National Park Service
U.S. Department of the Interior

Natural Resource Stewardship and Science

Mount Rainier National Park

Natural Resource Condition Assessment

Natural Resource Report NPS/MORA/NRR—2014/894

ON THE COVER
Mount Rainier from Paradise Park
Photograph by: Michael Heck, USGS FRESC, January 2011

Mount Rainier National Park

Natural Resource Condition Assessment

Natural Resource Report NPS/MORA/NRR—2014/894

Robert L. Hoffman[1]
Andrea Woodward[1]
Patricia Haggarty[1]
Kurt Jenkins[1]
Paul Griffin[1]
Michael J. Adams[1]
Joan Hagar[1]
Tonnie Cummings[2]
Dan Duriscoe[2]
Karen Kopper[2]
Jon Riedel[2]
Barbara Samora[2]
Lelaina Marin[3]
Guillaume S. Mauger[4]
Karen Bumbaco[5]
Jeremy S. Littell[6]

[1] U.S. Geological Survey, Forest and Rangeland Ecosystem Science Center, 777 NW 9th Street, Suite 400, Corvallis, OR 97330
[2] U.S. Department of the Interior, National Park Service
[3] U.S. Fish and Wildlife Service
[4] Climate Impacts Group, College of the Environment, University of Washington
[5] University of Washington Office of the Washington State Climatologist
[6] U.S. Department of the Interior Climate Science Center, Alaska

This report was prepared under Task Agreement F9453100026 between the National Park Service and the U.S. Geological Survey, Forest and Rangeland Ecosystem Science Center.

December 2014

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

The National Park Service, Natural Resource Stewardship and Science office in Fort Collins, Colorado, publishes a range of reports that address natural resource topics. These reports are of interest and applicability to a broad audience in the National Park Service and others in natural resource management, including scientists, conservation and environmental constituencies, and the public.

The Natural Resource Report Series is used to disseminate high-priority, current natural resource management information with managerial application. The series targets a general, diverse audience, and may contain NPS policy considerations or address sensitive issues of management applicability.

All manuscripts in the series receive the appropriate level of peer review to ensure that the information is scientifically credible, technically accurate, appropriately written for the intended audience, and designed and published in a professional manner. This report received informal peer review by subject-matter experts who were not directly involved in the collection, analysis, or reporting of the data.

This report has been peer reviewed and approved for publication consistent with USGS Fundamental Science Practices (http://pubs.usgs.gov/circ/1367/).

This report is available in digital format from the North Coast and Cascades Network Inventory and Monitoring website (http://science.nature.nps.gov/im/units/nccn/publications.cfm) and the Natural Resource Publications Management website (http://www.nature.nps.gov/publications/nrpm/). To receive this report in a format optimized for screen readers, please email irma@nps.gov.

Please cite this publication as:

Hoffman, R. L., A. Woodward, P. Haggerty, K. Jenkins, P. Griffin, M. J. Adams, J. Hagar, T. Cummings, D. Duriscoe, K. Kopper, J. Riedel, B. Samora, L. Marin, G. S. Mauger, K. Bumbaco, and J. S. Littell. 2014. Mount Rainier National Park: Natural resource condition assessment. Natural Resource Report NPS/MORA/NRR—2014/894. National Park Service, Fort Collins, Colorado.

NPS 105/127528, December 2014

Contents

Page

Contents (continued)

Page

Contents (continued)

Page

Contents (continued)

Page

Contents (continued)

Contents (continued)

Page

Contents (continued)

Page

Contents (continued)

Page

Figures

Page

Figures (continued)

Page

Figures (continued)

Page

Figures (continued)

Page

Tables

Page

Tables (continued)

Tables (continued)

Page

Tables (continued)

Page

Executive Summary

Natural Resource Condition Assessments (NRCAs) evaluate current conditions for a subset of natural resources and resource indicators in national parks. 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. Although the primary objective of NRCAs is to report on current conditions relative to logical forms of reference conditions and values, NRCAs also report on trends, when appropriate (i.e., when the underlying data and methods support such reporting), as well as influences on resource conditions. These influences may include past activities or conditions that provide a helpful context for understanding current conditions and present-day threats and stressors that are best interpreted at park, watershed, or landscape scales (though NRCAs do not 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. It is also important to note that NRCAs do not address resources that lack sufficient data for assessment. For Mount Rainier National Park, this includes most invertebrate species and many other animal species that are subject to significant stressors from climate change and other anthropogenic sources such as air pollutants and recreational use. In addition, we did not include an analysis of the physical hydrology associated with streams (such as riverine landforms, erosion and aggradation which is significant in MORA streams), due to a loss of staff expertise from the USGS-BRD staff conducting the work, and human disturbance landcover issues such as the effects of roads, trails, and other anthropogenic developments due to lack of funds.

Mount Rainier National Park (MORA) was established as the nation's fifth national park in 1899. MORA was created from lands already set aside as forest reserves, and lands within the park granted to the Northern Pacific Railroad Company were reclaimed, thus establishing MORA entirely under federal ownership. Subsequent congressional actions designated 97% (228, 400 ac; 92,430 ha) of the park as wilderness (1988) and a 1700-ac (688-ha) area as the Mount Rainier National Historic Landmark District (1997).

MORA is located in the Cascade Range of west-central Washington (Figure 1). The park encompasses 236,381.49 ac (95,660 ha) within the authorized, legislative Park boundary, with an additional 140 ac (57 ha) lying outside the current boundary. Eighty-eight percent of the park, plus the additional acres outside the current boundary lie within Pierce County, and 12% is in Lewis County (Figure 2). The Seattle-Tacoma metropolitan area is approximately 65 mi (105 km) northwest of MORA's northern boundary and Yakima is 65 mi (105 km) to the southeast of the park's southern and eastern boundaries. Park elevations extend from about 1700 ft (518 m) above sea level to 14,411 ft (4392 m) at the summit of Mount Rainier, which is an active volcano, the focal point of the park, and a prominent landmark in the Pacific Northwest. The base of the snow- and ice-covered volcano spreads over an area of about 100 sq mi (260 sq km). Mount Rainier has 26 major glaciers that cover 35 mi^2 (91 km^2), constituting the largest single-mountain glacial system in the contiguous 48 states. Mount Rainier is also the second most seismically active, and the most hazardous volcano in the Cascade Range. The park's topography is predominantly rugged and precipitous, and consists mainly of peaks and valleys.

A Natural Resource Condition Assessment Workshop was convened in 2010. The multiple purpose of this two-day workshop was to review and brainstorm the natural resources of MORA, to identify and prioritize key indicators of the park's natural resources and their stressors for resources having sufficient existing information, and to develop a plan for creating and completing an assessment of the conditions of the natural resources. General resource categories addressed at the workshop were air quality, water quality, climate change, landscape, wildlife (including amphibians, birds, fish, and mammals), glaciers, riverine landforms, terrestrial vegetation, soundscapes, and night skies. Following the scoping workshop, all available data, reports, and references pertinent to each of the 10 general natural resource categories identified during the workshop were collected from MORA staff. This information was uploaded to a USGS SharePoint site and made available to all participants in this assessment. Individuals responsible for completing an assessment reviewed available resource-specific information and selected material that would allow them to complete their assessment. These materials included, in part: (1) existing databases that could be analyzed without revision; (2) databases that could be analyzed after appropriate revision; (3) published and unpublished reports that already analyzed, evaluated, and summarized the status and trends of a particular resource; (4) executive summaries and annual resource status reports; and (5) assorted administrative reports, summaries, and checklists of past resource program activities. Resource assessors also determined how the condition of a resource could best be assessed and gathered appropriate references and documentation that would support the metrics and reference conditions chosen to complete their assessment. As a result of this process, and after reassessing the staff expertise available to support the assessment, focal natural resources and their assessment categories were identified for inclusion in this report.

A total of 14 focal MORA natural resources were assessed as a part of this NRCA (see Table 5, Chapter 3). A detailed discussion of each resource, presented in Chapter 4, includes: (1) Introduction; (2) Approach (methods used to complete assessment); (3) Reference Conditions and Comparison Metrics (used to determine resource condition); (4) Results and Assessment; (5) Emerging Issues; (6) Information and Data Needs–Gaps; and (7) Literature Cited. Trend analysis was conducted for select resources with appropriate and sufficient data that allowed for such analysis. The introduction subsection introduces a specific resource by providing background information about the resource, places the resource in the context of its importance to the park, and summarizes the primary objectives of the resource-specific assessment. The approach subsection outlines the methods used to conduct the assessment. The reference and comparison metrics subsection summarizes the conditions and metrics used to make a determination as to the overall condition of the resource. The results and assessment subsection presents details of the outcome of the analysis of resource-specific data used to complete the assessment, and the overall condition assessment of the resource.The emerging issues subsection is designed to identify present or future potential stressors of a resource, and the data needs subsection is used to identify gaps in presently available data as well as suggest additional sampling and data collection that could be useful for better assessing the condition of a resource. The overall objective of this approach is to assess and articulate the present condition of each focal resource based on a reasonably thorough review of available information (e.g., data, publications, and reports) generated by park staff, and by research and monitoring cooperators.

Overall, 79% (22 of 28) of the natural resource categories for which disturbance-level and condition could be assessed were identified as having some documented signs of moderate to significant change and degradation; and 10 of these categories were estimated to have been seriously to significantly disturbed (see Table 67, Chapter 6). These resources include: (1) Air Quality–Nitrogen and Sulfur deposition; (2) Air Quality–Persistent Bioaccumulative Toxics deposition; (3) Lake Water Quality–Contaminants; (4) Stream Water Quality–Temperature and Flow; (5) Forest Health–Disturbance Regime; (6) Forest Health–Whitebark Pine and White Pine Blister Rust; (7) Amphibians–Species of Concern; (8) Stream Fish–Endangered Species and Species of Concern; (9) Land Birds–Species with Evidence of Decline; and (10) Glaciers. Three resources (Biodiversity–Wetlands, Mammalian Carnivores, and Bats) did not have sufficient data for estimating or predicting relative level of disturbance or condition.

