National Park Service
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Natural Resource Stewardship and Science

Crater Lake National Park

Natural Resource Condition Assessment

Natural Resource Report NPS/NRSS/WRD/NRR—2013/724

ON THE COVER
Crater Lake in June.
Photo courtesy of the National Park Service

Crater Lake National Park

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Natural Resource Report NPS/NRSS/WRD/NRR—2013/724

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Executive Summary

We compiled existing data and information to characterize the condition and trends in high priority natural resources in Crater Lake 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 of the park's natural resources, we followed generally the Environmental Protection Agency's "Framework for Assessing and Reporting on Ecological Condition" (Young and Sanzone 2002). Specifically, we first identified seven natural resource themes considered by this park's managers and scientists to be most important. They are:

- Precipitation, Temperature, Snowpack, and Lake Levels
- Surface Water Quality
- Aquatic Life
- Terrestrial Vegetation
- Wildlife
- Air Quality
- Natural Quality of the Park Experience

We identified 24 indicators to evaluate these seven resource concerns. For each indicator we then attempted to define reference conditions to which we could compare present conditions. Making that comparison, we described the condition of each indicator as "Good," "Somewhat Concerning," "Significant Concern," or "Indeterminate." We described each 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 24 indicators, we determined that the condition of three indicators is of Significant Concern in this park. Those are: the distribution of forest stand ages, fire rotations, and extent of invasive pathogens. 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 forest types. This can restrict the park's capacity to effectively support the region's wildlife and plant diversity.

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

- Changes in Productivity and Diversity in Non-caldera Water Bodies
- Changes in Ecologically Harmful Aquatic Species

- Recovery of Disturbed Areas
- Diversity of Native Terrestrial Wildlife Species; Rare Species
- Connectivity and Extent of Important Terrestrial Habitats
- Deposition of Airborne Contaminants
- Ozone Levels

Park managers have limited capacity to influence the condition of the last three indicators. 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 (11), including the condition of the caldera lake itself, was rated “Good.” However, information was insufficient to rate the present condition or trends of four important indicators throughout all areas of the park:

- Annual Depth, Volume, and Persistence of Snowpack
- Water Quality in Non-caldera Water Bodies
- Rare Plants and Native Plant Diversity
- Dark Night Sky

Information sufficient to estimate *trends* was lacking for 16 of the 24 indicators, and none of the trends calculations 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 useful input during preparation of this assessment, from Crater Lake National Park we thank Mac Brock (Chief of Resource Management), Jeff Runde (Data Manager), Chris Wayne (GIS Coordinator), Mark Buktenica (Aquatic Ecologist), Dave Hering (Fisheries Biologist), Greg Holm (Wildlife Biologist), and Jennifer Beck (Botanist). Overall guidance was provided by the NPS Project Managers – initially David Larson from Lava Beds National Monument, succeeded by Mac Brock.

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), attempts to address these questions as they pertain to Crater Lake 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 focus 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 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 hierarchic 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 reporting 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 statistic 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; those data, methods, and reference values are designed to be appropriate for the stated purpose of the project, and are 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

Crater Lake National Park is in southwest Oregon in the south-central portion of the Cascade Range (Figures 1, 2). The park encompasses approximately 182,304 acres and is heavily forested, except for scattered wetlands, sub-alpine meadows, and extensive pumice-covered flats. Elevations range from about 3,800 feet in the park's southwest corner to just over 8,900 feet at Mount Scott. Generally, the vegetation reflects a mosaic of forested and open nonforested areas typical of mainly-unaltered areas of the Southern Cascades. Vegetation ranges from a mixed conifer forest dominated by ponderosa pine at the south to mountain hemlock and whitebark pine forest at higher elevations (Appendix C).

Near the center of the park is the park's most scenic and renowned resource, Crater Lake. With a depth of 1,943 feet, it is the deepest lake in the United States. The lake is in a caldera which was formed when the top of a 12,000-foot volcano, Mt. Mazama, erupted and collapsed about 7,700 years ago. Over the centuries, the caldera has collected water from rain and snow to form the lake. It is about 5 miles in diameter and is surrounded by the jagged, steep-walled cliffs of the caldera left by the climactic eruption and collapse. The cliffs surrounding the lake rise from 500 to 2,000 feet above the lake's surface.

Crater Lake holds the world record for clarity among lakes. The lake has no inlets or outlets, and evaporation and seepage prevent it from accumulating water and becoming deeper. Crater Lake is considered a youthful lake with a high level of purity, attributable to the lack of inflowing streams that otherwise would introduce minerals and other debris. The lack of stream inflow greatly restricts the growth of aquatic plants, and the absence of sufficient carbonates inhibits the development of large shelled animals. The result is a high level of light penetration, one that exceeds the level found in other alpine lakes.

The park's land slopes gradually downward in all directions outward from the caldera rim. Streams originating on the slopes of the caldera form headwaters of the Rogue River to the west or join the Klamath Basin to the south and east. Steep-walled canyons cut in pumice, such as at Annie, Castle, and Sun Creeks, contribute to the ruggedness of the terrain.

Among many objectives described in the CRLA Resource Management Plan (NPS 1999), the following pertain specifically to natural resources and were used to help guide this NRCA:

1. To know, qualitatively and quantitatively, the park's natural resources through comprehensive inventories.

2. To understand inter- and intra-specific relationships, ecological roles, and the environmental, physical, and chemical conditions of these resources through research and monitoring.

3. To develop our understanding in order to be able to determine the limits of natural variation, predict system health, and facilitate development of the best possible management strategies for resource protection.

4. To restore and maintain the natural terrestrial, aquatic, and atmospheric ecosystem conditions and processes, to the degree that is physically possible and politically practical, so they may operate unimpaired from human influences.

5. In areas designated as "natural zones" (General Management Plan), to maintain or restore indigenous flora, fauna, and natural communities to the extent possible, to achieve species diversity and community structure equivalent to pre-Columbian times or post-Columbian conditions which would have been created by natural events and processes.

6. To protect rare species by measures aimed at preserving habitat and preventing extirpation, but which minimize adverse influences on other indigenous species.

7. Within proposed Wilderness, to provide outstanding opportunities for solitude, with minimal evidence of modern civilization.

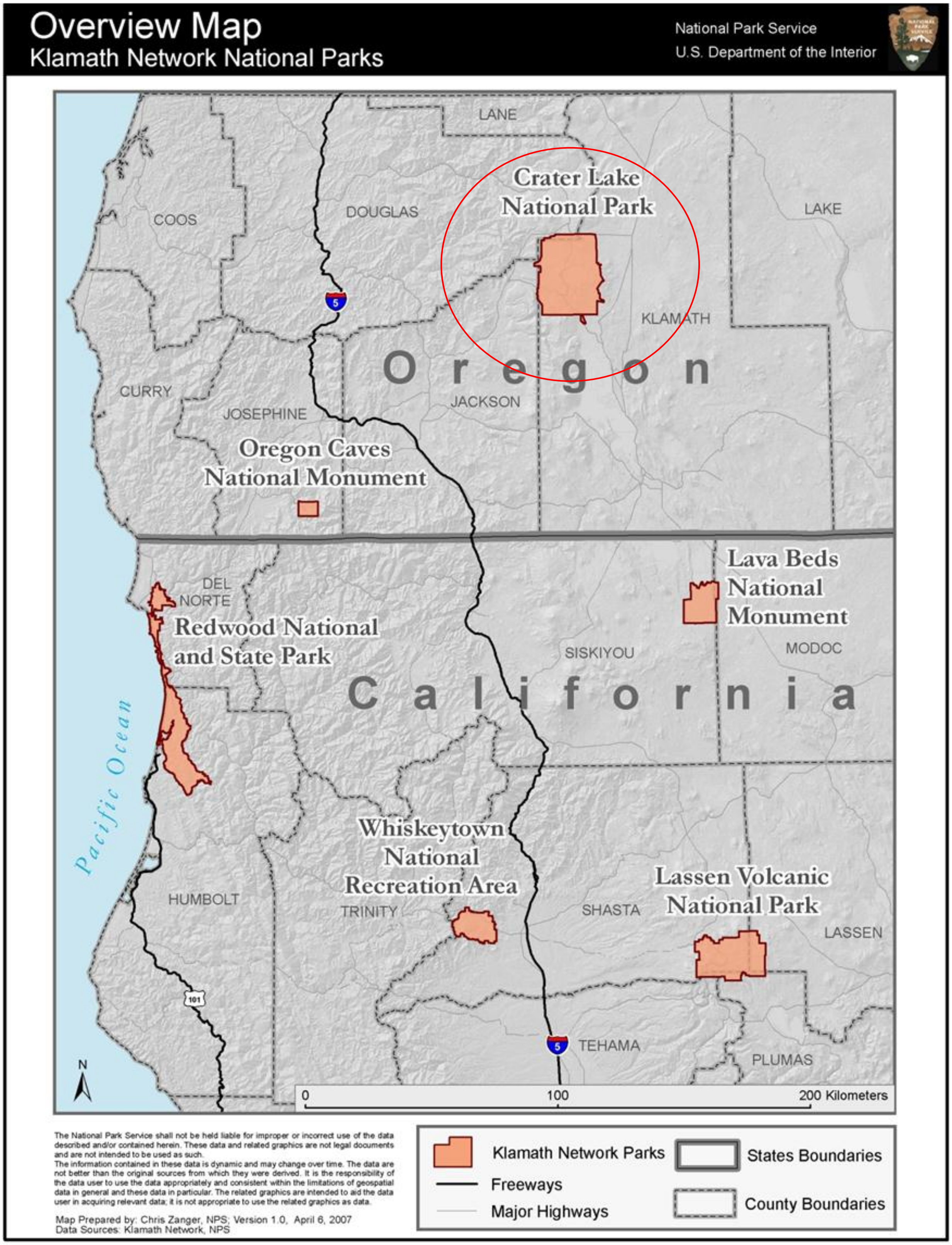

Figure 1. General location of Crater Lake National Park.

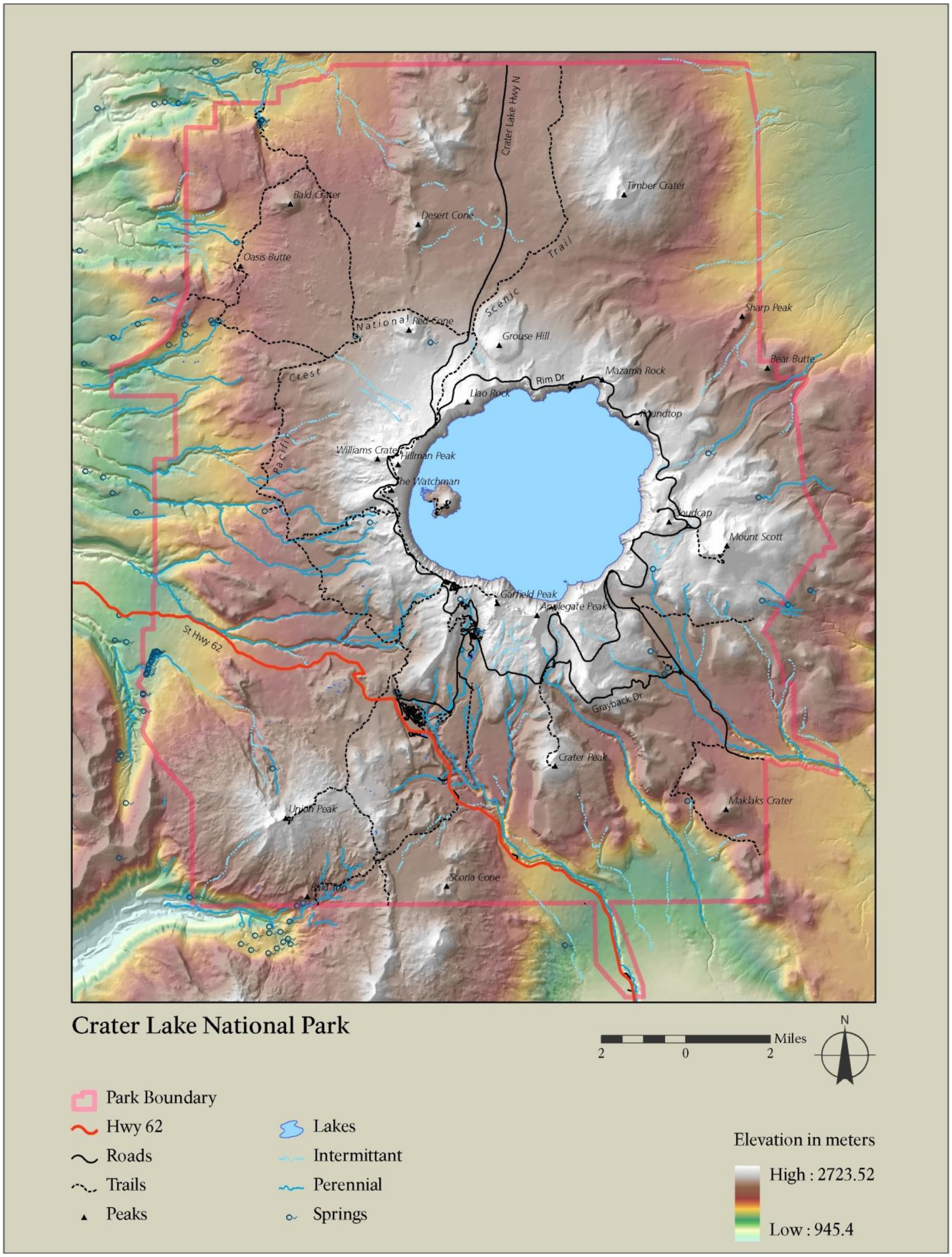

Figure 2. Base map of Crater Lake National Park.

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 climatologic data. Dr. Adamus served as report editor, as well as writing all sections except section 4.4, which addresses vegetation and fire regime. Those sections were prepared by Dennis Odion, vegetation ecologist, Southern Oregon University. 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, Reporting Areas, 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 and Lassen Volcanic National Park. 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 Crater Lake 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, which was a great help in focusing our efforts. In no particular order, the 18 "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
- Clean Water
- Water Rights
- Groundwater Flow
- Logging or Habitat Conversion
- Fire Regimes

[9] From Crater Lake National Park: 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). From Lassen Volcanic National Park: Louise Johnson (formerly, Chief of Resources), Nancy Nordensten (formerly, Resource Management Specialist; Biologist), Janet Coles (Plant Ecologist).

- Fire Suppression and Fuels Management
- Areas of Pristine or Old-growth Vegetation
- Native Plant Restoration
- Invasive Species (plants)
- Invasive Species (animals)
- Phenological Cycles
- Solitude and Silence
- Natural Quiet
- Dark Night Sky
- Moisture and Climate Cycles
- Global Warming

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

Subsequently, all relevant documents from the parks were identified. This task was made easier by the Klamath Network having recently completed a "data mining" report (Smith et al. 2006). That report was followed by a bibliographic database of nearly all published and unpublished documents and maps for these parks, up to about 2007. We augmented that database using online search engines (Web of Science, Google Scholar) to identify newer publications from the three parks, as well as locating relevant documents pertaining to the regions surrounding these parks, searching with phrases such as "Southern Cascades." We obtained complete digital copies (PDFs) of many publications that reported relevant research results from the park and surrounding region. We then indexed all digital documents in an Excel spreadsheet so they could be sorted by topic and year. The database and all the digital documents, as well as spatial data layers, were placed on a server computer at SOU that was accessible to the project team throughout this project.

We reviewed and considered several frameworks for organizing our NRCA effort. We decided to follow generally the Environmental Protection Agency's "Framework for Assessing and Reporting on Ecological Condition" (Young and Sanzone 2002). Specifically, for each priority resource we identified multiple *indicators* of resource condition and defined reference conditions that could be used as a basis for assessing these. An ecological indicator is any measurable attribute that provides insights into the state of the environment and provides information beyond its own measurement (Noon 2003). Indicators are usually surrogates for properties or system responses that are too difficult or costly to measure directly. 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.

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

Certainty: High, Medium, or Low.

We defined these terms in the context of each specific resource or issue we evaluated. Most indicators were assessed at the park scale, although connections to regional conditions were noted where supported by previously published analyses. The maps prepared for this assessment potentially reveal differences in resources at a finer scale, i.e., within the park. Some of the spatial data were also compiled in tables organized by major watersheds that the park intersects. These "analysis units" are shown in Figure 3.

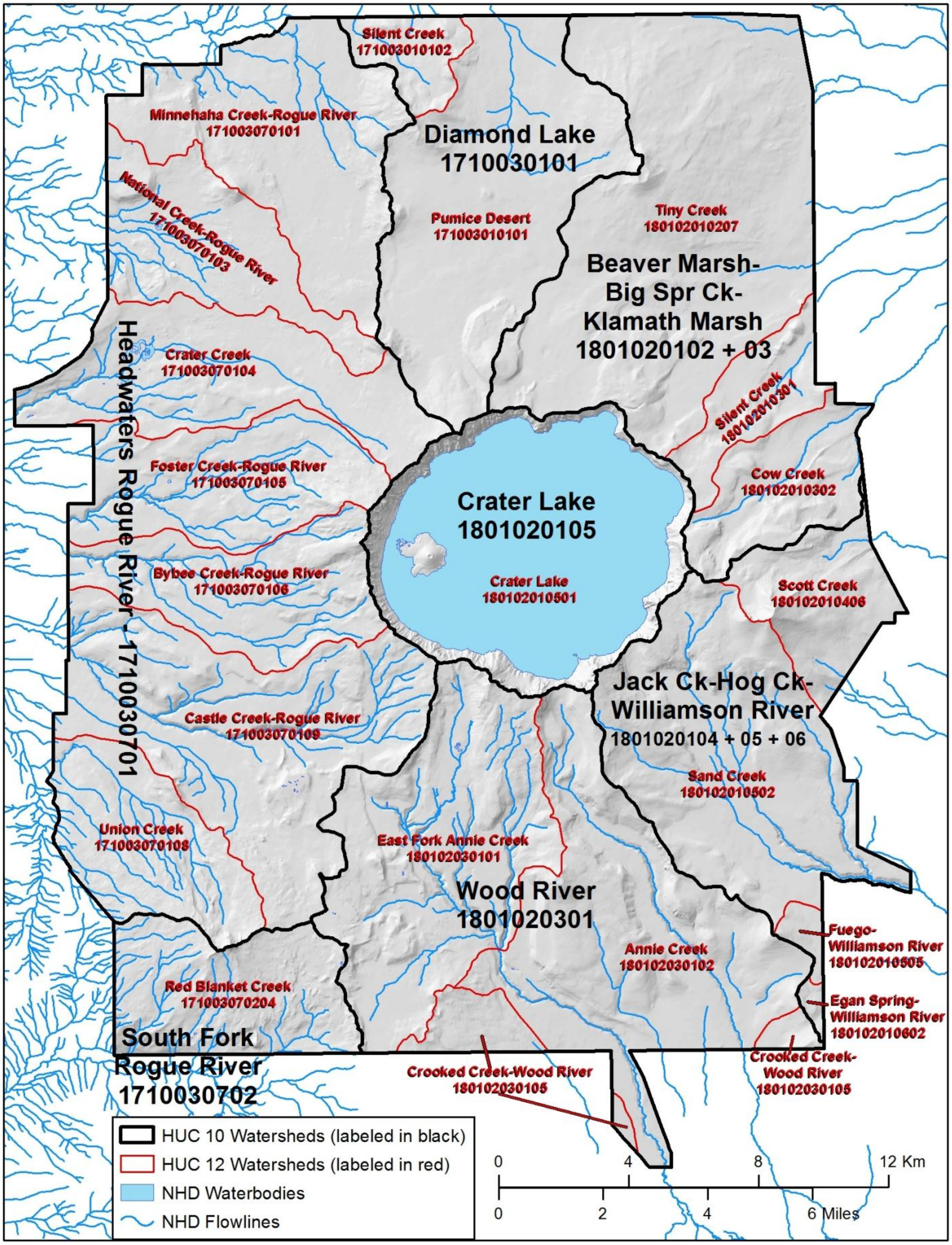

Figure 3. Watershed analysis units intersecting Crater Lake National Park. Numbers are USGS Hydrologic Unit Codes.

4.0 Natural Resource Conditions and Trends

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

1. Changes in precipitation, snowpack, and water availability

2. Changes in the chemistry, transparency, and biological communities of Crater Lake itself (hereinafter called "the caldera lake") and other surface water bodies—streams, other lakes, wetlands, and riparian systems

3. Changes in the diversity, condition, distribution, and connectivity of vegetation

4. Changes in the diversity, abundance, and distribution of wildlife within the park

5. Changes in the overall natural quality of the park experience

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

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

4.1 Changes in Precipitation, Temperature, Snowpack, and Lake Levels

4.1.1 Background

Precipitation is essential for reducing fire risk, supporting forests and wildlife, and sustaining stream flow and water table levels that support ponds, lakes, and wetlands. Long term changes in air temperature influence the proportion of precipitation that falls and the proportion that is retained longer in the season as snow. Snow deposition (Figure 4) is sensitive to wintertime (November-March) warming trends, whereas snowmelt is sensitive to changes in springtime temperatures (Knowles et al. 2006). Snow depth affects the overwinter survival and springtime germination of plants, as well as affecting wildlife movements and shelter. 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, snowmelt water infiltration into soils and groundwater is more complete. Consequently, stream flow from snowmelt is sustained longer into the growing season, and natural processes may have longer to detoxify any pollutants present in precipitation and snowpack. 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).

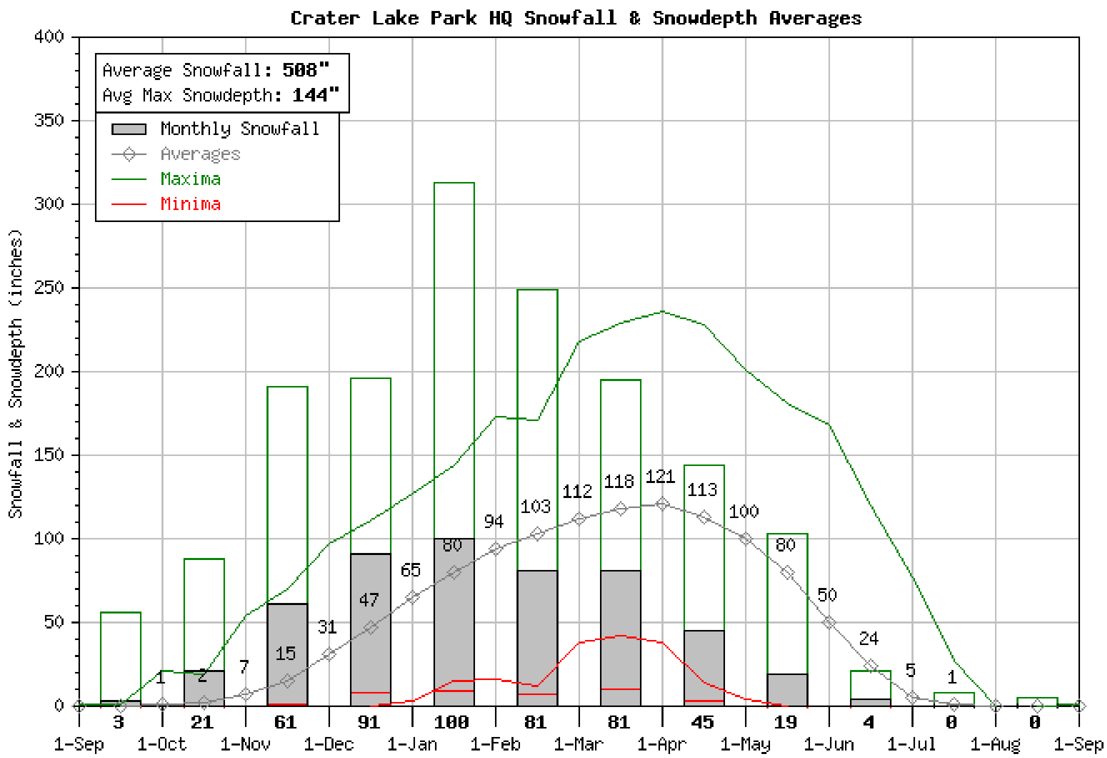

Figure 4. Seasonal variation in snowfall and snow depth, 1930-2005, at Crater Lake park headquarters (Andalkar 2005).

Long-term precipitation and temperature averages for Crater Lake are shown in Appendix A. Rainfall, snowfall, and temperatures within this park's region vary greatly depending on elevation and are strongly modified by the rain shadow configuration of the Cascade crest and the distance of the recording area from it. The most rapid change in precipitation amounts within the park occurs down the eastern flank, where the heavy precipitation of the High Cascades gives way to the semiarid high plateau country of central Oregon. Approximately 70 percent of the annual precipitation falls from November through March in the park, and practically all of it falls as snow. Snow depths of 100 to 200 inches on the ground are common at park headquarters, and the annual total snowfall there is nearly 600 inches. In about half of the winters, the first measurable snowfall occurs by the end of September, and at the park's lower elevations by the end of October. Snow depth has been monitored at park headquarters (6400 ft elevation) since

1916, with some gaps in coverage during 1925-26, 1928-29, and 1942-46. Snow depth has also been monitored at Annie Springs (elevation 6000 ft), which averages about a foot less accumulation at mid-winter than at park headquarters, and at the caldera rim (7100 ft), as well as northeast of the park at Chemult (4760 ft) and southwest of the park at Prospect (1500 ft).

4.1.2 Regional Context

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

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

4.1.3 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 from 1916 to 2003 (Hamlet et al. 2007). The rate of temperature increase from 1947 to 2003 was roughly double that averaged for the entire period from 1916 to 2003. This was largely attributable to the fact that much of the observed warming occurred from 1975 to 2003. Regionally averaged spring and summer temperatures for 1987 to 2003 were 0.87°C higher than those for 1970 to 1986, and spring and summer temperatures for 1987 to 2003 were the warmest since the beginning of the record in 1895 (Westerling et al. 2006). The largest warming trends have occurred in January-March (Hamlet and Lettenmaier 2007).

The snowpack has declined over much of the West (Mote 2003a, 2003b, Hamlet et al. 2005, McCabe and Clark 2005), despite increases in winter precipitation in many places. The largest reductions have occurred where winter temperatures are mild, especially in lower elevations of the Cascade Mountains (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 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 2003b).

4.1.3.2 Future Climate Change

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

4.1.3.3 Other Potential Impacts on Water Quantity

There have been applications for geothermal exploration leases on Forest Service lands adjacent to the park and as close as 600 feet from the park boundary. Exploratory drilling to 1,675 meters (5,500 feet) depth has occurred at one drill site east of Mt. Scott and at a second site adjacent to the east boundary of the Panhandle. Additional drill sites have been identified and numbered, in the area east of Mt. Scott and Sharp Peak, and more permits for new drill locations may be forthcoming. Numerous test wells are planned at elevations around 1,830 meters (6,000 feet), and with drill depths to 1,675 meters (5,500 feet). Development of geothermal resources near the park has the potential to affect the amount of groundwater within the park, including hydrothermal vents within the caldera lake (Bacon and Nathenson 1996). However, this has not been investigated comprehensively. If test wells are successful and a commercially significant geothermal resource is developed, a power plant might be constructed adjacent to the park.

4.1.4 Indicators and Criteria to Evaluate Condition and Trends

Although little or nothing can be done within the park to address this issue (changes in precipitation, temperature, snowpack, and lake levels), improved knowledge of current conditions and anticipated changes can help resource planning efforts. Informative indicators for this issue might include the condition and trends of the following:

1. Annual snowfall and depth, volume, and persistence of snowpack;
2. Water level elevations in Crater Lake;
3. Discharge volume and timing in streams and springs;
4. Number and area of wetlands, ponds, and lakes

Aside from the lake level elevations, existing data from the park are insufficient to determine past or likely future trends in any of the above indicators. 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 snowpack horizontal extent (not just depth) or spring melt conditions, nor flow characteristics in the park's perennial and intermittent streams before they exit the park. The areas of most of the park's wetlands, ponds, and lakes are known but should be re-measured with updated aerial imagery at intervals of one decade or less, depending on apparent rates of climate change.

<u>4.1.4.1 Annual Snowfall and Depth, Volume, and Persistence of Snowpack</u>

Because most of the park is at the top of a watershed and receives nearly all its precipitation as snow, the annual snowpack is of obvious importance to the park's resources. A smaller snowpack could mean longer periods of drought in downstream areas during late summer and fall, thus stressing aquatic life and making terrestrial vegetation more susceptible to damage from insects, disease, and fire. Much of the park drains to the Rogue, Umpqua, and Klamath River Basins. As much as 60-80% of the summer flows in these rivers originate in 10-15% of their respective watersheds, coming primarily from the groundwater-dominated upper parts, such as where the park is located (Mayer and Naman 2011).

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. A rating of "Good" would describe a condition where annual snowfall and the amount (depth, volume, persistence) of snowpack is at or above the average historical condition in all parts of the park. "Somewhat Concerning" and "Significant Concern" conditions would be defined as an amount and timing of snowpack and snowmelt that are less than necessary to sustain the park's ecosystems close to their present state.

Condition and Trends

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

Trends in precipitation and temperature are somewhat concerning. Monthly and annual data for snow depth at park headquarters and at two monitoring stations near the park (Prospect, Chemult) show a long term decline during the period 1931–2007 as well as 1947-2007, but not during 1971–2007 (Daly et al. 2009) or 1983-2007 (Girdner et al. 2009). The long term decline in snow depth may correspond at least partly to an increased proportion of the annual precipitation being in the form of rain rather than snow (Barnett et al. 2008). Snowmelt from the caldera walls, which contributes a maximum of 4.16 m^3/s or 149 cfs water, is essential to offset lake water losses due to evaporation and seepage and thus maintain the level of the lake (Redmond 1990, Girdner et al. 2009). On average, each 10 inch drop in April snow water equivalent results in 7.4 days earlier arrival of thermal stratification in the lake, an annual event of major biological importance. Historically, particularly severe droughts are reported to have occurred in this region from 1856 to 1865, 1870 to 1877, and 1890 to 1896 (Herweijer et al. 2006).

Separately, we analyzed trends in temperature and precipitation as monitored at park headquarters for the period 1919 through 2011. The following trends were statistically significant:

- decrease in maximum observed minimum temperatures (maximum Tmin)
- increase in minimum observed minimum temperatures (minimum Tmin)
- decrease in the warmest nighttime temperatures (% of Days Tmin >90th Percentile)
- increase in the number of days with Tmax below freezing (# of Days Tmax <0°C)
- increase in the number of days with Tmin below freezing (# of Days Tmin <0°C)
- decline in one-day precipitation amounts (maximum 1-day precipitation)
- decline in the Simple Precipitation Intensity Index
- decline in extreme rainfall (events greater than the 99^{th} percentile)

In addition, Daly et al. (2009) computed trends in temperature and precipitation at park headquarters *for each month*, but for a shorter time period, 1971-2007 (Appendix A).

They commented:

> “There has been little trend in annual precipitation during either time period. The five-year moving average highlights a precipitation minimum around 1930, a maximum in about 1950, then a series of variations with a wavelength of about 10 years. There has been a significant drying trend in September precipitation, however, that appears in both periods in the average, and also for the three stations. A sharp precipitation decrease in the late 1980s is largely responsible for the overall trend. This is consistent with an unpublished analysis done by Daly for the HJ Andrews Experimental Forest east of Eugene in the Oregon Cascades, and suggests that the summer drought has been extending into late summer and early fall more often than before.
>
> “Temperature trends are significantly positive for several months and for the annual average. While trends in maximum temperature are weak, minimum temperature has seen significant increases over both the short and long time periods. Trends are not the same among stations, and it is important not to conclude too much from trend statistics at one location. However, it is clear that annual minimum temperatures have been increasing since the 1970s. This trend is relatively weak at Chemult, however. All locations show upward trends significant at the 90% level for the period 1971–2007 in January, April,

> May, and July… Elevations in the park are generally high enough to prevent these recent temperature increases from negatively affecting the snowpack.”

Examining a longer period of record (1931-2008 instead of 1970-2007) from the park headquarters, Girdner et al. (2009) also found no trend in *maximum* air temperature, except for the months of March and September (warmer maximums) and February (cooler maximums). But like Daly et al. (2009), they noted significant warming of average annual temperature in more recent years, and commented that the rate of increase since 1983 at park headquarters (0.23°C per decade) is higher than the globally-averaged rate of atmospheric warming of 0.07°C per decade (Jones and Moberg 2003). Both studies found a significant cooling of *minimum* air temperature, at least for the summer months, with May and July showing the greatest cooling. Segregated by period, from the 1930s to the early 1980s temperatures trended towards cooling but towards warming from the 1980s to the present.

In the lake itself, there was a highly significant warming trend of surface waters during summer months from 1965 to 2008. The average rate of summer surface water temperature increase was 0.6°C per decade, or approximately 2.6°C since 1965. The average rate of summer surface water temperature increase at Crater Lake (0.57°C/decade, or about 2.6°C since 1965), is more than twice that of Lake Tahoe (Coats et al. 2006). Deeper portions of the lake are warmed locally by geothermal vents, but air temperature is by far the larger driver of lake temperature overall, accounting for 73% of the variation in surface water temperature during the summer (Girdner et al. 2009).

Assessment Confidence and Data Gaps

Low. Despite the park’s reputation for heavy snowfall, the distributional patterns of snowfall in the park unit are severely under sampled (Davey et al. 2007). The snow data come from only two locations within the park and cannot be extrapolated to other parts. In addition, it is uncertain to what degree apparent trends in snow and precipitation can be attributed to the El Niño Southern Oscillation (ENSO) weather phenomena (Table 2). This complicates attempts to interpret what degree of deviation from average conditions should be considered “normal” (Redmond and Koch 1991, Aguedo et al. 1992, Beebee and Manga 2004).

Table 2. Average annual snowfall at Crater Lake associated with ENSO conditions, 1950-2004 (from Andalkar 2005).

Condition	Average Annual Snowfall (inches)
Strong El Niño	468
Weak El Niño	510
Neutral	470
Weak La Niña	510
Strong La Niña	615
Average	*508*
Maximum	*836*
Minimum	*243*

4.1.4.2 Water Level Elevations in Crater Lake

Crater Lake, the gem of this park and the deepest lake in North America, is in no danger of drying up in response to even the most extreme projected climate changes. However, its color, transparency, and unique geochemical and biological environment are partly influenced by climate. Abnormal water level changes could be an indicator and precursor of potentially significant changes in its aesthetic and other characteristics. A survey by Rolloff (1998) of over 1000 visitors used simulated images of the lake at elevations that are 25, 75, and 125 feet lower. The survey indicated that present lake levels are strongly preferred by visitors.

Lake levels are measured daily to annually, and are referenced to September 30 to allow a standardized comparison among years.

The lake's levels vary in response to the changing balance between precipitation amount, evaporation, and seepage rate. The lake's water budget is controlled more by precipitation than evaporation and seepage, as confirmed by measurements of these factors as well as a highly significant correlation of lake levels with air temperature at park headquarters measured from 1962-2003 (Redmond 2007). The lake rises 1.4 cm for every cm of measured precipitation over equilibrium value (168.6 cm) at park headquarters. Evaporation is about 76 cm/year and seepage at 0.347 cm/day or 127 cm/year, equivalent to an outlet stream with discharge 2.14 m^3/s. The residence time of water is about 225 years (Collier et al. 1990). The lake almost never freezes completely. Evaporation is greatest during the cool season because of the lake's unfrozen condition and occurrence of stronger winds at that time of year. However, despite the lake's 4.1 km radius, the caldera rim shelters much of it from strong winds. Large daily decreases in lake level occur often on autumn days when cool dry air overlays the warm water left from summer.

Criteria

Historical lake levels are used as the reference for assessing current conditions and trends. “Good” condition would be represented by a lake level close to the one prevailing over the past century or slightly greater. “Somewhat Concerning” would be a lake level that is less, but within 5 m of the recent historical maximum. “Significant Concern” would be a lake level outside that range.

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

Given its enormous depth, there is no chance the caldera lake will go completely dry within any foreseeable time as a result of climate factors. Although levels in the lake over the last century have varied over a range of 5 m (Redmond 2007), a statistically significant decline occurred from 1892 to 2008 (Girdner et al. 2009). Lake levels are highly correlated with precipitation, and reconstructions of past precipitation using tree rings support this conclusion (Peterson et al. 1999).

Assessment Confidence and Data Gaps:
Medium Certainty. Data are relatively complete and thoroughly analyzed.

<u>4.1.4.3 Flow in Streams and Springs</u>
The park’s named streams include Annie, Whitehorse (feeds Castle), Wheeler (feeds Sand), Sun, Bybee, Munson, Bear, Red Blanket, Copeland, Crater, National, Trapper Creek, and Lost Creek. Most of these streams originate in headwater springs, many of which have also been mapped and described (Dutton 1935). Because of the large extent of permeable volcanic rock (e.g., pumice), large areas of the park lack well-defined surface-drainage systems. Above elevation 5500 ft, the northern park has no springs or streams with permanent flow. Initiation points of perennial flow have not been located on most streams but those could be determined by walking the uppermost parts of the streams during their driest period each year and using GPS to determine that average location, which is of biological interest as well as a potential indicator of climate change.

The park’s streams, like most streams of the younger High Cascades volcanics, are groundwater-dominated and thus have much more uniform flows with muted winter peaks, slower recession rates, and higher summer base flows relative to runoff-dominated streams draining the older Western Cascades volcanics (Tague and Grant 2004). This may make them less sensitive to future climate change than runoff-dominated streams (Jefferson et al. 2008, Tague et al. 2008, Chang and Jung 2010). In recent years there also has been an increase in requests for diversion of stream water originating within Crater Lake National Park and flowing through US Forest Service lands. Such diversions, intended for small-scale production of electricity, could affect upstream migrations of fish into the park.

Groundwater flow from springs is generally warmer in winter and cooler in summer than surface water. As such, the amount, duration, and timing of flow from springs are extremely important to aquatic life in the streams, lakes, and wetlands that often are fed by those springs (Brown 2007). Warmer water from discharging springs in winter can ameliorate ice conditions that can stress fish and other aquatic life. Cooler summer flows are important in reducing thermal stress, especially along narrow streams where shading tree canopies have been decimated by fire, insects, or disease. Spring flows that percolate through gravels provide excellent spawning habitat for bull trout. And in all locations and seasons, the natural chemical composition of springs differs markedly from other surface waters, thus influencing their quality and ecological relationships.

Nineteen reaches of the park's streams were characterized in 1947, mainly in terms of trout distribution (Wallis 1948). Water temperature, average station width and depth, and velocity were measured and stream habitat was described. A more extensive survey of park streams and springs was conducted in 1967-1968 (Frank and Harris 1969). That survey recorded 106 flow measurements for 46 streams and 21 springs. Habitat conditions of four streams (Sun, Annie, Bear, and Sand) were characterized by Dambacher et al. 1993, who described how those conditions changed under different flows. Flows in Sun Creek have been monitored periodically since about 1997 in connection with the bull trout restoration program there.

Criteria
Local and regional data on stream flows and lengths of perennial stream are insufficient to quantify reference conditions appropriate for this park, so qualitative statements will define the reference conditions. "Good" would be a condition wherein no spring nor section of a perennial stream within the park is ephemeral more often than it has historically, or where the number or extent of perennial stream reaches and springs is greater. "Somewhat Concerning" would be a condition wherein shrinkage is noted in no more than a few such features, e.g., less than 5% shrinkage. Also of interest 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.

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

Flow has been monitored consistently over many years at only one USGS gauging station within the park (Annie Spring, 11503000). There are also two stations located downstream from the park and within a few miles:

11502950 Sun Creek at Ranger Station near Fort Klamath (2011 data only)

14333500 Red Blanket Creek near Prospect (discontinued in 1981)

Monitoring gauge data at Annie Spring is unlikely to represent surface runoff conditions in the park generally because it receives little surface runoff, being only about 10 m downstream from its groundwater source. Nonetheless, USGS stream flow data were obtained for the Annie Spring station. For the years 1977-2004, the median date of peak flow was June 14 (range = May 13 to July 14). For each year, the date of annual peak flow was plotted against year. No evidence was found that the date of peak flow (of groundwater, primarily) is occurring earlier in the spring; in fact there is slight but statistically insignificant trend towards peak flow occurring later (Figure 5).

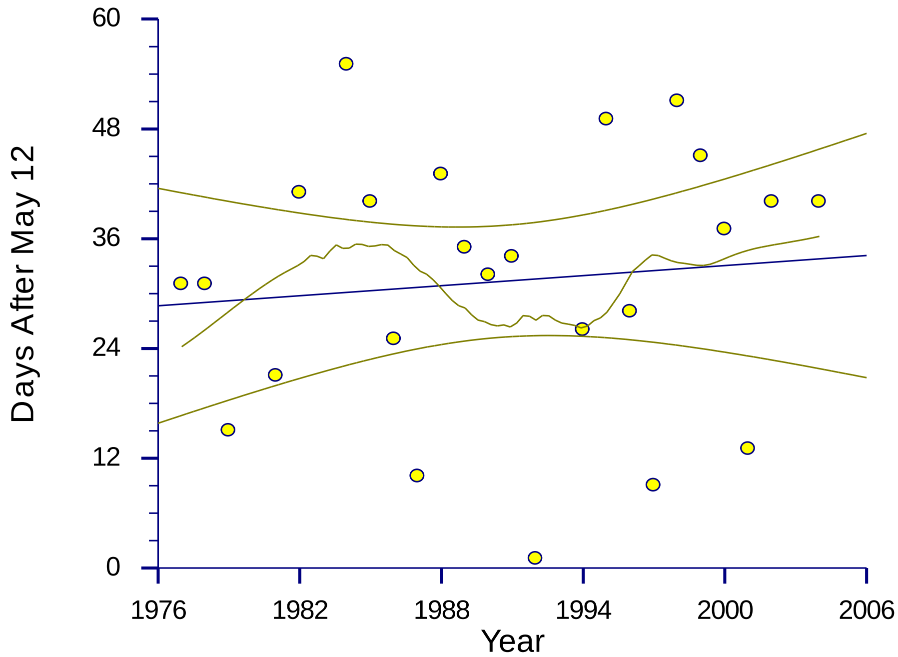

Figure 5. Days after May 12 during which annual peak flow occurred each year at Annie Springs USGS gauging station. The curved line is the locally weighted regression line (with 40% smoothing). The straight line is the least squares regression with confidence bands. R^2 =0.0002, p=0.9458, slope =0.0272, n=25.

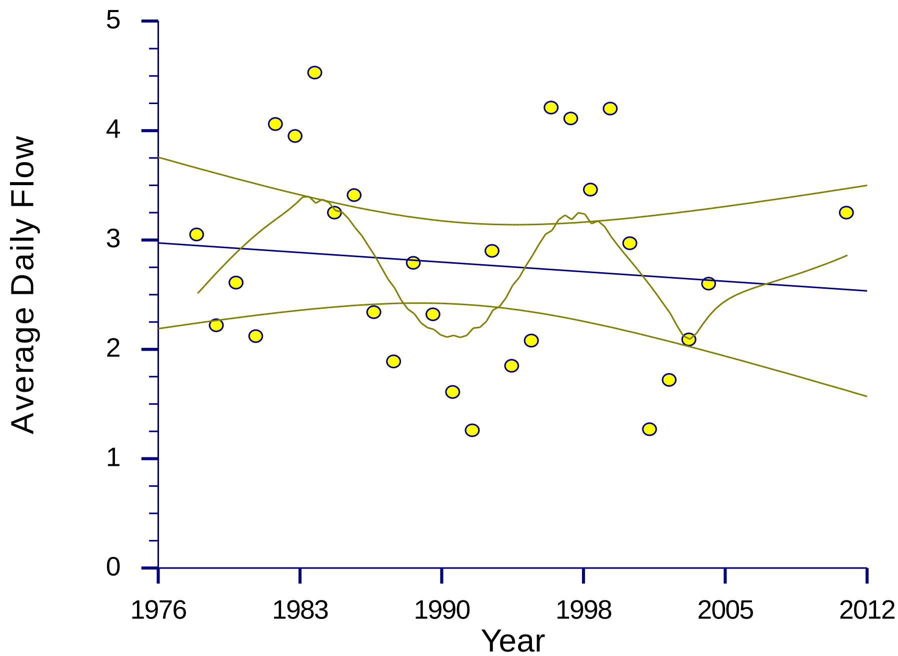

Figure 6. Average daily flow (cfs) by year for Annie Springs USGS gauging station. The curved line is the locally weighted regression line (with 40% smoothing). The straight line is the least squares regression with confidence bands. R^2 =0.0124, p=0.5731, slope =-0.0122, n=28.

Average daily flow was also plotted against year (Figure 6). Although daily flows appear to be lessening overall, the downtrend is not statistically significant.

Assessment Confidence and Data Gaps:
Low. Although flow rates of some of the park's streams and springs were reported by USGS in 1923 and 1960, those and other data are sporadic (Frank and Harris 1969). The hydrologic and other physical characteristics of most of the park's streams and springs have not been quantified over multiple seasons and years.

<u>4.1.4.4 Number, Area, and Distribution of Wetlands, Ponds, and Lakes</u>
Although the caldera lake draws the most attention, the park also hosts many much smaller ponds and wetlands. These are largely groundwater-driven, often coincident with springs, and less numerous than in landscapes with soils that are less porous than those in this park. It is estimated that the park contains 6 to 10 perennial lakes and ponds and at least 254 wetlands. Non-perennial ponds are included in the wetland total.

Criteria
Local and regional data on the number, area, and distribution pattern of wetlands, lakes, and ponds are insufficient to quantify reference conditions appropriate for this park's particular landscape, so qualitative statements will define the reference conditions. "Good" conditions would mean that wetlands of all types are present at or near their recent historical extent, with no permanent loss of a wetland in any part of the park. "Somewhat Concerning" conditions would mean shrinkage or disappearance of a limited number of wetlands, considering that (a) wetlands are naturally dynamic and some wetlands fluctuate between years from being seasonally to persistently flooded, and (b) those cycles are beneficial to their productivity. Ideally, the criteria would specify that there also be no loss of wetland *quality* (ecological condition) as determined partly by using the variables recorded by Adamus & Bartlett (2008).

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

The park's wetlands were mapped by the National Wetlands Inventory (NWI), and refinements and additions were made by Adamus & Bartlett (2008), who visited 76 wetlands comprising a probability sample of the park's wetlands. The sample wetlands were visited once and they were mapped using GPS, with the coordinates reported in a database provided to the Klamath Network. Permanent markers were placed in each sample wetland and plants were identified to species in 101 vegetation plots. These assessments determined that *nearly all wetlands are in good condition* as defined mainly by their plant communities. No data are available on trends in the number or area of wetlands, ponds, and lakes within the park, nor trends in their quality (ecological condition). The maps provide a reasonably complete baseline for wetland area and distribution in the park, and the Adamus & Bartlett assessment data provide a partial baseline for comparing future wetland quality.

Assessment Confidence and Data Gaps
Medium. The Adamus & Bartlett (2008) survey ground-truthed many of the NWI- 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, atmospheric deposition of nitrogen and sulfur, other water quality variables, groundwater levels, amphibians, underwater aquatic plants, or several other indicators of wetland ecological condition.

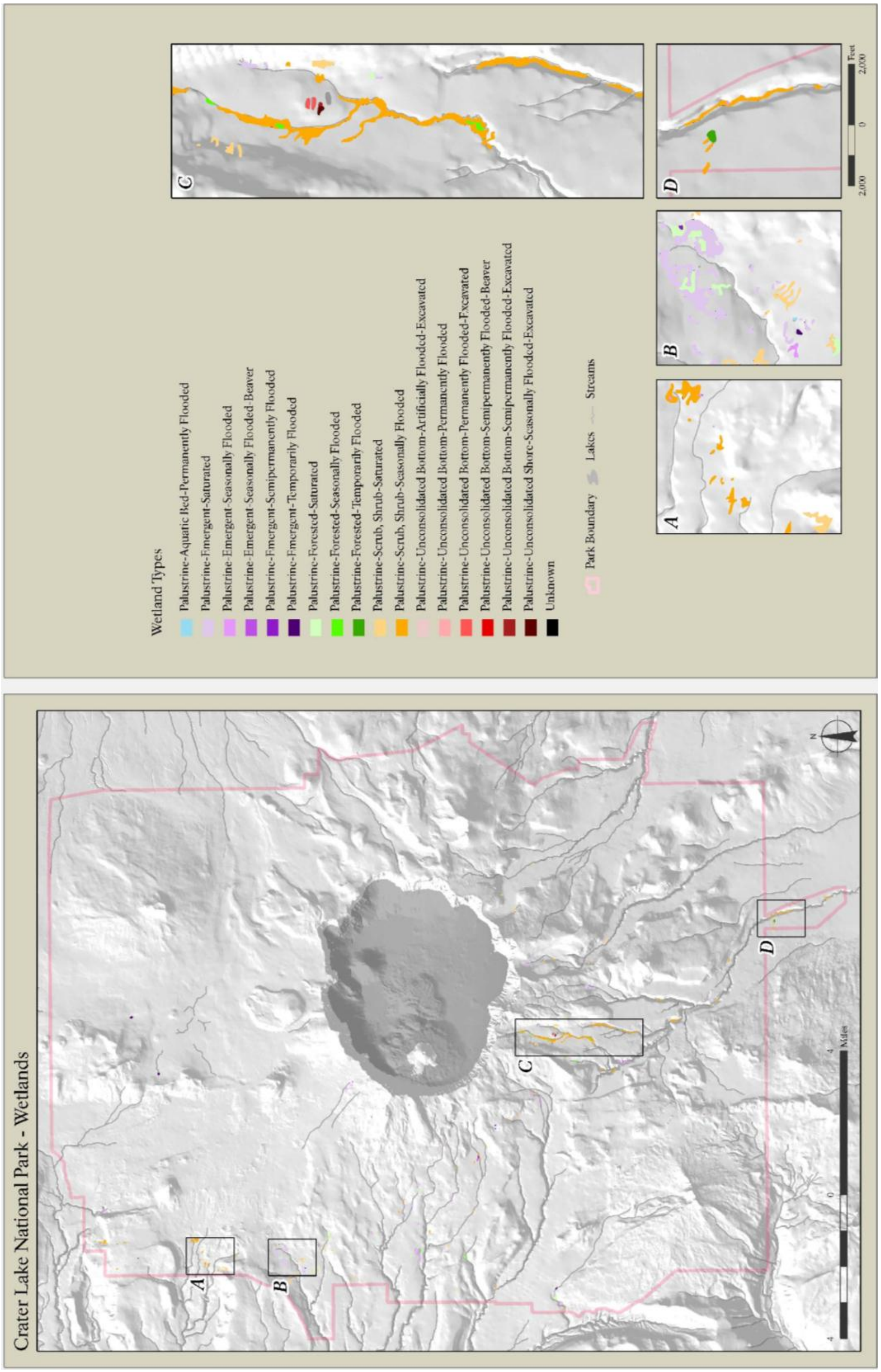

Figure 7. Example of wetlands map available in Crater Lake spatial data archive (Adamus & Bartlett 2008)

4.2 Changes in Surface Water Quality

4.2.1 Background

This section discusses the quality of surface water, meaning water that is above the land surface in lakes, streams, springs, and wetlands. Especially in complex terrains such as Crater Lake National Park, surface water and ground water are often highly connected.

