is likely to be very accurate (>80%) as well.

Criteria
Good condition would be vegetation change is occurring, but which is not causing a net directional replacement of one vegetation type for another. In other words, processes like transition to late-successional vegetation are generally matched by transition to early successional vegetation, resulting in a steady state when the whole park landscape is considered. *Somewhat Concerning* and *Significant Concern* would represent increasingly greater amounts of directional vegetation change or "ecological drift."

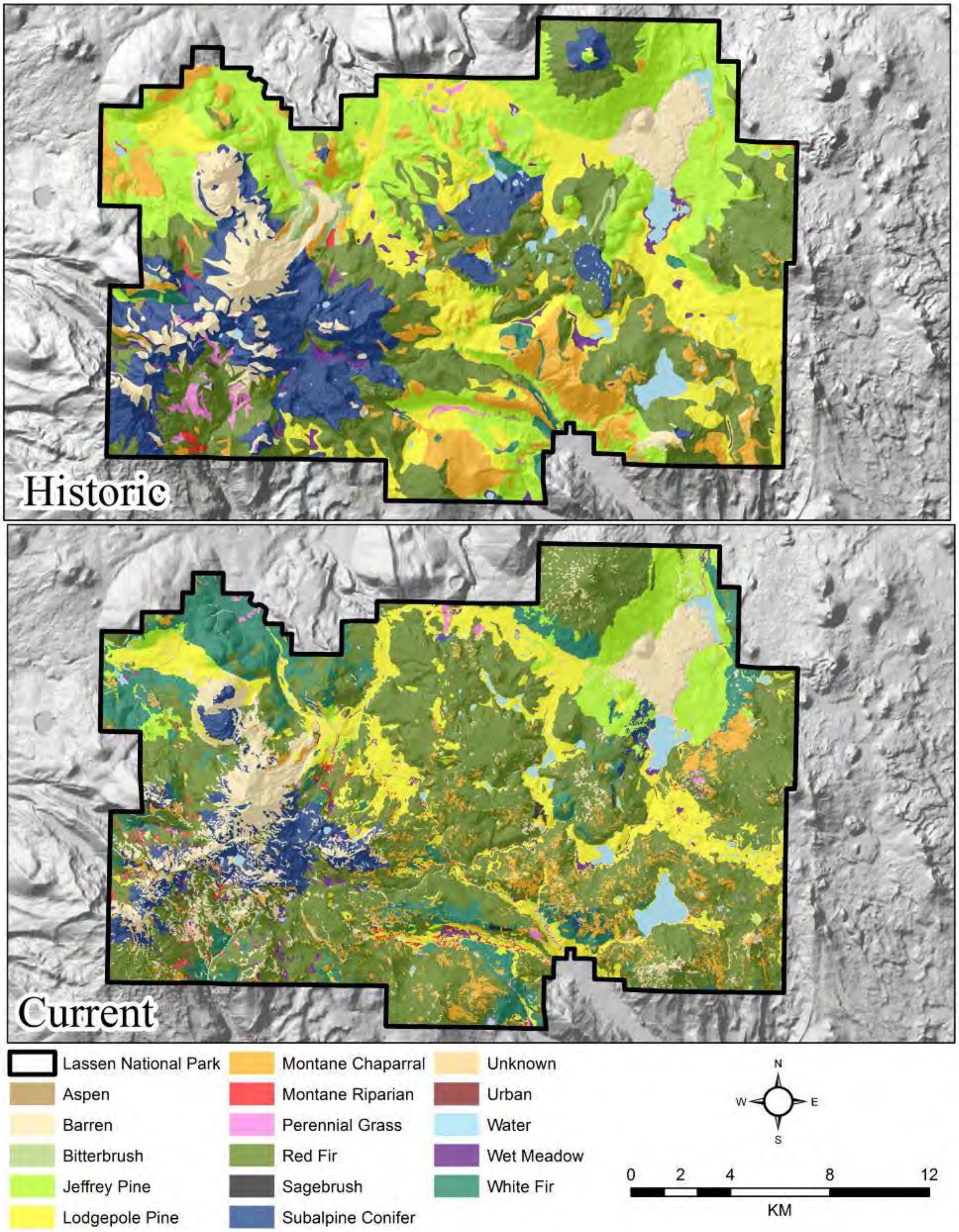

Figure 13. The VTM map for Lassen (circa 1930) and the current vegetation map. Both have been crosswalked to a common cover type classification.

Condition and Trends

We provisionally assign a condition of *Somewhat Concerning – Medium Certainty* for the vegetation indicator. There have been substantial changes in some vegetation, as described below under trends. In particular, early successional vegetation has decreased markedly and it has been replaced by later-successional forests, with increasing dominance by species of fir.

However, some of these changes may be slowed by an increase in fire with warming temperatures. In addition, the loss or early successional vegetation must be weighed against the gain of conifer vegetation, and especially the late successional stage of conifers. Although these changes are related to management, they have benefits for a number of species of concern that have declined regionally due to loss of late successional forests from logging (SNEP 1996). The late-successional forests at Lassen are important to regionally threatened species like spotted owl, fisher, and marten.

Table 10 summarizes the vegetation transitions based on comparison of the VTM map and the current vegetation map. The first data column shows the historic vegetation and the second column the current extent of the same vegetation type. The rows provide the area of current vegetation into which the historic vegetation transitioned, while the columns provide the historic vegetation from which the current vegetation transitioned. The concordance between the areas mapped as lakes between the two time periods is an indication that the differences between the two time periods are minimally related to the difference in base maps used and the processing of the VTM map. There are a number of striking vegetation transitions that have occurred that are not explained by differences in vegetation classification between the maps. These transitions are highlighted in light green in Table 10; each is discussed below.

Table 10. Changes in area of broad vegetation types in Lassen Volcanic National Park, circa 1930 to present. Units are square km. Current vegetation classes are based on the 2007 vegetation map prepared by James von Loh, but using the classification of Wildlife Habitats (WHR) from the California Vegetation Map (Cal-Veg) prepared by the USDA Forest Service http://www.fs.fed.us/r5/rsl/projects/frdb/layers/ev_mid.html. Historical vegetation is from the Wieslander Vegetation Type Map (VTM) surveys.

Analysis 3																		
Combined ADS and SCN. Plus combinations from Analysis 2. Changed Lupine and Wyethia mollis to Barren in vtm this version. O																		
			Current vegetation															
Historic vegetation	Historic Km^2	Current Km^2	Aspen	Barren	Bitterbrush	Jeffrey pine	Lake	Lodgepole pine	Montane chaparral	Montane riparian	Perennial grassland	Red fir	Subalpine conifer	Sagebrush	Unknown	Urban	White fir	Wetland
Aspen	0.95	0.02		0.01		0.1	0.07	0.32		0.17	0.01	0.22	0.02				0.01	0.02
Barren	34.71	41.94		25.5		0.85	0.1	1.48	0.48	0.03	0.03	2.54	3.27			0.04	0.26	0.13
Bitterbrush	4.15			0.79		0.36	0.01	1.51	0.16	0.08		0.83	0.02	0.08			0.3	0.01
Jeffrey pine	101.83	26.25		1.66		20.3	0.43	10.67	2.42	0.25	0.45	39.00	1.06			0.01	25.3	0.3
Lake	8.34	8.44		0.33		0.15	6.54	0.51	0.01	0.03		0.63	0.12				0.02	
Lodgepole pine	65.22	55.74	0.01	0.57		2.21	0.41	28.26	1.29	0.22	0.44	29.15	0.23	0.15		0.01	1.76	0.51
Montane chaparral	40.48	21.24		0.64		0.64	0.01	1.18	8.86	0.06	0.16	18.38	0.33	0.14	0.04	0.05	9.97	0.02
Montane riparian	0.89	1.81		0.02		0.02		0.08		0.09	0.01	0.34					0.32	0.01
Perennial grassland	3.45	1.45		1.11			0.02	0.41	0.04	0.19	0.05	0.9	0.14				0.12	0.47
Red fir	115.62	215.43		3.13		1.55	0.44	6.92	5.92	0.39	0.14	88.06	0.69	0.11	0.01	0.08	7.71	0.47
Subalpine conifer	57.38	19.95		7.39			0.09	1.82	1.7	0.13	0.1	30.66	13.83	0.01		0.05	1.21	0.39
Sagebrush		0.52																
Unknown	0.33	0.05		0.06					0.04			0.1	0.1	0.03				
Urban		0.24																
White fir	5.34	47.53		0.15			0.05	1.19	0.29	0.04	0.05	3.02	0.03				0.51	0.01

Aspen. Note that the 0.95 km^2 historical extent of aspen in the VTM map has been almost completely replaced by conifer forests in the modern map, primarily lodgepole pine and red fir (Table 10). Figure 14 shows the past occurrence of aspen and the few remnant stands that remain today. Most of the loss occurred on the east side of Snag Lake. Aspen are still common in this area, but conifers have become more common. There was also a lot of aspen loss in the Warner Valley in the Park's southeast corner, although outside the park (not shown) there was a much greater loss. This entire valley used to have a large, continuous corridor of aspen.

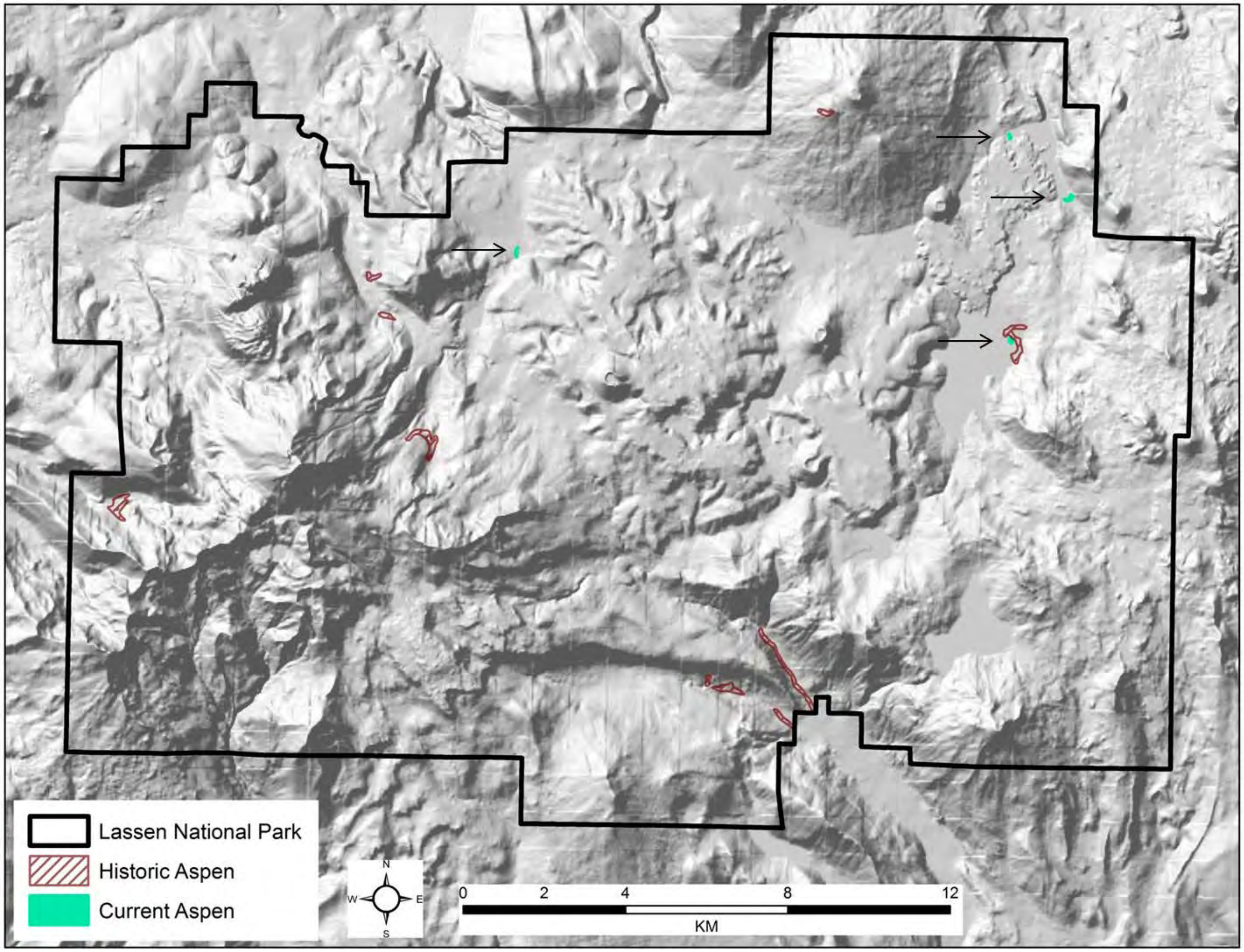

Figure 14. Historic distribution of aspen- (*Populus tremuloides*) dominated forests at Lassen as depicted in VTM mapping, and current distribution. Arrows help point out the current distribution.

Jeffrey pine. This vegetation type declined from 101 km^2 in the VTM map to 26 km^2 in the modern one. Jeffrey pine transitioned to mainly red and white fir as well as to some lodgepole pine (Table 10). There has not necessarily been a significant loss of Jeffrey pines, but the dominance in many forests containing Jeffrey pine has now shifted to fir in the absence of fire. This shift may occur in as little as 30 years in the southern Cascades (Agee 1993), or about the average historic fire rotation.

Mountain hemlock and whitebark pine. There has been a similar transition of most of the subalpine conifer woodlands to red fir forest (Table 10) which may also reflect an increase in red fir density rather than a loss of subalpine trees like mountain hemlock (*Tsuga mertensiana*) and whitebark pine (*Pinus albicaulis*). In fact, the abundance of mountain hemlock has been found to be increasing (Taylor 1995), but the cover may not be increasing as much relative to the cover of red fir.

Montane chaparral. This shrub type is only half as abundant in the modern map as the VTM map, with the bulk of the transition being from chaparral to red fir (Table 10). These afforested areas are now mostly open red fir with an understory of *Arctostaphylos nevadensis*. This is the most common vegetation type in the modern map. In the VTM map, these areas may have also contained some firs, but at a considerably lower density than they do today. Thus, this transition is not necessarily a case of wholesale change from treeless shrublands to shrubless treelands. However, such wholesale conversion has also probably occurred in some areas, particularly where dense white fir has displaced chaparral dominated by *Arctostaphylos patula* and *Ceanothus velutinus*.

Red fir and white fir forest. With the transition from Jeffrey pine, subalpine woodlands, and chaparral to red and white fir woodlands and forests, there has been a substantial increase in these fir forests (Table 10). This is shown in Figure 15. Much of the shift appears to be downward in elevation, reflecting the succession in areas previously dominated by Jeffrey pine and chaparral. While shrubs may have promoted this increase in red fir (see explanation in section 4.3.3.2 Vegetation succession above), it is also possible that it might be related to climate change. An analysis of FIA plots from the Pacific Northwest has found that forest trees are growing 5 to 23 percent faster, with those in upper montane zones being the most affected (Latta et al. 2010). This likely is partly attributable to lengthening of growing seasons due to climate warming, and partly to increased atmospheric carbon dioxide (Huang et al. 2007). The latter is supported by CO2-enhanced growth of ponderosa pine and western juniper (Knapp et al. 2001, Soulé and Knapp 2006). Longer growing season and increased atmospheric CO_2 may thus expand the environment favorable to red fir. They would also promote growth of firs in subalpine woodlands, which is where increased growth rates of subalpine coniferous trees in recent decades was first described (Graumlich 1991).

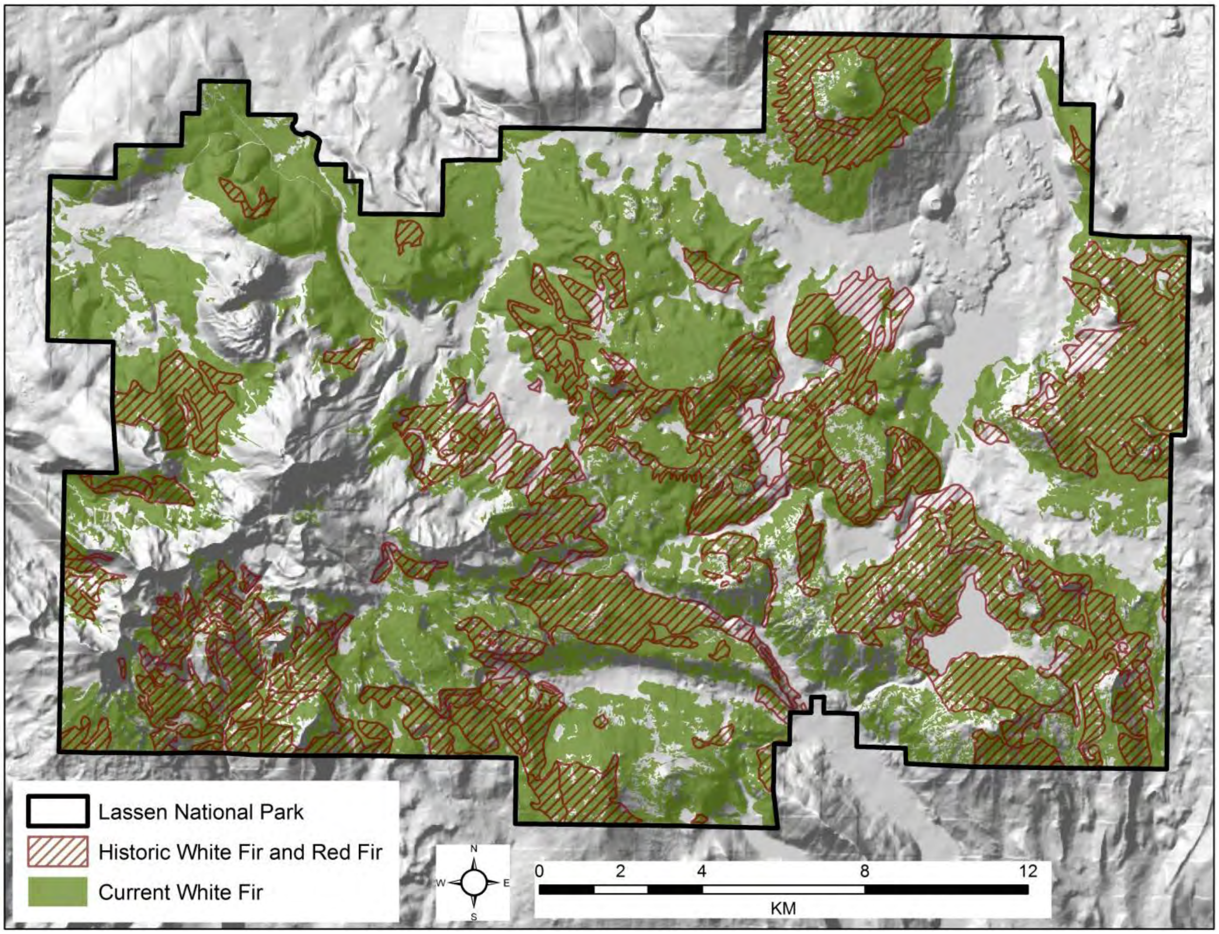

Figure 15. Historic distribution of red and white fir (*Abies magnifica* and *A. concolor*) dominated forests at Lassen as depicted in VTM mapping, and current distribution of forests dominated by these species.

Wetlands and riparian. There has been a considerable loss of wetland vegetation (5.5 to 3.6 km^2). This transition has mainly been to lodgepole pine and red fir. Growth of these trees in meadows generally occurs around the meadow margin and has been described in studies from Lassen (Taylor 1990).

It is likely that current transitions caused by lack of fire will continue, although climate change is projected to increase rates of fire. This subject is discussed in the previous two sections and the discussion of issues. The occurrence of the Reading Fire helped restore the fire process. The fire was predominantly low in severity, but did restore some early successional habitat, and it reduced fir dominance in some areas. Future assessments are needed to ascertain the full effects of the Reading Fire. In contrast, prescribed burning is very limited in the amount of area that can be treated, elevating the importance of wildfires in terms of restoration (Odion and Hanson 2006).

Assessment Confidence and Data Gaps
Medium. Vegetation transitions have to be evaluated carefully to consider the possibility that they are not caused by differences in the classification between the two maps. When this is done judiciously, it is possible to identify clear and consistent trend, but the magnitude of change estimated is not considered precise, and the error cannot be quantified.

4.3.4.4 Invasive Plants

Criteria
Good condition would be a low amount of invasion by exotic species and *Somewhat Concerning* and *Significant Concern* would represent increasingly greater problems with invasive exotic species.

Condition and Trends
With only very limited occurrences of invasive species and no areas of the park in which the vegetation structure, function, and composition have been transformed by invasive species, the condition with regard to this indicator may be considered *Somewhat Concerning – Medium Certainty*. Current control efforts and other management practices are paying dividends, and lack of fire also benefits conditions related to this indicator.

Invasive species found so far in Lassen are listed in Appendix D. There are no comprehensive sources of information on the locations and extent of invasions by non-native plants at Lassen. There are records of where control efforts have been undertaken and there are records from fire monitoring (FMH) plots where fire treatments have been done. There are also monitoring surveys from the Klamath Network along a subset of roads and trails. None of these data were collected from a probability sample of the entire park, or even of areas necessarily at highest risk of invasives. There are, however, data covering non-native plants from probabilistic sampling done for the 2005 park-wide wetlands assessment as described in section 4.2.4.3 (Adamus and Bartlett 2008) as well as from one vegetation mapping project. Vegetation sampling for a second, comparative vegetation mapping project used a relevé approach to subjectively locate plots across the range of variation in vegetation types. In concert, these three databases comprise 1050 plots.

In the combined database of 1050 plots, only 29 plots (3%) had a total of 52 infestations by 14 species. Figure 16 shows the distribution of infestations and the locations of all plots sampled. This does not include the FMH plots or monitoring by the Klamath Network.

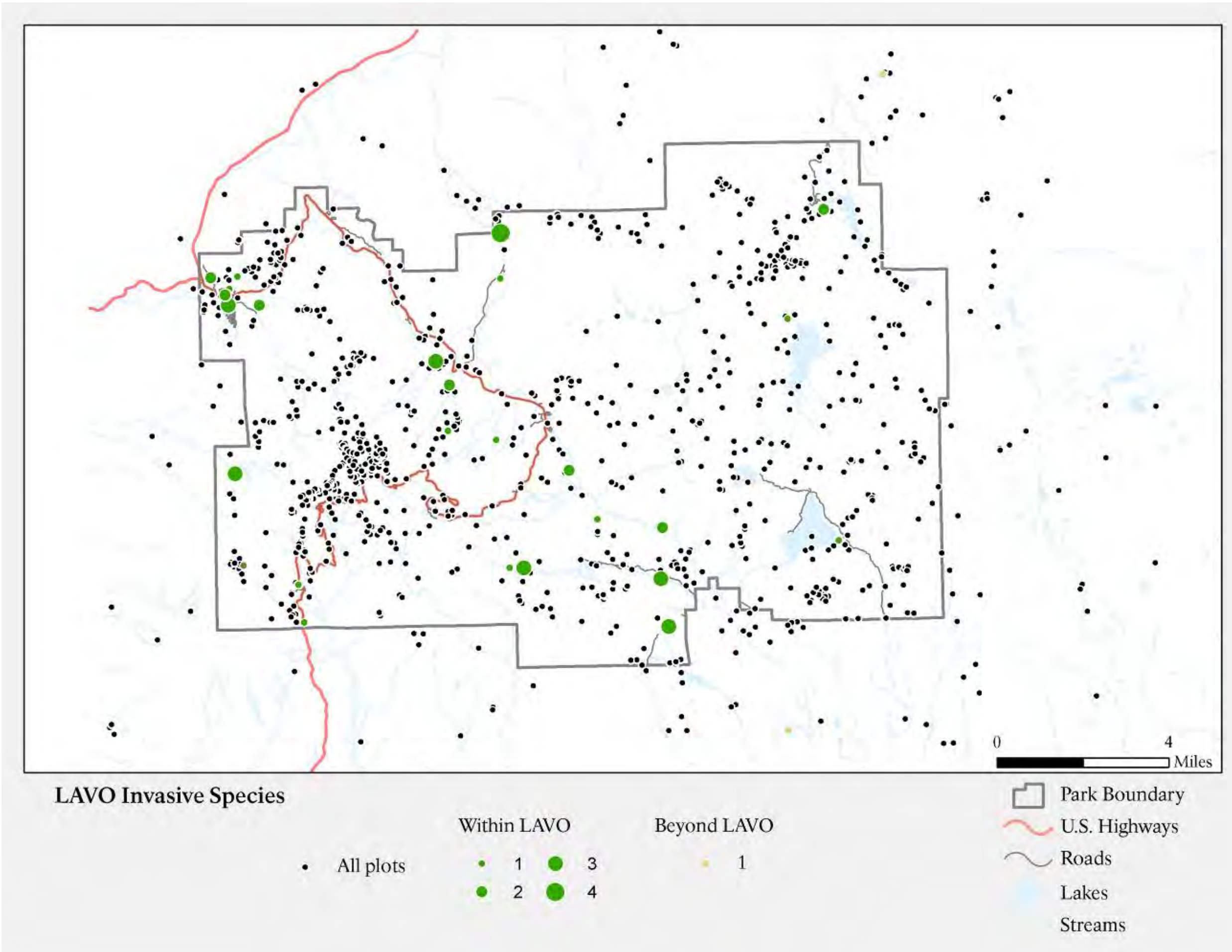

Figure 16. Locations of infestations and all sampling locations (n=1050) at Lassen from the two vegetation sampling databases and the wetlands assessment database. Green dots indicate plots with an invasive species. The smallest green dots indicate one invasive species present, while increasingly larger dots indicate 2, 3, and 4 invasives.

Most (34) of the 52 infestations in these vegetation sampling plots were in wetlands, which comprise only a small fraction of park area. The high apparent incidence could be due partly to the heightened intensity of sampling and thoroughness of taxonomic identification within the wetlands visited. Cover values for the invasives were less than one percent except in two infestations of *Poa pratensis*, one *of Cirsium vulgare*, and one of *Taraxacum officinale*, all from wetlands, where cover was 1-25% (most were at the low end of this range). The invasives in these plots are listed in Table 11. They tended to occur at the lowest park elevations, except for *Spergularia rubra*, which was found in an alpine plot. Of the invasives found in the 1050 plots, most are not ecosystem transformers, which are the primary concern with biological invasions (Davis et al. 2011). The exceptions are *Bromus tectorum* and *Cirsium vulgare*. *Bromus* is an ecosystem transformer in the Great Basin through its effects in causing more frequent surface fires and altering the nitrogen cycle in its favor. *Cirsium* can quickly invade and dominate disturbed areas like burns. *Verbascum thapsus* is also frequently considered a pernicious invader.

It is a very conspicuous species and often invades open areas lacking other vegetation. But, strictly speaking, it may not be an ecosystem transformer.

Table 11. Species found in 1050 vegetation sampling plots from 2007-2010 in Lassen National Park.

Species	Number of Plots	Elevations (M)
Agrostis gigantea	4	2075-2206
Bromus inermis	2	1880-2026
Bromus tectorum	1	1861
Cirsium vulgare	6	17-851982
Festuca pratensis	1	1879
Phleum pratense	1	1656
Plantago major	1	1785
Poa annua	1	1785
Poa pratensis	12	1639-1982
Prunella vulgaris	1	1956
Spergularia rubra	1	2791
Taraxacum officinale	15	1879-1982
Tragopogon dubius	1	1880
Verbascum thapsus	6	1639-1918

The Klamath Network I&M program has implemented a protocol for early detection of invasive plant species. This protocol targets only the most invasive species, so there is no record of occurrence for most of the species. A total of 65.7 road and trail kilometers were sampled by the Network's monitoring; three of the targeted species were detected in that sample. The species, by descending abundance, included: musk thistle (*Carduus nutans*), bull thistle (*Cirsium vulgare*), and goat's beard (*Tragopogon dubius*). Musk thistle is a very invasive species that had not been previously detected according to National Park Service Database, and its identification needs to be confirmed. Figure 17 shows the locations of infestations found by the Network's monitoring in 2011.

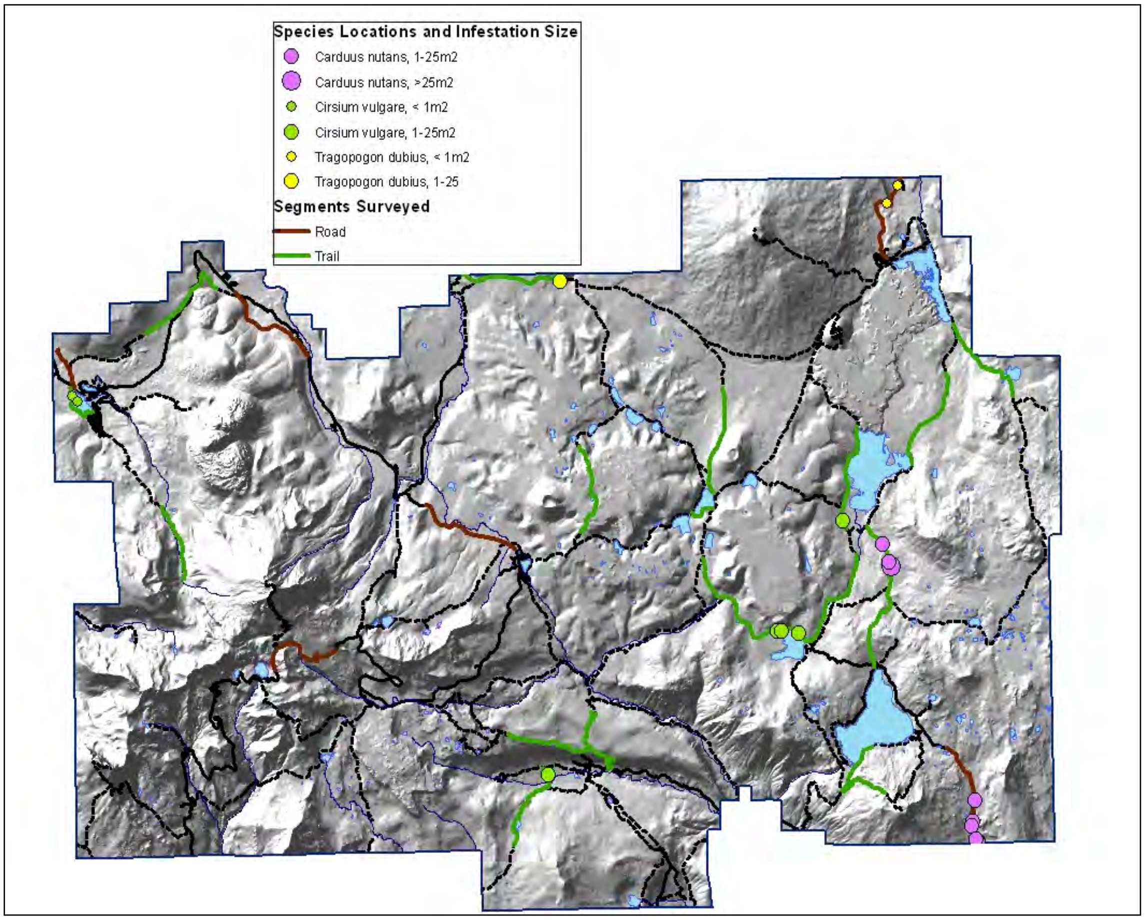

Figure 17. Locations of invasive species found during the Klamath Network Monitoring in 2011. The green lines show the routes that were surveyed.

In general, the findings from vegetation sampling and invasives monitoring confirm qualitative assessments for the Park. Among the more invasive species, bull thistle (*Cirsium vulgare*) and woolly mullein (*Verbascum thapsus*) are the two most widespread weeds in the park. Intermediate wheatgrass (*Elytrigia intermedia* ssp. *intermedia*) and smooth brome (*Bromus inermis*) are found in the southwest corner of the park near the old ski slope. Yellow salsify (*Tragopogon dubium*) is widely distributed but not abundant in disturbed areas. Other exotic species such as dandelion (*Taraxacum officinale*) and self-heal (*Prunella vulgaris*) are found in moist or disturbed areas of the park, but are not expected to transform ecosystems, nor are they currently targeted for treatment. Surveys in 2003 found a population of five Canada thistle (*Cirsium arvense*), a potential ecosystem transformer, on the west shore of Snag Lake, but a survey in 2005 and 2009 did not find this species there. Canada thistle is also found in the sewage mounds area near the southwest park entrance. A stray Himalayan blackberry (*Rubus discolor*) was found but not removed at Terminal Geyser. Reed canary grass (*Phalaris arundinacea*) was reported at the Warner Valley horse corral in 2003 and a large infestation was found in Dersch Meadows in 2009. Park staff is treating *Phalaris* as an invasive exotic, because of its location (adjacent to existing or historic corrals) and its behavior (rapid spread, exclusion of other species). Cheatgrass (*Bromus tectorum*) was mapped in 2005 on the edge of Butte Lake.

It has since been documented from seven other sites throughout the park, including most recently in a severely burned area northeast of Lost Creek Campground (Janet Coles, pers. comm. 2012).

Of 74 burned fire monitoring (FMH) plots, 18 (24%) had infestations by four species. Thus, burned plots had a greater than tenfold higher incidence of infestation compared to the rest of the landscape (there were 20 infestations in almost 1000 non-wetland and unburned plots). This highlights a difficult tradeoff for park managers: fire and fire management activities tend to promote invasives, but fire needs to be re-established as an ecological process to restore historical conditions. The most common invasive in burn plots was *Cirsium vulgare*, found in 12 plots after burning. Its maximum cover was 4% in one montane chaparral burn at year 7, but it was subsequently absent at year 10. This may be because of intensive control efforts that removed all *Cirsium* from this burn area several years in a row. There were no pre-fire data available. All other plots had <1% cover of *Cirsium*. *Poa pratensis* was found in three forest plots prior to burning but not after. It was also found in three forest plots two years after fire and post-fire cover was 0.3%, 1.5%, and 2.4%. These plots have not been subsequently sampled. Two additional species not known to the park were also found: *Antennaria umbrinella* (one plant observed in one forest plot five years post-fire); and *Hypochaeris radicata* (observed as being present one year post-fire in two forest plots, but then was not observed in the year-two post-fire read). A possible explanation for such an unexpected disappearance is misidentification. It cannot be assumed that all species in FMH plots were correctly identified.

There are no specific data on invasive plant species' trends in Lassen. In general, there are ever increasing numbers of potential invaders. Climate change may increase the susceptibility of higher elevations to invasive species. So will increasing fire and/or fire suppression efforts should these occur.

Assessment Confidence and Data Gaps

Medium. More remote areas of the park that are not traversed by trails are 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 invasives. The park staff has initiated (as of 2010) a systematic survey for invasives in the highest probability areas of the park (burned areas and developed areas past and present, and areas scheduled for prescribed burning and mechanical treatment). This system is derived from methodology developed by Steve Dewey and Kim Andersen at Utah State University (Janet Coles, pers. comm. 2012). It has been very successful at finding weeds in out-of-the way places and accurately defining the extent of infestations. Ideally, such a program should be designed to feed into rapid response control programs and adaptive management as shown in Figure 18, and this is the intent of the Lassen program. However, it remains to be determined how adequate it may be for determining long-term trends.

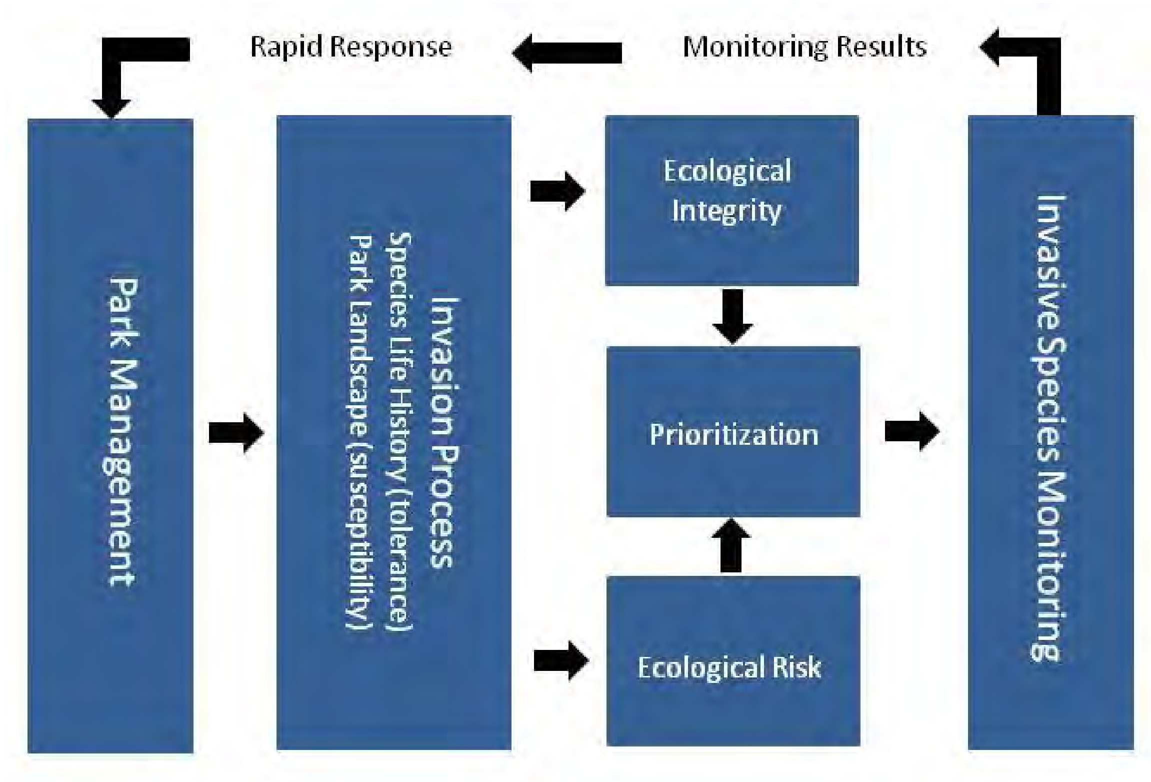

Figure 18. Conceptual model of an invasive species early detection program and the feedbacks with management (From Odion et al. 2010a).

4.3.4.5 Invasive Pathogens

Criteria
Good condition would be a complete lack of blister rust and other exotic pathogens, or perhaps a very low amount and poor prospects for it to spread. *Somewhat Concerning*, would be a moderate amount of blister rust that would reduce whitebark pine populations, and *Significant Concern* would be a greater amount, significantly reducing whitebark pine.

Condition and Trends
Condition of this indicator is *Significant Concern – Very Low Certainty.* As summarized below, previous information suggested that whitebark pine infection rates were very low. However, new information (Jules et al. 2012) suggests that they may be much higher. The existing sources of information are based on very limited (spatially) sampling.