Although only 10 resource categories were assessed as being seriously to significantly disturbed, many, if not all, of the MORA resources are also susceptible to increased levels of disturbance and change due to anthropogenically-generated perturbation, especially climate change. Projections of future climate change, though limited by the low resolution of global climate models, are consistent with the trends indicated by the following observations. These show a continued warming trend that exceeds the range of historical variability by mid-century, and no clear trend in precipitation. Seasonally, projections indicate greater warming in summer than in winter, and a slight tendency towards drier summers and wetter winters. These changes in temperature and precipitation regime have important implications for water stress and ecosystem health. For example, climate change continues to be a global, regional, and local threat to aquatic ecosystems, with the potential of leading to chronically degraded water quality due to episodes of climate-induced stress related to changes in precipitation and temperature regimes. MORA lake and stream water quality, including native biota such as aquatic insects, fish, and amphibians, will certainly be affected and potentially degraded by this climate-induced stress. Both direct and indirect effects of climate change on birds can be expected, although predictability of specific effects is currently low because of the complexity of interacting factors. Changes in temperature and precipitation regimes are expected to cause changes in distribution and structure of plant communities that provide important food and cover for birds in the park. Thus, a major effect of climate change is expected to be changes in bird species presence and distributions. The most consistent conclusions drawn from projections of changes in spatial distributions and vulnerability of plant communities and species due to changing climate agree that subalpine, alpine, and tundra communities and species will decline or disappear; and wetland communities will also be vulnerable to climate change. Finally, MORA may, in the future, experience an increase in the area burned by wildfires as a consequence of climate change. The fire season will be longer, given that summer temperatures are expected to increase and snowpack levels decrease with climate change.

Four major fundamental threats that are now and will in the future affect the continued persistence and viability of the natural resources and ecosystems of MORA were identified. They are: (1) climate change; (2) the continued atmospheric deposition of nutrients and pollutants; (3) the presence and emergence of pests and pathogens; and (4) introduction and range expansions of non-native invasive and non-resident native plant and animal species. These threats are discussed in Chapter 6. In addition, continued fragmentation of habitat surrounding the park, and threats to migratory and wide-ranging species outside boundaries, including increased roads, vehicle collision, energy development, and increased human development affect park resources. Additional threats to specific resources are identified and discussed in each resource subsection in Chapter 4.

In this assessment report we include a chapter that evaluates the historical and possible future climate of MORA in the context of Pacific Northwest regional climate (Chapter 5). This evaluation suggests that although there is some diversity of responses among long-term stations, minimum temperatures are increasing sharply in MORA. The trends are less evident for maximum temperature, a pattern which is consistent with observations elsewhere in the Pacific Northwest. All trends for temperature show a tendency towards more warming in the recent record (1950 to present), particularly in summer. Precipitation trends are essentially flat. Snowpack measurements show clear trends that are consistent among stations, though not all stations show significant trends. Projections of future change, though limited by the low resolution of global climate models, are consistent with the trends indicated by the observations. These show a continued warming trend that exceeds the range of historical variability by mid-century, and no clear trend in precipitation. Seasonally, projections indicate greater warming in summer than in winter, and a slight tendency towards drier summers and wetter winters. These changes have important implications for water stress and ecosystem health. These changes, though useful, lack the granularity needed to identify areas that may be impacted by climate change more strongly. Additional work is needed to assess the merits of these approaches within MORA and understand what they imply for changes to the climate of the park.

An impressive amount of research, inventories and surveys, and monitoring of MORA natural resources have been conducted by NPS staff, as well as by university, state, and federal scientists, and non-profit agency cooperators. This effort spans decades, and the results have been reported in various types of reports and factsheets, presented at symposia and conferences, and published in peer-reviewed scientific journals. Much of this information has been reviewed and synthesized as a part of this assessment. One of the objectives of the assessment was to identify future data needs that could help park management plan for and focus future sampling effort, and fill data gaps that would complement already gathered information and further enhance existing knowledge of the park's natural resources. A general summary of the data needs identified by this assessment is presented in Table 68 (Chapter 6). A more detailed discussion of data needs for specific resource categories is available in Chapter 4 for each assessed natural resource.

Acknowledgments

We thank Roger Andrascik, Chief of MORA Natural and Cultural Resources, and his staff for their assistance in the preparation of this report, especially their help in coordinating the accumulation of and making available the data and reports used to complete this assessment, and for reviewing earlier drafts of this report. We thank Barbara Samora, Biologist, Mount Rainier National Park, for her ongoing support and coordination of NPS internal reviews of previous drafts of this report; her assistance was instrumental in helping to complete this assessment. We also thank the following people for their support, comments, and suggestions that contributed to the preparation of this report: Jeff Albright, Catherine Copass, Rex Crawford, Marsha Davis, Gary Fellers, Andrew Fountain, Paul Kennard, Rebecca Lofgren, Carl Medley, Todd Neel, Jason Ransom, Mason Reid, Joe Rocchio, Judy Rocchio, Regina Rochefort, Gary Rosenlieb, Frank Sannino, Tanya Shenk, Lou Whiteaker, and Robin Wills. We thank Lise Grace for her patience and perseverance with formatting and editing. Any use of trade, product, or firm names is for descriptive purposes only and does not imply endorsement by the U.S. Government.

Acronyms

ADS – Aerial Detection Survey

AQRV – Air Quality Related Values

ARD – Air Resources Division

BBS – Breeding Bird Survey

BCR – Bird Conservation Regions

BMI – Benthic Macroinvertebrate

CASTNET – Clean Air Status and Trends Network

CBC – Christmas Bird Count

CESU – Cooperative Ecosystem Studies Unit

CIG – Impacts Group

CMAQ – Community Multi-scale Air Quality

COOP – Cooperative Observer Network

COSWIC – Committee on the Status of Endangered Wildlife in Canada

CRLA – Crater Lake National Park

ESA – Endangered Species Act

FRESC – Forest and Rangeland Ecosystem Science Center

GLAC – Glacier National Park

HUC – Hydrologic Unit Code

IMPROVE – Interagency Monitoring of Protected Visual Environments

LANDFIRE – Landscape Fire and Resource Management Planning Tools Project

LAVO – Lassen Volcanic National Park

MDN – Mercury Deposition Network

MORA – Mount Rainier National Park

MTSB – Monitoring Trends in Burn Severity

NAAQS – National Ambient Air Quality Standard

NABCI – North American Bird Conservation Initiative

NADP – National Atmospheric Deposition Program

NCCN – North Coast and Cascades Network

NCDC – National Climate Data Center

NOCA – North Cascades National Park Service Complex

NOAA – National Oceanographic and Atmospheric Administration

NPS – National Park Service

NRA – National Recreation Area

NRCA – Natural Resource Condition Assessment

Acronyms (continued)

NRCS – Natural Resource Conservation Service

NSNSD – National Sounds and Night Sky Division

NTN – National Trends Network

NVC – National Vegetation Classification

NWI – National Wetlands Inventory

OLYM – Olympic National Park

PBT – Persistent Bioaccumulative Toxics

PIF – Partners in Flight

PNW – Pacific Northwest

PRISM – Parameter Regressions on Independent Slopes Model

RAWS – Remote Automated Weather Stations

RLN – Research Learning Network

ROMO – Rocky Mountain National Park

SEKI – Sequoia and Kings Canyon National Parks

SNOTEL – Snowpack Telemetry

USCRN – U.S. Climate Reference Network

USDA – U.S. Forest Service

USEPA – U.S. Environmental Protection Agency

USFWS – U.S. Fish and Wildlife Service

USGS – U.S. Geological Survey

USHCN – U.S. Historical Climatology Network

WACAP – Western Airborne Contaminants Assessment Project

WDFW – Washington Department of Fisheries and Wildlife

WDNR – Washington Department of Natural Resources

WDOE – Washington Department of Ecology

WFMI – Wildland Fire Management Information

WNHP – Washington Natural Heritage Program

WRCC – Western Regional Climate Center

YELL – Yellowstone National Park

YOSE – Yosemite National Park

Chapter 1 NRCA Background Information

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

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

- are multi-disciplinary in scope;[1]
- employ hierarchical indicator frameworks;[2]
- identify or develop reference conditions/values for comparison against current conditions;[3]
- emphasize spatial evaluation of conditions and GIS (map) products;[4]
- summarize key findings by park areas; and[5]
- follow national NRCA guidelines and standards for study design and reporting products.

NRCAs Strive to Provide…

Credible condition reporting for a subset of important park natural resources and indicators

Useful condition summaries by broader resource categories or topics, and by park areas

Although the primary objective of NRCAs is to report on current conditions of select resources relative to logical forms of reference conditions and values, NRCAs also report on trends, when appropriate (i.e., when the underlying data and methods support such reporting), as well as influences on resource conditions. These influences may include past activities or conditions that provide a

---

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

[2] 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

[3] 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”).

[4] 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.

[5] In addition to reporting on indicator-level conditions, investigators are asked 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.

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 do not report on condition status for land areas and natural resources beyond park boundaries). Intensive cause-and-effect analyses of threats and stressors, and development of detailed treatment options, are outside the scope of NRCAs.

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

The credibility of NRCA results is derived from the data, methods, and reference values used in the project work, which are designed to be appropriate for the stated purpose of the project, as well as adequately documented. For each study indicator for which current condition or trend is reported, we will identify critical data gaps and describe the level of confidence in at least qualitative terms. Involvement of park staff and National Park Service (NPS) subject-matter experts at critical points during the project timeline is also important. These staff will be asked to assist with the selection of study indicators; recommend data sets, methods, and reference conditions and values; and help provide a multi-disciplinary review of draft study findings and products.

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.

Important NRCA Success Factors

Obtaining good input from park staff and other NPS subject-matter experts at critical points in the project timeline

Using study frameworks that accommodate meaningful condition reporting at multiple levels (measures ⇨ indicators ⇨ broader resource topics and park areas)

Building credibility by clearly documenting the data and methods used, critical data gaps, and level of confidence for indicator-level condition findings

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[6] and help parks to report on government accountability measures.[7] 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.