Several factors can potentially impair the quality of the park's water bodies. The more notable of the potential threats at Crater Lake National Park include the following, which are described after first describing the regional context:

- Climate change
- Deposition of atmospheric nitrogen and sulfur
- Deposition of other airborne contaminants
- Changes resulting from fires and fire control activities
- Visitor-associated pollution
- Ecologically harmful aquatic plants and animals

4.2.2 Regional Context

Crater Lake is the deepest lake in the U.S., the second deepest in the Western Hemisphere, and seventh deepest lake (592 m) in the world. In 1985 the EPA's Western Lake Survey documented the status of lake water chemistry across the region, and results indicated that lakes of the Oregon Cascades had the second most pristine and dilute lake water chemistry in the nation. Accompanying this finding were indications of the extreme vulnerability of many of these lakes to acidification due to unique geology and hydrology. They are particularly sensitive to additions of atmospheric sulfur and nitrogen because their waters have a low capacity to buffer these additions (Sullivan et al. 2001, Mutch et al. 2008). Emissions of sulfur dioxide (SO_2) into the atmosphere from presumably distant sources result in the formation of fine (<2.5 mm) particulate sulfate via a number of physiochemical mechanisms. Most sensitive are water bodies that are small (i.e., ponds and wetlands), lack surface water outlets, have prolonged ice cover, and are fed by relatively small catchments. Phytoplankton and epiphytic and benthic algae in these waters are likely to be most sensitive to acidification and nitrogen deposition, for example. Consequences of these and other water quality stressors for aquatic food webs are largely unknown.

In 2009, six lakes from the 1985 EPA survey were resampled (Logan 2010). Crater Lake was not sampled in either survey. Statistically significant increases were noted among the lakes in acid neutralizing capacity, sodium, and potassium, but causes were not apparent.

4.2.3 Issues Description

The park's aquatic systems are less exposed to waterborne pollutants than aquatic systems in many other areas because they are at the top of several watersheds and no surface water enters from outside the park. Nonetheless, the following are of concern.

4.2.3.1 Effects of Climate Change

The changes in temperature, precipitation, and snowpack that will likely occur as a result of predicted climate change (as described in section 4.1) will surely have implications for the quality of the park's surface waters and the aquatic life that depends on them.

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

The potential for harmful nutrient enrichment is a significant concern in all of the park's water bodies, including the caldera lake itself. This is partly because most of the park's waters are nutrient-poor as a result of being in a headwater position. Their aquatic flora and fauna is thus not accustomed to significant increases in nutrients or other chemical substances.

4.2.3.3 Impacts from Air Pollution: Deposition of Other Contaminants

Although relatively few pollution sources are present within the park, long-distance airborne transport of pesticides, other hydrocarbons, mercury, and other contaminants poses a potential threat. Long distance transport of airborne pesticides has been noted in the California Sierras (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 park's fire regime is described in section 4.3.

While fires themselves are major agents of change, fire-fighting, especially in steep terrain, potentially results in additional disturbance that affects aquatic systems by means of soil compaction (NCASI 2004) and contamination from fire retardants. NPS current policy is to avoid the use of fire retardant as much as possible. Fire retardants 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 (USGS 2006).

4.2.3.5 Water Contamination from Visitors and Park Management Activities

Soils in many parts of this park are highly prone to erosion. Soil erosion has been accelerated locally within a few heavily traveled areas of the park, due to compaction, vegetation damage, and changed runoff patterns. Damage potentially includes temporary or persistent loss of vegetation and abnormally increased sediment loads in water bodies, with concomitant reduction in aquatic productivity. Hydrocarbons from park roads is another potential contaminant source.

4.2.4 Indicators and Criteria to Evaluate Condition and Trends

Indicators that might be used to monitor this issue (Changes in Surface Water Quality) include the following:

1. Water quality conditions and trends in Crater Lake
2. Water quality conditions and trends in other water bodies

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. However, few relevant data are available, either from within the park or from analogous areas, for estimating the expected range of variation of any of these. 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 in Crater Lake

The caldera lake is one of the most extensively-monitored lakes of its size in the world, and measurements of its water quality have been analyzed or summarized in several publications (e.g., Drake et al. 1990, Mast and Clough 2000, Larson et al. 2007a, b). Although the lake's waters had been sampled since early in the 1900s, it was not until 1983 that a concerted effort was initiated—the Long-term Limnological Monitoring Program (LTLMP). Sampling has occurred mostly during July, August, and September, with occasional sampling in January, March, April, May, June, and October. Samples have been collected regularly at predetermined depths from 0–550 m. Physical and chemical variables that are measured the most routinely include:

> Lake level, Secchi disk depth, Light transmission and penetration, Temperature, pH, Alkalinity, Specific conductance, Dissolved oxygen, Total phosphorus, Orthophosphate, Nitrate-nitrogen, Total Kjeldahl nitrogen, Ammonia-nitrogen, Sulfate, Silica, Chloride, Sodium, Calcium, Magnesium, Potassium, Sulfur, and Iron.

The entire database is housed at Oregon Institute for Technology in Klamath Falls.

For this NRCA report a query was also done of the EPA's STORET database in April 2012. This yielded 160,550 records of 128 water quality parameters (chemical, physical) from 311 sample points within the park, nearly all in the caldera itself, covering 471 dates between July 1901 and September 2004 (the most recent data available online). Years with the most samples were 1984 and 1999.

Criteria

Because the caldera lake is essentially "one of a kind," there is no good reference for making comparisons. We considered "Good" condition to mean that the levels of all chemical substances in the caldera lake are at levels close to (or better than) those found in the least disturbed of the largest natural lakes in the region. "Somewhat Concerning" condition would mean there are no chronic exceedance of legal criteria for substances potentially harmful to the caldera lake's aquatic life, but levels of some substances of potential concern are elevated. "Significant Concern" would be chronic exceedance of a water quality standard at concentrations that are acutely lethal to the caldera lake's aquatic life.

Condition and Trends
Condition: *Good – High Certainty*.
Trends: *Somewhat Concerning – Medium Certainty*.

Although no other lakes in the region are geomorphically very similar to the caldera lake, many reports highlight the exceptional clarity and quality of the caldera lake's water. This is recognized by the lake being included as just one of 50 monitoring stations nationwide in the USGS Hydrologic Benchmark Network. The lake's long-term average Secchi depth (an indicator of water clarity) is 30.4 m with a maximum of 40.6 m in August 1994, apparently making this the clearest lake *in the world*. Nutrient concentrations are extremely low. Clarity of the lake may be inhibited more by dissolved organic matter produced by phytoplankton than by suspended inorganic solids (Boss et al. 2007).

As expected, from our review of the STORET data and published reports, we identified no chronic violations of water quality standards in the lake. Brief and minor reductions in water clarity occasionally occur as a result of sediments being transported from the caldera rim during summer thunderstorms. Hydrothermal fluids emitting naturally and steadily from the lake bottom help maintain the long-term stability of the lake's water quality, and also contribute to the lake's salt content.

Hydrocarbon-based compounds of human origin have been found in lake waters and sediments, with highest levels measured near the two boat operation facilities at Cleetwood Cove and on Wizard Island, but concentrations are barely detectable (Oros et al. 2007). Concentrations in lake sediments are at least three orders of magnitude less than reported as threshold effects levels for an aquatic invertebrate test organism (the amphipod, *Hyalella azteca)*. The park and its concessionaire currently operate four tour boats, two research boats, and three skiffs. These are the only boats allowed on the lake, and are likely the main source of the minute amounts of human-originated hydrocarbons. Additional hydrocarbon pollution may occur from vehicle exhaust (although roads are hundreds of meters from the caldera lake) and from deposition of airborne pesticides that have been transported mainly from outside the park (see section 4.6).

In the lake, trends in most substances are expected to be too small to be detected. This is because the lake receives only 15% of its water from land surface runoff, the park is distant from major sources of airborne contaminants, and the water column is well mixed. Nonetheless, because the residence time of water in the lake is around 225 years (Collier et al. 1990), whatever contaminants do enter the lake are likely to remain long enough to potentially affect that ecosystem.

In the 1980s, concerns were expressed that the clarity of the lake might be declining. However, from a subsequently-intensified sampling program, scientists concluded that the lake, though potentially threatened by various pollutant sources, was in good condition (Larson et al. 1996). They also noted that possible trends up to that time could not be verified because of the lack of historical data. For the period 1967-1995, Mast and Clow (2000) tested for trends in 12 lake water quality parameters using 91 samples. They identified a credible and statistically-significant trend only for potassium, which for unknown reasons decreased in the lake by 17% during that period. Unpublished analyses by NPS scientists at the park (Girdner et al. 2009, J. Runde pers.

comm.) indicate the following trends in physical and chemical parameters in the lake are statistically significant:

- Water transparency (as estimated by Secchi disk) increased during the period 1978-2008.
- Light attenuation did not change at any depth from 1995 to 2008.
- Within the period 1966-2008, the annual onset of thermal stratification of the lake (an event of critical importance to its ecology) is now occurring earlier, an average of 7 days earlier per decade and a remarkable 29 days earlier since 1966. About 78% of the variation in stratification date is explained by increased springtime air temperature and decreased springtime snow depth.
- Although difficult to determine, there is some evidence that the lake may not cool down as fast in the fall as it used to.
- The depth of the lake's thermocline (an ecologically important zone of rapid temperature transition) is shallower now, having risen at an average rate of 1.8 m per decade since 1983, with the strongest trend occurring in September.
- Water column nutrient concentrations from 1985 to 2008 did not change, with the exception of nitrate (declined at 500 m depth) and phosphate (declined at 100 m). The nitrate trend is related to nitrate-poor cold surface waters intruding during more winters now into greater depths. The phosphate trend may be an artifact of laboratory analysis difficulties.
- At depths of greater than 100 m the lake has become more acidic, but only slightly.

Assessment Confidence and Data Gaps
High. Water quality in the caldera lake has been monitored using standardized protocols for over 20 years. Additional monitoring could include substances that may influence the lake's clarity directly (e.g., soot from fires) or indirectly as nutrients that spur growth of the lake's phytoplankton (e.g., soluble iron, dissolved organic carbon, nitrate).

4.2.4.2 Water Quality in Other Water Bodies
Many, if not most, of the park's springs and seasonal ponds could also be classified as wetlands. Compared to Crater Lake itself, the park's wetlands and streams experience greater physical and chemical extremes. In winter they are covered with several feet of snow and in spring the fast melting snow flushes ponds and wetlands and fills them with seasonal water. To a greater extent than is the case with the well-buffered caldera lake, the quality of the ponds and wetlands depends strongly on the quality of the precipitation and any discharging groundwater.

The water quality of the park's streams and wetlands has been determined only sporadically. A 1992-1993 survey of the Whitehorse ponds, a complex of 15 wetlands located on Whitehorse Bluff, measured some of their physical, chemical, and biological characteristics (Salinas et al. 1994). Data on stream temperature, turbidity, conductivity, pH, and other water quality variables have been collected periodically from Sun Creek as part of the bull trout restoration effort there. Water chemistry of 21 springs was described by Frank and Harris (1969). Between 6 and 10 springs feeding the caldera lake were sampled and chemically characterized in 1981–1985 by Thompson et al. (1987) and Gregory et al. (1987, 1990). Water quality of as many as 41 springs within the caldera was sampled beginning in 1987, but this was reduced to 5 beginning in 1990.

Because of the sensitivity of their vegetation and water, camping is prohibited within one-quarter mile of Sphagnum Bog, Boundary Springs, Thousand Springs, and within 100 feet of any meadow. Camping in other areas outside of campgrounds requires a wilderness permit.

Criteria
Criteria and standards for protection of aquatic life conditions, as published by federal and state agencies, were used to define the reference conditions. "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 chronic exceedance of a water quality standard at concentrations that are acutely lethal to aquatic life.

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

As expected, from our review of the STORET data and published reports, we identified no chronic violations of water quality standards in any of the park's other lakes, ponds, or streams. However, recent data are sparse. Water quality measurements from those park waters are insufficient to calculate trends; an exception is the data for five springs that feed the caldera lake. Among those springs, during the period 1985-2008, there was little agreement on the direction of trends in nutrients or the statistical significance of other water quality trends (Girdner et al. 2009).

Assessment Confidence and Data Gaps
Low. Confidence is limited by the non-systematic temporal and spatial coverage of past water sampling efforts outside of the caldera lake. However, data from a new, relatively comprehensive sampling program measuring water quality in a statistical sample of the park's lakes and streams should be available in a few years.

4.3 Changes in Aquatic Life

4.3.1 Background
As used herein, "aquatic life" refers to microbes, plants, and animals that live in water or water-saturated soils. The park's aquatic species serve vital ecological roles, influencing the clarity of the caldera lake, cycling nutrients, and serving as food for many terrestrial wildlife species.

4.3.2 Regional Context
The park supports an assemblage of species found nowhere else in the region – extensive mosses growing at extreme lake depths, unusual microbial assemblages associated with hydrothermal vents, a headwater stream with a healthy bull trout population, at least one large undisturbed peatland, and a diverse assemblage of other wetlands that mostly have not been invaded by non-native plants. Also, in contrast to much of the lands surrounding it, the park's forests have not been extensively logged for nearly a century, and thus its aquatic systems have been spared some of the detrimental impacts of ground disturbance and shade removal.

4.3.3 Issues Description

4.3.3.1 Climate Change, Water, and Snowpack

Changing temperatures and precipitation are a concern because they are likely to eventually affect the stratification and mixing of waters within the caldera lake, and thus affect its biological productivity. They also will affect the productivity and habitat quality of wetlands, streams, springs, and ponds throughout the park.

4.3.3.2 Contaminants

Effects of contaminants on the park's aquatic species have not been monitored. Contaminants such as mercury and persistent pesticides are a potential concern because aerial transport of contaminants into the park from distant areas has been documented (Landers et al. 2008).

4.3.3.3 Impacts from Ecologically Harmful Aquatic Plants and Animals

In other parts of Oregon, several exotic plants and a few non-native animals have extensively invaded lakes, streams, or wetlands. When this happens on a large scale, native species are extirpated and ecosystem processes are altered in unpredictable ways. Invasions are most likely to occur at lower-elevation aquatic sites that are visited the most, as well as those experiencing unnatural water level fluctuations as a result of human activities.

4.3.3.4 Fire Suppression and Natural Succession

To some degree, decades of wildland fire suppression may have affected the type, cover density, and distribution of riparian vegetation. This has implications both for shade (water temperature) and for the type, amount, and timing of nutrients and sediments that reach streams, ponds, and wetlands. As in other areas of the Cascades and Sierras, climate change and altered fire regime can facilitate invasion of montane meadows by conifers. Such afforestation can diminish water levels in the invaded parts of the meadows, reducing or eliminating wetland-associated plants.

4.3.4 Indicators and Criteria to Evaluate Condition and Trends

The following are addressed as indicators of change in the park's aquatic life:

1. Changes in Aquatic Productivity and Biodiversity in Crater Lake
2. Changes in Aquatic Productivity and Biodiversity of Other Water Bodies
3. Changes in Ecologically Harmful Species

Meaningful criteria for evaluating these indicators would need to account for the natural range of variation in species colonization and extirpation, and the expected annual fluctuations in population levels. However, data for estimating these parameters are not generally available from the park or from analogous areas nearby. As well, there are no legally-based numeric criteria for evaluating the degree of "intactness" of any of the park's aquatic 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 aquatic species in this particular park. Therefore, the assessment of this indicator is based mainly on professional judgment of the authors.

4.3.4.1 Changes in Aquatic Productivity and Biodiversity in Crater Lake

The caldera lake is termed an "ultra-oligotrophic" lake, meaning its natural aquatic productivity is considered to be extremely low. As noted earlier, this is a consequence of its headwater position and the limited proportional extent of shallow depths. In many water bodies, increased aquatic productivity would be welcomed because of the benefits it provides to humans, e.g., more fish to catch, more waterfowl to hunt or watch. However, the primary attraction of the caldera lake is aesthetic, and that is largely related to the exceptional clarity of its water. That clarity depends on maintaining phytoplankton (algae) populations at or below current levels, which in turn depends on (a) minimizing atmospheric and runoff-borne nutrient additions to the lake, and (b) maintaining high rates of grazing on the phytoplankton by zooplankton whose populations are sometimes reduced by fish within the lake.

Criteria

For purposes of this assessment, "Good" conditions would be represented by sustained naturally-occurring turnover rates and/or cycles of all aquatic species currently inhabiting the caldera lake. More detailed goals might be to sustain multiple representatives of each functional group in proportions characteristic of intact but dynamic ecosystems and well-functioning complex food webs. "Somewhat Concerning" conditions might be reflected by slightly-elevated species turnover rates and/or slight loss of aquatic biodiversity that does not measurably affect the rates of ecosystem functions in the lake. "Significant Concern" condition would be loss of several native aquatic species historically present in excess of natural turnover rates and/or in a manner that measurably affects ecosystem functions of the lake.

Condition and Trends

Condition: *Good – Medium Certainty*.

Trends: *Indeterminate*.

Based on long term limnological studies of the lake, scientists have repeatedly concluded that the lake is in nearly pristine condition except for the introduction of non-native fish, and none of the observed changes in the lake's plankton, fish, or other biological components can be attributed to human activities within the park (Larson et al. 1993, Larson et al. 2007a). However, few of the lake's biological components have been systematically monitored over long periods. What is known about the condition and trends of particular taxonomic groups is described as follows.

Microbes. Surveys of about 2% of the lake floor from 1987-1989 revealed unusual bacterial communities associated with saline fluids discharging naturally from hydrothermal vents. Yellow-orange mats, visible to the unaided eye, are comprised of *Gallionella* and *Leptothrix* bacteria. The lake also supports communities of suspended, naturally-occurring bacteria (bacterioplankton) whose taxonomic composition is unlike that in most other lakes, and instead being more like that of marine habitats (Urbach et al. 2001). The contributions of both bacterioplankton and bottom-dwelling bacterial mats to the productivity of the lake have not been quantified.

Plankton. The lake's phytoplankton (suspended algae) and zooplankton (suspended invertebrate) communities are relatively sparse, diverse, and complex. During each spring, phytoplankton production starts when the water temperature reaches about 4°C, which triggers vertical mixing of nutrients. The lake's phytoplankton are believed to be limited not only by the exceptionally low amounts of available nitrogen, but also by concentrations of some trace metal, most likely iron (Groeger 2007). Atmospheric deposition currently is the immediate and primary source of most of the dissolved iron in the lake (Collier et al. 1990) and some of the nitrogen. However, in the euphotic zone where phytoplankton density is highest, up to 85% of the nitrogen and much of the dissolved iron comes not from atmospheric deposition, but from upwelling of deeper waters (Dymond et al. 1996), which may be greater during years of heavier snowfall. Once in the lake system, the availability of iron for spurring phytoplankton growth is increased by yet another substance (a chelator) that most likely is dissolved organic carbon (Groeger 2007) but which may be in short supply due to net downward movement (Fennel et al. 2007). Neither phosphorus nor silica limits phytoplankton in the lake (Groeger 2007). Of the two diatoms (algae) that dominate Sierra subalpine lakes that are being overloaded with nitrate (*Asterionella formosa* and *Fragilaria crotonensis;* Interlandi and Kilham 1998, Wolfe et al. 2003, Saros et al. 2010), neither is a dominant component of the caldera lake's algae (e.g., McIntire et al. 2007).

The abundances of the largest species of zooplankton (such as *Daphnia*) are cyclic. When the populations of the lake's introduced plankton-eating fish are at the highest levels, zooplankton populations are significantly reduced; consequently, less phytoplankton is grazed by the zooplankton, and the subsequent increased phytoplankton population thus temporarily impacts water transparency.

Underwater Plants. Unlike most lakes, Crater Lake lacks vegetated shoreline wetlands. However, a distinctive feature of the lake is its large biomass of an aquatic moss, *Drepanocladus aduncus*, which grows between a depth of 85 and 460 feet (McIntire et al. 1994). The estimated horizontal extent of the moss is shown in Figure 8. All together, the moss biomass, including epiphytic (attached) algae, has been estimated to be 100 to 1000 times larger than that of all of the phytoplankton in the lake, suggesting that it might be an extremely influential component of the lake system. The moss grows slowly, laying down an underwater mat of peat as thick as 9 m and as old as 4000 years in some areas of the lake. The presence of the peat in shallow areas not currently occupied by living moss suggests that the moss' extent has shrunk. Specifically, analyzed core samples indicate the moss started growing about 4500 years before present but for unknown reasons stopped growing in some of these shallow areas about 2000 years ago. (Dartnell 2008)

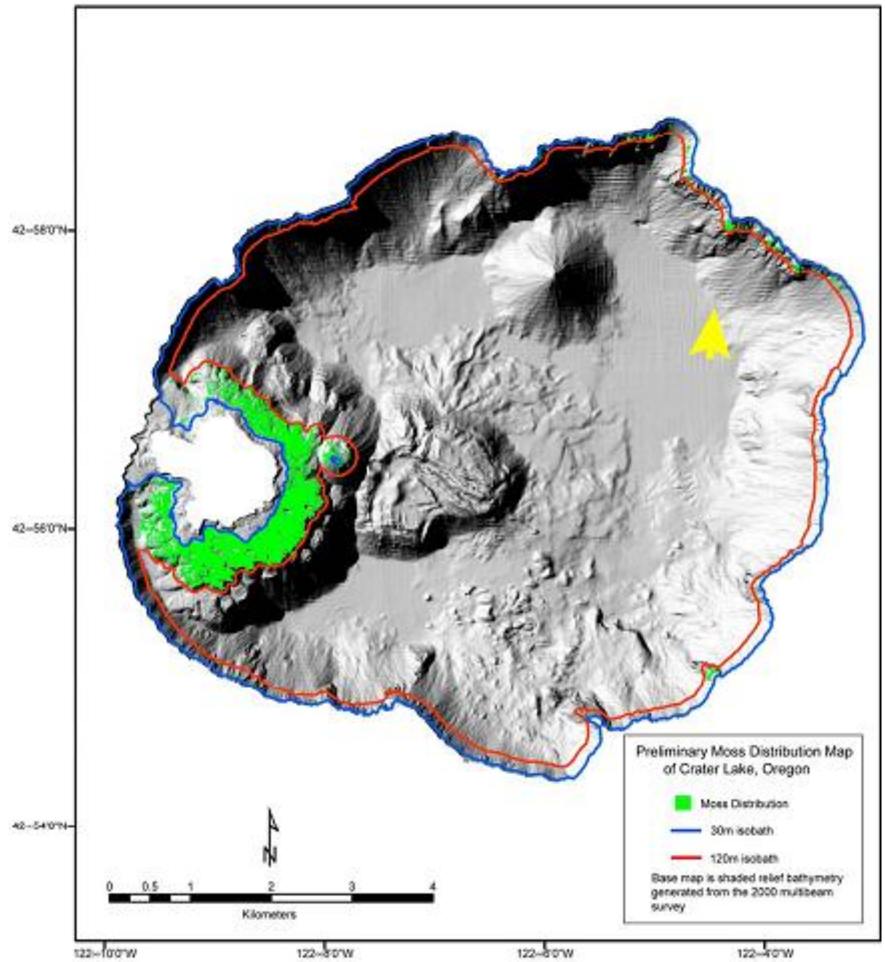

Figure 8. Preliminary determination of underwater moss distribution in Crater Lake (Dartnell 2008).

Benthic Invertebrates. Benthic (bottom-dwelling) invertebrates, including snails and various aquatic insects, have not been systematically quantified or monitored in the lake. However, incidental observations indicate that some flatworms, nematodes, earthworms, copepods, ostracods, and the midge fly *Heterotrissocladius* are present at great depths, some living as deep as 589 m (1,932 ft). A snail, the Crater Lake tightcoil (*Pristiloma arcticum crateris*), may be limited to the park.

Of particular note is the crayfish, *Pacifastacus leniusculus*. Recent studies have found this in two discontinuous parts of the lake—around Wizard Island and the north shore from Steel Bay to just east of Palisades Point, including all of Cleetwood Cove. Where crayfish are present, densities of other benthic invertebrates are approximately one-eighth as great as in the areas of the lake where crayfish are absent. Similarly, areas occupied by crayfish appear to lack newts (*Taricha granulosa*) which are present elsewhere. Besides invertebrates and newts, crayfish feed on algae, salamanders, frogs, and small fish. The lake's crayfish are believed to be the result of intentional introductions that occurred around 1914. The crayfish have been found deeper (down to 250 m) than reported anywhere else in the world. Trends have not been quantified.

Fish. Crater Lake was originally barren of fish, but between 1888 and 1947 was stocked with approximately 1.8 million rainbow trout (*Oncorhynchus mykiss*) and kokanee salmon (*Oncorhynchus nerka*). Kokanee are cyclic in abundance, live both near the shore and in open deep water, and feed on zooplankton and small bottom-dwelling insects. Rainbow trout live along the edges of the lake and feed on terrestrial insects, large-bodied bottom fauna, and kokanee. These fish species potentially alter the food webs within open-water and near-shore habitats and thus could affect nutrient cycling within the lake.

Amphibians. Rough-skinned newts (*Taricha granulosa*) within the Crater Lake caldera have been proposed as an endemic subspecies, the "Mazama newt" (*T. granulosa mazamae*). Preliminary genetic analyses seem to indicate that the population is distinct but its taxonomic status has not yet been resolved conclusively.

Assessment Confidence and Data Gaps
Medium. Confidence in the existing data from the caldera lake is good mainly because of the relatively long period of record. The main limitation is that not all biological components have been monitored, so an overall rating of medium certainty is assigned. The role of aquatic moss in the lake's productivity, and factors which control that, are poorly known. Continued monitoring of the lake's phytoplankton and its taxonomic composition would provide an early sign of enrichment that could eventually impact the lake's clarity.

4.3.4.2 Changes in Aquatic Productivity and Biodiversity of Other Water Bodies
Indices of Biotic Integrity (IBIs) are often used to evaluate the condition of aquatic invertebrate or fish communities. They are often a composite of several variables, such as taxonomic richness, richness of taxa within major groups, total abundance, and proportional representation of particular sensitive groups. None have been developed or calibrated to conditions present in the park, but one was developed for second to fourth order streams in nearby areas of southwestern Oregon (Fore et al. 1996).

Criteria
For purposes of this assessment, "Good" conditions would be sustained naturally-occurring turnover rates and/or cycles of all aquatic species currently inhabiting the park's streams and wetlands. More detailed goals might be to sustain multiple representatives of each functional group in proportions characteristic of intact but dynamic ecosystems and well-functioning complex food webs. "Somewhat Concerning" conditions might be reflected by slightly-elevated species turnover rates and/or slight loss of aquatic biodiversity that does not appear to be affecting the rates of ecosystem functions in the park's streams and wetlands. "Significant Concern" condition would be loss of several native aquatic species historically present in excess of natural turnover rates, and/or in a manner that measurably disrupts ecosystem functions.

Condition and Trends
Condition: *Somewhat Concerning – Low Certainty*
Trends: *Indeterminate* (but *Improving – High Certainty* for bull trout).
A higher rating is not assigned because bull trout have not yet been re-established in other parts of the park that they presumably once occupied, and because some invasive species have become established. The rating is not lower because of the good condition of the park's wetlands, numerous Cascades frogs, and improved bull trout population.

Another way of evaluating biological resources might be to consider which of the park's individual species or species assemblages might be most sensitive to predicted climate changes. In general, the most sensitive species tend to be boreal species near the southern edge of their range that occur at higher elevations and have limited mobility and low reproductive rates. Several of the park's aquatic plants and animals may fit one or more parts of this description. To date, there have been no confirmed extirpations of park aquatic flora or fauna, in part owing to the lack of data.

Wetland Plants. As noted earlier, during 2006, Adamus & Bartlett (2008) visited 76 wetlands comprising a probability sample of an estimated 254 wetlands in the park. The sample wetlands were visited once, permanent markers were placed in each and referenced using a handheld GPS, and plants were identified to species in a total of 101 vegetation plots. These assessments determined that *nearly all wetlands are in good condition* as defined mainly by their plant communities. The survey detected two thirds of the park's known wetland flora. In most wetlands, more than 45 plant species and 21 families were found, and most of the 100 m^2 plots that were surveyed had more than 24 species and 15 families, with a maximum of 51 species.

The park contains a large wetland – called Sphagnum Bog – that is recognized by the Oregon Natural Heritage Program as a Research Natural Area (RNA). The flora of this area has been surveyed several times, beginning with Seyer (1979). Parts of the Bog (technically a fen) were surveyed for plants during the parkwide wetlands assessment described above, and subsequent one-day inventories by volunteers have added several mosses and lichens to the list of plants known to occur there. Key components of this RNA are few-flowered spikerush and brown moss, intermixed with Engelmann spruce and lodgepole pine. Also, a wetland complex known as the Whitehorse Ponds was surveyed both by Salinas et al. (1994) in 1993 and by Adamus and Bartlett (2008) in 2006. Because different methods were used, results are not comparable.

Aquatic Invertebrates. Aquatic invertebrates have not been surveyed systematically in the park's streams, ponds, wetlands, or springs. From what little data exist, the invertebrate communities of some of the streams appear to be in good condition, but trends are indeterminate.

Data from limited surveys of "fish food organisms" in the park's streams were reported by Wallis (1948). A more taxonomically precise survey was done in 1985-1986 by Gregory et al. (1987) but covered parts of just four streams (Munson, Sun, Dutton, and Goodbye Creeks). Although that study found differences in the primary productivity and invertebrate richness, abundance, and composition of those streams, the authors found no evidence the differences were due to recent or ongoing human activities, and noted that conditions were "not abnormal for high elevation streams in the Cascade Mountains."

We reviewed the Gregory et al. data in light of a newer publication (Fore et al. 1996) from this region that provides criteria for interpreting stream invertebrate data in terms of human impacts. Despite modest differences in protocols used by the two studies (e.g., season and method of collection, level of taxonomic identification), application of the criteria in the newer publication support the interpretation of Gregory et al. that the parts of those streams that were sampled were in excellent condition, i.e., deviate little or not at all from conditions expected for unaltered streams of their size in southwest Oregon.

Fish. Bull trout (*Salvelinus confluentus*) are the only native fish known to inhabit the park currently. Regionally, they represent a remnant population. They were first listed as Threatened under the Endangered Species Act, by the U.S. Fish and Wildlife Service in June 1998. They once were present throughout Sun Creek starting below Sun Falls, a natural waterfall 3 km below the headwaters, with their distribution continuing downstream across the park boundary (Wallis 1948). But by 1989, hybridization and competition with non-native brook trout threatened the park's bull trout population. Abundance declined to about 100-300 adult fish, and their distribution became limited to a 1.9 km stream reach in Sun Creek. Brook trout inhabited the entire creek, and hybrids with bull trout were also found. Bull trout are protected from public fishing in Sun Creek and Lost Creek.

From 1991 to 2005, a bull trout restoration project was conducted to remove the alien brook trout from 14.6 km of Sun Creek. Some of the bull trout were transplanted to Lost Creek in 1996, increasing their distribution in the park from one to two streams. The estimated bull trout population increased from approximately 200 in 1992 to nearly 2000 in 2005, and distribution increased to 11.2 km of Sun Creek. An exclusion barrier precludes re-invasion by brook trout, and no brook trout have been found in Sun Creek since 2005. Other entities recently have initiated efforts to similarly remove brook trout populations from connected waters outside of the park, with the hope of eventually extending the local distribution of bull trout.

Aquatic Amphibians. Noteworthy reports of aquatic amphibians in the park include Vincent (1947), Farner and Kezer (1953), Bergmann (1997), Bury et al. (2002), and Bury & Wegner (2005). Also, amphibians were noted incidentally in the wetland survey by Adamus & Bartlett (2008). The park's wetlands appear to be a stronghold for Cascades frog (*Rana cascadae*), a species whose numbers have dropped sharply in much of the rest of its limited range, to the point where it has now been extirpated from about 99% of its range in the northern Sierras of California. The Oregon Natural Heritage Program lists it as "Vulnerable" and it is listed as a Candidate species for Federal designation. Vincent (1947) described it as "one of the most common animals in the park… found in abundance along all streams and water courses." Bury et al. (2002) found this species in 12 of 14 (86%) of areas they surveyed within the park in 2002. The Adamus & Bartlett survey confirmed this species in 12% of the 76 wetlands they visited (and reported those locations), but they were not intentionally searching for amphibians. They reported "frog species undetermined" from an additional 41% of the wetlands and in most cases those were likely this species. The species is seldom if ever noted in the caldera lake itself, apparently preferring smaller ponds, wetlands, and occasionally streams.

The western (boreal) toad (*Anaxyrus boreas*) occurs in several areas of the park, including the caldera lake, but has become sparse in several other parts of the Pacific Northwest and is listed by Oregon Department of Fish and Wildlife as "vulnerable" statewide. The northwestern salamander (*Ambystoma gracile*) was reported from Whitehorse Ponds by Bergmann (1997), but there have been few if any sightings since then, perhaps due to limited search effort. Data from the adjoining Umpqua National Forest suggest that during the terrestrial phase of its life cycle, this species favors uncut forest (McDade 2001). Apparently more widespread is the long-toed salamander (*Ambystoma macrodactylum*), which occurs in the caldera lake as well as elsewhere in the park. Steep headwaters of many of the park's streams are known to support coastal tailed frogs (*Ascaphus truei)*, e.g., Bury and Wegner (2005), which are listed as "vulnerable" statewide by the Oregon Department of Fish and Wildlife. Pacific treefrogs (*Pseudacris regilla*) are widespread, being detected in at least 14% of the 76 wetlands surveyed during the Adamus & Bartlett survey in 2006 (2008). Perhaps at one time spotted frogs (*Rana pretiosa*), red-legged frogs (*Rana aurora*), and Pacific giant salamanders (*Dicamptodon tenebrosus*) were present, but there have been no recent records. The same is true of the foothill yellow-legged frog (*Rana boylii*), also considered Vulnerable in Oregon and declining throughout much of the western United States. One was collected and described by Vincent (1947) from a pond near Red Blanket Creek, but apparently none have been found since.

Assessment Confidence and Data Gaps
Outside of the caldera lake, confidence in the condition of the park's aquatic life is *Low* because there have been no comprehensive surveys. Exceptions are wetland plants and bull trout populations, which have been well-characterized.

4.3.4.3 Changes in Ecologically Harmful Aquatic Species

Criteria
For purposes of this assessment, "Good" conditions would be represented by the complete absence of 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" conditions would reflect increasing degree and extent to which native species are being impacted by invasive aquatic species.

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

Inside the caldera lake, alien aquatic organisms that are suspected of causing ecological disruptions are the two introduced fish (kokanee and rainbow trout) and the crayfish. Elsewhere, eastern brook trout for many years threatened the survival of the small bull trout population in Sun Creek, and brown trout (*Salmo trutta*) are also present. Infestations of non-native plants have been very limited in the park's ponds and wetlands. To date, there are no park records of the New Zealand mud snail (*Potamopyrgus antipodarum)* or other ecologically harmful invertebrates known to occur in Oregon. However, no surveys targeting such species have been conducted. The Adamus & Bartlett (2008) survey found nonnative plant species in only 14 (18%) of the 76 wetlands visited in 2006. From zero to four such species were found per wetland, and they never dominated the vegetation cover. No individuals of the American bullfrog (*Rana catesbiana*) have been recorded from the park, though it is present many miles away in valleys to the east and west of the park. That non-native species is known to prey extensively on native amphibians.

Assessment Confidence and Data Gaps
Medium. Trends in the park's three alien fish are fairly well known, but data are not sufficient to determine if there are long term trends in crayfish in the caldera lake. Although significant occurrences of invasive plants have mostly been surveyed in a sample of wetlands, not all wetlands were surveyed. Also, no surveys have been conducted to determine if invasive underwater plants or invertebrates are present in any of the park's ponds, streams, or wetlands.

4.4 Changes in Terrestrial Vegetation

4.4.1 Background

Vegetation is a foundation for terrestrial ecosystem composition, structure, and function. Vegetation ranked as a key vital sign for monitoring of ecological integrity in the Klamath Network Inventory and Monitoring Program. Vegetation *composition* includes an array of ecosystem components such as species, populations, genetic composition, and special habitats. Vegetation *structure* refers to the vertical and horizontal arrangement of components, such as canopy structure and corridors for species movement. Vegetation *function* refers to ecosystem processes such as cycling of nutrients, carbon, and water—which interact with disturbance processes and biological components such as interspecific competition and demographic and reproductive processes. Vegetation dominates biomass and energy pathways and defines the habitat for most other forms of life. Indicators for vegetation composition, structure, and function 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 9). 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.

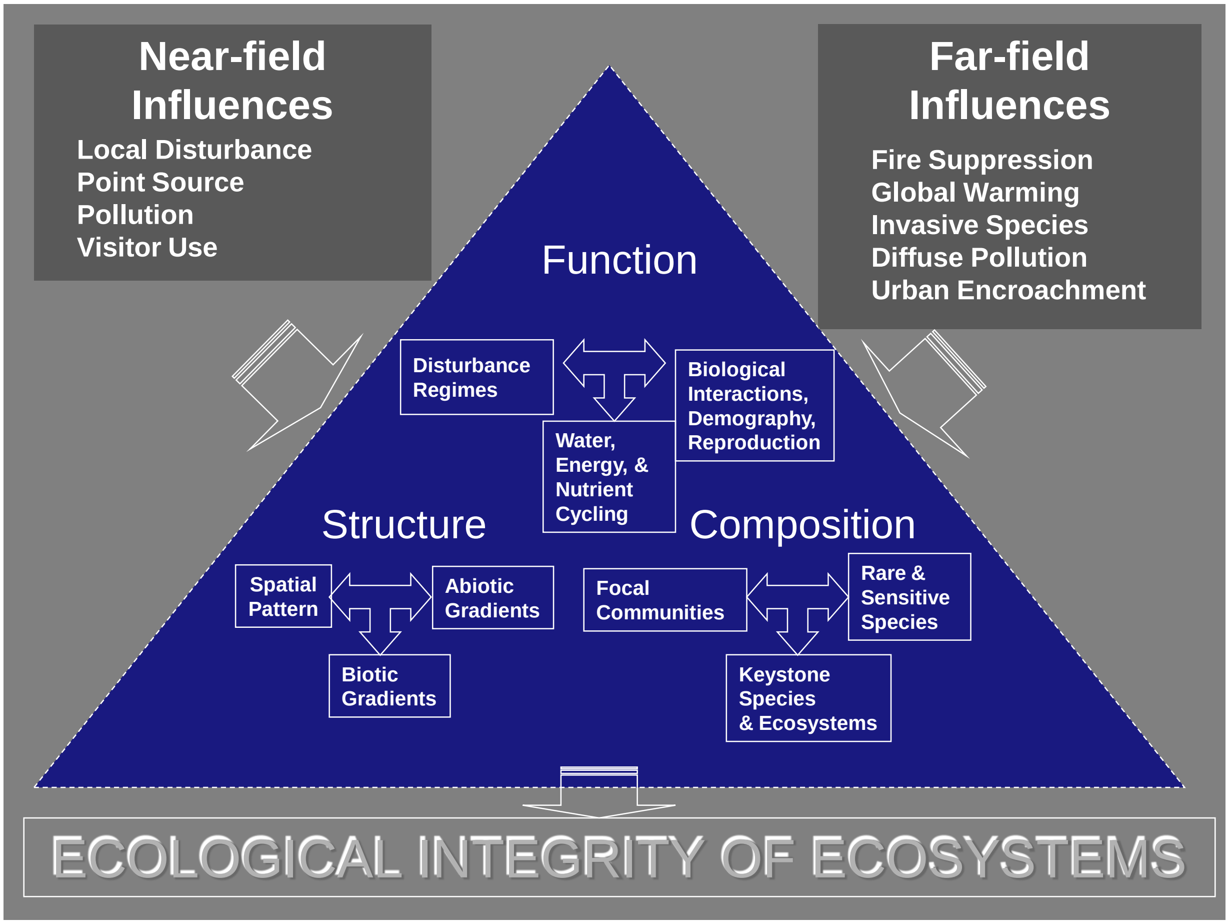

Figure 9. Human influences on the structure, function, and composition of ecosystems.

4.4.1.1 Vegetation

The park's vegetation has been studied since the late nineteenth century, when Frederick Coville first explored the area and discovered several species of rare, endemic vascular plants. Esther Applegate completed the Park's first comprehensive botanical survey in 1939. In the 1940's, Henry Hansen completed a study of forest succession and climate, and Lyle Wynd observed the botanical features of the life zones found within the Park. A thorough vegetation survey was undertaken in 1936 by the Civilian Conservation Corps, which resulted in the most detailed information about vegetation types, and a report and detailed map (Anonymous 1936). This map was done with substantial ground sampling, which none of the subsequent vegetation mapping efforts has involved (sampling for a new map is ongoing). The 1936 sampling and map represents the best available vegetation inventory for descriptive purposes as long as the changes since 1936 are recognized. In addition, a small portion of the current park area (~12%) was not included in the 1936 mapping. This area is on the east and west sides and includes mainly mixed conifer forest and lodgepole pine. Consequently, the map and description slightly underrepresent these vegetation types. The 1936 vegetation map identified the broad vegetation types shown in Table 3, and 151 subtypes.

Table 3. Vegetation or landcover types enumerated and mapped in the 1936 vegetation survey of Crater Lake National Park (Anonymous 1936).

Vegetation or Land Cover	Area (hectares)
Lake	4,511.7
Barren	693.1
Herb-grass and semi-barren herb-grass	2,370.9
Residential	11.6
Chaparral	617.0
Woodland (aspen)	4.8
Douglas-fir belt	406.9
Ponderosa pine belt	2,434.8
Pine-fir belt	16,651.0
Lodgepole pine-hemlock	29,736.8
Fir belt	7,241.7
White bark pine	225.5
Spruce	5.8
Total	*64,911.7*

The vegetation of the park has been more recently mapped by the Oregon Gap Analysis project, a statewide vegetation-mapping effort. This map (Appendix C, Figure C1) was not done with the high level of detail and field work of the 1936 effort, but it is useful for assessing some changes in general vegetation since 1936. There is also a vegetation map that was created using Landsat data with a coarser resolution. A new vegetation map that will be more detailed is currently being prepared by the Klamath Network. This will enable direct comparison with the 1936 vegetation map and allow for more robust estimates of vegetation change. This would involve a complicated procedure to register the two maps, which could not be done as part of the condition assessment herein. To the extent possible, changes in vegetative conditions are summarized in the following description. We do not consider this a formal condition assessment because it is not sufficiently systematic. A brief discussion of the vegetation types described in the 1936 effort is provided here.

Ponderosa Pine Belt. Forests in which ponderosa pine is a dominant tree principally occur up to 1,675 meters (5,500 feet) elevation. This broad vegetation type occurs primarily in the southern panhandle, southeast corner and a narrow band on the east side of the park. The lowest elevations in the park occur in the south west corner of the park in Red Blanket canyon, but this area is dominated by Douglas fir and very little ponderosa pine occurs there. Ponderosa pine forests contain of mixture of ponderosa pine (*Pinus ponderosa*), white fir (*Abies concolor*), and scattered sugar pine (*Pinus lambertiana*) and Douglas fir (*Pseudotsuga menziesii*). Ponderosa pine may share dominance in many cases, and these forests could be called mixed conifer. Here, the aesthetically appealing ponderosa pine is visual dominant. On the east side of the park, lodgepole pine (*Pinus contorta* var. *murrayana*) is a common associate with ponderosa pine, and understory species may include the Great Basin shrub, antelope bitterbrush (*Purshia tridentata*), the montane chaparral shrub, greenleaf manzanita (*Arctostaphylos patula*), and a greater abundance of native grass. The 1936 map identified 1998 hectares of forest dominated by ponderosa pine, defined as having 20 percent or more of the stem dominance in a stand.

It is not possible to discern how much of this area may have been more open forest or woodland. Nor is it possible to conclude how much ponderosa pine forest may have shifted to more fir dominance since 1936. Current vegetation mapping by the Gap Analysis Project and the Landfire project shows only 852 hectares of ponderosa pine forests/woodlands, mainly on the east side of the park. Other vegetation now dominated by ponderosa pine was mapped as mixed conifer.

There is concern that an absence of fire has led to increases in shade tolerant species, such as white fir. These may grow into the canopy in a period of just 30 years (Agee 2002). Many ponderosa pines have perished in prescribed burn areas (Swezy and Agee 1991, Perrakis et al. 2011), likely leading to more fir-dominated forests in the Panhandle area. The 1936 survey report (Anonymous 1936) described the ponderosa pine type as largely of even-aged mature trees with a diameter of 1 m or slightly more. Even-aged implies that they regenerated as a cohort, most likely after stand-replacing fire. The woodlands were described as open (they had mostly been selectively logged [McNeill and Zobel 1980]) with localized accumulations of woody debris.

Lodgepole Pine Belt. Lodgepole pine (*Pinus contorta* var. *murraya*) is nearly ubiquitous in the park except in the higher elevations. Lodgepole pines are commonly associated with several other trees, such as mountain hemlock (*Tsuga mertensiana*), western white pine (*Pinus monticola*), noble fir (*Abies procera*), and subalpine fir (*Abies lasiocarpa*). Shrubs, forbs, and grasses are generally sparse in lodgepole dominated stands, which often occur on coarse, dry pumice soils; however, lodgepole pines also occur on meadow margins where there is a lush and diverse herbaceous understory. Lodgepole pine averages about 20 m in height and trees are generally 12-25 cm in diameter. They may grow in very dense stands.

Lodgepole pine was the most abundant tree mapped in the 1936 surveys, dominating over 29,000 hectares (Table 3). The relatively flat-bottomed valleys that radiate on all sides from the rim of the crater support a heavy growth. In 1936 they occurred in pure or almost pure stands (Anonymous 1936). However, forests dominated by lodgepole pine are four times less common in the current vegetation map. A reduction in lodgepole pine is an expected consequence of the reduction in fire (i.e., partial or complete stand-replacing fires) due to fire suppression. In the absence of fire or other disturbances, succession in lodgepole stands may lead to greater dominance by noble (red) fir (*Abies procera*) and other more shade tolerant species. Coops and

Waring (2011) suggests that lodgepole pine tree may be substantially reduced in amount by climate change.

As noted in the 1936 surveys and various literature, as well as readily observed, nearly all lodgepole stands have much down and dead material. As of 1936, bark beetles were said to have left many stands with about 50 % dead trees (Anonymous 1936). Such beetle disturbance presumably has been a recurring pattern and is common today at maximal levels. Recent research has found that a decrease in foliar fuels will tend to decrease fire intensity for several decades after beetle attack (after a brief increase while dead foliage is still clinging to trees) (Simard et al. 2011). Fuel loading increases as dying trees fall, but this increase is not fuel that contributes demonstrably to fire behavior, which is influenced mainly by fuels in very small size classes. The numerous standing and down poles caused by beetles are largely (~90%) unconsumed in wildfires (Turner et al. 2003) and often burn by smoldering when they are consumed. Because beetle disturbances lead to only a short-term increase in forest flammability, and a long-term decrease, the changes caused by lack of fire disturbance in lodgepole stands are not likely to be self-correcting (i.e., the probability of a mixed severity fire are still low). Continued lack of fire and disturbance by beetles instead may favor more noble (red) fir and mountain hemlock.

Pine-Fir Belt. The 1936 surveys mapped much of the park as pine-fir forest (16,651 ha, Table 3). These forests are a mixture of any of the following trees in order of rank abundance, where no single species exceeds 20% cover and at least one pine and one fir are both common: white fir, noble (red) fir, Douglas-fir, ponderosa pine, lodgepole pine, western white pine, western hemlock, and sometimes mountain hemlock and subalpine fir. The Pine-fir forest belt may be generally comparable to what are typically called mixed conifer forests today, and it may be more fir-dominated. In fact, mixed conifer forests in the current Landfire and Oregon Gap Project vegetation maps cover a similar sized area as the Pine-fir belt in 1936. In general these mixed conifer forests occupy steeper slopes and shallower soils adjacent to more lodgepole-dominated stands on flatter terrain (which now may be dominated by white and noble (red) fir).

Fir Belt. Fir forests are abundant and mostly dominated by noble fir (*Abies procera or A. procera x magnifica* var. *shastensis)*, with lesser amounts of white fir (*A. concolor*) and subalpine fir (*A. lasiocarpa*). This forest type typically occurs on shadier slopes in the mid to upper elevations. The 1936 report (Anonymous 1936) notes how there were very few areas of pure fir, which also appears to be the case today. Typically, the red and subalpine firs are associated with mountain hemlock in moister areas, lodgepole pine where conditions are harsher, and western white pine in a wide variety of conditions. The 1936 map has only 7,241 hectares of fir forests. In contrast, the current Oregon Gap map has 19,175 hectares of red fir forest and another 333 hectares of white fir forest. The increase has occurred largely at the expense of lodgepole dominated forests, the main forest type to shrink in extent since 1936 and found at the same elevations as the firs.

Herb Grass Types. Sparse herbaceous vegetation (20% or more cover) dominates the slopes around the Crater Lake caldera rim and the surrounding pumice flats. The dominant herbs are Davis' knotweed (*Polygonum davisiae*), oval-leaved eriogonum (*Eriogonum ovalifolium*), Geyer's everlasting (*Antennaria geyeri*), and silvery ragwort (*Senecio canus*) along with grasses such as squirreltail (*Elymus elymoides*).

Chaparral. The 1936 vegetation survey mapped 617 hectares of chaparral dominated by tobacco brush (*Ceanothus velutinus*) and green leaf manzanita (*Arctostaphylos patula*). The current map shows 431 hectares of chaparral (Anonymous 1936). As with lodgepole pine forests, the loss is attributable to a reduction in fire that create early successional vegetation. Baker (2012) summarizes numerous descriptions of chaparral occurring abundantly in the ponderosa pine and mixed conifer zones in the Crater Lake region. Their abundance had been due to fire disturbances (partial or complete stand-replacement) prior to settlement. It appears that chaparral, like lodgepole pine, has declined dramatically due to fire suppression.

Wetlands. Wetland vegetation occurs locally where soils and snowmelt conditions provide suitable conditions. Wetlands were not mapped by the 1936 effort. They include riparian forests, mountain meadows, and the distinctive Sphagnum Bog.

4.4.2 Regional Context

The park's terrestrial vegetation is mostly a relatively pristine example of the regional vegetation on young pumice and other volcanic substrata in the central Cascades. Importantly, the park straddles the Cascade crest, encompassing much of the range of variation in vegetation over the west (moister) to east (colder and drier) gradient. The park also lies in a latitudinal transition zone. To the north in the Cascades, particularly the west side, low to mid-montane forests become dominated by western hemlock, which is at its southern extent and not as common in the park as northwards. A similar pattern occurs with silver fir (*Abies amabilis*) and subalpine fir (*Abies lasiocarpa*) in upper montane zones. Occurring slightly to the north and not within the park are also the important forest trees western red cedar (*Thuja plicata*) and western larch (*Larix occidentalis)* (Franklin and Dyrness 1988). Conversely, the park lacks a dominant forest tree from the southern Cascades, the Jeffrey pine (*Pinus jeffreyi*), which is common at Lassen Volcanic National Park, for example.