Whitebark pines are currently suffering severe impacts in many parts of their range. Where Whitebark pine has been monitored in Lassen under a California state-wide program of the US Forest Service (Patricia Maloney, Research Associate UC-Davis, pers. comm. August 2006). The USFS monitoring effort established 44 plots in the Sierra and Southern Cascades ranges. Four of these plots were in Lassen. A very low incidence of blister rust (~3% of trees) was reported from those four plots. To the south of Lassen, blister rust has rarely been found in whitebark pine (McKinney et al. 2012) until a recent study by Maloney et al. in the Lake Tahoe area. They studied eight populations and found a mean incidence of blister rust of 35%. To the north, at Crater Lake, Smith et al. (2011) found about 25 percent of whitebark pine trees were infected with blister rust. More recently, Jules et al. (2012) found that in ten plots, on average, white pine blister rust had infected 69% of whitebark pine in Crater Lake and 53% in Lassen.

Available data are insufficient to assess *trends* in blister rust or other plant pathogens within Lassen. Future monitoring by the Klamath Network should provide a much better assessment of current condition (McKinney et al. 2012).

Assessment Confidence and Data Gaps
Poor. Monitoring for blister rust has not been spatially or temporally intensive. Only a rough idea of present disease levels exists. However, it seems unlikely that blister rust would not affect the whitebark pine at Lassen to a similar degree as those at Crater Lake, which have been hit hard, or in the Lake Tahoe area, where the disease is also common.

4.3.4.6 Rare Plant Species and Species Diversity

Criteria
For purposes of this assessment, "Good" conditions would be represented by naturally-occurring turnover rates of all native plant species currently inhabiting the park. This might include intentionally re-establishing those which were extirpated but have the potential to become re-established. More detailed goals might be to sustain multiple representatives of each functional group of plants in proportions characteristic of intact but dynamic ecosystems, as well as sustaining metapopulations and gene pool diversity. "Somewhat Concerning" and "Signficant Concern" would represent increasingly high turnover rates of all native plant species currently inhabiting the monument.

Condition
Although there are no federally listed plant species within the park, Lassen hosts at least 23 plant species that are termed "special status" by the California Native Plant Society. Almost all are found either in wetlands or in the high elevation subalpine zone. Two bryophytes with arctic-alpine distributions (*Andreaea nivalis* and *Polytrichum sexangulare*) reach the southern extreme of their range in late snow melt beds at Lassen (Showers 1982), and would thus be expected to be highly vulnerable to a warming climate.

The Klamath Network Inventory and Monitoring program, like many other network I&M programs, analyzed the potential for using rare species as vital signs (reviewed in Sarr et al. 2007). Analyses of statistical power and other issues have shown that rare plants are impractical to use as ecological indicators (Manley et al. 2004). Thus, the policy of the Klamath Network has been to avoid focusing on just rare species and instead to sample all vegetation. Diversity patterns within vegetation (composition) are a key component of this vital sign.

Trends
Trends in Lassen's plant species diversity and rare species in particular are *Indeterminate*. Populations of three rare plant species on the summit of Lassen Peak have been monitored

regularly with transects since 1997, but data are probably insufficient to determine any trends. Sampling for the ongoing vegetation mapping project, as well as the 2005 wetlands survey, documented several new taxa for the park. Whether there are species that have been extirpated 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 of these species has been extirpated from the park.

Assessment Confidence and Data Gaps
Low. Although the park's flora has been relatively well inventoried, no permanent plots or transects representing a probabilistic sample of plant communities in the park have been monitored. Only a few locations known to support rare plants are checked regularly to determine if those individuals are extant.

4.4 Changes in Wildlife

4.4.1 Background
As used herein, "wildlife" refers to terrestrial vertebrates and invertebrates. 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.

4.4.2 Regional Context
For its size, the park has a particularly rich array of plant and animal species. This is partly due to the great range in elevation with associated diversity of climates, and partly due to the park's position at the crossroads of four major bioregions—the Cascades to the north, the Central Valley to the west, the Sierra Nevada to the south, and the Great Basin to the east. In addition, the diversity of both new and old geological phenomena, combined with occasional wildfires and some human influences, have created a particularly rich flora and fauna.

4.4.3 Issues Description

4.4.3.1 Fire Suppression and Natural Succession
The volcanic blast in 1915 removed all vegetation in parts of the park. In areas that were relatively unaffected, decades of wildland fire suppression have affected the types of habitat available to wildlife. Undoubtedly some species have benefitted from the shrinkage of shrub habitat and open meadows where succession to conifer forest has occurred, whereas others—such as snowshoe hare, Cascades frog, and fox sparrow—may have found the new conditions less hospitable. Fire suppression also can result in fewer snags, which are necessary for some bats, woodpeckers, and other wildlife. Prescribed burns and thinning for the purpose of reducing understory fuels may affect some species as well, at least based on evidence from other regions of the United States (Pilliod et al. 2003). Fuel treatments are sometimes accompanied by indirect loss of woody debris, litter, and shade, as well as changes in stream bed substrates and stream characteristics such as flow, temperature, and sedimentation. However, fuel build up may ultimately lead to unnaturally severe fires that result in loss of habitat, also resulting in increased stream and air temperatures, and in increased sedimentation in streams.

4.4.3.2 Climate Change, Water, and Snow Pack

Boreal species whose geographic range is predominantly in states and provinces north of California are expected to decline the most—and possibly be lost entirely from the park—as a result of warming climate. This includes all the characteristically subalpine plant and animal species. Because the park's wetlands, streams, and ponds are so dependent on snowmelt, many fish, amphibians, and other organisms that live in or feed over water could suffer as well. 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, the terrestrial species that are likely to have formerly or currently nested in the park include sooty (blue) grouse, northern saw-whet owl, common nighthawk, common poorwill, Vaux's swift, black-backed woodpecker, pileated woodpecker, gray jay, Swainson's thrush, Brewer's sparrow, fox sparrow, and red crossbill.

4.4.3.3 Contaminants

Effects of contaminants on the park's terrestrial species have not been monitored, but are a potential concern because of well-documented aerial transport of contaminants into the park from distant areas. Bats, swallows, and other aerial foragers are likely to be at greatest risk.

4.4.3.4 Human Disturbance

Some wildlife species, including many avian nest predators (raven, Steller's jay) are attracted to congregations of people such as at campgrounds and picnic areas, with potentially detrimental effects on many songbird species. Other species, such as badger, appear to partially avoid human-inhabited areas.

4.4.3.5 Habitat Fragmentation

When the home ranges of some forest-dwelling species are interrupted by roads and other cleared areas, undesired results are termed habitat fragmentation. Individuals are often subjected to greater predation, and feeding and reproductive attributes (e.g., genetic isolation) also can be interrupted. Roads and traffic result in more road killed animals, and in extreme cases, noise associated with roads impairs reproductive success of some wildlife. 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 (salamanders, plants). Connectivity can also be provided by some types of broad habitat mosaics over large, relatively natural areas or as stepping stones of habitat patches.

4.4.4 Indicators and Criteria to Evaluate Condition and Trends

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

1. Presence and Persistence of Native Terrestrial Wildlife Species
2. Connectivity and Extent of Important Terrestrial Habitats

4.4.4.1 Presence and Persistence of Native Terrestrial Wildlife Species

At least 280 native vertebrate species are believed (or have been confirmed) to regularly visit or breed in the park. Analyses by the California Department of Fish and Wildlife (2013a) using coarse land cover characteristics (circa 2000) and geographic range information predicts where species are likely to occur throughout the state. Their analysis suggests that for birds, the rarity-weighted richness would be expected to be highest within the park around Snag Lake and also near the Warner Valley. For mammals the analysis suggests the highest expected richness, weighted by species rarity, is near the southwest entrance and also near Warner Valley. For amphibians the highest expected richness, weighted by species rarity, is mostly in the southern half of the park and also near Manzanita Lake. For rarity-weighted plant richness, the entire western half of the park is expected to be more significant.

Criteria

Local and regional data on native terrestrial wildlife species are insufficient to quantify reference conditions for this park, so qualitative statements will define the reference conditions. "Good" conditions would be represented by the sustaining of naturally-occurring turnover rates of all native terrestrial species currently inhabiting a park. This might include intentionally re-establishing those species which were extirpated but have the potential to become re-established. More detailed goals would 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 reflect the degree to which species turnover rates and/or terrestrial biodiversity are likely to affect adversely the rates of important ecosystem functions.

In national forests of the Sierra Nevada region, the USDA Forest Service (2008) has chosen and is monitoring the following terrestrial vertebrates and their associated habitats as "management indicator species":

fox sparrow – west slope chaparral shrubland

mountain quail – early and mid-seral coniferous

sooty grouse – late seral open canopy coniferous

spotted owl, American marten, northern flying squirrel – late seral closed canopy coniferous

hairy woodpecker – snags in unburned forest

black-backed woodpecker – snags in burned forest

Meaningful criteria for evaluating these indicators would need to account for the natural range of variation in species colonization and extirpation, and for the expected annual fluctuations in population levels. However, data for estimating these are not generally available from the park or from analogous areas nearby. As well, there are no legally-sanctioned numeric criteria for evaluating the degree of "intactness" of any of the park's terrestrial 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.

Condition
Good – Low Certainty. Compared with the rest of California, large sections of the park fall within the highest of six categories for rarity-weighted richness of birds, mammals, and plants, and the next-to-highest category for rarity-weighted richness of amphibians (CDFW 2013a).

Among non-native mammals, there are apparently no records from the park of house mouse, non-native rat species, feral cats, or feral pigs. Virginia opossum (*Didelphis virginiana*) was introduced to California from the eastern United States about a century ago and there is an old record from the Manzanita Lake area of the park. Of the more than 200 bird species recorded in the park, none which nest in the park are non-native in this region. Two other birds not native to the area—house sparrow and barred owl—have been recorded just outside the park boundary. Although they are native, brown-headed cowbirds are regularly found at lower elevations, have increased in numbers in the last 75 years, and parasitize the nests of many songbirds (Borgmann & Morrison 2010). Their numbers are declining in the Sierras and possibly in the park as well (Sauer et al. 2011). Of the park's seven documented amphibians, only one (American bullfrog, *Rana catesbiana*) is non-native; none of the reptiles are non-native.

Ungulates, Omnivores, and Predatory Mammals. The park's most common ungulate is mule deer (*Odocoileus hemionus columbianus*). In summer, one of the largest deer herds in California is present in the park; this herd migrates nearly 20-50 miles to lower elevations in winter. Elk (wapiti) have been reported on a few occasions. Attempts were made in the 1970s to introduce mountain bighorn sheep (*Ovis canadensis*), but those attempts failed due to a disease outbreak. The park's larger omnivores include black bear, raccoon, and possibly ringtail. Black bears are relatively common. The park is outstanding for its relatively high number of predatory mammals which include: mountain lion; bobcat; badger; coyote; gray fox; red fox; and six mustellids—mink, ermine, long-tailed weasel, marten, and river otter.

Lassen is one of only a few places in the world where a native subspecies of the red fox, the Sierra Nevada red fox (*Vulpes vulpes necator*), is found. Its presence has also been confirmed at Yosemite National Park and in the Humboldt-Toiyabe and Stanislaus National Forests. The species is listed as Threatened under the California Endangered Species Act, and the population is believed to be relatively small. As summarized by Perrine et al. (2010), most records are from elevations of between 1500 m and 2100 m in the Sierra Nevada and southern Cascade Ranges. Greatest densities appear to occur near Lassen Peak, and they are primarily forest-dwellers (Grinnell et al. 1937, Schempf and White 1977). In winter, they use forests with large trees (>60 cm diameter) and >40% canopy closure. Summer home range size is about 2300 hectares. Concern has been expressed about the potential for increased mortality from disease and reduced genetic adaptation to local conditions if interbreeding with non-native red foxes occurs, as those appear to be expanding into high elevation areas that overlap. Although seeming to usually prefer areas relatively remote from humans, Sierra Nevada red foxes occasionally linger near human residences and roads where they may find food and denning sites, and where competition with coyotes is sometimes lessened (Gosselink et al. 2003, Perrine 2006).

Another native predatory mammal is American (or pine) marten. The park and surrounding national forest may provide some of the most extensive suitable habitat for this species in northern California (Figure 19). Suitable habitat consists of large patches of higher-elevation forest with large diameter (>11 inch dbh) red fir, white fir, or riparian and subalpine conifers with a moderate to dense canopy (Perrine 2006, Green 2006, Kirk and Zielinski 2009). Wintering martens do not appear to avoid or leave areas with limited presence of off-highway vehicles and over-snow vehicles (Zielinski et al. 2008). Populations of the closely related Pacific fisher (*Martes pennanti pacifica*) are much less in the region surrounding the park, and it may not occur at all within the park. If it does, it would be expected to inhabit a lower average elevation than marten.

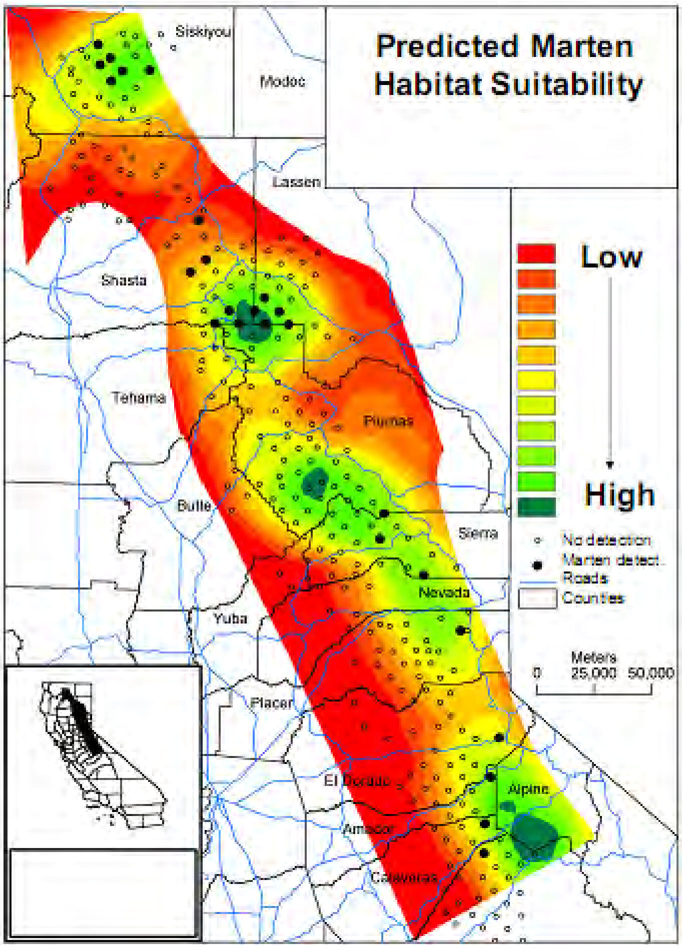

Figure 19. Predicted habitat suitability for American marten in the vicinity of the park (from Zielinski et al. 2005).

Other Mammals. The park's riparian areas have been found to support a greater diversity of mammals than higher elevation forests and subalpine habitat (Perrine 2006). American pika (*Ochotona princeps*) 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) such as one photographed in a lava field near Butte Lake (Paul Adamus and Cheryl Bartlett, 11 July 2005) which was also detected by Perrine & Conroy (2007). Other recent sightings are (for example) from the subalpine zone of Brokeoff

Mountain (Perrine 2006) and near King's Creek Falls (Perrine & Conroy 2007). Monitoring is ongoing as part of the NPS "Pikas in Peril" project.

Sierra Nevada snowshoe hare (*Lepus americanus tahoensis*) is a California Species of Concern that is found sporadically in the park's brush thickets. Inyo shrew (*Sorex tenellus*) is also rare, and the park is one of only a few localities outside of the Sierra Nevada where it has been found. Both that shrew and Preble's shrew (*Sorex preblei*) were added to the park list in the last decade by a concerted NPS-sponsored Small Vertebrate Inventory Project (Shohfi et al. 2006, Perrine 2006). Botta's Pocket Gopher (*Thomomys bottae*) is projected to occur in the park by CDFW (2013a) but the mammal survey documented only the closely related *Thomomys monticola*. Other small mammal species projected to occur but for which no recent records exist include Belding's ground squirrel (*Spermophilus beldingi*), western harvest mouse (*Reithrodontomys megalotus*), black-tailed jackrabbit (*Lepus californicus*), house mouse (*Mus musculus*), mountain cottontail (*Sylvilagus nuttallii*), striped skunk (*Mephitis mephitis*), and western spotted skunk (*Spilogale gracilis*). It is not possible to tell if they are currently present, were ever present, and/or if survey methods used so far have not been optimal for their detection. While not rare in the park, long-eared chipmunk (*Tamias quadrimaculatus*) is notable because it occurs only in the Sierra Nevada ecoregion.

Eight species of bats were documented in the park in a 2001-2003 survey (Morrell 2002), with the long-eared myotis (*Myotis evotis*) being captured most frequently. None of the park's known bat species are particularly rare in California, but bats in general are a concern due to low resilience to many environmental disturbances, which is partly because of their low reproductive potential.

Birds. The park's bird diversity has been relatively well-surveyed, notably in 1999-2000, by Humple (2001) and by a Breeding Bird Survey route (Chaos Crater, #308). The latter is part of the national network of Breeding Bird Survey routes. As part of that, birds have been surveyed annually since 1977 by the park's wildlife biologist along a 25-mile roadside route through the park (Table 12). Over 200 bird species have now been documented in the park one or more times, and about half have nested. Nesting species that are the most common and widespread within the park are mountain chickadee, dark-eyed (Oregon) junco, and yellow-rumped (Audubon's) warbler (Humple 2001).

Two pairs of the California spotted owl (*Strix occidentalis caurina*) have bred in the park most years, with one pair near Crags Campground and one in the Terminal Geyser area (Blakesley and Noon 1999). The California Endangered Species Act lists the willow flycatcher (*Empidonax traillii brewsteri*) as Endangered. This species may nest in the park; Warner Valley meadow, nearby and south of the park, is believed to support one of the most significant breeding populations in California (King et al. 2001), and historically this species might also have bred in Sulfur Creek Meadows and around Snag Lake. Bald eagle and peregrine falcon have both been delisted from the federal endangered species list. The bald eagle is still listed as endangered by the State of California. There is one bald eagle nest and one peregrine falcon aerie in the park, and these are monitored annually.

The California DFG has designated four nesting birds in the park as statewide Species of Concern: northern goshawk, Vaux's swift, olive-sided flycatcher, and yellow warbler. They are all fairly common to uncommon in the park. Also, the US Fish and Wildlife Service has designated as Birds of Conservation Concern the white-headed woodpecker (a fairly common resident) and rufous hummingbird (a non-breeding visitor). Species that are particularly rare breeders in the park, but which are more common in parts of California with more suitable habitat, include eared grebe, ring-necked duck, golden eagle, prairie falcon, common poorwill, western bluebird, Brewer's sparrow, black-headed grosbeak, and gray-crowned rosy finch (Humple 2001, Burnett & King 2004).

Reptiles. No comprehensive surveys have been conducted of the park's reptiles. Eighteen species have either been documented or could potentially occur in the park (Appendix D).

Terrestrial Invertebrates. Approximately 83 species of butterflies and 147 species of moths have been recorded in the park, and a guide to those is available (Crabtree 1998). No park-wide inventories of other invertebrates have been conducted. Two uncommon species—Edith's checkerspot (*Euphydryas editha*) and Sheridan's hairstreak (*Callophrys sheridanii*)—have been reported from the Lassen Peak area. In 2007 an annual parkwide butterfly count was initiated and is being conducted by the North American Butterfly Association and park staff. This may be useful in tracking changes in montane meadow conditions.

Special Habitats. Non-living areas with very different physical structure, such as rocky outcrop areas, talus slopes, cliffs, and lava flows provide habitat for very specialized animal species and/or species with limited regional distribution. In this park, cliff faces are likely to be important to some roosting bats and nesting swallows. Talus and volcanic deposits, which are regionally rare, are important to pika, yellow-bellied marmot, and bushy-tailed woodrat. Among types of vegetation, aspen is renowned for its ability to support a particularly wide array of birds and mammals (see section 4.3.4.6). Large snags of all tree species are required by many bird species and are important roosting sites for bats. Data on the size and age of snags in parts of the park have been collected from five permanent plots since 1988. Snags are most common in lightly-burned areas and where trees have recently been killed by insects, disease, or beaver. Their importance to the park's woodpecker species was documented by Farris et al. (2004) and Farris & Zack (2008). Of 23 habitat types surveyed in the park, burned areas were found to have the most diverse assemblages of breeding birds, owing at least partly to their abundant snags (Humple 2001).

Trends

Indeterminate. No Lassen data spanning more than a decade have been collected to determine changes in abundance of any species, except for birds. Within the park, there is no definitive evidence so far of changes in any species distribution that can be attributed to long-term climate change. However, the park has begun participating in the National Phenology Network (NPN) and California Phenology Project (CPP) whose aims are to measure changes in the timing of seasonal or periodic biological events such as flowering, leaf-out, insect emergence, and animal migration. Populations of eight plants are being monitored: quaking aspen, lodgepole pine, ponderosa pine, greenleaf manzanita, blue elderberry, mountain pride (*Penstemon newberryi*), satin lupine (*Lupinus obtusilobus*), and woolly mule's ears (*Wyethia mollis*). Monitoring sites are at Loomis Museum, Manzanita Air Quality Station, Emigrant Trail, Sunflower Flats, Manzanita Lake, Hot Rock, and Devastated Area. For the Northern Hemisphere as a whole, in the past century the number of species of birds, butterflies, and alpine herbs has shown an average shift of 6.1 km per decade northward (or 6.1 m per decade higher in elevation), and a mean shift toward earlier onset of spring events (frog breeding, bird nesting, first flowering, tree budburst, and arrival of migrant butterflies and birds) of 2.3 days per decade (Parmesan and Yohe 2003).

While the park maintains a wildlife observations database, those data are not systematic so no inferences can yet be made about relative abundance or shifts in elevational or geographic ranges or species productivity.

Mammals. Gray wolf, grizzly bear, and wolverine are believed to have occurred in the park historically but with high certainty are no longer present. Wolverine was thought to have been extirpated from California around 1922, but a single individual was confirmed in Tahoe National Forest in 2010. Except for a lone straggler in early 2012, the last wolf reliably documented in California was trapped in Lassen County in 1924. The disappearance from the park of river otter and ringtail, implied by Newmark (1995), is untrue. It remains uncertain whether Nuttall's cottontail, Pacific fisher, striped skunk, and pronghorn have been permanently extirpated from the park, as implied by Newmark (1995).

During the late 1950s and early 1960s, the deer herd bordering the park in Tehama County numbered over 100,000, but drought in the 1980s caused a decline. As of 2001 numbers were down to about 22,000. The herd may now be limited by lack of sufficient openland with its associated food plants; that insufficient openland is the result of fire suppression and land use changes.

Trends in populations of the Sierra Nevada red fox within the park are uncertain, but statewide this species was believed to be declining (Schempf and White 1977). Perrine (2006) suspected that the park's population might be under stress, as evidenced by abundance of low-palatability foods in their stomachs (insects, shrews), below-average body size, large home ranges, and their regular "begging" at campsites and parking areas. Zielinski (2004) and Zielinski et al. (2005) suspected that populations of American marten may now be less well distributed in the area around Lassen than they were in the early 1900s, but evidence is not definitive.

Bat populations in many areas of the U.S. are believed to be declining, but data from California and this park are insufficient to determine if this is true here. Likewise, trends in population or distribution of pika within the park are unknown. In a broad geographic area that included the park, Massing (2012) resurveyed pika sites reported by Grinnell in the 1930s as part of the historical Lassen transect, plus some additional sites. Eleven of 17 (65%) of the historical pika sites were occupied; 6 of 17 (35%) additional surveyed sites were occupied.

Birds. Our analysis of data from the annual Breeding Bird Survey route through the park, 1972 to 2009, shows statistically significant increases in the number of species (Figure 20) but a decrease in the individual birds detected (Figure 21). Nine species show a statistically significant increase while eleven show a statistically significant decrease. For the most part, trends in the park mirror those in the Sierra Region as a whole, as reported by the BBS for the period 1977-2007. However, the in-park decrease in green-tailed towhee and common nighthawk, and the in-park increase in warbling vireo, is counter to the regional trend and suggests in-park factors (e.g., vegetative succession, weather on survey days) might have influenced the estimates for these species. Green-tailed towhee is associated with manzanita vegetation, whose extent in the park may be less than half what it was 70 years ago. Common nighthawk nests in open lodgepole and grassy areas, which also have likely decreased in the park as vegetation became re-established following the eruption of Mount Lassen.

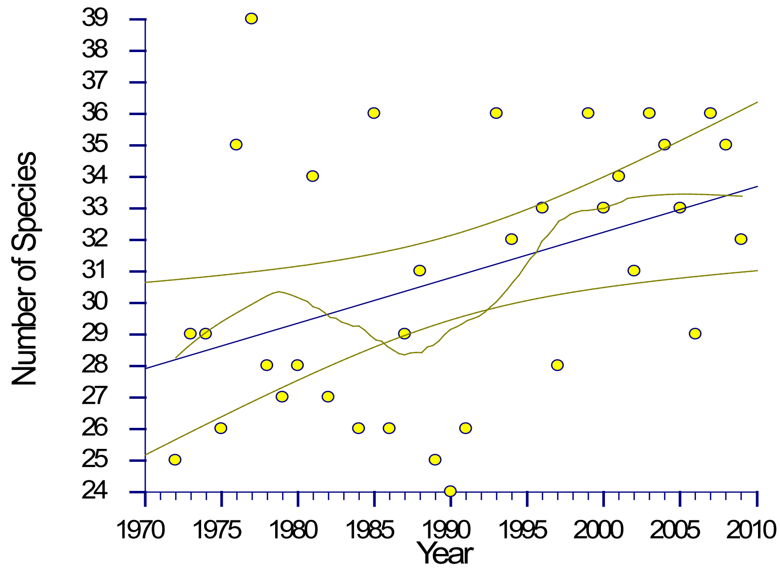

Figure 20. Number of bird species found on the annual Breeding Bird Survey route through the park, 1972-2009. The curved line is the locally weighted regression line (with 40% smoothing). The straight line is the least squares regression with confidence bands. R^2=0.164, p=0. 0175, slope= 0. 1445, n= 34. Only the data primarily from the park (i.e., stops 1-30) were analyzed.

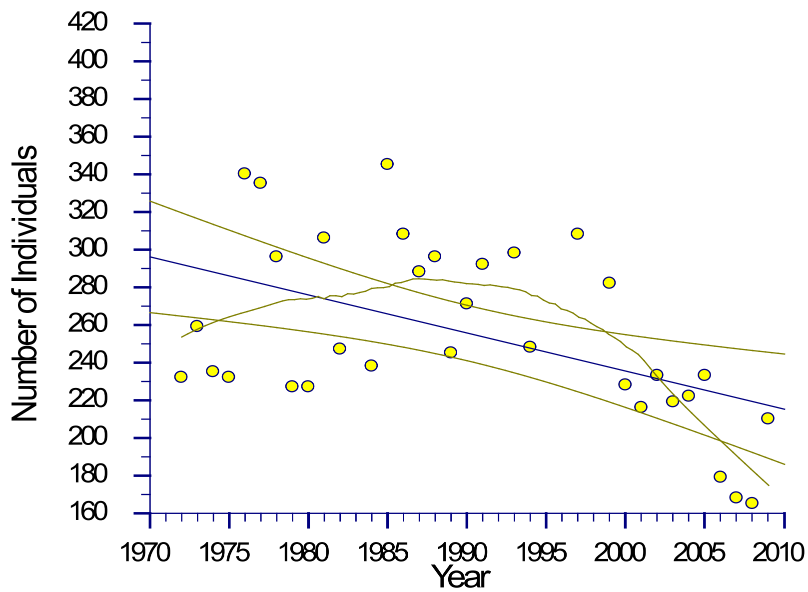

Figure 21. Number of individual birds found on the annual Breeding Bird Survey route through the park, 1972-2009. The model is: R^2=0.1458, p=0.0259, slope=-1.7936, n=34.

Table 12. Species with statistically significant increase or decrease on the annual Breeding Bird Survey Route through the park, 1972-2009. Only the data primarily from the park (i.e., stops 1-30) were analyzed. "B" is the slope of the least-squares regression line, "R^2" is the coefficient of determination (goodness of fit), "p" is the significance level (<0.05 was considered statistically significant).

Common Name	Route Trend	Sierra Trend, 1977-2007	% of yrs Found on Route	B	R^2	p
Purple Finch	decrease	decrease	26%	-0.4747	0.3454	0.0003
Western Wood-Pewee	decrease	decrease	100%	-0.4214	0.4394	0.0000
Steller's Jay	decrease	decrease	100%	-0.3173	0.2513	0.0025
Dark-eyed Junco	decrease	decrease	100%	-0.2800	0.1256	0.0398
Olive-sided Flycatcher	decrease	decrease	91%	-0.1904	0.1658	0.0168
White-breasted Nuthatch	decrease		26%	-0.1707	0.2634	0.0019
Northern Flicker	decrease	decrease	85%	-0.1460	0.2903	0.0010
Green-tailed Towhee	decrease	increase	24%	-0.1382	0.3095	0.0006
Common Nighthawk	decrease	increase	50%	-0.0510	0.2400	0.0033
Mountain Quail	decrease	decrease	50%	-0.0482	0.1347	0.0327
Pacific-slope Flycatcher	decrease		18%	-0.0402	0.1704	0.0152
Spotted Sandpiper	increase		9%	0.0095	0.1457	0.0259
Song Sparrow	increase	increase	26%	0.0242	0.1287	0.0372
Common Raven	increase		35%	0.0423	0.3524	0.0002
White-headed Woodpecker	increase	increase	62%	0.0445	0.1166	0.0481
Lincoln's Sparrow	increase		29%	0.0483	0.5627	0.0000
Canada Goose	increase	increase	15%	0.0730	0.1371	0.0311
Dusky Flycatcher	increase	increase	59%	0.1118	0.1920	0.0096
Warbling Vireo	increase	decrease	74%	0.2044	0.3362	0.0003
Yellow-rumped Warbler	increase	increase	100%	0.6358	0.4334	0.0000

At least three native species that are known to have nested in the park historically have not been documented nesting for at least a decade: great gray owl (uncertain if ever nested in the park), ruby-crowned kinglet, and Swainson's thrush. The Lassen transect surveyed by Grinnell in the 1930s was resurveyed for birds in 2006 (Tingley 2007). Grinnell et al (1930). had found ruby-crowned kinglet (a boreal species) during the nesting season at six locations above 4800 feet elevation, but neither Tingley (2007) nor others have found it nesting during recent decades. Swainson's thrush has nearly been extirpated from the Sierras. The geographic ranges of all seven of these species are boreal, suggesting the possibility that warming climate might be an influence. In addition, four gamebird species—ruffed grouse, wild turkey, ring-necked pheasant, and common peafowl—appear to have been introduced in or near the park but there are no recent sightings from within the park. One species not reported in the park by Grinnell et al. (1930) but found since at least 1981 is gray jay.

Assessment Confidence and Data Gaps

Status of the park's birds and amphibians is generally well known. Less is known about mammals, reptiles, and invertebrates. Some trend information is available for breeding birds, but reliable information on long term trends is lacking for nearly all species.

4.4.4.2 Connectivity and Extent 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 (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. For example, gaps in the forest that are wider than 80 m might restrict the long-distance movements of marten (Heinemeyer 2002).

Criteria

For purposes of this assessment, "Good" conditions would be represented by unbroken connectivity of natural vegetation on all sides of the park. At a landscape scale, another goal might be to sustain corridors or stepping-stones of relatively unaltered habitat, especially along elevational gradients, so as to facilitate upward "migration" of plants and species with limited mobility in response to global warming. "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. The reference condition is imagined to be the landscape within and around the park as it may have existed in the early 1800s, prior to settlement and prior to the volcanic eruptions of the early 1900s.

Condition

Good – Medium Certainty. With regard to habitat fragmentation, the park is surrounded mainly by other forested public lands and so has much better habitat connectivity than comparable-sized areas in many parts of California. This fact is recognized by maps prepared by CDFW (2013b), which show the park as a hub with radiating spokes (corridors) to other natural lands in the region (Figure 22). Nonetheless, clearcut logging and road construction in the adjacent public lands could make species like California spotted owl more vulnerable to interbreeding with barred owl (which inhabits more open-canopied forests), and could increase the numbers of nest predators such as ravens. Commenting on one species, American marten, Rustigian-Romsos & Spencer (2010) recommended:

> "The large area of suitable and occupied marten habitat centered on Mount Lassen should be better connected to the smaller occupied polygons elsewhere in the study area via habitat that is suitable, at least during winter, for marten occupancy or dispersal. The

following general areas should be considered for vegetation management actions to increase winter habitat quality and connectivity between the Mount Lassen polygon and other winter occupancy areas:

— Higher-elevation areas lying between Mount Lassen and the Thousand Lakes Wilderness to the north, including in and around Ashpan Butte, Huckleberry Mountain, and Bear Wallow Butte.

— Higher-elevation areas between Mount Lassen and Butte Mountain to the south, including the ridges on either side of Mill Creek (i.e., in and near Doe Mountain, Morgan Hill, and Wild Cattle Mountain).

Kirk and Zielinski (2009) also recommended that east-west corridors from Lassen Volcanic National Park to the Swain Mountain Experimental Forest should be studied with regard to their likely importance to marten movements.

At one time at least one-third of the park boundary had been fenced to exclude livestock, but fences also have the potential to interfere with movements of deer. Most of this fencing has fallen into disrepair, allowing most animals (including alien cattle) to move freely in and out of the park.

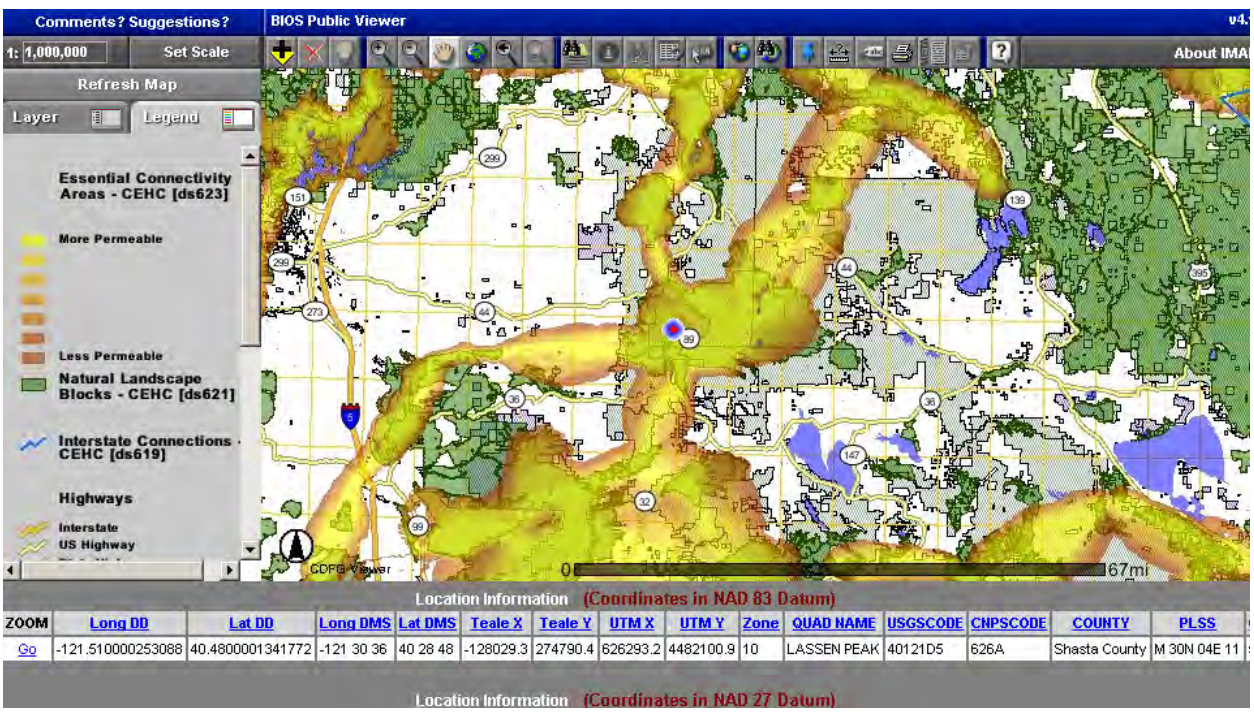

Figure 22. Essential Connectivity Areas as mapped by CDFW (2013b) in the vicinity of the park.

Trends
Good – Low Certainty. Using the NPScape mapping tool[14], we compared coarse-resolution land cover within 30 km of the park in 2001 to the same within that area in 1992. Conversions of natural land to agriculture or urban (or vice versa) were so limited that they are barely visible on the conversion map. The closest conversions of any extent were more than 10 km away. It is possible some habitat corridors not visible at this scale might have been severed over time, while others might have become more suitable for animal passage.

Assessment Confidence and Data Gaps
Medium. For the landscape surrounding the park, maps exist that show terrestrial land cover; their evaluations of connectivity are based mostly on sound principles of conservation biology. However, they do not consider needs of individual species and may not have fine enough resolution to portray suitability for movements of some species.

4.5 Changes in Air Quality

4.5.1 Background
Air quality is of interest aesthetically, and for ecological and health reasons. Ozone, particulates and wet and dry atmospheric deposition are monitored at Lassen because of their potentially harmful effects on park resources and visitors. Special studies at the park have also monitored toxic airborne contaminants.

4.5.2 Regional Conditions
The park is a Class I airshed, which is given the highest level of protection under the Clean Air Act. Although many parts of California are notorious for detrimental levels of air pollution, this has not usually been a significant concern in the northern Sierras and southern Cascades, except during major wildland fires.

4.5.3 Issues Description
Soils and vegetation in the park are, like lakes, sensitive to nutrient enrichment from nitrogen (N) deposition. In some parts of the nation, including areas in California, nitrogen deposition has altered soil nutrient cycling and vegetation species composition. In some cases, native plants that evolved under nitrogen-poor conditions have been replaced by invasive species that are able to take advantage of increased nitrogen levels. Even in the absence of invasive species, nitrogen deposition can cause shifts in the species assemblages of native plants, especially lichens and mosses which largely obtain their nitrogen directly from atmospheric sources (Geiser & Neitlich 2003, Jovan & McCune 2006). Because most of Lassen is higher than the surrounding terrain outside the park, the park likely receives relatively little runoff-borne nitrate, which typically is a major source of N to plants in human-altered landscapes. This suggests that the park’s plants might be ones that are particularly sensitive to atmospheric deposition of N.

Levels of sulfate, ozone, and other contaminants are also potential concerns. Atmospheric sulfur (S), mainly in the form of deposited sulfate, can acidify surface water and soils. Ozone, in the lower atmosphere, is an air pollutant, forming when nitrogen oxides from vehicles, power plants,

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[14] http://science.nature.nps.gov/im/monitor/npscape/

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. In the upper atmosphere, ozone absorbs the sun's harmful ultraviolet rays and helps to protect all life on earth.

4.5.4 Indicators and Criteria to Evaluate Condition and Trends

Two indicators used to monitor the effects of air pollution on park resources and people are: 1) atmospheric deposition of nitrogen, sulfur, and contaminants; and 2) ambient ozone.