NRCAs also provide a useful complement to rigorous NPS science support programs, such as the NPS Natural Resources Inventory & Monitoring (I&M) Program.[8] For example, NRCAs can provide current condition estimates and help establish reference conditions, or baseline values, for some of a park's vital signs monitoring indicators. They can also draw upon non-NPS data to help evaluate current conditions for those same vital signs. In some cases, I&M data sets are incorporated into NRCA analyses and reporting products.

Over the next several years, the NPS plans to fund a NRCA project for each of the approximately 270 parks served by the NPS I&M Program. For more information on the NRCA program, visit http://nature.nps.gov/water/nrca/index.cfm.

---

[6] 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.

[7] 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.

[8] The I&M program consists of 32 networks nationwide that are implementing "vital signs" monitoring in order to assess the condition of park ecosystems and develop a stronger scientific basis for stewardship and management of natural resources across the National Park System. "Vital signs" are a subset of physical, chemical, and biological elements and processes of park ecosystems that are selected to represent the overall health or condition of park resources, known or hypothesized effects of stressors, or elements that have important human values.

NRCA Reporting Products…

Provide a credible, snapshot-in-time evaluation for a subset of important park natural resources and indicators, to help park managers:

Direct limited staff and funding resources to park areas and natural resources that represent high need and/or high opportunity situations
(near-term operational planning and management)

Improve understanding and quantification for desired conditions for the park's "fundamental" and "other important" natural resources and values
(longer-term strategic planning)

Communicate succinct messages regarding current resource conditions to government program managers, to Congress, and to the general public
("resource condition status" reporting)

Chapter 2 Introduction and Resource Setting

2.1 Introduction

2.1.1 Enabling Legislation and Organization

Mount Rainier National Park (MORA) is the nation's fifth national park, established on 2 March 1899 by Congress (30 Stat. 993) under the Mount Rainier National Park Act (30 Stat. 993) signed by President McKinley for "...the benefit and enjoyment of the people…for the preservation from injury or spoliation of all timber, mineral deposits...natural curiosities, or wonders within said park and their retention in their natural condition." Subsequent congressional actions designated 97% of the park as wilderness (1988) and a 1700-ac (688-ha) area as the Mount Rainier National Historic Landmark District (1997). According to Catton (1996), MORA was created from lands already set aside as forest reserves, and lands within the park granted to the Northern Pacific Railroad Company were reclaimed, thus establishing MORA entirely under federal ownership.

2.1.2 Background and Geographic Setting (Summarized from Final General Management Plan/Environmental Impact Statement, Mount Rainier National Park [NPS 2001]; and additional sources)

MORA is located in the Cascade Range of west-central Washington (Figure 1). The park encompasses 236,381.49 ac (95,660 ha) within the authorized, legislative Park boundary, with an additional 140 ac (57 ha) lying outside the current boundary. Eighty-eight percent of the park, plus the additional acres outside the current boundary lie within Pierce County, and 12% is in Lewis County (Figure 2). The Seattle-Tacoma metropolitan area is approximately 65 mi (105 km) northwest of MORA's northern boundary and Yakima is 65 mi (105 km) to the southeast of the park's southern and eastern boudaries. Park elevations extend from about 1700 ft (518 m) above sea level to 14,411 ft (4392 m) at the summit of Mount Rainier, which is an active volcano, the focal point of the park, and a prominent landmark in the Pacific Northwest. The base of the snow- and ice-covered volcano spreads over an area of about 100 sq mi (260 sq km). Mount Rainier has 26 major glaciers that cover 35 mi^2 (91 km^2), constituting the largest single-mountain glacial system in the contiguous 48 states. Mount Rainier is also the most hazardous volcano in the Cascade Range and second only to Mount St. Helens in seismic activity. The park's topography is predominantly rugged and precipitous, and consists mainly of peaks and valleys.

Figure 1. Geographical setting of Mount Rainier National Park.

Figure 2. Mount Rainier National Park and adjacent land ownerships.

MORA protects a variety of landscapes containing biological and cultural resources in the central Washington Cascade Range. Primary legislative purposes of the park is to preserve, "...from injury or spoliation of all timber, mineral deposits...natural curiosities, or wonders within said park and their retention in their natural condition." The park is designated as a Class I air quality area by the Clean Air Act of 1977. The Butter Creek Research Natural Area was established in 1942 and consists of the approximately 2000 ac (809 ha) Butter Creek watershed located in the Tatoosh Range in the southern part of the park. The parks significant thermal features are protected under the Geothermal Steam Act Amendments of 1988.

The Mount Rainier Wilderness, comprising 228,480 ac (92,463 ha) of the park, was established by the Washington Wilderness Act of 1988 (P.L. 100-668) and is to be managed according to the Wilderness Act of 1964 (P.L. 88-577), which states:

> "A wilderness, in contrast with those areas where man and his works dominate landscape, is hereby recognized as an area where the earth and its community of life are untrammeled by man, where man himself is a visitor who does not remain."

In addition, wilderness shall retain "its primeval character and influence...." and is protected and managed such that it "appears to have been affected primarily by the forces of nature, with the imprint of man's work substantially unnoticeable..." and offers "outstanding opportunities for solitude or a primitive and unconfined type of recreation...."

MORA was designated a National Historic Landmark (NHL) district in 1997 and the designation is focused on the park's representation of the NPS master planning process developed in the late 1920s and 1930s. The NHL of the park encompasses all the roads, historic developed areas, and historic backcountry structures. The Wonderland Trail, a 93-mi (150-km) loop trail system around the mountain, and the Northern Loop Trail are also included. Historic districts, with the exception of Camp Muir, are all within the continuous NHL district, which follows the park's road system.

At 14,411 feet (4392 m), Mount Rainier is the most prominent peak in the Cascade Range. It dominates the landscape of a large part of western Washington State. The mountain stands nearly 3 mi (4.8 km) higher than the lowlands to the west and 1.5 mi (2.4 km) higher than the adjacent mountains. It is an active volcano that last erupted approximately 150 yrs ago. The glacial system on Mount Rainier is the largest single mountain system in the contiguous 48 states consisting of 26 major glaciers. Other water resources in the park include 470 mapped rivers and streams, 405 mapped lakes and ponds, over 3,000 ac (1214 ha) of other wetland types, numerous waterfalls, and mineral springs. Vegetation is diverse, reflecting the varied climatic and environmental conditions encountered across the park's 12,800-ft (3901-m) elevation gradient; 973 vascular plant species have been documented in the park (Rochefort 2010). Thermal features of the park fall into 6 separate groups: the summit thermal area, upper-flank thermal areas, Winthrop Springs, Paradise Springs, Longmire Mineral Springs, and Ohanapecosh Hot Springs. The summit thermal area, upper- flank thermal areas, and the Winthrop and Paradise Springs on the lower flanks are probably all part of a single geothermal system within the edifice of the Mount Rainier volcano (Korosec 1989). The system probably has an areal extent of a few square kilometers centered at the volcanic center, extending out to about the locations of the upper-flank thermal features. The lower flank thermal springs are probably "leaks" from the central geothermal system, as thermal waters flow out and down from the reservoir through stratigraphic horizons.

Approximately 58% of the park is covered by forests, much of it old growth. The subalpine parkland covers approximately 23% of the park. The alpine zone extends from treeline to the mountain's summit, with approximately 50% of the zone covered by permanent snow and ice and the remainder by alpine vegetation. The park provides habitats for about 162 species of birds, 55 species of mammals, 4 species of reptiles, 14 species of amphibians, and 14 species/subspecies of native fish, and several species of introduced and non-native fish.

The park includes significant wilderness resources and provides numerous opportunities to enjoy a relatively pristine environment located <70 mi (<113 km) from a large metropolitan area. In addition to the abundance of natural wonders, there is a long history of human activities within the park. The area was used seasonally by Native Americans for hunting and gathering, as well as for spiritual and ceremonial purposes.

Climate is an important influence on the Mount Rainier ecosystem, affecting all biotic and abiotic ecosystem components. Available weather data within and in the vicinity of the park are sparse and not integrated. MORA is situated within a temperate, maritime climate. A high pressure region over the North Pacific Ocean shifts southward during fall and winter, and warm, moist air moves from a southwesterly direction into the Cascade Range. Condensation of this cooling air as it rises along the mountain slopes results in a rainy season during late fall and winter and continues almost without break until March or April. At the higher elevations, snow begins accumulating in early November. These wet seasons end when high pressure again develops over the region, and July and August are usually comparatively dry.

Annual precipitation is heavy, ranging from about 60 in (1524 mm) at the lowest elevations to over 100 in (2540 mm) in the subalpine parklands. A rain shadow occurs on the east side of the park because southwesterly winds bear much of the moisture. Over 90% of the precipitation falls between November and April. Much of the winter precipitation is snow that accumulates into snowpacks 20 to over 63 ft (6 to 19 m) deep at higher elevations. At Paradise, the average annual snowfall is about 50 ft (15 m); 86 ft (26 m) during the winter of 1998 to 1999. Winter temperatures are relatively warm; mean January temperatures of about 25 to 30°F (–4 to –1°C). Summers tend to be cool; mean July temperatures of 50 to 60°F (10 to 16°C), and extended periods of cloudiness are not uncommon. Fog and high winds may be expected any day of the year.

Several climate zones exist elevationally and geographically around the park. However, the southeast side of the park is generally the driest, and the northwest side of the park is the wettest (especially during spring and summer months).