A number of other upper montane and subalpine areas of the central and southern Cascades have vegetation on young volcanic substrata (e.g., Mt. Lassen, Mt. Shasta, Newberry Caldera), but the vegetation of each is markedly different in composition from the park's. The park's large areas of herb-grass vegetation on pumice are regionally unique.

4.4.3 Issues Description

Issues pertinent to vegetation composition, structure, and function that were given the highest priority by park managers for consideration in this condition assessment include: 1) Fire regimes and their function, 2) Fuels management in relation to fire regime and ecosystem health, 3) Extent and impact of invasive plants, and 4) Condition of subalpine communities. These are discussed below.

<u>4.4.3.1 Fire Regimes, Fire Suppression, and Fuels Management</u>

With two of four top-ranked vegetation issues involving fire management, park managers clearly recognize the potential for fire management to impact park ecosystems. As noted by Keane et al. (2008): “Many politicians, members of the public, and government agency land managers have come to believe that large wildfires (fires >10 000 ha) are an ecological disaster because they are perceived to burn vast areas with high fire intensities and burn severities (Brown 1985; Mutch et al. 1993; GAO 2002; Daniel et al. 2007). However, these same fires can return fire to deteriorating ecosystems where fires have been excluded for over 70 years, thereby restoring rates of natural processes."

Nonetheless, because fire is a threat to human assets and human safety and interferes with visitation or visitor enjoyment in other ways (e.g., smoke interfering with the view of Crater Lake), fire control efforts may necessarily take precedence over other park goals. Management policies of adjacent public lands may also affect otherwise natural cross border introductions of fire onto park lands from outside the park or vice versa. The result is that fire's role in shaping vegetation patterns has been considerably restricted in and around Crater Lake, despite some fires that were allowed to burn in the park, and the options for restoration of more natural fire regimes are limited.

Within Crater Lake National Park, evaluating how fire management, and fire suppression in particular, has altered vegetation is difficult because the effects may differ at lower elevations, where fires were historically more frequent than at higher elevations. Where a low-severity regime operated, forests with more open and park-like structure may have existed in a steady state with continuous regeneration of trees (Agee 1993). In this regime, fires were frequent (<20 year recurrence interval) and this limited fuels and fire severity. Fire suppression has greatly reduced the likelihood of fire, but there are concerns that the probability of high severity fire has increased where low-severity fire regimes occurred historically. This is shown in Figure 10.

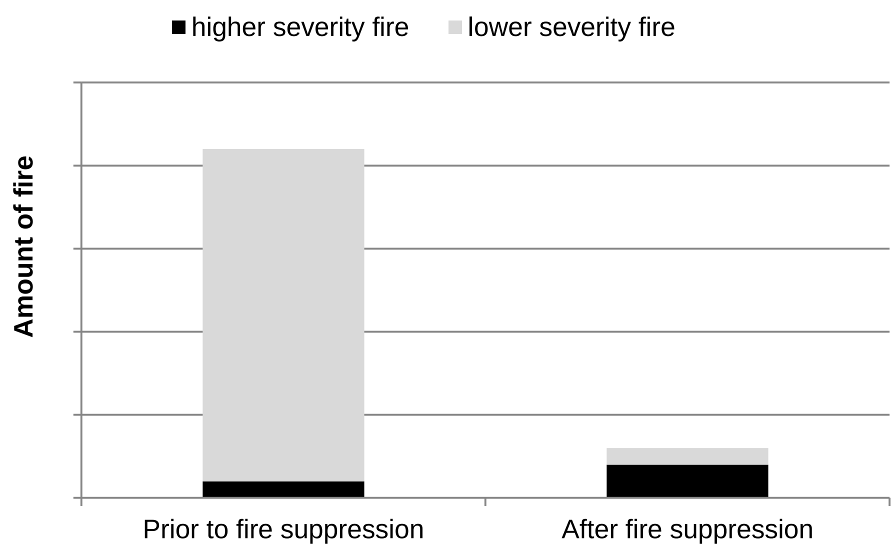

Figure 10. Hypothetical changes in the amount of higher and lower severity fire with fire suppression where a low-severity fire regime and steady-state conditions historically occurred.

In mixed severity fire regimes (Baker et al. 2009: Table 1, Perry et al. 2011), fire operated in a patch-wise 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 is to generally reduce amounts of all fire: low-, moderate-, and high-severity (Figure 11).

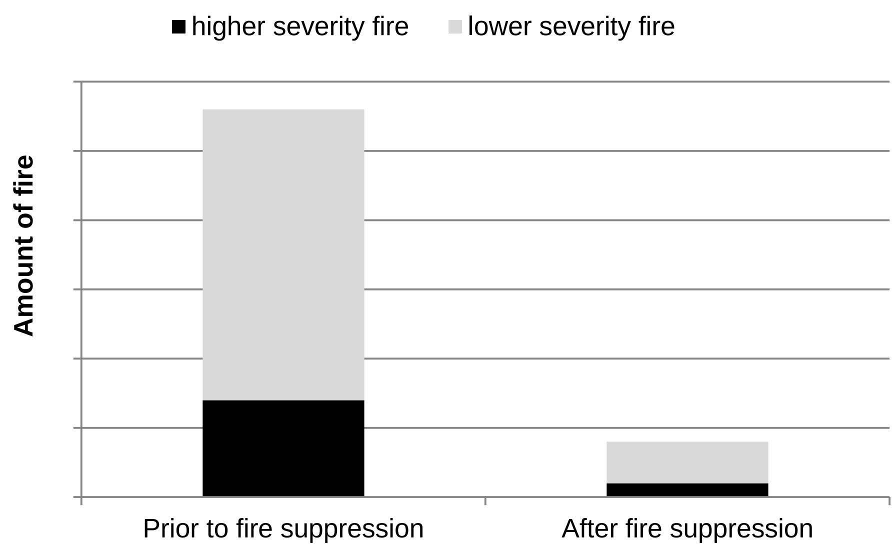

Figure 11. Changes in the amount of higher and lower severity fire with fire suppression under a historical model of mixed severity fire.

<u>4.4.3.2 Fire and Climate Change</u>

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) since fire suppression became effective (Heyerdal et al. 2008, Morgan et al. 2008). PDO oscillates on a frequency of about 30 years. From the 1970s until recently, PDO has been in the warm phase, but has shifted to a cool phase (Mantua 2000) particularly in the last 4-5 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.

A recent analysis that does not incorporate possible PDO effects predicts a near doubling by the 2080s of the mean area burned in Washington (Littell et al. 2010). A similar prediction might be made for the central Cascades where Crater Lake occurs. This prediction assumes decreased summer precipitation as a main driver of more fire. Future precipitation trends are an area of particular uncertainty. Some data indicate a pattern of increasing, not decreasing, summer precipitation in the Pacific Northwest (Mote 2003a, Hamlet et al. 2007), which could work to offset temperature increases. Modeling is needed that considers these changes in precipitation, and, to the degree possible, PDO, to better understand future fire trends.

In terms of actual patterns in fire occurrence under changing climate, it is somewhat surprising in the context of current concerns about excessive fire severity, that there is no ongoing trend that has been detected in the proportion or amount of fire that is high in severity in the drier portions of the Cascades (Hanson et al. 2009) or Pacific Northwest (Schwind et al. 2008, Dillon et al. 2011). Thus, there may be factors that are mitigating the effects of warmer temperatures on fire behavior. In dry fuels, wind speed is the most important factor in determining fire behavior (Cruz et al. 2004; Cruz and Alexander 2010). Recent research indicates that with climate change, the wind speed probability distribution may be shifting towards slower winds, particularly in mid-latitudes (Pryor and Barthelmie 2010; Pryor and Ledolter 2010). Pryor and her colleagues found that wind speeds appear to be waning in most of the USA, in many locations by more than 1 percent per year. But, this has not been directly linked to any changes in fire activity. Lastly, the water use efficiency of plants increases with increasing atmospheric CO_2 (Huang et al. 2007), such that the ongoing increases in atmospheric CO_2 could partially mitigate temperature effects on live fuel moisture. Mapping of fire severity exists only since 1984, so it may require more time before patterns in fire severity that may be occurring become apparent. The point here is that impacts of fire suppression may continue even though warming temperatures are more conducive to fire.

In addition, fire managers are currently implementing fuel treatments to improve fire suppression capabilities and reduce fire behavior. It is unclear the extent to which treatments on federal lands may help suppress fires or their behavior in the future. It is also unclear whether fire suppression capabilities will improve due to technological advances or changes in funding. These factors add to climate uncertainty to make predictions about future fire more difficult.

4.4.3.3 Extent and Impact of Invasive Plants

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

Across the Klamath network, the number of non-native species declines sharply from low elevations of Whiskeytown to the higher elevations at Lassen (Figure 12). This pattern has been well-established in the western U.S. (Mooney et al. 1986, Rejmanek and Randall 1994, Schwartz et al. 1996, Keeley et al. 2011).

We reviewed the physiological tolerances of invasive plants that are present or expected in all Klamath Network Parks (see Odion et al. 2010, Odion and Sarr in press). We found that Crater Lake 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 Crater Lake 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, defined as ecosystem transformers, are shown in Table 4.

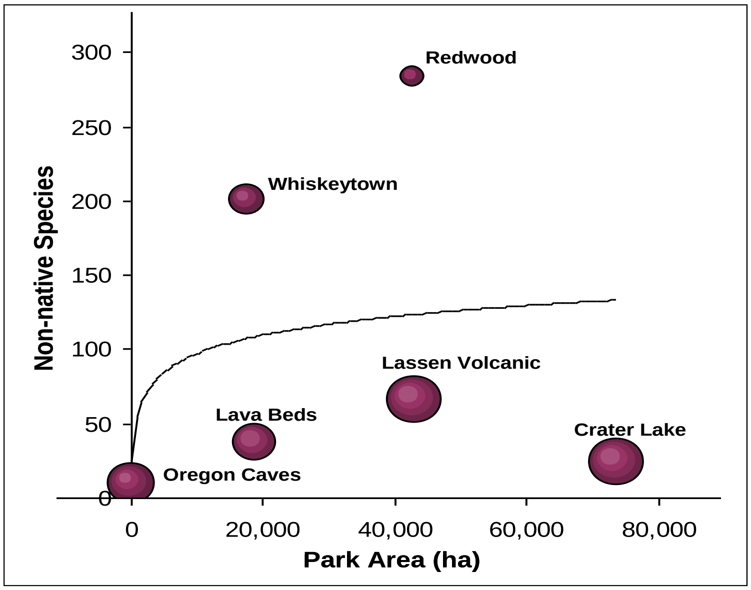

Figure 12. Non-native plant species richness as a function of park area and elevation in the Klamath Network. A logarithmic line illustrates the expected species/area relationship across park sizes, and oval size is proportional to mean park elevation. The lower elevation parks have more nonnative species than expected for their size, whereas higher elevation parks have fewer recorded species.

Table 4. Invasive plants of greatest concern at Crater Lake National Park as determined by the prioritization process used by the Klamath Network and involving park resource staff.

The ranking is a semi-quantitative 0-1 score. The species in this list are invaders that are considered capable of transforming ecosystems that are still not yet well-established. 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 Crater Lake.

Scientific Name	Common Name	Invasion Phase	Ranking Score
Cytisus scoparius	Scotch Broom	Colonization	0.875
Centaurea solstitialis	Yellow Starthistle	Colonization	0.873
Centaurea maculata	Spotted Knapweed	Colonization	0.854
Bromus tectorum	Cheatgrass	Establishment	0.827
Holcus lanatus	Velvet Grass	Colonization	0.769
Centaurea diffusa	Diffuse Knapweed	Colonization	0.750
Linaria genistifolia ssp. dalmatica	Yellow Toad Flax	Colonization	0.744
Leucanthemum vulgare	Ox-eye Daisy	Colonization	0.740
Cirsium arvense	Canada Thistle	Establishment	0.642
Brassica rapa	Mustard	Colonization	0.610
Melilotus albus	White sweet clover	Colonization	0.591
Hypochaeris radicata	Rough Cat’s Ear	Establishment	0.564
Poa bulbosa	Bulbous Bluegrass	Colonization	0.556
Festuca arundinacea	Tall Fescue	Establishment	0.538
Melilotus officinalis	Sweet Clover	Colonization	0.532
Bromus inermis	Smooth Brome	Establishment	0.507
Dactylis glomerata	Orchard grass	Establishment	0.499
Lactuca serriola	Wild Lettuce	Establishment	0.477
Tragopogon dubius	Goat’s Beard	Establishment	0.401
Agrostis gigantea	Bentgrass	Establishment	0.393
Senecio sylvaticus	Ragweed	Colonization	0.322

Species such as Klamath weed that are well-established are considered to be in the equilibrium phase (Table 5), and many of these are monitored in the Crater Lake backcountry.

Table 5. Equilibrium species in Crater Lake National Park 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?
Hypericum perforatum	Klamath Weed	0.673	Yes
Cirsium vulgare	Bull Thistle	0.667	Yes
Verbascum thapsus	Common Mullein	0.657	Yes
Rumex acetosella	Sheep Sorrel	0.545	No (control infeasible)
Poa pratensis	Kentucky Bluegrass	0.532	No (control infeasible)
Taraxacum officinale	Dandelion	0.517	No (control infeasible)

Invasive Pathogens and the Condition of Subalpine Vegetation

The outstanding non-native species and plant pathogen of concern at Crater Lake National Park is the blister rust fungus (*Cronartium rubicola*). It is the main factor impacting the condition of the park's subalpine vegetation, particularly whitebark pine, which was a top management concern raised by park staff. The Klamath Network identified whitebark pine as a vital sign of ecosystem health to monitor and has initial monitoring results (Smith et al. 2011, Jules et al. 2012.).

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 Crater Lake National Park, 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 noticeable. In contrast, the pine mortality at many areas along the Crater Lake caldera rim, where visitation is high, is quite conspicuous.

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. Blister rust on whitebark pine has been found to be more common in the western portions of the park, and where tree density is higher (Smith et al. 2011). On the east side of the park, it is positively associated with the alternate host shrubs *Ribes* spp.

The rust has been in the park for many decades, but has become a greater concern in recent years as the picturesque whitebark pines on the caldera rim have begun to die in greater numbers. Park staff began formal monitoring of the blister rust in 1999 (Murray and Rasmussen 2003, Murray 2010). At monitoring plots, Murray (2010) estimated that pines were dying at a rate of 1 percent per year, and Smith et al. (2011) reported that about 25 percent of trees in 20 monitoring plots had blister rust cankers. Much higher rates of infection occur farther north in the Cascades

(Rochefort et al. 2008), and, to date, lower rates occur southward (McKinney et al. 2012). However, preliminary assessments of 2012 monitoring data suggest that blister rust infections may be more common than previously believed, both at Crater Lake and at Lassen. Jules et al. (2012) found that white pine blister rust infected 69% of whitebark pine in ten plots at Crater Lake. Future monitoring by Dr. Jules and colleagues, in collaboration with the Klamath Network Inventory and Monitoring Program, should clarify the status and trends in blister rust in whitebark pine.

From the 2009 distribution of blister rust, 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 in the park.

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. 2005). 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.

4.4.4 Indicators and Criteria to Evaluate Condition and Trends in Vegetation

The following indicators of vegetation structure, function and composition were chosen for use in this NRCA to evaluate condition and trends in the park's vegetation (Table 6):

Table 6. Vegetation indicators and the ecological conditions for which they are indicators.

Indicator	Conditions Tracked
Stand Age Distributions	Fire regimes, disturbance processes
Fire Rotations	Fire regime
Invasive Plants	Vegetation/ecosystem transformation
Invasive Pathogens	Vegetation/ecosystem transformation
Rare Plants and Diversity of Native Plants	Climate change, natural succession

4.4.4.1 Stand Age Distributions

Criteria
For purposes of this assessment, "Good" conditions would be current stand ages that appear to be similar to historical stand ages, with effects of fire suppression not apparent. "Somewhat Concerning" would be stand ages moderately altered by fire suppression. "Significant Concern" would be stand ages substantially altered by fire suppression. To assess which condition applies, it is necessary to define reference conditions for stand ages.

The transition between low- and mixed-severity fire regimes may occur at particular elevations within the park, but this has not been systematically investigated. 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 types of changes that have occurred with fire suppression. Where low severity fire regimes occurred, we expect an increase in all fire except low-severity fire leading to forest instability (Figure 13). Where mixed-severity regimes occurred, we expect a decrease in all fire, leading to a reduction in early successional vegetation and age class diversity created by fire (Figure 14).

The distribution of stand ages in a landscape can illustrate whether low- or mixed-severity fire regimes occurred historically. Using the stand age distributions, as affected by historical fire, is also consistent with recommendations for using a statistical distribution to describe reference conditions for an indicator rather than 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 13 shows the stand-age distributions that would exist where a low-severity regime historically occurred. In this distribution, most stand ages are determined by the lifespan of trees because stand-initiation by fire has not occurred. Therefore stands are mostly several centuries old. However, an increase in fire severity due to fire suppression would lead to some young stands being created in recent decades, creating a bimodal distribution. Conversely, Figure 14 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 found in a low-severity regime.

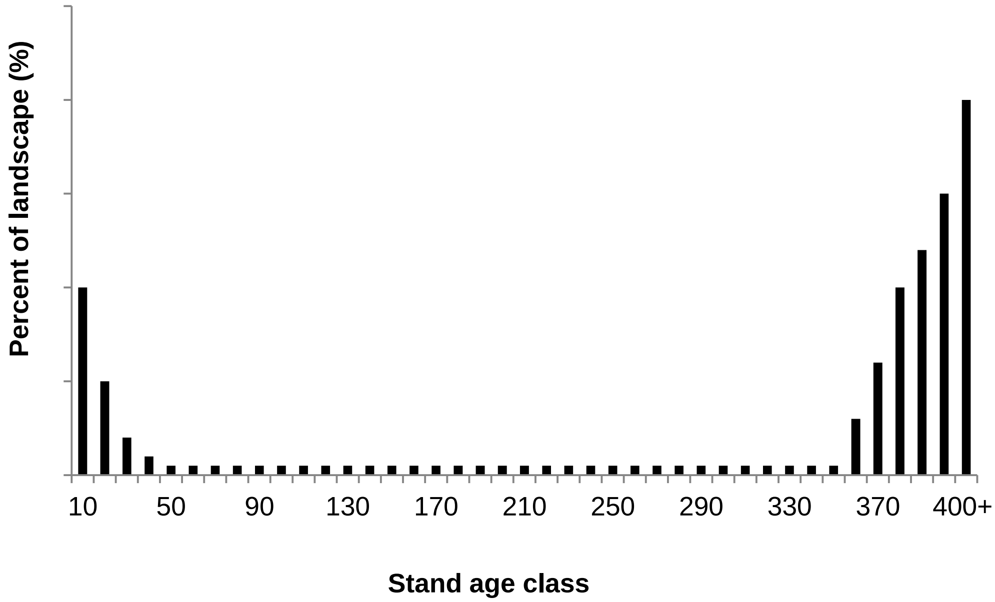

Figure 13. Theoretical stand age distribution in forests affected by a low-severity fire regime and an increase in susceptibility to more severe fire in recent decades due to fire suppression.

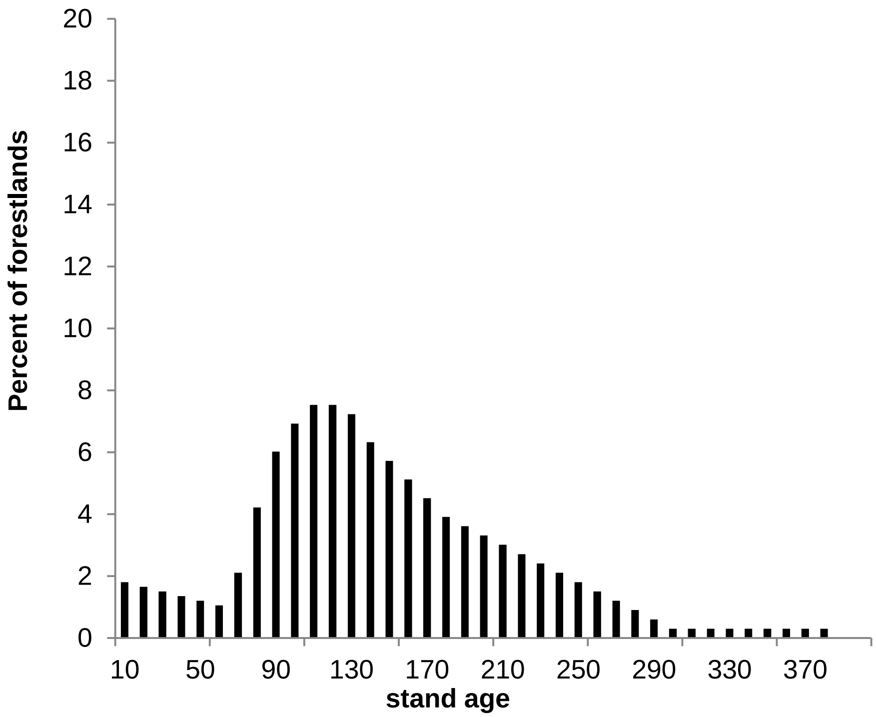

Figure 14. Hypothetical stand age distribution for forests affected by a mixed-severity fire regime and 70-90 years of reduced fire due to fire suppression.

Condition and Trends
Condition: *Significant Concern -Medium Certainty*.
Trends: *Significant Concern -Medium Certainty*.

The condition and trend for the stand age indicator are rated Stand age analyses indicate that both low-mid-elevation and mid-to upper elevation forests in the central and eastern Cascades were shaped by mixed severity fire because stands were initiated continuously prior to fire suppression (Figure 15 and 16). 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).

After the onset of fire suppression, landscape vegetation patterns have been shaped far less by fire. Figures 15 and 16 clearly show 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 underrepresented compared to a scenario in which fire suppression never occurred, 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.

The mean and median Forest Service Inventory and Analysis (FIA) stand-age of never-managed forests has increased considerably since 1930, reflecting a lack of stand-initiating disturbance (Table 7). The scarcity of fire disturbances in the last 70-90 years is a pattern consistent with the recent history of fire in the park. There has been very little fire since recordkeeping began, around 1930. We quantify this under the next indicator, fire rotations. The substantial reduction in lodgepole pine forests since the 1936 vegetation surveys at Crater Lake is also consistent with a similar reduction in mixed-severity fire. Lodgepole is often an early successional forest type.

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 central and eastern Cascades. Only plots from the same forest types were selected, and these occurred in similar proportions as the forest types that occur presently in Crater Lake (Appendix A). 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 by fire suppression management. However, it should be noted that fire suppression has likely been more effective in Crater Lake National Park than surrounding areas.

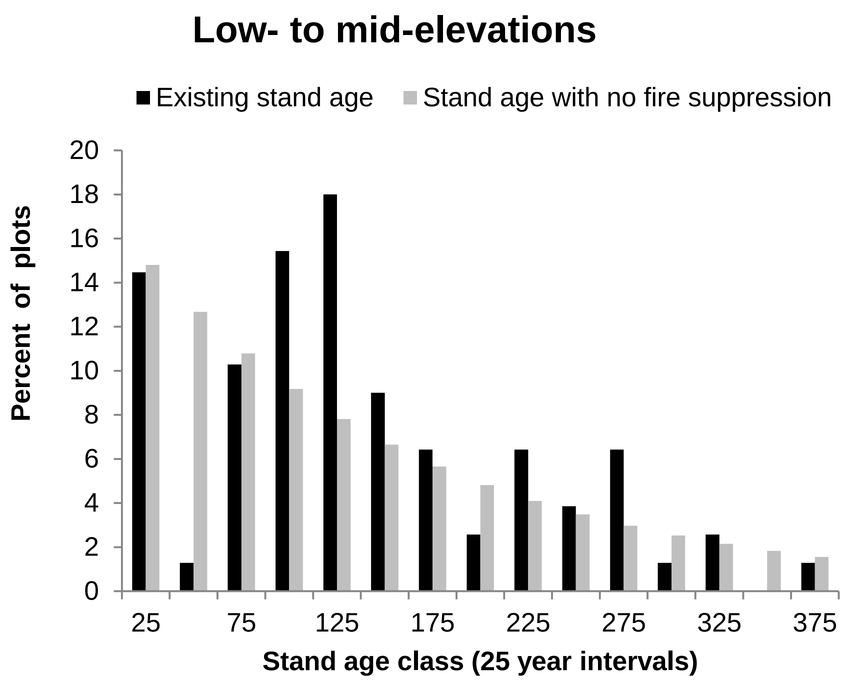

Figure 15. Never-managed forest stand age distribution in the low- to mid- montane zones of the eastern Cascades (black bars), compared with the theoretical distribution that would be present had pre-suppression fire disturbances not been interrupted by fire suppression (gray bars).

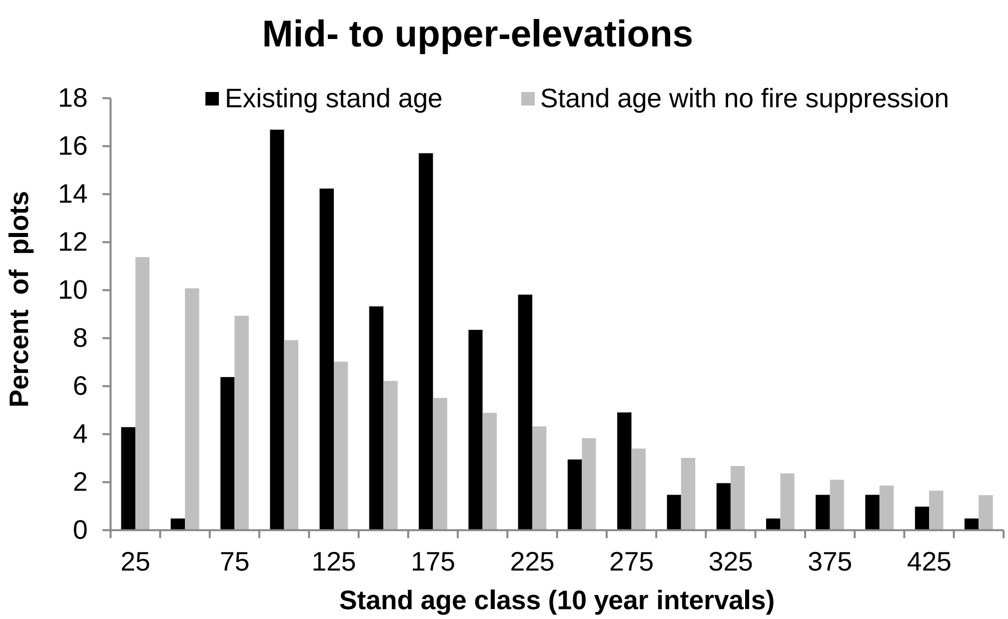

Figure 16. Never-managed forest stand age distribution in the upper montane zones of the eastern Cascades (black bars), compared with the theoretical distribution that would be present had pre-suppression fire disturbances not been interrupted by fire suppression (gray bars).

Table 7. Mean and median stand ages for mid-montane forests of the eastern Cascades low-to mid-elevation forests, and upper montane forests of the central and eastern Cascades in Oregon.

	Stand age in 1930 (yrs)		Current stand age (yrs)	
	Mean	Median	Mean	Median
Low- to mid-montane forests	83	57	128	106
Upper montane forests	95	70	157	137

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 the age class distributions, but also greater homogeneity as younger age classes are diminished and older 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.

For stand age conditions to reverse themselves and the former pattern to return would require an order of magnitude more wildfire than presently occurs (see next section on fire rotations) over a period of about 80 years. About half of all forests in the park, and most of the lodgepole pine, would have to burn with stand-initiating fire over that time. However, planned prescribed burns are very constrained in area and are mostly limited to surface fires. Wildland fire use (allowing unplanned fires to burn) is also constrained for pragmatic reasons (see discussion above in section 4.4.3). Thus, the pattern of greatly reduced mixed-severity fire will likely continue.

However, the effects of fire suppression in reducing fire might be reversed, at least in part, by the effects of climate change. In fact, in low- to mid-elevation forests, mixed-severity fire in recent decades may be similar to historic rates (Figure 15), thus, lack of fire may be less of a concern in these forests. However, as discussed earlier (see discussion above in section 4.4.3), the future is difficult to predict with any degree of precision.

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. On the other hand, at least some of these species may benefit most from heterogeneous landscapes shaped by mixed-severity fire (Franklin 2000).

As discussed in the next section, it appears that fire suppression has been more of an influence in the park than over the broader regions from which the stand age data originate, with the exception of the Panhandle where prescribed fire has been frequent. However, this may mean that our assessment is conservative. 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 (Beaty and Taylor 2001, Bekker and Taylor 2001, 2010, Hessburg et al. 2007, Baker 2012). These general effects can therefore be accepted with a relatively high degree of confidence.

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. Ongoing analysis of LiDAR imagery from the park and other areas of the eastern Cascades by Van Kane, Forest Structure and Dynamics Lab, University of Washington, will yield a better understanding of the park's vegetation structure generally and will place it in the context of the region generally.

4.4.4.2 Fire Rotations

The fire rotation is the amount of time during which fires occur naturally with sufficient frequency and/or extent to completely burn a pre-defined area of interest one time. 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.[10]

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/(1,000/3,000) 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).

Criteria

For purposes of this assessment, "Good" conditions 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

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[10] This can occur because the fire scars are not probabilistic samples (i.e., the target population they provide inference for is not the landscape) (Johnson and Gutsell 1994), and scars 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 <16 years over the same time period (Stephens et al. 2003). Therefore we use fire rotation here as a standard that allows comparison of the specific amount of fire affecting a landscape over time.

suppression. To assess which condition applies, it is necessary to define reference conditions for stand ages.

Condition and Trends
Condition: *Significant Concern – Medium Certainty*.
Trends: *Significant Concern -Medium Certainty*.

As detailed below, only a limited area within the park has burned since the onset of fire suppression, leading to rotations for fire with fire suppression management that are an order of magnitude longer than those from prior to fire suppression. The current probability of all fire, including stand-initiating fire is much lower than it was historically, as illustrated by the near cessation of stand-initiation (Figures 15 and 16).

The overall fire rotation since 1930, over the approximately 63,693 hectares of burnable vegetation, is about 744 years. There has been more fire since 1984, and the rotation from 1984 to the present is 287 years. This is a parkwide estimate, ignoring variations in different areas. It is important to note that the forests in the panhandle part of the park have burned frequently in recent decades as a result of prescribed burning and thus those forests have had a very short rotation interval since 1984. However, the total acreage burned by these prescribed fires is relatively small at the scale of the whole park, and therefore has little effect on the parkwide rotation. There has also not been mixed-severity fire in the panhandle.

The parkwide rotations are far longer than pre-suppression fire rotations in comparable vegetation in the southern and central Cascades, as summarized in Table 8. These data, described next, are the best available for defining reference conditions for this indicator even though they do not incorporate the full range of variation that has occurred with fire over longer time scales appropriate for defining reference conditions (Whitlock et al. 2010).

Information on historical fire rotations from within the park is lacking. Fire scar studies have been done (e.g. McNeil and Zobel 1980), but these did not map the area burned, a requirement to calculate rotations. One such study that did determine past area burned over time was done by Bork (1984) in ponderosa pine forests in the eastern Oregon Cascades at the Pringle Falls Research Area (40 km south of Bend). From area-burned data presented in Figure I-22 of her study (Bork 1984), the fire rotation for three separate study areas was 29, 78, and 71 years, while the composite fire scar frequency for the same areas was 11, 15, and 24 years, respectively (Baker 2012). This composite fire scar frequency is similar to that obtained by McNeil and Zobel (1980), suggesting that the ponderosa pine forests studied by Bork, and those in the Crater Lake Panhandle by McNeil and Zobel (1980), burned at similar frequencies historically. The study Pringle falls study area had a mixed severity regime. The rotation for only low severity fire was estimated by Baker (2012) as 47-142 years.

Fire rotations have been calculated in the southern Cascades in forests similar to those in the park. Table 8 shows the findings from Prospect Peak in Lassen Volcanic National Park, 257 km (160 miles) to the south (Taylor 2000), as well as the Thousand Lakes Wilderness just northwest of Lassen (Bekker and Taylor 2001, 2010), and the Cub Creek Research Area on the Lassen National Forest (Beaty and Taylor 2001). These are all protected areas in the southern Cascades which have past land use history generally similar to that of Crater Lake National Park.

Historical rotations, like those from Bork (1984), are an order of magnitude shorter than current rotations, indicating the widespread effect of fire suppression. Table 8 also shows the fire frequencies at individual points where fire scar samples were collected[11]. This shows that certain areas burned much more frequently than the landscape average while others burned less frequently (compare the ranges and differences in point intervals fire rotations). Again, this suggests that conditions were so variable that the occurrence of long fire intervals like those of today are not necessarily unprecedented if they occur in some portions of a landscape, but the widespread occurrence of such long rotations over a landscape may be.

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[11] As discussed earlier, these are not probabilistic samples of the whole landscape because not every tree/location has an equal probability of being sampled: They are representative of the particular sites sampled.

Table 8. Mean fire frequency prior to fire suppression from studies in the central and southern Cascades. The current fire rotation is calculated from Crater Lake National Park fire history data for the time period beginning in the parenthesized calendar years.

Forested zone	Location	Forest types	Historical Fire Rotation from Mapped Fires (yrs)	Historical Point Fire Return Interval (yrs)	Current Fire Rotation since (yr)	Source
Upper and mid-montane	CRLA (all)	All	n.a.	n.a.	744 (1930)	CRLA fire history data
					287 (1984)	
Mid-montane	CRLA panhandle	Ponderosa pine, mixed conifer, white fir	n.a.	12-48(55)	(currently very short due to prescribed burns)	McNeil and Zobel (1980)
	Central, east Cascades, Oregon	Ponderosa pine, mixed conifer, white fir	31-79	n.a.	n.a.	Bork (1984)
	Southern Cascades, Northern California	white-fir, sugar pine, Jeffrey pine	22-50	7-55	No fire since 1942	Bekker and Taylor (2001)
	Southern Cascades, Northern California	white fir, ponderosa pine, red fir	17-43	5-108	No fire since 1926	Beaty and Taylor (2001)
Mid-upper montane	Southern Cascades, Northern California	white-fir, Jeffrey pine, red-fir	46-147	4-91	No fire since 1942	Bekker and Taylor (2001)
	Southern Cascades, Northern California	Jeffrey pine, white fir, red fir (Prospect Peak, Lassen NF)	17.1-75.9	9.5-109	Dramatic decline in fire since 1906	Taylor 2000

Lower montane drier forests in the Cascades (e.g., ponderosa pine and mixed conifer) have been assumed by many to have been park-like (meaning semi-open canopy with little understory), maintained by low-severity fires, and to have become denser since the era of fire suppression began. And in fact, the 1936 vegetation surveys describe ponderosa pine forests at Crater Lake as park-like (Anonymous 1936). However, these surveys and most other descriptions are from after settlement and do not consider impacts of logging and burning by settlers. A recent analysis of vegetation over 400,000 hectares of the eastern Cascades dry forests from Government Land

Office Surveys (Baker 2012) analyzed the pre-settlement condition. The methods used allowed accurate reconstruction of detailed forest structure. They were calibrated by collecting the same data in current vegetation and seeing how accurately the data could reconstruct current vegetation (Williams and Baker 2012). The reconstructions show that only about 13.5% of these forests had low tree density of park-like forests. Hessburg et al. (2007), in an extensive analysis of the historical conditions of the drier forests of the Cascades, concluded that park-like forests were rare. Both studies found that forests were generally dense, both in their understory and overstory, but density varied by a factor of 2–4 across about 25,000-ha areas. Given the likely historical fire rotation, there was likely ample time between fires for trees like white fir to regenerate and even grow into the canopy, a process that may take only 30 years in the park (Agee 2002). This may help explain the widespread occurrence of mixed conifer forests where shade tolerant firs are common overstory trees. These studies also corroborate the stand age analysis presented above and the conclusion that forests were not maintained in a steady state by low-severity fire (Figure 10), but were characterized by non-equilibrium (Figure 11). In terms of historic conditions, this means that complex early successional vegetation created by fire would have been common.

Within the park, the current rotations for fire of different severities (not including prescribed burns) can be inferred from fire severity data. Fire severity data are available from MTBS.gov for 1984-2009. We used these data and included a 2 km buffer area surrounding the park in our calculations. We intersected burn severity by vegetation type. Most fire has occurred in mountain hemlock, red fir, and mixed conifer forests. Applying the same percent burn severity where these fires with mapped severity occurred to additional areas burned in the park since 1984 where severity was not mapped (a small additional area), we found very long rotations for low, moderate, and high severity fire since 1984 (Table 9). An estimate of the current rotation of stand-initiating fire can also be made from the stand-age data presented in the preceding section. These rotations are also presented in Table 9. Both of these estimates of the current rotations of low, moderate, and high severity fire are much longer (fire is less frequent) than historical estimates discussed next.

Studies that map historical fires from old air photos can be used to calculate fire rotations that occurred prior to fire suppression. This was done in many of the above cited studies in the southern Cascades by Taylor and colleagues and by Hessburg et al. (2007) over a large area of the eastern Oregon and Washington Cascades. Historical fire rotations for moderate and high severity fire have also been estimated from the presettlement Government Land Office (GLO) data for the eastern Cascades of Oregon (Baker 2012). In addition, the rotation for pre-suppression stand-initiating fire (similar to moderate to high severity) can be calculated from the stand age data presented in the preceding section on stand ages. The methods for calculating rotations from all of these data sources are the same. The time period of interest (years) is divided by the proportion of the area burned by a type of fire (e.g., low or high severity) over that time period.

Results of calculations for different fire severities are shown in Table 9. There has been a dramatic decline in all forms of fire (increase in rotation length), consistent with Figure 11 and with the stand-age analysis. The length of historical rotations for high-severity fire compared to the rotations for low-severity fire indicate that historically, about 25 percent of all fire in the park and up to 2 km outside the park was high in severity. This is comparable to current percentages as estimated from the MTBS.gov data for fires in the park since 1984 (22% was high severity).

As discussed in the previous section, the suppression of low, moderate, and high severity fire causes a loss of earlier successional vegetation and age class diversity. In addition, older stands become increasingly dominated by shade tolerant firs, and lodgepole pine may be replaced by fir. These changes are evident from the comparison of the 1936 vegetation map and more current mapping (see section 4.4.1, Background: vegetation). 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.

Table 9. Rotations for different severities of fire from MTBS.gov fire severity data for Crater Lake, or published studies that used Government Land Office presettlement surveys or early aerial photos for different landscapes in the Cascades.

Study Location and size (km^2)	Source	Time period	Type of fire	Rotation (years)	Forest types
CRLA	MTBS.gov fire severity data and park fire history data	1984-2010	Unburned and low severity	585	Mountain hemlock, noble fir, and mixed conifer (white fir, Douglas fir, ponderosa pine)
			Moderate severity	987	
			High severity	1308	
Dry Cascades[1]	FIA stand age data	1930-present	Stand- initiating	732	Upper montane forests
				419	Mid montane forests
Dry Cascades[1]	FIA stand age data	1750-1875	Stand-initiating	151	Upper montane forests
				156	Mid montane forests
East Cascades, Oregon	Baker (2012)	1850s and 1860s (prior to most impacts of settlement)	High severity (>70% tree mortality)	435	Ponderosa pine and mixed conifer
			Low severity	47-147	
			All fire	29-78	
East Cascades, Oregon and Washington	Hessburg et al. (2007)	1830-1930	High severity (>70% tree mortality)	379-505	Ponderosa pine and mixed conifer
			Moderate and high severity (30-100 % tree mortality)	115-128	

Table 9 (continued). Rotations for different severities of fire from MTBS.gov fire severity data for Crater Lake, or published studies that used Government Land Office presettlement surveys or early aerial photos for different landscapes in the Cascades.

Study Location and size (km^2)	Source	Time period	Type of fire	Rotation (years)	Forest types
S. Cascades	Bekker and Taylor (2001)[2]	1864-1939	High severity**	165-210	Jeffrey pine, white and red fir
			High/moderate severity†	111-225	
			Low severity‡	24-91	
			All fire	22-50	
S. Cascades	Beaty and Taylor (2001)[3]	1883-1926	High severity**	101-394	Mixed conifer, white and red fir, Douglas-fir and ponderosa pine
			High/moderate severity†	83-114	
			Low severity	19-89	
			All fire	17-43	
			Low severity	31-79	

[1] Upper montane forests are from the central and eastern Cascades of Oregon. Lower montane forests are from the eastern Cascades of Washington and Oregon. Stand-initiating fire is fire that creates a new cohort of trees that is dominant.

* High severity was consistent with a definition of >70% basal area mortality (Hessburg et al. 2007) was identified by forested areas having a percentage of small trees >50% and a percentage of large trees <20% in early air photos. Mixed severity included all areas not meeting the definition of high severity or a definition of low severity in which the maximum percentage of small trees was 48.6% and the minimum percentage of large trees was 28.8% in a given area, as interpreted from early air photos.

** “High severity” defined as <10 emergent trees/ha remaining after fire.

† "High" and "moderate" severity defined as <20 emergent trees/ha remaining after fire. This 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] The 75 year time period from 1864-1939 started and ended with 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 of an area burned to calculate fire rotation. The range in fire rotations reflects the minimum and maximum rotations from different forest types (Table 2 of Bekker and Taylor [2001]).

[3] The 43 year time period from 1883-1926 started and ended with large fires. 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 of area burned to calculate rotation. The range in fire rotations reflects the minimum and maximum based on different slope/aspect categories (Table 8 in Beaty and Taylor [2001]).

For fire rotations to return to more historical levels, an order of magnitude more wildfire than presently take place would need to occur (planned prescribed burns are very constrained in area and are limited to mainly surface fire effects). In a relatively small landscape, such as in this park, a large portion could burn in a single fire and substantially shorten rotations. This is a very low probability in any one year, but eventually will likely occur.

In sum, it is likely that fire suppression will continue to override the effects of climate change and other factors that might favor more fire. Lack of fire could be somewhat mitigated in a large national park due to the greater possibility of managed fire use, and eventually, a large wildfire is likely to occur that will help restore fire as an ecological process.

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 are for mid-montane forests in the eastern Cascades (Hessburg et al. 2007) and the Oregon Cascades (Baker 2012), and often consider only small landscapes (Bork 1984, Beaty and Taylor 2001, Bekker and Taylor 2001, 2010, Taylor 2000). However, it appears that, if anything, the effects of fire suppression may be underestimated in the park (with the exception of the Panhandle, where prescribed fire has been frequent).

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.

4.4.4.3 Extent of Invasive Plants
Locations and extent of invasions by non-native plants in the park have not been documented comprehensively. Records do exist where efforts to control invasives have been undertaken and where prescribed burning and fuel reduction treatments have been done (FMH plots). Invasive plants were also surveyed by 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 collected from areas necessarily at highest risk of invasion by non-native plants. There are, however, data covering non-native plants from probabilistic sampling done for the 2005 park-wide wetlands assessment (Adamus and Bartlett 2008). In addition, vegetation sampling for an ongoing vegetation mapping project used a relevé approach to subjectively locate plots across the range of variation in vegetation types. In concert, the wetland and vegetation mapping databases comprise 275 plots.

Criteria
For purposes of this assessment, “Good” conditions would be a low level of invasion by exotic species and “Somewhat Concerning” and “Significant Concern” would represent increasingly greater problems with invasive exotic species based on their extent within the park and their observed effects on native plant populations.

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

A few infestations by the kind of invasive species that are ecosystem transformers have been documented, but these are rare considering the size of the park. The apparent paucity of invasive species attests to management efforts by the park, and to a general lack of fire and other disturbances which are often a catalyst for plant invasions.

In fact, the most serious known invasive species infestations are found in the Middlefork burn area. This burn occurred in 2008 in the extreme southwest corner of the park. Species with relatively high potential to be ecosystem transformers, including bull thistle (*Cirsium vulgare*) and Canada thistle (*Cirsium arvensis*), subsequently invaded. The infestations were described in a park report (Beck 2011) and noted by the crew sampling plots for the vegetation mapping project. Beck (2011) points out that the infestations in the burn are likely the worst invasive species infestations in the history of the park. This highlights a resource management conundrum. Lack of fire is one of the biggest contributors to uncharacteristic park conditions, but restoring historical fire regimes would likely worsen conditions related to non-native plant invasions.

Figure 17 shows the locations where invasive plants have been encountered in the park, as well as their abundance in the wetland plots, the vegetation mapping plots, and park surveys. In the wetlands sampling (100 total plots across all wetland types), there were nine invasive species occurrences in seven plots. These were mainly mountain dandelion (*Taraxacum officinale*), a naturalized species that is not an ecosystem transformer. However, there was one occurrence of a species with relatively high potential to be an ecosystem transformer, bull thistle (*Cirsium vulgare*). This species was also found in two of the vegetation mapping plots. In all these cases its cover was "trace" (<0.1%) or .3%. Virtually all of these records are from locations near a road or in the developed area around the visitor center. The exceptions are five infestations on the west side of the park.

Three infestations were found among the fire monitoring plots (Farris, pers. comm.). One is a species of everlasting (*Gnaphalium*), whose identification as a non-native species may be incorrect. The other two infestations were bull thistle (*Cirsium vulgare*).

Invasive species were surveyed by the Klamath Network Inventory and Monitoring Program during the summers of 2009 and 2011. The Network surveyed a random sample of road and trail segments comprising a total of 71.3 km in 2009, and 68.4 km in 2011. These surveys target ecosystem transforming invasive species that are just becoming established, except in backcountry areas, where additional species are also monitored. Some segments monitored by Network staff had already been subject to invasive plant control efforts by park staff, so some infestations could have been missed. The segments surveyed and the infestations detected, and their size in 2011, are shown in Figure 18. In 2009, only one infestation was found, ox-eye daisy (*Leucanthemum vulgare*), along Highway 62.

The trend in invasive species is uncertain. There are no specific data on invasive plant species' trends in Crater Lake National Park. In general, there are ever-increasing numbers of potential invaders. Climate change may increase the susceptibility of higher elevations to invasive species. An increase in fire or fire severity or mechanical treatments will lead to more plant invasions.

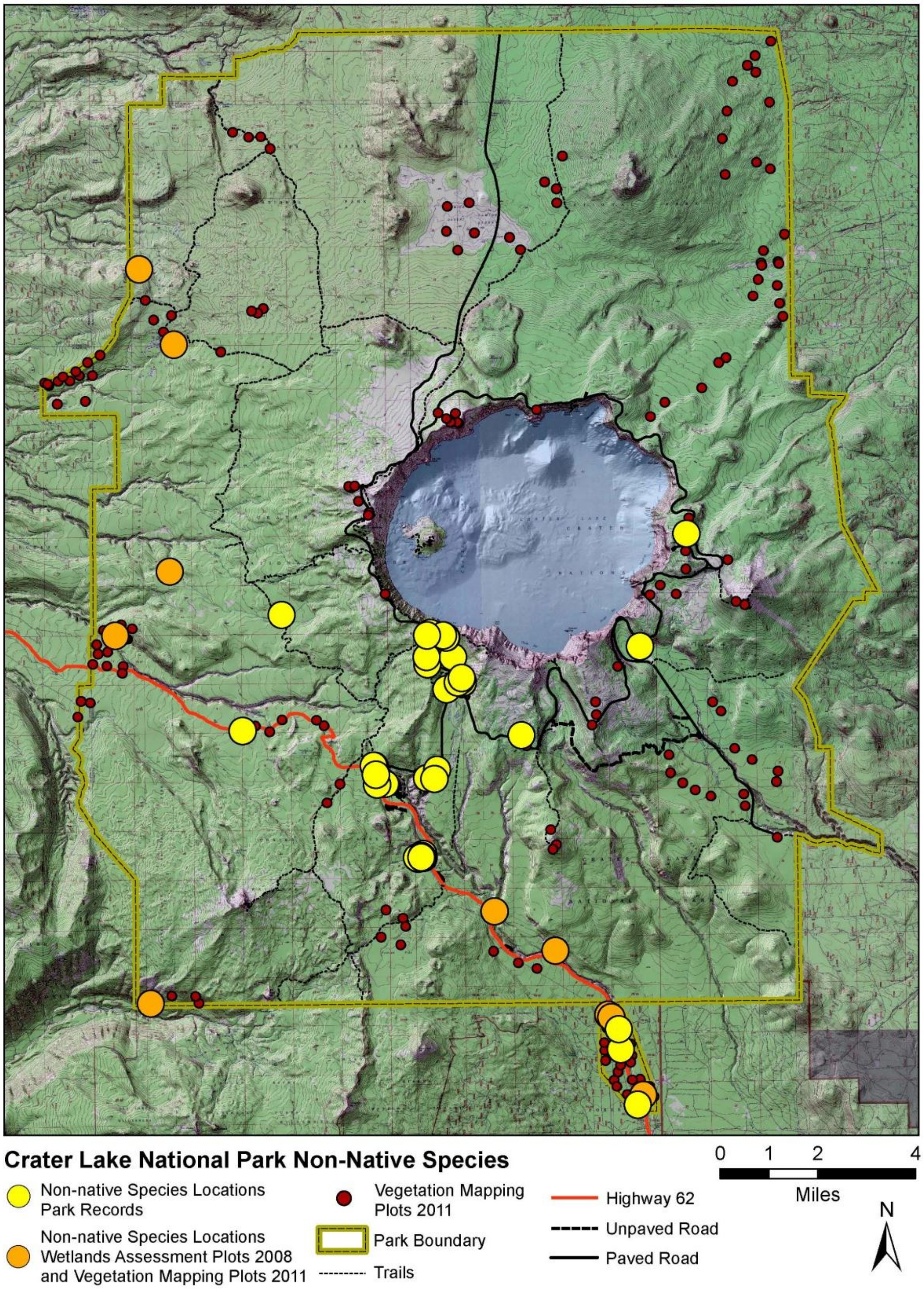

Figure 17. Locations of non-native plants documented at Crater Lake National Park in vegetation mapping plots and wetland plots.