4.5.4.1 Atmospheric Nitrogen Deposition

Criteria

Some aquatic ecosystems respond to wet nitrogen deposition rates of 1.5 kg per hectare per year, whereas there is no evidence of ecosystem harm at deposition rates less than 1 kg per hectare per year (Fenn et al. 2003a). A study of algae (diatoms) in other parts of the eastern Sierras determined that 1.4 kg N per ha per year (wet N deposition) was a threshold above which a shift in diatom community structure is commonly detected (Saros et al. 2011). The NPS Air Resources Division has suggested that wet nitrogen deposition less than 1 kg per hectare per year indicates "Good" condition, 1-3 kg per hectare per year indicates moderate (or "Somewhat Concerning"), and >3 kg per hectare per year indicates a "Significant Concern." In the western Sierra Nevada, Fenn et al. (2008) recommended a threshold of 3.1 kg N per hectare per year to protect all components of the forest ecosystem from the adverse effects of N deposition. For the current assessment the most conservative category of <1 kg per hectare per year (NPS ARD 2010) was used as the ecological threshold for water bodies. Lassen is the only park in the NPS Klamath Network with on-site monitoring of both wet and dry deposition of N and sulfate.

Condition

Somewhat Concerning – Medium Certainty. Data from the park (Figures 23, 24) indicate the wet N deposition rate (2.18 kg N per ha per year, measured during the 2005-2009 period) is well within the Fenn et al. (2008) criteria described above, but does not meet the NPS guideline for "good" condition. Throughfall N deposition during 2000-2003 (exempting fire episodes) was measured at 1.4 kg N per hectare per year (Fenn et al. 2008). Measurements of N deposition in Lassen in 1996-1999 indicated 0.46-0.56 kg per hectare per year (inorganic N) dry deposition, but data for wet deposition were missing (Clow et al. 2002). The 2005-2009 CASTnet data indicate a dry deposition rate of 0.22 nitrate and 0.07 ammonium. The Western Airborne Contaminants Assessment Project (Landers et al. 2008) found levels of N deposition in Lassen were not significantly higher than in other western parks.

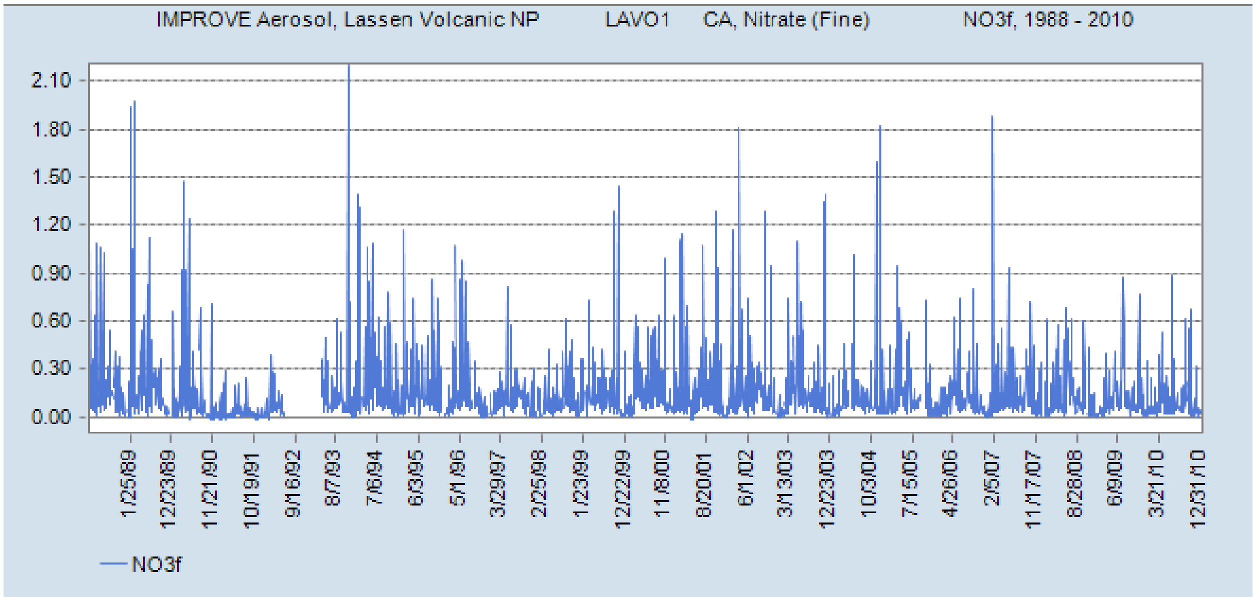

Figure 23. Nitrate deposition at Lassen Volcanic National Park, 1988-2010. (IMPROVE web site: http://views.cira.colostate.edu/web)

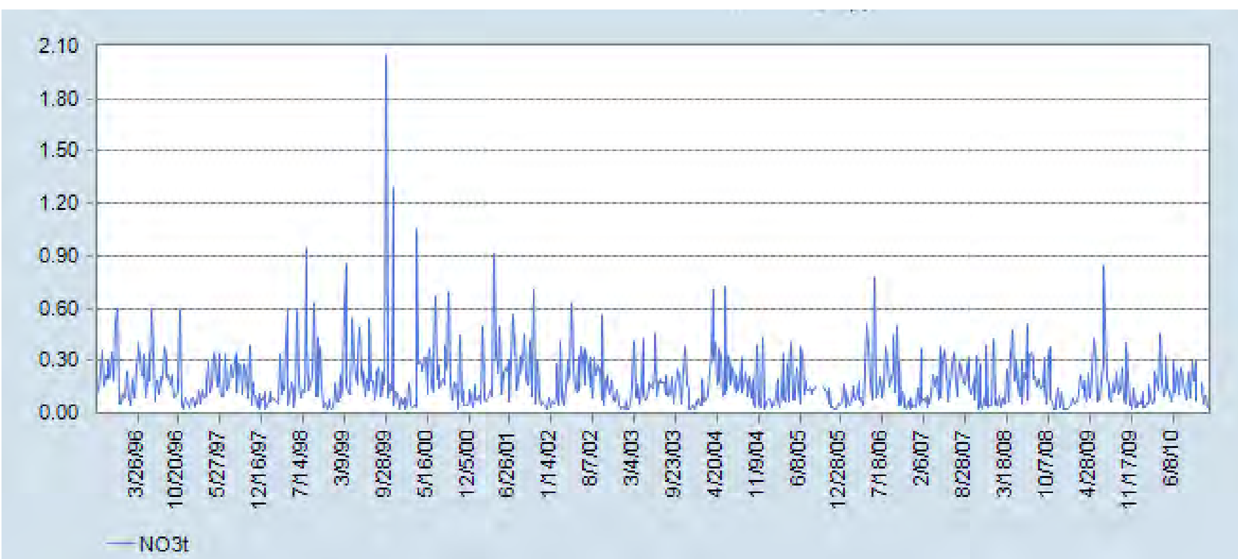

Figure 24. N-deposition at Lassen Volcanic National Park, 1996-2010. (CASTnet)

Trends
Good – Medium Certainty. No trend is apparent in the graph of nitrate deposition.

4.5.4.2 Atmospheric Sulfate Deposition

Criteria
The NPS Air Resources Division has suggested the same criteria for sulfate deposition as for nitrogen deposition: less than 1 kg per hectare per year indicates “Good” condition, 1-3 kg per hectare per year indicates moderate (or “Somewhat Concerning”), and >3 kg per hectare per year indicates a “Significant Concern.” The current assessment uses the <1 kg per hectare per year to evaluate the park’s condition.

Condition
Good – Medium Certainty. The park’s rate in 1996-1999 for dry deposition of sulfate was 0.13-0.15 kg sulfate per hectare per year (Clow et al. 2002). CASTnet data covering 2005-2009 similarly indicates dry deposition of 0.15 kg sulfate per hectare per year, plus wet deposition of 1.16 sulfate per hectare per year in the park. This wet deposition rate is barely above the NPS guideline for ecological effects, suggesting marginally degraded conditions. It is possible that sulfate deposition levels may naturally be higher than the threshold in some localized areas of the park that are near or fed by natural hot springs.

Trends
Somewhat Concerning – Medium Certainty. Although a trend is not obvious in graphs of sulfate dry deposition (Figures 25, 26), Lassen is one of only three sites nationwide that was reported to show a statistically significant increase in 80th percentile sulfate concentration during the period 1988-1999 (Malm et al. 2002). The increase was 0.86 mg/m^3 per 11-year time increment, or about a 32% increase, and levels are greater than expected at natural deposition rates. In contrast, Clow et al. (2003) found that sulfate (and nitrate) levels in the Lassen lakes they sampled were significantly lower in 1999 than in 1985, but they cautioned this may have been due to annual precipitation at Lassen being over 30% greater in the later year.

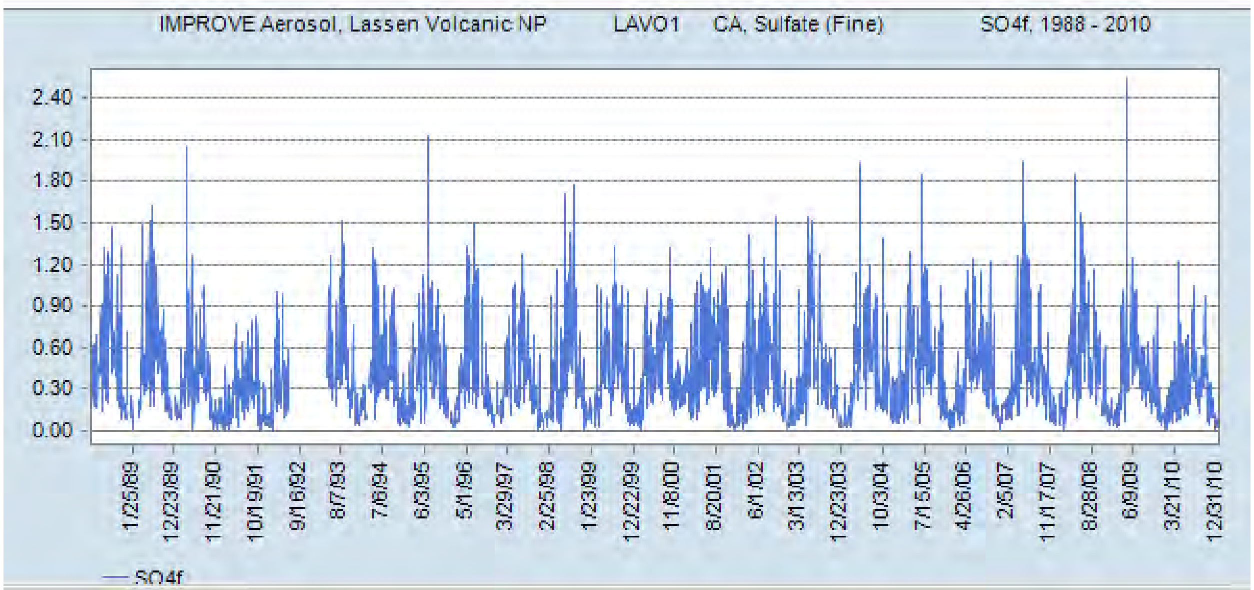

Figure 25. Sulfate deposition at Lassen Volcanic National Park, 1988-2010. Source: IMPROVE web site http://views.cira.colostate.edu/web

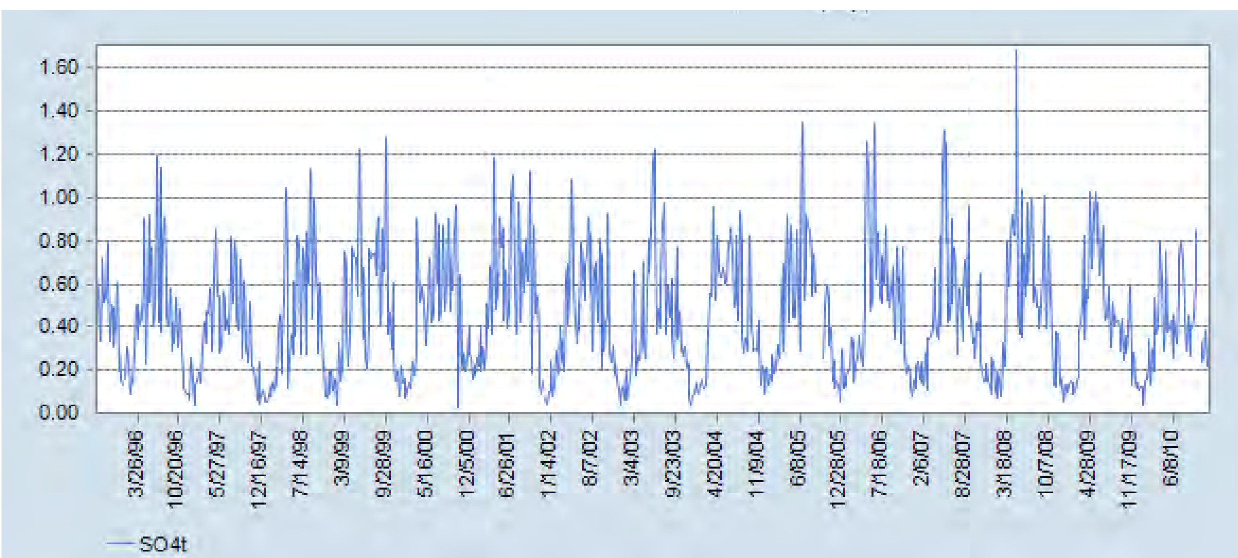

Figure 26. Sulfate deposition at Lassen Volcanic National Park, 1996-2010. Source: CASTnet.

4.5.4.3 Airborne Contaminant Deposition

Criteria
For other airborne contaminants, the preferred condition in the park is none.

Condition
Significant Concern – Medium Certainty. The Western Airborne Contaminants Assessment Project (Landers et al. 2008) determined that lichens and conifers sampled at five sites were contaminated with several pesticides currently used outside the park, especially endosulfans and dacthal, but also chlorpyrifos and g-HCH (lindane), and historically-used DDT, hexachlorobenzene, chlordanes, dieldrin, and PCB. Lichens and/or conifers also had relatively high levels of PAHs (combustion by-products). These contaminants were also present in air samples at levels mostly greater than found in other western parks. Concentrations increased with elevation within the park. Also present in air samples at above-median concentrations were triuralin (an herbicide) and the historically-used pesticides chlordane, DDT, HCB, and a-HCH (alpha hexachlorocyclohexane). Concentrations of some pesticides in rain and snowmelt from the Sierras are generally below but sometimes near the published effects thresholds for aquatic invertebrates (McConnell et al. 1998) and amphibians (Dimitrie 2010) exposed to these chemicals.

In 2001, evidence of DNA damage in juvenile frogs was documented in the park by Cowman (2005), who also found elevated levels of DDE in 15% of her samples, and found elevated levels of endosulfans in 9% of her samples. Contamination levels were significantly less than in frogs raised in Sequoia or Yosemite National Parks.

Trends
Indeterminate. No contaminants have been sampled in the same manner at Lassen over multi-year periods.

4.5.4.4 Ozone

Criteria
The NPS-ARD (2010) guidance contains ozone criteria based on the average annual fourth highest daily maximum 8-hour ozone concentration for protecting human health, and two metrics (SUM06 and W126) for evaluating risk to vegetation. Those were used for this assessment. The California ozone standard is that ozone levels not exceed 0.07 ppm averaged over 8 hours. Summarizing the literature, Geiser & Neitlich (2007) noted that ozone levels of 20 to 60 µg per m^3 may harm some lichens (Egger et al. 1994, Eversman and Sigal 1987) but repeated peak concentrations of 180-240 µg per m^3 are more often the harmful threshold (Ross and Nash 1983, Scheidegger and Schroeter 1995, Sigal and Nash 1983).

Table 13. Data from CASTnet show ozone levels at Lassen for the period 2005-2009:

OZONE	
Concentration (ppb), 4th highest 8-hr	74.8
Sum06 (ppm-hr)	22.1
3-month cumulative 12-hr W126	13.2

Condition and Trends

Significant Concern – Medium Certainty. By NPS guidelines (NPS-ARD 2011), the concentration (74.8 ppb) is barely below the 76 ppb considered a "Significant Concern" level for human health. As well, the NPS guidelines indicate a "Significant Concern" with regard to ozone threat to vegetation at Lassen. Specifically, the Sum06 value of 22.1 ppm-hr is well above the NPS guideline of 15 ppm-hr, and above an 8 ppm-hr level which some studies have shown can damage vegetation. An older source (Odion et al. 2005) reported a Sum06 of 19.2 ppm/hr.

With regard to the W126 guideline, the value of 13.2 ppm-hr is slightly above the guideline of 13 ppm-hr, and well above a threshold of 5.9 ppm-hr that has been shown to damage some sensitive plant species. An older source (Odion et al. 2005) reported a seasonal W126 of 35 ppm/hr from the park. Concern about the park's ozone levels was also expressed by Jaffe et al. (2008) who analyzed data from several national parks. Also, limited surveys have found foliar symptoms of ozone injury to both ponderosa and jeffrey pine, and on approximately 20% of yellow pines studied near Manzanita Lake. Effects of ozone on yellow pine, as well as the incidence of pathogens and insects, were monitored in 1991-1995 and 2001 by Project FOREST (USFS Riverside, Dr. Paul Miller). The American Lung Association (http://www.stateoftheair.org/2011/states/california/tehama-06103.html) assigned an air quality grade of F (failing) to Tehama County, which is one of the counties intersected by the park, but noted an improving trend.

Ozone levels are known to have increased in the park from 1990-1999 (Odion et al. 2005). For a somewhat broader period (1987-2007), ozone increased significantly with a trend of 0.827 +/- 0.14% per year in daytime ozone concentrations (Oltmans et al. 2008).

Assessment Confidence and Data Gaps

Medium. The existing monitoring of ozone is probably adequate and should continue, but as is the case with N and S deposition, there has been little effort to quantify damage throughout the park to vegetation, especially to lichens and mosses.

4.6 Changes in the Natural Quality of the Park Experience

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

4.6.2 Regional Context
Lassen Volcanic National Park and the adjacent Caribou Wilderness together comprise the largest contiguous protected area in northeastern California. They are within a day's drive of San Francisco, the Silicon Valley, Sacramento, Reno, and other major urban areas, providing recreation and a connection with nature to hundreds of thousands of visitors each year.

4.6.3 Issue Description
While some infrastructure is obviously necessary to support the immediate safety and comfort of visitors, some artificial features—mostly ones that remain from when land uses were unrestricted before the park was established—can be a visual blight, can 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 the National Park Service. With increasing population growth projected for the region surrounding the park, an opportunity exists for more people to experience the park's resources, including solitude, quiet settings, dark night skies, and clear distant views. However, air pollution, artificial lighting, and noise potentially threaten these attributes.

4.6.4 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. Disturbed Area Recovery
2. Visibility
3. Dark night sky
4. Soundscape
5. Physical Remoteness and Solitude

These are now discussed individually.

<u>4.6.4.1 Disturbed Area Recovery</u>

Criteria
For purposes of this assessment, "Good" conditions would be represented by a park landscape in which no lands have signs of being disturbed by humans except those lands 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

Somewhat Concerning – High Certainty. Historically disturbed lands not currently vital to visitor support are not extensive and were inventoried by Ziegbein & Wagner (2000). Since completion of that report, all have been physically restored and are being revegetated, with the following exceptions:

1. A 1.1 acre gravel overflow parking area adjacent to the Peak parking lot.

2. The Inholders Road. There are three small private inholdings on Hat Creek totaling about 1.5 acres.

3. Private cabins that line Juniper Lake. The park General Management Plan has the stated goal of acquiring these inholdings on a "willing seller-willing buyer" basis, and removing infrastructure as they are acquired.

4. The Twin Lakes ranger cabin. This is in a wilderness area and is currently uninhabitable.

5. Parts of Manzanita Lake which originated when a dam was enlarged in 1911 for a small hydro-power operation. Water was also diverted from Manzanita Creek to Reflection Lake, originally a closed basin lake, to provide water-generated power and to improve fish production.

The park contains 42 miles of paved roads, 15 miles of unpaved roads, five small bridges, and 146 miles of trails; however, these are currently vital to visitor support.

Trends
Improving – High Certainty. The NPS began successfully restoring the Drakesbad Meadow site in 2006, and data and reports are available (Patterson 2005, Patterson & Cooper 2007). Filling of ditches that drained wetlands there has been completed, and Dream Lake has been drained and its dam removed. For the park as a whole, natural succession, aided by the planting of thousands of plugs and native seed, appears to be gradually leading to visual recovery in nearly all areas historically disturbed by earth-moving, logging, clearing (former ski hill), or grazing.

Assessment Confidence and Data Gaps
High. The Ziegbein & Wagner (2000) survey established a baseline, and park managers not only have made steady progress in remedying nearly all the disturbances noted, but have monitored ecological recovery following the completion of the most important restoration efforts.

<u>4.6.4.2 Visibility</u>
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 is 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 near Lassen, 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% of the visibility reduction, whereas carbon (organics and light absorbing carbon) was responsible for about 20% and nitrates and coarse mass was responsible for 10%. 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).

The park is in a designated Class I air quality area, and the USEPA has regional haze regulations that require states to establish goals for each such area, to improve visibility on the haziest days and ensure no degradation occurs on the clearest days. For this park specifically, the California Regional Haze Plan has suggested that the worst condition expected under natural circumstances is about 7.3 deciview (dv). One deciview represents the minimal perceptible change in visibility to the human eye.

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 40^{th} through the 60^{th} 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: 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 (or "Somewhat Concerning") and parks with visibility condition estimates greater than 8 dv above natural conditions are considered to have a "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
Somewhat Concerning – High Certainty. As part of the IMPROVE[15] network, Lassen visibility has been monitored using an aerosol sampler (1988-present) and an automatic 35mm camera (1988-1995). The average visual range in the park is about 175 km (108 miles). Although this is better than in many parts of the United States, visibility is often noticeably impaired by haze. The most recent NPS assessment (NPS-ARD 2011), measured during 2006-2010, suggests the condition of the park's visibility should be categorized as "Somewhat Concerning" because the average annual Group 50 visibility after adjustment for natural conditions was measured as 3.5 dv.

[15] Interagency Monitoring of Protected Visual Environments

Trends
Indeterminate. Although not obvious from the graph (Figure 27), the NPS-ARD (2002) analysis of 1989-2008 IMPROVE data indicated that visibility in the area improved significantly on the clearest days during that period and may have degraded on the haziest days (but was not statistically significant).

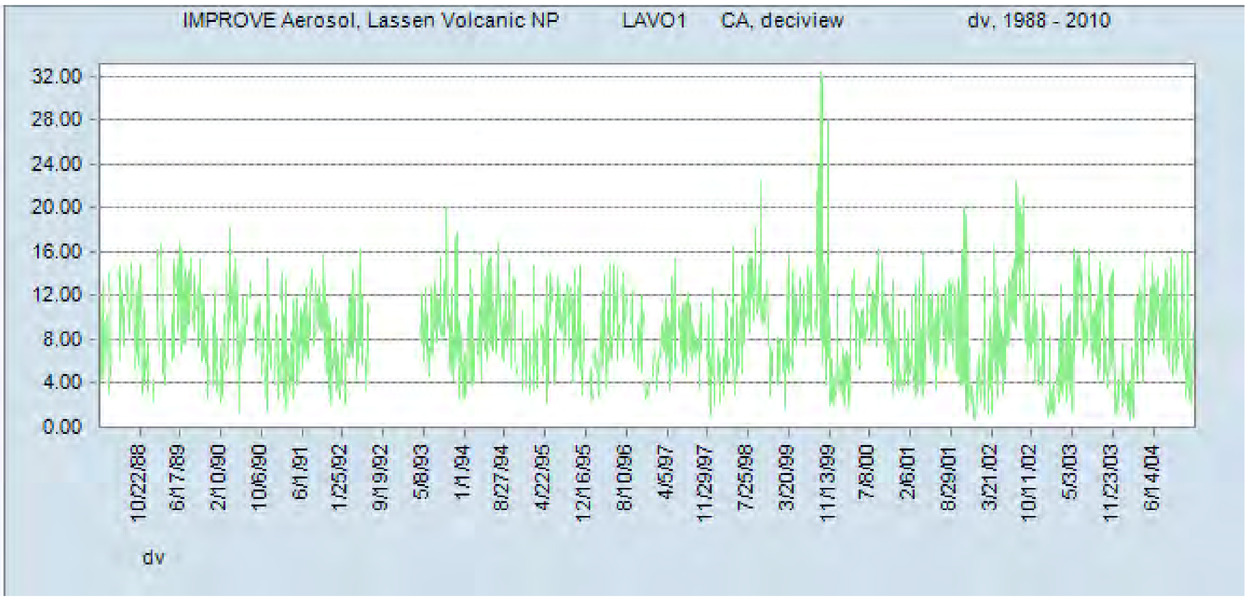

Figure 27. Visibility (in deciview units) from the park, 1988-2005. (IMPROVE web site: http://views.cira.colostate.edu/web)

Assessment Confidence and Data Gaps
High. The IMPROVE data describe the visibility conditions well.

4.6.4.3 Dark 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 to 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 developed a system for measuring sky brightness to quantify the source and severity of light pollution. This system, developed with the assistance from professional astronomers and the International Dark-Sky Association, utilizes a research-grade digital camera to capture the entire sky with a series of images. Sky brightness is measured in astronomical magnitudes in the V-band, abbreviated as "mags." The V-band measures mostly green light, omitting purple through ultraviolet and orange through infrared. The magnitude scale is a

logarithmic scale: a difference of 5 magnitudes corresponds to a 100x difference in brightness; lower values (smaller or more negative) are brighter.

Condition
Good – Medium Certainty. Because of its isolation from urban areas and other major sources of artificial light, the park's night sky can probably be assumed to be in good condition. However, data are few. Baseline condition was established for the park on July 16, 2004, when an NPS team imaged the night sky using the NPS protocol. The condition then was interpreted as "a pretty dark site." Numbers supporting that assessment are reported at: http://www.nature.nps.gov/air/lightscapes/monitordata/Lassen/lp20040716.cfm

Trends
Indeterminate. It can be assumed that nighttime light levels have increased somewhat over those present when the park was created, as surrounding areas have slowly become more developed. However, the rate at which this is has occurred is unknown.

Assessment Confidence and Data Gaps
Medium, due to the night sky condition having been measured only once using a standard protocol, and with no comparison to a quantified reference standard.

4.6.4.4 Soundscape

Criteria
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 also to protect species that require often-subtle auditory cues for reproduction, predator avoidance, navigation, and communication about food locations. Data necessary to establish reference condition criteria or a baseline for Lassen have not been collected.

Condition
Good – Medium Certainty. Because of its isolation from urban areas and other major sources of noise, the park's soundscape can probably be assumed to be in good condition overall. However, data are lacking. Senior staff in 2009 noted the following important components of the park's soundscape:

> **Wildlife.** During the morning and throughout the day, the vocalizations of songbirds are a dominant feature, along with the chattering of chipmunks and squirrels. Pika can be heard frequently in alpine areas and the low throbbing call of blue grouse at edge of fir forests. In the evening and at night, tree frogs and crickets are common, along with owls (great-horned, spotted, saw-whet) and coyotes.
>
> **Water.** Flowing water in streams and waterfalls, water dripping off of snow banks. Near geothermal areas, the sounds of steam hissing and mud pots bubbling.
>
> **Wind.** Especially on high peaks, and the silence of snowfall, heavy and light rainfall on vegetation and the ground, and occasionally some terrific thunderstorms. Leaves rustling, particularly aspen and cottonwood. Wind blowing through the trees, and trees creaking/rubbing against each other.

They further noted the presence of loud sounds that sometimes adversely affect the park's acoustical environment and soundscape:

> **Vehicle traffic on park roads.** This intrusion can be heard from many places in the park. Traffic is generated from many sources (visitors, staff, contractors) using many vehicle types. The most intrusive noises tend to be generated from big rigs and motorcycles, although noise from passenger cars and RVs is persistent during the day.
>
> **Hikers.** Laughing and talking on trails and in the backcountry, particularly when they are on the Lassen Peak trail. These sounds can be heard from areas surrounding peak.
>
> **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.
>
> **Construction and maintenance noise.** Work on and around buildings and other facilities such as bridges and campground areas can be very noisy. The plowing that is a part of the spring road opening is very loud, but humans other than the roads crew are generally not around to hear it.
>
> **Aircraft.** This intrusion is mostly high elevation commercial flights but heard regularly everywhere in park. Occasionally what sounds like a military overflight goes past; these have been heard in the Butte Lake area (northeast part of park) and circling the parks higher peaks. Aircraft used in fire suppression and fire monitoring also have an impact, and helicopters occasionally pass over the park.
>
> **Forestry work.** This intrusion is created by chainsaws, chippers, and other powered equipment used to cut hazard trees or to do thinning in campground areas and for some trail work. These sounds are significant but infrequent and irregular in occurrence.

Trends
Indeterminate. It can probably be assumed that as visitation has increased, noise levels have increased somewhat over those present when the park was created. However, trends data are lacking.

Assessment Confidence and Data Gaps
Medium, but quantitative data are lacking.

4.6.4.5 Physical Remoteness and Solitude
Wilderness qualities, each of which has been defined administratively, are:

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

Criteria
For Lassen, several indicators and measures of these—but not criteria—are described in a report "Wilderness Stewardship Core Elements" (Tarpinian 2010).

Condition
Good – Medium Certainty. Most of the park visitors who seek it are likely to find many opportunities for physical remoteness and solitude. This is partly the result of the park's protective resource management practices: wilderness use is concentrated at lakes along a few popular loop trails, and a few areas of designated and proposed wilderness are off-limits to overnight camping in order to prevent damage to sensitive areas—including Hot Springs Creek and Devil's Kitchen, and the area around Cinder Cone and Painted Dunes. Policies also prohibit campfires throughout the designated and proposed wilderness. Horseback riders must remain on particular trails, and even then, riding is allowed only when the potential for muddy conditions is low. About 400,000 visitors come to the park each year, mainly between June and September. Most visitors spend the bulk of their time in the developed zone along the main park road between Mineral and Manzanita Lake.

Trends
Indeterminate. It can probably be assumed that as visitation has increased, the sense of physical remoteness and solitude has decreased somewhat over what was present when the park was created. However, trends data are lacking.

Assessment Confidence and Data Gaps
Medium. Although total visits to the park are tallied annually, visits to various areas (especially wilderness areas) are not routinely tallied, nor are the disturbances potentially associated with those visits. The park will be producing a new Wilderness Stewardship Plan that will guide long term wilderness management in the park.

5.0 Discussion

Table 14 summarizes what this document has reported about the condition and trend of each of the major resource concerns at Lassen Volcanic National Park. Based on existing data, this review noted that a significant concern is the distorted age distributions of forest stands and lengthened fire rotations as a result of fire suppression. This will restrict the park's capacity to effectively support the region's wildlife and plant diversity—in particular, early successional vegetation like aspen and chaparral. Forest succession in the absence of fire has made fir dominant in much of the park. These changes may be reversed by fire; however, lack of fire also helps minimize the local loss of native plant species as a result of invasive plants, and helps maintain habitat for late-successional species. This creates a resource management conundrum.

Another significant concern is air quality, particularly the increasing levels of ozone. Also, restriction of long-distance visibility as a result of airborne particulates was rated "somewhat concerning," as were potential threats to native amphibians (as indicated by the very recent extirpation from the park of Cascades frog). Snowfall is a key water source for the park's many ponds, wetlands, and streams, as well as some native subalpine plants and animals. However, its annual depth distribution and melting phenology have not been measured throughout the park. This is a concern, given the inevitability of climate change. Understanding the condition and trends of the park's natural resources is essential to their sound management and could benefit from new or expanded research on the extent of ozone damage to vegetation, the extent of blister rust infection in whitebark pine, and the effects of airborne contaminants and vegetation change on amphibians. Also, given the probability of climate warming in this region, more regular and extensive monitoring is warranted of the park's subalpine plants and animals (e.g., gray-crowned rosy finch), timing and amount of snowmelt, stream flows and points of flow initiation, pond and wetland water quality, aquatic plants (especially invasives), and aquatic invertebrates.

Table 14. Summary of ratings for indicators of natural resource condition and trend used in this analysis of Lassen Volcanic National Park. See chapter narratives for criteria and justification of each rating. “Spatial coverage” refers to the extent and spatial resolution of data from the park that is suitable for assessing that indicator’s condition. “Temporal coverage” refers to the length of time period and frequency of measurement with which that indicator has been measured in the park.

Table 14. **Priority Issue**	**Indicators**	**Potential Value as Indicator**	**Condition Rating**	**Certainty**	**Trend Rating**	**Certainty**	**Spatial Coverage**	**Temporal Coverage**
Changes in Precipitation, Snowpack, and Water Availability	Maximum Annual Depth and Volume of Snowpack	Excellent	Indeterminate		Somewhat Concerning	Low	Poor	Poor
	Timing and Rate of Spring Melt and Discharge in Springs and Streams	Excellent	Indeterminate		Somewhat Concerning	Low	Poor	Poor
	Perennial Stream Extent, Seasonal Flow Volume, Wetted Width	Good	Indeterminate		Indeterminate		Poor	Poor
	Number, Area, and Distribution Pattern of Wetlands, Ponds, and Lakes	Good	Good	Medium	Indeterminate		Excellent	Poor
Changes in Surface Waters & Their Resources	Water Quality Threshold Exceedances	Fair	Good	Low	Indeterminate		Fair	Poor
	Diversity of Native Aquatic Species and Habitats	Fair	Somewhat Concerning	Low	Indeterminate		Poor	Poor
	Water Bodies With Ecologically Harmful Species	Good	Somewhat Concerning	Low	Indeterminate	Medium	Good	Poor

Table 14. Priority Issue	Indicators	Potential Value as Indicator	Condition Rating	Certainty	Trend Rating	Certainty	Spatial Coverage	Temporal Coverage
Changes in Terrestrial Vegetation	Distributions of Stand Age Classes	Excellent	**Significant Concern**	Medium	**Significant Concern**	Medium	Good	Fair
	Fire Rotations	Good	Somewhat Concerning	Medium	Somewhat Concerning	Medium	Good	Fair
	Changes in Abundance of Major Vegetation Types	Good	Somewhat Concerning	Medium	Somewhat Concerning	Medium	Good	Fair
	Invasive Plants	Fair	Somewhat Concerning	Medium	Medium		Fair	Poor
	Invasive Pathogens	Fair	**Significant Concern**	Very Low	**Significant Concern**	Poor	Poor	Poor
	Rare Plant Species and Species Diversity	Poor	Indeterminate	Low	Indeterminate		Poor	Poor
Changes in Wildlife	Presence and Persistence of Native Terrestrial Wildlife Species	Fair	Good	Low	Indeterminate		Fair	Fair
	Connectivity and Extent of Important Terrestrial Habitats	Good	Good	Medium	Good	Low	Good	Poor

Table 14. Priority Issue	Indicators	Potential Value as Indicator	Condition Rating	Certainty	Trend Rating	Certainty	Spatial Coverage	Temporal Coverage
Changes in Air Quality	Atmospheric Nitrogen Deposition	Fair	Somewhat Concerning	Medium	Good	Medium	Poor	Good
	Atmospheric Sulfate Deposition	Fair	Good	Medium	Somewhat Concerning	Medium	Poor	Good
	Airborne Contaminants Deposition	Fair	**Significant Concern**	Medium	Indeterminate		Poor	Poor
	Ozone	Good	**Significant Concern**	Medium	**Significant Concern**	Medium	Poor	Good
Changes in the Natural Quality of the Park Experience	Disturbed Area Recovery	Fair	Somewhat Concerning	High	Improving	High	Excellent	Poor
	Visibility	Good	Somewhat Concerning	High	Indeterminate		Poor	Poor
	Dark Night Sky	Good	Good	Medium	Indeterminate		Poor	Poor
	Soundscape	Good	Good	Medium	Medium		Poor	Poor
	Physical Remoteness and Solitude	Fair	Good	Medium	Indeterminate		Excellent	Poor