MORA is subject to regional long-distance transport of air pollutants (e.g., sulfur and nitrogen oxides, ozone, particulates, and toxic pollutants) from various mobile and stationary sources, from as far north as Vancouver, British Columbia, south to Portland, Oregon. Most stationary and mobile sources are in the metropolitan Seattle-Tacoma region. Trans-Pacific transport of persistent organic pollutants is also occurring, although contaminants in the park have also been documented from regional sources. While the air quality of the region is generally considered better than other areas of the United States, there is potential for both long-term and short-term degradation that could affect human health, vegetation, aquatic resources, and biogeochemical processes. Of particular concern are: (1) tropospheric ozone, which is highest during the summer months and is higher at higher elevations of the park, potentially damaging vegetation and reducing respiratory function in humans; (2) acidic deposition, which could increase the acidity of poorly buffered aquatic systems and soils over the long term, potentially affecting fish, amphibians, and soil dependent organisms; (3) particulate pollutants, which reduce visibility of scenic vistas, and cause respiratory distress in some visitors; and (4) persistent organic pollutants and other toxic substances. Little is known about the presence, amounts, or distributions of toxics in the park but potential effects on park resources may be significant.

Major natural disturbances affecting the mountainous regions in the Pacific Northwest include episodic floods, volcanic eruptions, earthquakes, geomorphic changes in stream channels and landforms, fire, wind, insect infestations, and glacial activity. Human-induced disturbances include alterations of water quality and quantity, habitat destruction or modification, and biological alterations (e.g. non-native species introductions, fish harvest and stocking, and logging, etc.).

The terrestrial vegetation of MORA is diverse because of the co-occurrence of climatic gradients and topographic diversity over relatively short distances. Diversity is observed in terms of numbers of species, as well as spatial variation in distribution and abundance. Vegetative assemblages vary across an elevational gradient, and a somewhat east to west precipitation gradient. High annual snowfall is the limiting factor to plant distribution and growth at higher elevations. There are at least 973 vascular species in the park, with many additional lichens and mosses. There are approximately 153 exotic plant species, generally located along transportation corridors (i.e. roads and trails), in developed zones, and in some riparian areas.

Patterns of vegetation distribution are also influenced by disturbance. The size and frequency of disturbances vary greatly among ecosystems. Fire, although relatively infrequent in the park, is the major disturbance creating diverse successional stages on a large scale. Avalanches and lahars are small to medium scale disturbances. Disturbance processes also act on a small scale, with windthrow, pathogens, and insects causing small gaps in vegetation and affecting local successional dynamics over time. Climatic variation is always an overarching factor that affects species regeneration and distribution on long time scales, resulting in non-equilibrium systems with unique assemblages of species co-occurring over centuries to millennia.

2.1.3 Visitation Statistics

MORA is visited by over 1 million visitors per year; between 1967 and 2012 there has been an average of 1,839,733 visitors/yr, ranging from a low of 1,495,514 visitors in 1974 to a high of 2,437,332 visitors in 1977 (Mount Rainier Annual Visitor Statistics available at http://www.nps.gov/mora/parkmgmt/upload/vis-stats-1967-2012.pdf). Wilderness overnight use is approximately 43,453, while day use of the Wilderness and sensitive resource zone areas of non-

Wilderness is estimated at >1 million visitors/year. Table 1 summarizes visitor use in the Paradise, Sunrise, and trailed areas of the Wilderness (Manni et al. 2013). Although Mount Rainier is the dominant landmark within the park, only 3% of park visitors visit MORA to climb the mountain. Between 2000 and 2010, the average annual number of climbers was 10, 282 (range: 8932–13,114) and the average annual number successfully summiting = 5381 (range = 4604–6438) (Mount Rainier Annual Climbing Statistics available at http://www.nps.gov/mora/parkmgmt/upload/climbing-stats-thru-2010.pdf).

Table 1. Activities of visitors to Mount Rainier National Park (MORA). Information derived from a park visitor survey completed as part of the National Park Service Visitor Services Project, University of Idaho Cooperative Park Studies Unit, conducted 18–27 August 2000 (n = 790 responses; MORA National Park Visitor Study Brochure 2000).

Activity	Percent
Dayhiking	73
Wildflower viewing	65
Driving to view scenery	63
Photography	56
Visiting Visitor Centers	53
Wildlife viewing	45
Visiting lodges/inns	32
Picnicking	26
Camping – developed CGs	15
Attending naturalist program	9
Camping – wilderness	6
Climbing Mount Rainier	3
Fishing	2
Bicycling	1
Other	6

2.2 Natural Resources

2.2.1 Ecological Zones and Watersheds

There are 3 major ecological zones in MORA: forest, subalpine, and alpine. The forest zone occurs from the lower elevations of the MORA boundary to the subalpine zone, and represents the majority of the park landscape (approximately 58%); the subalpine zone extends from approximately 5000 ft (1524 m) to treeline, and represents 23% of the park landscape; and the alpine zone is generally above an elevation of 6000 ft (1829 m), mostly above treeline, and accountins for about 19% of the park landscape. At the 6th field hydrologic-unit level, there are 10 major and 3 relatively minor watersheds in MORA (see Figure 6). The tributaries of all but 2 watersheds (Huckleberry Creek, Ohanapecosh River) are glacially influenced by large valley glaciers. Major tributaries originating within the park include the Carbon, Huckleberry, Mowich, Muddy Fork of the Cowlitz, Nisqually, Ohanapecosh, Puyallup, West Fork White, and White.

2.2.2 Resource Descriptions

Air Quality

Visitor enjoyment, the health of park ecosystems, and the integrity of cultural resources depend upon clean air. MORA is 1 of 48 Class I air quality areas managed by the NPS. The 1977 Clean Air Act amendments give federal land managers an “affirmative responsibility” to protect the air quality related values in Class I areas. Air quality related values include resources sensitive to air quality including visibility, lakes, streams, vegetation, soils, and wildlife. MORA is downwind of Seattle and Tacoma, Washington, and the only coal-fired power plant in the state located near Centralia, Washington, is 31 mi (50 km) west of the park. There are also agricultural and livestock operations east and west of the MORA. Air pollutants of concern include sulfur (S) and nitrogen (N) compounds, particulates, ground-level ozone, and persistent bioaccumulative toxics (PBTs), including mercury (Hg). Visitor surveys have shown that clean air is one of the most important attributes to park visitors (Simmons et al. 2001, Manni et al. 2013). To better understand and protect air quality, the NPS and collaborators have monitored air quality and air pollution-sensitive resources at MORA since the early 1980s.

Scenery

Scenic resources of the park include the natural scenery in general, many vista points located along roads and trails, wildflowers, wildlife, clean air, relative lack of development, and the 228,480 ac (92,430 ha) of Wilderness which provide opportunities for solitude and recreational challenge. Visitor survey results have consistently shown scenic resources to be an important attribute to their visits (Simmons et al. 2001, Manni et al. 2013).

Water Quality

Lakes, ponds, rivers, and steams are prominent features of the MORA landscape. Documenting and monitoring the status and trends in the water quality of these aquatic systems in protected wilderness areas and national parks is important because these landscapes often comprise ecosystems least affected and modified by anthropogenic disturbances. At MORA, 406 lakes and ponds have been inventoried and approximately 470 rivers and streams have been mapped. Water quality comprises physical, chemical, and biological constituents that express the overall health and condition of aquatic ecosystems; at MORA, these systems are generally oligotrophic relative to nutrient status, low in acid neutralizing capacity and high in chemical quality, and typically cool in temperature. Visitor surveys have shown that clean water is one of the most important attributes to park visitors (Simmons et al. 2001, Manni et al. 2013).

Vegetation

Microclimates and varied topography coupled with volcanism, glacier activity, and a variety of geologic substrates and soil types have resulted in rich vegetation diversity over relatively short distances at MORA. Approximately 58% of the park is forested, and temperature, moisture, and disturbance regimes strongly determine the distribution of forest types. Forest age-structure is determined by disturbance regime, which in MORA includes fire, windthrow, avalanches, insects, diseases, and lahars (volcanic mudflows). Temperature regime determined by elevation drives the distribution of forest zones. Specifically, the Western Hemlock (Tsuga heterophylla) zone occurs to approximately 900 m (2953 ft), the Silver Fir (*Abies amabilis*) zone occurs at approximately 900–1500 m (2953–4922 ft), and the Mountain Hemlock (*Tsuga mertensiana*) zone occurs from approximately 1500–2200 m (4922–7218 ft), including subalpine parklands. Communities within zones depend on moisture regime, which is influenced by elevation, aspect, and topography. Subalpine meadow types reflect snowpack and are classified into 2 groups: shrub dominated and herbaceous. Herbaceous meadows are further classified as lush herbaceous meadows, low herbaceous meadows, and dry grasslands. The alpine environment occurs above the subalpine parklands where available substrate is inhabited by fell-field and snowbed plant communities and dwarf-heath shrublands, including primarily heathers. Various wetlands such as bogs, fens, marshes, wet meadows, aquatic beds, and riparian forests and shrublands are found throughout the park. Although they occupy a very small portion of the landscape, wetlands often support a disproportionately high percentage of landscape biodiversity. Fifteen plant species are listed as federal or state species of concern. In this assessment, we focus on indicators of landscape-scale vegetation dynamics, forest health (including tree mortality, fire regime, and air quality effects), and the status and trends of plant biodiversity.

Terrestrial and Aquatic Fauna

Wildlife includes both aquatic and terrestrial species. This resource category has been broken down into several components: Amphibians, Fish, Invertebrates, Land Birds, and Mammalian Fauna. Visitor surveys have shown that wildlife is one of the most important attributes to park visitors (Simmons et al. 2001, Manni et al. 2013).

Amphibians

Amphibians are a class of vertebrate defined by moist glandular skin. Some species have complex life cycles and rely on both aquatic and terrestrial habitats for different parts of their life history. Because of the relatively low mobility of amphibians compared to other vertebrates, all species found in MORA complete all aspects of their life history within the park. Fourteen species, 4 frogs, 1 toad and 9 salamanders, have been identified as present in MORA. Three of these species are federally listed as Species of Concern. All but 4 of the 14 species have wide distributions within the park, and within their respective ranges, although population trends are unknown. The statuses of all but 4 species are classified as stable within their entire range.