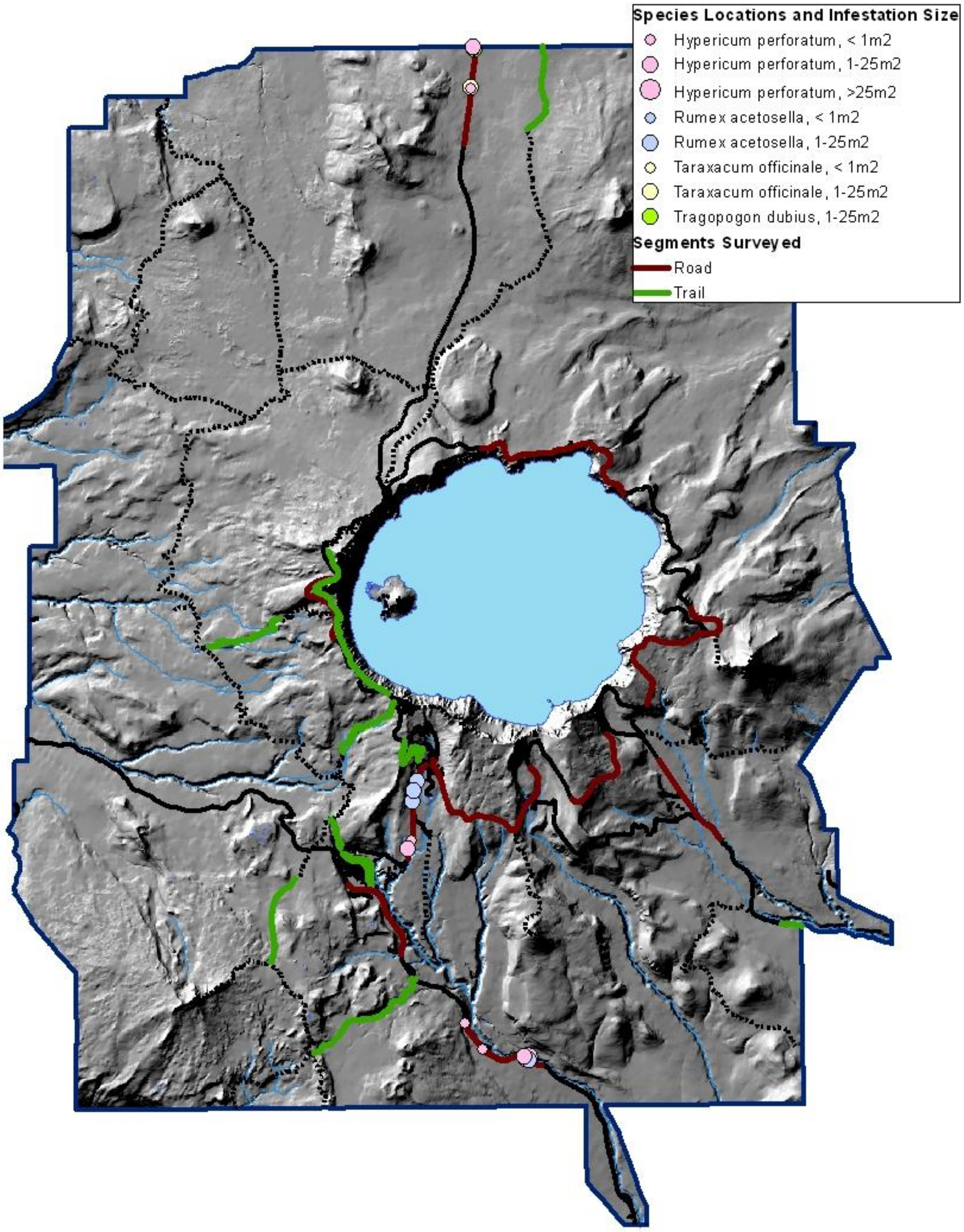

Figure 18. Road and trail segments surveyed for prioritized invasive species in 2011 by the Klamath Network Inventory and Monitoring Program. The locations of infestations, the species, and the infestation size are shown as colored circles.

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 also less likely to be invaded. An early detection program implemented coincident with fire management would address the issue of much higher levels of invasion due to fire and fire management treatments. Such a program could be designed to feed into rapid response control programs and adaptive management as shown in Figure 19.

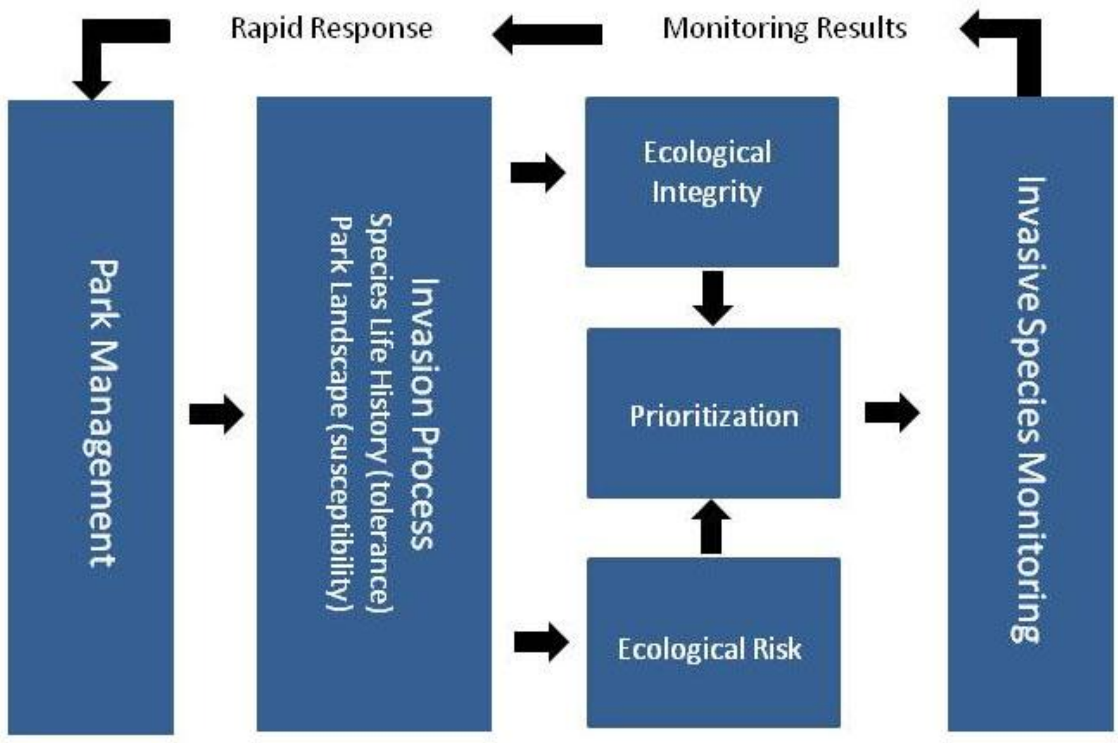

Figure 19. Conceptual model of an invasive species early detection program and the feedbacks with management (Odion et al. 2010).

4.4.4.4 Extent of Invasive Pathogens
Concern about blister rust in whitebark pine stems from the tree's role as both a foundation and keystone species in high-elevation forest communities where it dominates, particularly in the Rockies. It can regulate ecosystem processes, community composition and dynamics, and can 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), and it is known that nutcrackers decrease in whitebark stands as tree mortality increases (McKinney et al. 2009). Whitebark pine also provides important habitat structure for high-elevation vertebrates.

The interactions between the current mountain pine beetle epidemic and blister rust in whitebark pine are not clear. Because the pines are already declining unnaturally due to a non-native pathogen through most of their range, any mortality of white pine, even if it is demonstrated to be independent of blister rust, should be cause for concern.

Criteria
For purposes of this assessment, "Good" conditions 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 greater amounts, significantly reducing the extent of whitebark pine.

Condition and Trends
Condition: *Significant Concern – High Certainty.*
Trends: *Significant Concern – High Certainty*.

Whitebark pine infection rates are about 25% (Smith et al. 2011) and the trees are dying at a rate of about 1% per year (Murray 2010). More recent information suggests that blister rust may be more common than previously believed (Jules et al. 2012).

Available data are insufficient to assess trends in blister rust or other plant pathogens. It is possible that infection rates will remain at 25% and about one percent of trees will continue to die until the population becomes depleted. It is also possible that some disease resistance exists and the rates of infection and mortality will decrease as the population becomes more dominated by resistant individuals. It is further possible that the disease will get worse with climate change, particularly if annual precipitation increases.

The Klamath Network will be monitoring whitebark pine at Crater Lake. From the data, a better assessment of whitebark pine condition will be forthcoming. Additional non-native pathogens may arrive in the future. These, like blister rust, may cause exceptionally high mortality due to host species having little or no evolved resistance.

Assessment Confidence and Data Gaps
Good. Monitoring for blister rust has not been spatially or temporally intensive. Only a rough idea of past and present disease levels exists; nonetheless, the general effects of blister rust described herein are likely to be reasonably accurate.

<u>4.4.4.5 Rare Plants and Diversity of Native Plant Species</u>
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 2000). 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.

Criteria
For purposes of this assessment, “Good” conditions would be represented by sustained 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.

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

Although none of the park’s plants are federally listed as threatened or endangered, three have been federally noted as Species of Special Concern: pumice grapefern (*Botrychium pumicola*), Mt. Mazama collomia (*Collomia mazama*), and Crater Lake rock cress (*Bochera suffrutescens* var. *horizontalis*). Efforts have been made to monitor and restore populations of the collomia impacted by trail maintenance. In addition, the following plant species have been documented in the park and are considered by the Oregon Natural Heritage Program to be vulnerable or imperiled throughout their Oregon range or globally:

Arnica viscosa – sticky arnica
Botrychium lanceolatum – triangle moonwort
Carex abrupta – abrupt-beaked sedge
Carex crawfordii – Crawford's sedge
Carex integra – smooth beaked sedge
Torreyochloa erecta – few-flowered mannagrass
Utricularia minor – lesser bladderwort

The park contains four Research Natural Areas (RNAs) designated by the Oregon Natural Heritage Program. The Desert Creek RNA was designated due to its excellent representation of unlogged and ungrazed ponderosa-lodgepole pine forest with antelope bitterbrush steppe. The Sphagnum Bog RNA is the most distinctive wetland complex in the park and supports an uncommon assemblage of herbaceous plants. Llao Rock RNA is located above the northwest shore of Crater Lake along the rim of the caldera and is one of the major peaks on the rim. Vegetative cover of Llao Rock is sparse and consists mainly of herbaceous species in the open pumice, including two rare species. Its lower parts contain a relatively undisturbed whitebark pine community. The Pumice Desert RNA is a 3055-acre flat, mostly barren area in the northern part of the park. It represents the lodgepole pine/Brewer's sedge community.

Trends in the park’s plant species diversity and rare species in particular are unknown. Whether there are plant species that have been extirpated from the park 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 plant species has been extirpated from the park since its establishment. The sensitivities of various plants to fire suppression and tree removal associated with fuel reduction programs are unknown.

Assessment Confidence and Data Gaps
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. Even the locations of known rare plants are not checked regularly to determine if those individuals are extant.

4.5 Changes in Wildlife

4.5.1 Background
As used herein, "wildlife" refers to terrestrial vertebrates and invertebrates. The opportunity to observe wildlife in natural settings is an important reason many people visit parks. Moreover, wildlife species serve vital ecological roles, such as pollinators, nutrient cyclers, and seed transporters.

4.5.2 Regional Context
In a region where commercial timber harvest operations are widespread, the park preserves a naturally wide range of vegetation associations and successional stages, and thus preserves a diverse forest wildlife community.

4.5.3 Issues Description

4.5.3.1 Fire Suppression and Natural Succession
To varying degrees depending on species, the decades of wildland fire suppression have affected the types of habitat available to wildlife. Reduced fire frequency as well as post-fire salvage logging can result in less shrub cover and fewer snags, which are necessary for many bats, woodpeckers, and other wildlife (Hanson and North 2008, Cahall and Hayes 2009). As in other areas of the Cascades and Sierras, there also is potential for montane meadows to be gradually invaded by conifers as a result of climate change and altered fire regime. This will reduce or eliminate distinctive plant and animal communities associated with that important habitat. Reduced fire frequency will further degrade ponderosa pine forest in the northeastern and southeastern corners of the park. Ponderosa pine is the historical climax tree species in areas frequently burned because it is more fire resistant than other associated tree species (see section 4.4 for further discussion). Reduced extent of ponderosa also increases the likelihood that landscape-level fires will degrade habitat used by both spotted owls (associated with closed-canopy forest) and a number of pine-dependent (open-canopy) species such as white-headed woodpecker (Buchanan 2009).

Figure 20 shows that the amount of mature forest is almost maximized at the current rotation for higher severity fire (i.e., very low rates). Not all of this mature forest would be habitat for all mature forest species. For example, spotted owls do not occur at higher elevations in the park, nor in forests with less than $27m^2$ basal area (Pidgeon 1995, Buchanan and Irwin 1998). Nonetheless, mature forest habitat is available in amounts that may be near historical highs due to lack of fire. With decreasing fire rotation (more fire), mature habitat would decline very little until rotations become far shorter than they presently are. This is because of the regrowth rate of mature forests, which takes only 94 years. Thus, the rotation would have to get close to 94 years before mature forests would begin to decrease substantially. For example, while increasing fire by a factor of three, from a rotation of 1150 to 350 years, would have almost no effect on mature forest amounts, this increase would quadruple habitat for some species. Therefore, the best balance between the habitat needs of fire-dependent and mature forest species would be at rates of fire considerably higher than those occurring today and closer to those that occurred in recent history, before fire suppression.

Because fire-dependent and mature forest dependent species are at opposite ends of the habitat spectrum, and most biodiversity lies between, balancing the habitat needs of these species will likely balance the needs for biodiversity in general. Current management favors mature forest species and disfavors fire-dependent species. However, outside the park mature forests are much less favored because the forests are more subject to logging.

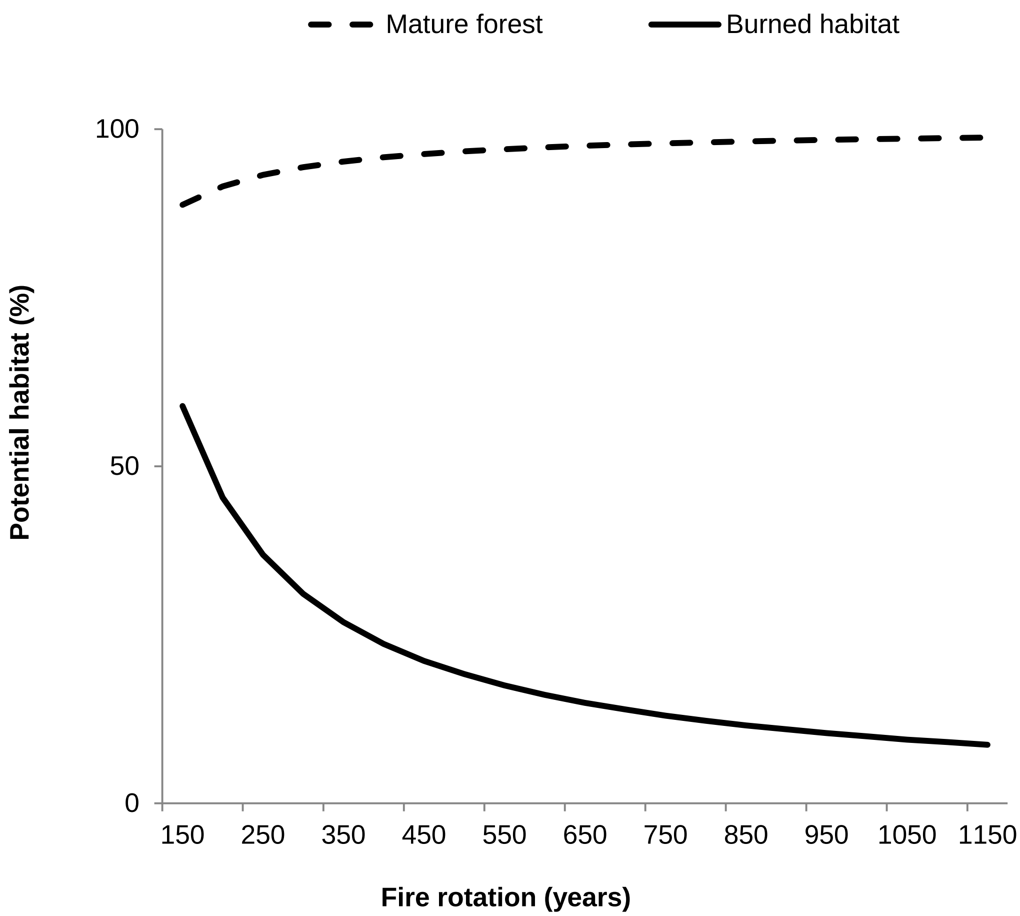

Figure 20. Changes in mature forest created by fire in the study area as a function of fire rotation.

Several wildlife species are also affected by prescribed burns and thinning (Pilliod et al. 2003), practices are implemented by the park for the purpose of reducing understory fuels. A study in the adjoining Umpqua National Forest (McDade 2001) determined that richness of small mammal and amphibian communities, as well as captures of northwestern salamander (*Ambystoma gracile*), were significantly higher in uncut stands than in either thinned forests or clearcuts. Trowbridge shrews, Haplotrema snails, and crickets were also sensitive to tree removal.

4.5.3.2 Climate Change, Water, and Snowpack

The park's boreal species (those whose geographic range is predominantly in states and provinces north of Oregon) are expected to decline the most as a result of warming climate, and some could possibly be lost entirely as breeders in the park. Among the more vulnerable northern bird species are Swainson's thrush (already extirpated from nearly all of the Sierra Nevada), varied thrush, Barrow's goldeneye, black-backed woodpecker, American three-toed woodpecker, northern goshawk, olive-sided flycatcher, hermit warbler, evening grosbeak, gray-crowned rosy finch, Lincoln's sparrow, and fox sparrow.

4.5.3.3 Contaminants

Effects of contaminants on the park's wildlife species have not been monitored. Contaminants such as mercury and persistent pesticides are a potential concern because aerial transport of contaminants into the park from distant areas has been documented (Landers et al. 2008). Bats, swallows, and other aerial foragers are likely to be at greatest risk.

4.5.3.4 Human Disturbance

Some wildlife species, including many avian nest predators (common raven, Steller's jay), are attracted to congregations of people such as at campgrounds, scenic pullouts, and picnic areas. Resulting increases in nest predation can have detrimental effects on songbird populations. Other species, such as badger, appear to avoid inhabited areas. Snowmobiles, a significant disturbance, are allowed only on the North Entrance Road between the northern park boundary and Rim Drive, and on designated routes detouring from that area. Partly to protect vegetation important as wildlife habitat, campfires and wood gathering are prohibited above 6900 feet elevation in this park. Unleashed pets are prohibited from all trails and areas more than 50 feet from roads, but pets on leash and pack animals are allowed with restrictions on certain trails. No private boats are allowed on any park waters, other than those of the permitted concessionaires on the caldera lake. Wildlife populations can also be affected by collisions with vehicles and excessive noise (see section 4.7.4).

4.5.3.5 Habitat Fragmentation

Habitat fragmentation frequently occurs when the home ranges of some forest-dwelling species are interrupted by roads and other cleared areas. In such situations, individuals are often subjected to greater predation, and feeding and reproductive attributes (e.g., genetic isolation) can be interrupted. Roads and traffic result in more road-killed animals, and in extreme cases, noise associated with roads degrades reproductive success of some species. To some degree, wildlife corridors (usually, unaltered bands of natural vegetation that connect larger patches and so create "connectivity") can lessen fragmentation impacts on wildlife, as can management practices that leave relicts of the original vegetation structure within the cleared areas. 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 comprised of suitable habitat patches.

4.5.4 Indicators and Criteria to Evaluate Condition and Trends

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

1. Diversity of native terrestrial wildlife species, including rare species

2. Extent and connectivity of important terrestrial habitats

4.5.4.1 Diversity of Native Terrestrial Wildlife Species; Rare Species

Criteria

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. Further, there are no legally-based numeric criteria for evaluating the degree of "intactness" of any of the park's wildlife communities. No agency, institution, or scientific researcher has defined minimum viable population levels, desired productivity or species richness levels, or other biological criteria relevant to any wildlife species in this particular park. Therefore, the reference basis for this indicator is mainly the professional judgment of the author.

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

Condition and Trends

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

A lower rating is not assigned to condition due to the lack of any evidence of recent extirpations of wildlife species from the park. A higher rating is not assigned because several species that historically were present have been extirpated, most likely because of changing conditions outside of the park. No systematic long term data are available on trends of any of the park's wildlife species.

Mammals. The most frequently seen large mammals in the park are black bear and mule deer. (Black bear were censused in 2009 using remote hair sampling stations.) Fewer numbers of elk and pronghorn are present, although no population or trend estimates are available for these or other mammals within the park. Poaching has been noted within the park but its prevalence is difficult to determine. Although rangeland habitat is not extensive in the park, it provides high-quality habitat for grazing ungulates, especially where close to wetlands (meadows and fens). American pika (*Ochotona princeps*) is found in about 30 locations within the park's subalpine areas; this rabbit relative is believed to be disappearing in many areas of the West (Beever et al. 2003), perhaps due to climate change. American marten is relatively common in the park, though considered "vulnerable" statewide by the Oregon Department of Fish and Wildlife.

Nine species of bats were documented in the park in a 2004-2005 survey that used multiple detection methods (Duff 2005). That investigator considered the bat fauna to be "relatively species poor," probably due to the park's relatively harsh climate. Four of the found species—long-legged myotis, California myotis, silver-haired bat, and hoary bat—are listed as "vulnerable" statewide by the Oregon Department of Fish and Wildlife. Bats in general are a concern due to their low resilience to many environmental disturbances, which is partly because of their low reproductive potential. Vidae Falls Picnic Area, Boundary Springs, and Annie Spring had the greatest abundance of bats.

Bighorn sheep, gray wolf, wolverine, grizzly bear, Pacific fisher, and Canada lynx are suspected to have occurred in the park historically. However, there are no well-documented records presently, and in some cases, there are also no historical records.

Birds. The northern spotted owl, listed by the USFWS as a threatened species, nests in older stands of conifers in 15-18 locations within the park. Overall, both fecundity and annual survival of spotted owls appears to be declining in the southern Oregon Cascades; this decline accelerated between 2003 and 2008 (Dugger 2012). The owl's regional decline is due to habitat loss and fragmentation from timber harvests over the last half of the twentieth century.

Since 1992 the park's spotted owl pairs have been surveyed annually using the established USFWS protocol. The number of adults varies considerably from year to year; since 1991 this has ranged from 6 to about 24. Productivity in the nearby Rogue River-Siskiyou and Fremont-Winema National Forests has followed a strong biannual pattern of alternating high and low years, disrupted by low productivity in both 2005-2006 and relatively high reproduction in both 2009-2010. In that area (and including data from the park), fecundity (number of female fledglings per female per year) fluctuated within the range of 0 to 0.7 between 1990 and 2011 (Dugger 2012). Fecundity in the park has averaged lower than the regional average, perhaps due partly to the park's deep snowpack which may limit prey availability more than at lower elevations (Murphy and Holm 2011). The park represents the uppermost elevation limits and eastern edge of the owl's range in Oregon.

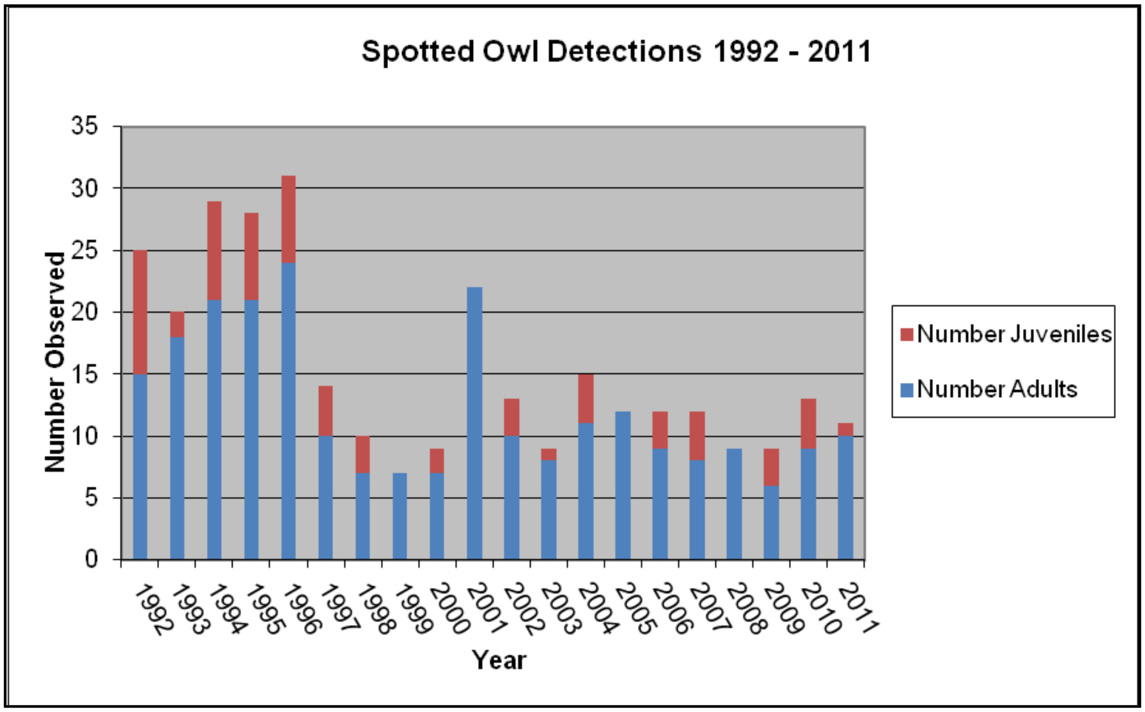

Figure 21. Number of adult and juvenile spotted owls detected in the park, 1992 to 2011 (from Murphy and Holm 2011).

Another species that has nested for many years in the park, peregrine falcon, was also listed for many years by the USFWS as threatened, but has since been delisted due to nationwide population recovery. Although not legally listed, several species that nest (or that may have nested historically) in the park are considered "Vulnerable" by the Oregon Natural Heritage Program due to declines in their statewide population or range extent. These are northern goshawk, black-backed woodpecker, white-headed woodpecker, and olive-sided flycatcher. Additional bird species that nest in the park and are designated as "Vulnerable" by the Oregon Department of Fish and Wildlife are common nighthawk, pileated woodpecker, and American three-toed woodpecker. Finally, gray-crowned rosy finch, a subalpine-nesting species that nests regularly in small numbers within the park, would be expected to be highly sensitive to regional climate warming. Surveys targeting these species have not been conducted. Fortunately, the park does not support any ecologically harmful non-native bird species. Brown-headed cowbird, a native species that parasitizes the nests of many songbirds, has been sighted only rarely.

We investigated the possibility that some bird species may have disappeared as breeders in the park by comparing Farner's (1952) annotated checklist from the 1940s and early 1950s with records from surveys done by volunteers during the 1995-1999 breeding seasons for the Oregon Breeding Bird Atlas project (BBA) (Adamus et al. 2001). Although neither survey sets were comprehensive or quantitative, it is apparent that at least two species once reported to be fairly common breeders in the park, ruby-crowned kinglet and Swainson's thrush, have disappeared as breeders. This is a potential concern. It could be a sign of climate change because these northern species have simultaneously nearly disappeared from the Sierra Nevada range to the south. Additional species reported to be fairly common breeders in the park by Farner (1952) but not detected by the BBA are MacGillivray's warbler, fox sparrow, green-tailed towhee, and lazuli bunting. All are associated with relatively open scrubland, so their decline or possible disappearance might be due to accelerated succession of scrubland to forest in the absence of extensive wildfire. Other species not found by the BBA but noted by Farner (1952) as breeding during the earlier period are killdeer, mountain quail, northern rough-winged swallow, evening grosbeak, and Williamson's sapsucker. All except the last species were described as uncommon or sporadic breeders, so it is possible that the BBA's failure to detect them during the latter period is attributable to their erratic nesting patterns or low numbers within the park.

No long term quantitative trends data are available from within the park for any bird species, with the possible exception of spotted owl which has been monitored using a standardized protocol only since the 1990s. The Klamath Bird Observatory has done mist-net surveys of migrant birds and comparisons of nesting bird abundance across several of the park's vegetation types.

Reptiles. Apparently only three lizard species and one snake species have been confirmed to be present in the park. Survey efforts have been limited so the reptile species total is likely greater. One of those lizard species, the northern sagebrush lizard (*Sceloporus graciosus*), has been designated as "Vulnerable" statewide by the Oregon Department of Fish and Wildlife.

Terrestrial Invertebrates. No systematic, park-wide inventories of terrestrial invertebrates have been conducted. Part of the park's butterfly fauna was described by Tilden and Huntzinger (1977), and additional records might be found in Hinchcliff (1994).

Assessment Confidence and Data Gaps
Low. Although 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.

<u>4.5.4.2 Extent and Connectivity of Important Terrestrial Habitats</u>
What constitutes "habitat fragmentation" depends on the species and the structural characteristics of the land uses that are purported to do the fragmenting. When assessing fragmentation, conservation biologists often consider first the needs of species that have the largest home ranges. Some biologists (e.g., Harrison 1992) have proposed that the width of a typical home range of the focal species be considered the minimum for assessing the sufficiency of a habitat corridor's width. At a landscape scale, an important ecological goal is to sustain corridors or stepping-stones of relatively unaltered habitat. This is especially important along elevational gradients, so as to facilitate upward "migration" of plants and species with limited mobility in response to global warming.

Criteria
For purposes of this assessment, "Good" conditions would be represented by unbroken connectivity of natural vegetation on all sides of the park. "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.

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

Condition is rated Somewhat Concerning because of threats to spotted owls from barred owls as probably related to logging-caused fragmentation of mature forests. The certainty of this linkage and other adverse effects of fragmentation under locally prevailing conditions is Medium. Although trends have not been quantified, an increase in timber operations near the park border during at least the past two decades is apparent. This includes areas of the Rogue River, Umpqua, and Winema-Fremont National Forests. It has been reported that until the 1970s one could not distinguish from aerial photographs where the park's legislative boundary was located in relation to the neighboring national forests, due to the structural homogeneity of connected forest. Since the 1980s, however, significant portions of the landscape along the park boundary have been cut and are now easily distinguishable from uncut forest within the park. Large patches of mature forest which have historically been used by many species as habitat have probably been removed, potentially impacting the species that spend a portion of their day or year foraging between such habitats inside and outside of the park. This is a particular concern because the park’s high elevation and considerable snow depths mean that the winter ranges of many of the park’s species are at lower elevations outside the park. Consequently, changes in those low elevation habitats outside the park will likely affect the park’s fauna. Nonetheless, relative to 30 years ago, timber harvests have been curtailed slightly in this region as a whole.

One species known to be highly sensitive to habitat fragmentation is the spotted owl. A high percentage of the park’s owl nests are near its boundary; this is a concern because some of the most recent and extensive timber harvest in the Winema-Fremont National Forest are also near the park’s boundary. It is plausible that off-site clearcutting could threaten the genetic integrity of the park’s spotted owl population. That is because forests disturbed by timber harvests are tolerated better by barred owl (*Strix varia varia*), a species native to eastern North America which competes, excludes, and sometimes interbreeds with spotted owl (Gutierrez 2006). (Barred owls have smaller home ranges.) Clearcutting also increases the “sharp edges” between mature forest and non-forest which spotted owls avoid (Schilling 2009).

Barred owls were first documented in the park in 1993, and at least seven were found in 2011 (Murphy & Holm 2011). Spotted owl fecundity in the park was substantially higher during the early 1990s before the barred owl arrived. Barred owl detections have risen from 10% of monitored areas before 2000, to over 45% since then. Many of the park’s spotted owl pairs have been displaced by barred owls, but there are still some park locations where barred owls have not yet been detected (Murphy & Holm 2011).

Only about 5% of the off-site land along the park boundary is protected by the Northern Spotted Owl Recovery Plan, which specifies a Designated Conservation Area (DCA) 13 miles south of the park. This designation has the potential to shift additional timber harvest activities on the

National Forest to lands adjacent to the park, thus possibly increasing the expansion of barred owls into the park.

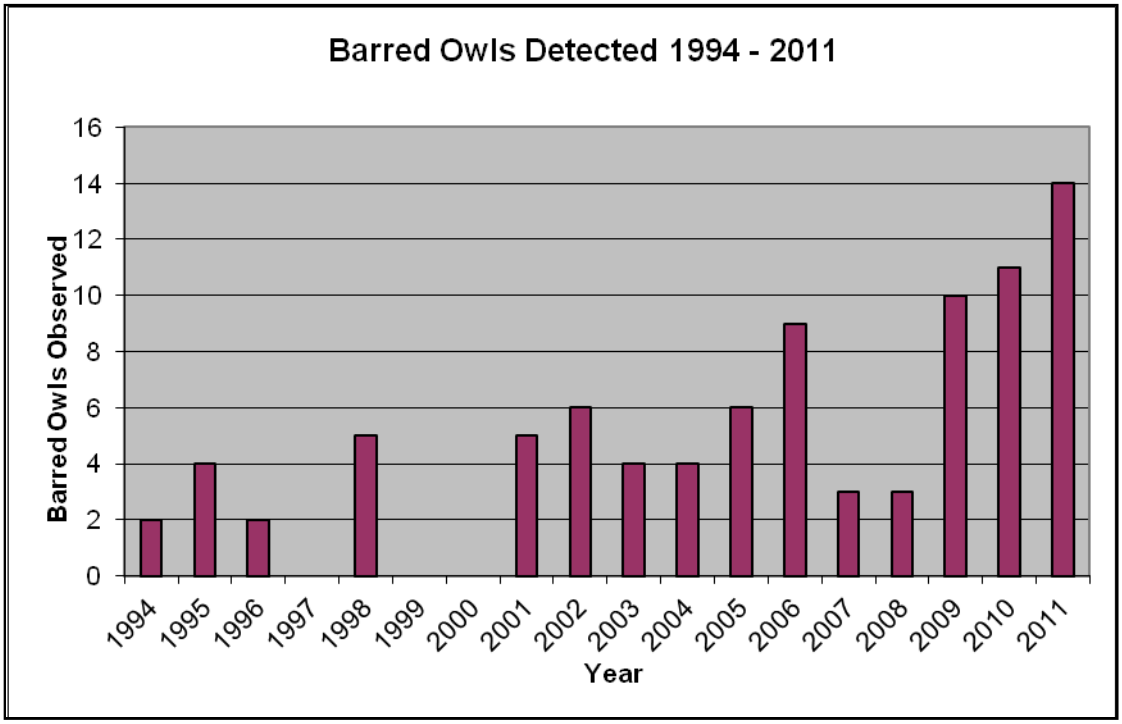

Figure 22. Number of barred owls detected in the park, 1994 – 2011 (Murphy and Holm 2011).

Assessment Confidence and Data Gaps
Low. Land cover change maps for the period 1992-2001 that were generated by the NPScape project do not portray most forest fragmentation that is known to have occurred near the park because they mainly address conversions to agriculture or urban cover. Biological thresholds for metrics relevant to fragmentation (e.g., minimum patch size, corridor width, permeability of disturbed lands to species movements) are species-specific, and these thresholds are unknown for most of the park's species. Various fragmentation metrics have not been measured in the park or in lands surrounding the park.

Assessment Confidence and Data Gaps
Low for condition and trends due to lack of actual monitoring data, but *High* for predictions of future conditions.

4.6 Changes in Air Quality

4.6.1 Background

Air quality is of interest aesthetic, ecologic, and health reasons. Ozone, particulates, wet and dry deposition of nutrients, acidifying substances, pesticides, and other contaminants are monitored in many areas of North America, mainly due to concerns regarding their potentially harmful effects on biological communities and/or human health.

4.6.2 Regional Context

The park is designated as a Class I airshed which is given the highest level of protection under the Clean Air Act. Air quality in this region is generally good. However, surface waters are unusually sensitive to chemical inputs, which are primarily transferred by precipitation. Based on a probability sample, more than 22% of the lakes in the Sierras and Cascades are highly sensitive to increased atmospheric deposition of nitrogen (Baron et al. 2011).

4.6.3 Issues Description

Fires within the park or region have temporarily impaired air quality. But of perhaps greater concern is the deposition of airborne—and mainly particulate—nitrate (N), sulfate (S), and contaminants that are carried to the park from more distant developed areas. Once they enter the caldera lake, these substances are likely to trigger biological changes which, at sufficient levels, will compromise its clarity and disrupt its food web. Specifically, those changes will ultimately increase the density of phytoplankton, thereby reducing water transparency. If N and S deposition causes a lake to be acidified even briefly (e.g., during snowmelt), zooplankton populations in some cases could be diminished. Zooplankton may also be adversely affected by increased N deposition because that added N can spur the growth of some phytoplankton that are less suitable food sources for zooplankton (Elser et al. 2009).

Also, these contaminants could alter soil biogeochemical processes and vegetation throughout the park. Lichens and mosses are particularly sensitive because they largely obtain their nitrogen directly from atmospheric sources (Jovan & McCune 2006, Geiser & Neitlich 2007, Geiser & Fenn 2012). Several other native plants that evolved under nitrogen-poor conditions typical of higher elevations that typify this park could be replaced by invasive species that are able to take advantage of increased nitrogen levels. Relatively high elevations are more at risk because they receive more precipitation and therefore more deposition of N and S particulates. And, short growing seasons and shallow soils at higher elevations limit the capacity of soils and plants to buffer or absorb N and S.

One might expect the caldera lake to be relatively resistant to water quality change because of its large volume and depth, as well as its high alkalinity which buffers it against acidification associated with atmospheric deposition of S and N. However, nutrient studies suggest that algae in Crater Lake are nitrogen-limited. This means they could increase substantially in response to increased nitrogen loading, causing noticeable reduction in the transparency of the caldera lake. An estimated 90% of the nitrogen and 30% of the phosphorus brought into the lake each year come from the atmosphere. Much of the N that enters the lake in atmospheric deposition may be assimilated by algae and subsequently buried in sediments on the bottom of the lake (Dymond et al. 1996). However, if N loading becomes excessive, algae in the water column (phytoplankton) will increase to the point where water transparency will be reduced.

In most areas of the planet, lakes and streams receive most of their N from surface runoff. However, because most of this park is higher than the surrounding terrain outside the park, the park likely receives relatively little runoff-borne nitrate. This suggests that many of the park’s aquatic plants might be ones that are particularly sensitive to N additions, such as from atmospheric deposition. Heightened N deposition in terrestrial areas can decrease the diversity of ectomycorrhizal fungi that are important to forest productivity, as well as triggering a shift from mosses to grasses (Lilleskov et al. 2001).

Ozone levels are also a potential concern. In the lower atmosphere, ozone is an air pollutant, forming when nitrogen oxides from vehicles, power plants, and other sources combine with volatile organic compounds from gasoline, solvents, and vegetation in the presence of sunlight. In addition to causing respiratory problems in people, ozone can injure plants. Ozone enters leaves through pores (stomata), where it can kill plant tissues, causing visible injury, or reduce photosynthesis, growth, and reproduction. In the upper atmosphere, ozone absorbs the sun's harmful ultraviolet rays and helps to protect all life on earth. Phytoplankton in the caldera lake (which reduce the lake's clarity) are more prevalent and occur at shallower depths in years with more stratospheric ozone, perhaps because ultraviolet rays that otherwise harm phytoplankton are absorbed by ozone to a greater degree before reaching the lake (Hargreaves et al. 2007).

4.6.4 Indicators and Criteria to Evaluate Condition and Trends

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

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

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

Criteria

Some aquatic ecosystems respond to wet nitrogen deposition rates of 1.5 kg per hectare per year, whereas there is little or no evidence of ecosystem harm at deposition rates less than 1 kg per hectare per year (Fenn et al. 2003a, b). A study of algae (diatoms) in the eastern Sierras determined that 1.4 kg N per hectares per year (wet N deposition) was a threshold above which a shift in diatom community structure is commonly detected (Saros et al. 2011). In montane lakes of the Yellowstone region, maximum species diversity of phytoplankton was maintained when N concentrations were below 0.7 micro-moles (μmol) of nitrate per liter (Interlandi & Kilham 1998). Diatom assemblages were changed by 1.5 kg N deposition per hectares (Baron 2011, Saros et al. 2011). A recent review and analysis suggested that 1-2 kg N deposition per hectare per year might be the most that many Sierra and Cascade lakes can tolerate (Baron et al. 2011).

To protect all components of the forest ecosystem in the western Sierra Nevada terrestrial environments, Fenn et al. (2008) recommended a critical load threshold of 3.1 kg N per hectare per year. In the Pacific Northwest, many of the most sensitive lichen species are absent from areas where mean annual wet deposition is more than 0.06 mg ammonium (Geiser et al. 2010) and N levels in lichens exceed 0.6% (and S levels exceed 0.07%).

The NPS Air Resources Division (NPS-ARD) has suggested that, for parks with N-sensitive resources (such as Crater Lake), wet nitrogen deposition greater than 1 kg per hectare per year indicates a "Significant Concern." Background levels for N wet deposition in the western U.S. are about 0.13 kg per hectare per year and 0.50 kg per hectare per year for total N deposition. Thus, "Good" condition would be represented by N and S deposition rates being close to the lowest ones detected in the region. "Somewhat Concerning" would be below the NPS-ARD criteria levels but without evidence of biological effects. "Significant Concern" would be when levels are above the NPS-ARD criteria levels and/or ecological changes can be traced to excessive N or S deposition.

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

Based on analysis of N deposition rates and ecosystem sensitivity in all national parks, Sullivan et al. (2011a) placed Crater Lake National Park in the highest category for N enrichment *risk*, terming it "Very High." However, current levels appear to be *Good*.

Levels of atmospheric deposition of N and S in the park as measured in 2007 and reported by Geiser and Fenn (2012) are low compared to other Pacific Northwest sites measured the same year, and are comparable to values observed in 2008 and 2009 in Southeast Alaska and historical background levels of 0.4-0.7 kg N per hectacre per year for North America (Holland et al. 1999). Measurements came from 4 samplers placed at an open site and 12 under the canopy of an adjacent forested site inside the western boundary of the park. For total N, the mean annual deposition at open sites (an estimate of wet deposition) was 0.75 kg N per hectare per year. Mean deposition under the forest canopy, an estimate of total deposition from wet plus solubilized dry deposition collected on conifer needles between precipitation events, was lower, i.e., 0.50 kg N per hectare per year, suggesting partial uptake of nutrients by the canopy. The park's good air quality as defined by the presence of these substances is probably due to its remote location and the absence of air inversions such as those that hold pollutants in the valleys elsewhere in the region.

However, in contrast to the direct measurements described above, estimates interpolated by the NPS Air Resources Division (2010, 2011) suggest the levels might be greater than natural deposition rates. Those interpolations predict that during the period 1999-2003, wet deposition in the park may have averaged 0.31 kg ammonium (NH_4) per hectare per year and 1.31 kg nitrate (NO_3) per hectare per year. During the period 2006-2010, wet deposition as estimated by spatial interpolation may have averaged 1.2 kg per hectare per year NH_4, 3.6 kg per hectare per year NO_3 and 1.7 kg per hectare per year total N (as opposed to 0.50-0.75 kg per hectare per year total N determined from direct measurement within the park). If N wet deposition levels have been correctly interpolated to the park, the current levels would slightly exceed the 1.0 kg per hectare per year NPS Air Resources Division criterion and should be considered a "Significant Concern" given the sensitivity of the receiving waters (NPS Air Resources Division 2010, 2011). However, the direct onsite measurements may be more accurate, and N deposition currently does not appear close to triggering significant ecological changes.

Total N taken up by lichens has also been measured. The Western Airborne Contaminants Assessment Project (Landers et al. 2008) found that nitrogen levels in lichens sampled at five locations in the park were within background ranges for remote sites in the Pacific Northwest. The species composition of the park's lichen community also indicates near-pristine conditions (Geiser and Fenn 2012). Further, lichen tissues from 2007 were analyzed by the same investigators, and they determined that percent N concentrations, measured at 0.025%, were within background ranges (and about half the threshold for ecological impact) as drafted by the Forest Service for clean sites in the region and for the species collected.

In the case of sulfate, the risk to the park's ecosystems of harmful acidification was termed "high" by Sullivan et al. (2011b). Spatially interpolated sulfate (NPS Air Resources Division

2010, 2011) was estimated at 1.70 kg sulfate per hectare per year during the period 1999-2003 and 2.9 kg sulfate per hectare per year (and 1.0 kg total S per hectare per year) during 2006-2010. If accurate, this would indicate a "Significant Concern" according to NPS-ARD (2011). However, analysis of S in lichen tissues collected directly in the park in 2007 by Geiser and Fenn (2012) indicated that the percent S composition (0.032%) is about half the threshold suggested by the Forest Service for ecological damage from S deposition.

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

Assessment Confidence and Data Gaps
Medium. The data from Geiser and Fenn (2012) provide a limited baseline because they were collected at just a single location in the park, at 4,875 ft elevation. The interpolated estimates from NPS-ARD were calculated only for the center of the park. Deposition is known to vary significantly by elevation. However, relative N-sensitivities and N exposures of other lichen species, aquatic species, ecosystems, and locations within the park are unknown.

<u>4.6.4.3 Airborne Contaminant Deposition</u>
Toxics, including heavy metals like mercury, accumulate in the tissue of organisms. When mercury converts to methylmercury in the environment and enters the food chain, effects can include reduced reproductive success, impaired growth and development, and decreased survival. Other toxic air contaminants of concern include pesticides, industrial by-products, and flame retardants for fabrics. Some of these are known or suspected to cause cancer or other serious health effects in humans and wildlife.

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

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

Although herbicides are used along park roads for controlling invasive weeds, none are currently used in areas that drain to the caldera lake.

Concentrations of air contaminants potentially toxic to aquatic life have been found to be elevated in air and vegetation samples from the park (Landers et al. 2008). These include combustion by-products (PAHs), current-use pesticides (endosulfans, dacthal), and historic-use pesticides (HCB, a-HCH). Among 18 western national parks that were sampled, Crater Lake ranked sixth in terms of mean pesticide concentration in conifer needles, including pesticides currently registered nationally for use. Total pesticide concentration averaged about 125 ng per gram lipid; no criteria are available to interpret biological consequences of such a level.

In addition, the Western Airborne Contaminants Assessment Project (WACAP, Landers et al. 2008) determined that lichens and conifers sampled at five sites within the park were contaminated with several pesticides currently used outside the park, especially endosulfans and dacthal, but also chlorpyrifos and g-HCH (lindane). These contaminants were mostly at or slightly above the levels found in other western parks. Concentrations increased with elevation within the park. Semi-volatile organic compounds of human origin were also present, especially PAHs (a combustion byproduct) and the historically used pesticides chlordane, DDT, HCB (hexachlorobenzene), and a-HCH (alpha hexachlorocyclohexane). Although at very low levels, PCBs were detected as well.

In contrast, the concentrations of heavy metals (including mercury) from lichen tissues collected in 2007 by Geiser and Fenn (2012) were within background ranges drafted by the Forest Service for clean sites in the region and for the species collected. Mercury concentrations and their potential for causing abnormalities in reproductive organs in fish are being examined by a separate study that includes Crater Lake as well as other parks, but results are not yet available.

Assessment Confidence and Data Gaps (all airborne pollutants)
Low. Too few measurements have been made to determine trends or even the existing levels of airborne contamination within the park. To date, the only data for airborne contaminants come from the few one-time measurements of selected hydrocarbons in conifer needles as determined by the WACAP project, and the single location sampled by Geiser and Fenn (2012).

<u>4.6.4.4 Ozone</u>

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. Summarizing the literature, Geiser & Neitlich (2007) note that ozone levels of 20 to 60 µg per m^3 may harm some lichens (Eversman and Sigal 1987, Egger et al. 1994). Of the park's many vascular plants, those most sensitive to ozone were predicted to be spreading dogbane, ponderosa pine, quaking aspen, Scouler's willow, and common snowberry. However, damage thresholds have not been determined.

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

Ambient concentrations of ozone are not regularly monitored within the park, but the NPS has interpolated concentrations from other locations. For the period 2005-2009, average ozone conditions were deemed a "moderate" risk to human health. An NPS risk assessment also projected that the park's vegetation is at "moderate" risk from ozone compared with other Klamath Network parks (NPS 2004). Exposures to concentrations of ozone greater than 100 ppb (a damage threshold) were highly variable, and in some years reached a significant number of hours. Because ozone information for the park has only been interpolated, trends cannot be validly determined.

Assessment Confidence and Data Gaps
Low. Ozone levels are not currently measured directly in the park. Instead they are interpolated from measurements elsewhere in the region. Ambient ozone monitoring and determination of ozone effects on the park's plants (especially the community composition of lichens and mosses) would be useful.

4.7 Changes in the Natural Quality of the Park Experience

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

4.7.2 Regional Context
Crater Lake National Park and adjoining national forests of the Cascades together comprise a large area with relatively minimal disturbance. They are within a day's drive of Portland, San Francisco, and some other major cities, providing recreation and a connection with nature to hundreds of thousands of visitors each year.

4.7.3 Issues Description
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.

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

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

<u>4.7.4.1 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, and when fossil fuels are burned which results in soot and tiny visibility-reducing particles (aerosols). In rural areas such Crater Lake, the greatest contributors to reduced visibility are carbon and, especially, sulfate. An NPS study in the Pacific Northwest during the summer of 1990 found that sulfates accounted for over 40 percent of the visibility reduction, whereas carbon (organics and light absorbing carbon) was responsible for about 20 percent, and nitrates and coarse mass for 10 percent. The 1977 amendments to the Clean Air Act declared the park a

mandatory Class I area and charged the Federal Land Manager with a responsibility to protect air quality related values, including visibility.

Criteria
The visibility criteria used by the NPS are based on the deviation of the current Group 50 visibility conditions from estimated Group 50 natural visibility conditions, where Group 50 is defined as the mean of the visibility observations falling within the range from the 40th through the 60th percentiles. Visibility is estimated from the interpolation of the five-year averages of the Group 50 visibility. Visibility in this calculation is expressed in terms of a Haze Index in deciviews (dv); as the Haze Index increases, the visibility worsens. The visibility condition is expressed as current Group 50 visibility minimums, the estimated Group 50 visibility under natural conditions. Good condition is assigned to parks with a visibility condition estimate of less than 2 dv above estimated natural conditions. Parks with visibility condition estimates of 2-8 dv above natural conditions are considered to be in Moderate condition, 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 and Trends
Condition: *Significant Concern – Medium Certainty.*
Trends: *Improving – Low Certainty.*

The most recent NPS assessment, based on measured conditions during 2005-2009, rated the park's visibility a "Significant Concern" (NPS-ARD 2011). Nonetheless, visibility is substantially impaired for only 4.6 percent of all daylight hours during a year, which is much less than for visibility monitoring stations further north in Oregon. Crater Lake is, in fact, often the standard used when judging air quality in other areas. By contrast, Mount Hood's visibility is impaired 21 percent of the time, while Oregon's Mount Washington registers 42 percent visibility impairment and Portland's visibility is 85 percent impaired.

Regardless of the park's current condition, during both the period 1999-2008 and the period 2005-2009, IMPROVE[12] data collected in the park indicated that visibility (measured in deciviews) improved significantly on the clearest days, and showed no trend on the haziest days.

Assessment Confidence and Data Gaps
Medium. The park began visibility monitoring in 1982 and is currently monitoring fine particles and visibility as part of the IMPROVE network. The IMPROVE data describe the visibility conditions well, but results have been interpreted in different ways. The park continues to monitor particulates with a year-round IMPROVE particulate sampling site and a summer-season nephelometer.

4.7.4.2 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

[12] IMPROVE = Interagency Monitoring of Protected Visual Environments

rely on natural patterns of light and dark for navigation, to cue behaviors, or hide from predators. Human-caused light may be obtrusive in the same manner that noise can disrupt a contemplative or peaceful scene. Light that is undesirable in a natural or cultural landscape is often called "light pollution."

Criteria
The NPS has 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. No consensus has been reached on what the reference values should be.

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

No baseline condition or trend has been established for this park using the standard protocols for measurement. Nonetheless, the park’s remote setting suggests that conditions are likely good.

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

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

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

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

Using automated acoustical monitoring systems, the NPS Natural Sounds Program measured sound for about 30 days at a time from June 2010 to October 2011 at 22 locations throughout the park. SPL measurements were taken, digital audio recordings were made, and meteorological data were collected. The equipment makes 33 SPL measurements for a set of frequency bands that span the range of human hearing (12.5 - 20,000 Hz). Results are summarized in Table 10.