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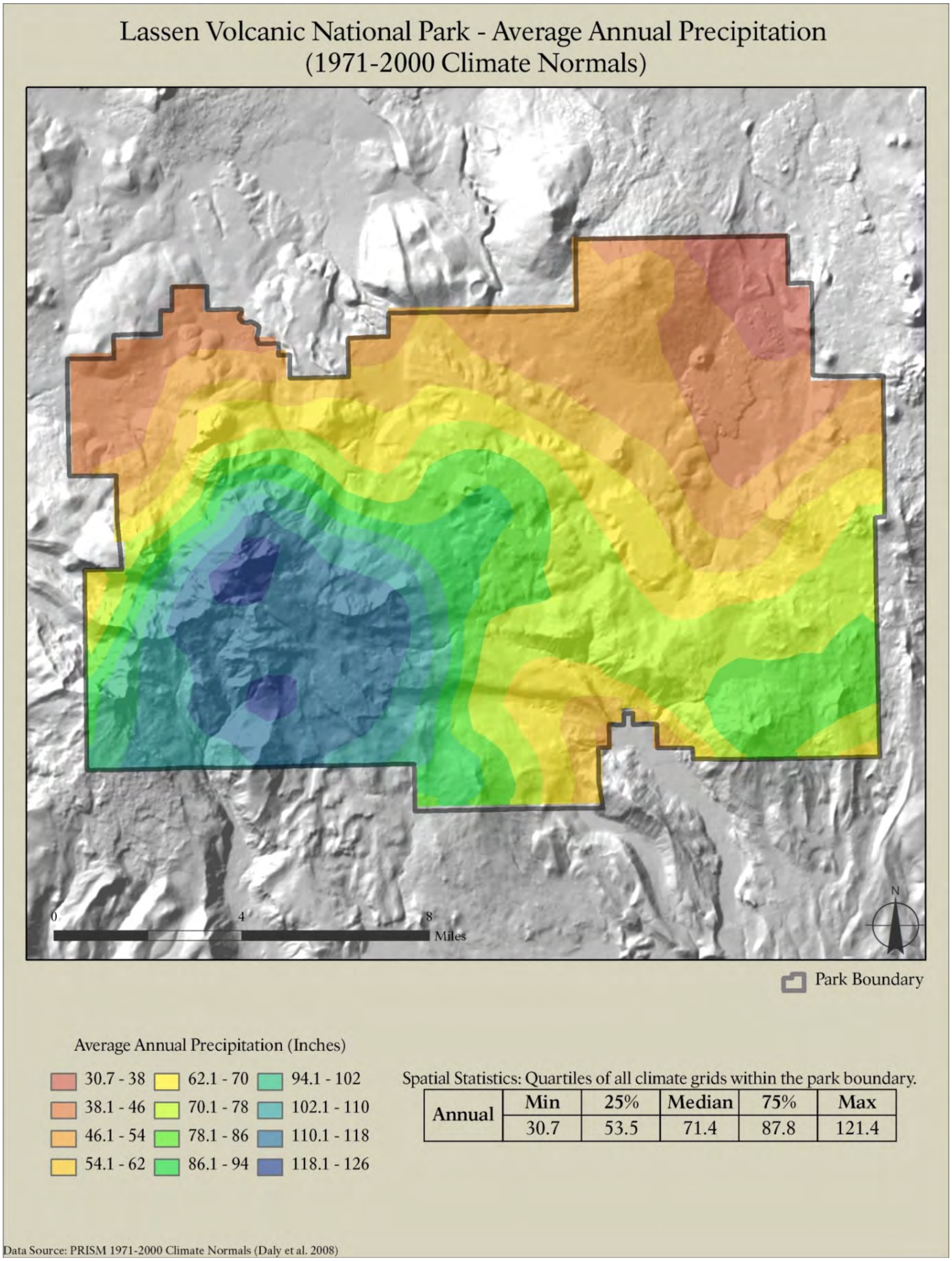
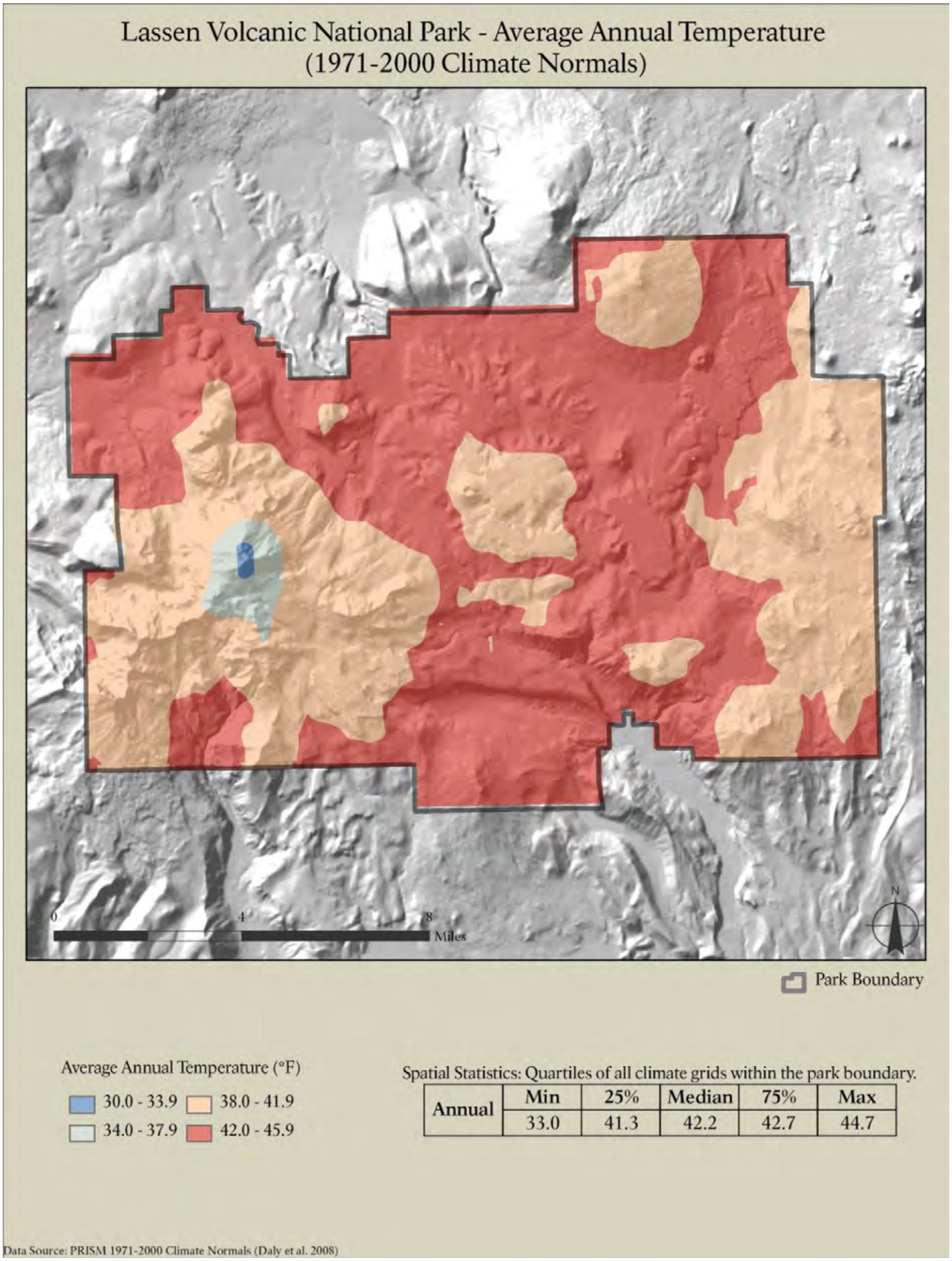
Appendix A. Climate of Lassen Volcanic National Park supporting data and maps



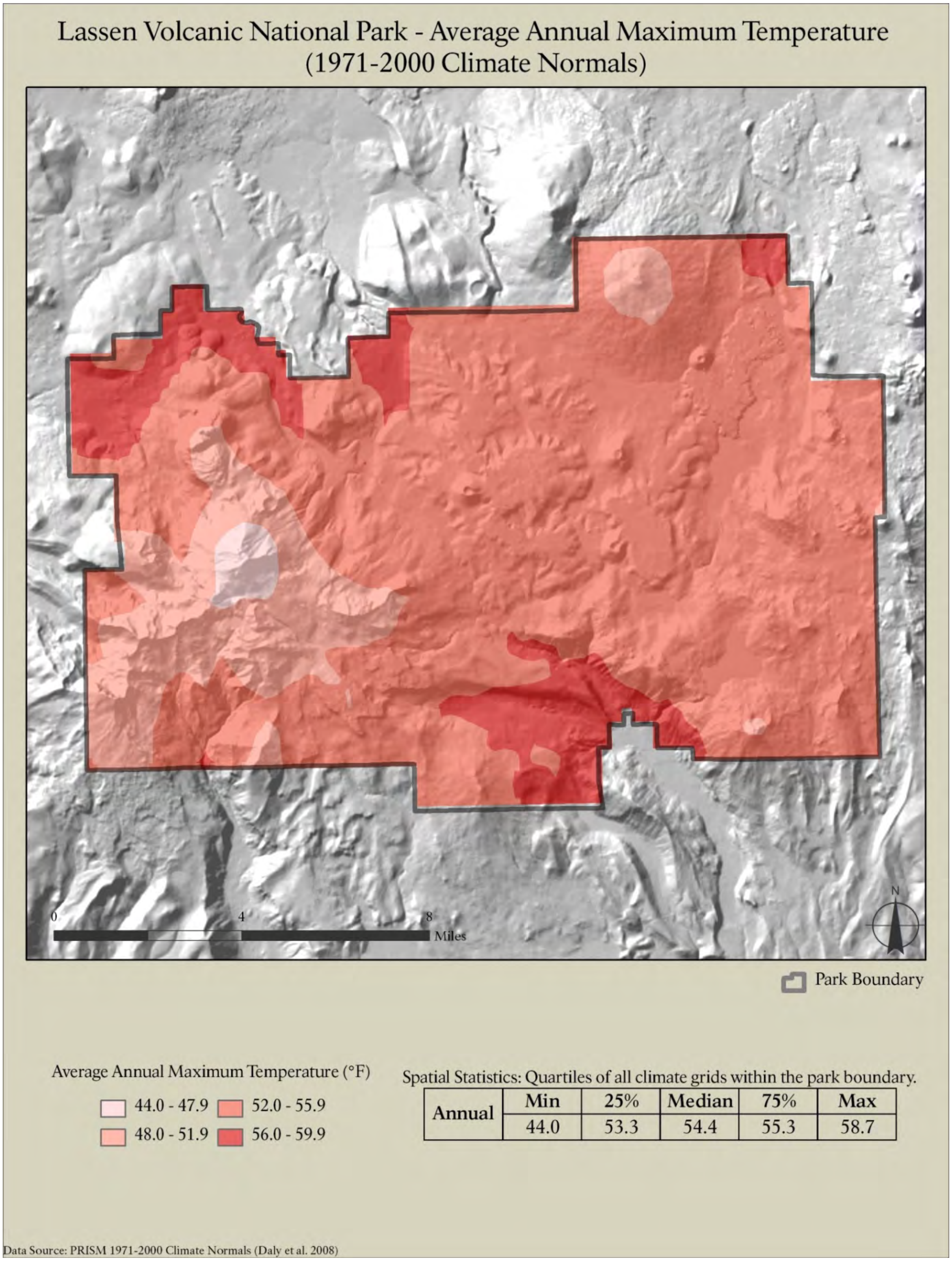
	Min	25%	Median	75%	Max
Annual	30.7	53.5	71.4	87.8	121.4

Figure A1. Average annual precipitation for Lassen Volcanic National Park (LAVO) from the PRISM 1971-2000 Climate Normals (Daly et al. 2008). The inset table gives the spatially derived quartiles of all grids that fall within the park boundary.



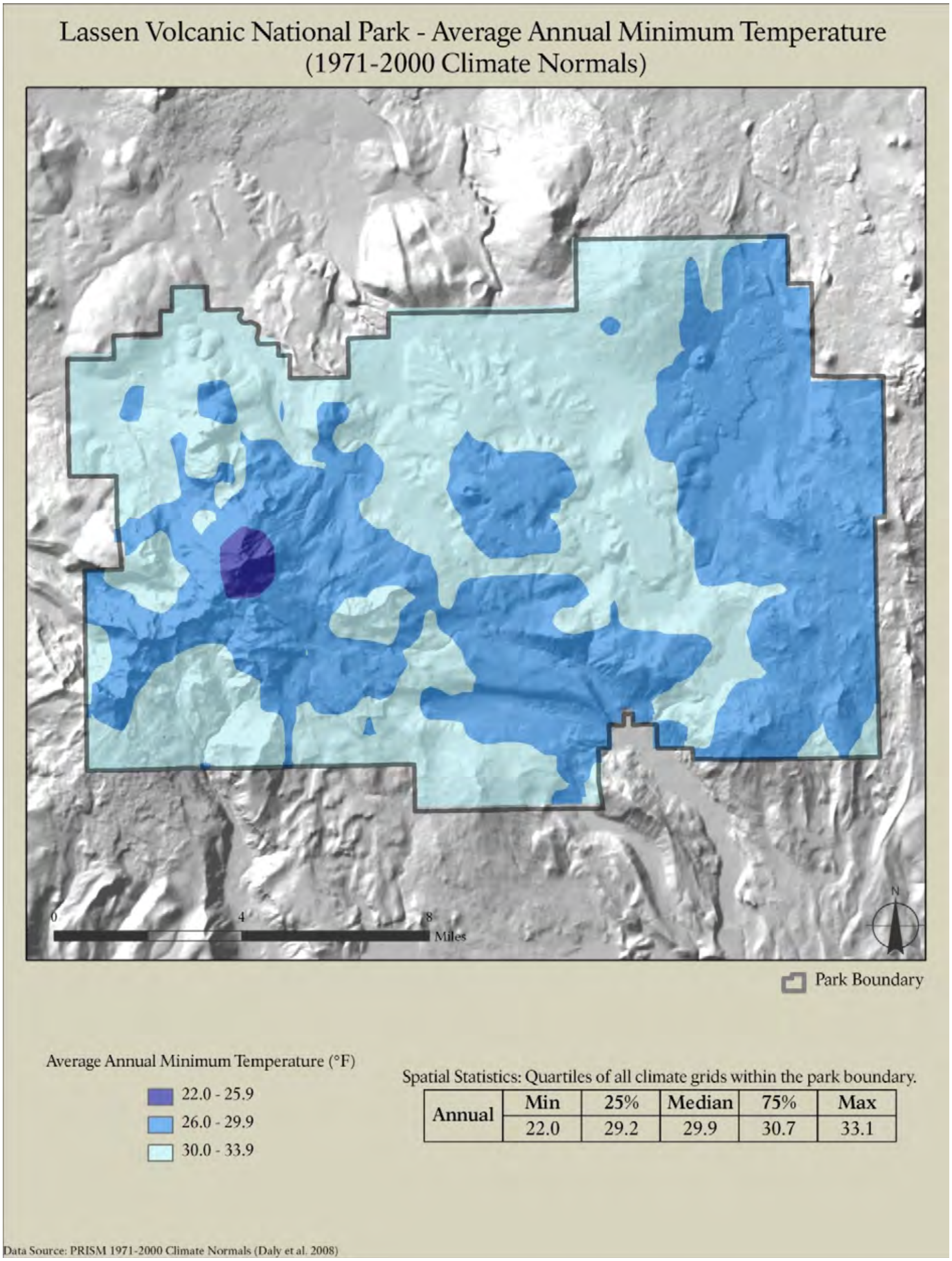
	Min	25%	Median	75%	Max
Annual	33.0	41.3	42.2	42.7	44.7

Figure A2. Average annual temperatures for Lassen Volcanic National Park (LAVO) from the PRISM 1971-2000 Climate Normals (Daly et al. 2008). The inset table gives the spatially derived quartiles of all grids that fall within the park boundary.



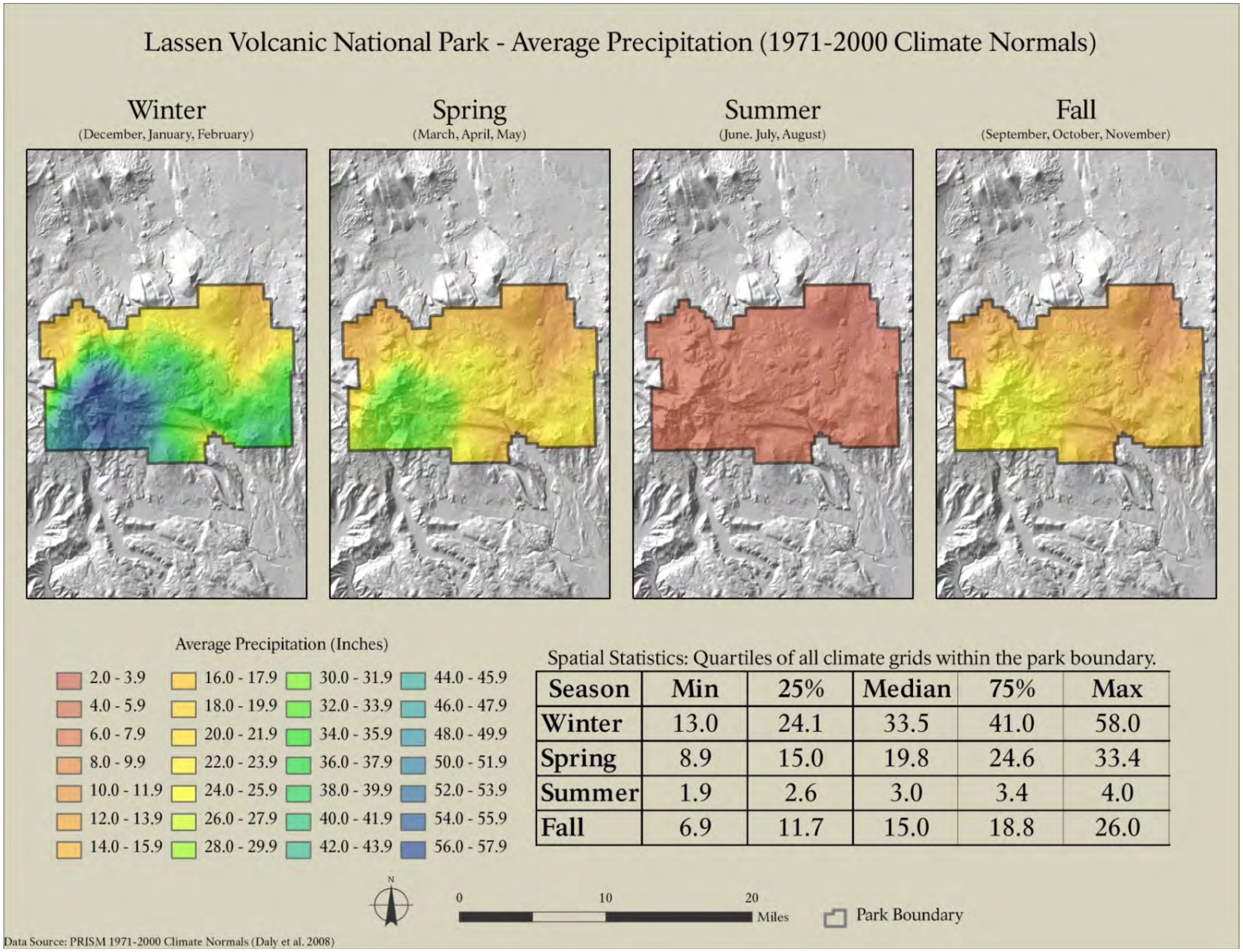
	Min	25%	Median	75%	Max
Annual	44.0	53.3	54.4	55.3	58.7

Figure A3. Average annual maximum temperatures for Lassen Volcanic National Park (LAVO) from the PRISM 1971-2000 Climate Normals (Daly et al. 2008). The inset table gives the spatially derived quartiles of all grids that fall within the park boundary.



	Min	25%	Median	75%	Max
Annual	22.0	29.2	29.9	30.7	33.1

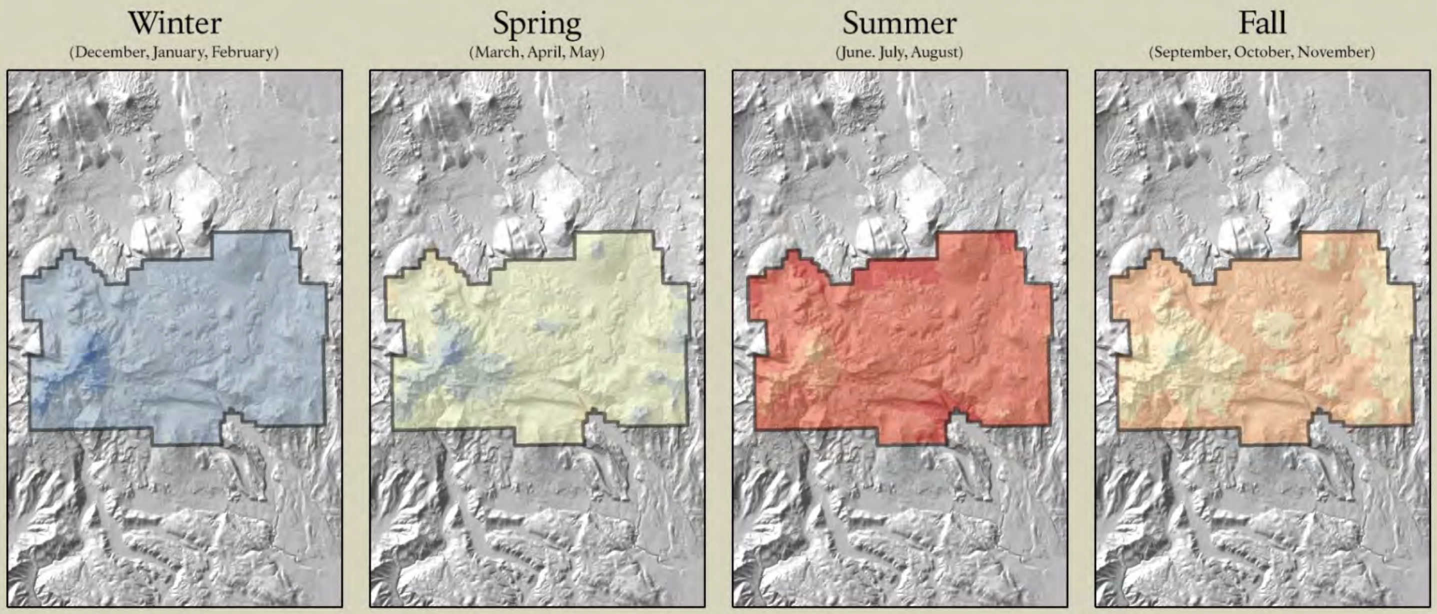
Figure A4. Average annual minimum temperatures for Lassen Volcanic National Park (LAVO) from the PRISM 1971-2000 Climate Normals (Daly et al. 2008). The inset table gives the spatially derived quartiles of all grids that fall within the park boundary.



Season	Min	25%	Median	75%	Max
Winter	13.0	24.1	33.5	41.0	58.0
Spring	8.9	15.0	19.8	24.6	33.4
Summer	1.9	2.6	3.0	3.4	4.0
Fall	6.9	11.7	15.0	18.8	26.0

Figure A5. Average precipitation for the winter (DJF), spring (MAM), summer (JJA), and fall SON) seasons for Lassen Volcanic National Park (LAVO) from the PRISM 1971-2000 Climate Normals (Daly et al. 2008). The inset table gives the spatially derived quartiles of all grids that fall within the park boundary.

Lassen Volcanic National Park - Average Temperature (1971-2000 Climate Normals)



Average Temperature (°F)

- 20.0 - 23.9
- 24.0 - 27.9
- 28.1 - 32
- 32.1 - 36
- 36.1 - 40
- 40.1 - 44
- 44.1 - 48
- 48.1 - 52
- 52.1 - 56
- 56.1 - 64

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

Season	Min	25%	Median	75%	Max
Winter	21.5	29.3	29.9	30.5	32.3
Spring	28.4	36.5	37.7	38.3	41.3
Summer	44.9	53.3	54.8	55.4	58.1
Fall	35.3	43.4	44.3	44.9	46.7

N

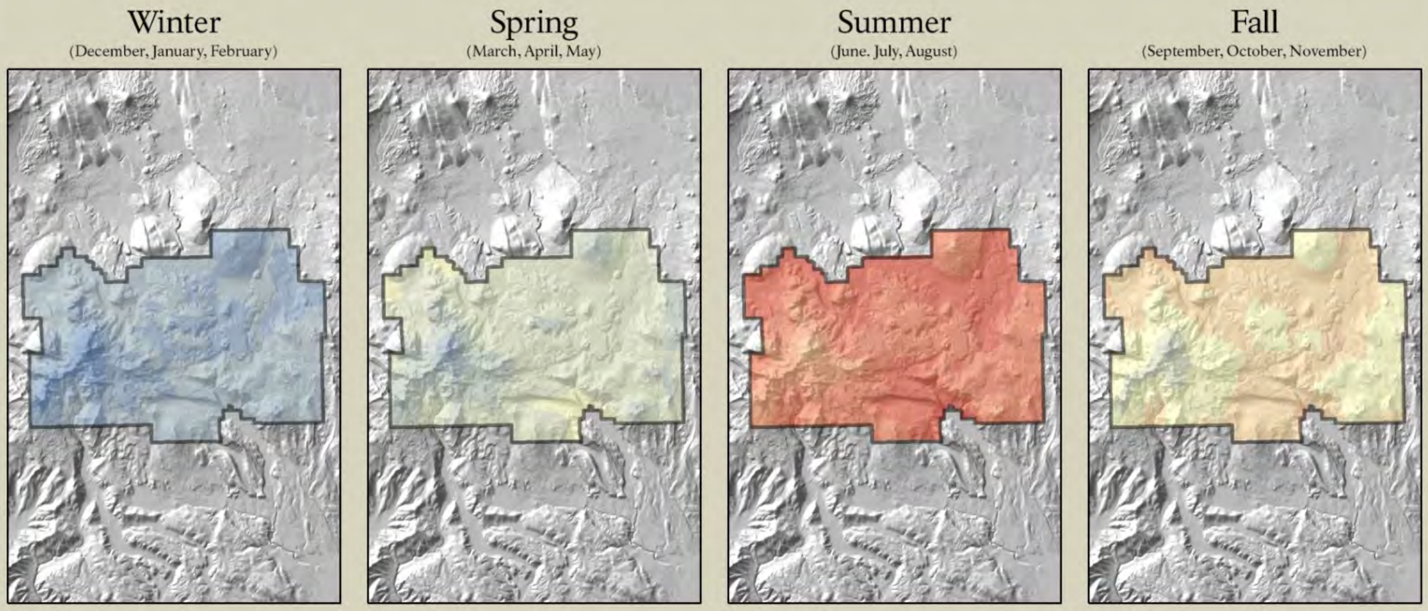
0 10 20 Miles

Park Boundary

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 Lassen Volcanic National Park (LAVO) from the PRISM 1971-2000 Climate Normals (Daly et al. 2008). The inset table gives the spatially derived quartiles of all grids that fall within the park boundary.

Lassen Volcanic National Park - Average Maximum Temperature (1971-2000 Climate Normals)



Average Maximum Temperature (°F)

- 28.0 - 31.9
- 32.0 - 35.9
- 36.0 - 39.9
- 40.0 - 43.9
- 44.0 - 47.9
- 48.0 - 51.9
- 52.0 - 55.9
- 56.0 - 59.9
- 60.0 - 63.9
- 64.0 - 67.9
- 68.0 - 71.9
- 72.0 - 75.9
- 76.0 - 79.9

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

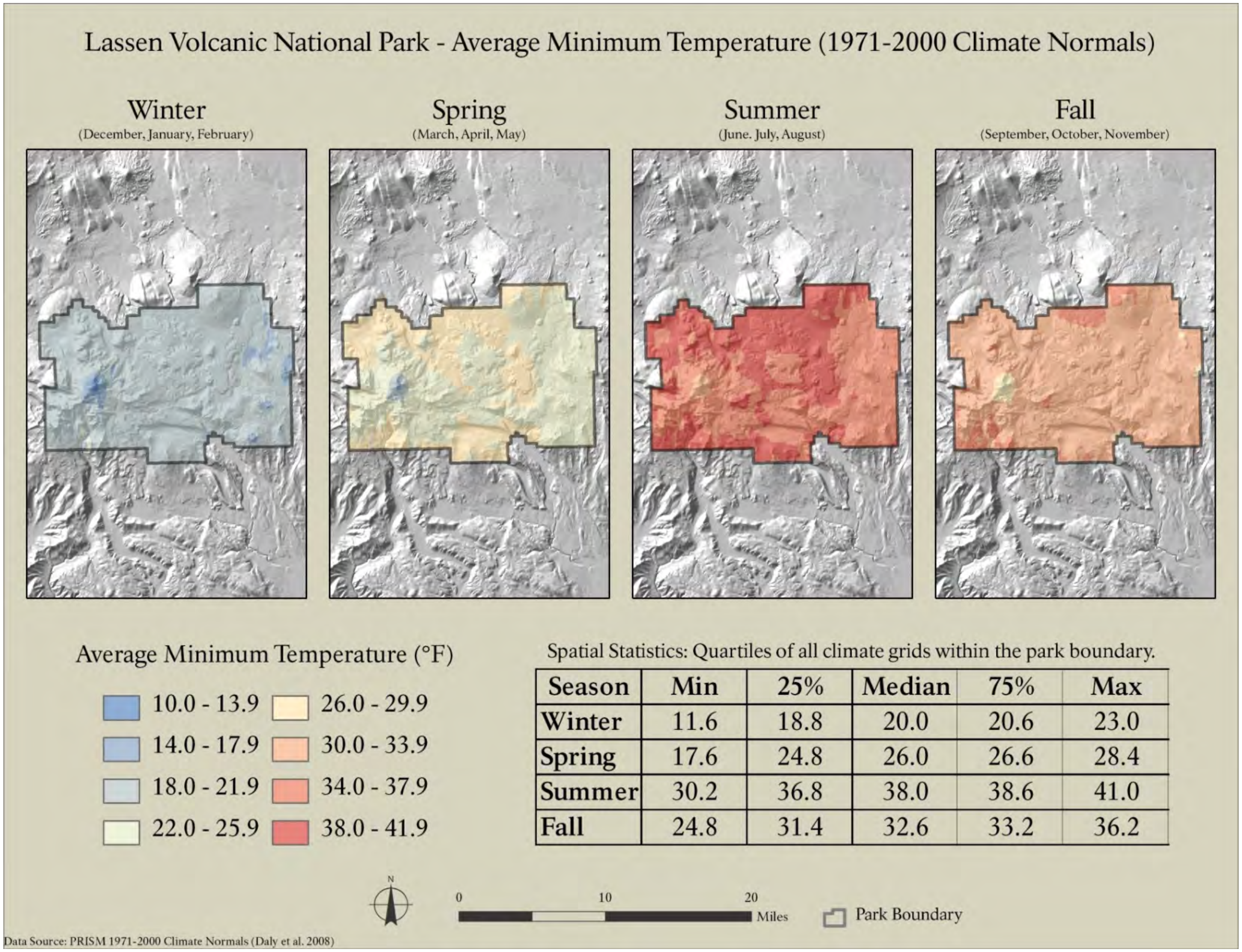
Season	Min	25%	Median	75%	Max
Winter	31.4	39.2	40.4	41.0	44.0
Spring	39.2	48.2	49.4	50.6	54.8
Summer	59.6	69.2	71.6	72.8	77.6
Fall	45.8	54.8	56.6	57.2	61.4

N 0 10 20 Miles

Park Boundary

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 Lassen Volcanic National Park (LAVO) from the PRISM 1971-2000 Climate Normals (Daly et al. 2008). The inset table gives the spatially derived quartiles of all grids that fall within the park boundary.



Season	Min	25%	Median	75%	Max
Winter	11.6	18.8	20.0	20.6	23.0
Spring	17.6	24.8	26.0	26.6	28.4
Summer	30.2	36.8	38.0	38.6	41.0
Fall	24.8	31.4	32.6	33.2	36.2

Figure A8. Average minimum temperatures for the winter (DJF), spring (MAM), summer (JJA), and fall SON) seasons for Lassen Volcanic National Park (LAVO) from the PRISM 1971-2000 Climate Normals (Daly et al. 2008). The inset table gives the spatially derived quartiles of all grids that fall within the park boundary.

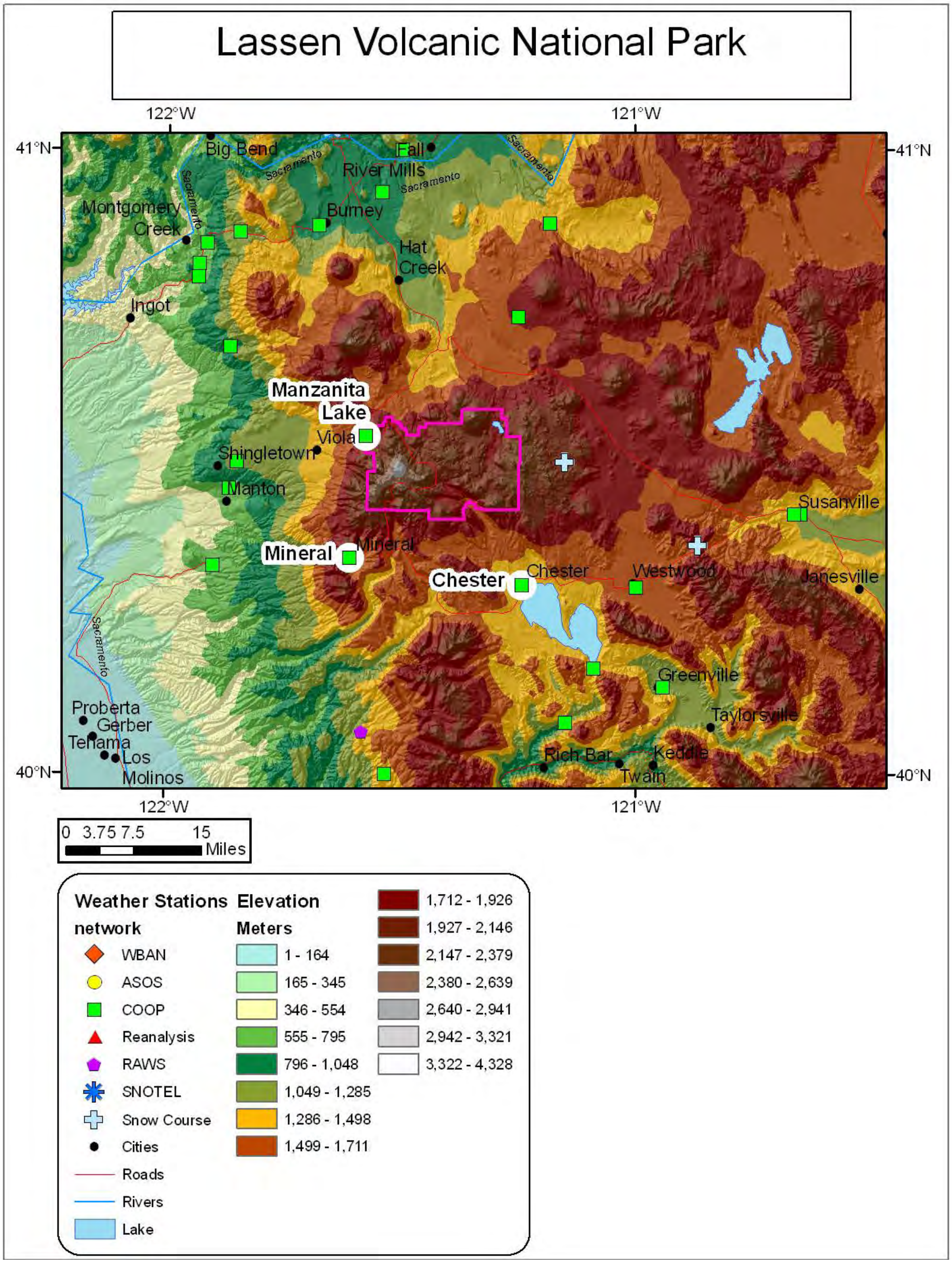


Figure A9. Climate stations in the vicinity of Lassen Volcanic National Park (LAVO) (Daly et al. 2009). Stations highlighted in the map are further referenced in the report.

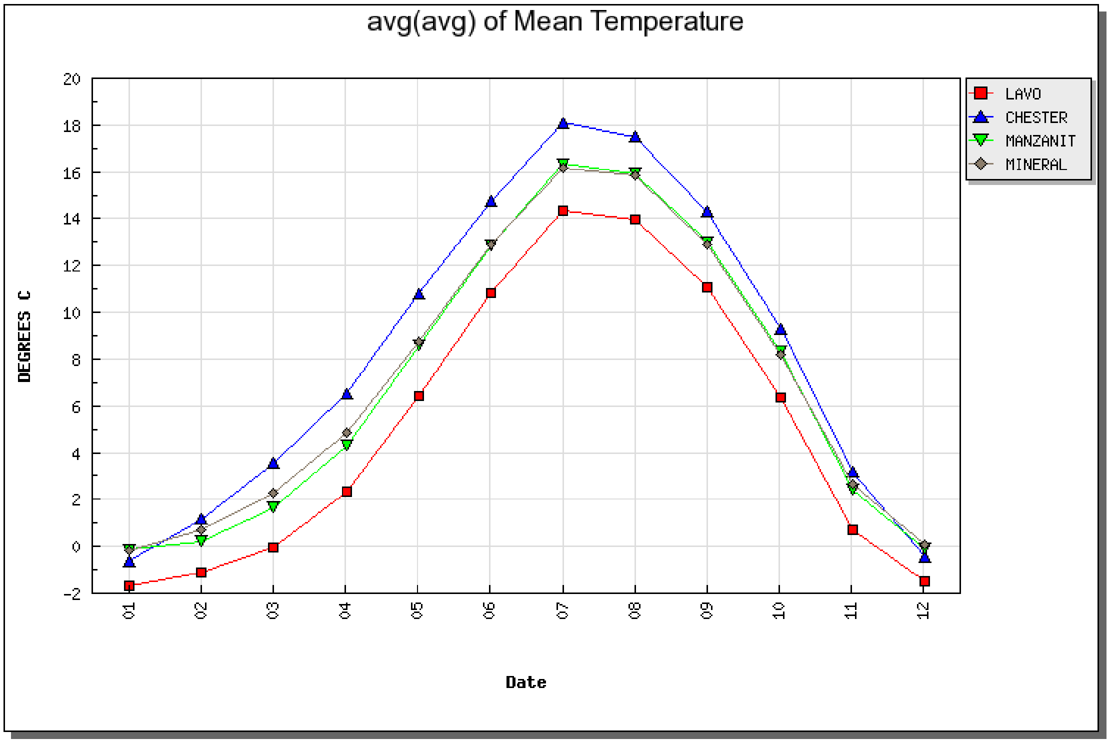


Figure A10. 1971–2000 average monthly average temperature for the stations at Chester, Manzanita Lake, Mineral, and the Lassen NP (LAVO) park average of the PRISM modeled data (Daly et al. 2009). Date refers to the month of the year.

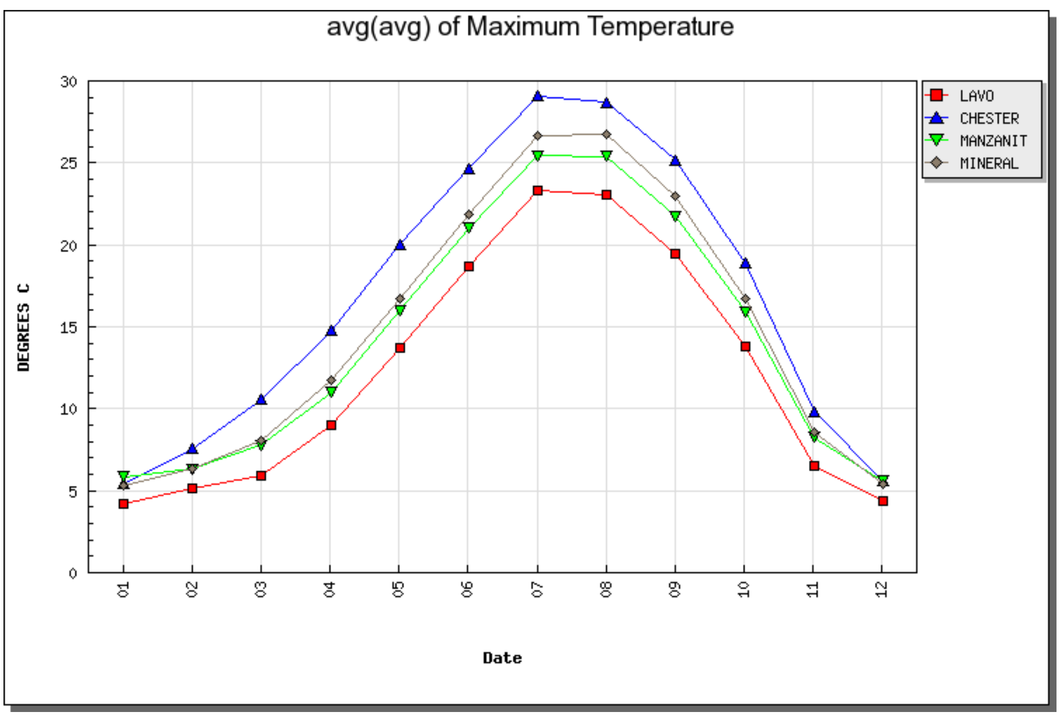


Figure A11. 1971–2000 average monthly maximum temperature for the stations at Chester, Manzanita Lake, Mineral, and the Lassen NP (LAVO) park average of the PRISM modeled data (Daly et al. 2009). Date refers to the month of the year.