Fish

Fourteen fish species have been confirmed as present in MORA rivers, streams, and lakes. These species include 2 sculpins (Cottidae), 1 stickleback (Gasterosteidae), and 11 salmonids (Salmonidae). Many species are native to park streams; however, all fish in park lakes have been introduced, and where they occur (presently estimated to be present in 37 lakes) they are detrimental to native amphibian populations. According to unpublished park records, the first officially recorded stocking of MORA rivers, streams, and lakes occurred in 1915; stocking was discontinued after 1972. Several species have been identified as species of special conservation or management concern at the federal and state levels. Bull Trout (*Salvelinus confluentus*), Chinook Salmon (*Oncorhynchus tshawytscha*), Coho Salmon (*Oncorhynchus kisutch*), Sockeye Salmon (*Oncorhynchus nerka*), and Steelhead (*Oncorhynchus mykiss*) have all been identified as threatened or endangered, at least partially within their ranges, by the U.S. Fish and Wildlife Service, and as state candidates of special concern by the Washington Department of Fish and Wildlife. In addition, Pink Salmon (*Oncorhynchus gorbuscha*) as well as other salmon species are protected under the Magnuson Stevens Fishery Management Conservation Act.

Invertebrates

It has been estimated that invertebrates represent up to 70% of all organisms on the planet, and invertebrate populations contribute substantially to biodiversity worldwide. Invertebrates also are an important component of ecosystem processes, they serve as important prey species for a variety of animals including bats and numerous bird species, and many invertebrate species have short generation times and high reproductive capacity, which can make them good indicators of environmental change. Invertebrates can also damage vegetation and some of these pest species may be non-native to the ecosystem. Invertebrates also can have great effects on public health (i.e. ticks acting as vectors for Lyme disease and mosquitoes as vectors for West Nile Virus). Little is known about the distribution, abundance, or even which species of invertebrates are found in MORA. They may represent 85% of the faunal biomass and contribute significantly to the ecological processes of the late successional and old growth forests found in Mount Rainier National Park (Asquith et al. 1990). Invertebrates inhabit many different areas of the coniferous forest of the park, including course woody debris, leaf litter, soil, understory vegetation, tree canopy and snags. It is estimated that there may be up to 20,000 species of invertebrates in the Pacific Northwest forests (USDA 1994). Outside of national parks in the Pacific Northwest, late successional forests have been harvested at great rates and this harvesting may have affected invertebrate populations inhabiting these forests. Invertebrates in the forest ecosystem of the park are of concern for many reasons. The dispersal of the flightless species may be very limited and therefore there could be a high number of endemic species. They also are key components of nutrient cycling of organic material in the forest. Invertebrates also include pest species, which may damage trees and vegetation making the forest more susceptible to fire and other perturbations. Invertebrates also play key roles in the subalpine and alpine areas of the park. Insects act as pollinators of many of the subalpine flowers which are one of the park's main attractions to visitors. The snowfields and glaciers are unique habitats which support a variety of invertebrates including annelid worms, insects and spiders. These in turn are fed upon by numerous birds especially in the summer time. Park information regarding invertebrates is very sparse but some baseline information has recently been collected in some areas of the park for mollusks (land snails, slugs, aquatic snails, mussels and clams), pollinators (bees and butterflies), aquatic invertebrates (benthic macroinvertebrates and zooplankton), and ice worms. Invertebrate Species of Concern include: (1) the mussel, California Floater (*Anodonta californiensis*); (2) the butterfly species, Valley Silverspot (*Speyeria zerene bremeri*) and Whulge (Edith's) Checkerspot (*Euphydryas editha taylori*); and (3) Fender's Soliperlan Stonefly (*Soliperla fenderi*). Data on invertebrates were insufficient to be included in this resource condition assessment.

Land Birds

The avifauna of MORA is characteristic of conifer forest, subalpine, and alpine habitats of the west slope of the Cascade Range. Dense, moist forests at lower elevations in the park support species that are representative of old-growth in the region, including the threatened Marbled Murrelet

(*Brachyramphus marmoratus*) and Northern Spotted Owl (*Strix occidentalis caurina*). Several passerine species which are strongly associated with mature and closed-canopy conifer forests, and have been experiencing regional population declines, are among the most abundant species at MORA. Two species in this category, the Varied Thrush (*Ixoreus naevius*) and Chestnut-backed Chickadee (*Poecile rufescens*), have large proportions of their geographic ranges restricted to the Pacific Northwest, giving the region principal responsibility for their conservation. Alpine and subalpine habitats at MORA also are important for some species of regional conservation concern, such as the White-tailed Ptarmigan (*Lagopus leucura*) and American Pipit (*Anthus rubescens*). In this assessment we focused on 48 bird species of management concern because of the large number of species that occur in the park (i.e., >175 bird species in the NPSpecies database), and because management and monitoring of each species is logistically infeasible. We included species listed as Management Priority in NPSpecies (15 species), and those identified as focal species for conservation strategies developed by Partners In Flight (PIF) and the North American Bird Conservation Initiative (NABCI).

Mammalian Fauna

MORA appears to have retained most of the historically present mammal species, except for the notable absence of 5 carnivores: grey wolf, Canada lynx, wolverine, fisher, and grizzly bear. MORA lands alone do not provide adequate habitat to maintain viable populations of many of the larger species, but are valuable for those species in a regional context. Up to 58 native mammal species may currently reside during some or all of the year in MORA based on documentation in NPSpecies and published literature; 12 species are federally or state listed or are candidates for listing as threatened or endangered. Three species of non-native mammals (Virginia opossum, house mouse, and Norway rat) may also inhabit the park complex. The Virginia opossum was documented at Kautz Creek, but its prevalence in the park is unknown. The non-native house mouse and Norway rat may be present near buildings, but they were not documented in materials we reviewed, suggesting that neither is currently widespread in MORA. Mammal groups of focused interest in this assessment include carnivores, Elk, and bats.

Geothermal Features

Geothermal features of the park fall into 6 separate groups: the summit thermal area, upper flank thermal areas, Winthrop Springs, Paradise Springs, Longmire Mineral Springs and Ohanapecosh Hot Springs. The summit thermal area, upper flank thermal areas, and the Winthrop and Paradise Springs on the lower flanks are probably all part of a single geothermal system within the edifice of the Mount Rainier volcano (Korosec 1989). The system probably has an areal extent of a few square kilometers centered at the volcanic center, extending out to about the locations of the upper flank thermal features. The lower flank thermal springs are probably "leaks" from the central geothermal system, as thermal waters flow out and down from the reservoir through stratigraphic horizons. Longmire Mineral Springs are part of a separate geothermal system of limited extent. They may be fault and/or fracture controlled, and the heat source is probably related to the Mount Rainier volcanic/magmatic system. This geothermal system has a most likely volume of about 3 km^3 (0.7 mi^3) covering about 3 km^2 (1.2 mi^2). Ohanapecosh Hot Springs is also part of a separate geothermal system, and is also believed to be of limited extent. The Geothermal Steam Act, Amendments of

1988, Public Law 100 443 and FR 28790, Vol. 52, No. 148, identified Mount Rainier National Park as having "significant thermal features". An evaluation was performed by the Bureau of Land Management (Korosec 1989), under contract to the NPS, to meet the requirements of the Act. Limited information is available on geothermal features. No recent studies have been completed on geothermal features in the park; however, approximately 14 studies were conducted on steam vents and other hydrothermal activity in the park. Geothermal resources were not addressed in the resource condition assessment due to the limited data available as well as having no expertise on the NRCA to address geothermal resources.

Soils

Soil is defined as the unconsolidated portion of the earth's crust modified through physical, chemical, and biotic processes into a medium capable of supporting plant growth. Soil properties influence the natural and the physical infrastructure of the landscape and ecosystems. Detailed information about the physical, chemical, and biological properties of soils in parks is essential for park resource management and protection, as well as providing park managers with the ability to predict the behavior of a soil under a variety of uses. Soil information is critical to understanding vegetation communities and landcover, planning of roads and trails, restoration of human impacts and identifying sites sensitive to soil erosion, delineation of wetlands, and assessing impacts of stressors such as air pollutants and climate change. Information on soils is also important in predicting potential habitat for sensitive organisms and archaeological sites. Given the location of MORA within the zone of deposition from numerous Cascade volcanoes, soil material within the park reflects a complex history of tephra deposits from Crater Lake (ancient Mount Mazama), Mount St. Helens, and Mount Rainier. As a result, the soils have many properties indicative of volcanic ash influence, such as high water holding capacity, high amounts of weathered iron and aluminum, and low bulk density. Due to abundant vegetative inputs and high precipitation amounts across the park, soils also exhibit evidence of strong pedogenic processes, or weathering, such as humification and podzolization. Most soil weathering processes take significant amounts of time to be visible within a soil profile and the preservation of this soil morphology can be useful in determining relative landscape stability over extended periods of time. More detailed analysis of chemical and physical properties such as naturally occurring levels of nitrogen and organic carbon can help tell the story of ecological dynamics through time as well as influence from factors outside of the park. Currently, 25 unique soils have been identified and classified according to U.S. Soil Taxonomy (Figure 2 available at http://www.nrcs.usda.gov/wps/portal/nrcs/detail/national/home/?cid=nrcs142p2_053577). Although these 25 soils are similar to soils found outside of the park, the morphology, physical and chemical properties, and physiography warrant the establishment of new endemic soil classifications (Rodgers 2013). Ecological variability associated with the various soils has also been described and 15 ecological groups have been identified as potential Ecological Site Descriptions (ESD) to be developed within the boundaries of the park. These groupings are separated by site dynamics through the changing bio-climatic zones of the park and by ecological interpretations that distinguish each grouping by responses to forces acting upon the site. Each ESD is designed to provide a better understanding of site and vegetation dynamics through time. In addition to the field-based descriptions, the ongoing soil survey is investigating physical and chemical properties instrumental in correctly identifying soil specific interpretations and limitations as well as taxonomic classifications.

Properties of particular note that will be reported include organic carbon, nitrogen, aluminum, and iron content as well as bulk density, water holding capacity, mineralogy, and percentages of sand, silt, and clay. These basic soil properties are used extensively in soil classification and in determining key soil interpretations. The baseline soils survey is ongoing and is expected to be completed by 2015; therefore soils were not assessed in this document.