Table 10. Percent of time sound levels exceeded various levels in two frequency ranges at 22 locations in Crater Lake National Park (from NPS-NSP 2012).

Frequency (Hz)	Statistic	% of time above sound level during hours of 0700 to 1900				% of time above sound level during hours of 1900 to 0700			
		35 dBA	45 dBA	52 dBA	60 dBA	35 dBA	45 dBA	52 dBA	60 dBA
12.5 to 20,000	Mean (n= 22 sites)	11.86	0.81	0.14	0.01	22.50	10.21	3.79	1.05
	Minimum	0.96	0.06	0.00	0.00	0.28	0.00	0.00	0.00
	Maximum	33.89	5.54	1.11	0.06	62.47	49.83	42.62	22.15
20 to 1250	Mean (n= 22 sites)	8.83	0.47	0.08	0.00	3.16	1.12	0.37	0.00
	Minimum	0.77	0.06	0.00	0.00	0.21	0.00	0.00	0.00
	Maximum	31.08	1.18	0.21	0.01	48.37	24.06	8.13	0.00

The most persistently "noisy" of the monitored locations was near Quillwort Pond, less than one mile south of one of the most recreationally active parts of the park. The Natural Sounds Program will be comparing the sound level data above with those from other national parks.

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

- *Wildlife:* During the morning and throughout the day, the vocalizations of songbirds are a dominant feature, along with the chattering of chipmunks and squirrels. In the evening and at night, tree frogs and crickets are common, along with owls (great-horned, spotted, saw-whet).
- *Water:* Flowing water in streams and waterfalls, water dripping off of snow banks.
- *Wind:* Especially on the caldera rim. Wind blowing through the trees, and trees creaking/rubbing against each other.
- The whisper of snowfall, and varied sounds of rainfall on vegetation and the ground.
- Occasionally some memorable thunderstorms.

Loud sounds that sometimes adversely affect the park's 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.
- *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/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.
- *Forestry work:* This intrusion is created by chainsaws, chippers, and other powered equipment used to cut hazard trees or do thinning in campground areas, and for some trail work. These sounds are significant but infrequent and irregular in occurrence.
- *Aircraft:* This intrusion is mostly high elevation commercial flights but heard regularly everywhere in park. Illegal lower-elevation overflights occur. Aircraft used in fire suppression and fire monitoring also have a transitory impact.
- *Boats on the caldera lake:* These are few and tightly controlled, so noise is experienced primarily by passengers.

Using acoustical monitoring systems, the NPS Natural Sounds Program measured sound from June 2010 to October 2011 at 22 locations throughout the park for about 30 days at a time. Sound pressure level (SPL) measurements were taken (in decibels), as well as digital audio recordings and meteorological data. The Natural Sounds Program equipment makes 33 SPL measurements for a set of frequency bands that span the range of human hearing (12.5 - 20,000 Hz). The amount of time that SPLs are above certain values is one way of quantifying human-sourced interference with natural sounds.

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

<u>4.7.4.4 Physical Remoteness and Solitude</u>

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

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

No numeric criteria exist for assessing these.

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

The number of tourist visits, hence the volume of automobile traffic, has increased gradually (1986 at 428,000; 1995 at 543,000), with a majority of all visitors coming to the park between June and September. However, the annual numbers of park visitors appear to have not varied significantly over the past decades. By far the most visitors spend the bulk of their time at the caldera lake overlooks and associated facilities.

Park staff proposed wilderness boundaries in 1974, 1984, and 1994. The park currently manages as wilderness only those areas that were proposed in 1974; the 1994 proposal modified earlier 1974 and 1984 wilderness proposals and delineated clearer boundaries for areas excluded from the wilderness designation. The 1994 wilderness proposal included the entire park except for exclusions for road corridors, utility lines, and administrative sites. The legislative process has not been completed for the Crater Lake National Park Wilderness Designation proposal. However, NPS policy is to "take no action that would diminish the wilderness suitability of an area possessing wilderness characteristics until the legislative process has been completed. Until that time, management decisions pertaining to lands qualifying as wilderness will be made in expectation of eventual wilderness designation. This policy also applies to potential wilderness, requiring it to be managed as wilderness…"

Partly as a result of the restrictions, most park visitors who seek it are likely to find many opportunities for physical remoteness and solitude. Data are insufficient to detect any trend in Physical Remoteness and Solitude.

Assessment Confidence and Data Gaps:
Medium. Although total visits to the park are tallied annually, visits to various areas within the park are not routinely tallied, nor are the disturbances potentially associated with those visits.

<u>4.7.4.5 Disturbed Area Recovery</u>
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 and 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 park staff.

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

Condition and Trends
Condition: *Somewhat Concerning– Moderate Certainty*.
Trends: *Improving.*

Since designation of the park, construction has occurred as necessary to provide for transportation, park administration, and visitor services and access. Inevitably, development has disturbed or displaced natural vegetation and soils. Among the most noticeable effects on vegetation are those resulting from construction of park facilities and roads, trail erosion, vegetative trampling at vistas and developed areas, and abandoned dumps and borrow pits. Known quarry and borrow pit sites that have been abandoned are described in the Resource Management Plan. However, there also may be several unknown landfills. For example, one year a release of oil was discovered near the south end of the park; while cleaning up the oil release, park staff found a buried railroad tanker car apparently used to store road oil and subsequently abandoned. During the same cleanup operation another asbestos lined tank was discovered that had apparently buried in a make-shift land fill (Mac Brock, pers. comm.).

Severe cuts along the park's major road system have resulted in slope erosion from water and wind action. Some previously paved areas have been abandoned as roads and visitor use areas have been relocated or developed. Often, few or no efforts were made to rehabilitate these areas following abandonment. In other cases the asphalt was simply covered with soil or was partially scarified and covered with soil. For the park as a whole, natural succession and planned restoration appears to be gradually leading to visual recovery in most areas historically disturbed by logging or other disruptions. However, some evidence of damage persists and may detract from the visitor experience. Specifically, these areas include the abandoned Annie Springs Campground, the abandoned East Entrance Road, abandoned portions of the South Entrance Road, and abandoned portions of the Rim Road. Disturbed areas are often more susceptible to invasion by alien plant species.

Backcountry impacts are resulting from erosion of trails, visitor short-cutting of trails, day use impacts at popular sites, and damage from overnight camping. Fill is often needed to repair trails, especially the filling and revegetation of social trails (unofficial shortcuts). Often only small amounts of gravel and soil are needed to repair washed-out trail sections, but sometimes relatively large quantities of rock are required to fill deeply eroded trails. Where possible, material is salvaged from roadside ditch-cleaning, and is brought in from outside the park only when no in-park alternative exists, so that the risk of introducing non-native plants is minimized. Virtually all trails through the park’s wilderness were originally fire roads. These trails are now a two-track remnant of an old road which, because of compaction, contains diminished vegetative cover.

Off-road vehicle use (which is illegal in the park) has occasionally occurred, especially in the Pumice Desert, a unique landform. This has resulted in long-lasting tracks, impacts to sparse vegetation, and possibly changes in vegetative succession.

Assessment Confidence and Data Gaps
Moderate. Land disturbances have not recently been systematically inventoried throughout this park, but staff is generally aware of locations.

5.0 Discussion

Table 11 summarizes what this document has reported about the condition and trend of each of the major resource concerns at Crater Lake National Park. Partly because the caldera lake is the main feature drawing people to the park, the greatest attention has been paid to monitoring and maintaining the lake's water quality, particularly its distinctive color and clarity. Factors that may support that will benefit from additional research, and could include the seasonal timing, sources, and transport and cycling rates of various micronutrients, fine particulates, and naturally-occurring organic substances. Linking these factors to the taxonomic composition of algae at various depths and seasons in the lake could provide an early warning of changes in lake nutrient status that could affect its clarity and color. Lake water quality is currently excellent, but a trend towards earlier thermal stratification of the lake (an event of critical importance to its ecology) is somewhat concerning. That trend appears to be related to increased springtime air temperature and decreased springtime snow depth. Relatively little is known of the water quality, water levels, and biology of the park's other ponds, nor of its streams. Understanding the condition and trends of these, as may be gained by additional monitoring and research, is essential to their sound management.

Aside from issues surrounding the caldera lake, the most significant natural resource concerns in this park are considered to be the altered distribution of forest stand ages. This is associated with major changes in physical structure at the stand and landscape scales, as well as longer periods between fires and increased extent of invasive pathogens (mainly, blister rust impacts to whitebark pine). 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 forest types. This will restrict the park's capacity to effectively support the region's wildlife and plant diversity. However, as explained earlier in this report, the lack of fire may be beneficial to some native plants by helping reduce the threat of invasive plants. This creates a resource management conundrum. A greater understanding is needed of possible relationships between timber harvests in adjoining national forests (and fuel reduction cuts within the park) and the recently increased occurrence of barred owls, which adversely affect the federally listed spotted owl. Also, given the probability of climate warming in this region, additional monitoring of the park's subalpine plants and animals (e.g., gray-crowned rosy finch), as well as streamflow points of initiation, seems warranted. A better understanding of the level of blister rust infection on whitebark pine is needed.

Table 11. Summary of ratings for indicators of condition and trend used in this analysis of Crater Lake National Park. See chapter narratives for criteria and justification of each rating.

Priority Issue	Indicators	Potential Value as Indicator	Condition Rating	Certainty	Trend Rating	Certainty	Spatial Coverage	Temporal Coverage
Changes in Precipitation, Snowpack, and Water Availability	Annual Depth, Volume, and Persistence of Snowpack	Excellent	Indeterminate	n/a	Somewhat Concerning	Medium	Poor	Poor
	Water Level Elevations in Crater Lake	Excellent	Good	High	Somewhat Concerning	Medium	Excellent	Excellent
	Flow in Streams and Springs	Excellent	Good	Low	indeterminate	n/a	Poor	Poor
	Number, Area, and Distribution of Wetlands, Ponds, and Lakes	Fair	Good	Medium	indeterminate	n/a	Excellent	Poor
Changes in Surface Water Quality	Water Quality in Crater Lake	Excellent	Good	High	Somewhat Concerning	Medium	Excellent	Excellent
	Water Quality in Other Water Bodies	Excellent	indeterminate	n/a	indeterminate	n/a	Poor	Poor
Changes in Aquatic Life	Changes in Productivity & Diversity in Crater Lake	Good	Good	Medium	indeterminate	n/a	Good	Fair
	Changes in Productivity & Diversity in Other Water Bodies	Good	Somewhat Concerning	Low	indeterminate	n/a	Fair	Poor
	Changes in Ecologically Harmful Aquatic Species	Good	Somewhat Concerning	Medium	indeterminate	n/a	Fair	Poor
Changes in Terrestrial Vegetation	Distributions of Stand Ages	Excellent	Significant Concern	Medium	Significant Concern	Medium	Good	Fair
	Fire Rotations	Good	Significant Concern	Medium	Significant Concern	Medium	Good	Fair
	Extent of Invasive Plant Species	Fair	Good	Medium	indeterminate	n/a	Good	Poor
	Extent of Invasive Pathogens	Fair	Significant Concern	High	indeterminate	n/a	Good	Poor

Table 11 (continued). Summary of ratings for indicators of condition and trend used in this analysis of Crater Lake National Park. See chapter narratives for criteria and justification of each rating.

Priority Issue	Indicators	Potential Value as Indicator	Condition Rating	Certainty	Trend Rating	Certainty	Spatial Coverage	Temporal Coverage
	Rare Plants and Native Plant Diversity	Poor	Indeterminate	n/a	indeterminate	n/a	Poor	Poor
Changes in Wildlife	Diversity of Native Terrestrial Wildlife Species; Rare Species	Fair	Somewhat Concerning	Low	indeterminate	n/a	Fair	Fair
	Connectivity and Extent of Important Terrestrial Habitats	Fair	Somewhat Concerning	Medium	Somewhat Concerning	Medium	Good	Poor
Changes in Air Quality	Deposition of Atmospheric Nitrogen and Sulfur	Fair	Good	Medium	indeterminate	n/a	n/a	Good
	Deposition of Airborne Contaminants	Fair	Somewhat Concerning	Low	indeterminate	n/a	n/a	Poor
	Ozone	Fair	Somewhat Concerning	Low	indeterminate	n/a	n/a	Good
Changes in the Natural Quality of the Park Experience	Visibility	Good	Good	Medium	Improving	Medium	Poor	Poor
	Dark Night Sky	Good	indeterminate	Low	indeterminate	n/a	Poor	Poor
	Soundscape	Good	Good	High	indeterminate	n/a	Good	Poor
	Physical Remoteness and Solitude	Fair	Good	Medium	indeterminate	n/a	Excellent	Poor
	Recovery of Disturbed Areas	Fair	Somewhat Concerning	Medium	Improving	Medium	Excellent	Poor

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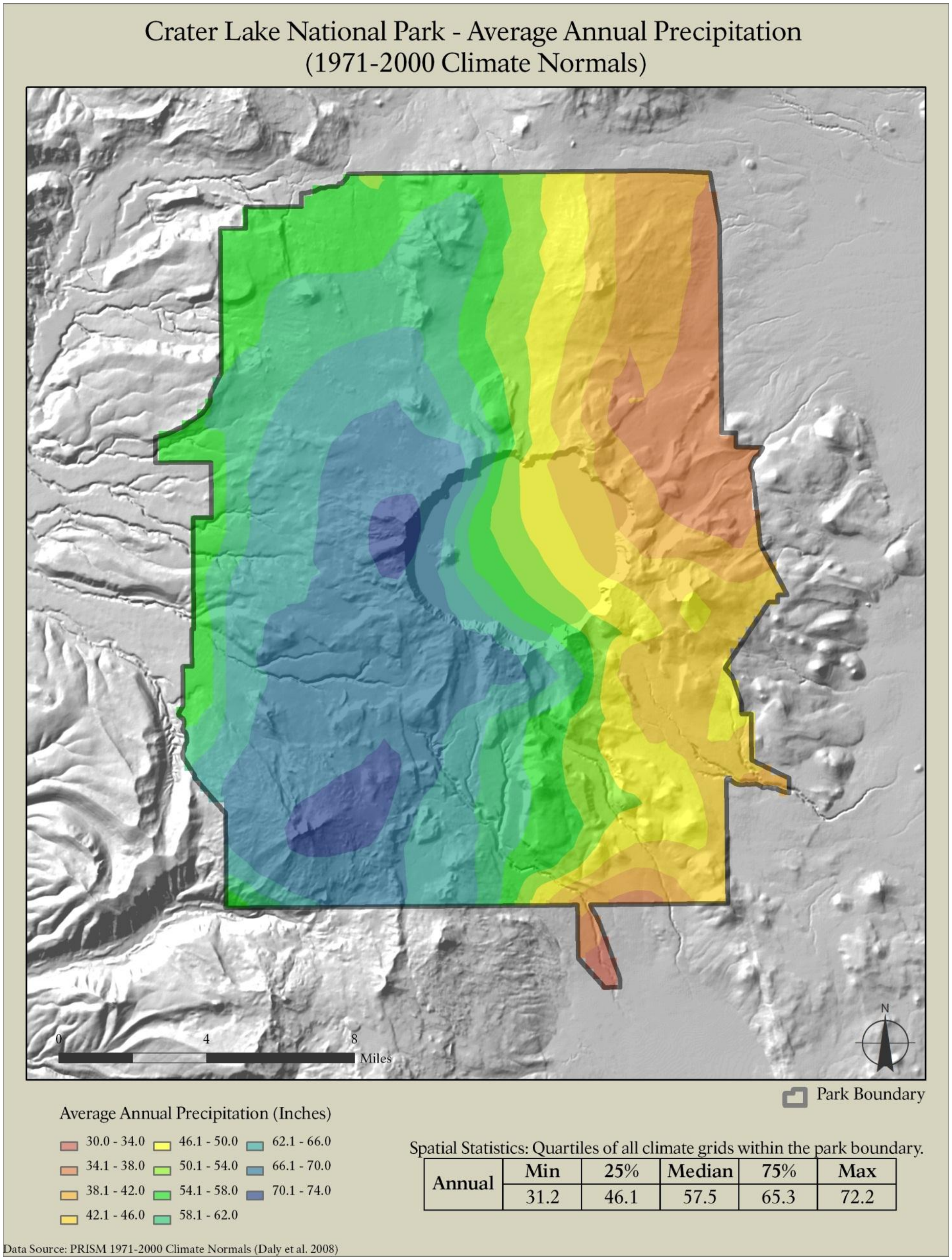
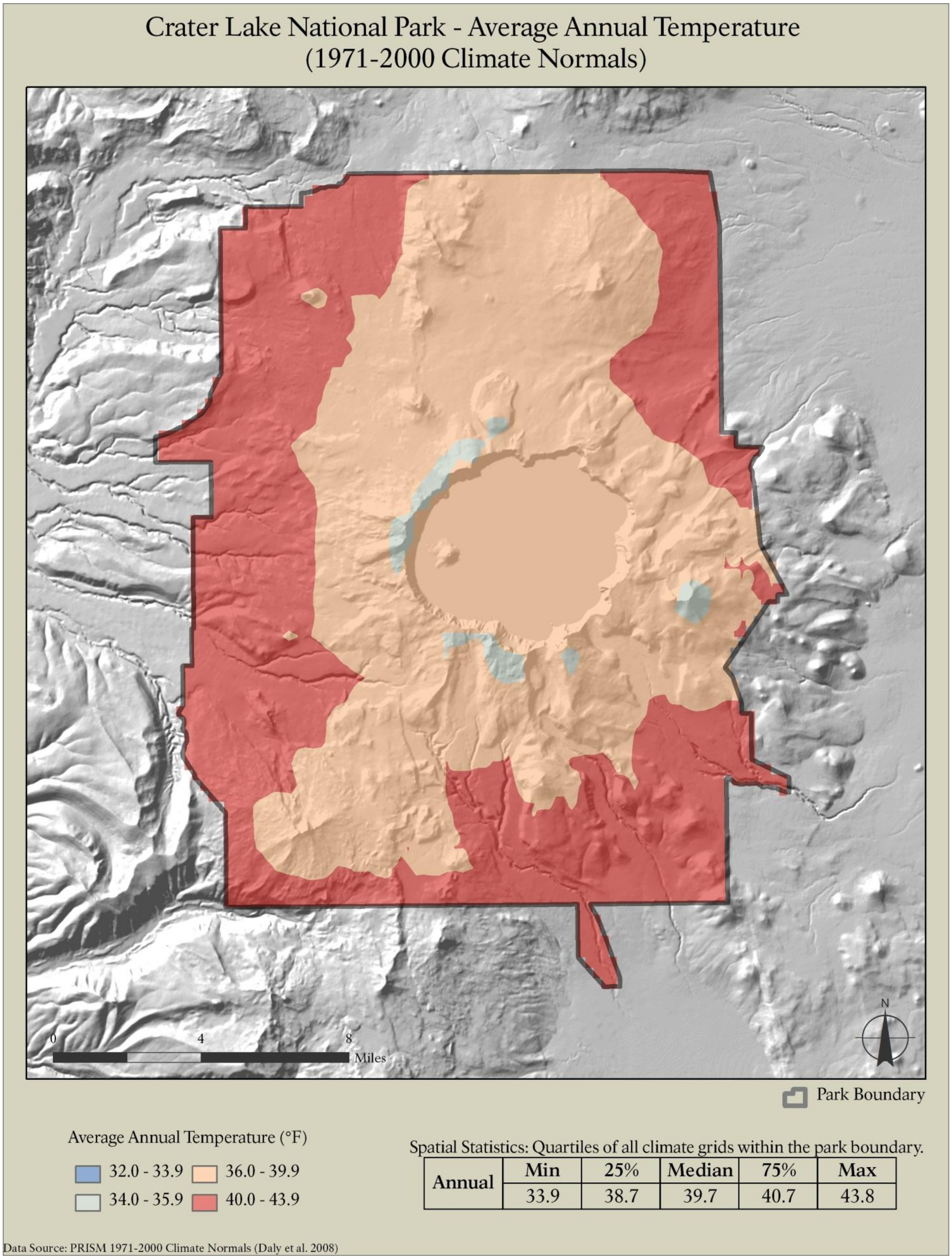
Appendix A. Climate of Crater Lake National Park: supporting data and maps



	Min	25%	Median	75%	Max
Annual	31.2	46.1	57.5	65.3	72.2

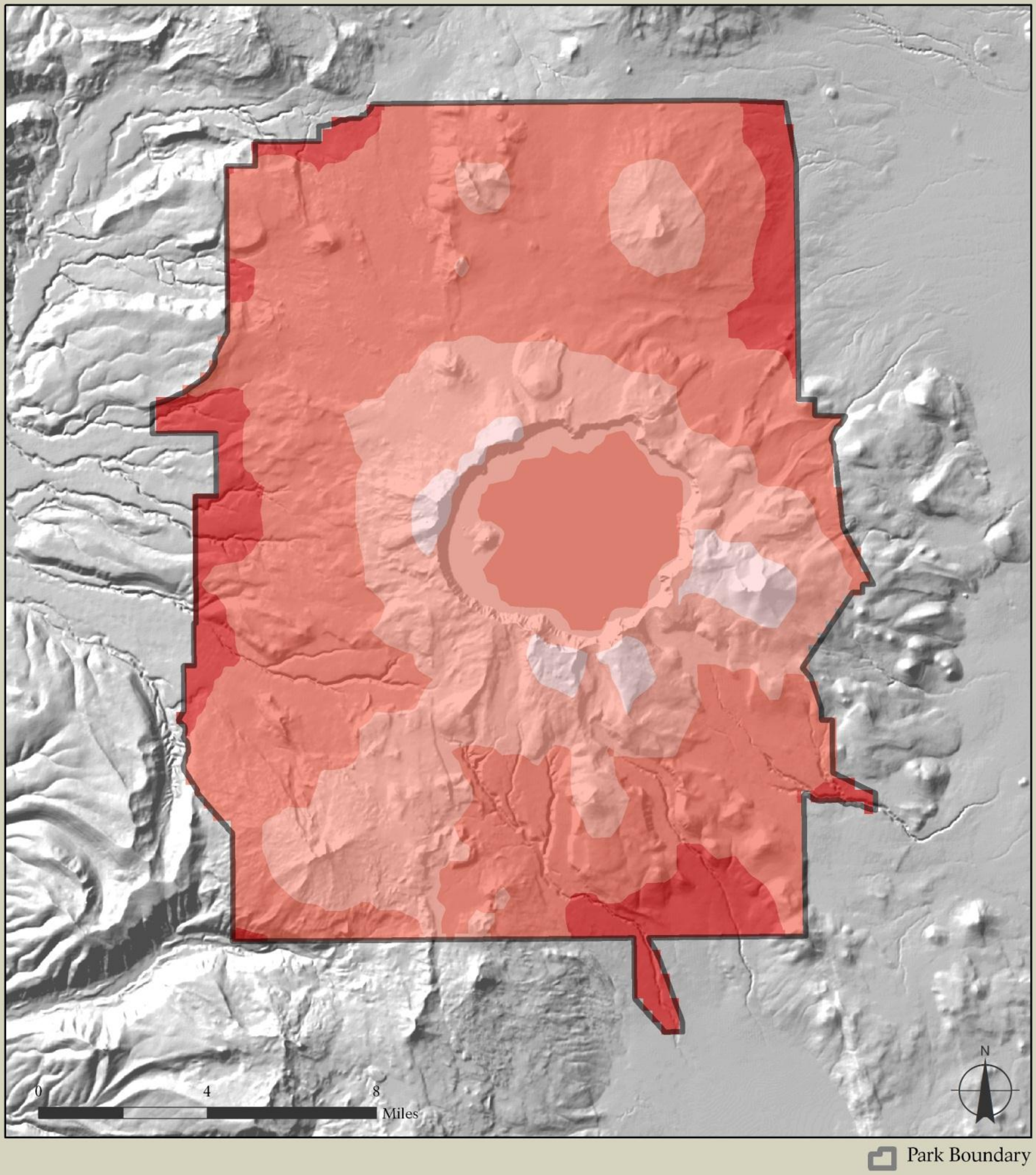
Figure A1. Annual precipitation for Crater Lake National Park (CRLA) from the PRISM 1971-2000 Climate Normals (Daly et al. 2008). This map was prepared by investigators for the LANDFIRE project who extrapolated information using Landsat Thematic Mapper and other data. The inset table gives the spatially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



	Min	25%	Median	75%	Max
Annual	33.9	38.7	39.7	40.7	43.8

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

Crater Lake National Park - Average Annual Maximum Temperature (1971-2000 Climate Normals)



Average Annual Maximum Temperature (°F)

- 42.0 - 45.9
- 46.0 - 49.9
- 50.0 - 53.9
- 54.0 - 57.9

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

	Min	25%	Median	75%	Max
Annual	42.5	49.3	50.8	52.4	57.1

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

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

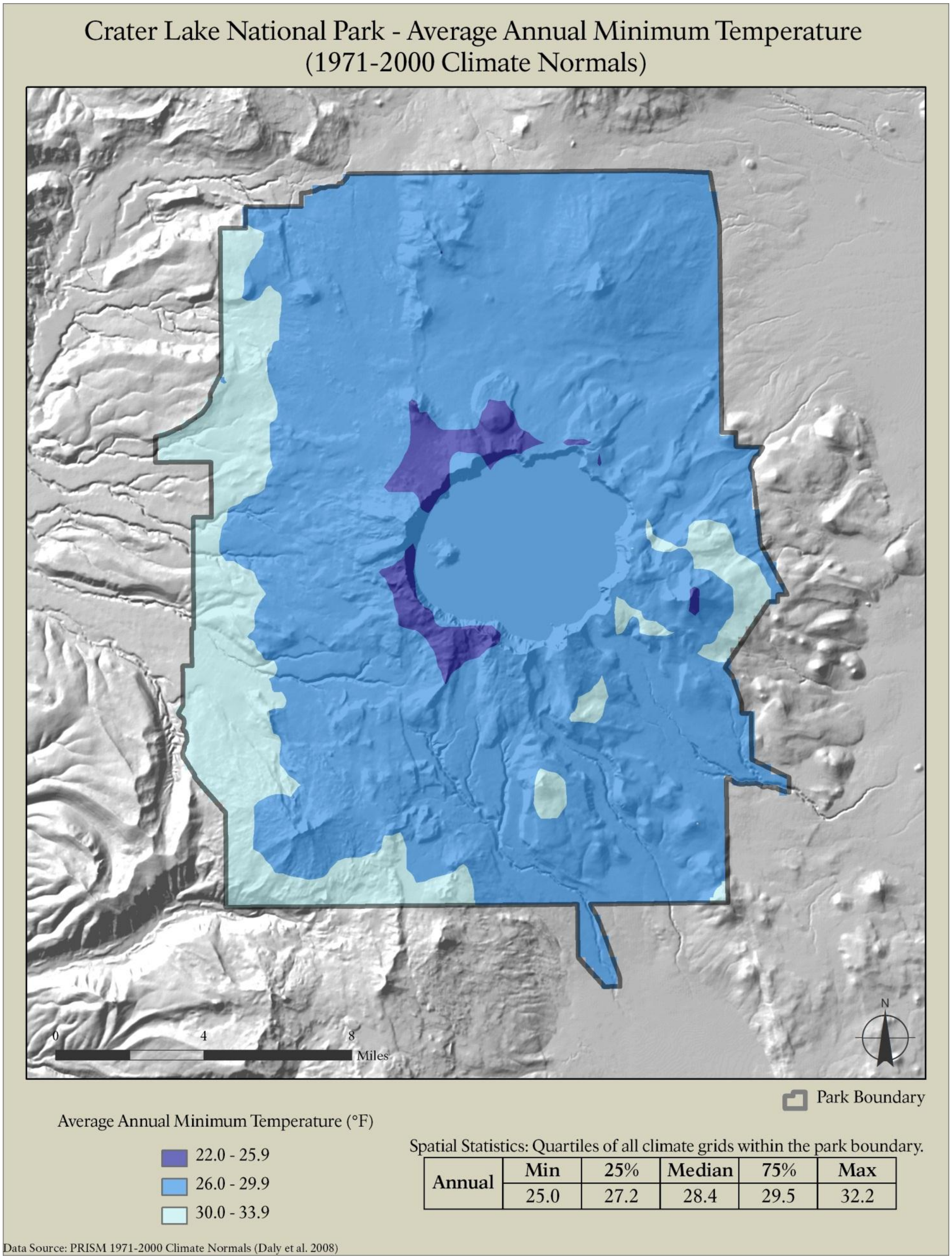
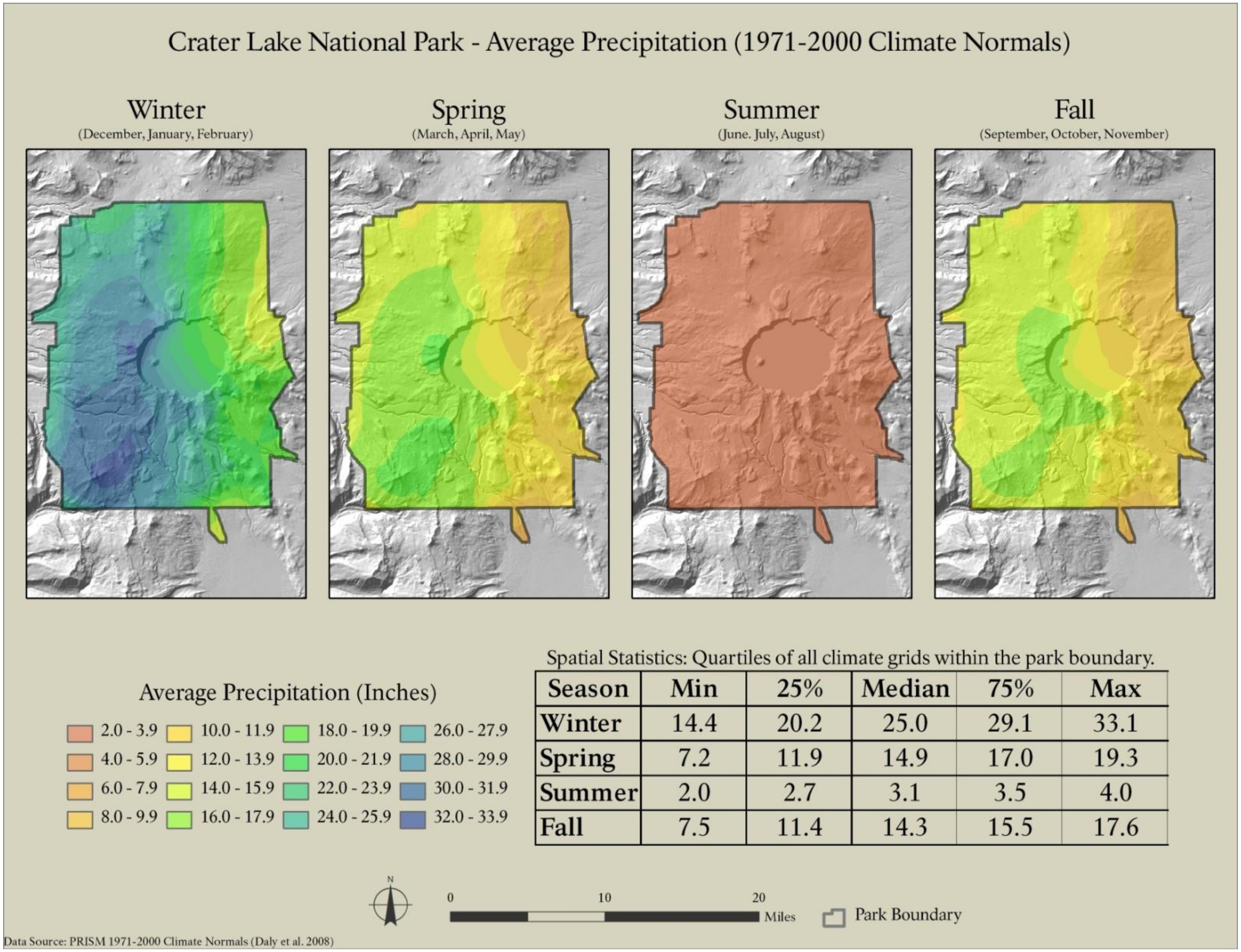
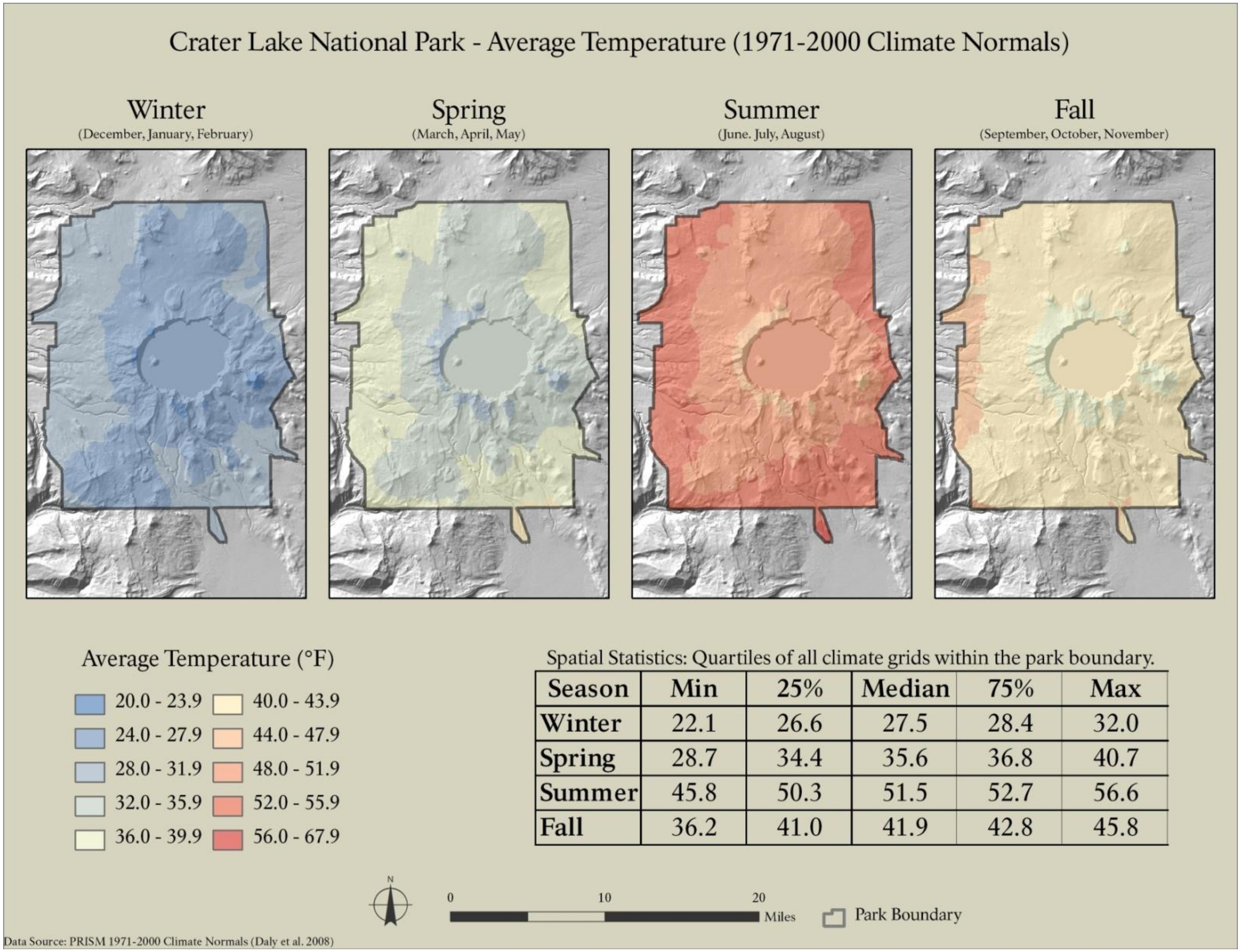


Figure A4. Average annual minimum temperatures for Crater Lake National Park (CRLA) from the PRISM 1971-2000 Climate Normals (Daly et al. 2008). This map was prepared by investigators for the LANDFIRE project who extrapolated information using Landsat Thematic Mapper and other data. The inset table gives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



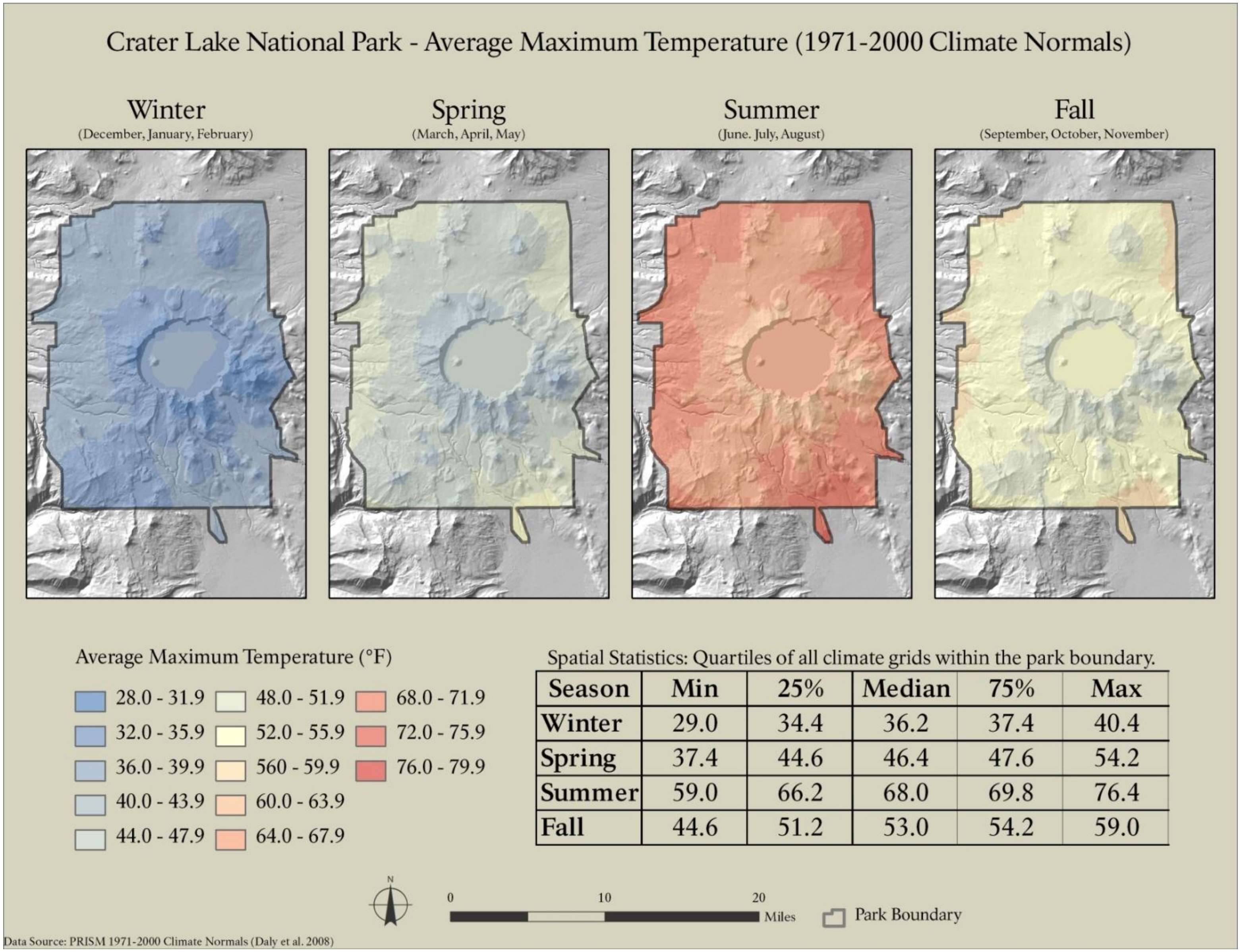
Season	Min	25%	Median	75%	Max
Winter	14.4	20.2	25.0	29.1	33.1
Spring	7.2	11.9	14.9	17.0	19.3
Summer	2.0	2.7	3.1	3.5	4.0
Fall	7.5	11.4	14.3	15.5	17.6

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



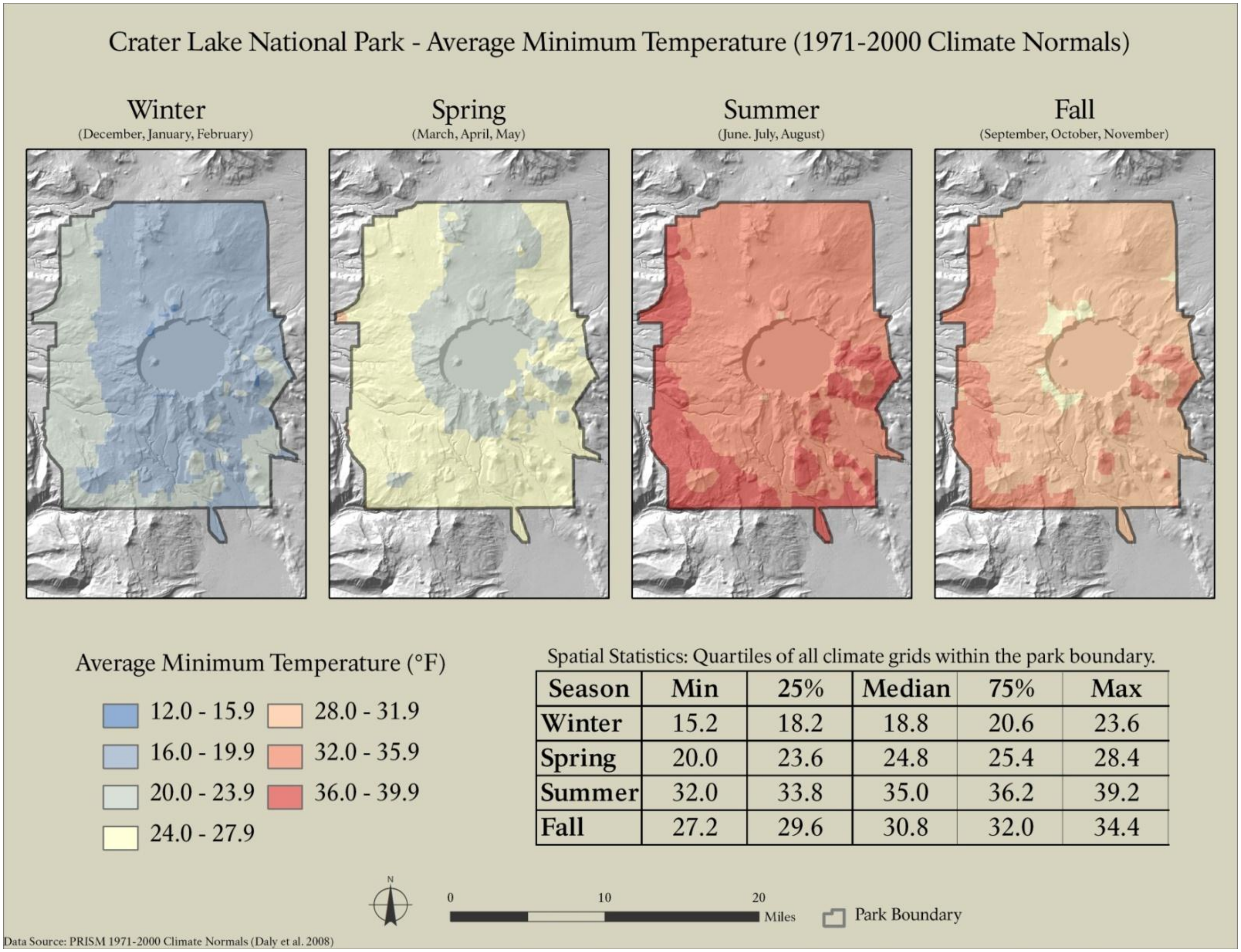
Season	Min	25%	Median	75%	Max
Winter	22.1	26.6	27.5	28.4	32.0
Spring	28.7	34.4	35.6	36.8	40.7
Summer	45.8	50.3	51.5	52.7	56.6
Fall	36.2	41.0	41.9	42.8	45.8

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



Season	Min	25%	Median	75%	Max
Winter	29.0	34.4	36.2	37.4	40.4
Spring	37.4	44.6	46.4	47.6	54.2
Summer	59.0	66.2	68.0	69.8	76.4
Fall	44.6	51.2	53.0	54.2	59.0

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



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

Season	Min	25%	Median	75%	Max
Winter	15.2	18.2	18.8	20.6	23.6
Spring	20.0	23.6	24.8	25.4	28.4
Summer	32.0	33.8	35.0	36.2	39.2
Fall	27.2	29.6	30.8	32.0	34.4

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

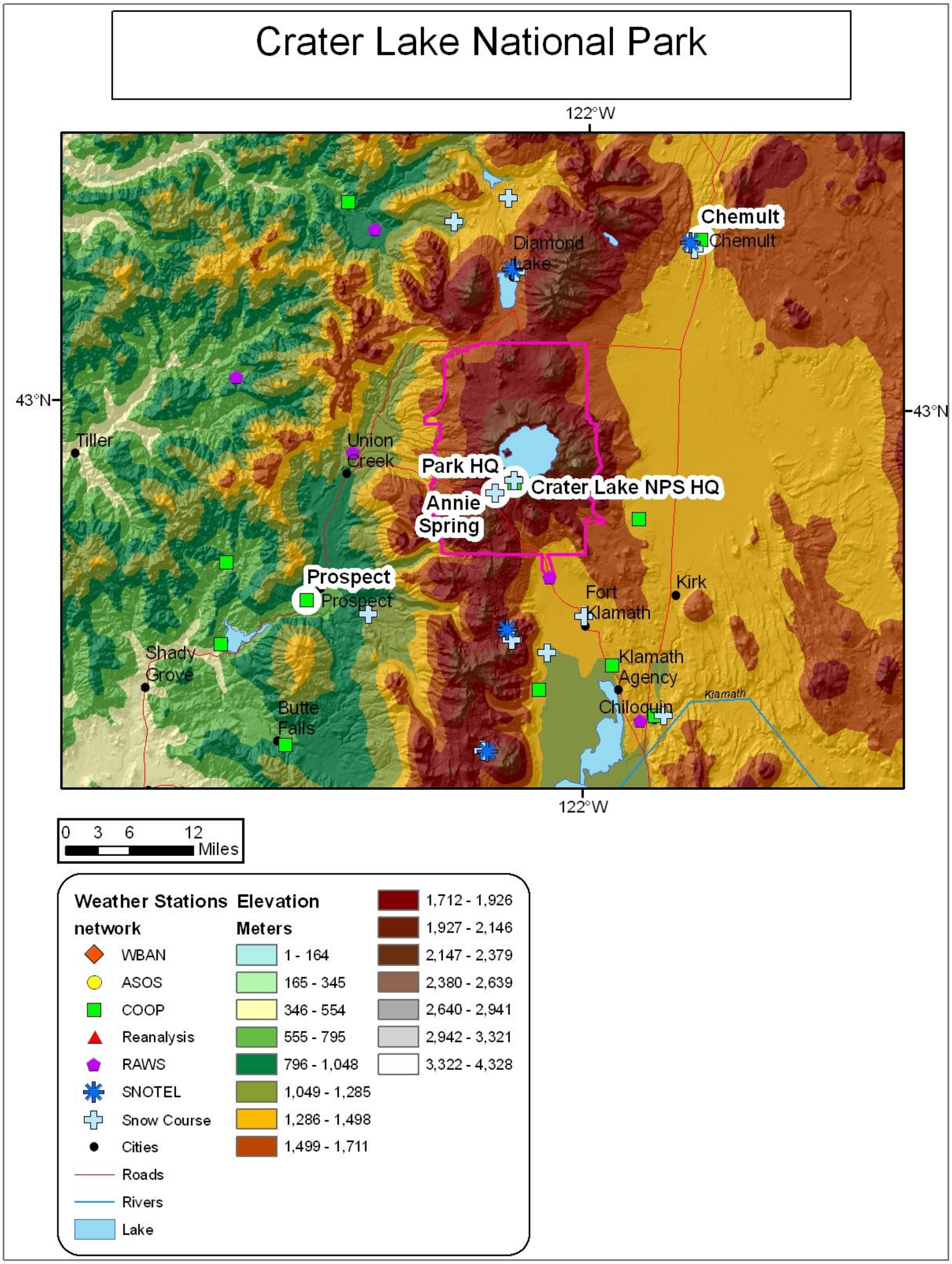


Figure A9. Climate stations in the vicinity of Crater Lake National Park (CRLA) (Daly et al. 2009). Stations highlighted in the map are further referenced in the report.

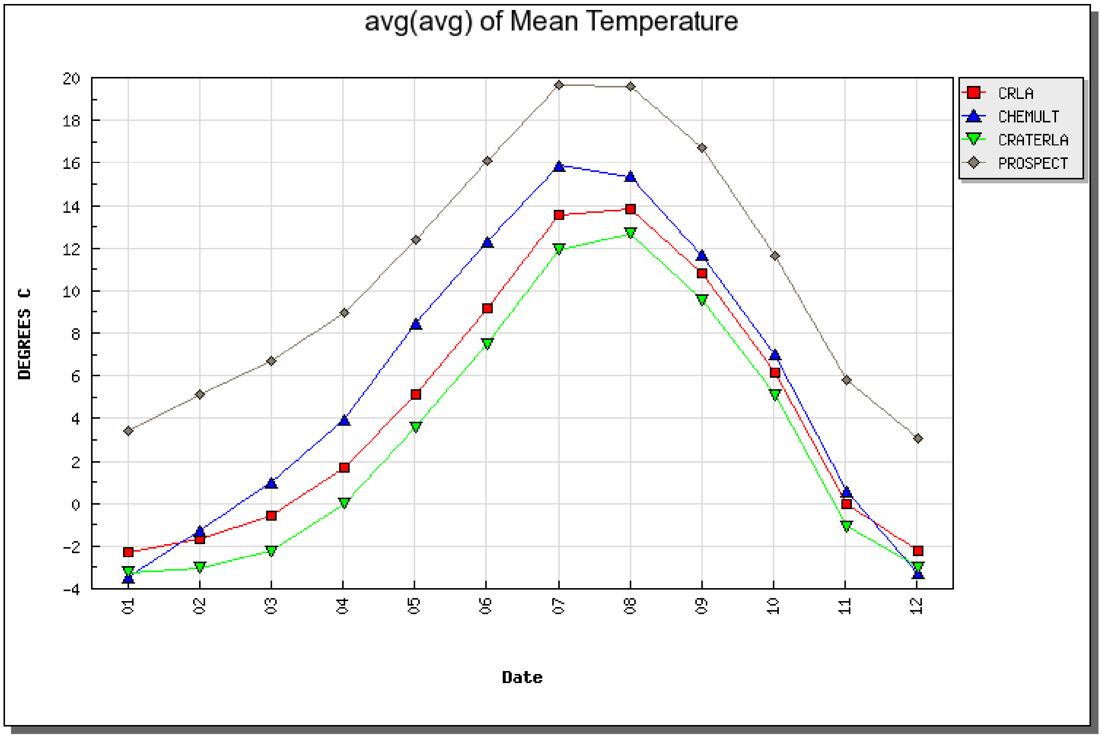


Figure A10. 1971–2000 average monthly mean temperature for the stations at Chemult, Crater Lake HQ, Prospect, and the Crater Lake National Park (CRLA) average of the PRISM modeled data (Daly et al. 2009). Date refers to the month of the year.