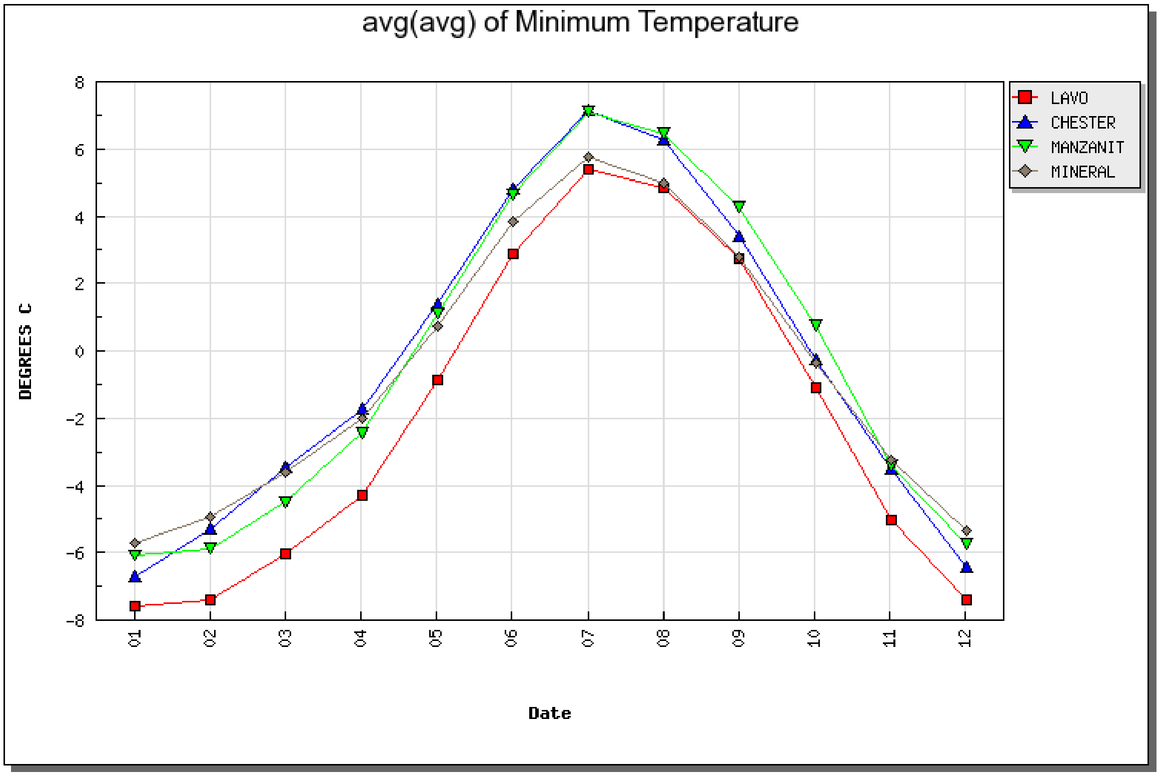


Figure A12. 1971–2000 average monthly minimum temperature for the stations at Chester, Manzanita Lake, Mineral, and the Lassen NP (LAVO) park average of the PRISM modeled data (Daly et al. 2009). Date refers to the month of the year.

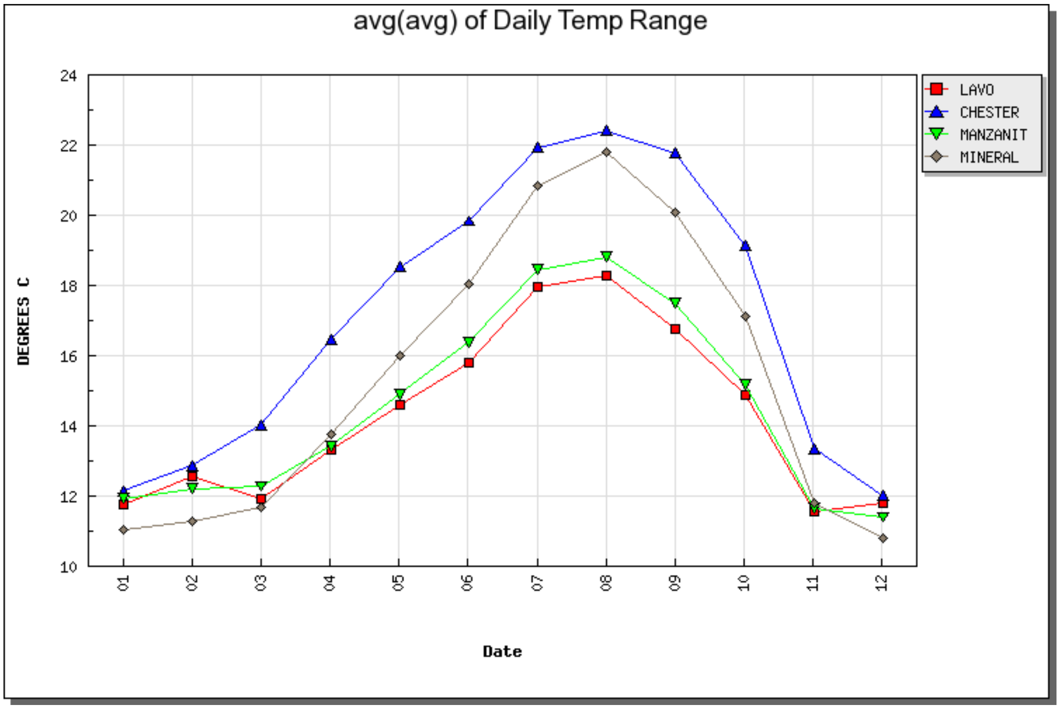


Figure A13. 1971–2000 average monthly daily temperature rangefor the stations at Chester, Manzanita Lake, Mineral, and the Lassen NP (LAVO) park average of the PRISM modeled data (Daly et al. 2009). Date refers to the month of the year.

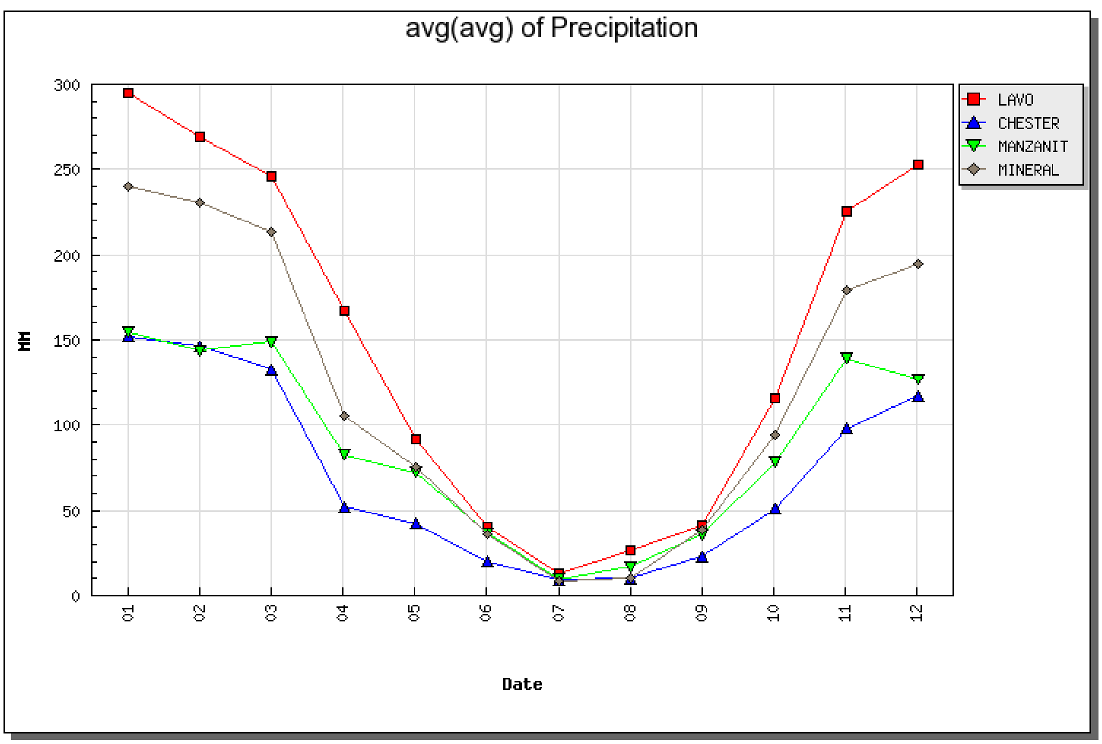


Figure A14. 1971–2000 average monthly precipitation for the stations at Chester, Manzanita Lake, Mineral, and the Lassen NP (LAVO) park average of the PRISM modeled data (Daly et al. 2009). Date refers to the month of the year.

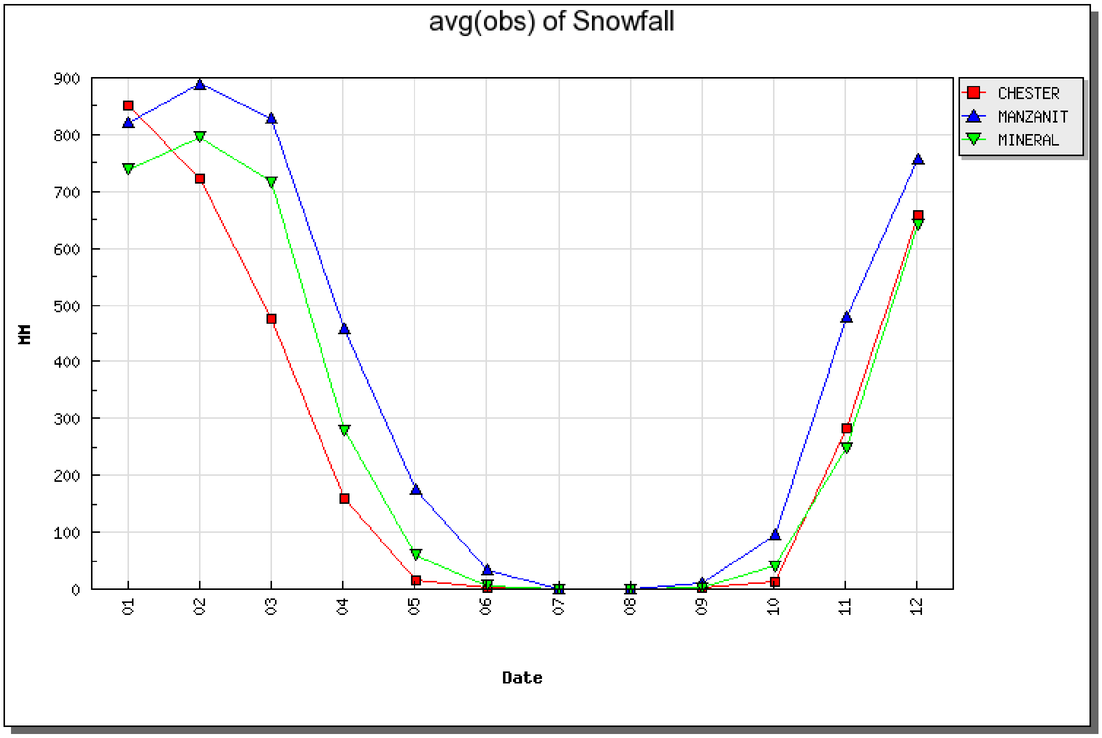


Figure A15. 1971–2000 average monthly snowfall for the stations at Chester, Manzanita Lake, and Mineral (Daly et al. 2009). Date refers to the month of the year.

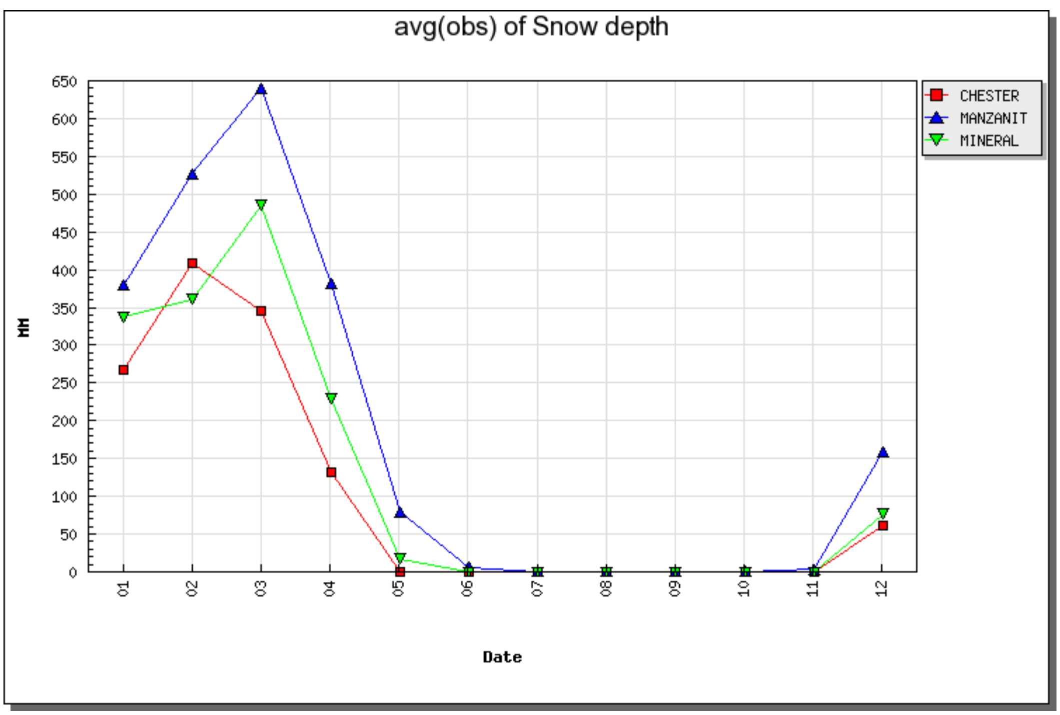


Figure A16. 1971–2000 average first of the month snow depth for the stations at Chester, Manzanita Lake, and Mineral (Daly et al. 2009). Date refers to the month of the year.

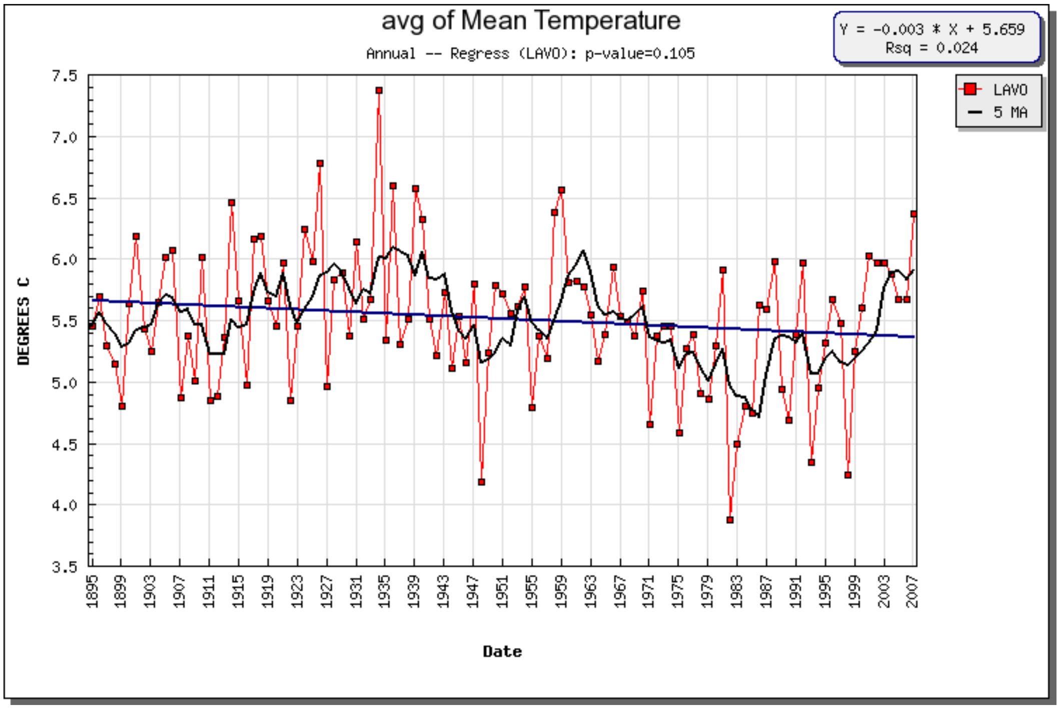


Figure A17. Time series of mean annual temperature for LAVO from the park average of the PRISM modeled data. Black line is a 5 year moving average and the blue line is the trend associated with the regression parameters (inset) (Daly et al. 2009). Date refers to year.

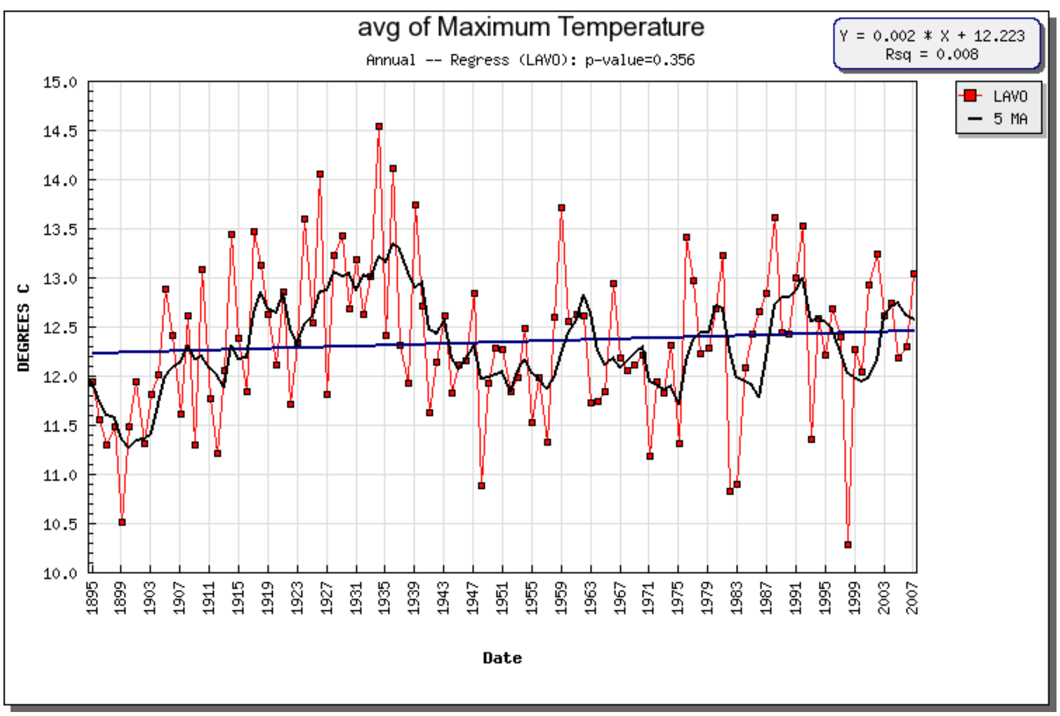


Figure A18. Time series of mean annual maximum temperature for LAVO from the park average of the PRISM modeled data (Daly et al. 2009). Black line is a 5 year moving average and the blue line is the trend associated with the regression parameters (inset). Date refers to year.

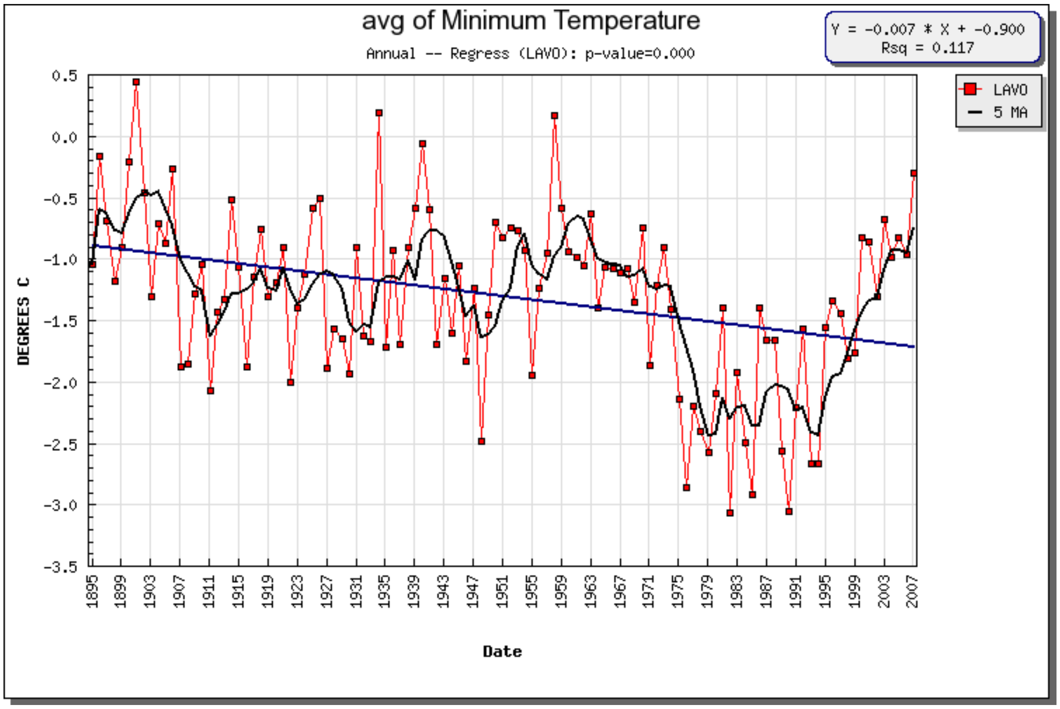


Figure A19. Time series of mean annual minimum temperature for LAVO from the park average of the PRISM modeled data (Daly et al. 2009). Black line is a 5 year moving average and the blue line is the trend associated with the regression parameters (inset). Date refers to year.

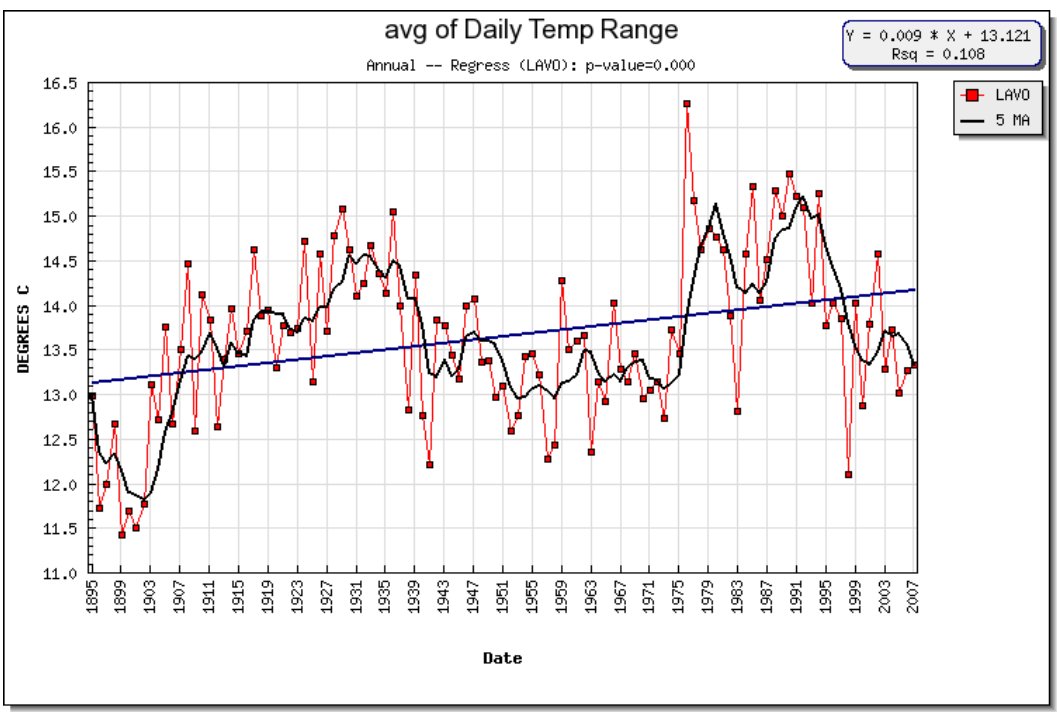


Figure A20. Time series of mean annual daily temperature range for LAVO from the park average of the PRISM modeled data (Daly et al. 2009). Black line is a 5 year moving average and the blue line is the trend associated with the regression parameters (inset). Date refers to year.

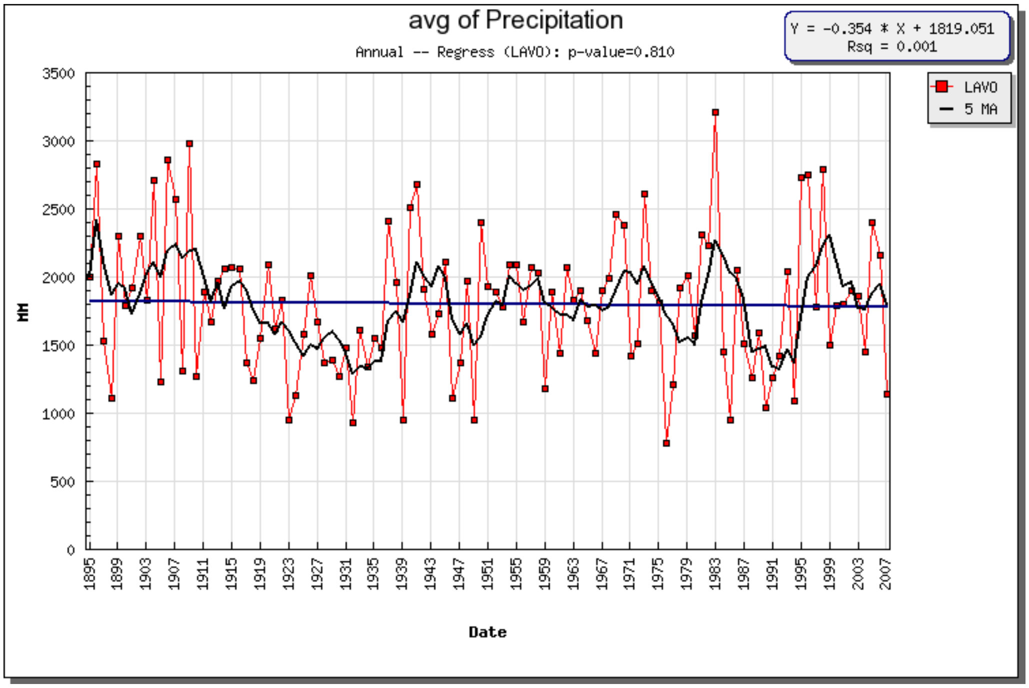


Figure A21. Time series of annual precipitation for LAVO from the park average of the PRISM modeled data. Black line is a 5 year moving average and the blue line is the trend associated with the regression parameters (inset) (Daly et al. 2009). Date refers to year.

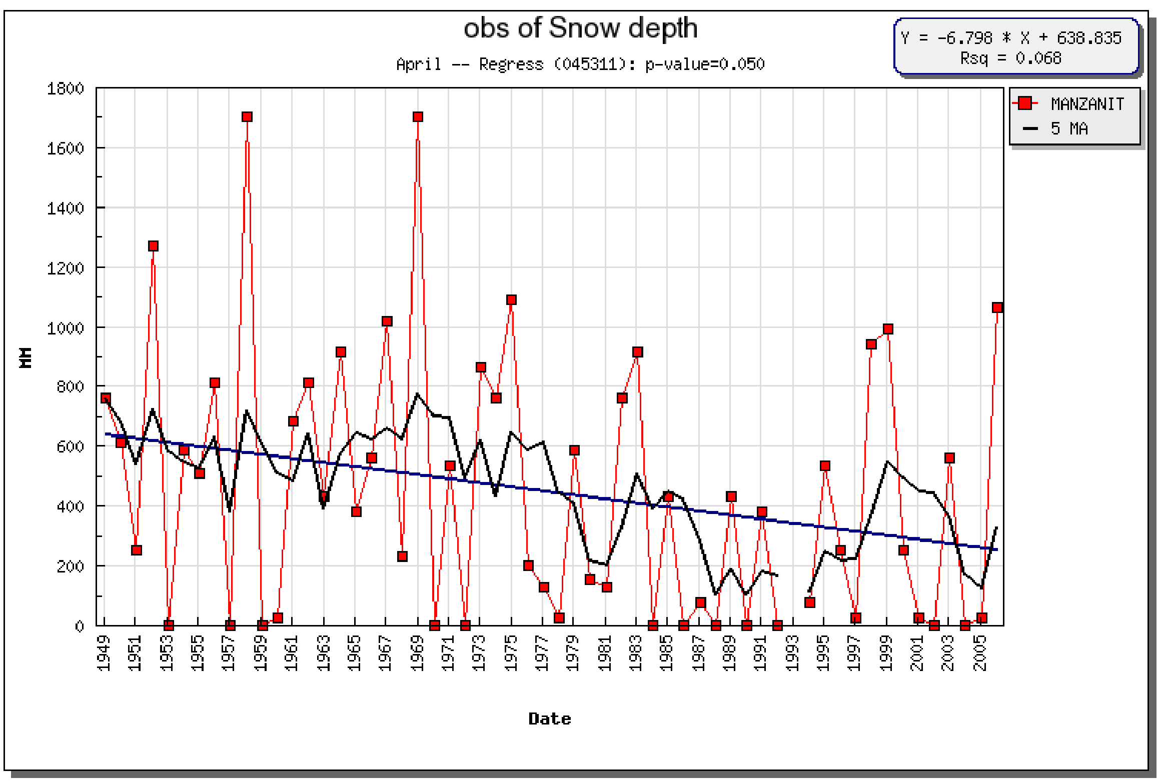


Figure A22. Time series of April 1st snow depth for Manzanita Lake. Black line is a 5 year moving average and the blue line is the trend associated with the regression parameters (inset) (Daly et al. 2009). Date refers to year.

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

Time Period (years)	Annual Precipitation		Annual Maximum Temperature		Annual Minimum Temperature		Annual Mean Temperature	
	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	-3.544	0.810	0.020	0.356	-0.073	0.000	-0.026	0.105
1971–2007	45.121	0.613	0.136	0.251	0.322	0.003	0.228	0.009

Table A2. Regression parameters and statistics for core climate elements for 1895–2007 for Lassen Volcanic National Park 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	-8.033	0.231	0.094	0.138	-0.029	0.596	0.033	0.538
February	-1.515	0.774	0.043	0.517	-0.084	0.122	-0.020	0.700
March	-2.672	0.527	0.059	0.433	-0.022	0.630	0.018	0.746
April	3.137	0.388	-0.088	0.251	-0.070	0.085	-0.079	0.158
May	-0.793	0.710	0.044	0.552	0.005	0.910	0.024	0.654
June	-0.618	0.580	0.012	0.834	-0.034	0.364	-0.011	0.810
July	0.524	0.112	0.005	0.915	-0.090	0.025	-0.042	0.291
August	0.961	0.251	0.033	0.502	-0.127	0.001	-0.048	0.217
September	-1.199	0.314	0.138	0.020	-0.089	0.029	0.024	0.588
October	-1.738	0.585	0.032	0.646	-0.100	0.009	-0.034	0.483
November	0.460	0.925	-0.079	0.256	-0.134	0.001	-0.106	0.024
December	7.942	0.216	-0.048	0.416	-0.107	0.038	-0.077	0.115
Annual	-3.544	0.810	0.020	0.356	-0.073	0.000	-0.026	0.105

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

Month	Precipitation		Maximum Temperature		Minimum Temperature		Mean Temperature	
	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	6.559	0.838	-0.101	0.711	0.479	0.068	0.187	0.391
February	15.436	0.579	-0.075	0.829	0.183	0.476	0.054	0.830
March	-22.069	0.394	0.697	0.070	0.444	0.073	0.570	0.052
April	24.257	0.185	0.060	0.882	0.430	0.037	0.245	0.407
May	15.691	0.205	-0.042	0.917	0.381	0.062	0.169	0.554
June	1.226	0.816	0.009	0.978	0.219	0.312	0.113	0.646
July	-1.975	0.315	0.302	0.251	0.362	0.124	0.332	0.160
August	-10.336	0.045	0.210	0.381	0.182	0.376	0.196	0.321
September	-12.479	0.043	0.332	0.328	0.301	0.166	0.316	0.213
October	-12.301	0.358	0.197	0.619	0.207	0.268	0.202	0.438
November	-28.241	0.352	0.275	0.482	0.239	0.310	0.257	0.348
December	69.352	0.069	-0.227	0.512	0.427	0.128	0.100	0.706
Annual	45.121	0.613	0.136	0.251	0.322	0.003	0.228	0.009

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

Month	Precipitation		Maximum Temperature		Minimum Temperature		Mean Temperature	
	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	17.057	0.397	-0.572	0.030	0.733	0.044	0.083	0.727
February	11.221	0.506	-0.701	0.069	0.225	0.457	-0.239	0.346
March	-8.295	0.623	0.082	0.852	0.285	0.202	0.186	0.526
April	10.253	0.092	-0.291	0.507	0.607	0.005	0.158	0.594
May	8.245	0.136	-0.265	0.480	0.729	0.001	0.247	0.332
June	0.422	0.874	-0.339	0.328	0.588	0.014	0.120	0.647
July	-0.096	0.953	0.101	0.699	0.979	0.000	0.534	0.023
August	-3.601	0.094	0.012	0.963	0.801	0.000	0.404	0.030
September	-7.411	0.025	-0.091	0.788	0.718	0.000	0.310	0.143
October	-5.363	0.450	-0.207	0.624	0.441	0.020	0.057	0.824
November	-8.743	0.496	-0.394	0.385	0.395	0.106	-0.009	0.975
December	20.209	0.181	-0.536	0.113	0.517	0.165	-0.012	0.967
Annual	38.612	0.455	-0.256	0.099	0.589	0.000	0.162	0.116

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

Month	Precipitation		Maximum Temperature		Minimum Temperature		Mean Temperature	
	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	12.428	0.443	-0.431	0.199	0.357	0.190	-0.041	0.879
February	-2.275	0.869	-0.189	0.626	0.101	0.721	-0.049	0.870
March	-12.888	0.360	0.451	0.231	0.415	0.205	0.438	0.190
April	8.054	0.382	0.674	0.226	0.603	0.077	0.636	0.149
May	11.307	0.233	0.053	0.917	0.320	0.216	0.188	0.604
June	-1.784	0.730	0.208	0.554	0.023	0.922	0.110	0.692
July	-1.375	0.498	0.312	0.365	0.167	0.530	0.232	0.417
August	-6.893	0.049	0.341	0.283	-0.009	0.970	0.141	0.579
September	-10.817	0.029	0.689	0.073	0.166	0.500	0.427	0.152
October	-10.702	0.226	0.205	0.644	-0.020	0.927	0.098	0.754
November	-15.706	0.341	0.038	0.929	-0.051	0.852	-0.014	0.967
December	19.989	0.260	-0.715	0.096	0.089	0.803	-0.316	0.377
Annual	25.920	0.747	0.142	0.449	0.207	0.096	0.169	0.193

Table A6. Regression parameters and statistics for core climate elements for 1971–2007 at Mineral (Daly et al. 2009). Slope *p*-values significant at the 90% confidence level (α=0.10) are shown in bold.

Month	Precipitation		Maximum Temperature		Minimum Temperature		Mean Temperature	
	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	19.601	0.513	0.037	0.894	0.524	0.110	0.288	0.233
February	15.053	0.538	-0.008	0.983	0.054	0.866	-0.035	0.900
March	-19.239	0.416	0.788	0.047	0.251	0.246	0.522	0.057
April	12.511	0.314	0.245	0.541	0.343	0.078	0.286	0.302
May	13.917	0.186	-0.076	0.865	0.485	0.007	0.208	0.458
June	-0.503	0.925	0.325	0.335	0.329	0.131	0.320	0.198
July	-3.542	0.112	0.392	0.249	0.275	0.264	0.397	0.146
August	-4.286	0.062	0.357	0.241	0.048	0.768	0.204	0.340
September	-12.908	0.067	0.932	0.072	0.411	0.027	0.673	0.032
October	-15.165	0.232	0.969	0.055	0.042	0.794	0.505	0.089
November	-13.447	0.615	0.382	0.371	0.271	0.296	0.320	0.265
December	54.259	0.117	0.023	0.945	0.492	0.116	0.253	0.344
Annual	76.714	0.480	0.312	0.081	0.308	0.012	0.300	0.008

Table A7. Regression parameters and statistics for April 1st snow depth at Manzanita Lake for different time periods (Daly et al. 2009). Slope *p*-values significant at the 90% confidence level (α=0.10) are shown in bold.

	April 1 Snow Depth	
Time Period (years)	**Slope (mm/10 yr)**	***p*-value**
1949–2007	-67.984	0.050
1971–2007	-35.379	0.560

Table A8. Regression statistics for the 27 core climate extremes indices for the three representative climate stations for LAVO. All trends statistically significant at the 0.05 level shown in bold.