Geologic Processes

Geologic processes are drivers of ecosystems in Mount Rainier and include volcanic history and linked geothermal features (described above), ongoing glacial and hydrologic processes and braided river geomorphology. Mount Rainier is the highest volcano in the Cascade Range, towers over a population of more than 2.5 million in the Seattle Tacoma metropolitan area and poses significant hazards to this area, and via the Columbia River potentially impacts another 500,000 residents of southwestern Washington and northwestern Oregon. Mount Rainier is the most hazardous volcano in the Cascades in terms of its potential for magma water interaction and sector collapse, and major eruptions or debris flows even without eruption. It poses significant dangers and economic threats to the region and the ability to significantly alter existing park ecosystem functions, components and processes. As a result of the International Association of Volcanology and Chemistry of the Earth's Interior (IAVCEI) designation of Mount Rainier as a Decade Volcano in 1989, additional research and monitoring was conducted to map the geology of the volcano's edifice, assess hydrothermal alteration, study hydrothermal hazards to improve knowledge of the nature and extent of hazardous geochemical processes associated with the hydrothermal system at Mount Rainier; and to monitor tectonic activity and deformation of the mountain. Seismic monitoring is continuous with several stations located on the mountain. Deformation monitoring is conducted periodically by USGS using the several GPS stations located on the mountain. Geologic processes affect many of the resources assessed in this document, but are not addressed as a separate resource.

Glaciers

Glaciers are significant features within the national parks of Washington State, and their condition is an important indicator of the status of park resources. At MORA, 27 glaciers cover about 33.7 mi2 (87.4 km2), or about 11% of the park. Total ice volume on the volcano is an estimated 4.4 km3. A number of glacier studies have been conducted in the park in the past century. The first description of Mount Rainier's glaciers was by A. Kautz in 1857 when he described the Nisqually Glacier. Geologists S. Emmons and A. Wilson collected information about the geology and location of glaciers on the mountain in 1870. The USGS began studying the park's glaciers in 1896 when I. C. Russell suggested a Nisqually Glacier project that included photo stations, measurements indicating flow rates, and mapping of the glacier termini. In 1905, J. LeConte studied the flow rate of the Nisqually Glacier. F. Matthes of the USGS made the first accurate determination of glacier locations with his 1913 topographic map of the mountain. The NPS began making measurements of some changes in terminus position in the 1930s (Catton 1996). In 1931, the Tacoma City Light Department initiated measurements of surface elevation along profiles upon the lower Nisqually Glacier. Measurements were continued by the USGS until 1985 when the USGS could no longer support the project. The park reinstituted the surface elevation monitoring in 1991 and continues to support the effort as long as funding is available. Other shorter-term glaciological studies have included observations at the summit (1970), mapping of ice caves (1971), velocity and surface elevation measurements (1974), terminus mapping (1976), and ice thickness studies (1984). This history is summarized from Driedger (1986) and Heliker et al. (1984). Current studies include glacier mapping (Wilson and Fountain 2014), Nisqually Glacier velocities (Kennard et al. In prep.), and a summary of the Nisqually Glacier surface ice elevation surveys (Stevens et al. In prep.). Wilson and Fountain (2014) and Nylen (2004) have also summarized MORA glacier areas. Page

The relatively small, temperate glaciers at MORA are valuable as sensitive and relatively dramatic indicators of climate change. They are also ecosystems linked to larger alpine food webs, and the sole habitat for some species such as the ice worm (*Mesenchytraeus solifugus*), which is preyed upon by rosy finches (*Leucostitche arctoa*) and other alpine species. MORA glaciers are valuable to downstream municipalities and regional ecosystems and industries because they provide vast quantities of cold, fresh melt-water during the regional hot, dry summer months. MORA glaciers also represent potentially significant hazards to park staff, visitors, and downstream municipalities in the form of stochastic events such as lahars, glacial outburst floods, and massive sediment debris flows. Glacier monitoring has been conducted on the Nisqually glacier for several decades and the Emmons and Nisqually glaciers since 2004.

Soundscape

Our ability to see is a powerful tool for experiencing our world, but sound adds a richness that sight alone cannot provide. Visitors to national parks often indicate that an important reason for visiting the parks is to enjoy the relative quiet that parks can offer. Sound also plays a critical role in intraspecies communication, courtship and mating, predation and predator avoidance, and effective use of habitat. Studies have shown that wildlife can be adversely affected by sounds and sound characteristics that intrude on their habitats. Acoustical monitoring has been conducted at 8 sites within the park. The primary goal of this monitoring is to characterize the ambient sound levels of MORA vegetation and management zones that occur at different elevations and are influenced by different climatic conditions. Visitor surveys have shown that natural quiet and sounds of nature are among the most important attributes to park visitors (Simmons et al. 2001, Manni et al. 2013)

Dark Night Skies

The resource of a dark night sky is important to the National Park Service for a variety of reasons: (1) the preservation of natural lightscapes, the intensity and distribution of light on the landscape at night, will keep the nocturnal photopic environment within the range of natural variability; (2) a natural starry sky absent of anthropogenic light is a key scenic resource, especially in large wilderness parks remote from major cities; (3) natural night sky may be a very important cultural resource, especially in areas where evidence of aboriginal cultures is present; (4) the recreational value of dark night skies is important to campers and backpackers, allowing the experience of having a campfire in frontcountry campgrounds, or “sleeping under the stars”; and (5) night sky quality is an important wilderness value contributing to the ability of park visitors to experience a feeling of solitude in a landscape free from signs of human occupation and technology. Baseline night sky data was collected at 2 locations in the park (south side and northeast side) by the NPS. MORA, although located in an area of central Washington that is relatively remote from cities and towns, is within 60+

mi (96+ km) of the large metropolitan areas of Seattle, Tacoma, and Olympia. Therefore, the park is influenced by anthropogenic sky glow from the west, leading to a significant gradient of expected night sky quality from northwest to southeast. Because the vast majority of the park is designated wilderness, it is particularly important that within-park sources of light be contained, eliminating light trespass and minimizing anthropogenic sky glow.

Climate

In the topographically complex terrain of MORA, climate varies substantially as a function of elevation, exposure, and the relative influence of the mild maritime climate of the coasts and the more arid continental climate of eastern Washington. Understanding how climate varies within topographically complex places like MORA is critical to assessing how future climate changes will affect the flora, fauna, and physical environment of the park, and thus how visitors will access and perceive them. Climate exerts strong controls over ecological processes as an ecosystem driver operating at multiple scales of time and space and influences almost all physical and ecological processes by controlling ecosystem fluxes of energy and matter as well as the geomorphic and biogeochemical processes underlying the distribution and structure of these ecosystems. Climate constrains ecosystem structure and function which influences the fundamental properties of ecologic systems, such as soil–water relationships, plant–soil processes, and nutrient cycling, as well as disturbance rates and intensity and in turn, influence the life-history strategies supported by a climatic regime. Climate is monitored via 6 weather stations located in the park.

2.2.3 Resource Threats Overview

The natural resources of MORA are potentially susceptible to a number of threats. Some of these threats like the atmospheric deposition of nutrients (e.g., nitrogen, phosphorus, sulfur) and pollutants (e.g., ozone, methylmercury, other bioaccumulative toxics), and climate change effects (e.g., changes in temperature gradients and precipitation frequency and amount) can cause changes in the quality and characteristics of ecosystems and habitats. Such changes could have significant effects on the presence, distribution, and survival of biota throughout the park, as well as diminish air quality within the park and alter precipitation chemistry. Changes in land use on U.S. Forest Service and private ownership lands surrounding the park could also contribute to changes in the quality and characteristics of park ecosystems and habitats. Naturally occurring geologic disturbances (e.g., volcanic activity, lahars, glacial outburst floods), and disturbance exacerbated by climate change, could profoundly re-organize the physical context and dynamics of the park landscape. Finally, the quality and condition of park ecosystems can also be altered by visitor impacts concomitant with recreational activities such as picnicking, hiking, backpacking, camping, climbing, driving in the park, and harvesting resources (e.g., legal – fishing, mushroom, and berry picking; and illegal – poaching, plant harvesting, etc.), as well as the management actions needed to support and maintain these activities. Recreational use activities have the potential to introduce and increase the presence of non-native species, diseases and pathogens into the park. Endangered, threatened and species of concern are also threatened by recreational activities and management actions focused on maintaining park infrastructure.

2.3 Resource Stewardship

2.3.1 Management Directives and Planning Guidance

The management and conservation of the natural resources of MORA are primarily mandated by the National Park Service Organic Act of 1916. Planning and guidance for MORA resource management are also provided as part of the MORA Final General Management Plan Environmental Impact Statement, last modified in 2007. Natural resources management goals are presented in Table 2. This plan is available online at http://www.nps.gov/mora/parkmgmt/upload/moragmp.pdf and includes management zones for the entire park (Figure 3) and descriptions of desired future conditions for these zones.

The 2540-ac (1028-ha) portion of Butter Creek Research Natural Area within MORA is an area set aside as a natural control for research activities. Wild and Scenic River eligibility status was determined for 9 mi (14.5 km) of the West Fork of the White River, 6.7 mi (10.8 km) of the Muddy Fork of the Cowlitz River, 12.7 mi (20.4 km) of the Ohanapecosh River, and 8 mi (12.9 km) of the Carbon River. These areas are all eligible for inclusion into the Wild and Scenic River system, but the park has taken no action since the eligibility determination in 1989.

Additional MORA-specific management plans that influence natural resources management include: (1) MORA Vital Signs Plan–2004; (2) Fire Management Plan–2005; (3) Long Range Interpretive Plan–2010; and (4) Wilderness Management Plan–1992. As mentioned earlier, 97% of the total park acreage is managed as designated Wilderness. Indicators and proposed standards for managing wilderness and sensitive resource zones have been developed, but formal planning and compliance has yet to begin. A Foundation document for the park is presently underway.