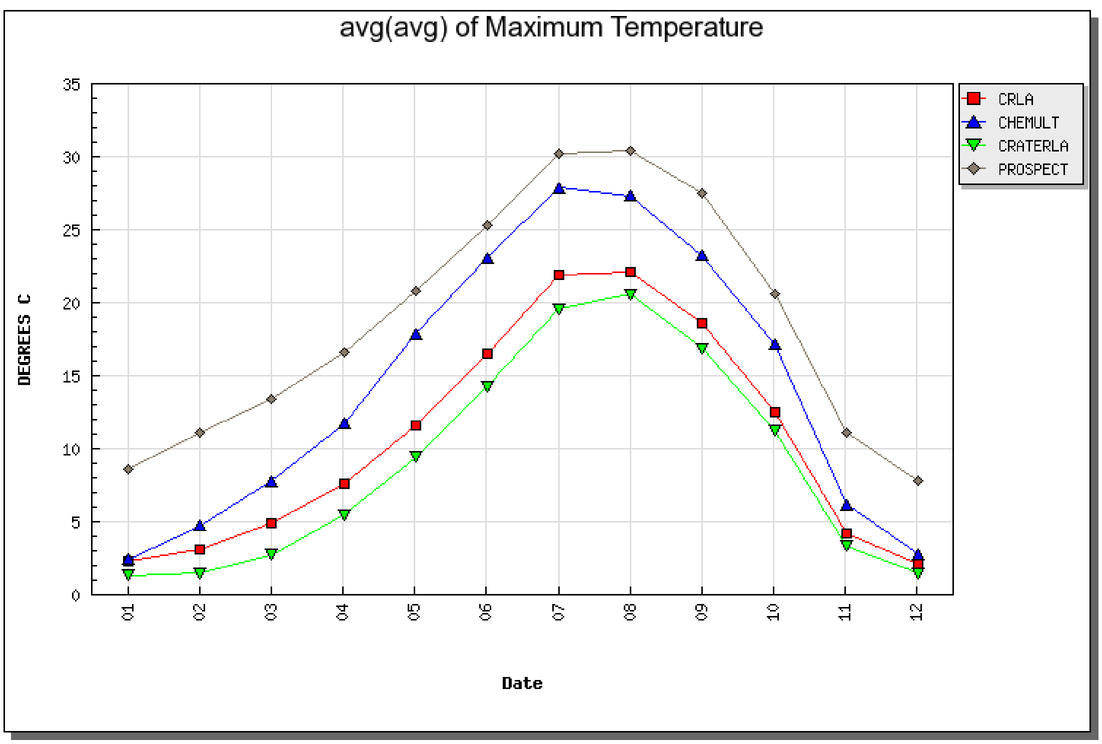


Figure A11. 1971–2000 average monthly maximum temperature for the stations at Chemult, Crater Lake HQ, Prospect, and the Crater Lake National Park (CRLA) average of the PRISM modeled data (Daly et al. 2009). Date refers to the month of the year.

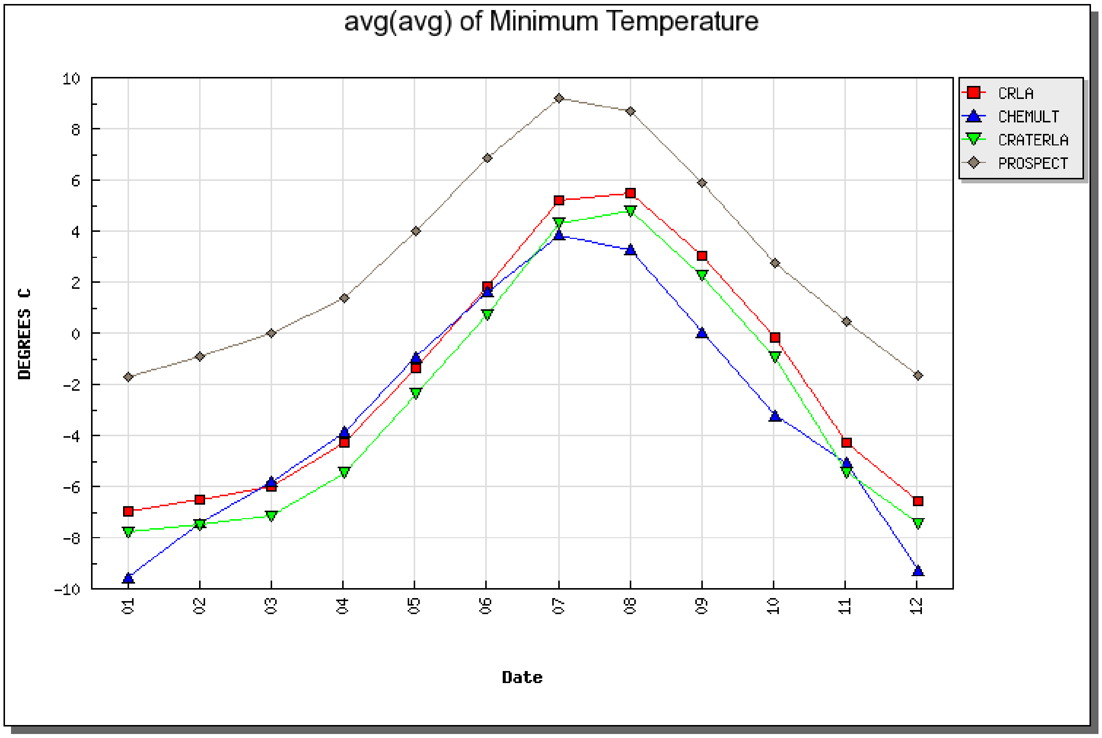


Figure A12. 1971–2000 average monthly minimum temperature for the stations at Chemult, Crater Lake HQ, Prospect, and the Crater Lake National Park (CRLA) average of the PRISM modeled data (Daly et al. 2009). Date refers to the month of the year.

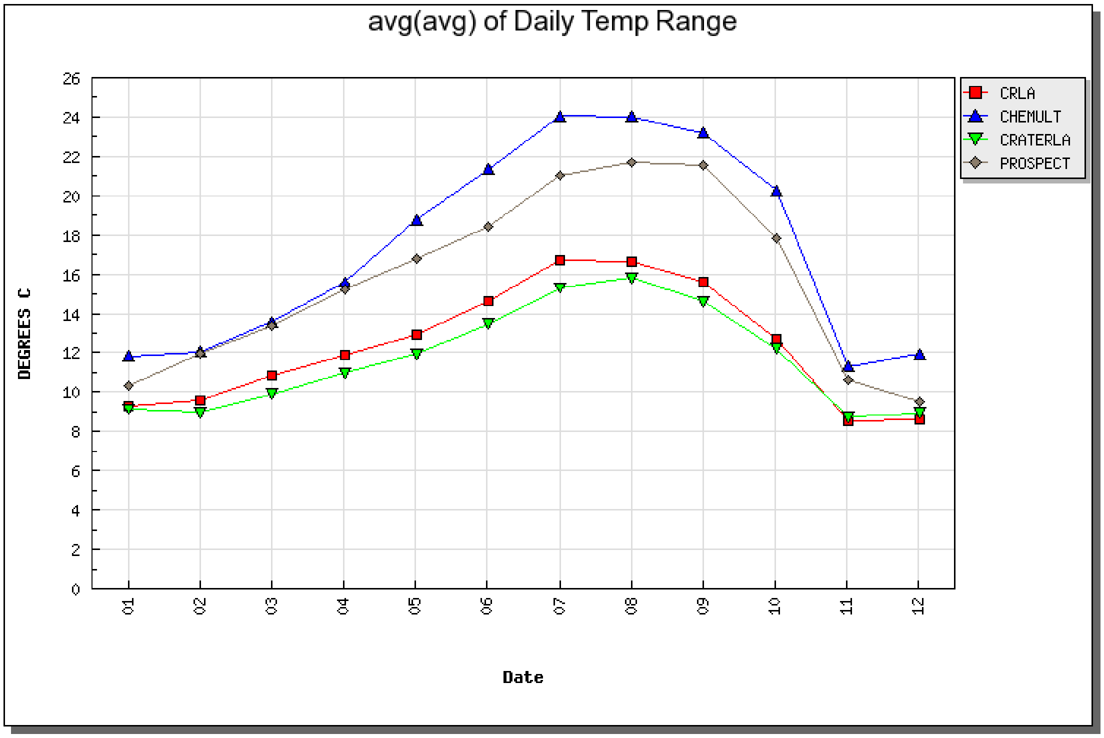


Figure A13. 1971–2000 average monthly daily temperature range for the stations at Chemult, Crater Lake HQ, Prospect, and the Crater Lake National Park (CRLA) average of the PRISM modeled data (Daly et al. 2009). Date refers to the month of the year.

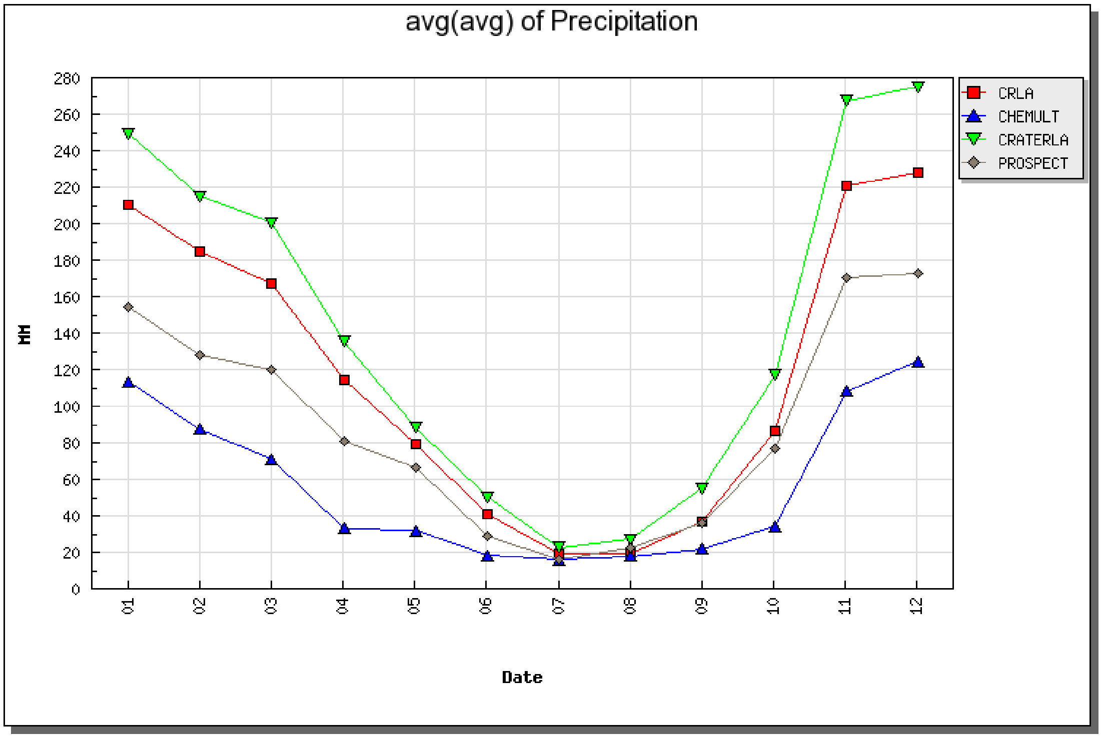


Figure A14. 1971–2000 average monthly precipitation for the stations at Chemult, Crater Lake HQ, Prospect, and the Crater Lake National Park (CRLA) average of the PRISM modeled data (Daly et al. 2009). Date refers to the month of the year.

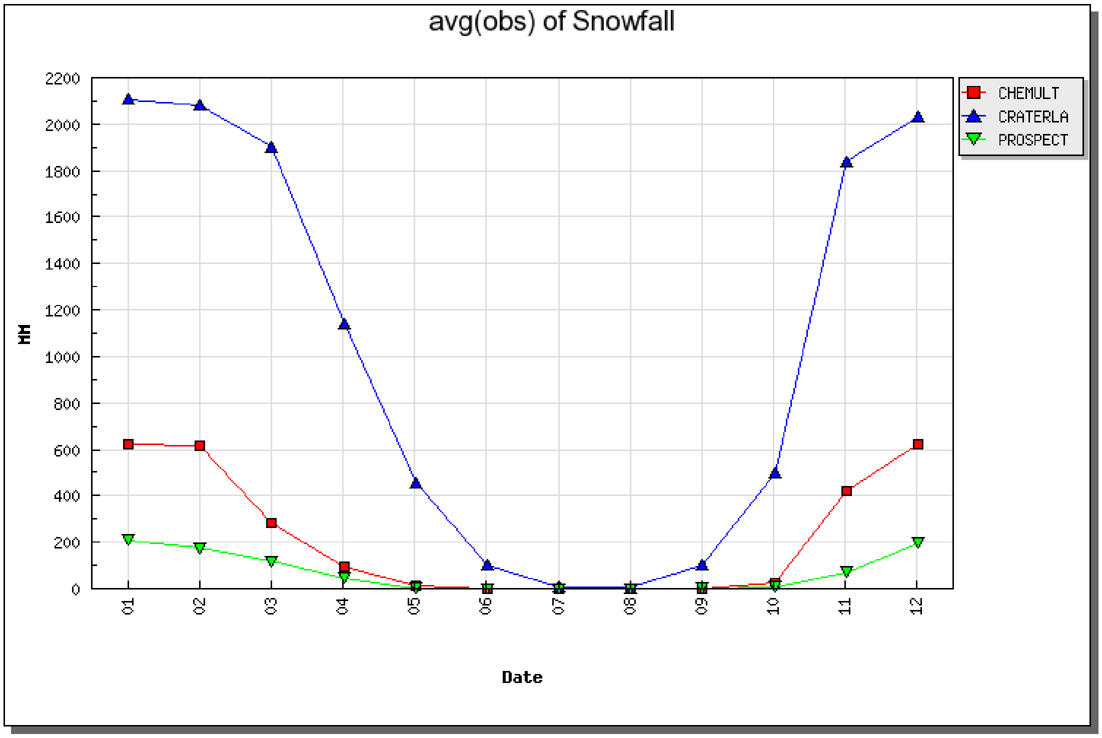


Figure A15. 1971–2000 average monthly snowfall for the stations at Chemult, Crater Lake HQ, and Prospect (Daly et al. 2009). Date refers to the month of the year.

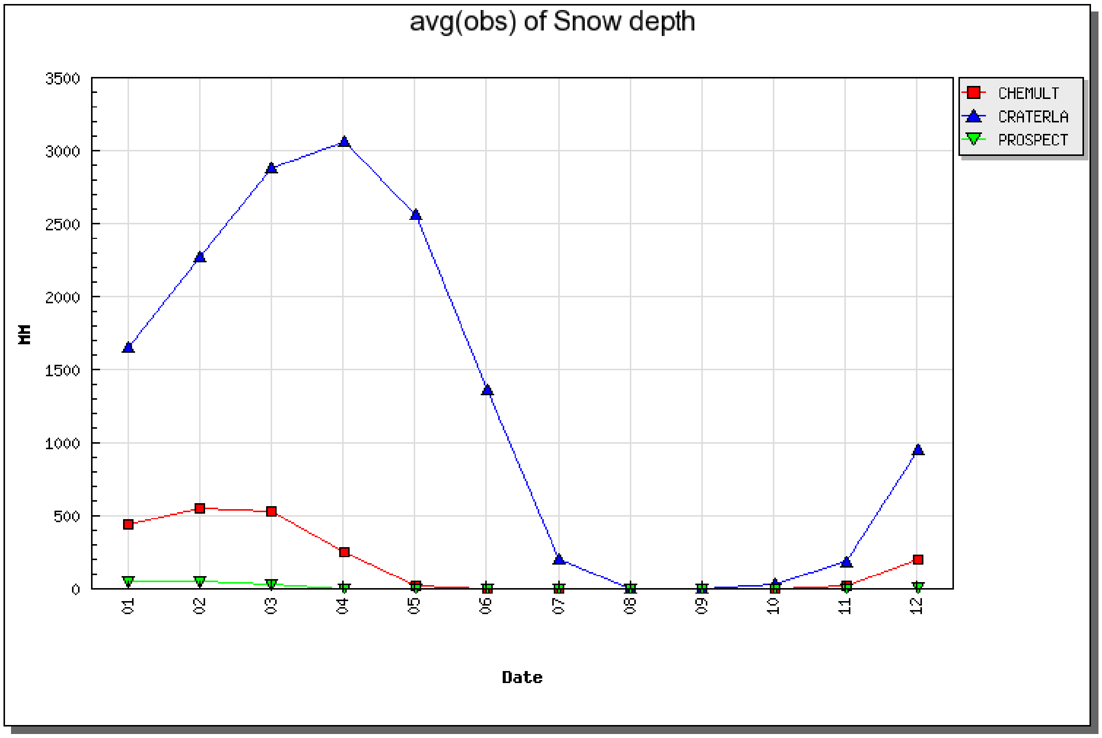


Figure A16. 1971–2000 average first of the month snow depth for the stations at Chemult, Crater Lake HQ, and Prospect (Daly et al. 2009). Date refers to the month of the year.

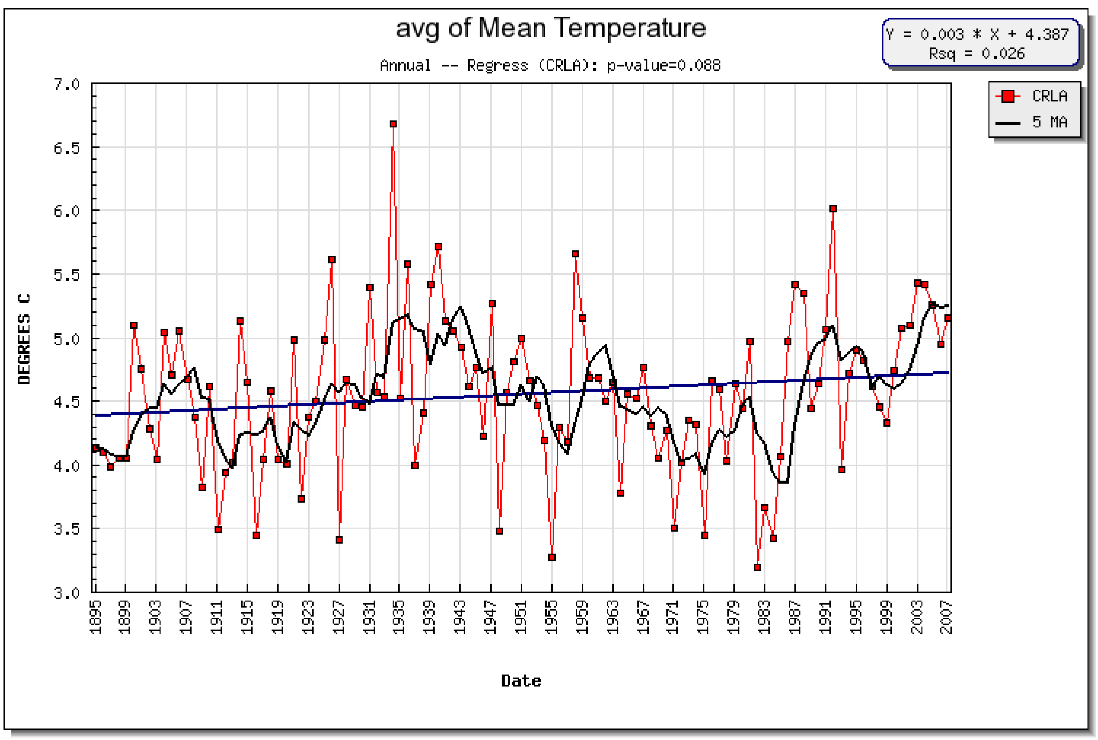


Figure A17. Time series of mean annual temperature for CRLA from the park average of the PRISM modeled data (Daly et al. 2009). Black line is a five year moving average and the blue line is the trend associated with the regression parameters (inset). Date refers to year.

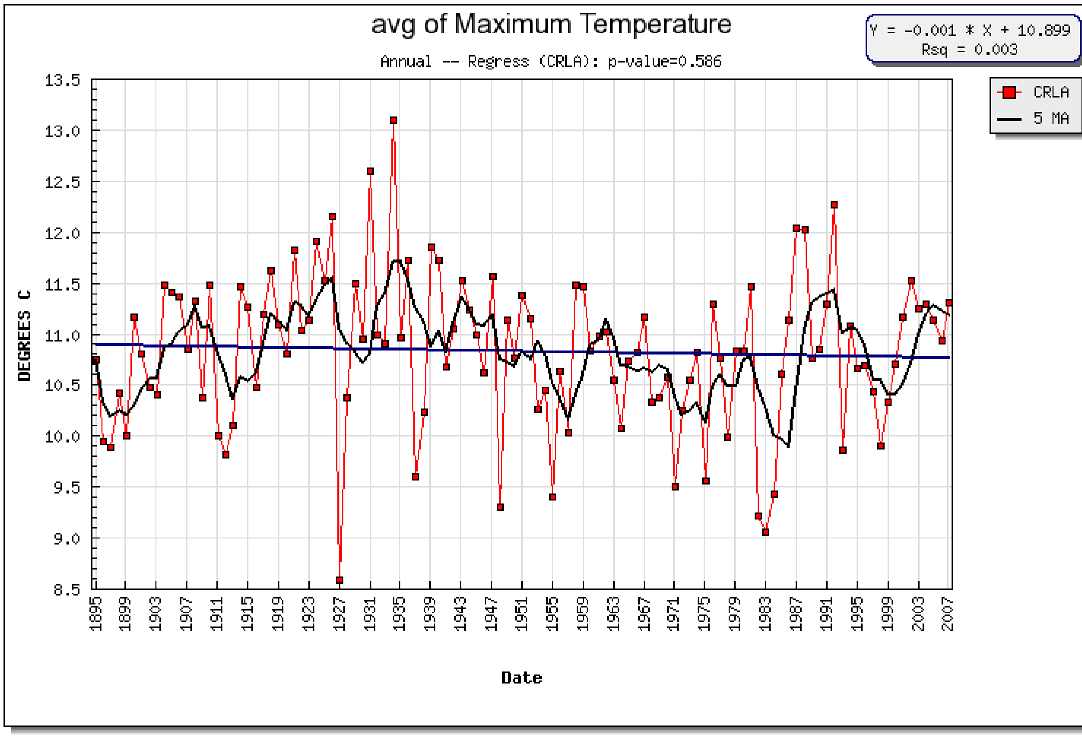


Figure A18. Time series of mean annual maximum temperature for CRLA from the park average of the PRISM modeled data (Daly et al. 2009). Black line is a five year moving average and the blue line is the trend associated with the regression parameters (inset). Date refers to year.

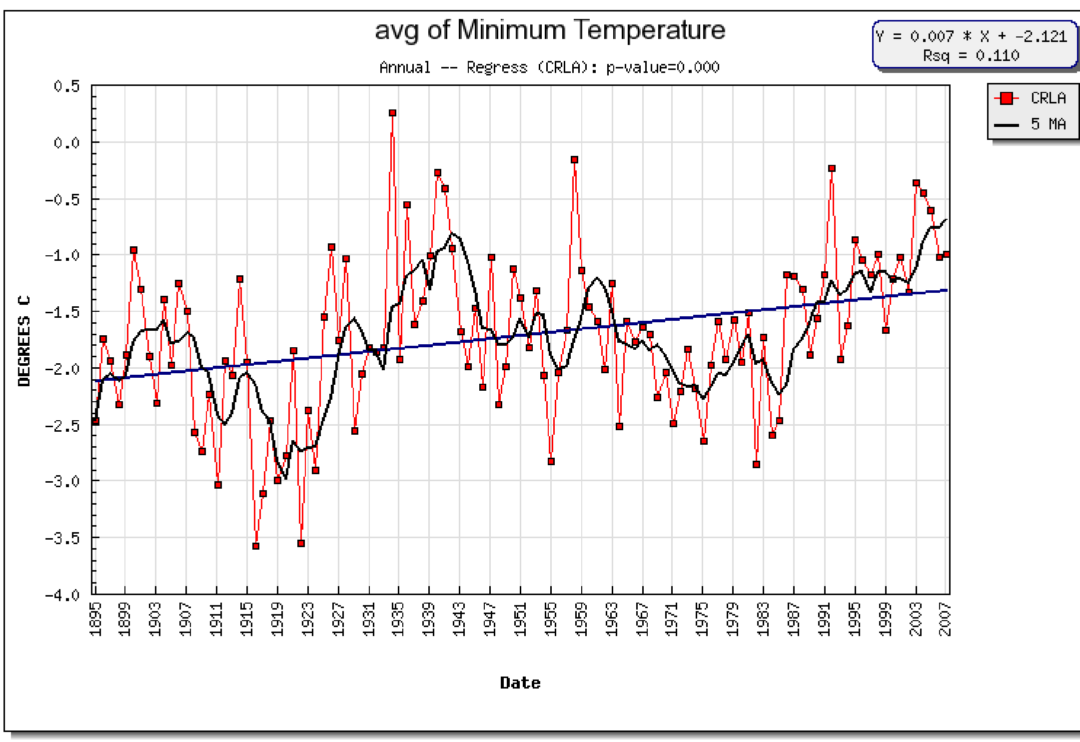


Figure A19. Time series of mean annual minimum temperature for CRLA from the park average of the PRISM modeled data (Daly et al. 2009). Black line is a five year moving average and the blue line is the trend associated with the regression parameters (inset). Date refers to year.

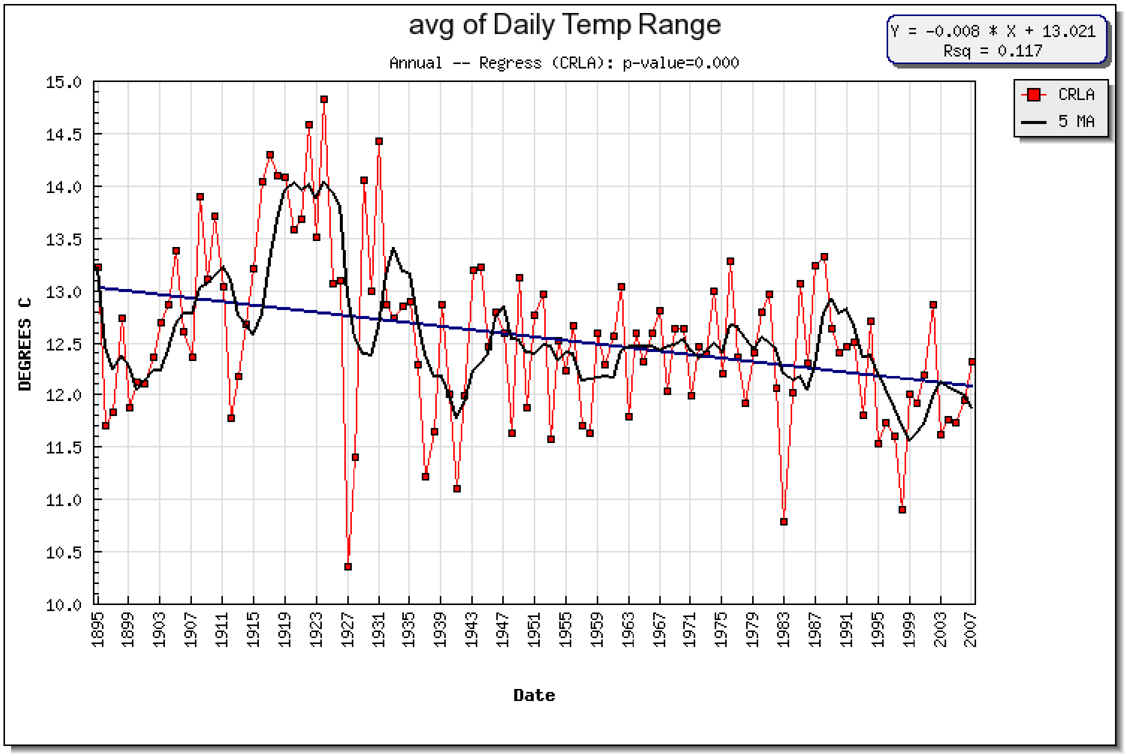


Figure A20. Time series of mean annual daily temperature range for CRLA from the park average of the PRISM modeled data (Daly et al. 2009). Black line is a five year moving average and the blue line is the trend associated with the regression parameters (inset). Date refers to year.

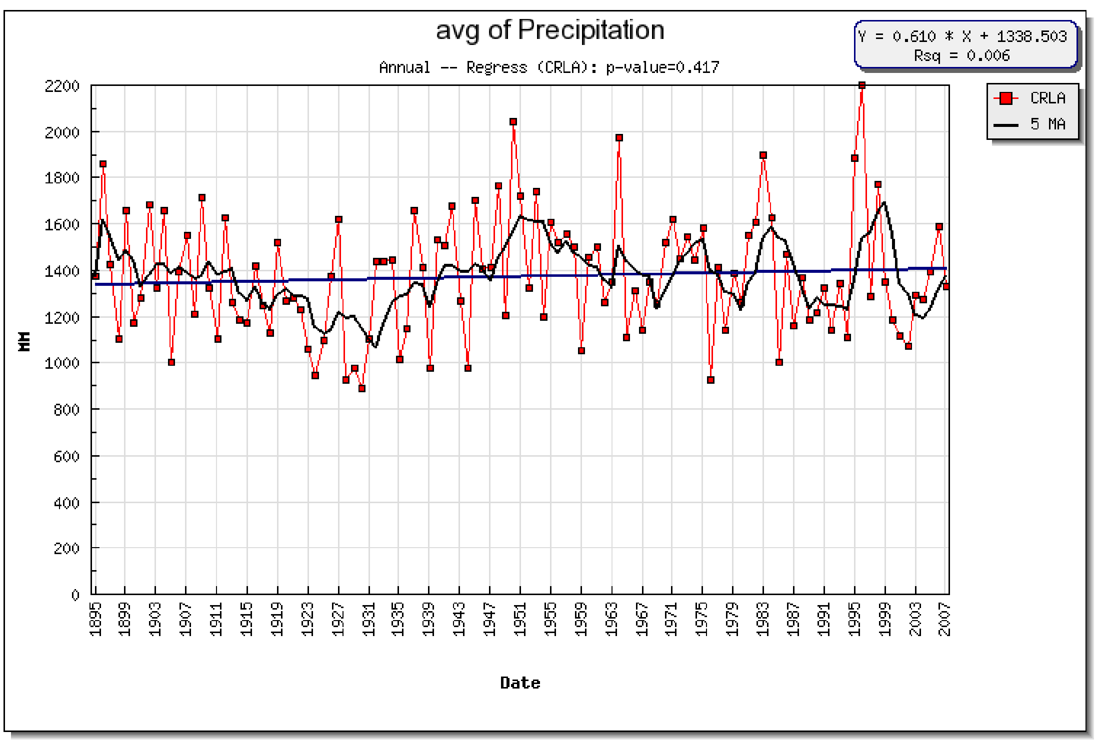


Figure A21. Time series of annual precipitation for CRLA from the park average of the PRISM modeled data (Daly et al. 2009). Black line is a five year moving average and the blue line is the trend associated with the regression parameters (inset). Date refers to year.

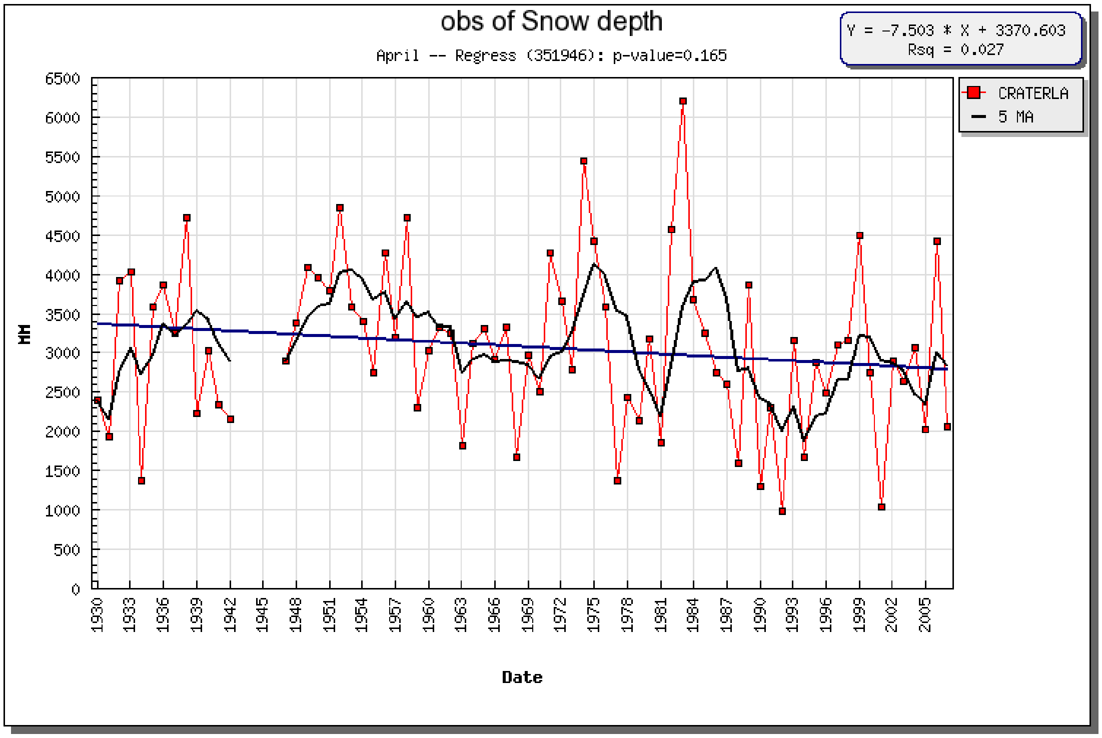


Figure A22. Time series of April 1st snow depth for Crater Lake NPS HQ Coop station (Daly et al. 2009). Black line is a five year moving average and the blue line is the trend associated with the regression parameters (inset). Date refers to year.

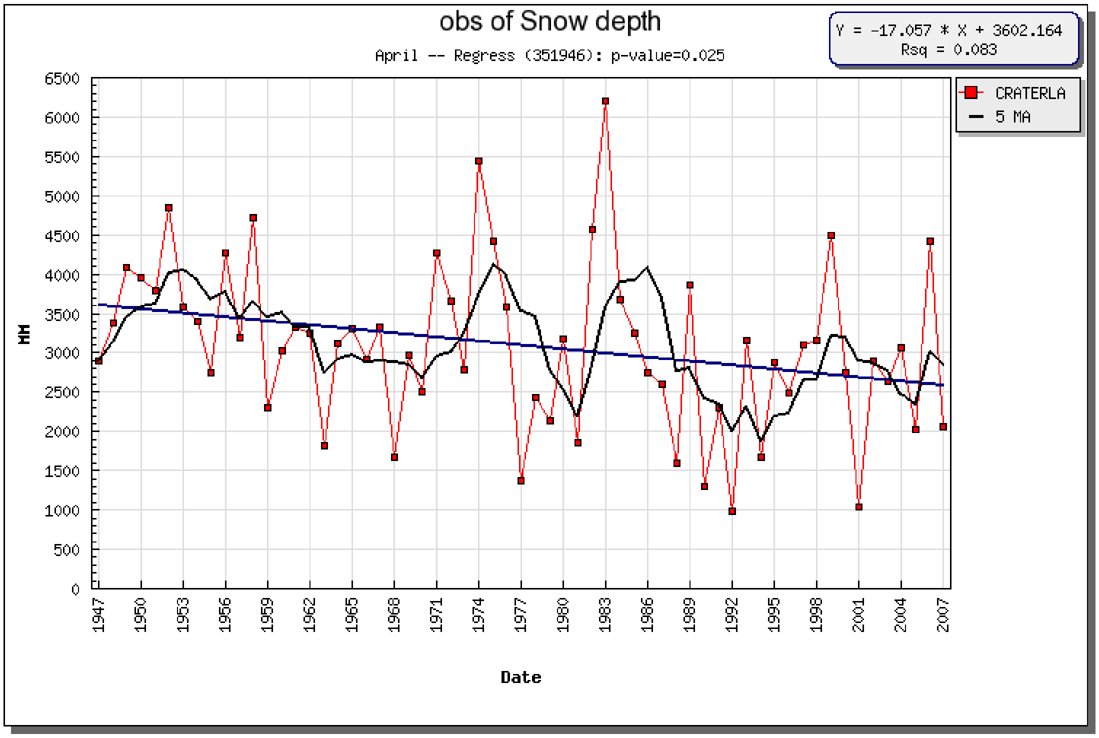


Figure A23. Same as A22, but for the 1947-2007 time series of April 1st snow depth for Crater Lake NPS HQ Coop station (Daly et al. 2009). Black line is a five year moving average and the blue line is the trend associated with the regression parameters (inset). Date refers to year.

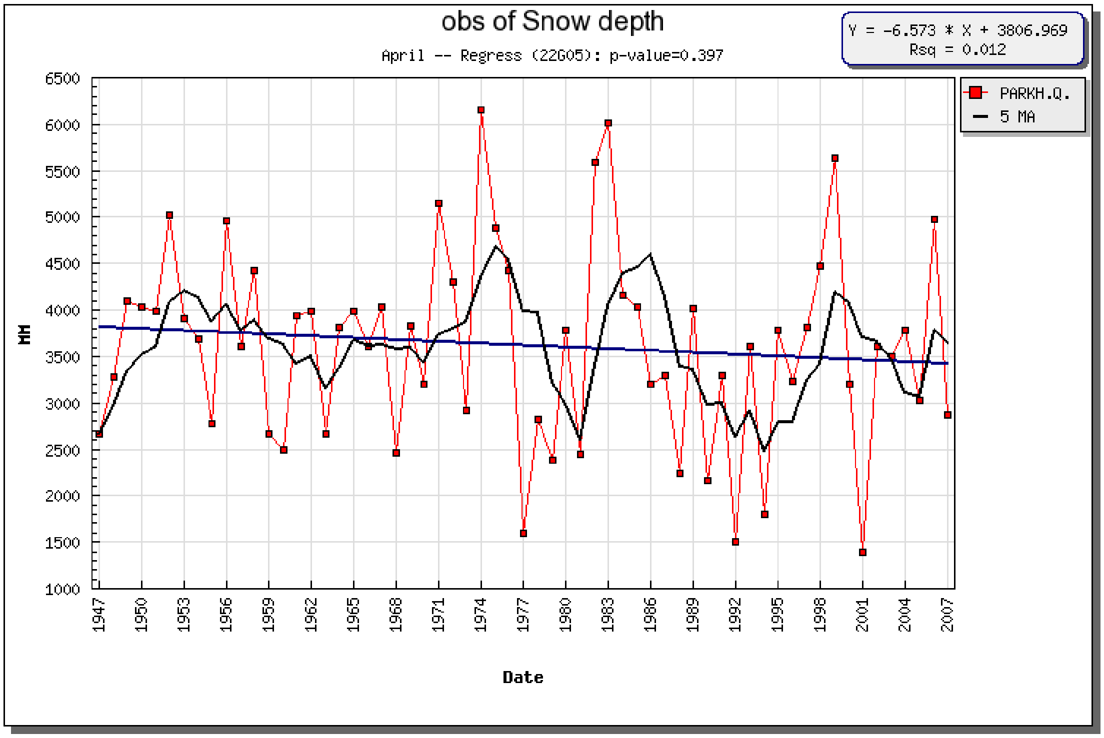


Figure A24. Time series of April 1st snow depth for Crater Lake Park HQ snow course (Daly et al. 2009). Black line is a five year moving average and the blue line is the trend associated with the regression parameters (inset). Date refers to year.

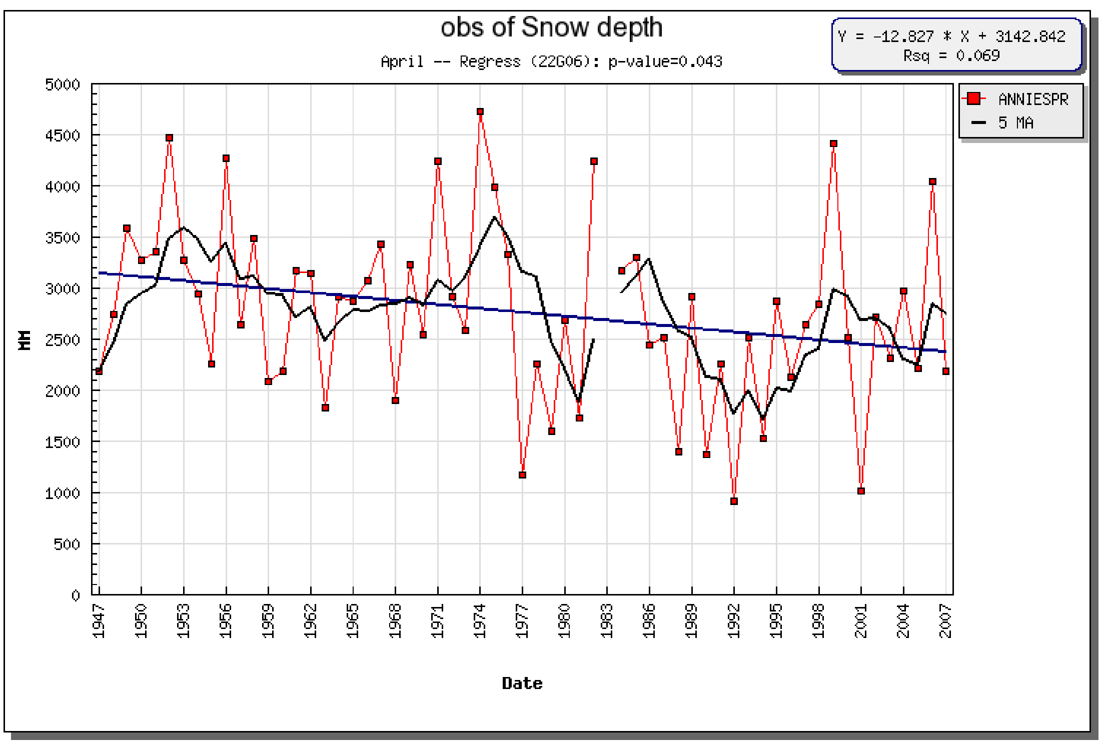


Figure A25. Same as A24, but for the 1947-2007 time series of April 1st snow depth for Crater Lake Park HQ snow course (Daly et al. 2009). Black line is a five year moving average and the blue line is the trend associated with the regression parameters (inset). Date refers to year.

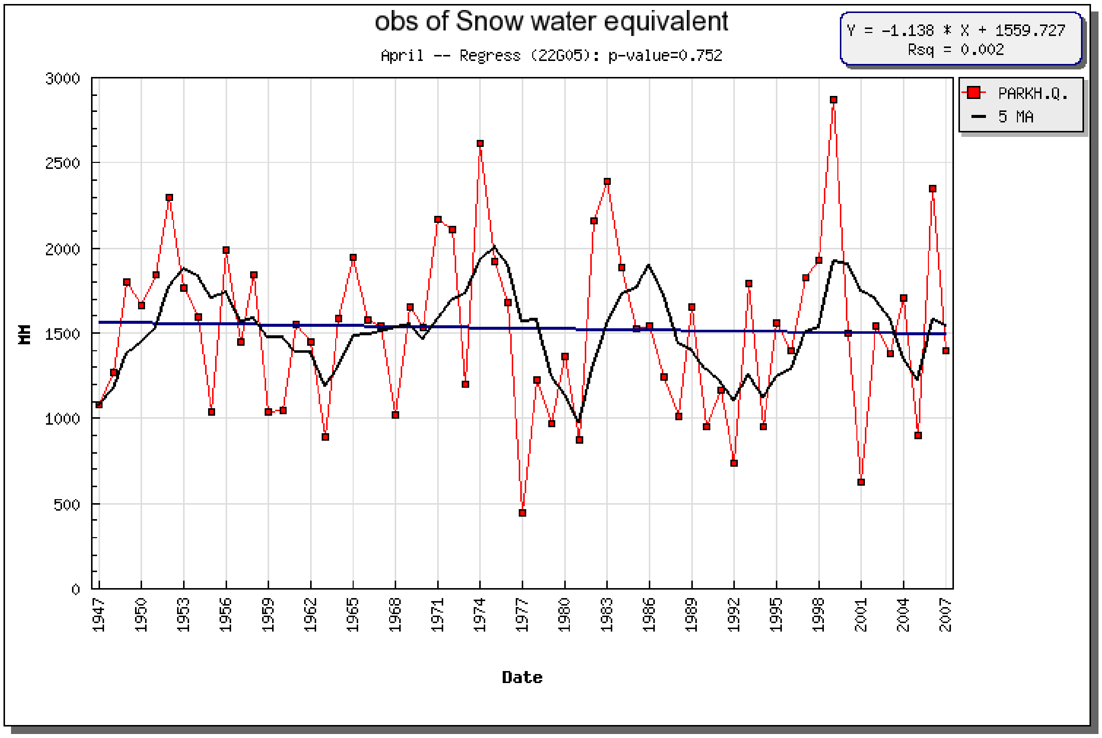


Figure A26. Time series of April 1st snow water equivalent for Crater Lake Park HQ snow course (Daly et al. 2009). Black line is a five year moving average and the blue line is the trend associated with the regression parameters (inset). Date refers to year.

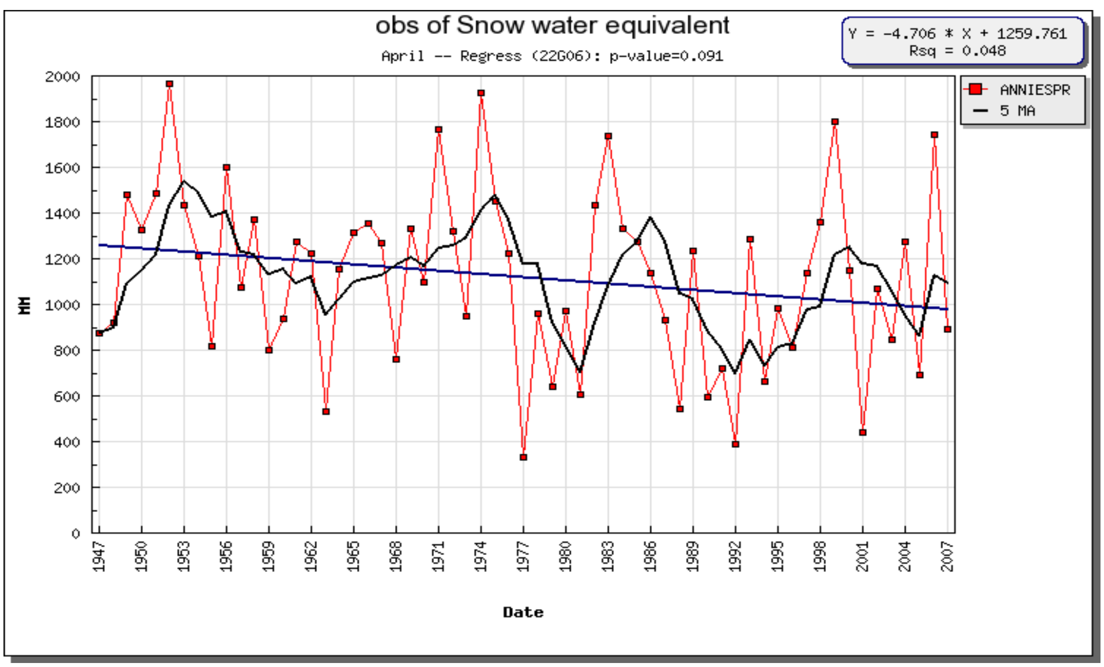


Figure A27. Time series of April 1st snow water equivalent for Annie Spring snow course (Daly et al. 2009). Black line is a five year moving average and the blue line is the trend associated with the regression parameters (inset). Date refers to year.

Table A1. Regression parameters and statistics for core climate elements for different time periods for Crater Lake 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.

	Annual Precipitation		**Annual Maximum Temperature**		**Annual Minimum Temperature**		**Annual Mean Temperature**	
Time Period (years)	Slope (mm/10 yr)	*p*-value	Slope (°C/10 yr)	*p*-value	Slope (°C/10 yr)	*p*-value	Slope (°C/10 yr)	*p*-value
1895–2007	6.072	0.417	-0.012	0.592	0.073	0.000	0.031	0.083
1971–2007	-21.047	0.614	0.247	0.035	0.437	0.000	0.341	0.000

Table A2. Regression parameters and statistics for April 1st snow depth and SWE at Crater Lake NPS HQ and April 1 SWE at Annie Spring for different time periods (Daly et al. 2009). Slope *p*-values significant at the 90% confidence level (α=0.10) are shown in bold.