Indices/Stations/Trend Statistics	Chester (1957-2011)			Mineral (1927-2011)			Manzanita Lake (1949-2011)		
	R^2	*p*-value	Slope	R^2	*p*-value	Slope	R^2	*p*-value	Slope
# of Days Tmax >25°C (days)	NS	0.998	0.000	0.08	0.006	0.144	NS	0.734	-0.014
# of Days Tmax <0°C (days)	NS	0.477	0.040	0.04	0.046	-0.013	0.06	0.049	0.163
# of Days Tmin >20°C (days)	NS	0.596	0.001	Not Observed			Not Observed		
# of Days Tmin <0°C (days)	0.15	0.008	-0.435	0.49	0.000	-0.694	0.15	0.001	0.272
# of Days Tmin <-10°C (days)	0.16	0.006	-0.309	0.10	0.002	-0.043	NS	0.831	0.012
Growing Season Length (days)	NS	0.854	-0.031	0.14	0.000	0.403	NS	0.341	-0.201
Maximum Tmax (°C)	NS	0.080	0.024	NS	0.467	0.004	NS	0.513	-0.006
Minimum Tmax (°C)	NS	0.226	-0.032	0.05	0.028	0.017	NS	0.518	0.009
Maximum Tmin (°C)	NS	0.496	0.015	0.17	0.000	0.025	0.24	0.000	-0.045
Minimum Tmin (°C)	NS	0.244	0.042	0.11	0.001	0.046	0.09	0.013	0.037
% of Days Tmax <10th Percentile (%)	NS	0.412	0.016	0.25	0.000	-0.068	NS	0.305	0.017
% of Days Tmax >90th Percentile (%)	NS	0.476	-0.016	0.05	0.030	0.029	NS	0.138	-0.034
% of Days Tmin <10th Percentile (%)	0.11	0.001	-0.124	0.47	0.000	-0.136	NS	0.314	0.015
% of Days Tmin >90th Percentile (%)	0.21	0.025	0.056	0.56	0.000	0.109	0.22	0.000	-0.091
Warm Spell Duration Index (days)	NS	0.056	-0.077	NS	0.939	-0.002	NS	0.088	-0.067
Cold Spell Duration Index (days)	NS	0.911	-0.005	0.21	0.000	-0.097	NS	0.326	0.013

Indices/Stations/Trend Statistics	Chester (1957-2011)			Mineral (1927-2011)			Manzanita Lake (1949-2011)		
	R^2	*p*-value	Slope	R^2	*p*-value	Slope	R^2	*p*-value	Slope
Diurnal Temperature Range (°C)	0.25	0.001	-0.029	0.15	0.000	-0.013	NS	0.924	0.000
Maximum 1-Day Precipitation (mm)	NS	0.825	-0.026	NS	0.632	0.032	0.06	0.042	-0.431
Maximum 5-Day Precipitation (mm)	NS	0.446	0.176	NS	0.800	0.044	NS	0.174	-0.456
Simple Precipitation Intensity Index (mm/day)	NS	0.086	0.016	NS	0.896	-0.001	0.12	0.003	-0.030
Annual # of Days Precipitation >10 mm (days)	NS	0.123	0.053	NS	0.688	0.011	NS	0.950	-0.004
Annual # of Days Precipitation >20 mm (days)	0.11	0.020	0.052	NS	0.310	0.017	NS	0.536	-0.025
Maximum Length of Dry Spell (days)	NS	0.948	0.007	NS	0.648	-0.033	NS	0.842	-0.018
Maximum Length of Wet Spell (days)	NS	0.368	-0.016	NS	0.497	0.010	NS	0.692	-0.007
Annual # of Days with Precipitation >95 Percentile (days)	NS	0.196	0.782	NS	0.736	0.158	0.10	0.006	-3.059
Annual # of Days with Precipitation >99 Percentile (days)	NS	0.935	0.027	NS	0.860	-0.045	0.14	0.001	-2.204
Annual Precipitation Total (mm)	NS	0.333	0.934	NS	0.509	0.491	NS	0.291	-1.860

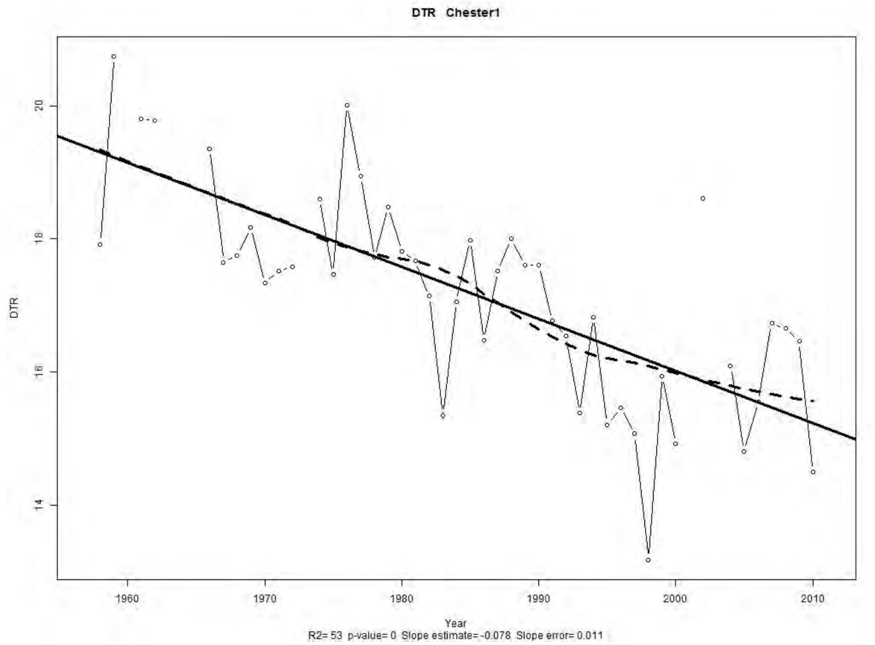


Figure A23. Example time series of the changes in the diurnal temperature range during the reference period observed each year at Chester, California, during 1957-2011. Trends are computed by linear least square (solid line) and locally weighted linear regression (dashed line). Missing data is handled as discussed in the text.

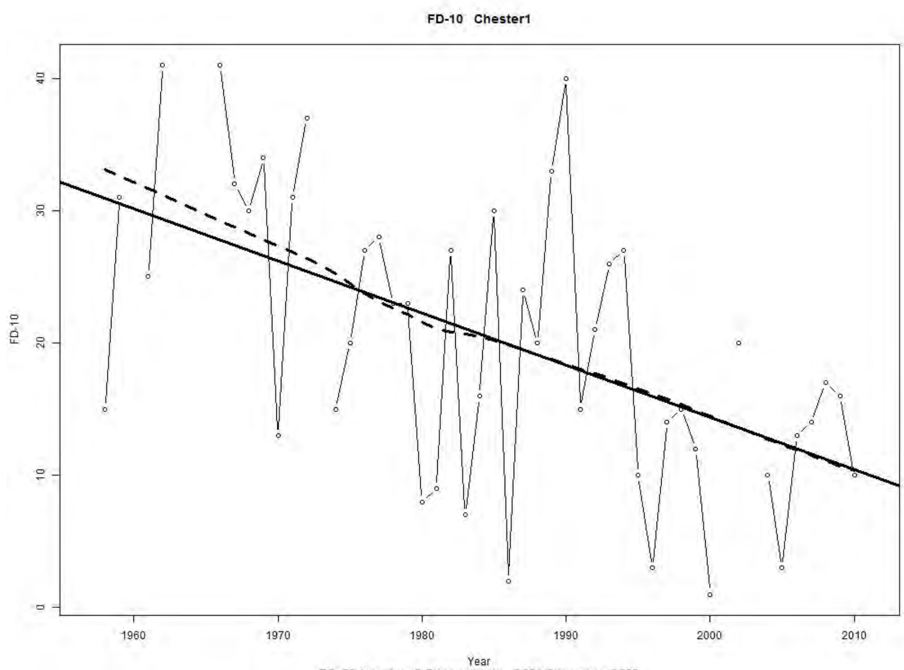


Figure A24. Example time series of the number of days below -10°C (14°F) observed each year at Chester, California, during 1957-2011. Trends are computed by linear least square (solid line) and locally weighted linear regression (dashed line). Missing data is handled as discussed in the text.

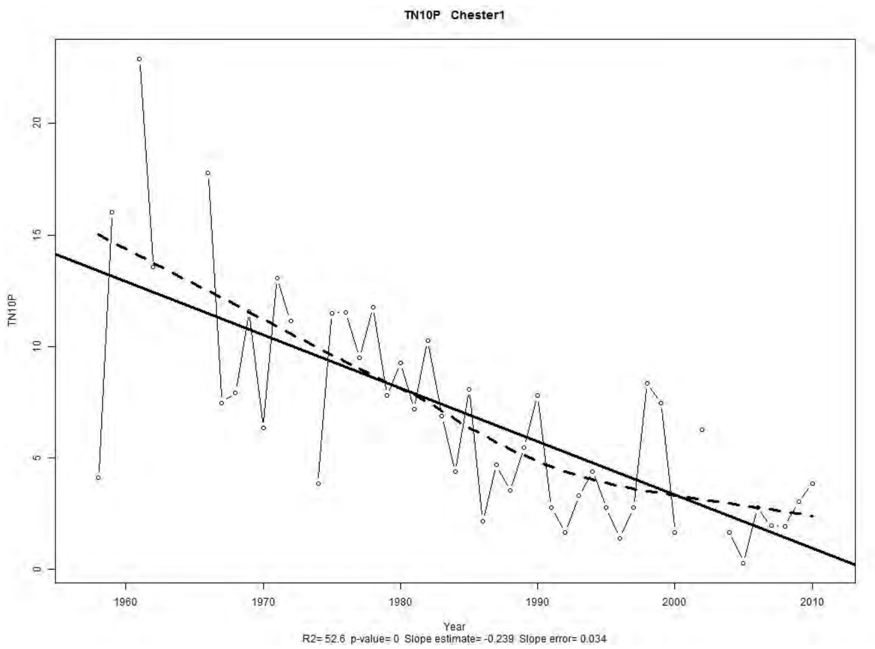


Figure A25. Example time series of the number of days when the minimum temperature is below the 10th percentile during the reference period observed each year at Chester, California, during 1957-2011. Trends are computed by linear least square (solid line) and locally weighted linear regression (dashed line). Missing data is handled as discussed in the text.

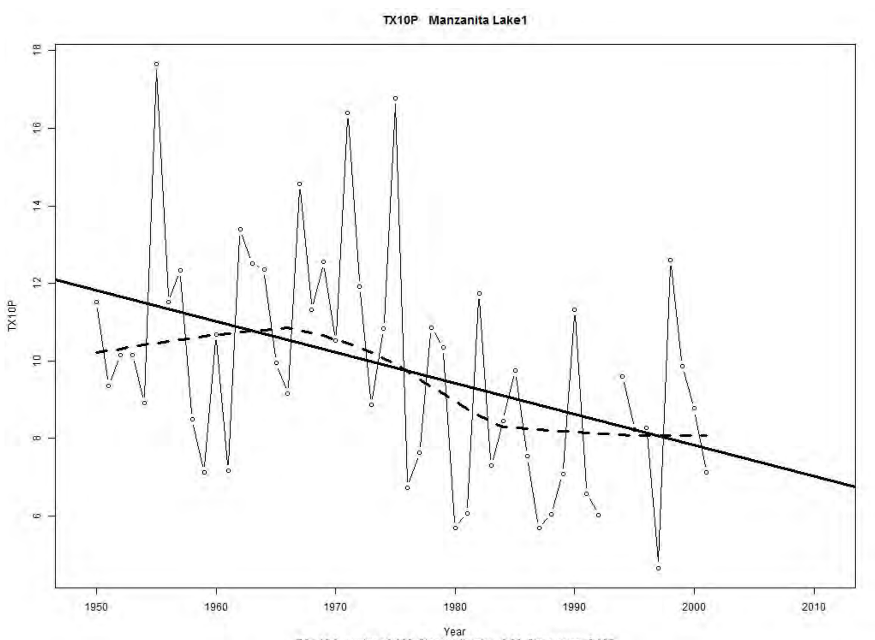


Figure A26. Example time series of the number of days when the maximum temperature is below the 10th percentile during the reference period observed each year at Manzanita Lake, California, during 1949-2011. Trends are computed by linear least square (solid line) and locally weighted linear regression (dashed line). Missing data is handled as discussed in the text.

Appendix B. Physical Characteristics of Lassen Volcanic National Park: supporting data and maps

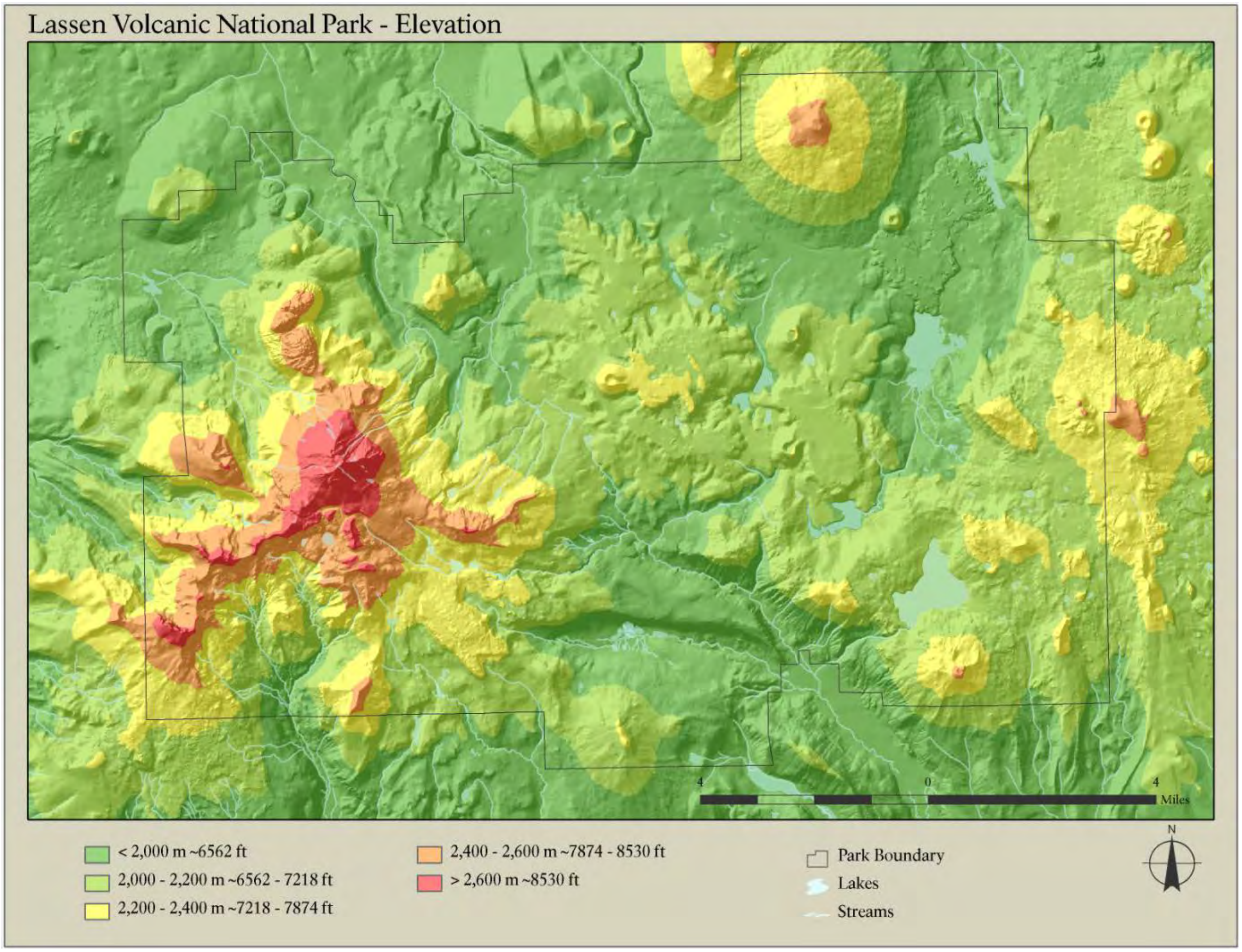


Figure B1. Mapped elevation classes in Lassen Volcanic National Park (USGS 2011). Scale: 10 meters.

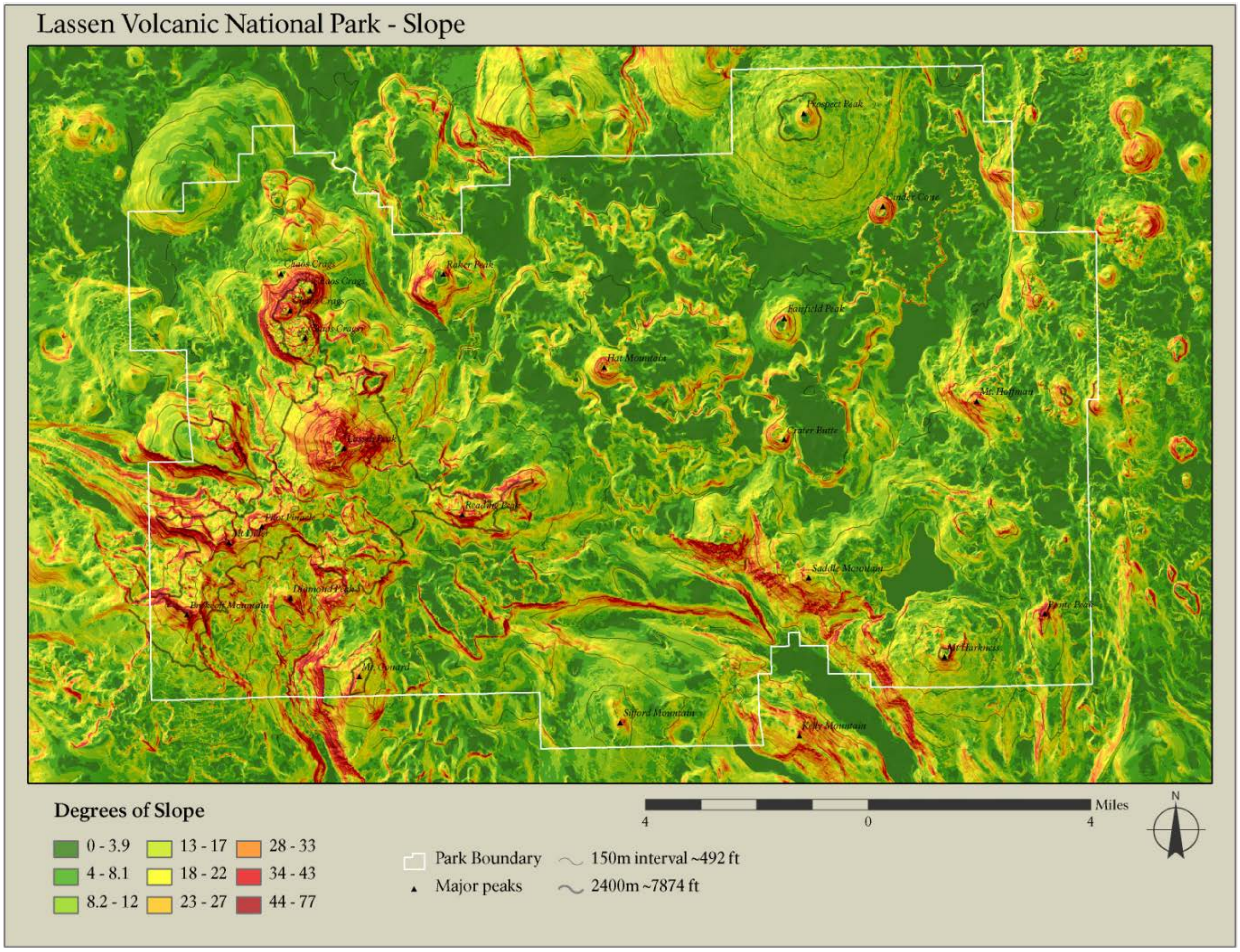


Figure B2. Mapped slope classes in Lassen Volcanic National Park (USGS 2011). Scale: 10 meters.

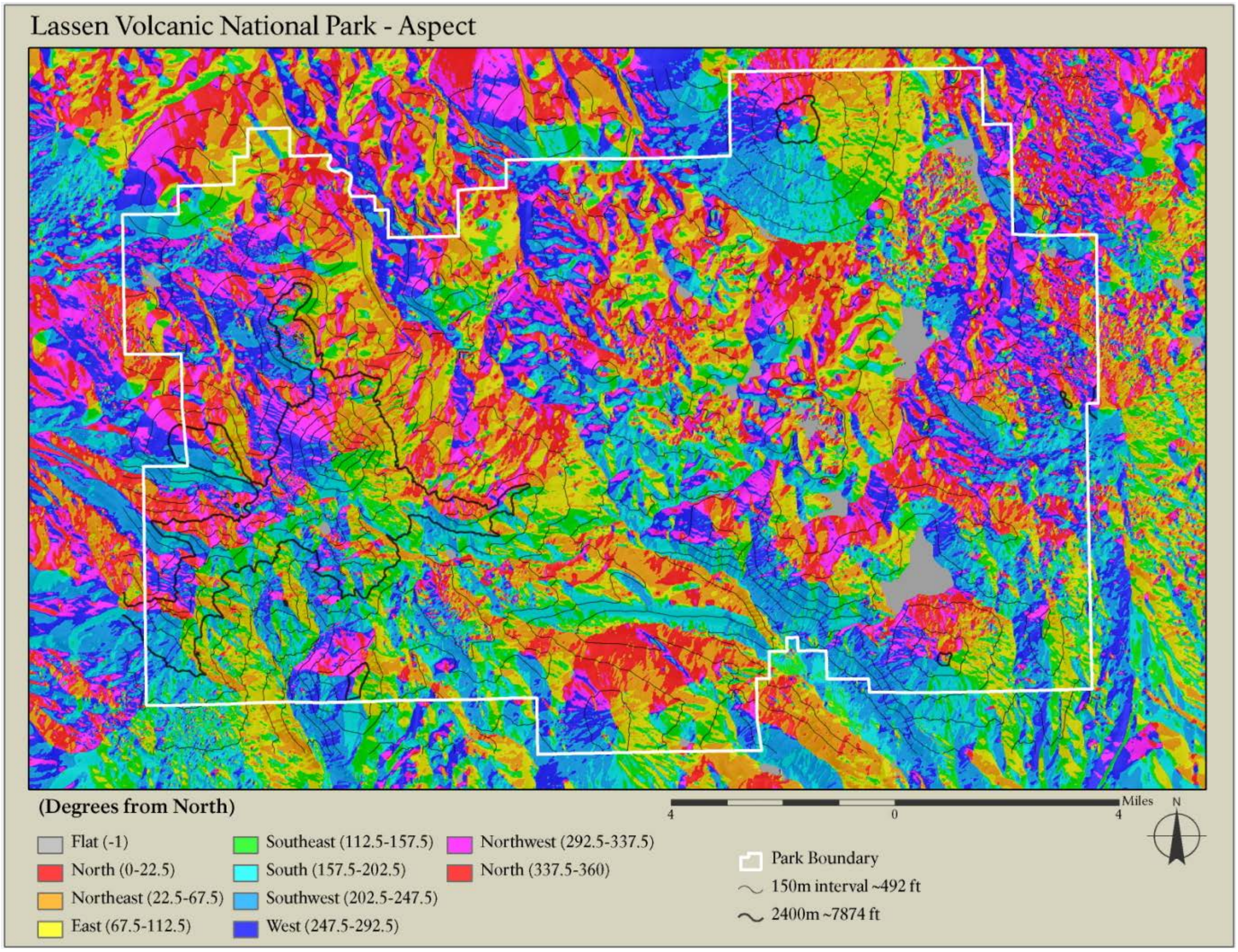


Figure B3. Mapped aspect classes in Lassen Volcanic National Park (USGS 2011). Scale: 10 meters. This is a raster file that identifies the orientation or direction of slope. Aspect is the down-slope direction of a cell to its neighbors. The cell values in an aspect grid are compass directions ranging 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.

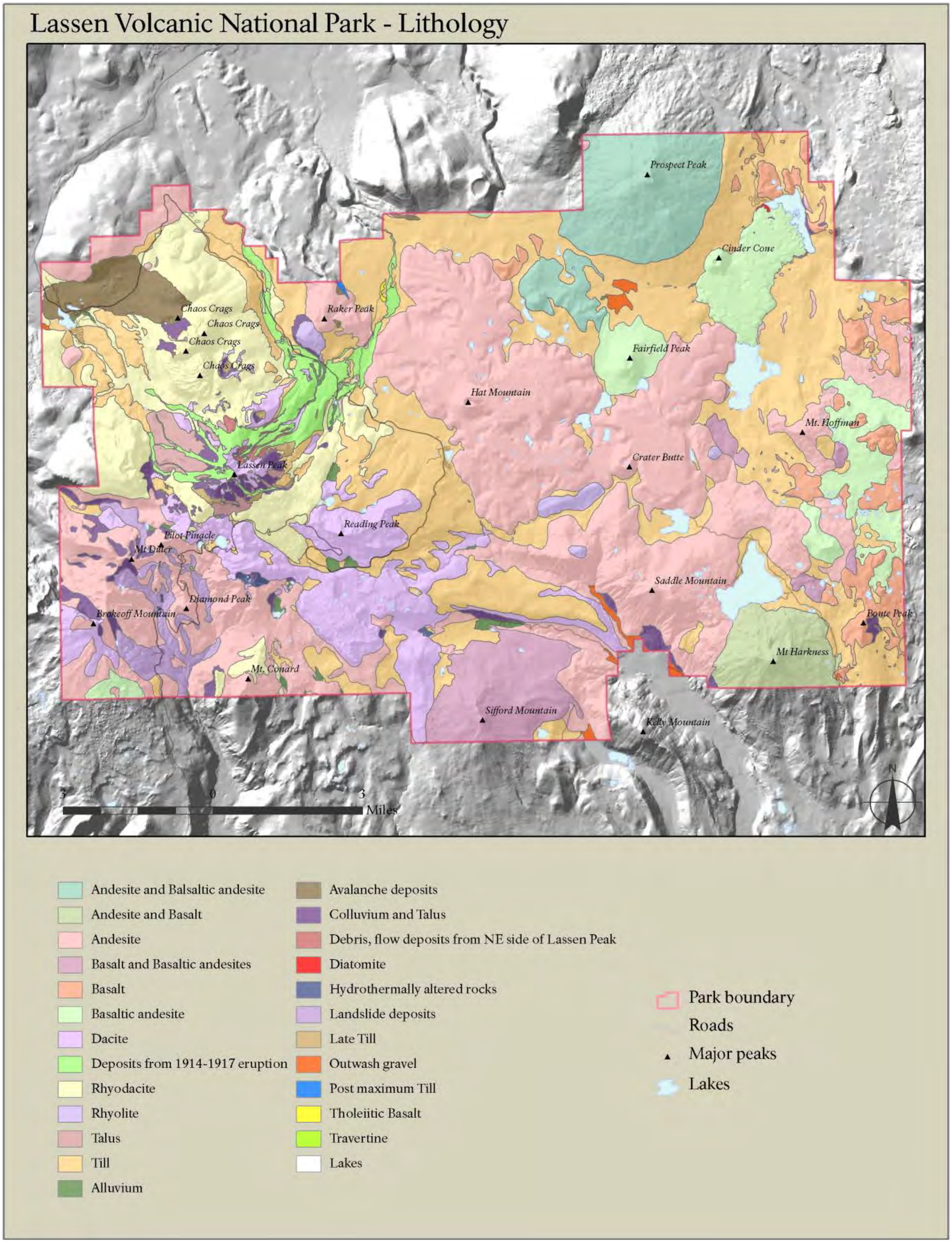


Figure B4. Mapped lithologic classes in Lassen Volcanic National Park (USGS 2005). Scale: 1:500,000 (Chris Wayne, NPS Klamath Network, pers. comm.)

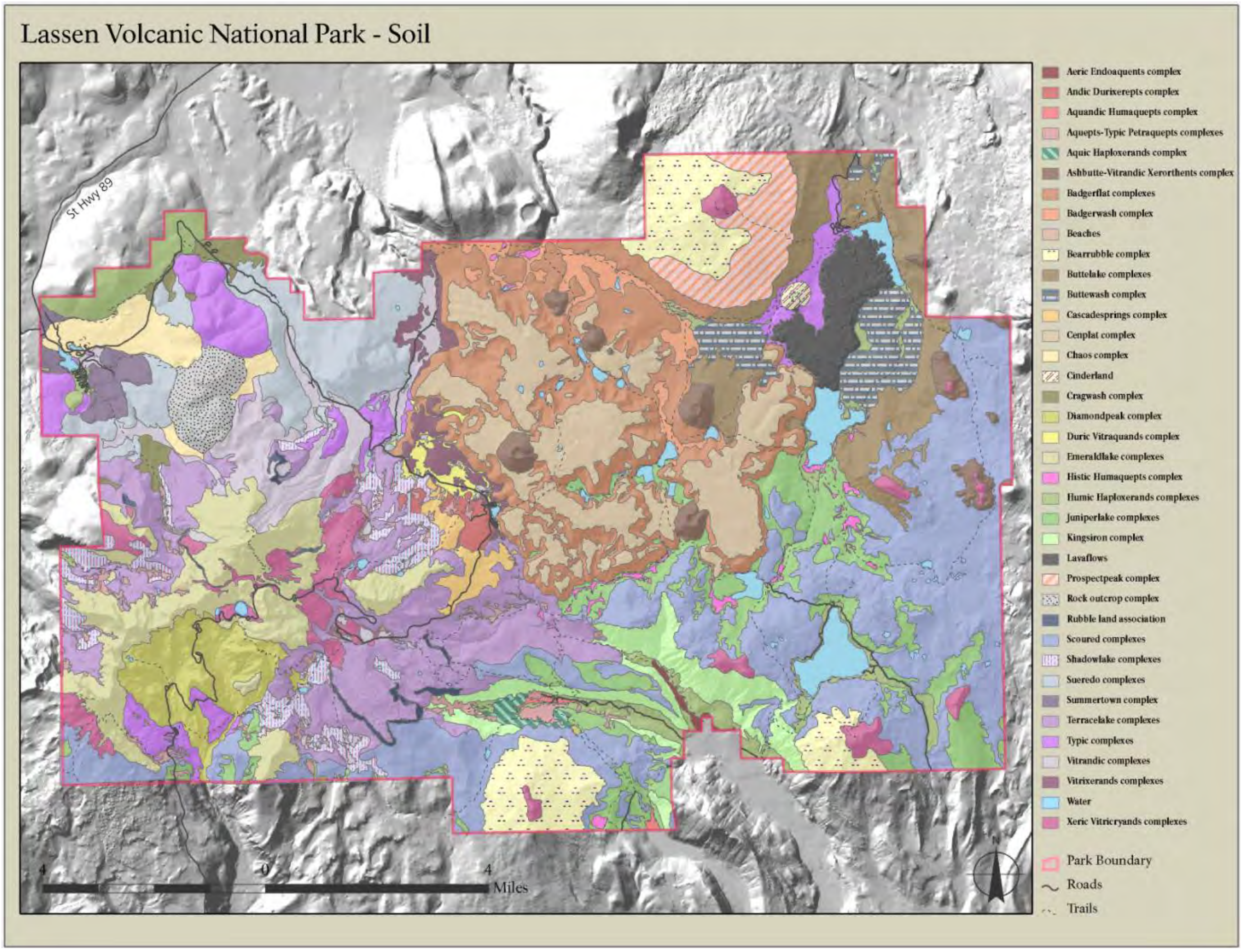


Figure B5. Mapped soil complexes in Lassen Volcanic National Park. Scale: 1:24,000. The SSURGO soil data map was simplified by using the dissolve tool, located in the Data Management toolbox provided in ArcGIS software, to combine multiple shapefiles of the same soil type into one single shapefile. The 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-related Characteristics of Lassen Volcanic National Park: supporting data and maps

Table C1. Invasive plant species found in Lassen Volcanic National Park.

Species	Common name	Family	Park-Status	Abundance	Highly invasive
Agrostis gigantea Roth	redtop	Poaceae	Present in Park	Uncommon	No
Alopecurus pratensis L.	meadow foxtail	Poaceae	Unconfirmed	NA	No
Alyssum minus ssp. micranthum	alyssum	Brassicaceae	Encroaching	NA	No
Bromus inermis Leyss. ssp. inermis	smooth brome	Poaceae	Present in Park	Uncommon	No
Bromus tectorum L.	cheatgrass	Poaceae	Present in Park	Uncommon	Yes
Capsella bursa-pastoris (L.) Medik.	shepherd's purse	Brassicaceae	Present in Park	Uncommon	No
Carduus nutans	musk thistle	Asteraceae	Unconfirmed	Uncommon	Yes
Centaurea stoebe ssp. micranthos	spotted knapweed	Asteraceae	Encroaching	NA	Yes
Cerastium fontanum Baumg. ssp. vulgare (Hartman) Greuter & Burdet	big chickweed	Caryophyllaceae	Present in Park	Uncommon	No
Chamaesyce maculata (L.) Small	spotted sandmat	Euphorbiaceae	Present in Park	Common	No
Chamaesyce maculata auct. non (L.) Small	= Chamaesyce nutans	Euphorbiaceae	Present in Park	Common	No
Chamomilla suaveolens (Pursh) Rydb.	= Matricaria discoidea	Asteraceae	Present in Park	Uncommon	No
Chenopodium album L.	lambsquarters	Chenopodiaceae	Encroaching	NA	No
Chenopodium album L. var. striatum (Krasan) Kartesz, comb. nov. ined.	lateflowering goosefoot	Chenopodiaceae	Encroaching	NA	No
Chenopodium botrys L.	Jerusalem oak goosefoot	Chenopodiaceae	Present in Park	Uncommon	No
Chenopodium pumilio R. Br.	clammy goosefoot	Chenopodiaceae	Present in Park	Rare	No

Species	Common name	Family	Park-Status	Abundance	Highly invasive
Cichorium intybus L.	chicory	Asteraceae	Unconfirmed	NA	No
Cirsium vulgare (Savi) Ten.	bull thistle	Asteraceae	Present in Park	Uncommon	Yes
Convolvulus arvensis L.	field bindweed	Convolvulaceae	Present in Park	Rare	Yes
Crepis capillaris (L.) Wallr.	smooth hawksbeard	Asteraceae	Present in Park	Uncommon	No
Crypsis schoenoides (L.) Lam.	swamp pricklegrass	Poaceae	Encroaching	NA	No
Cytisus scoparius (L.) Link	scotchbroom	Fabaceae	Encroaching	NA	Yes
Dactylis glomerata L.	orchardgrass	Poaceae	Unconfirmed	NA	No
Digitalis purpurea L.	purple foxglove	Scrophulariaceae	Encroaching	NA	No
Elytrigia intermedia ssp. intermedia	crested wheatgrass	Poaceae	Present in Park	Uncommon	No
Erodium cicutarium (L.) L'Hér. ex Ait.	redstem stork's bill	Geraniaceae	Present in Park	Rare	No
Erodium cicutarium (L.) L'Hér. ex Ait. ssp. jacquinianum (Fisch., C.A. Mey. & Avé-Lall.) Briq.	redstem stork's bill	Geraniaceae	Present in Park	Rare	No
Festuca pratensis Huds.	= Lolium pratense	Poaceae	Present in Park	Uncommon	No
Gnaphalium luteoalbum L.	= Pseudognaphalium luteoalbum	Asteraceae	Encroaching	NA	No
Herniaria hirsuta L. ssp. hirsuta	hairy rupturewort	Caryophyllaceae	Encroaching	NA	No
Hirschfeldia incana (L.) Lagrèze-Fossat	shortpod mustard	Brassicaceae	Encroaching	NA	Yes
Holcus lanatus L.	common velvetgrass	Poaceae	Present in Park	Uncommon	No
Hordeum marinum ssp. gussoneanum	Mediterranean barley	Poaceae	Present in Park	Rare	Yes

Species	Common name	Family	Park-Status	Abundance	Highly invasive
Hypericum perforatum L.	common St. Johnswort	Clusiaceae	Present in Park	Rare	Yes
Koeleria phleoides (Vill.) Pers.	= Rostraria cristata	Poaceae	Unconfirmed	NA	No
Lactuca serriola L.	prickly lettuce	Asteraceae	Present in Park	Uncommon	No
Lepidium heterophyllum Benth.	purpleanther field pepperweed	Brassicaceae	Present in Park	Rare	No
Lepidium latifolium	tall whitetop	Brassicaceae	Encroaching	NA	Yes
Leucanthemum vulgare Lam.	oxeye daisy	Asteraceae	Present in Park	Uncommon	Yes
Linaria genistifolia (L.) P. Mill. ssp. dalmatica (L.) Maire & Petitm.	= Linaria dalmatica ssp. dalmatica	Scrophulariaceae	Unconfirmed	NA	Yes
Lolium multiflorum Lam.	= Lolium perenne ssp. multiflorum	Poaceae	Unconfirmed	NA	No
Lolium perenne L.	perennial ryegrass	Poaceae	Present in Park	Uncommon	No
Lotus corniculatus L.	birdfoot deervetch	Fabaceae	Encroaching	NA	No
Lythrum hyssopifolia L.	hyssop loosestrife	Lythraceae	Encroaching	NA	No
Melilotus alba Medikus	white sweetclover	Fabaceae	Present in Park	Uncommon	No
Melilotus indica (L.) All.	sourclover	Fabaceae	Present in Park	Rare	No
Phalaris arundinacea	reed canarygrass	Poaceae	Present in Park	Uncommon	Yes
Phleum pratense L.	timothy	Poaceae	Present in Park	Common	No
Plantago lanceolata L.	narrowleaf plantain	Plantaginaceae	Present in Park	Uncommon	No
Plantago major L.	common plantain	Plantaginaceae	Present in Park	Common	No
Poa annua L.	annual bluegrass	Poaceae	Present in Park	Uncommon	No

Species	Common name	Family	Park-Status	Abundance	Highly invasive
Poa bulbosa L.	bulbous bluegrass	Poaceae	Present in Park	Common	No
Poa palustris L.	fowl bluegrass	Poaceae	Present in Park	Rare	No
Poa pratensis L. ssp. pratensis	Kentucky bluegrass	Poaceae	Present in Park	Common	No
Polygonum arenastrum Jord. ex Boreau	oval-leaf knotweed	Polygonaceae	Present in Park	Uncommon	No
Potentilla anglica Laicharding	English cinquefoil	Rosaceae	Unconfirmed	NA	No
Rumex acetosella L.	common sheep sorrel	Polygonaceae	Present in Park	Common	No
Rumex crispus L.	curly dock	Polygonaceae	Present in Park	Uncommon	No
Sisymbrium orientale L.	Indian hedgemustard	Brassicaceae	Encroaching	NA	No
Solanum sarrachoides auct. non Sendtner	= Solanum physalifolium	Solanaceae	Unconfirmed	NA	No
Sonchus asper ssp. asper	spiny sowthistle	Asteraceae	Present in Park	Rare	No
Sonchus oleraceus L.	common sowthistle	Asteraceae	Unconfirmed	NA	No
Spergularia rubra (L.) J.& K. Presl	red sandspurry	Caryophyllaceae	Present in Park	Common	No
Stellaria media (L.) Vill.	common chickweed	Caryophyllaceae	Encroaching	NA	No
Taraxacum officinale G.H. Weber ex Wiggers	common dandelion	Asteraceae	Present in Park	Abundant	No
Tragopogon dubius Scop.	yellow salsify	Asteraceae	Present in Park	Uncommon	No
Trifolium hybridum L.	Alsike clover	Fabaceae	Present in Park	Rare	No
Trifolium pratense L.	red clover	Fabaceae	Unconfirmed	NA	No
Trifolium repens L.	white clover	Fabaceae	Present in Park	Common	No

Species	Common name	Family	Park-Status	Abundance	Highly invasive
Verbascum blattaria L.	moth mullein	Scrophulariaceae	Unconfirmed	NA	No
Verbascum thapsus L.	common mullein	Scrophulariaceae	Present in Park	Common	Yes
Vicia benghalensis L.	reddish tufted vetch	Fabaceae	Encroaching	NA	No
Vulpia myuros (L.) K.C. Gmel. var. hirsuta Hack.	= Vulpia myuros	Poaceae	Present in Park	Uncommon	No

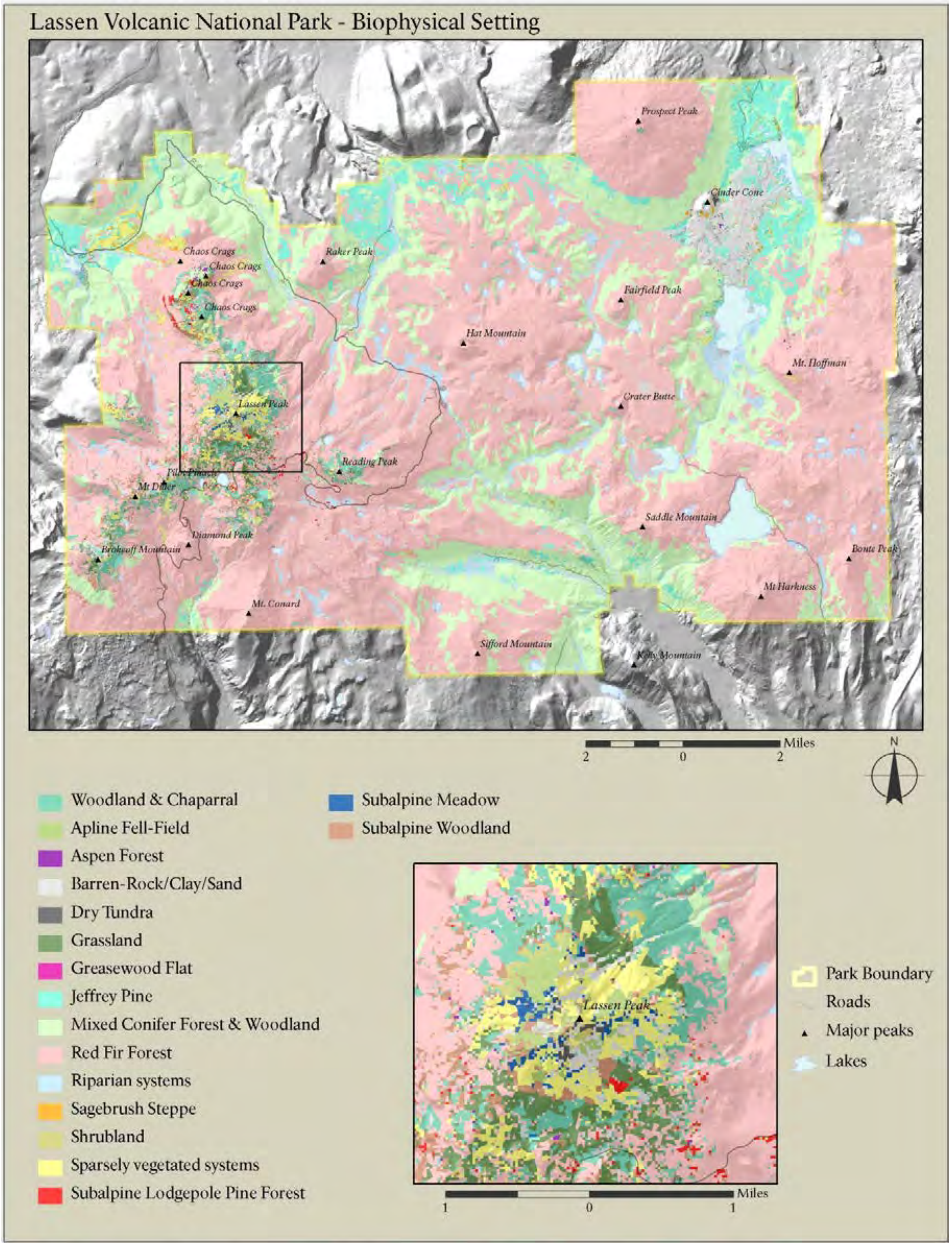


Figure C1. Mapped biophysical classes of Lassen Volcanic National Park (LANDFIRE 2006). Scale: 30 meters. This map was prepared by other investigators who extrapolated information using Landsat Thematic Mapper and other data. Lands were assigned to map classes by experts in LANDFIRE workshops. The classes 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.