As 1 of 7 units comprising the North Coast and Cascades Network (NCCN) monitoring plan, MORA also uses the North Coast and Cascades Network Vital Signs Monitoring Report (Weber et al. 2009) as guidance for natural resource planning and management, and is specifically implementing several NCCN natural resource monitoring protocols and 1 data management plan listed in Table 3.

Table 2. Natural Resource Management Goals (from MORA General Management Plan). The primary responsibility of the National Park Service is the protection of park resources from internal and external impairment.

Resource Stewardship and Protection
The natural and cultural resources and associated values of Mount Rainier National Park are protected, restored, and maintained in good condition and managed within their broader ecosystem and cultural context.
Mount Rainier National Park contributes to knowledge about natural and cultural resources and associated values; management decisions are based on adequate scholarly and scientific information.
Visitor Access and Enjoyment
The park will be managed to provide the nation's diverse public with access to and recreational and educational enjoyment of the lessons contained in Mount Rainier National Park, while maintaining unimpaired those unique attributes that are its contribution to the national park system.
Education and Interpretation
It is the responsibility of the National Park Service to interpret and convey the contributions of each park unit and the park system as a whole to the nation's values, character, and experience.
Stimulate visitor appreciation of park resources; respect for values; understanding of management policies; and safe, acceptable recreation through onsite interpretive services.

Impart an understanding and appreciation of the National Park Service values, management policies, diversity of park system resources, and environmental stewardship to all segments of the population through education outreach.

Science and Research

The National Park Service must engage in a sustained and integrated program of natural, cultural, and social science resource management and research aimed at acquiring and using the information needed to manage and protect park resources.

Establish and maintain inventory and long-term monitoring programs for measuring the status and health of the park's natural, cultural, and social resources.

Establish a proactive research program responsive to park management needs and providing sound scientific information that affords greater insight into natural resource components, systems, and processes.

Achieving the Desired Future Condition

Achieving the desired future conditions stated in this plan for park resources requires that a regional perspective be considered, recognizing that actions taken on lands surrounding the park directly and indirectly affect the park. Many of the threats to park resources, such as invasive species and air pollution, come from outside of the park boundaries, requiring an ecosystem approach to understand and manage the park's natural resources. Imperative in this effort is understanding the health or condition of the ecosystem. Key indicators of resource or system conditions must be identified and monitored.

Cooperation, coordination, negotiation, and partnerships with agencies and neighbors are also crucial to meeting or maintaining desired future conditions for the park while recognizing the need to accommodate multiple uses on a regional scale. This approach to ecosystem management may involve many parties (e.g., the National Park Service's involvement with the Northwest Forest Plan and the collaborative decision-making process involving regional air quality negotiations) or cooperative arrangements with state agencies or tribes to obtain a better understanding of trans-boundary issues (e.g., Elk and Northern Spotted Owl population dynamics).

Figure 3. Developed area within Mount Rainier National Park.

Table 3. North Coast and Cascades Network natural resource monitoring protocols and plan.

Resource	Reference
Alpine-Subalpine Vegetation	Rochefort et al. 2012
Climate	Lofgren et al. 2010
Data Management Plan	Boetsch et al. 2009
Elk	Griffin et al. 2012
Fish Assemblages	Brenkman and Connolly 2008
Forest Vegetation	Acker et al. 2010
Glaciers	Riedel et al. 2010
Landscape Dynamics	Antonova et al. 2012
Landbirds	Siegel et al. 2007
Mountain Lakes	Glesne et al. 2012
Water Quality	Rawhouser et al. 2012

2.3.2 Status of Supporting Science

MORA coordinates in-park research efforts with multiple federal, state, academic, and non-profit agencies, universities, and organizations. MORA is also a participant in the North Coast and Cascades Research Learning Network (NCCRLN) established in 2001, the NCCN Inventory and Monitoring Network, and the Pacific Northwest Cooperative Ecosystems Studies Unit (PNWCESU), as well as other CESUs. The NCCRLN and PNWCESU assist the park in developing and implementing collaborative research studies at member parks. MORA has received long-standing support from the U.S. Geological Survey staff, especially the biological staff at the Forest and Rangeland Ecosystem Science Center (formerly NPS scientists, National Biological Survey, and USGS-BRD) and geological staffs at the Cascades Volcano Observatory. A partial list of partners-collaborators includes 8 federal and state agencies and 13 universities. MORA natural resources staff also actively engaged in collaborative research agreements with federal and state agencies, and universities to support park science.

NCCN Vital Signs long-term monitoring projects at MORA include Climate, Glaciers, Landbirds, Landscape Dynamics, and Mountain Lakes. Alpine-Subalpine Vegetation, Forest Vegetation, and Elk are monitored subject to funding availability. Water chemistry and benthic macroinvertebrates are monitored through a Network water quality monitoring program at 6 stream-river sties.

2.4 Literature Cited

Acker, S. A., A. Woodward, J. R. Boetsch, K. Hutten, M. Bivin, R. Rochefort, C. C. Thompson, and L. Whiteaker. 2010. Forest vegetation monitoring protocol for the North Coast and Cascades Network. Natural Resource Report NPS/NCCN/NRR—2010/242. National Park Service, Fort Collins, Colorado.

Antonova, N., C. Copass, R. K. Kennedy, Z. Yang, J. Braaten, and W. Cohen. 2012. Protocol for Landsat-based monitoring of landscape dynamics in North Coast and Cascades Network Parks: Version 2. Natural Resource Report NPS/NCCN/NRR—2012/601. National Park Service, Fort Collins, Colorado.

Asquith, A., J. D. Lattin, A. R. Moldenke. 1990. Arthropods: The invisible diversity. Northwest Environmental Journal 6:404–405.

Boetsch, J. R., B. Christoe, and R. E. Holmes. 2009. Data management plan for the North Coast and Cascades Network Inventory and Monitoring Program (2005). Natural Resource Report NPS/NCCN/NRR—2009/078. National Park Service, Fort Collins, Colorado.

Brenkman, S. J., and P. J. Connolly. 2008. Protocol for monitoring fish assemblages in Pacific Northwest National Parks. U.S. Geological Survey Techniques and Methods 2–A7.

Catton, T. 1996. Wonderland: An administrative history of Mount Rainier National Park. National Park Service, Cultural Resources Program. Seattle, Washington.

Driedger, C. L. 1986. A visitor's guide to Mount Rainier glaciers. Pacific Northwest National Parks and Forests Association.

Glesne, R. S., S. C. Fradkin, B. A. Samora, J. R. Boetsch, R. E. Holmes, and B. Christoe. 2012. Protocol for long-term monitoring of mountain lakes in the North Coast and Cascades Network: Version July 9, 2012. Natural Resource Report NPS/NCCN/NRR—2012/549. National Park Service, Fort Collins, Colorado.

Griffin, P. C., K. J. Jenkins, P. Happe, M. Reid, D. Vales, B. J. Moeller, S. McCorquodale, M. Tirhi, J. R. Boetsch, K. Beirne, and J. Schaberl. 2012. Elk monitoring protocol for Mount Rainier National Park and Olympic National Park: January 11, 2012. Natural Resource Report. NPS/NCCN/NRR—2012/485. National Park Service, Fort Collins, Colorado.

Heliker, C. C., A. Johnson, and S. M. Hodge. 1983. The Nisqually Glacier, Mount Rainier, Washington, 1857–1979: A summary of long-term observations and a comprehensive bibliography, U. S. Geological Survey Open-File Report 84-541.

Kennard, P., L. Walkup, J. Ohlschlager, and S. Beason. In prep. Surficial velocities of the Nisqually Glacier, Mount Rainier National Park, 2011 and 2012. Natural Resource Data Series NPS/XXXX/NRDS–20XX/XXX. National Park Service, Fort Collins, Colorado.

Korosec, M. A. 1989. Geothermal resource evaluation of Mount Rainier. U.S. Department of the Interior, Bureau of Land Management, Lacey, Washington.

Lofgren, R., B. Samora, B. Baccus, and B. Christoe. 2010. Climate monitoring protocol for the North Coast and Cascades Network (Mount Rainier National Park, Olympic National Park, North Cascades National Park, Lewis and Clark National Historical Park, Ebey’s Landing National Historical Reserve, San Juan Island National Historical Park, Fort Vancouver National Historic Site): Volume 1. narrative and appendices, version 5/26/2010. Natural Resource Report NPS/NCCN/NRR—2010/240. National Park Service, Fort Collins, Colorado.

Manni, M. F., Y. Le, and S. J. Hollenhorst. 2013. Mount Rainier National Park visitor study: Summer 2012. Natural Resource Report NPS/NRSS/EQD/NRR—2013/736. National Park Service, Fort Collins, Colorado.

[NPS] National Park Service. 2001. Final General Management Plan/Environmental Impact Statement, Mount Rainier National Park, Washington. U.S. National Park Service, Denver Service Center [last modified in 2007].

Nylen, T. 2004. Spatial and temporal variation of glaciers on Mount Rainier between 1913–1994 [thesis]. Portland State University, Portland, Oregon.

Rawhouser, A.K., L.P. Grace, R.A. Lofgren, R.S. Glesne, J.R. Boetsch, C.A. Welch, B.A. Samora, P. Crain, and R.E. Holmes. 2012. North Coast and Cascades Network water quality monitoring protocol. Natural Resource Report NPS/NCCN/NRR–2012/571. National Park Service, Fort Collins, Colorado.

Riedel, J. L., J. M. Wenger, and N. D. Bowerman. 2010. Long term monitoring of glaciers at Mount Rainier National Park: Narrative and standard operating procedures version 1.0. Natural Resource Report NPS/NCCN/NRR—2010/175. National Park Service, Fort Collins, Colorado.

Rochefort, R. M. 2010. Vascular plant inventory of Mount Rainier National Park. Natural Resource Technical Report NPS/NCCN/NRTR—2010/347. National Park Service, Fort Collins, Colorado.