	Crater Lake NPS HQ April 1 Snow Depth		**Crater Lake NPS HQ April 1 SWE**		**Annie Spring April 1 SWE**	
Time Period (years)	Slope (mm/10 yr)	*p*-value	Slope (mm/10 yr)	*p*-value	Slope (mm/10 yr)	*p*-value
1947–2007	-170.574	0.025	-11.380	0.752	-47.060	0.091
1971–2007	-300.22	0.103	-41.000	0.642	-59.220	0.365

Table A3. Regression parameters and statistics for core climate elements for 1895–2007 for Crater Lake 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	0.405	0.880	0.060	0.304	0.112	0.078	0.086	0.123
February	-1.890	0.440	0.021	0.737	0.075	0.191	0.048	0.361
March	0.263	0.893	-0.026	0.714	0.052	0.272	0.013	0.805
April	1.726	0.180	-0.115	0.106	0.038	0.373	-0.038	0.470
May	-1.083	0.395	0.009	0.897	0.082	0.043	0.045	0.362
June	-0.305	0.708	0.004	0.947	0.074	0.030	0.039	0.347
July	0.146	0.761	-0.003	0.958	0.131	0.001	0.064	0.133
August	0.830	0.083	0.002	0.968	0.131	0.001	0.066	0.097
September	-1.388	0.079	0.121	0.070	0.104	0.007	0.113	0.019
October	0.343	0.838	-0.027	0.688	0.058	0.134	0.016	0.742
November	0.906	0.767	-0.142	0.028	-0.005	0.912	-0.074	0.137
December	6.119	0.071	-0.045	0.424	0.022	0.681	-0.011	0.826
Annual	6.072	0.417	-0.012	0.592	0.073	0.000	0.031	0.083

Table A4. Regression parameters and statistics for core climate elements for 1971–2007 for Crater Lake 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	3.881	0.788	0.142	0.609	0.749	0.007	0.445	0.066
February	-9.376	0.446	0.227	0.489	0.288	0.293	0.257	0.334
March	-18.133	0.076	0.752	0.026	0.676	0.009	0.714	0.011
April	4.933	0.427	0.344	0.329	0.759	0.001	0.550	0.045
May	7.144	0.283	0.134	0.714	0.590	0.002	0.363	0.161
June	-0.352	0.912	0.023	0.940	0.229	0.195	0.126	0.593
July	0.347	0.908	0.405	0.200	0.590	0.006	0.497	0.054
August	-2.431	0.479	0.234	0.398	0.120	0.522	0.177	0.387
September	-8.687	0.084	0.341	0.392	0.237	0.211	0.290	0.307
October	-3.561	0.650	-0.142	0.721	0.107	0.584	-0.018	0.950
November	-6.503	0.714	0.370	0.296	0.430	0.124	0.399	0.167
December	11.691	0.552	0.133	0.704	0.472	0.086	0.303	0.293
Annual	-21.047	0.614	0.247	0.035	0.437	0.000	0.341	0.000

Table A5. Regression parameters and statistics for core climate elements for 1971–2007 for Prospect (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	5.858	0.618	0.402	0.150	0.720	0.010	0.559	0.018
February	-8.106	0.424	0.382	0.282	0.181	0.415	0.271	0.249
March	-16.652	0.047	0.891	0.018	0.324	0.073	0.602	0.015
April	8.743	0.127	0.280	0.448	0.617	0.001	0.454	0.064
May	5.894	0.345	-0.024	0.951	0.663	0.000	0.315	0.193
June	2.694	0.415	-0.161	0.631	0.279	0.089	0.058	0.800
July	1.370	0.677	0.187	0.561	0.673	0.000	0.437	0.060
August	-3.732	0.427	0.172	0.608	0.469	0.025	0.330	0.126
September	-8.054	0.137	0.319	0.403	0.224	0.156	0.276	0.246
October	-3.077	0.669	0.375	0.356	0.208	0.226	0.294	0.215
November	0.458	0.975	0.457	0.177	0.226	0.384	0.340	0.157
December	10.889	0.514	0.424	0.167	0.434	0.088	0.428	0.065
Annual	-8.054	0.822	0.300	0.031	0.488	0.000	0.386	0.000

Table A6. Regression parameters and statistics for core climate elements for 1971–2007 for Crater Lake NPS HQ (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	0.448	0.979	0.016	0.960	0.551	0.046	0.277	0.293
February	-15.287	0.300	0.129	0.703	0.217	0.442	0.176	0.518
March	-22.145	0.075	0.556	0.119	0.623	0.038	0.587	0.058
April	2.570	0.749	0.270	0.453	0.694	0.005	0.484	0.093
May	4.142	0.610	0.286	0.455	0.623	0.004	0.448	0.112
June	-0.070	0.987	0.239	0.476	0.075	0.701	0.166	0.520
July	2.747	0.540	0.807	0.025	0.549	0.021	0.683	0.019
August	-2.328	0.643	0.513	0.109	0.074	0.727	0.296	0.205
September	-13.395	0.089	0.587	0.171	0.236	0.278	0.412	0.189
October	-3.812	0.724	-0.078	0.853	0.005	0.983	-0.025	0.937
November	-8.051	0.710	0.315	0.410	0.326	0.269	0.318	0.308
December	8.687	0.709	-0.003	0.994	0.321	0.238	0.157	0.615
Annual	-38.985	0.486	0.248	0.075	0.377	0.000	0.300	0.005

Table A7. Regression parameters and statistics for core climate elements for 1971–2007 for Chemult (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	7.224	0.507	0.355	0.213	1.091	0.024	0.720	0.026
February	-3.906	0.568	0.114	0.635	-0.154	0.614	-0.012	0.948
March	-12.119	0.093	0.527	0.137	0.439	0.155	0.515	0.090
April	2.395	0.454	0.413	0.311	0.419	0.013	0.422	0.087
May	4.942	0.319	0.089	0.851	0.391	0.026	0.242	0.384
June	1.141	0.634	0.071	0.855	0.109	0.447	0.072	0.767
July	-0.806	0.762	0.591	0.039	0.402	0.086	0.489	0.030
August	-0.411	0.909	0.461	0.285	-0.182	0.512	0.126	0.632
September	-6.871	0.025	0.491	0.325	-0.183	0.438	0.153	0.594
October	-2.797	0.561	0.007	0.988	-0.294	0.276	-0.148	0.538
November	-4.508	0.723	0.278	0.402	-0.098	0.828	0.146	0.646
December	12.562	0.383	0.248	0.347	0.063	0.904	0.136	0.682
Annual	32.425	0.416	0.309	0.030	0.208	0.209	0.247	0.048

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

Indices/Stations/Trend Statistics	Chemult (1937-2011)			Prospect (1908-2011)			Crater Lake (1931-2011)		
	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

Indices/Stations/Trend Statistics	Chemult (1937-2011)			Prospect (1908-2011)			Crater Lake (1931-2011)		
	R^2	*p*-value	Slope	R^2	*p*-value	Slope	R^2	*p*-value	Slope
% 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
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	NS	0.196	0.782	NS	0.736	0.158	0.10	0.006	-3.059

Indices/Stations/Trend Statistics	Chemult (1937-2011)			Prospect (1908-2011)			Crater Lake (1931-2011)		
	R^2	*p*-value	Slope	R^2	*p*-value	Slope	R^2	*p*-value	Slope
(days)									
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

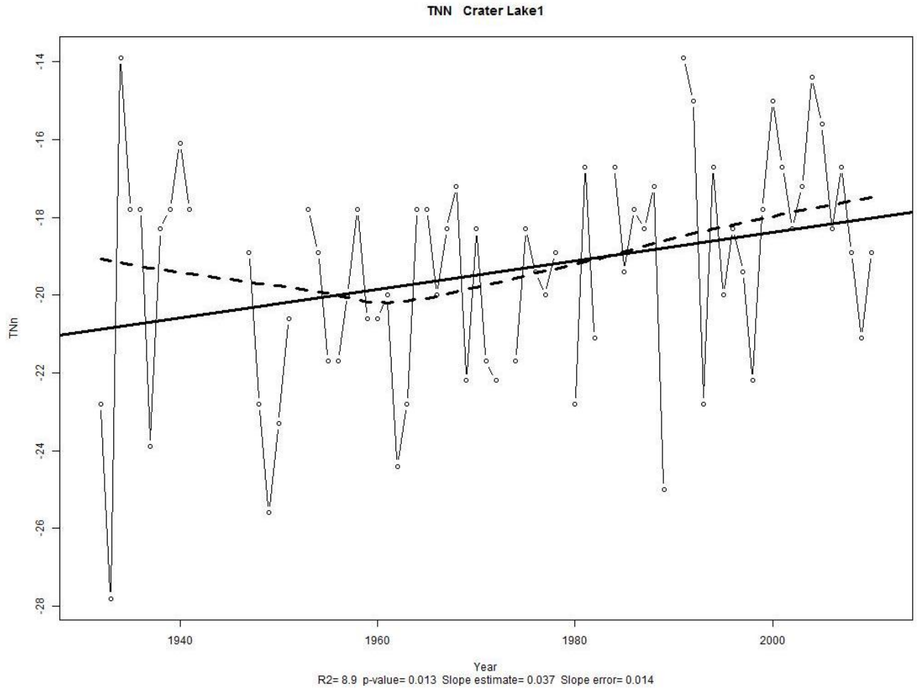


Figure A28. Example time series of the lowest minimum daily temperature observed each year at Crater Lake National Park Headquarters during 1931-2011 (from Daly et al. 2009). Trends are computed by linear least square (solid line) and locally weighted linear regression (dashed line). Missing data is handled as discussed in the text.

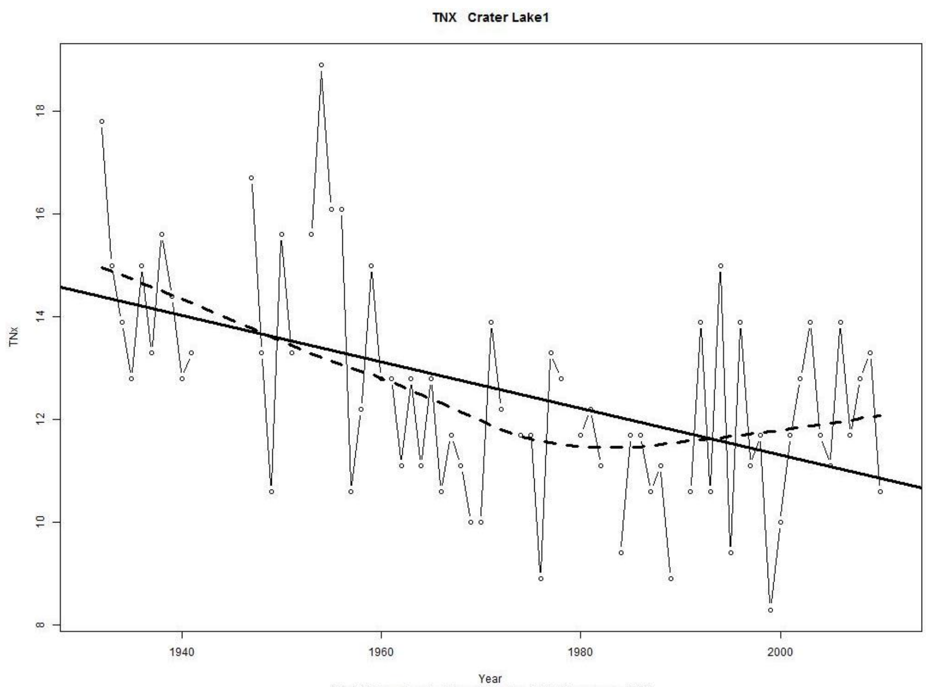


Figure A29. Example time series of the highest minimum daily temperature observed each year at Crater Lake National Park Headquarters during 1931-2011 (from Daly et al. 2009). Trends are computed by linear least square (solid line) and locally weighted linear regression (dashed line). Missing data is handled as discussed in the text.

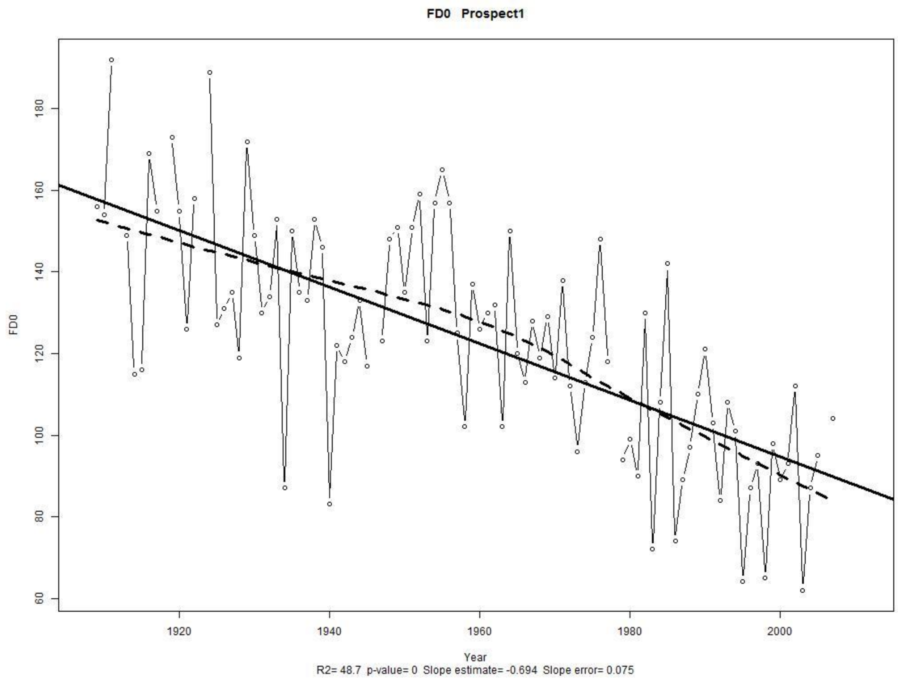


Figure A30. Example time series of the number of days below 0°C (32°F) observed each year at Prospect, Oregon, during 1908-2011 (from Daly et al. 2009). Trends are computed by linear least square (solid line) and locally weighted linear regression (dashed line). Missing data is handled as discussed in the text.

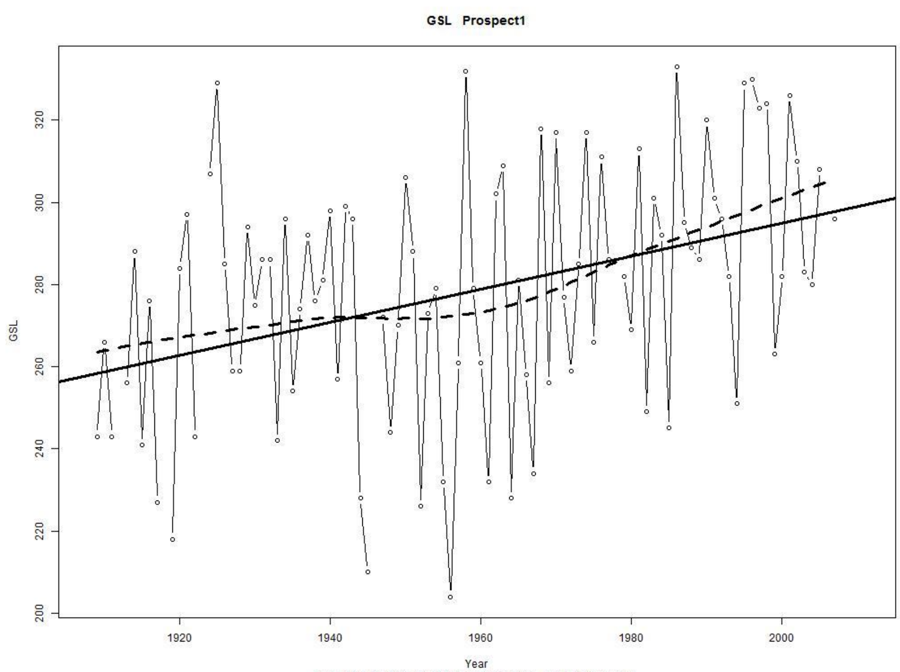


Figure A31. Example time series of the length of the growing season (number of days between the first and last frosts each year) observed each year at Prospect, Oregon, during 1908-2011 (from Daly et al. 2009). Trends are computed by linear least square (solid line) and locally weighted linear regression (dashed line). Missing data is handled as discussed in the text.

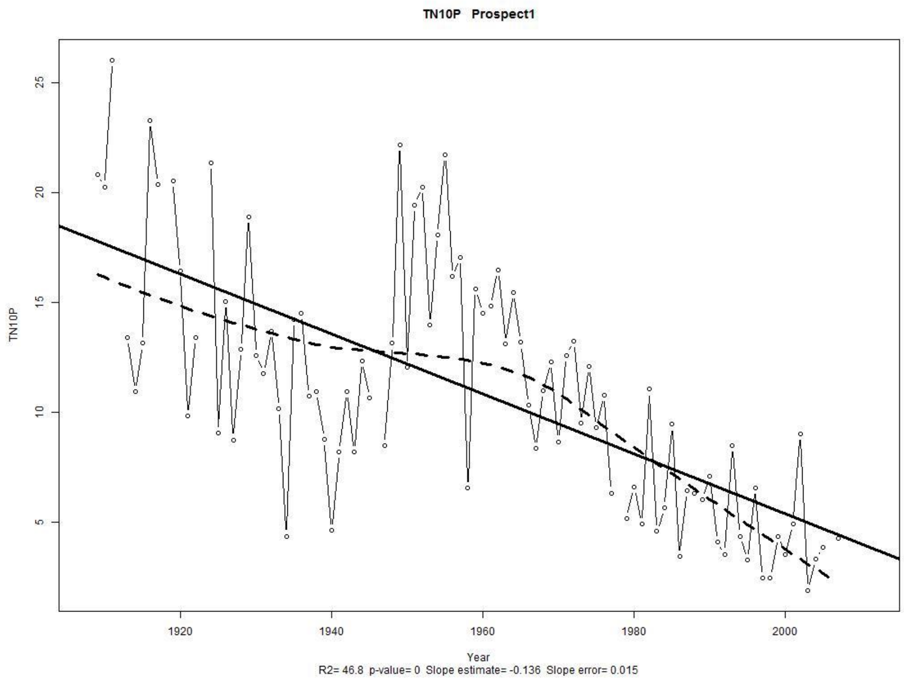


Figure A32. Example time series of the number of days when the minimum temperature is below the 10th percentile during the reference period observed each year at Prospect, Oregon, during 1908-2011 (from Daly et al. 2009). Trends are computed by linear least square (solid line) and locally weighted linear regression (dashed line). Missing data is handled as discussed in the text.

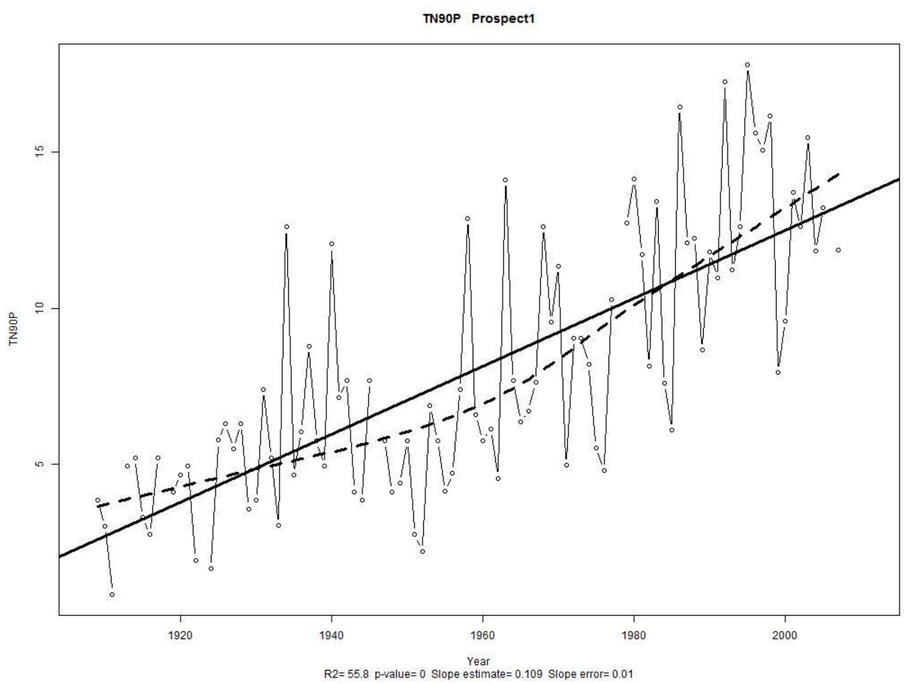


Figure A33. Example time series of the number of days when the minimum temperature is below the 10th percentile during the reference period observed each year at Prospect, Oregon, during 1908-2011 (from Daly et al. 2009). Trends are computed by linear least square (solid line) and locally weighted linear regression (dashed line). Missing data is handled as discussed in the text.

Appendix B. Physical Characteristics of Crater Lake National Park: supporting data and maps

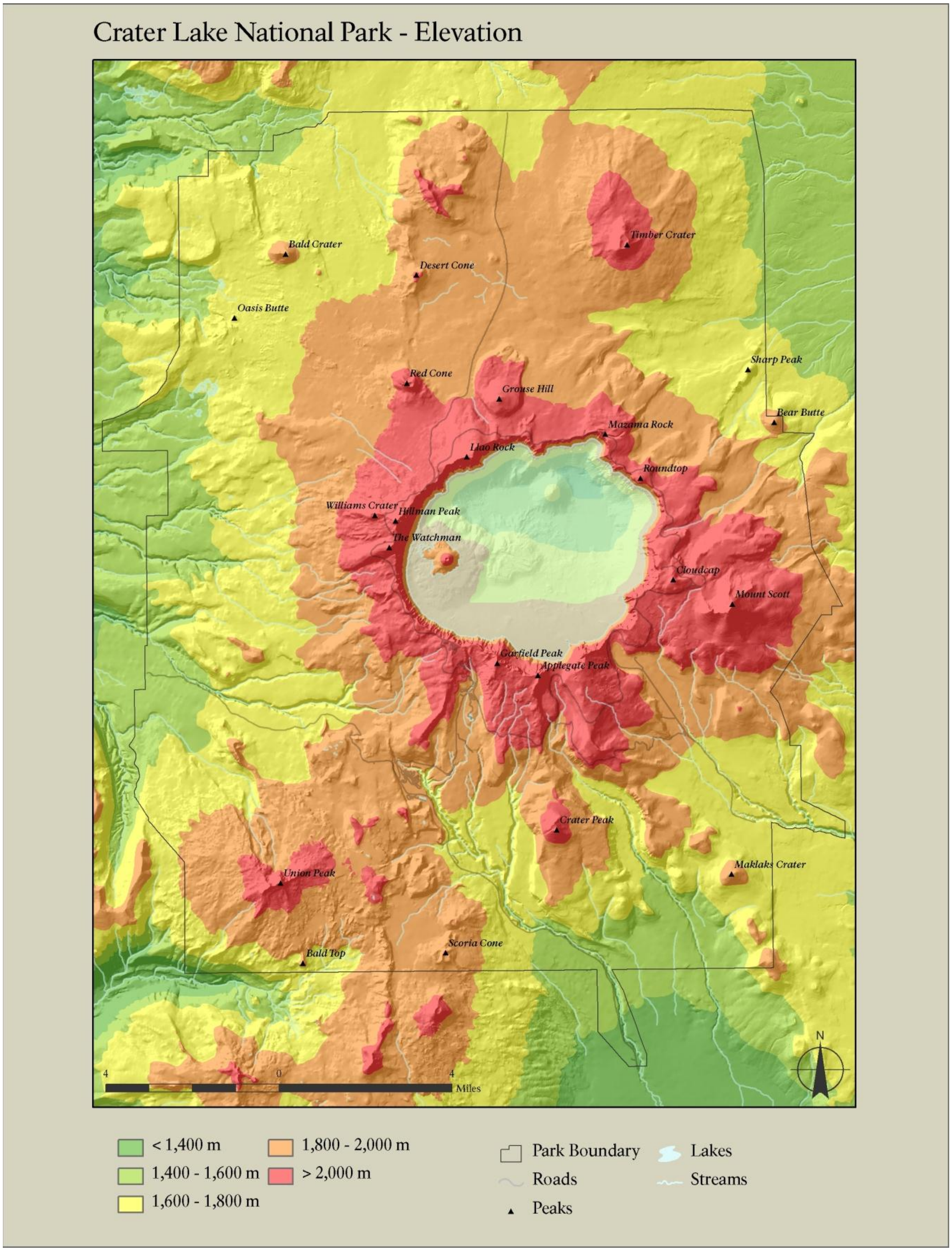


Figure B1. Mapped elevation classes in Crater Lake National Park (USGS 2011). Scale: 10 meters.

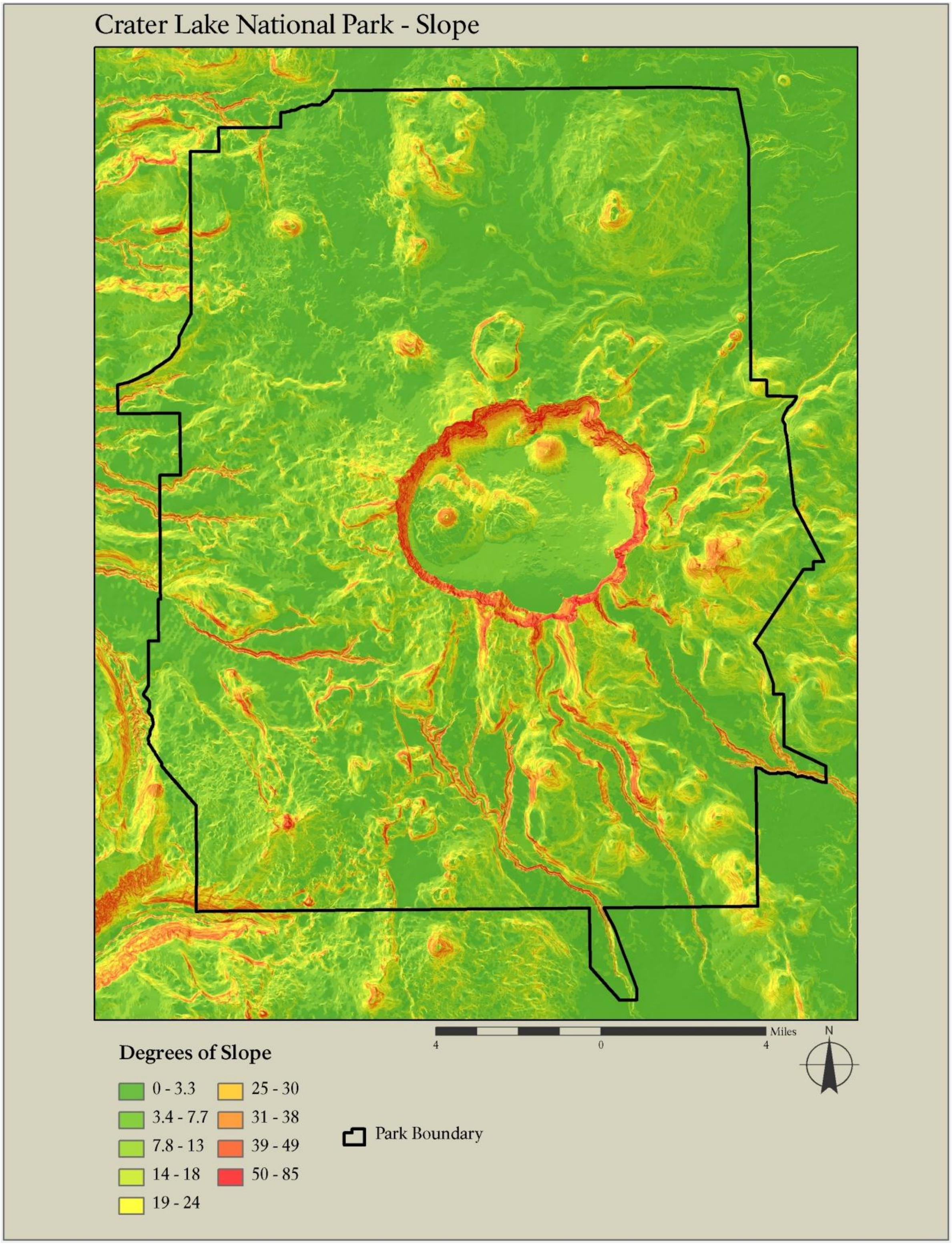


Figure B2. Mapped slope classes in Crater Lake National Park (USGS 2011). Scale: 10 meters.

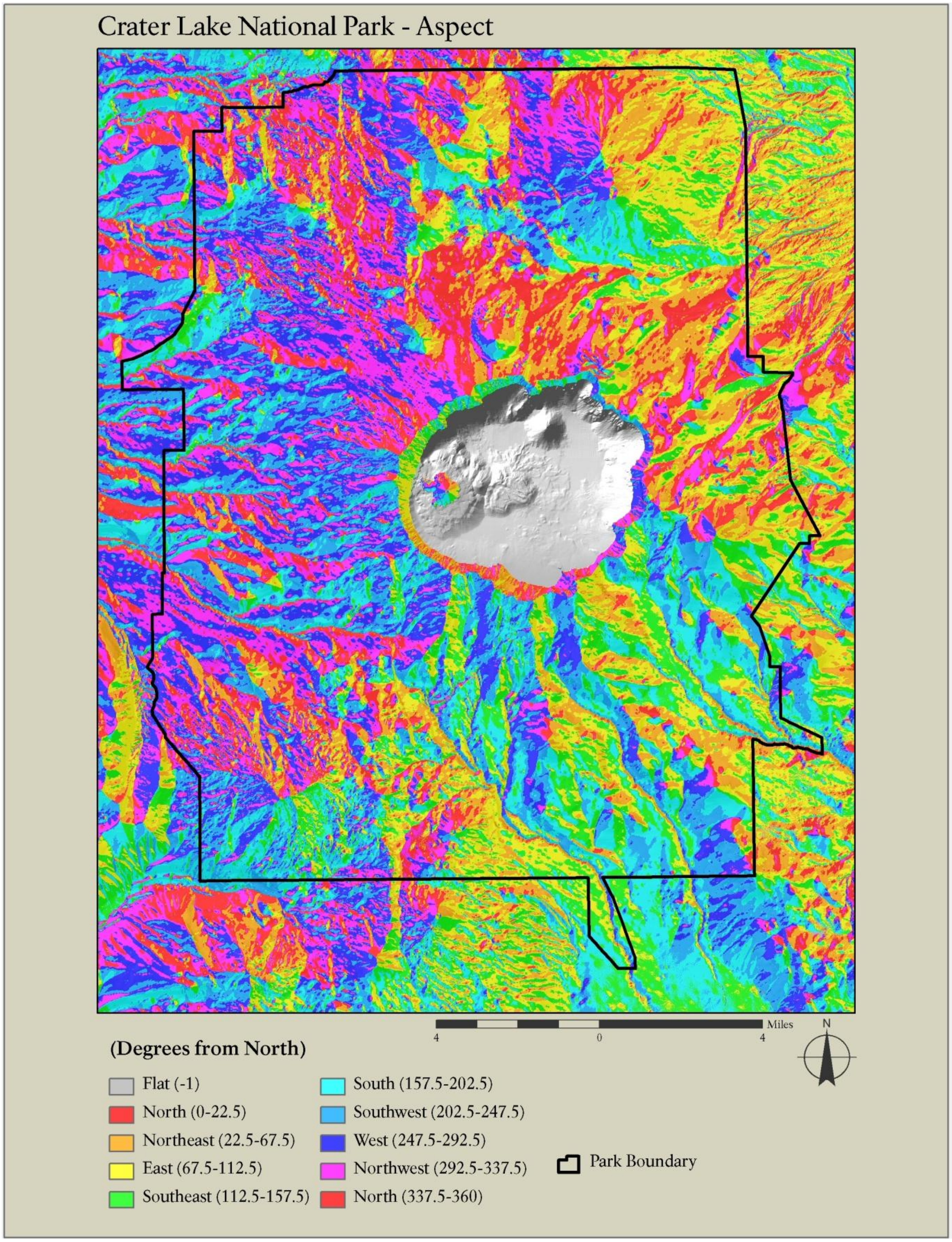


Figure B3. Mapped aspect classes in Crater Lake National Park (USGS 2011). Scale: 10 meters. This is a raster file that identifies the orientation or direction of slope. Aspect is the down-slope direction of a cell to its neighbors. The cell values in an aspect grid are compass directions ranging from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

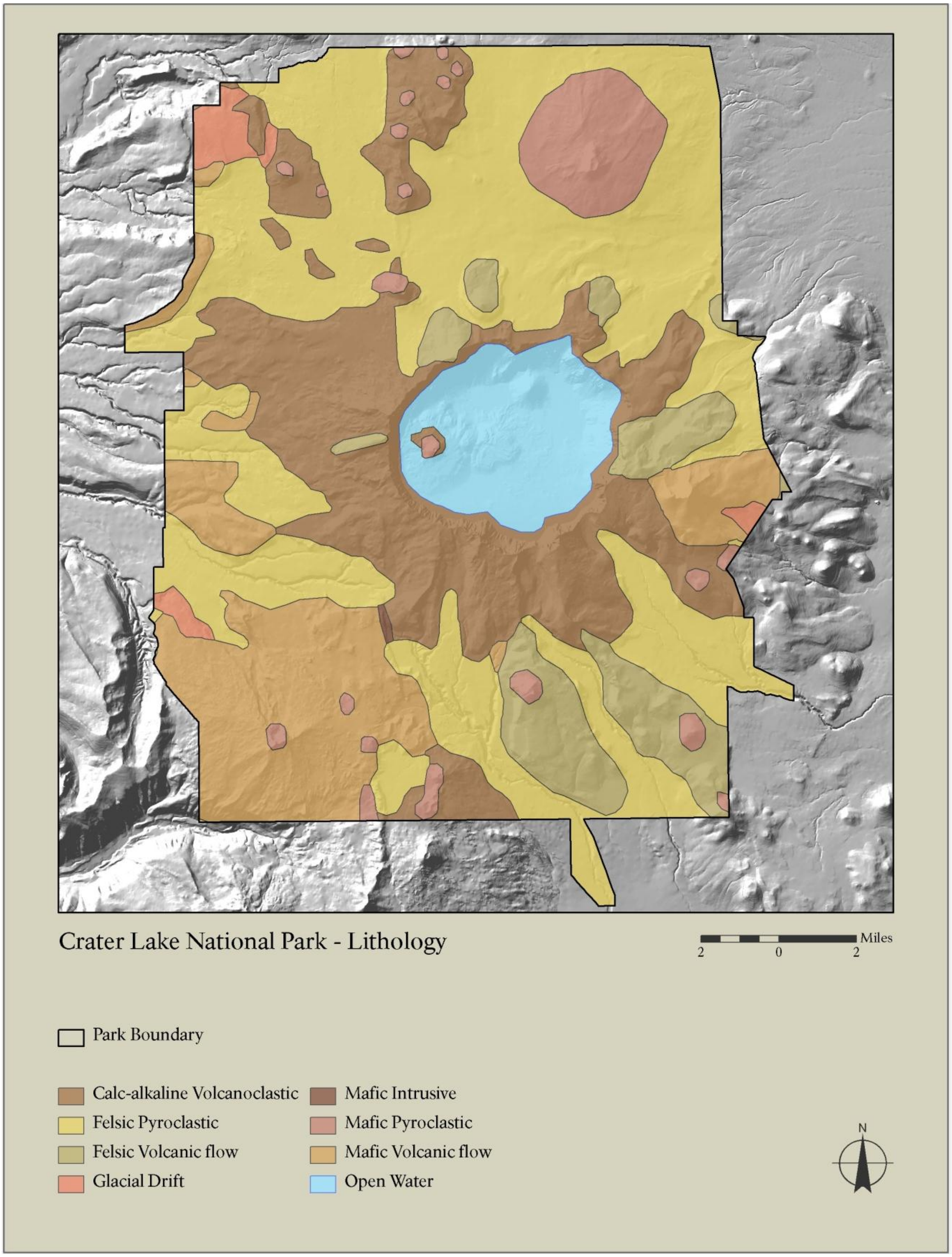


Figure B4. Mapped lithologic classes in Crater Lake National Park (USGS 2005). Scale: 1:500,000 (Chris Wayne, pers. comm.)

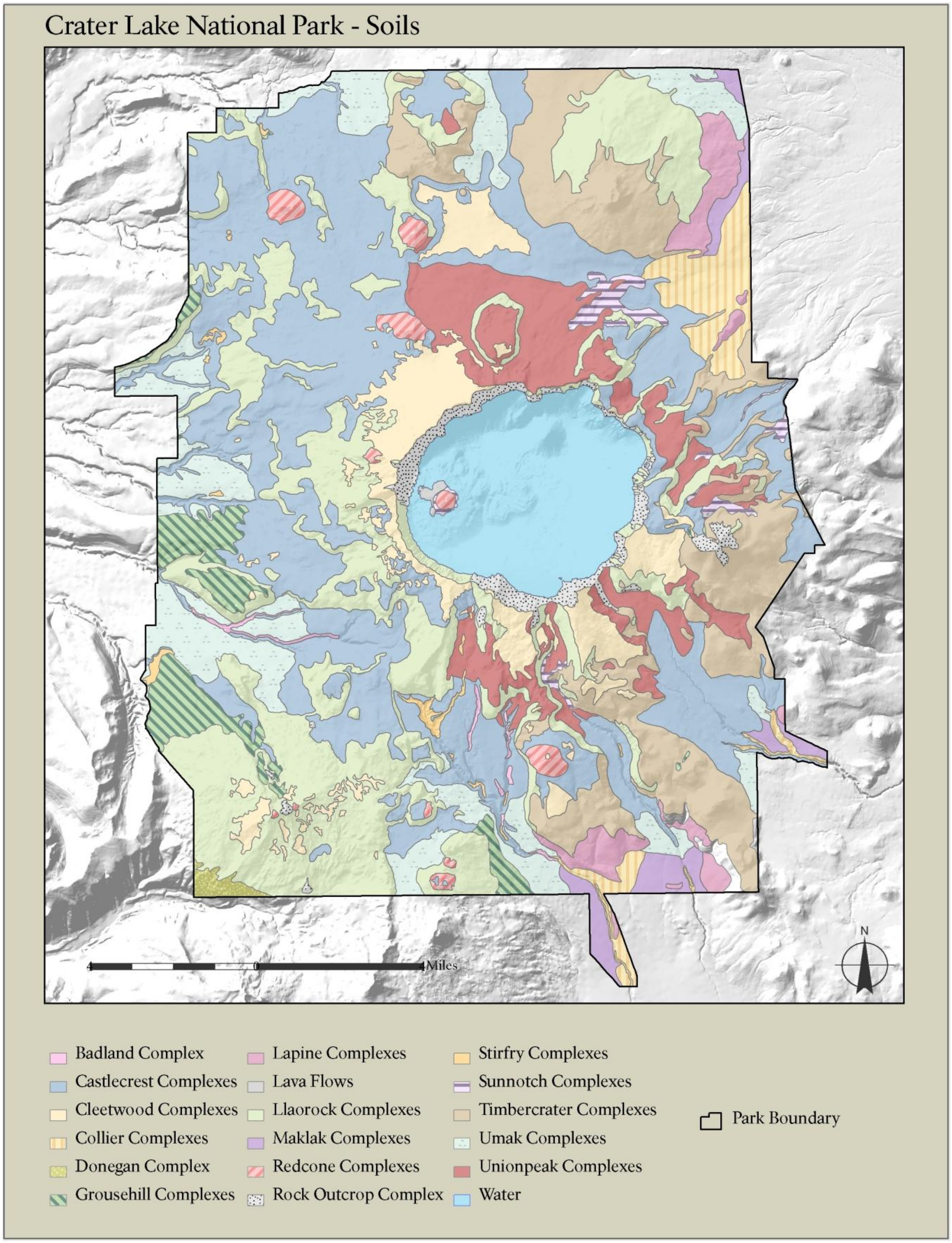


Figure B5. Mapped soil complexes in Crater Lake National Park (Soil Survey Staff 2011). Scale: 1:24,000. The SSURGO soil data map was simplified by using the dissolve tool, located in the Data Management toolbox provided in ArcGIS software, to combine multiple shapefiles of the same soil type into one single shapefile. The single shapefile was then grouped with other dissolved soil shapefiles of the same soil complex root name. The final output was single shapefiles of soil complexes, each containing multiple individual soil types from the same soil complex. The goal of 'simplifying' the data was to make the map less congested and easier to read.

Appendix C. Vegetation and Fire Characteristics of Crater Lake National Park: supporting data and maps

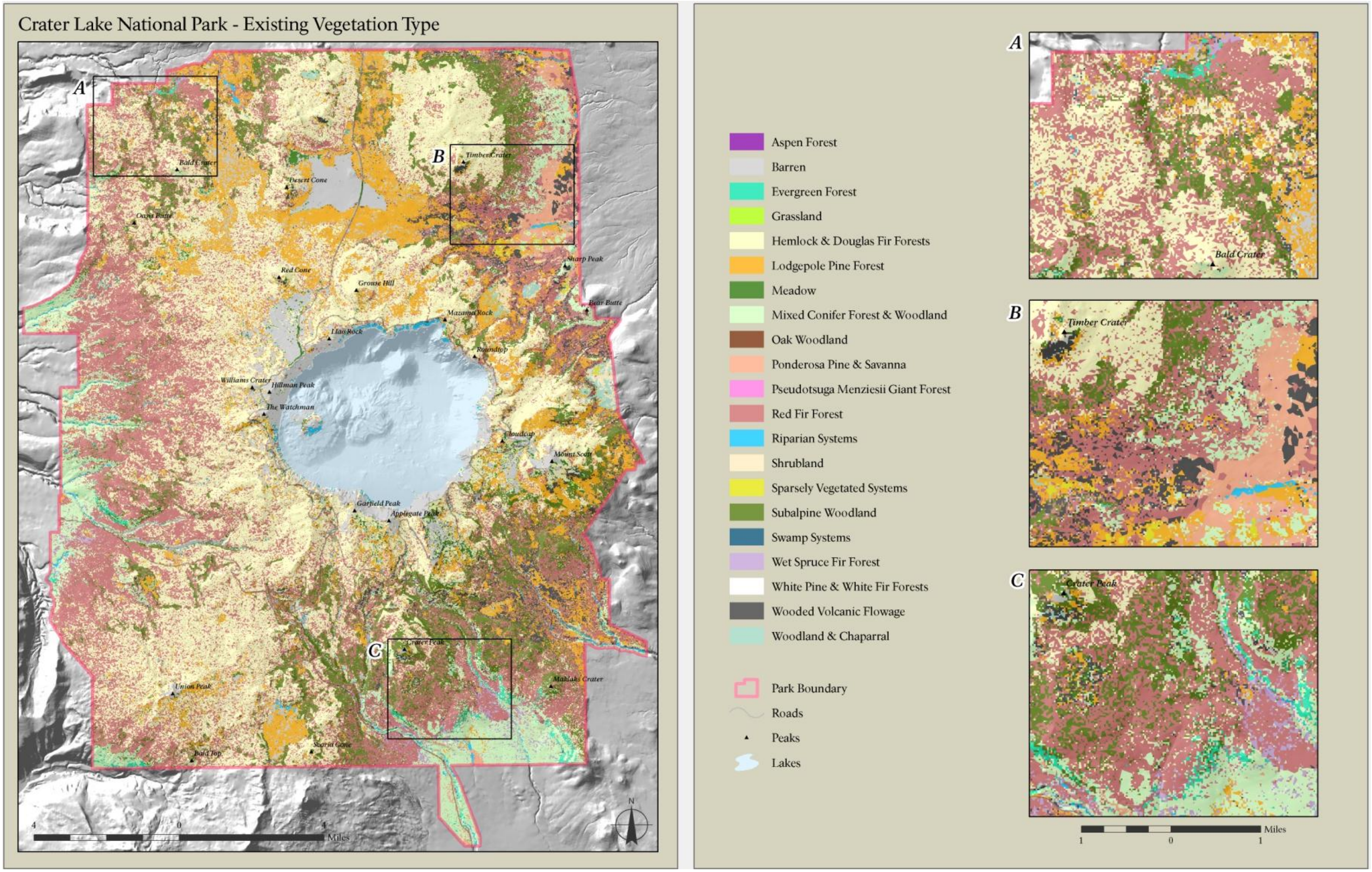


Figure C1. Mapped existing vegetation in Crater Lake National Park (LANDFIRE 2008). This map was prepared by other investigators who extrapolated information using Landsat Thematic Mapper and other data. Lands were assigned to map classes by experts in LANDFIRE workshops.

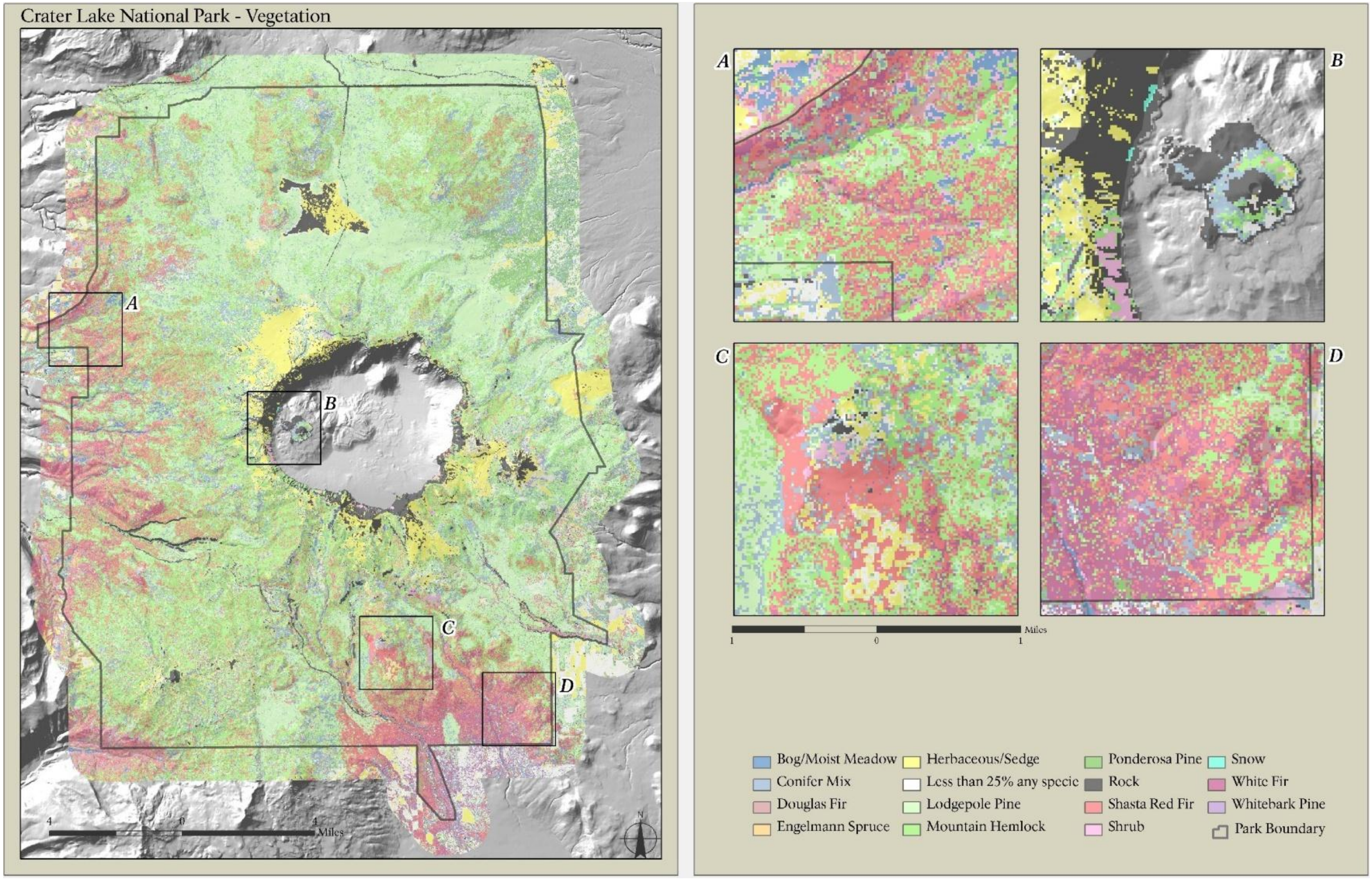


Figure C2. Mapped vegetation classes in Crater Lake National Park (Wieslander 1945). This map was prepared by other investigators who extrapolated information using Landsat Thematic Mapper and other data. Lands were assigned to map classes by experts in LANDFIRE workshops.

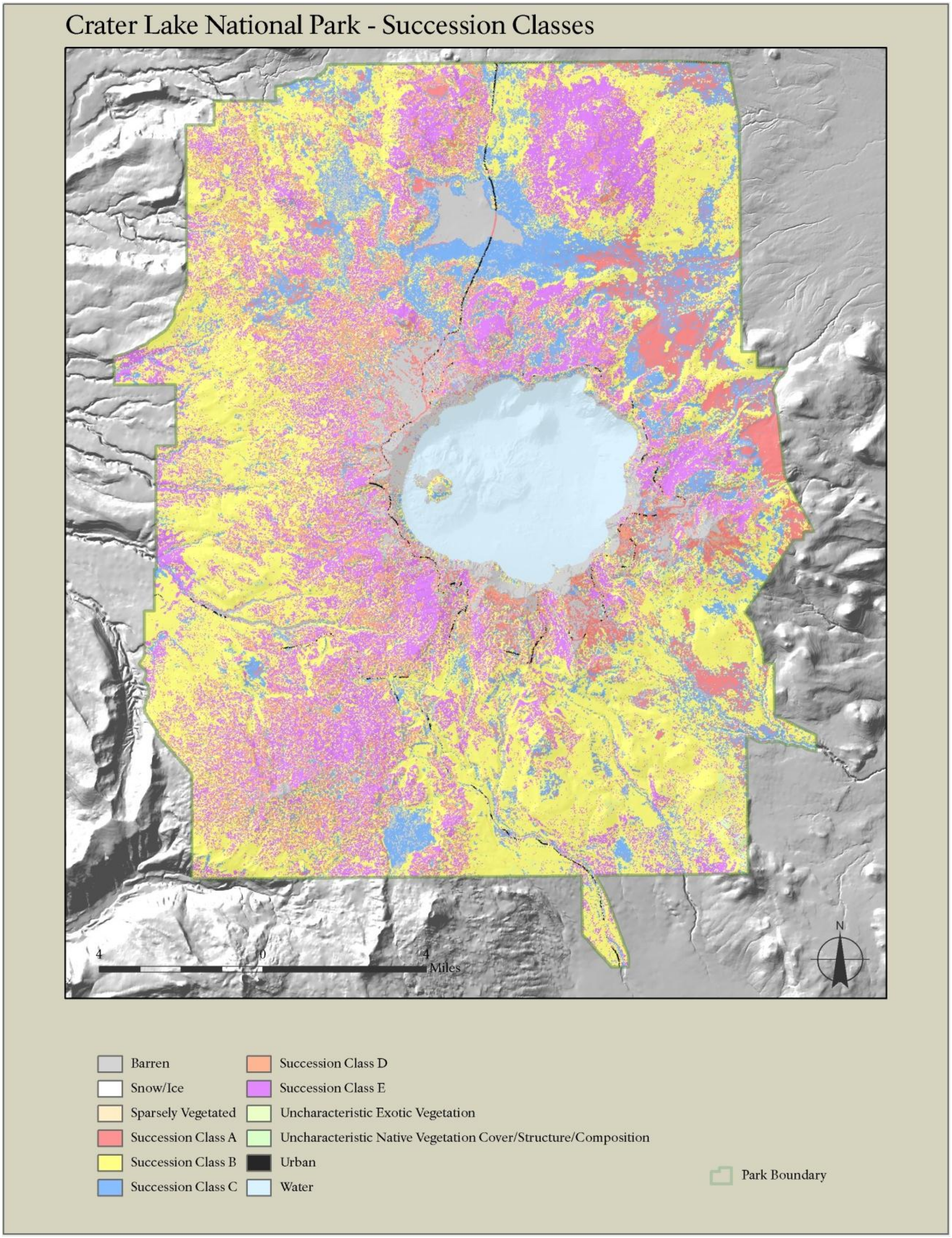


Figure C3. Mapped successional classes in Crater Lake National Park (LANDFIRE 2008). This map was prepared by other investigators who extrapolated information using Landsat Thematic Mapper and other data. Lands were assigned to map classes by experts in LANDFIRE workshops.