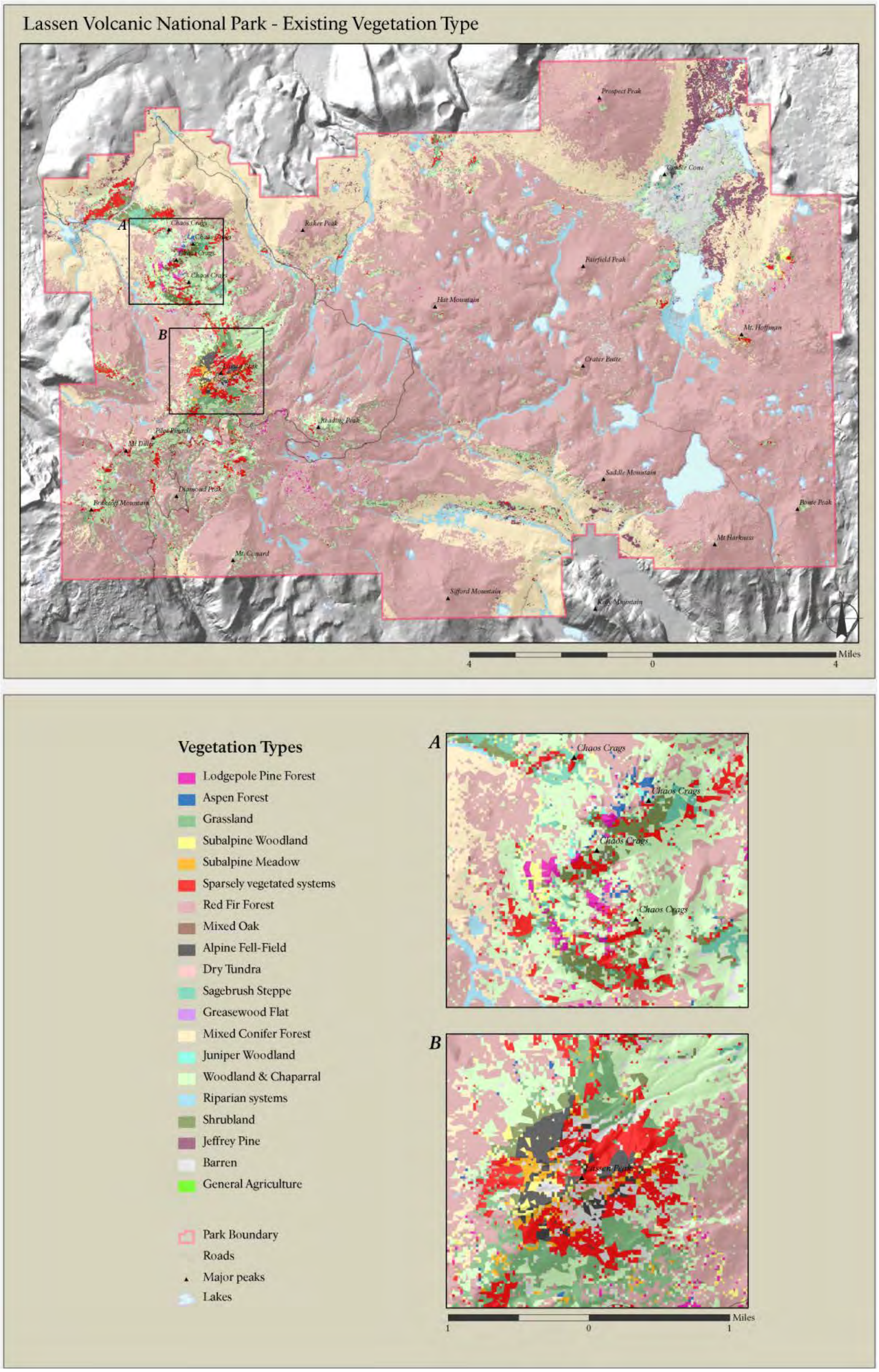


Figure C2. Mapped existing vegetation types in Lassen Volcanic National Park (LANDFIRE 2008). This map was prepared by other investigators who extrapolated information using Landsat Thematic Mapper and other data. Lands were assigned to map classes by experts in LANDFIRE workshops.

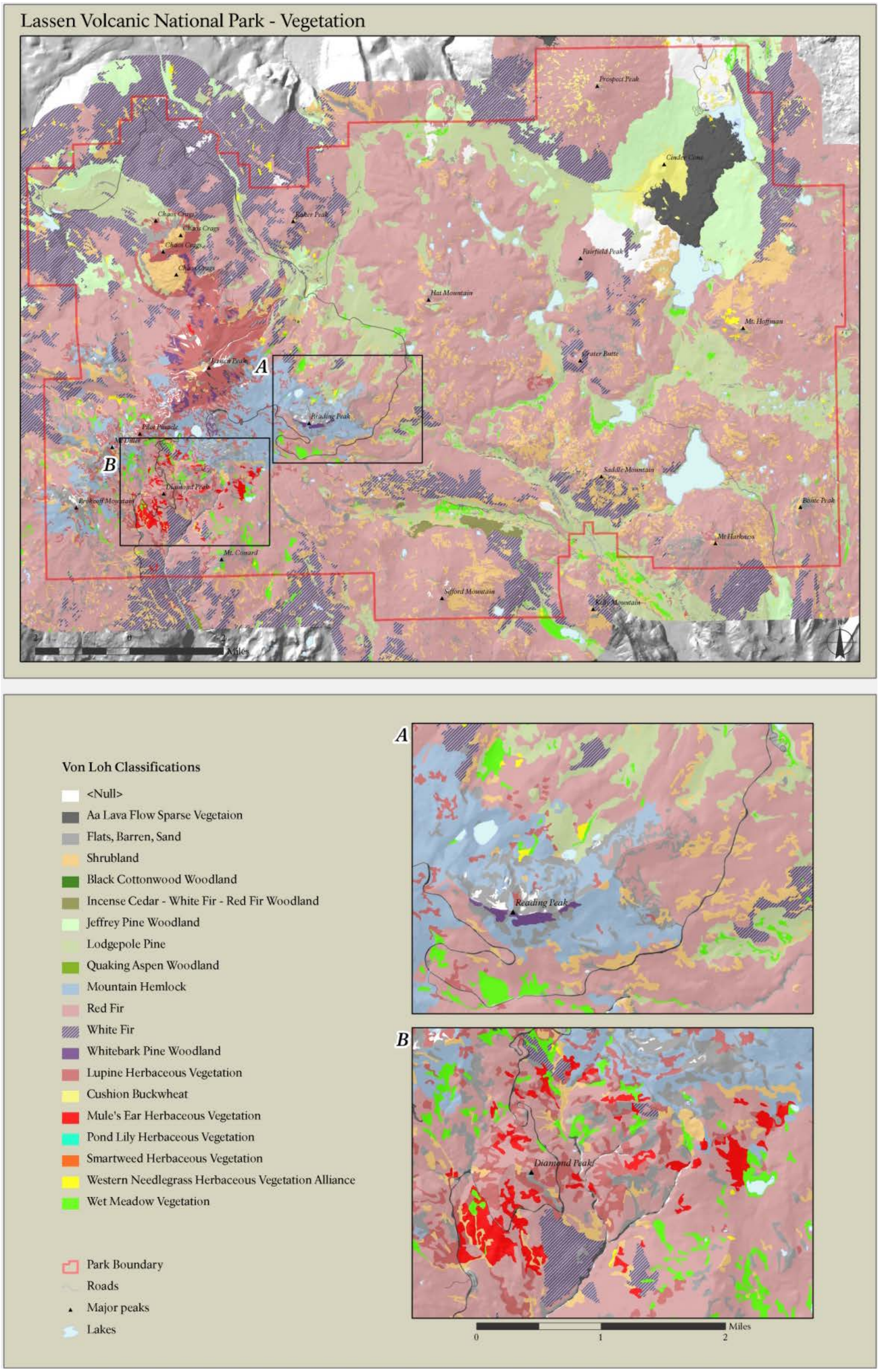


Figure C3. Mapped existing vegetation in Lassen Volcanic National Park (LANDFIRE 2008). This map was prepared by other investigators who extrapolated information using Landsat Thematic Mapper and other data. Lands were assigned to map classes by experts in LANDFIRE workshops.

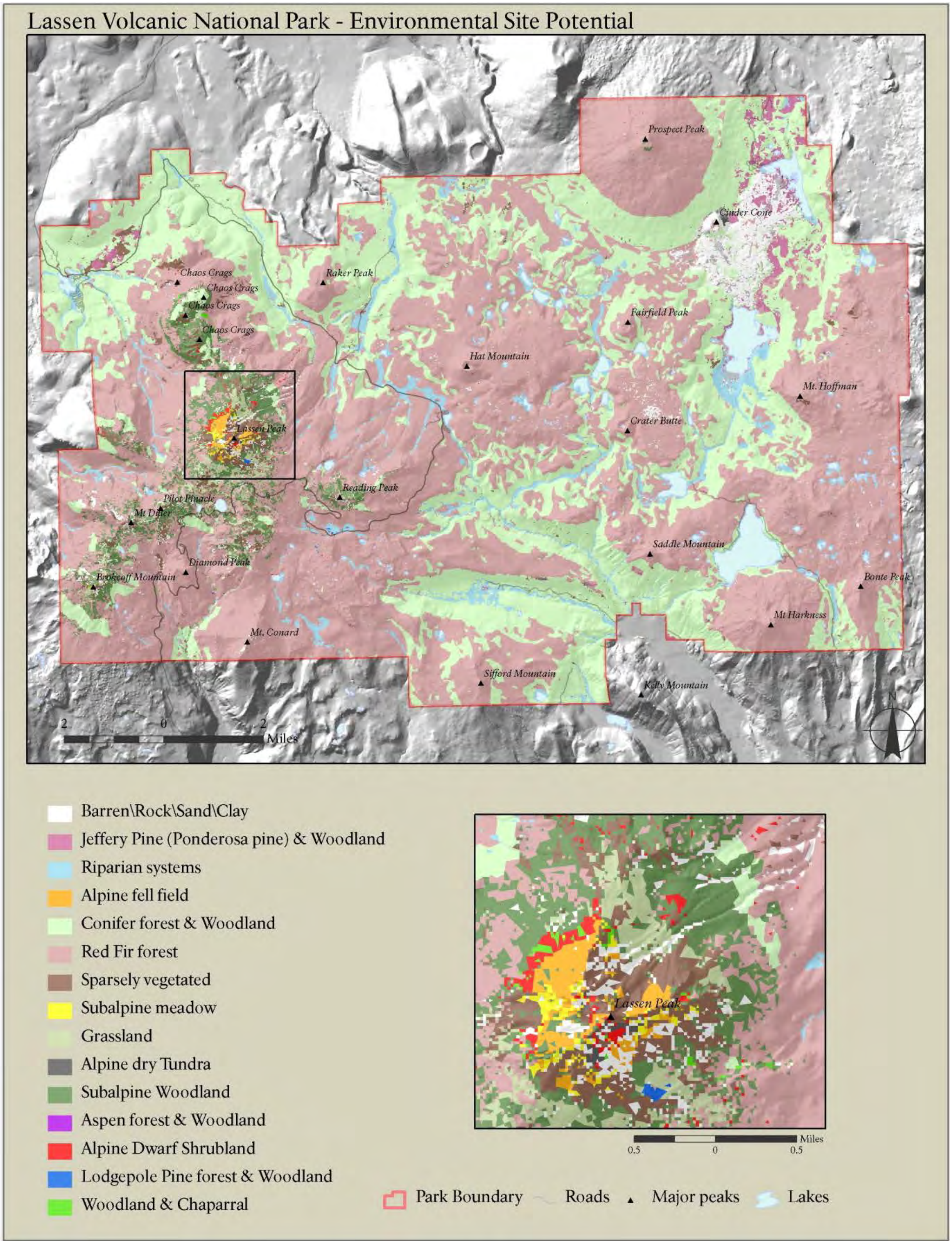


Figure C4. Mapped environmental site potential of Lassen Volcanic National Park (LANDFIRE 2008). This map was prepared by other investigators who extrapolated Landsat Thematic Mapper and other data. Lands were assigned to map classes by experts in LANDFIRE workshops.

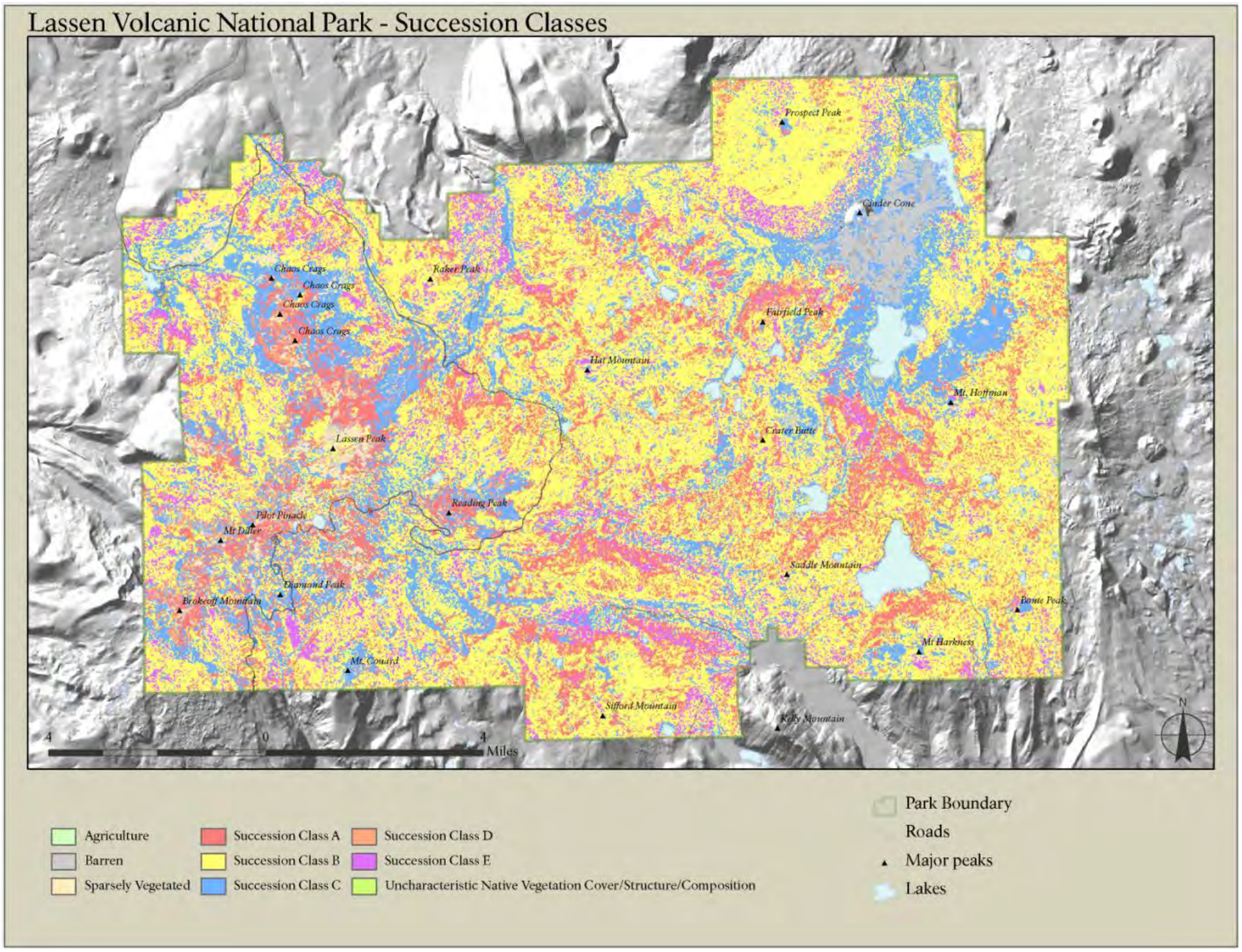


Figure C5. Mapped successional classes in Lassen Volcanic National Park (LANDFIRE 2008). This map was prepared by other investigators who extrapolated information using Landsat Thematic Mapper and other data. Lands were assigned to map classes by experts in LANDFIRE workshops.

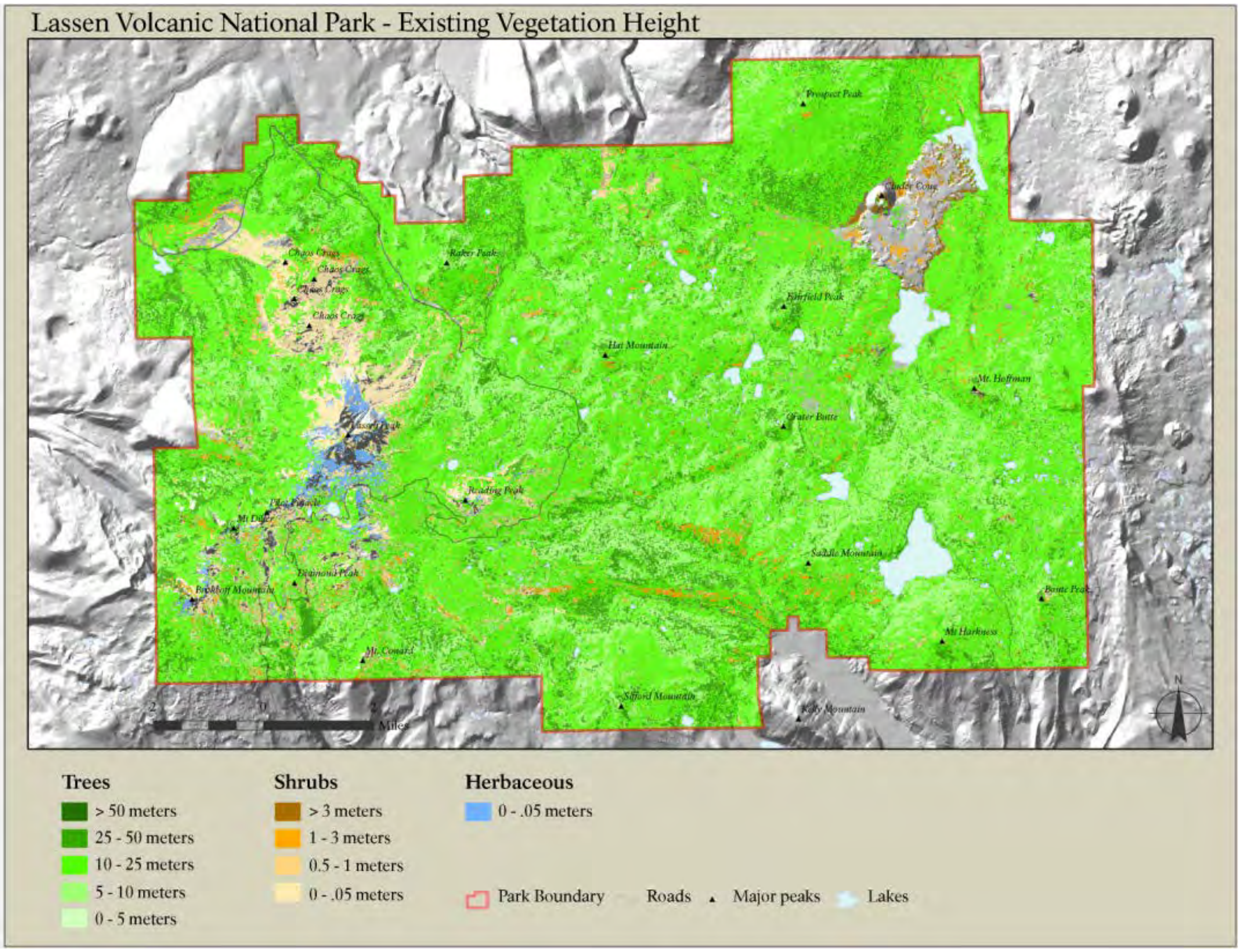


Figure C6. Mapped existing vegetation height of Lassen Volcanic National Park (LANDFIRE 2008). This map was prepared by other investigators who extrapolated information using Landsat Thematic Mapper and other data. Lands were assigned to map classes by experts in LANDFIRE workshops.

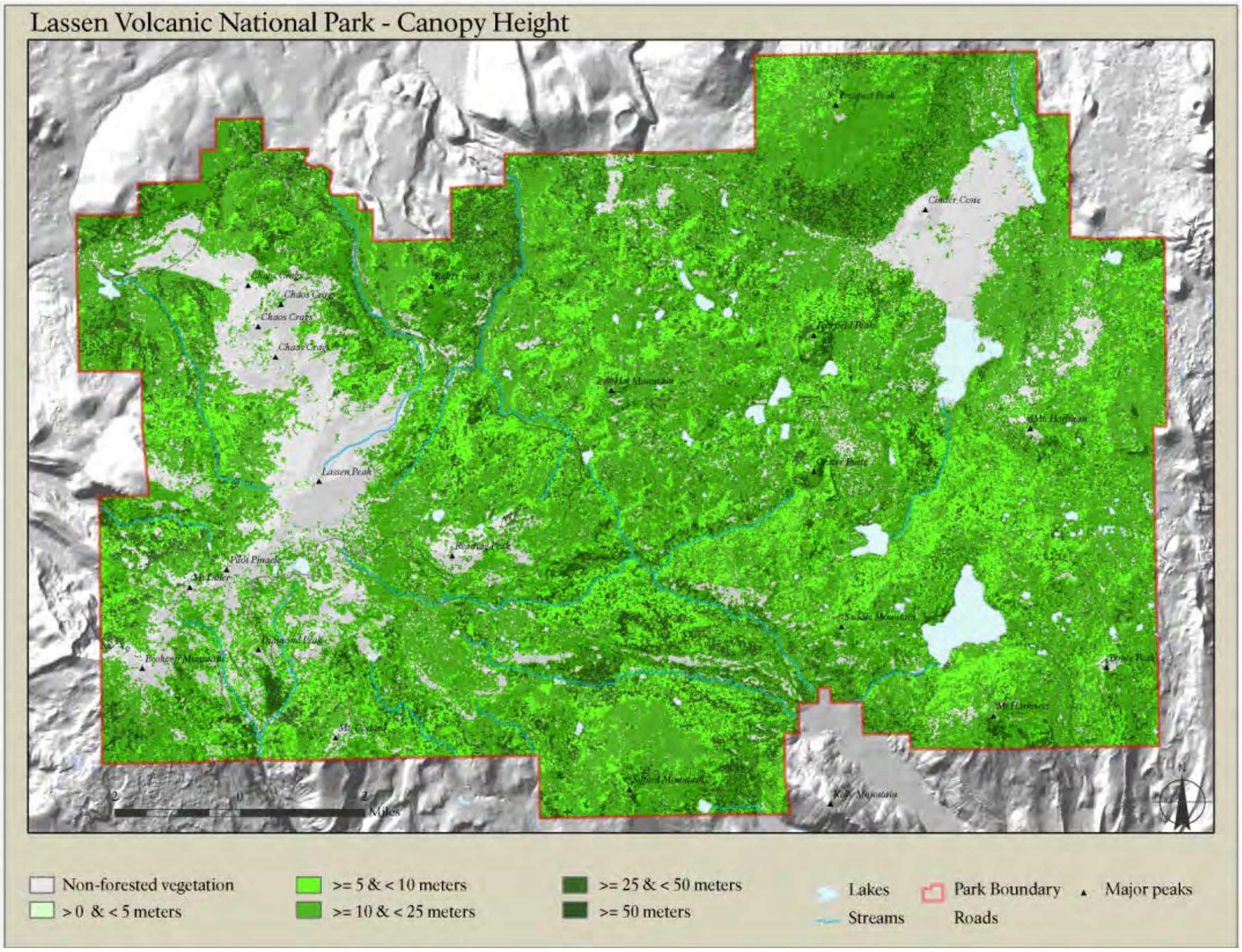


Figure C7. Mapped canopy height of Lassen Volcanic National Park (LANDFIRE 2008). This map was prepared by other investigators who extrapolated information using Landsat Thematic Mapper and other data. Lands were assigned to map classes by experts in LANDFIRE workshops.

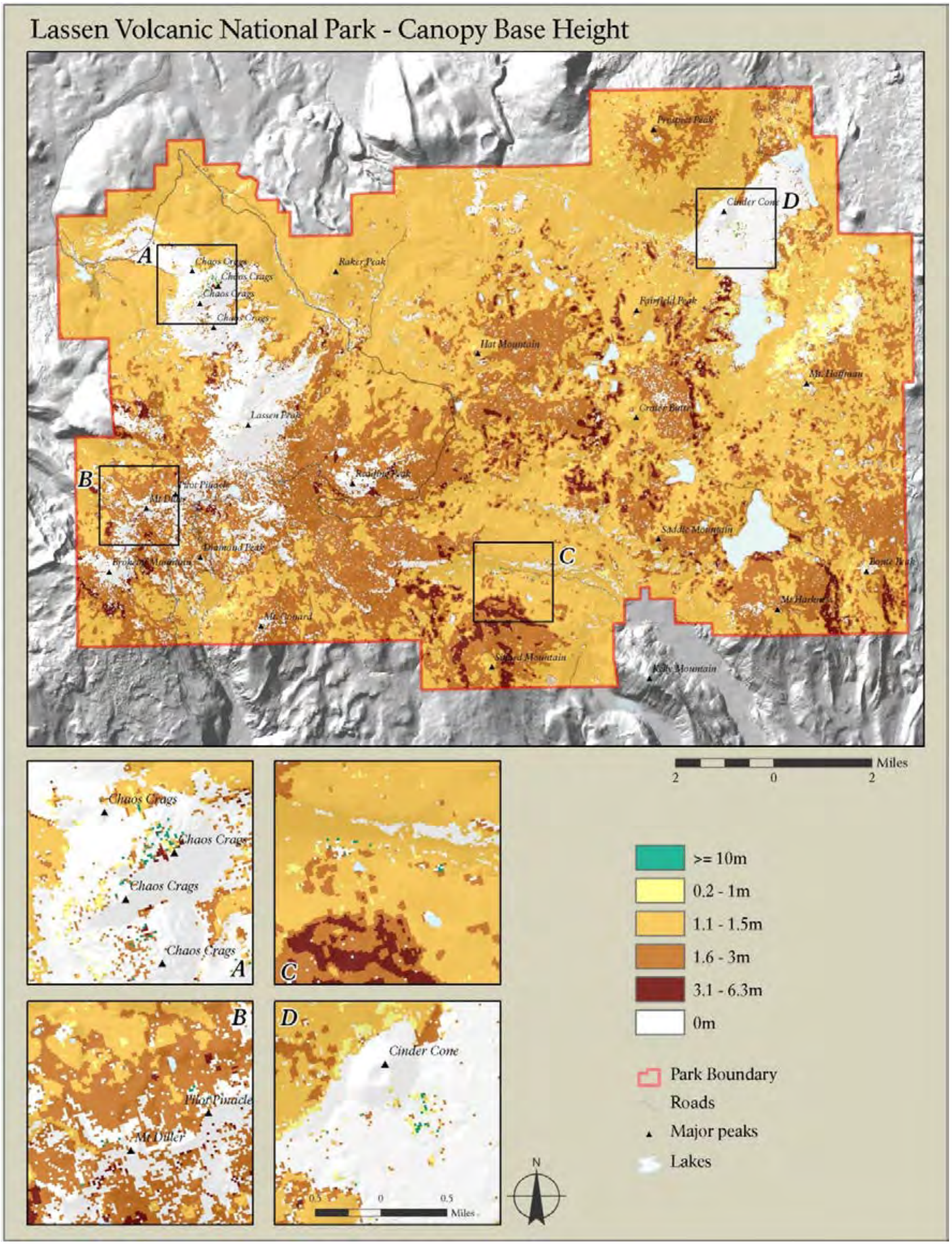


Figure C8. Mapped canopy base height of Lassen Volcanic National Park (LANDFIRE 2007). Scale: 30 meters. This map was prepared by other investigators who extrapolated information using Landsat Thematic Mapper and other data. Lands were assigned to map classes by experts in LANDFIRE workshops. The map 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.

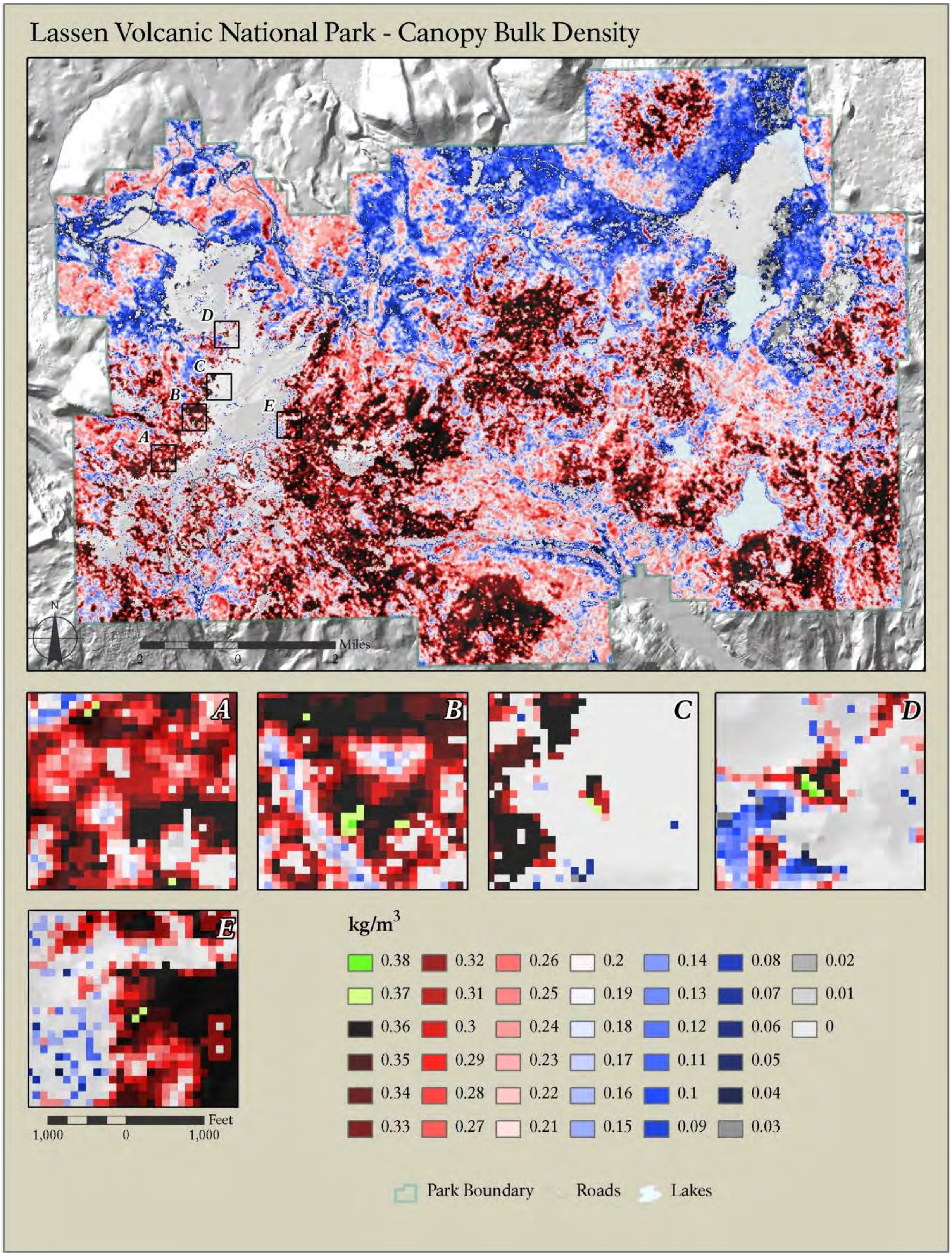


Figure C9. Mapped canopy bulk density of Lassen Volcanic National Park (LANDFIRE 2008). This map was prepared by other investigators who extrapolated information using Landsat Thematic Mapper and other data. Lands were assigned to map classes by experts in LANDFIRE workshops.

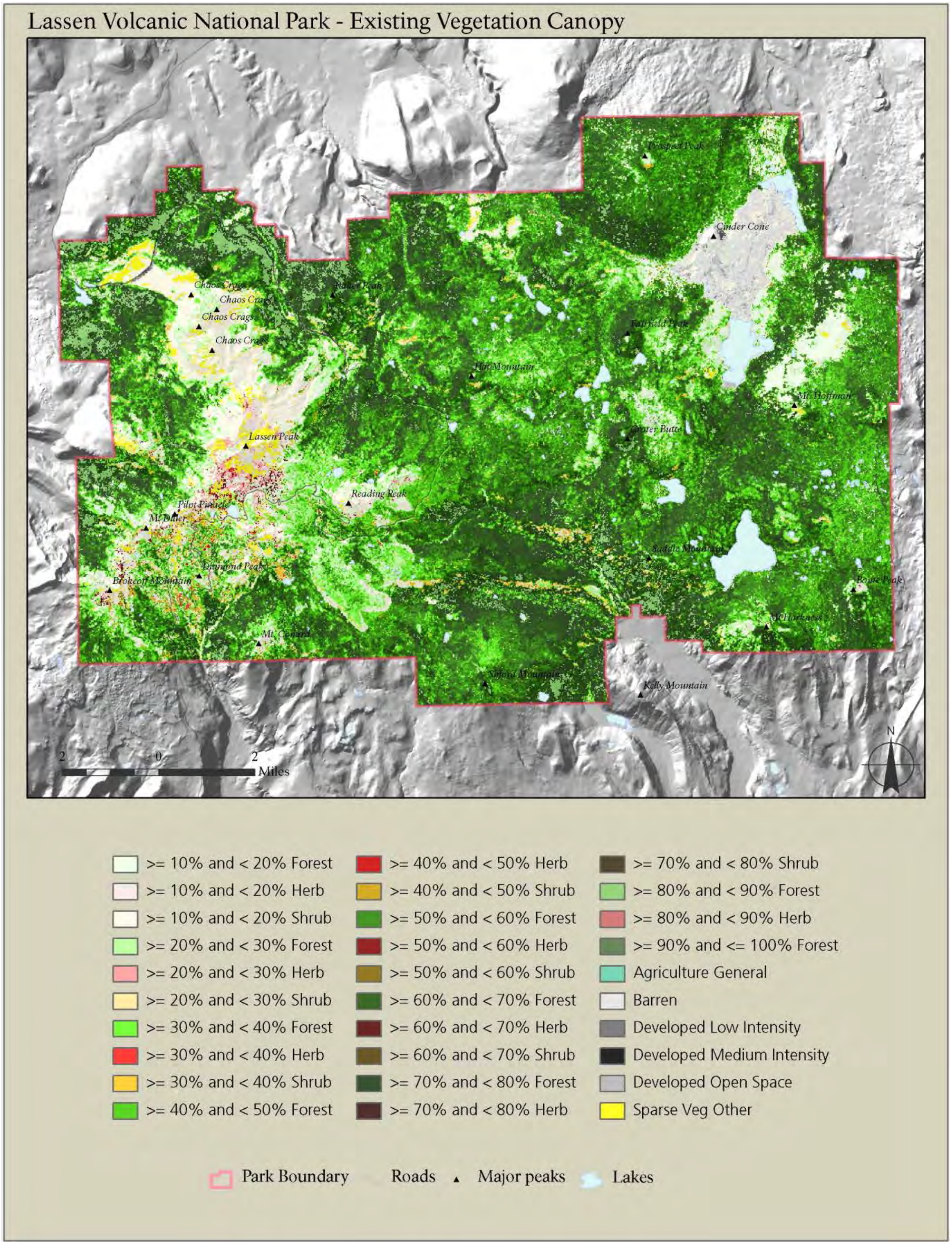


Figure C10. Mapped existing vegetation canopy of Lassen Volcanic National Park (LANDFIRE 2007). Scale: 30 meters. This map was prepared by other investigators who extrapolated information using Landsat Thematic Mapper and other data. Lands were assigned to map classes by experts in LANDFIRE workshops.