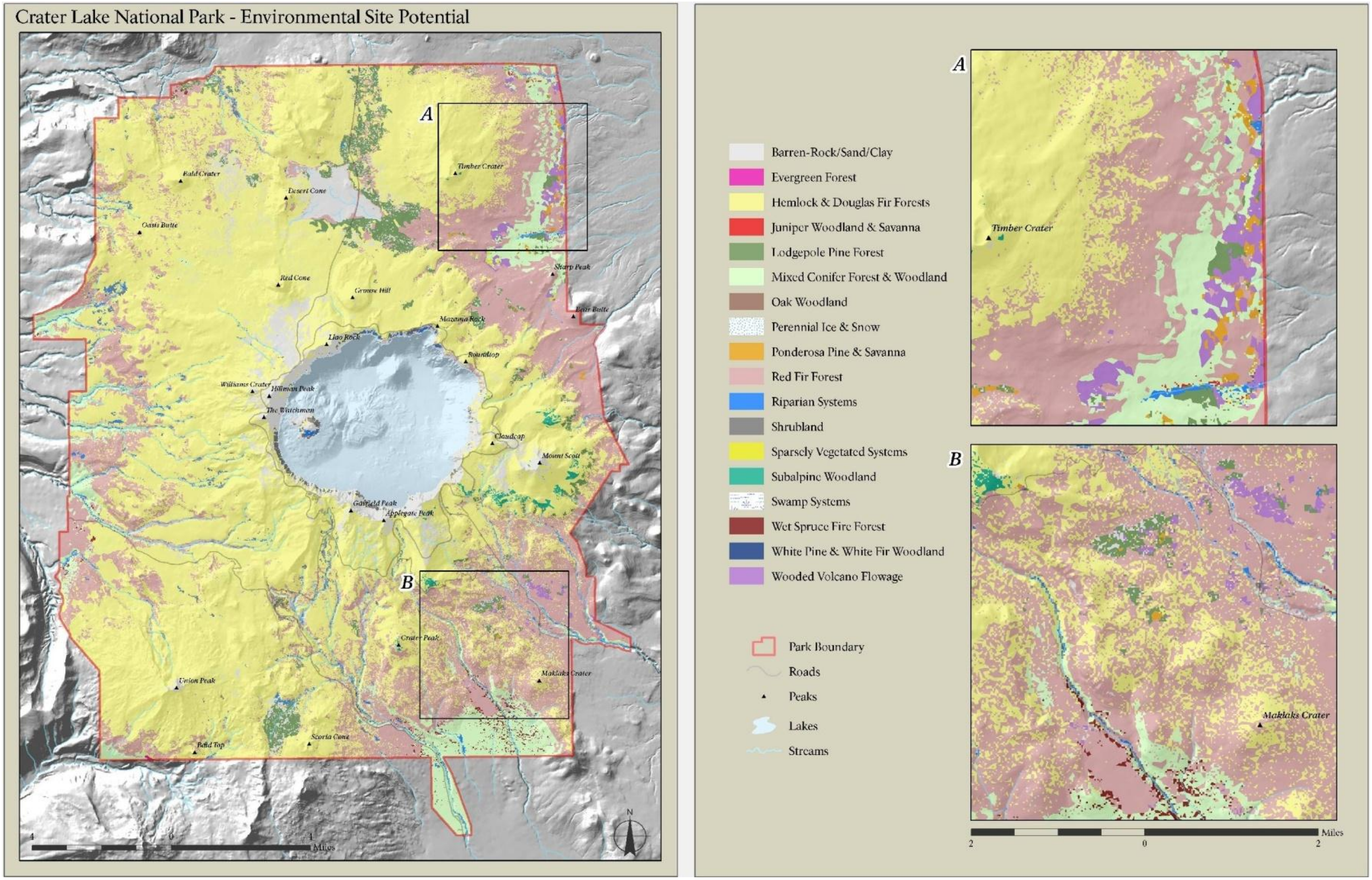


Figure C4. Mapped potential vegetation in Crater Lake National Park (LANDFIRE 2008). This map was prepared by other investigators who extrapolated information using Landsat Thematic Mapper and other data. Lands were assigned to map classes by experts in LANDFIRE workshops.

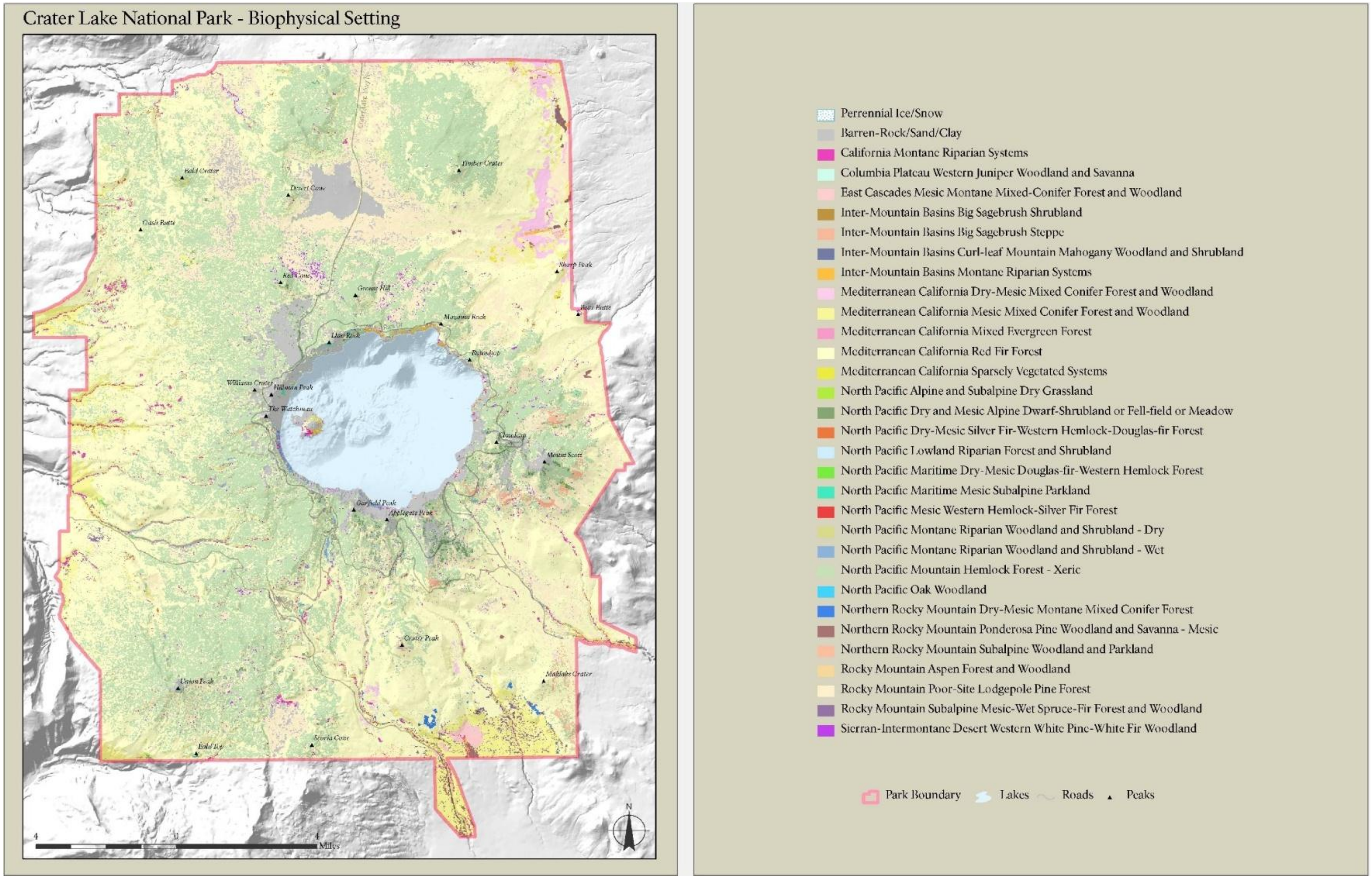


Figure C5. Mapped biophysical classes of Crater Lake National Park (LANDFIRE 2006). Scale: 30 meters. This map was prepared by other investigators who extrapolated information using Landsat Thematic Mapper and other data. Lands were assigned to map classes by experts in LANDFIRE workshops. The classes 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.

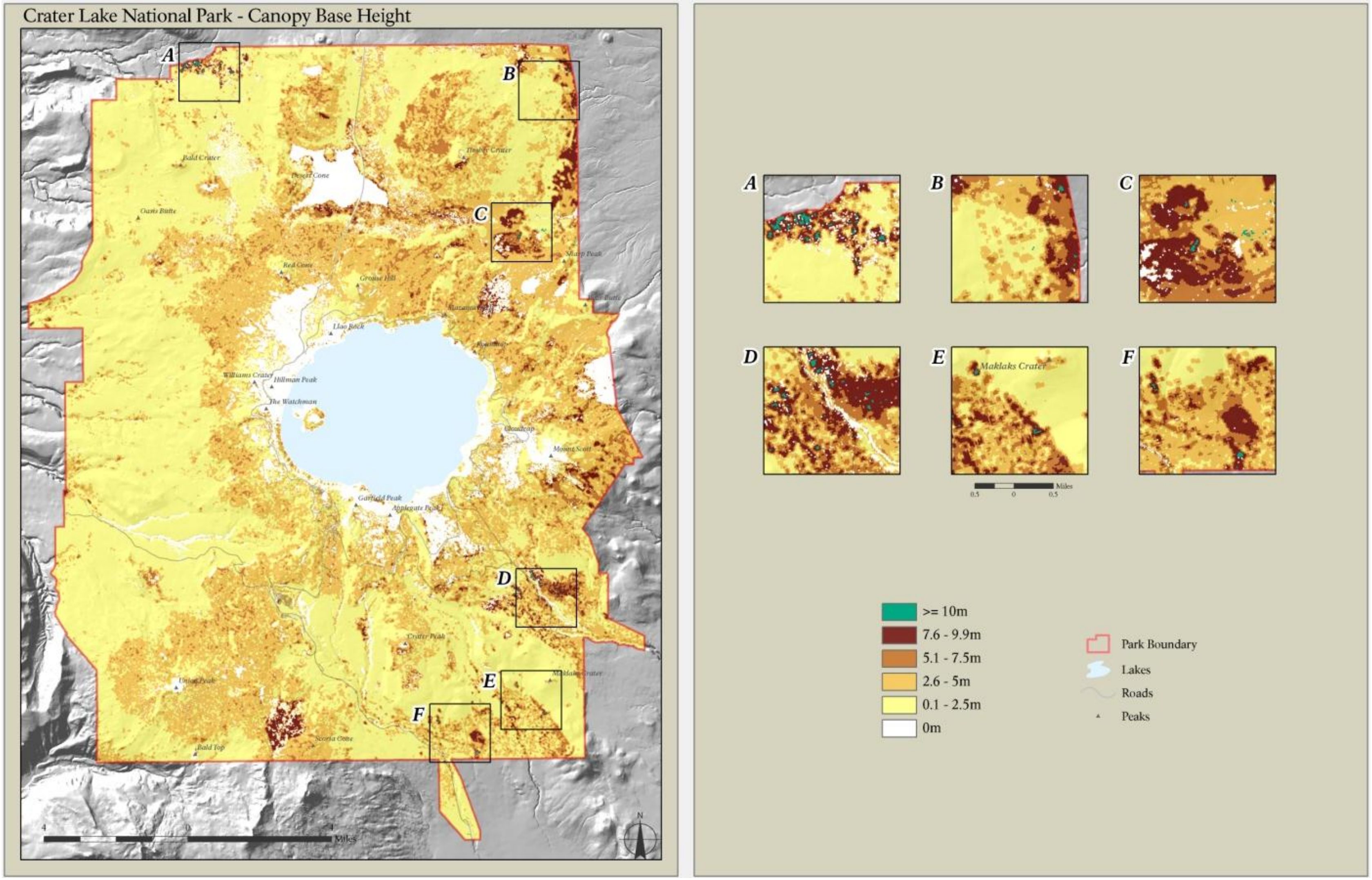


Figure C6. Mapped canopy base height of Crater Lake National Park (LANDFIRE 2007). Scale: 30 meters. This map was prepared by other investigators who extrapolated information using Landsat Thematic Mapper and other data. Lands were assigned to map classes by experts in LANDFIRE workshops. The map describes 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.

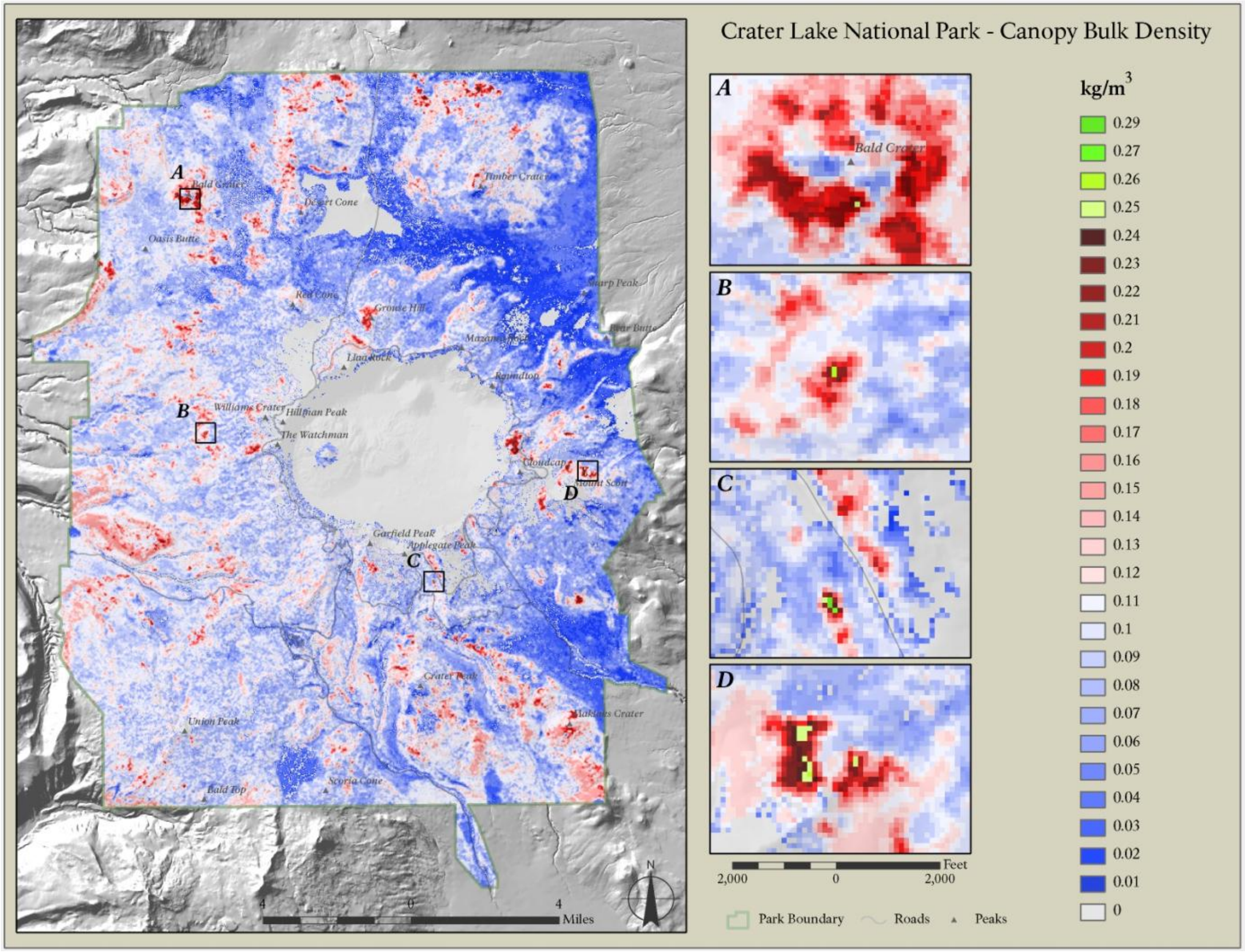


Figure C7. Mapped canopy bulk density of Crater Lake National Park (LANDFIRE 2008). This map was prepared by other investigators who extrapolated information using Landsat Thematic Mapper and other data. Lands were assigned to map classes by experts in LANDFIRE workshops.

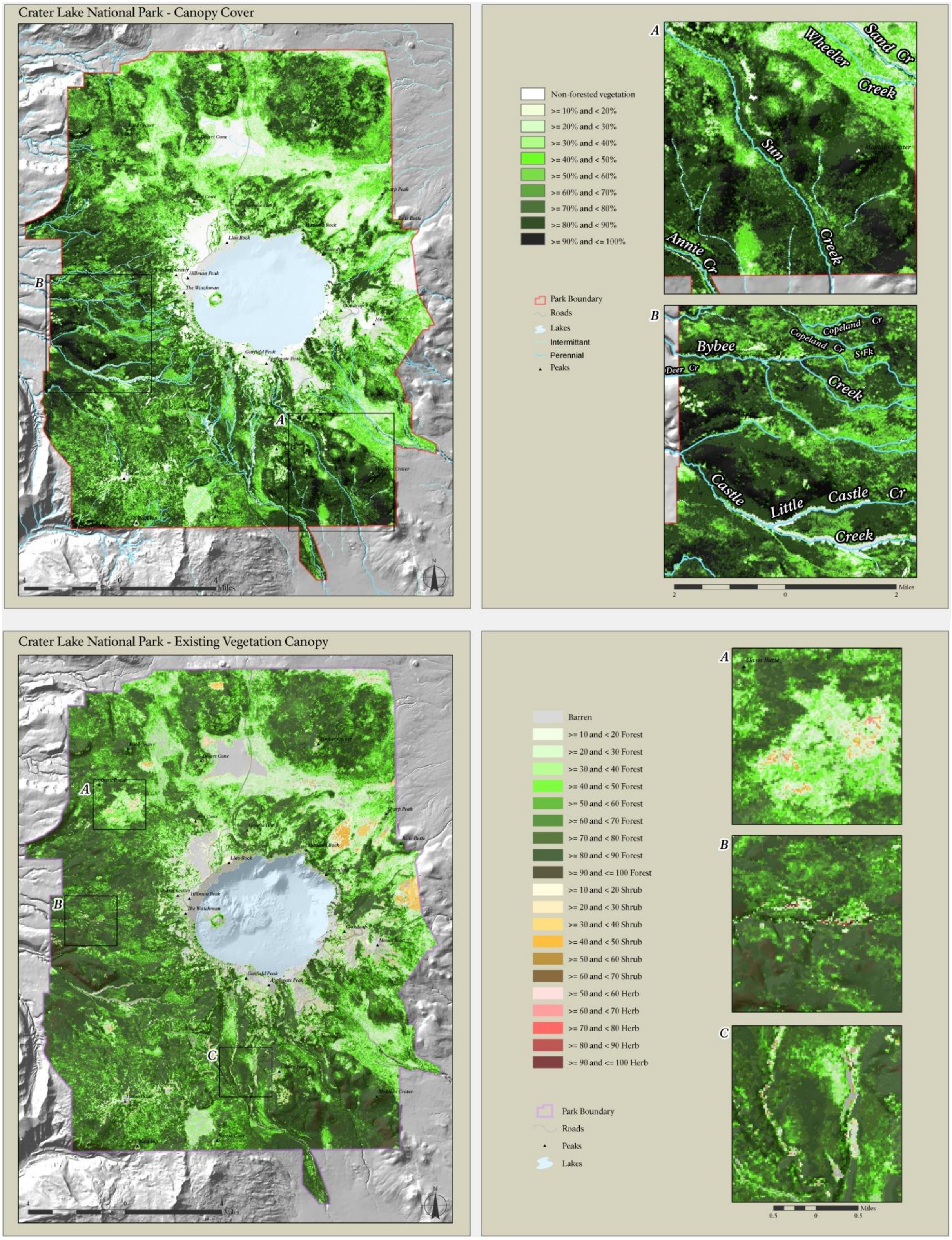


Figure C8. Mapped canopy cover and existing vegetation of Crater Lake National Park (LANDFIRE 2008). This map was prepared by other investigators who extrapolated information using Landsat Thematic Mapper and other data. Lands were assigned to map classes by experts in LANDFIRE workshops.

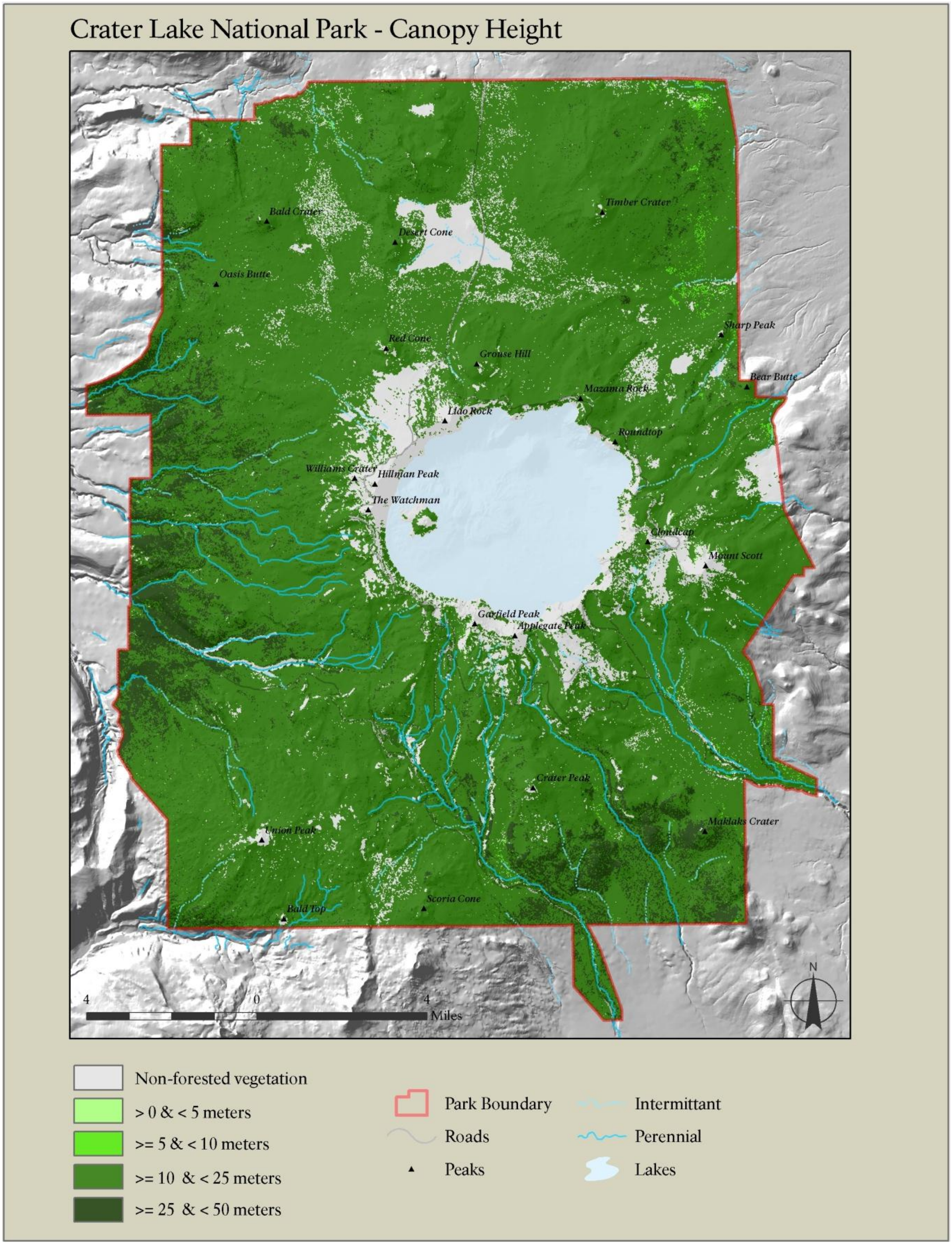


Figure C9. Mapped canopy height of Crater Lake National Park (LANDFIRE 2008). This map was prepared by other investigators who extrapolated information using Landsat Thematic Mapper and other data. Lands were assigned to map classes by experts in LANDFIRE workshops.

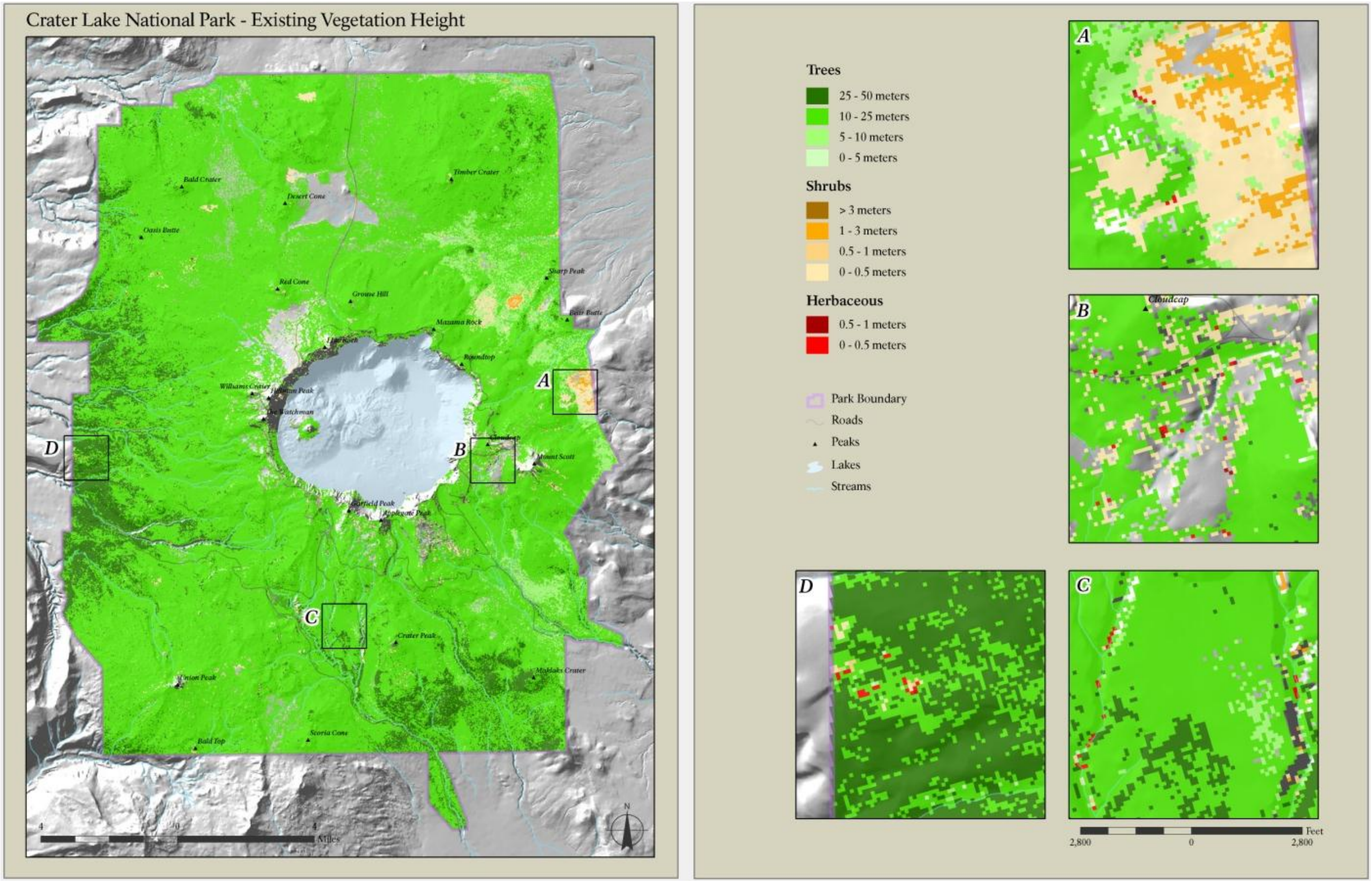


Figure C10. Mapped existing vegetation height of Crater Lake National Park (LANDFIRE 2008). This map was prepared by other investigators who extrapolated information using Landsat Thematic Mapper and other data. Lands were assigned to map classes by experts in LANDFIRE workshops.

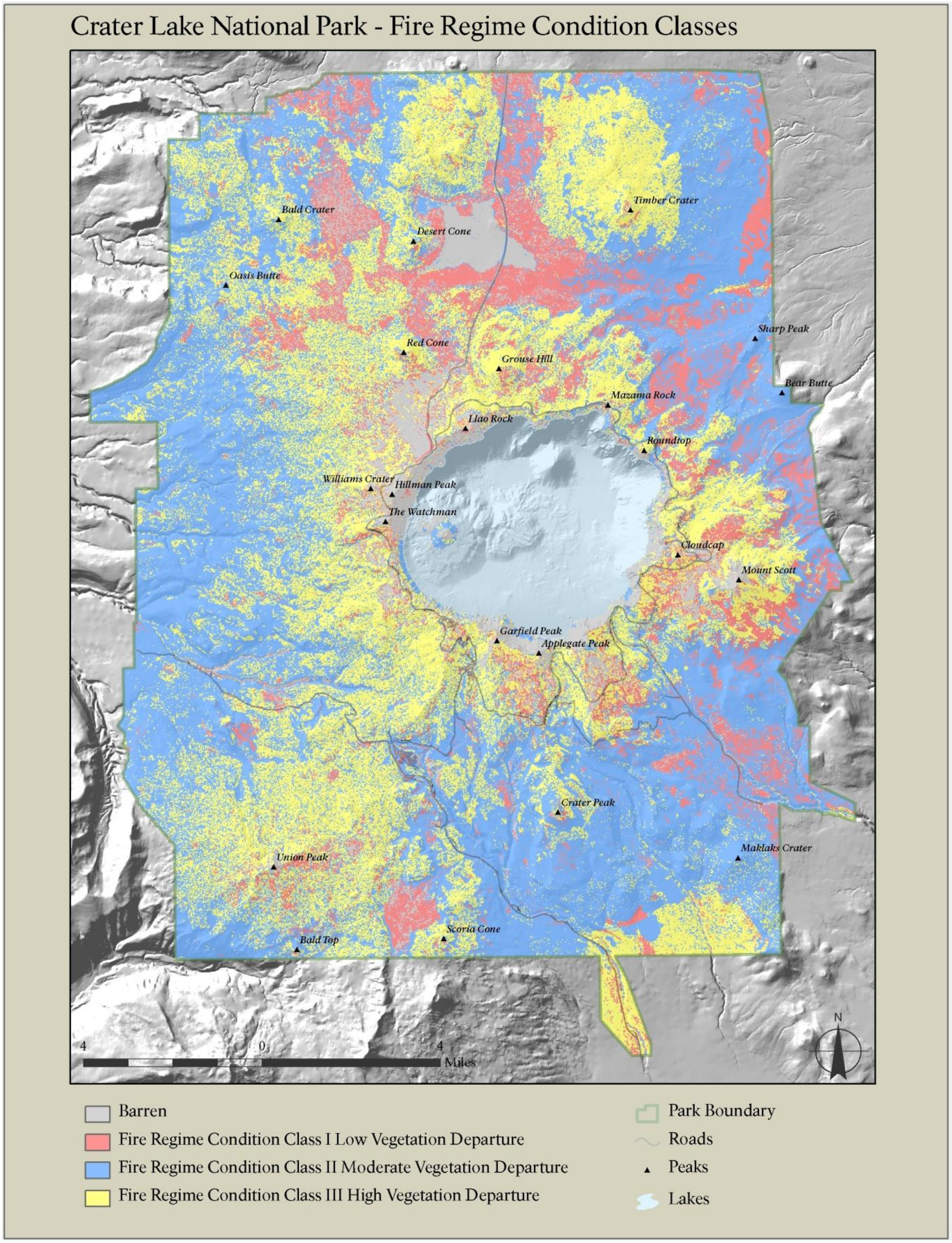


Figure C11. Mapped fire regime condition classes of Crater Lake National Park (LANDFIRE 2008). This map was prepared by other investigators who extrapolated fuels information using Landsat Thematic Mapper and other data. Lands were assigned to map classes by experts in LANDFIRE workshops. The map does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

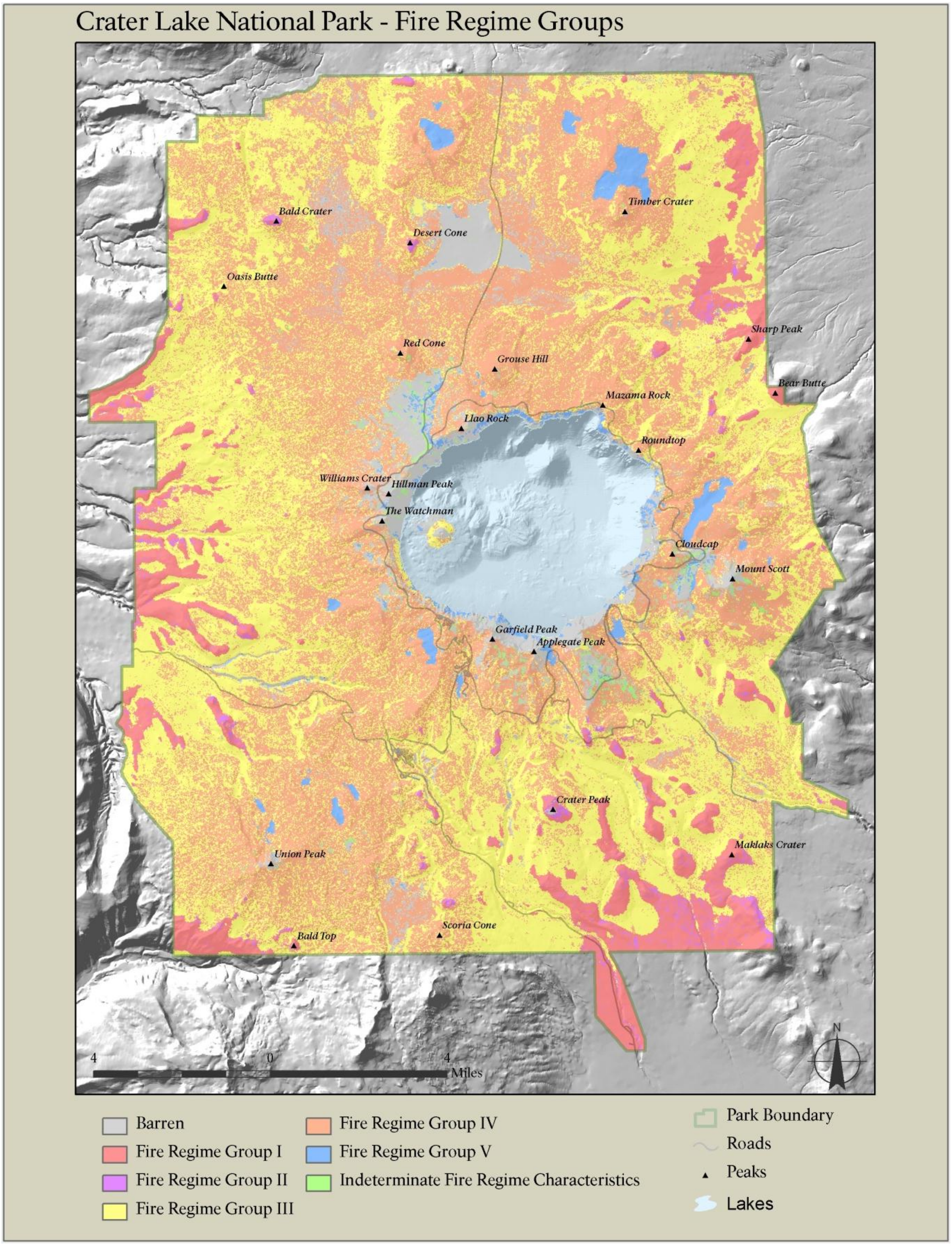


Figure C12. Mapped fire regime groups of Crater Lake National Park (LANDFIRE 2008). This map was prepared by other investigators who extrapolated fuels information using Landsat Thematic Mapper and other data. Lands were assigned to map classes by experts in LANDFIRE workshops. The map does not portray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

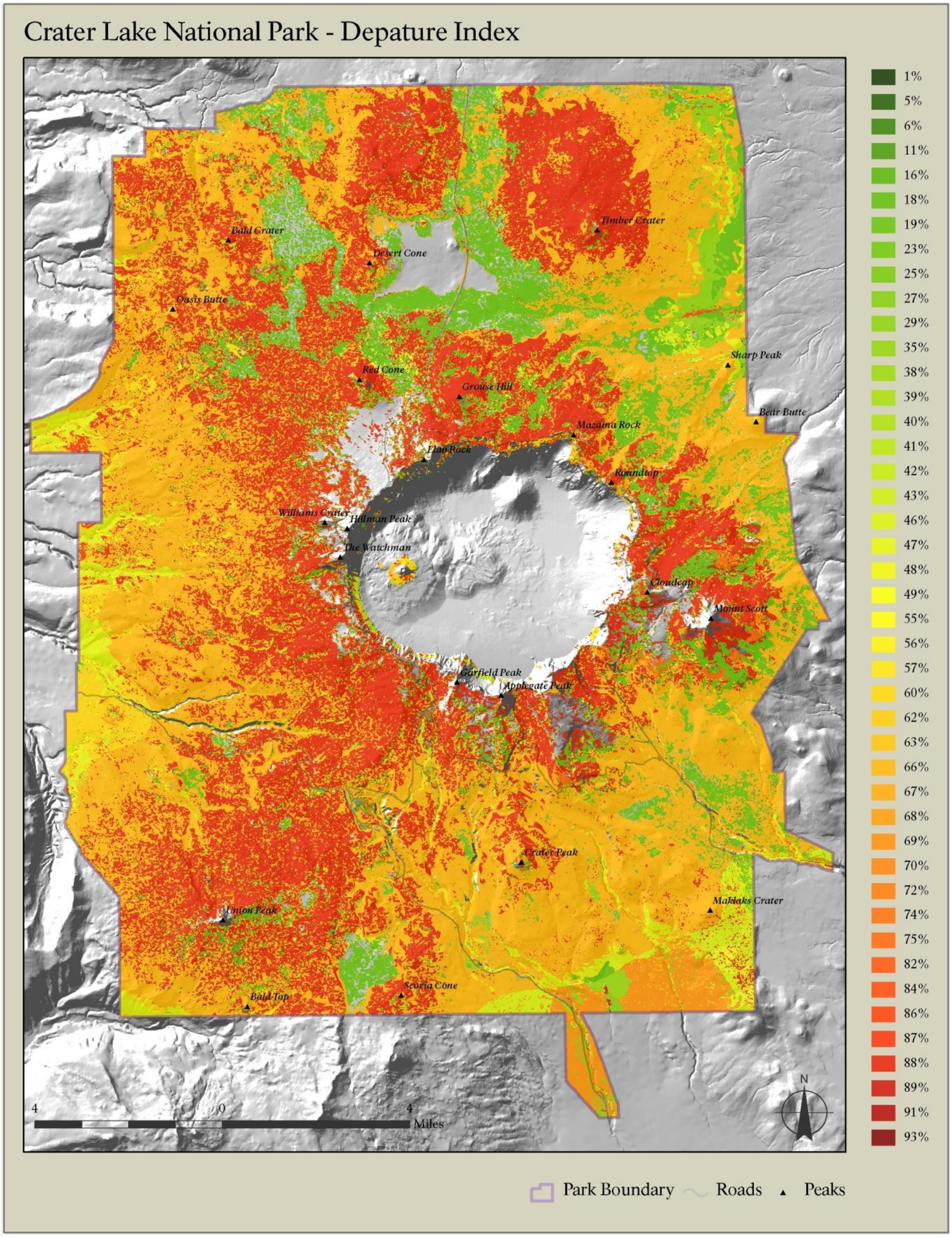


Figure C13. Mapped departure index of Crater Lake National Park (LANDFIRE 2008). This map was prepared by other investigators who extrapolated fuels information using Landsat Thematic Mapper and other data. Lands were assigned to map classes by experts in LANDFIRE workshops. The map does not portray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

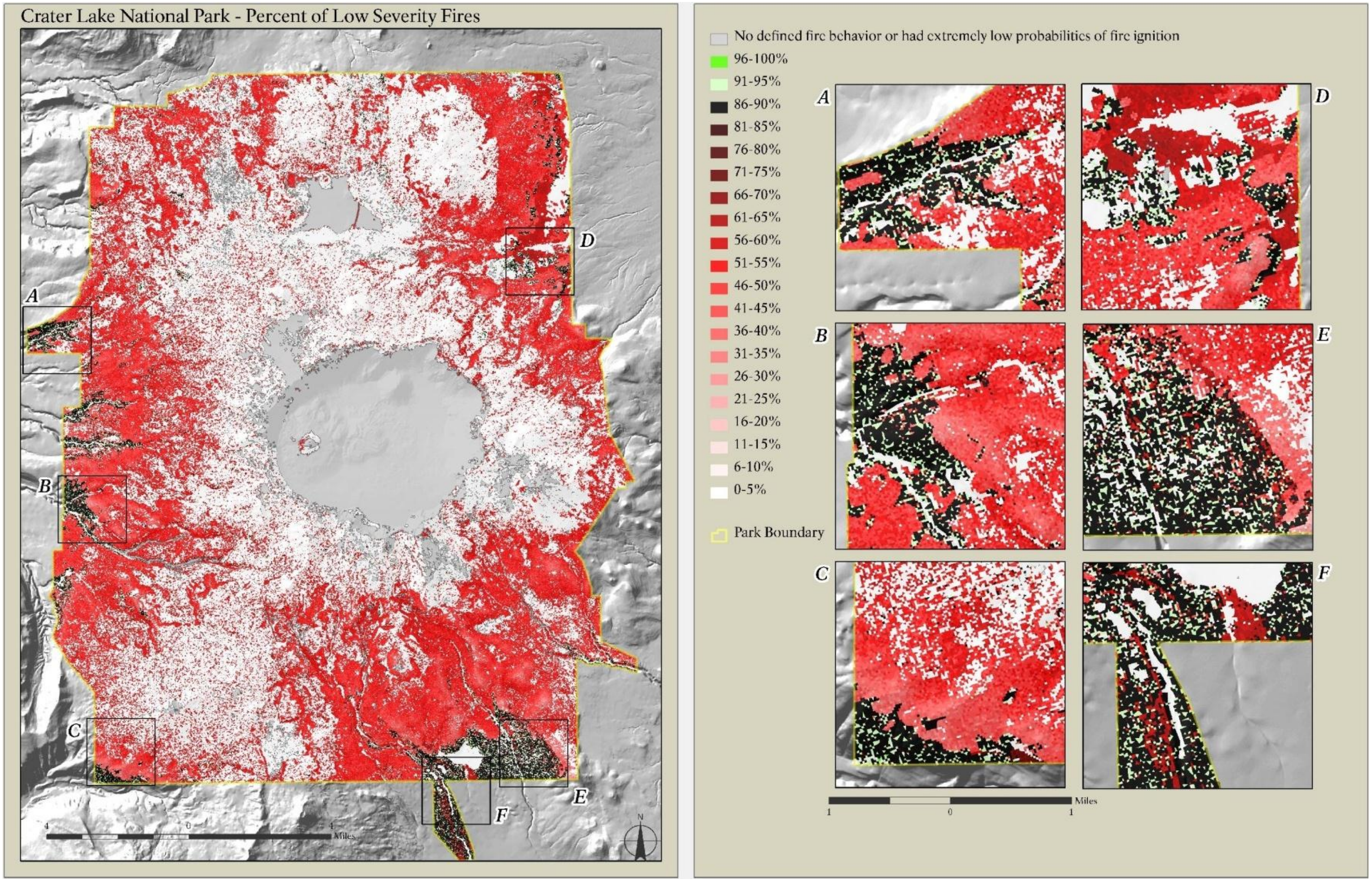


Figure C15. Mapped percent of low severity fires of Crater Lake National Park (LANDFIRE 2008). This map was prepared by other investigators who extrapolated fuels information using Landsat Thematic Mapper and other data. Lands were assigned to map classes by experts in LANDFIRE workshops. The map does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

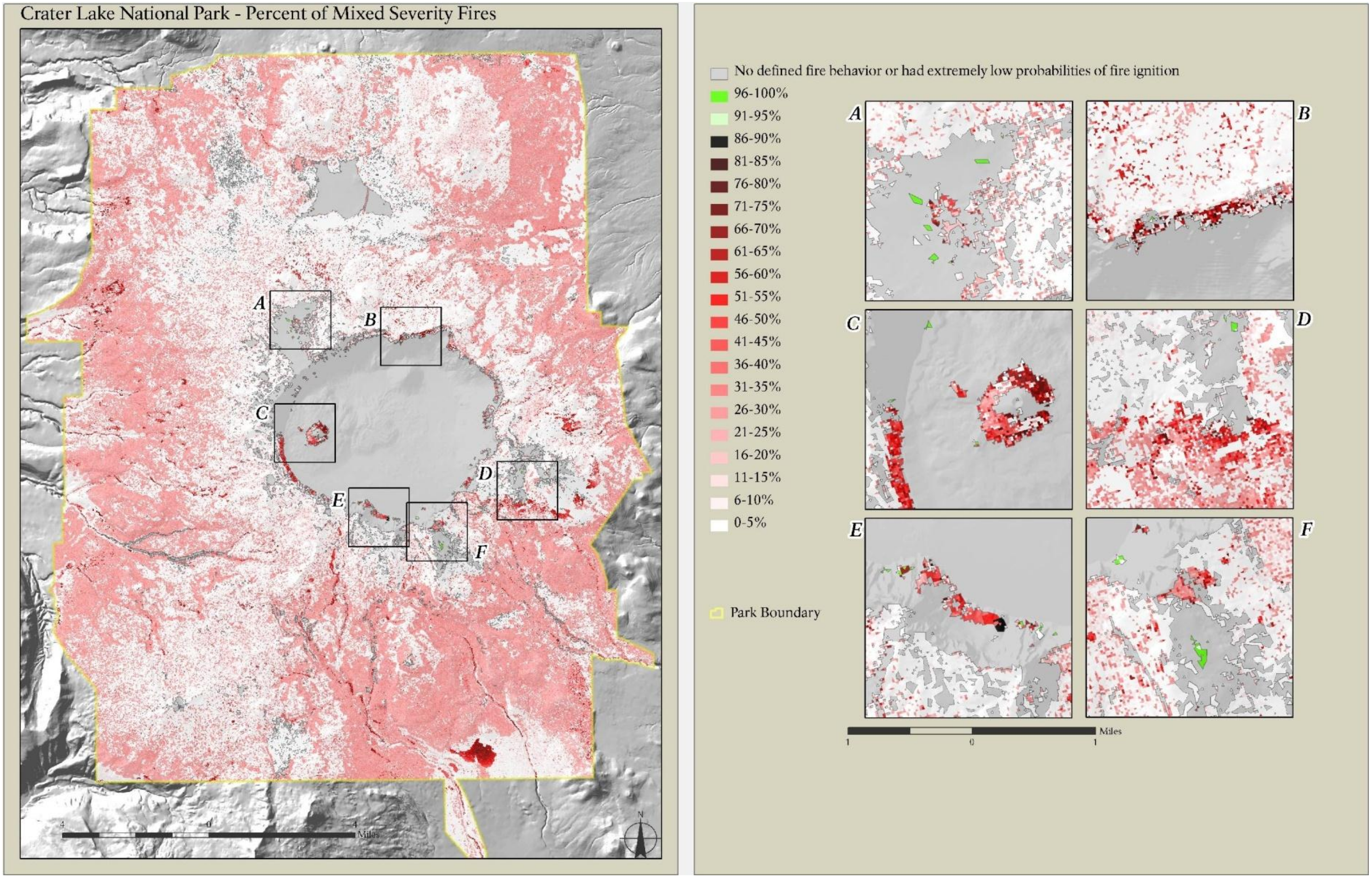


Figure C16. Mapped percent of mixed severity fires of Crater Lake National Park (LANDFIRE 2008). This map was prepared by other investigators who extrapolated fuels information using Landsat Thematic Mapper and other data. Lands were assigned to map classes by experts in LANDFIRE workshops. The map does not portray fuel, fuel arrangement, or vegetation flammability.

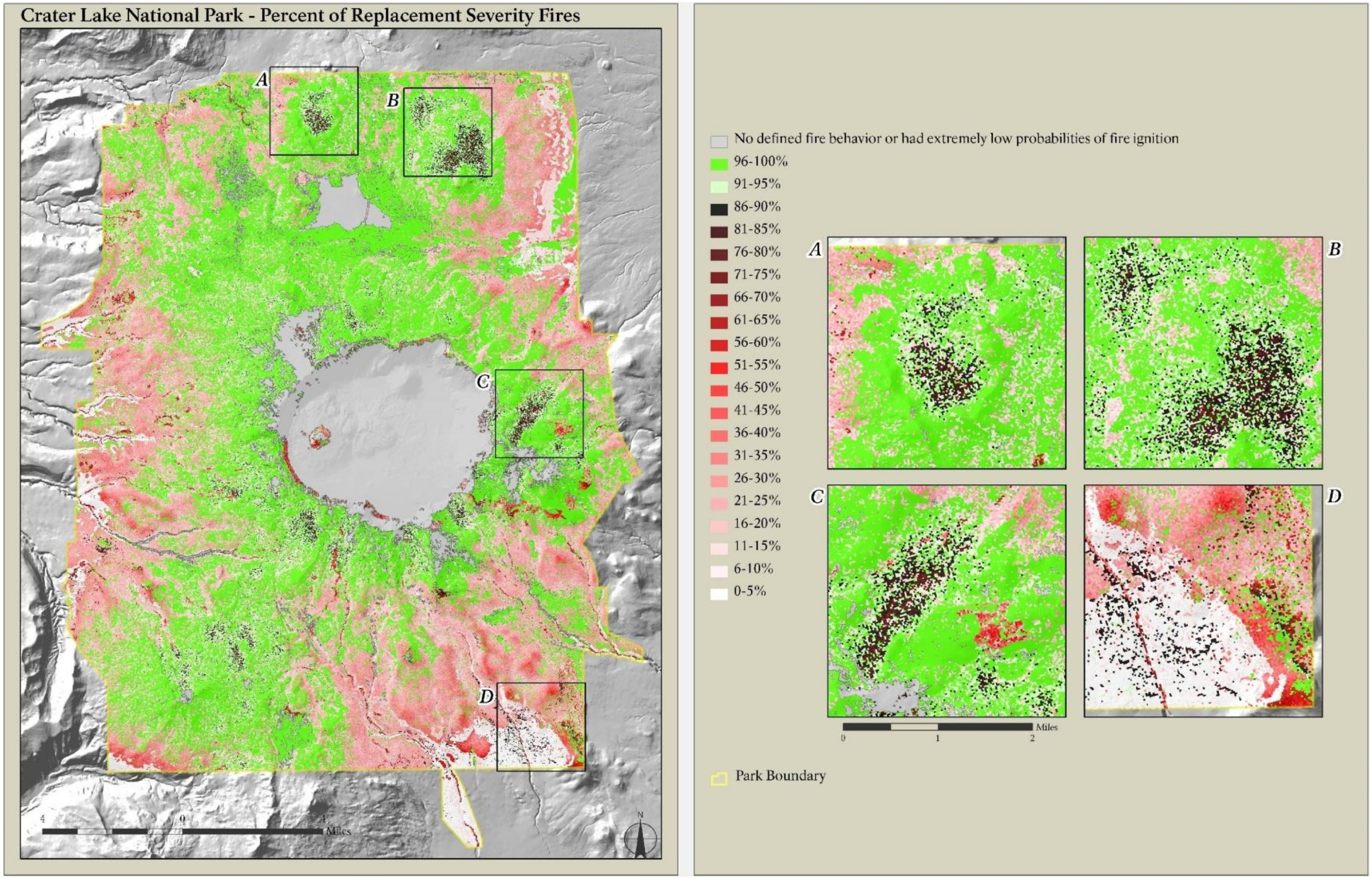


Figure C17. Mapped percent of replacement severity fires of Crater Lake National Park (LANDFIRE 2008). This map was prepared by other investigators who extrapolated fuels information using Landsat Thematic Mapper and other data. Lands were assigned to map classes by experts in LANDFIRE workshops. The map does not portray fuel, fuel arrangement, or vegetation flammability.

The Department of the Interior protects and manages the nation's natural resources and cultural heritage; provides scientific and other information about those resources; and honors its special responsibilities to American Indians, Alaska Natives, and affiliated Island Communities.

NPS 106/122745, November 2013

National Park Service
U.S. Department of the Interior

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