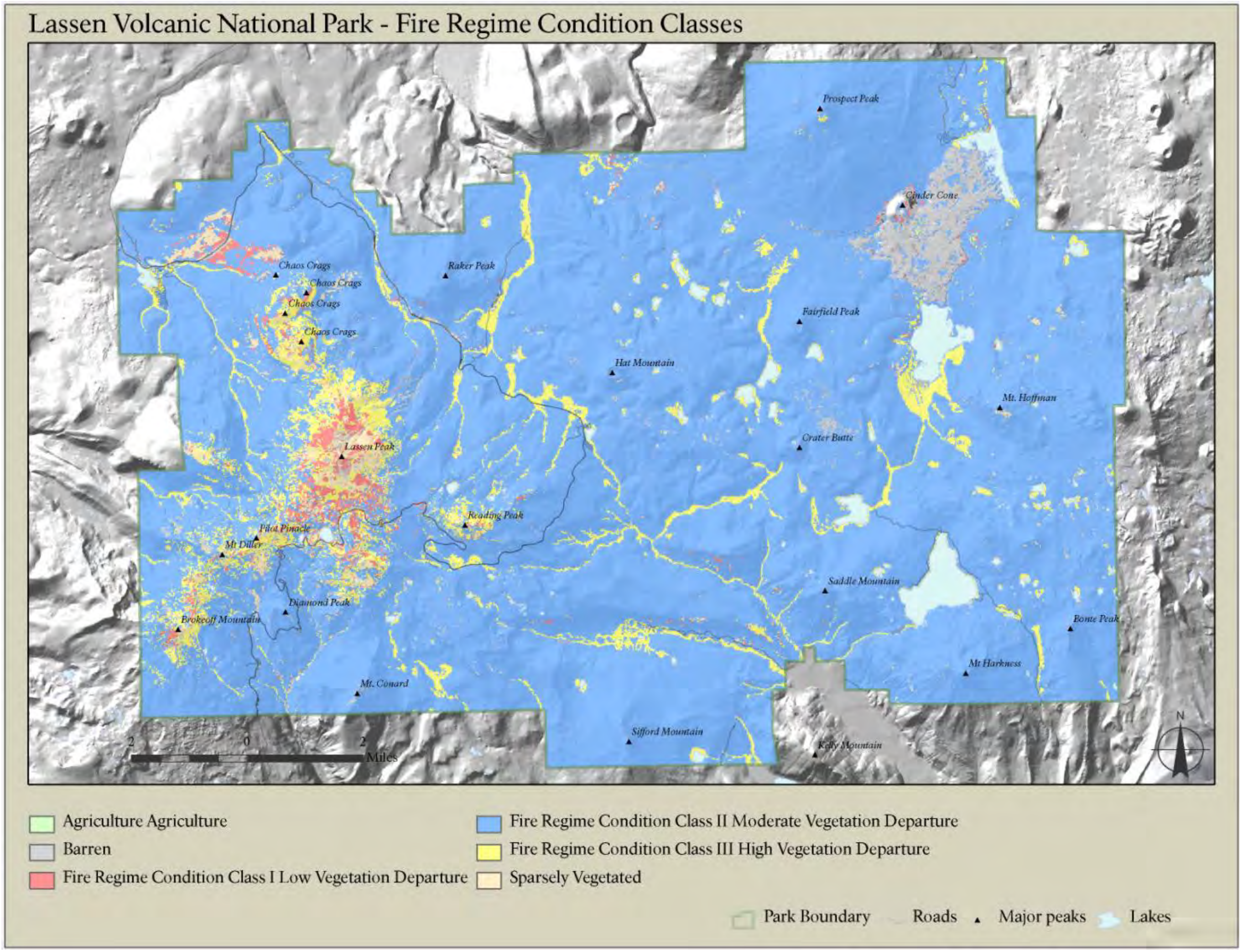


Figure C11. Mapped fire regime condition classes of Lassen Volcanic National Park (LANDFIRE 2008). This map was prepared by other investigators who extrapolated fuels information using Landsat Thematic Mapper and other data. Lands were assigned to map classes by experts in LANDFIRE workshops. The map 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.

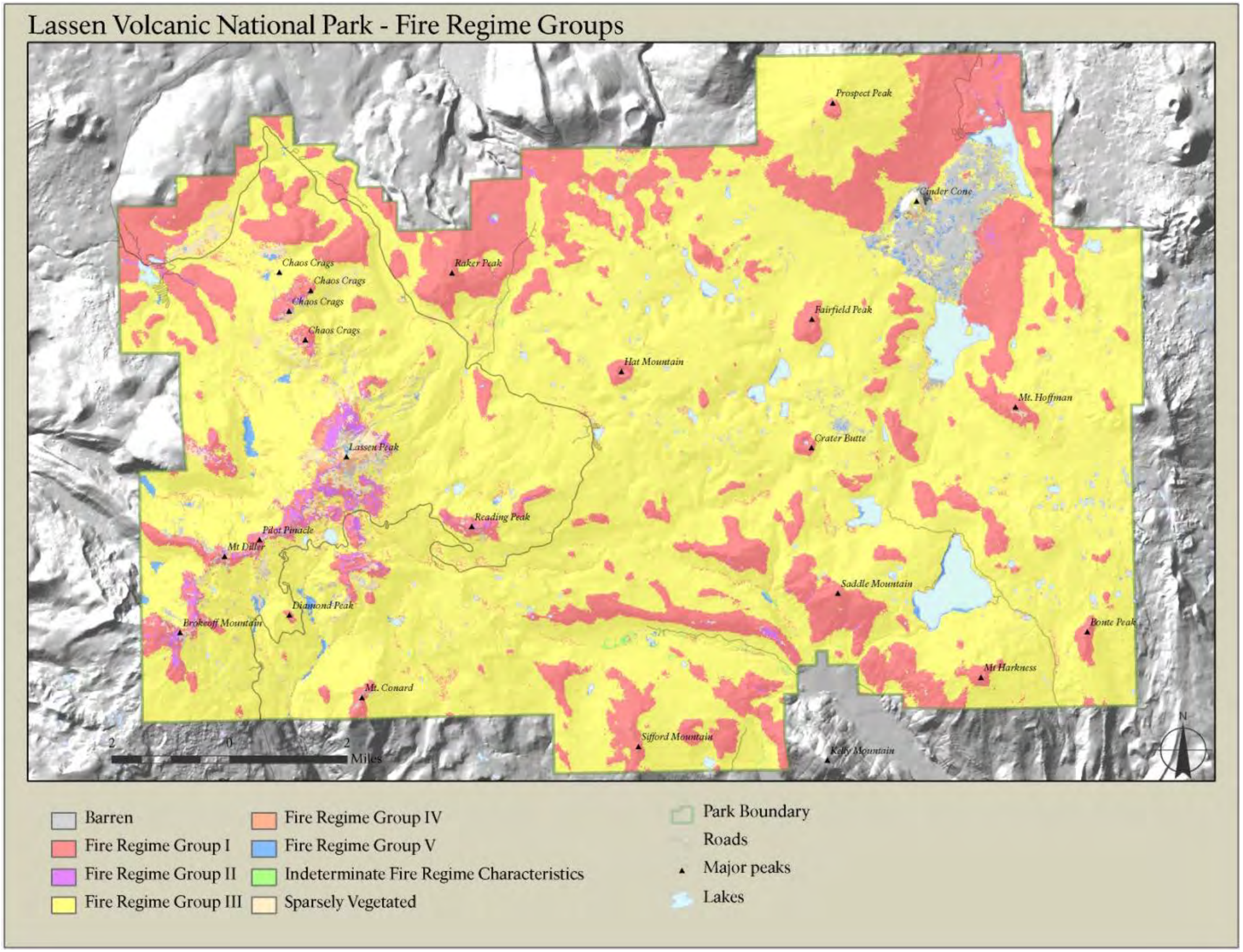


Figure C12. Mapped fire regime groups of Lassen Volcanic National Park (LANDFIRE 2008). This map was prepared by other investigators who extrapolated fuels information using Landsat Thematic Mapper and other data. Lands were assigned to map classes by experts in LANDFIRE workshops. The map does not portray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

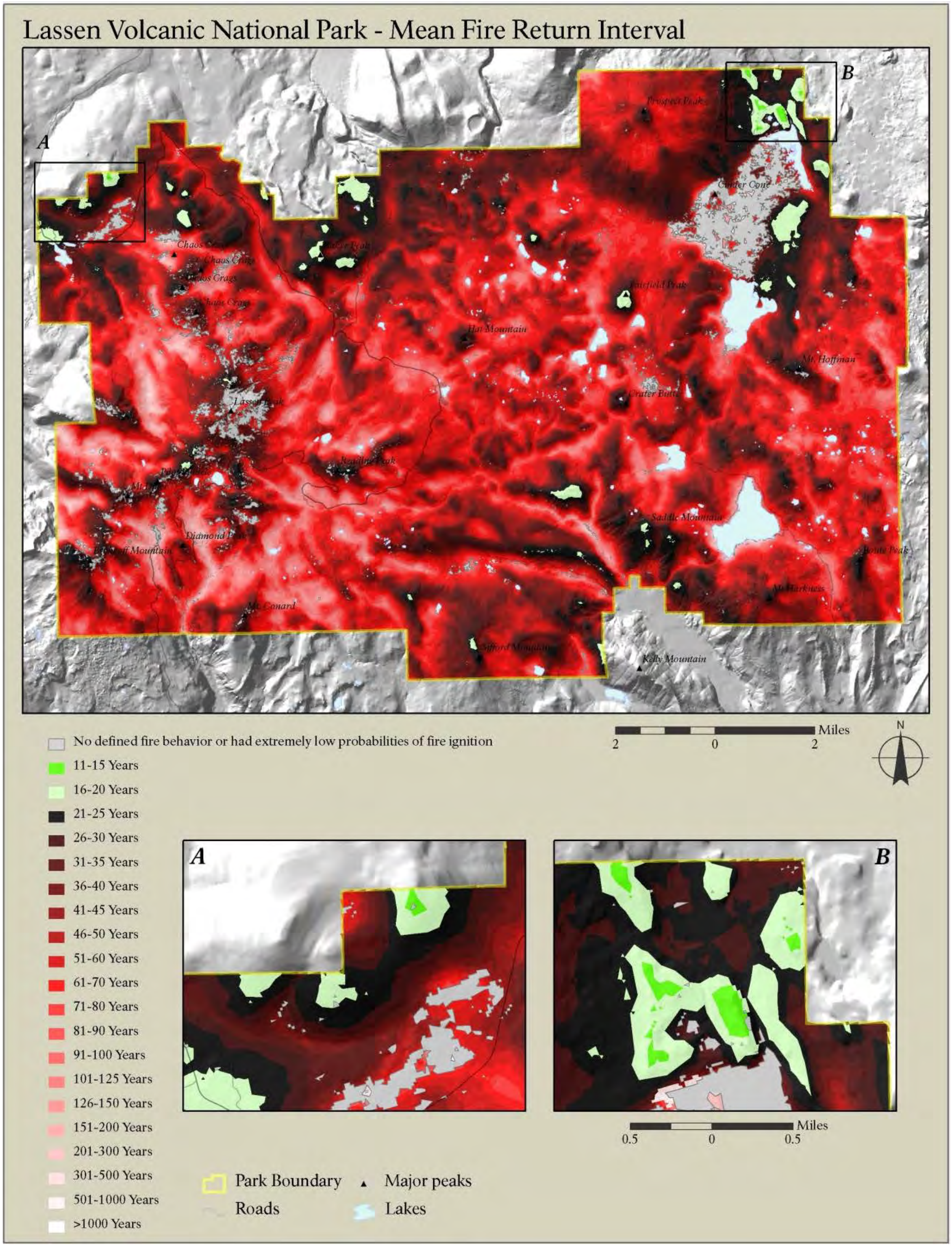


Figure C13. Mapped mean fire return interval of Lassen Volcanic National Park (LANDFIRE 2008). This map was prepared by other investigators who extrapolated fuels information using Landsat Thematic Mapper and other data. Lands were assigned to map classes by experts in LANDFIRE workshops. The map does not portray fuel, fuel arrangement, or vegetation flammability.

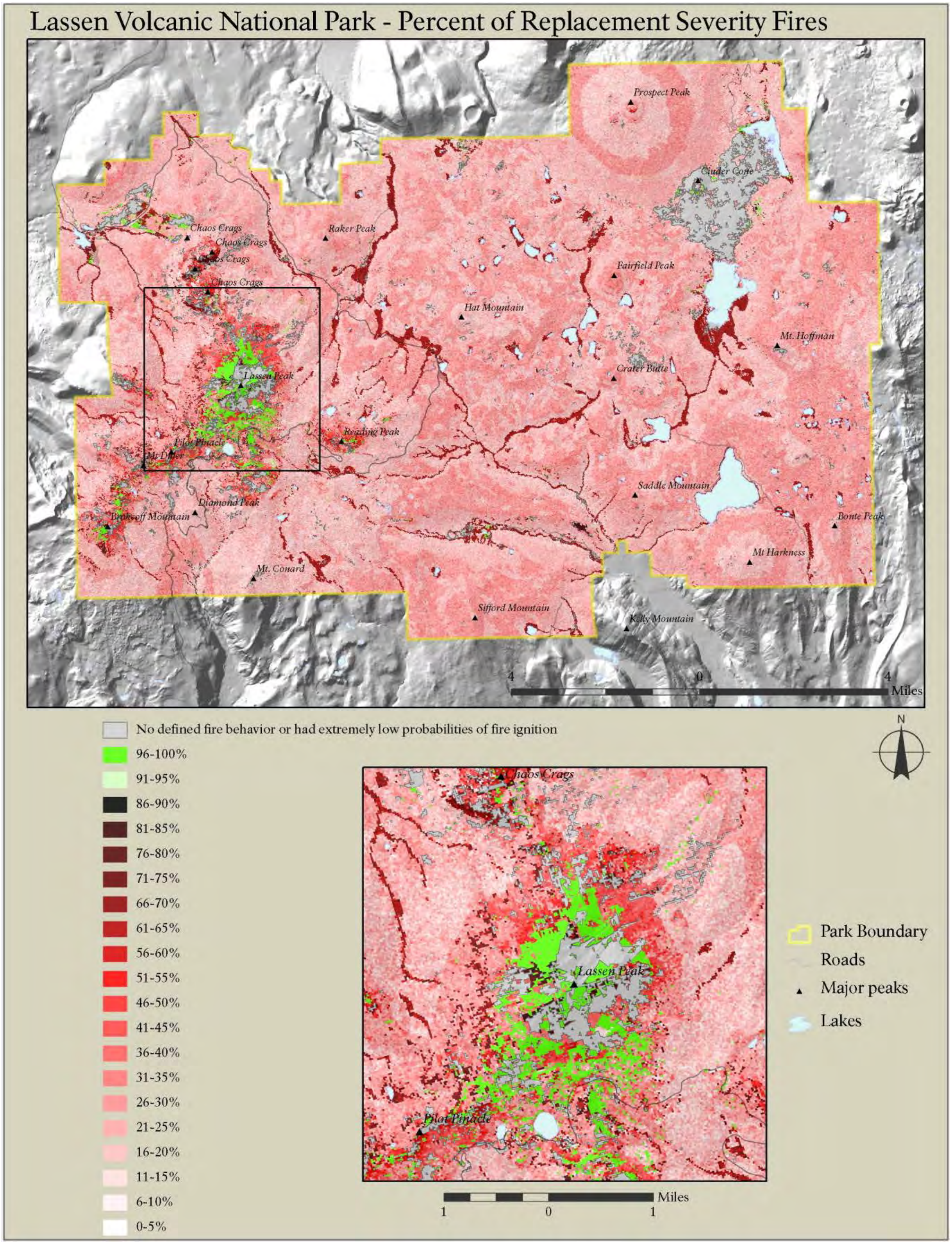


Figure C14. Mapped percent of replacement severity fires of Lassen Volcanic National Park (LANDFIRE 2008). This map was prepared by other investigators who extrapolated fuels information using Landsat Thematic Mapper and other data. Lands were assigned to map classes by experts in LANDFIRE workshops.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

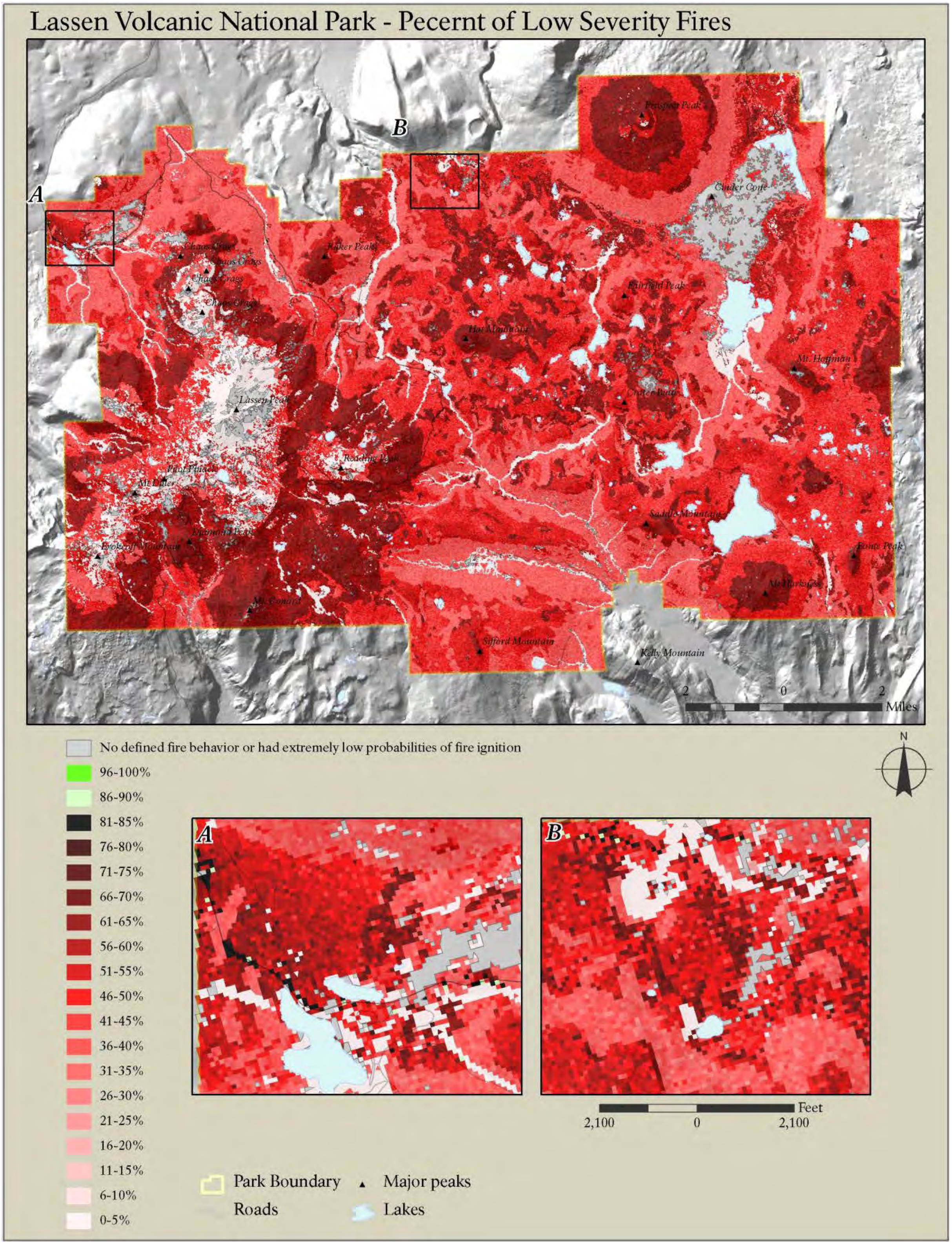


Figure C15. Mapped percent of low severity fires of Lassen Volcanic National Park (LANDFIRE 2008). This map was prepared by other investigators who extrapolated fuels information using Landsat Thematic Mapper and other data. Lands were assigned to map classes by experts in LANDFIRE workshops. The map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

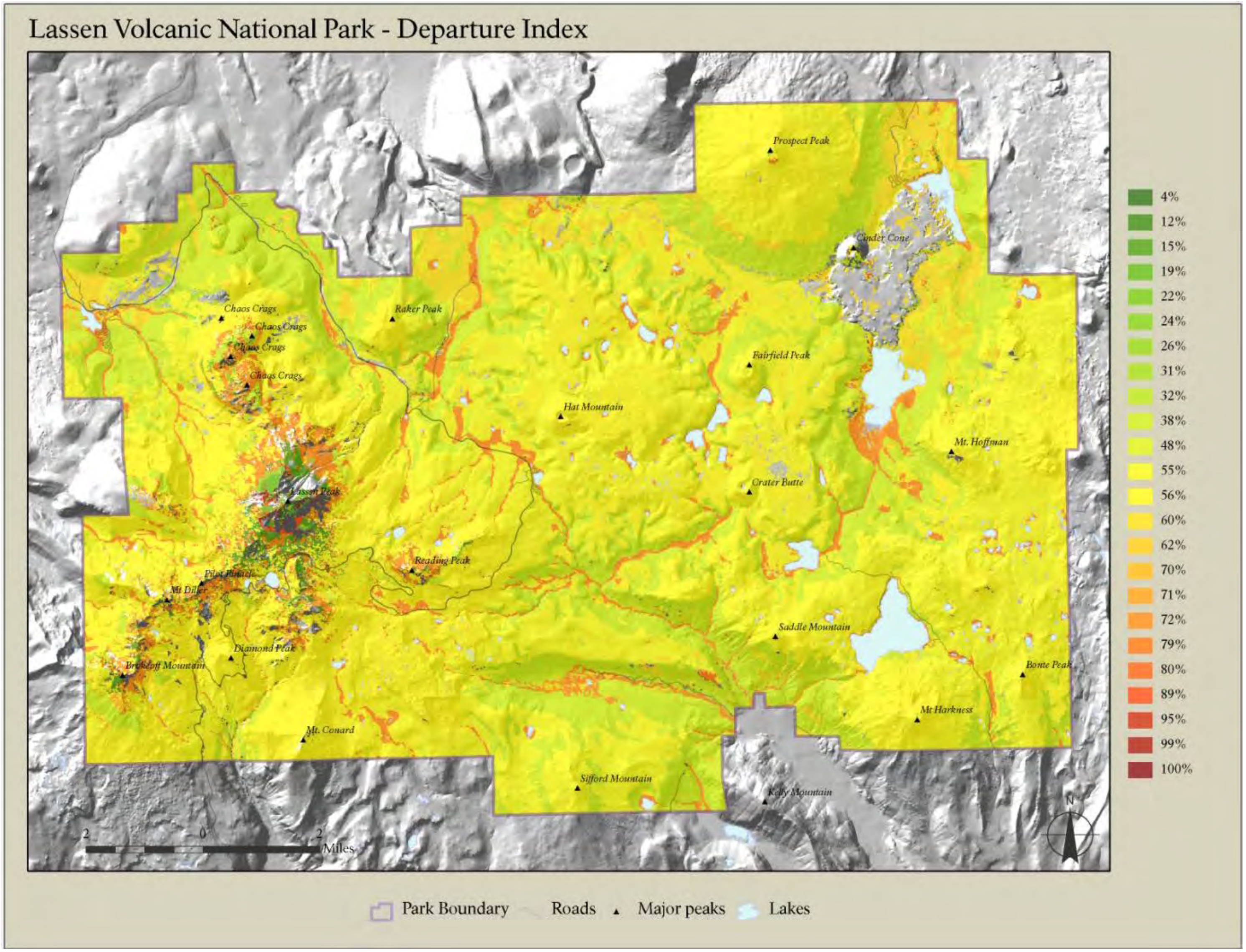


Figure C16. Mapped departure index of Lassen Volcanic National Park (LANDFIRE 2008). This map was prepared by other investigators who extrapolated information using Landsat Thematic Mapper and other data. Lands were assigned to map classes by experts in LANDFIRE workshops.

Appendix D. Vertebrates of Lassen Volcanic National Park

Table D1. Bird species of Lassen Volcanic National Park (Burnett and King 2004).
H = historically only. ? = unconfirmed

Species	Status	Breeds	Resident	Introduced
Greater White-fronted Goose	very rare	No	No	no
Snow Goose	rare	No	No	no
Canada Goose	common	Yes	No	no
Tundra Swan	very rare	No	No	no
Wood Duck	uncommon	Yes	No	no
Gadwall	very rare	No	No	no
American Wigeon	rare	No	No	no
Mallard	common	Yes	No	no
Blue-winged Teal	very rare	No	No	no
Cinnamon Teal	very rare	No	No	no
Northern Shoveler	rare	No	No	no
Northern Pintail	rare	No (H?)	No	no
Green-winged Teal	rare	No	No	no
Canvasback	very rare	No (H)	No	no
Redhead	very rare	No (H)	No	no
Ring-necked Duck	rare	Yes	No	no
Lesser Scaup	very rare	No	No	no
Surf Scoter	very rare	No	No	no
Bufflehead	fairly common	Yes	No	no
Common Goldeneye	very rare	No	No	no
Barrow's Goldeneye	rare	No (H)	No	no
Common Merganser	fairly common	Yes	No	no
Ruddy Duck	rare	No	No	no
Ring-necked Pheasant	very rare	No	No	Yes
Common Peafowl	very rare	No	No	Yes
Ruffed Grouse	very rare	No?	No	Yes
Sooty (Blue) Grouse	uncommon	Yes	Yes	no
Wild Turkey	very rare	No	No	Yes
Mountain Quail	uncommon	Yes	Yes	no
California Quail	very rare	No	No	no
Pacific Loon	very rare	No	No	no
Common Loon	rare	No (H)	No	no
Pied-billed Grebe	uncommon	Yes	No	no
Eared Grebe	rare	Yes	No	no
Western Grebe	uncommon	No	No	no
Clark's Grebe	rare	No	No	no
American White Pelican	very rare	No	No	no
Double-crested Cormorant	uncommon	No	No	no
American Bittern	very rare	No	No	no

Species	Status	Breeds	Resident	Introduced
Great Blue Heron	uncommon	No	No	no
Great Egret	very rare	No	No	no
Snowy Egret	very rare	No (H?)	No	no
Green Heron	very rare	No	No	no
Black-crowned Night-Heron	very rare	No	No	no
Turkey Vulture	uncommon	No	No	no
California Condor	extirpated	No (H)	No	no
Osprey	uncommon	Yes	No	no
Bald Eagle	fairly common	Yes	Yes	no
Northern Harrier	rare	No	No	no
Sharp-shinned Hawk	uncommon	Yes	Yes	no
Cooper's Hawk	uncommon	Yes	Yes	no
Northern Goshawk	uncommon	Yes	Yes	no
Red-shouldered Hawk	very rare	No	No	no
Broad-winged Hawk	very rare	No	No	no
Swainson's Hawk	very rare	No	No	no
Red-tailed Hawk	fairly common	No?	No	no
Ferruginous Hawk	rare	No	No	no
Rough-legged Hawk	very rare	No	No	no
Golden Eagle	rare	Yes	Yes	no
American Kestrel	uncommon	No	No	no
Merlin	rare	No	No	no
Peregrine Falcon	uncommon	Yes	No	no
Prairie Falcon	rare	Yes	No	no
Virginia Rail	very rare	No?	No	no
Sora	very rare	No?	No	no
American Coot	common	Yes	No	no
Sandhill Crane	rare	No?	No	no
Semipalmated Plover	very rare	No	No	no
Killdeer	uncommon	Yes	No	no
Band-tailed Pigeon	uncommon	No?	No	no
Greater Yellowlegs	rare	No	No	no
Willet	very rare	No	No	no
Spotted Sandpiper	common	Yes	No	no
Marbled Godwit	very rare	No	No	no
Western Sandpiper	uncommon	No	No	no
Least Sandpiper	uncommon	No	No	no
Pectoral Sandpiper	very rare	No	No	no
Long-billed Dowitcher	very rare	No	No	no
Common Snipe	fairly common	Yes	No	no
Wilson's Phalarope	very rare	No	No	no

Species	Status	Breeds	Resident	Introduced
Red-necked Phalarope	very rare	No	No	no
Bonaparte's Gull	very rare	No	No	no
Ring-billed Gull	very rare	No	No	no
California Gull	fairly common	No	No	no
Sabine's Gull	very rare	No	No	no
Caspian Tern	rare	No	No	no
Forster's Tern	very rare	No	No	no
Black Tern	very rare	No	No	no
Rock Pigeon	uncommon	No	No	no
Mourning Dove	uncommon	No	No	no
Barn Owl	rare	No	No	no
Western Screech-Owl	very rare	No	No	no
Great Horned Owl	uncommon	Yes	Yes	no
Northern Pygmy-Owl	uncommon	Yes	Yes	no
Spotted Owl	uncommon	Yes	Yes	no
Great Gray Owl	very rare	No	No	no
Northern Saw-whet Owl	uncommon	Yes	No	no
Common Nighthawk	common	Yes	No	no
Common Poorwill	rare	Yes	No	no
Black Swift	very rare	No	No	no
Vaux's Swift	fairly common	Yes	No	no
White-throated Swift	very rare	No	No	no
Anna's Hummingbird	uncommon	No	No	no
Calliope Hummingbird	uncommon	Yes	No	no
Rufous Hummingbird	common	No	No	no
Allen's Hummingbird	very rare	No	No	no
Belted Kingfisher	uncommon	No?	No	no
Lewis' Woodpecker	rare	No	No	no
Acorn Woodpecker	very rare	No	No	no
Williamson's Sapsucker	uncommon	Yes	No	no
Red-breasted Sapsucker	common	Yes	Yes	no
Downy Woodpecker	uncommon	Yes	Yes	no
Hairy Woodpecker	common	Yes	Yes	no
White-headed Woodpecker	fairly common	Yes	Yes	no
Black-backed Woodpecker	fairly common	Yes	Yes	no
Northern Flicker	common	Yes	Yes	no
Olive-sided Flycatcher	fairly common	Yes	No	no
Western Wood-Pewee	common	Yes	No	no
Pileated Woodpecker	uncommon	Yes	Yes	no
Willow Flycatcher	rare	Yes	No	no
Hammond's Flycatcher	fairly common	Yes	No	no

Species	Status	Breeds	Resident	Introduced
Gray Flycatcher	rare	No	No	no
Dusky Flycatcher	common	Yes	No	no
Pacific-slope Flycatcher	rare	No	No	no
Black Phoebe	very rare	No	No	no
Say's Phoebe	very rare	No	No	no
Ash-throated Flycatcher	very rare	No	No	no
Cassin's Vireo	fairly common	Yes	No	no
Warbling Vireo	common	Yes	No	no
Gray Jay	uncommon	Yes	Yes	no
Steller's Jay	common	Yes	Yes	no
Western Scrub Jay	very rare	No	No	no
Clark's Nutcracker	common	Yes	Yes	no
American Crow	very rare	No	No	no
Common Raven	fairly common	Yes	Yes	no
Horned Lark	very rare	No	No	no
Purple Martin	very rare	No	No	no
Tree Swallow	common	Yes	No	no
Violet-green Swallow	rare	No	No	no
Cliff Swallow	very rare	No	No	no
Northern Rough-winged Swallow	rare	No	No	no
Barn Swallow	fairly common	Yes	No	no
Mountain Chickadee	common	Yes	Yes	no
Bushtit	very rare	No	No	no
Red-breasted Nuthatch	common	Yes	Yes	no
White-breasted Nuthatch	fairly common	Yes	Yes	no
Pygmy Nuthatch	uncommon	Yes	Yes	no
Brown Creeper	common	Yes	Yes	no
Rock Wren	uncommon	Yes	No	no
Canyon Wren	very rare	No	No	no
Bewick's Wren	very rare	No	No	no
House Wren	uncommon	No	No	no
Winter Wren	uncommon	Yes	No	no
Marsh Wren	very rare	No	No	no
American Dipper	fairly common	Yes	Yes	no
Golden-crowned Kinglet	common	Yes	Yes	no
Ruby-crowned Kinglet	rare	No (H)	No	no
Blue-gray Gnatcatcher	very rare	No	No	no
Western Bluebird	rare	Yes	No	no
Mountain Bluebird	fairly common	Yes	No	no
Townsend's Solitaire	common	Yes	No	no
Swainson's Thrush	very rare	No (H)	No	no

Species	Status	Breeds	Resident	Introduced
Hermit Thrush	common	Yes	No	no
American Robin	common	Yes	Yes	no
Varied Thrush	rare	No	No	no
Wrentit	very rare	No	No	no
European Starling	very rare	No	No	Yes
American Pipit	rare	No	No	no
Cedar Waxwing	very rare	No	No	no
Orange-crowned Warbler	common	No?	No	no
Nashville Warbler	fairly common	Yes	No	no
Yellow Warbler	uncommon	Yes	No	no
Yellow-rumped Warbler	common	Yes	No	no
Black-throated Gray Warbler	rare	No	No	no
Townsend's Warbler	uncommon	No	No	no
Hermit Warbler	common	Yes	No	no
Northern Waterthrush	very rare	No	No	no
MacGillivray's Warbler	common	Yes	No	no
Common Yellowthroat	very rare	No	No	no
Wilson's Warbler	common	Yes	No	no
Western Tanager	common	Yes	No	no
Green-tailed Towhee	uncommon	Yes	No	no
Spotted Towhee	rare	No	No	no
Rufous-crowned Sparrow	very rare	No	No	no
Chipping Sparrow	fairly common	Yes	No	no
Brewer's Sparrow	rare	Yes	No	no
Vesper Sparrow	rare	No?	No	no
Sage Sparrow	very rare	No	No	no
Savannah Sparrow	very rare	No	No	no
Fox Sparrow	common	Yes	No	no
Song Sparrow	common	Yes	No	no
Lincoln's Sparrow	fairly common	Yes	No	no
White-crowned Sparrow	uncommon	Yes	No	no
Golden-crowned Sparrow	uncommon	No	No	no
Dark-eyed Junco	common	Yes	Yes	no
Black-headed Grosbeak	rare	Yes	No	no
Lazuli Bunting	uncommon	Yes	No	no
Bobolink	very rare	No	No	no
Red-winged Blackbird	common	Yes	No	no
Tricolored Blackbird	very rare	No	No	no
Western Meadowlark	rare	No	No	no
Yellow-headed Blackbird	very rare	No	No	no
Brewer's Blackbird	common	Yes	No	no

Species	Status	Breeds	Resident	Introduced
Great-tailed Grackle	very rare	No	No	no
Brown-headed Cowbird	fairly common	Yes	No	no
Bullock's (Northern) Oriole	very rare	No	No	no
Gray-crowned Rosy Finch	rare	Yes	No	no
Pine Grosbeak	very rare	No	No	no
Purple Finch	rare	Yes	No	no
Cassin's Finch	common	Yes	Yes	no
House Finch	very rare	No	No	no
Red Crossbill	fairly common	Yes	Yes	no
Pine Siskin	common	Yes	Yes	no
Lesser Goldfinch	very rare	No	No	no
American Goldfinch	very rare	No	No	no
Evening Grosbeak	fairly common	Yes	Yes	no

Table D2. Reptiles of Lassen Volcanic National Park

Common Name	*Scientific Name*
Western Pond Turtle*	*Clemmys marmorata*
Sagebrush Lizard	*Sceloporus graciosus*
Western Fence Lizard	*Sceloporus occidentalis*
Western Whiptail	*Cnemidophorus tigris*
Western Skink	*Eumeces skiltonianus*
Northern Alligator Lizard	*Elgaria coerulea*
Southern Alligator Lizard	*Elgaria multicarinata*
Rubber Boa	*Charina bottae*
Racer	*Coluber constrictor*
Sharp-tailed Snake	*Contia tenuis*
Ring-necked Snake	*Diadophis punctatus*
Common Kingsnake	*Lampropeltis getula*
California Mountain Kingsnake	*Lampropeltis zonata*
Pine Snake	*Pituophis melanoleucus*
Couch's Garter Snake	*Thamnophis couchii*
Western Terrestrial Garter Snake	*Thamnophis elegans*

Common Name	*Scientific Name*
Common Garter Snake	*Thamnophis sirtalis*
Western Rattlesnake	*Crotalus viridis*

* May be extirpated from the park. Current status of most of these species in the park is unknown.

Table D3. Amphibians of Lassen Volcanic National Park

Common Name	*Scientific Name*
Rough-skinned Newt	*Taricha granulosa*
California Newt	*Taricha torosa*
Long-toed Salamander	*Ambystoma macrodactylum*
Ensatina	*Ensatina eschscholtzii*
Western Toad	*Bufo boreas*
Pacific Chorus (Tree) Frog	*Pseudacris regilla*
Cascades Frog	*Rana cascadae*
Bullfrog	*Rana catesbeiana*

Table D4. Mammals of Lassen Volcanic National Park. Aside from the bats and some of the small mammals, the status of most of these species in the park is unknown.

Common Name	*Scientific Name*
Virginia Opossum	*Didelphis virginiana*
Northern Water Shrew	*Sorex palustris*
Preble's Shrew	*Sorex preblei*
Inyo Shrew	*Sorex tenellus*
Trowbridge's Shrew	*Sorex trowbridgii*
Vagrant Shrew	*Sorex vagrans*
Shrew-Mole	*Neurotrichus gibbsii*
Broad-footed Mole	*Scapanus latimanus*
Big Brown Bat	*Eptesicus fuscus*
Fringed Myotis	*Myotis thysanodes*
Silver-Haired Bat	*Lasionycteris noctivagans*
Hoary Bat	*Lasiurus cinereus*
California Myotis	*Myotis californicus*
Western Small-footed Myotis	*Myotis ciliolabrum*
Long-legged Myotis	*Myotis volans*

Common Name	*Scientific Name*
Long-eared Myotis	*Myotis evotis*
Little Brown Bat	*Myotis lucifugus*
Yuma Myotis	*Myotis yumanensis*
American Pika	*Ochotona princeps*
Snowshoe Hare	*Lepus americanus*
Mountain (Nuttall's) Cottontail	*Sylvilagus nuttallii*
Mountain Beaver	*Aplodontia rufa*
Northern Flying Squirrel	*Glaucomys sabrinus*
Yellow-bellied Marmot	*Marmota flaviventris*
Western Gray Squirrel	*Sciurus griseus*
California Ground Squirrel	*Spermophilus beecheyi*
Belding's Ground Squirrel	*Spermophilus beldingi*
Golden-mantled Ground Squirrel	*Spermophilus lateralis*
Yellow-pine Chipmunk	*Tamias amoenus*
Merriam's Chipmunk	*Tamias merriami*
Least Chipmunk	*Tamias minimus*
Douglas' Squirrel	*Tamiasciurus douglasii*
Beaver	*Castor canadensis*
Mountain Pocket Gopher	*Thomomys monticola*
Western Red-backed Vole	*Clethrionomys californicus*
Long-tailed Vole	*Microtus longicaudus*
Montane Vole	*Microtus montanus*
Muskrat	*Ondatra zibethicus*
Deer Mouse	*Peromyscus maniculatus*
Bushy-tailed Woodrat	*Neotoma cinerea*
Western Jumping Mouse	*Zapus princeps*
Porcupine	*Erethizon dorsatum*

Common Name	*Scientific Name*
Coyote	*Canis latrans*
Gray Wolf*	*Canis lupus*
Gray Fox	*Urocyon cinereoargenteus*
Red Fox	*Vulpes vulpes*
Black Bear	*Ursus americanus*
Ringtail	*Bassariscus astutus*
Raccoon	*Procyon lotor*
River Otter	*Lutra canadensis*
Marten	*Martes americana*
Long-tailed Weasel	*Mustela frenata*
Ermine	*Mustela erminea*
Mink	*Mustela vison*
Badger	*Taxidea taxus*
Striped Skunk	*Mephitis mephitis*
Spotted Skunk	*Spilogale putorius*
Mountain Lion	*Felis concolor*
Bobcat	*Lynx rufus*
Pronghorn (Antelope)*	*Antilocapra americana*
Elk (Wapiti)*	*Cervus elaphus*
Mule Deer	*Odocoileus hemionus*

* not resident in the park

NPS 111/122753, November 2013

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