Rochefort, R. M., M. M. Bivin, J. R. Boetsch, L. Grace, S. Howlin, S. A. Acker, C. C. Thompson, and L. Whiteaker. 2012. Alpine and subalpine vegetation monitoring protocol for the North Coast and Cascades Network. Natural Resource Report NPS/NCCN/NRR—2012/570. National Park Service, Fort Collins, Colorado.

Rodgers, T. 2013. Investigator's Annual Report for the Mount Rainier National Park Soil Survey. Natural Resources and Conservation Service, Mount Vernon, Washington.

Siegel, R. B., R. L. Wilkerson, K. J. Jenkins, R. C. Kuntz II, J. R. Boetsch, J. P. Schaberl, and P. J. Happe. 2007. Landbird monitoring protocol for national parks in the North Coast and Cascades Network. U.S. Geological Survey Techniques and Methods 2–A6.

Simmons, T., M. Littlejohn, and W. Morse. 2001. Mount Rainier National Park visitor study: Summer 2000. Visitor Services Project Report 124, Cooperative Park Studies Unit, University of Idaho. Moscow Idaho.

Stevens et al. In prep.

[USDA] U.S. Forest Service and U.S. Bureau of Land Management (USDA). 1994. Final supplemental environmental impact statement on management of habitat for late-successional and old-growth forest related species within the range of the Northern Spotted Owl. Portland, Oregon.

Weber, S., A. Woodward, and J. Freilich. 2009. North Coast and Cascades Network vital signs monitoring report (2005). Natural Resource Report NPS/NCCN/NRR—2009/098. National Park Service, Fort Collins, Colorado.

Wilson, S., and A. Fountain. 2014. Field mapping glacier extents at Mount Rainier for hazard recognition. Report to Mount Rainier National Park. Portland State University, Department of Geology, Portland, Oregon.

Chapter 3 Assessment—Scope and Design

3.1 Preliminary Scoping

A Natural Resource Condition Assessment Workshop was convened in Seattle, Washington, 2–3 November 2010. The purpose of this 2-day workshop was to review and brainstorm the natural resources of MORA, to identify and prioritize key indicators of the natural resources and their stressors, and to develop a plan for creating and completing an assessment of the conditions of MORA natural resources. The workshop was attended by 31 individuals including 23 NPS and 7 USGS representatives. One University of Washington Climate Impacts Group (CIG) representative was also present. The workshop began with an overview of the Natural Resource Condition Assessment goals and objectives, and a general discussion of reference conditions and how to develop and use them as part of the resource assessments. Break-out groups were then convened to brainstorm and prioritize a list of natural resources, their associated indicators, and reference conditions or other comparative sources useful for the assessment of the condition of each resource. The general categories of discussion by the break-out groups included: (1) landcover pattern and structure – disturbance, hydrology, topography, ecosystems, and communities; (2) animals – mammals and birds; (3) animals – amphibians and fish; (4) air and water quality; and (5) plants – vegetation. An additional considered resource category, riverine landforms, was dropped due to loss of staff expertise and limitations of funds to address this topic. The riverine landforms category was meant to define and quantify the extent of alteration in riverine landform condition, explore the potential implications of these types of changes, especially for aquatic biota, and discuss how this index might be used by the park as an integrated metric for monitoring climate change stressors. The systems of focus for riverine landforms are representative glacial rivers (e.g., Fryingpan, Emmons, Kautz and Nisqually). Questions created and prioritized to help facilitate the development of long-term monitoring at MORA as part of the park's Vital Signs identification process and the NCCN Long-Term Ecological Monitoring Program were used as a foundation for guiding and informing break-out group discussions. This small-group activity was followed by a presentation and discussion of the results of each break-out group by the reconvened workshop participants, and the results of this discussion were collated and summarized in a table that listed and identified 11 general natural resource categories, their associated indicators, reference conditions, and comparison metrics (Table 4). The criteria used to prioritize resource categories and indicators included: (1) key resource questions previously identified as part of the Vital Signs identification process; (2) data richness of each resource including spatial and temporal extent and continuity; (3) data overlap of resources; (4) determination of the importance or level of priority or concern of a resource to park management; and (5) expertise of scientists and NPS staff working on the project. The workshop concluded with a general discussion and prioritization of the preferred natural resources for inclusion in the assessment and a review of the project timeline.

Table 4. Focal resources and their indicators-stressors and reference conditions.

Resource	Indicators-Stressors	Reference Condition/Comparison Metric
Air Quality	Nitrogen-Sulfur deposition	Best attainable condition
	Contaminants deposition	Best attainable condition
	Ozone	Best attainable condition
	Visibility	Natural conditions
Amphibians	Number of species	Conservation and management status designations (NatureServe; U.S. ESA; IUCN; WA-Species of Concern)[1]
	Presence-absence and distribution	
	Climate change	
	Construction and maintenance of roads and trails	
	Atmospheric deposition of contaminants	
	Disease	
	Introduced species	
Fish	Number of species	Conservation and management status designations (NatureServe; U.S. ESA; IUCN; WA-Species of Concern)[1]
	Presence-absence and distribution	
	Climate change	
	Habitat alteration, fragmentation, and loss	
	Atmospheric deposition of contaminants	
	Introduced species	
	Stocking	
Glaciers	Extent (quality and quantity)	Total glacial area (extent)
	Mass balance (cumulative balance)	Surface mass balance of 4 indicator glaciers
	Volume	
	Nisqually ice surface elevations	
	Climate change	
Land Birds	Breeding density and trends	Historical condition; Partners in Flight (PIF) conservation plan goals and targets
	Harlequin Ducks	Minimally disturbed
	Raptors–nesting occupancy and productivity	Minimally disturbed
	Threatened and endangered species	Conservation and management status designations (NatureServe; U.S. ESA; IUCN; WA-Species of Concern)[1]
	Climate change	

[1]U.S. ESA: United States Endangered Species Act; IUCN: International Union for Conservation of Nature; WA: Washington

Table 4. Focal resources and their indicators-stressors and reference conditions (continued).

Resource	Indicators-Stressors	Reference Condition/Comparison Metric
Mammalian Fauna	Carnivores	Reference conditions identified and defined by Stoddard et al. (2006), 'Minimally Disturbed Condition' Conservation and management status designations (NatureServe; U.S. ESA; IUCN; WA-Species of Concern)[1];
	Elk	Range of densities of Elk using the subalpine meadows in MORA over the last decades[2],
	Bats	Minimally disturbed; Best attainable condition
Night Skies	Sky luminance	Sky brightness/natural conditions
	Sky quality	Sky Quality Index
	Anthropogenic light	Maximum vertical illuminance from anthropogenic source
Soundscapes	Acoustical monitoring	Comparison to results summarized for 189 sites in 43 national parks (Lynch et al. 2011); sound level (measure in decibels), percent time human-caused noise is audible, noise free interval, natural ambient sound level, existing sound level
	Ambient sound levels	
	Intensity, duration, and distribution of sound	
Vegetation	Landscape –Scale Vegetation Dynamics Climate Change	Recently developed vegetation map will serve as basis for assessing future changes Western Washington: Risk assessment (Aubry et al. 2011); Range change (Shafer et al. 2001) U.S.: Percent range maintained (Coops and Waring 2011); Percent area change (Rehfeldt et al. 2006) North America: Percent area change (Rehfeldt et al. 2006); Percent area loss- worst scenario (McKenney et al. 2007)
	Forest health: (forest insects and diseases, air pollution, exotic plant species, white pine blister rust, exotic plant species), climate change	Historic range of variation; current conditions; distribution; absence of White Pine blister; effects of air pollution on vegetation is pre-industrial air quality levels; Climate reference period to be from the beginning of the ADS record (1949) until 1985 -
	Tree mortality	abundance; biological integrity for backcountry; best attainable condition for frontcountry;
	Biodiversity (alpine and subalpine vegetation, exotic plants, sensitive vegetation species, wetlands)	Exotic plants: absence of species transported to the park through human activities; wetlands: current inventory of wetlands extent as baseline for identifying future change; alpine and subalpine vegetation: present condition serves as reference for future change; sensitive vegetation species: 1997 reference conditions as published by the Washington Natural Heritage Program.
	Fire	stand reconstruction performed by Hemstrom and Franklin (1982)

[1]U.S. ESA: United States Endangered Species Act; IUCN: International Union for Conservation of Nature; WA: Washington

[2]With the exception of increased populations observed in the 1980s

Table 4. Focal resources and their indicators-stressors and reference conditions (continued).

Resource	Indicators-Stressors	Reference Condition/Comparison Metric
Water Quality (Lentic)	Trophic status	Trophic State Index (TSI); comparison to historical and regional conditions; synthesis of past reports
	Ion chemistry	comparison to historical and regional conditions; synthesis of past reports
	Physical parameters (Alka, Cond, pH, DO)[3]	comparison to historical and regional conditions; synthesis of past reports
	Zooplankton, benthic macroinvertebrates	occurrences and distributions of taxa
	Atmospheric deposition	
	Ice out	
	Climate change	
Water Quality (Lotic)	Nutrient concentrations	Washington DOE surface water quality standards; EMAP disturbance thresholds; Oregon DEQ Level II assessment indices[4]
	Ion chemistry	
	Physical parameters (Alka, Cond, pH, DO)[3]	
	Water temperature	
	Benthic macroinvertebrates	occurrences and distributions of taxa[4]

[3]Alka: Alkalinity; Cond: Conductivity; DO: Dissolved Oxygen

[4]DEQ: Department of Environmental Quality; DOE: Department of Environment; EMAP: Environmental Monitoring and Assessment Program

3.2 Design—General Approach and Methods

Following the scoping workshop, all available data, reports, and references pertinent to each of the 11 general natural resource categories identified during the workshop were collected from MORA staff. This information was uploaded to a USGS SharePoint site and made available to all participants in this assessment. Individuals responsible for completing an assessment reviewed available resource-specific information and selected material that would allow them to complete their assessment. These materials included, in part: (1) existing databases that could be analyzed without revision; (2) databases that could be analyzed after appropriate revision; (3) published and unpublished reports that already analyzed, evaluated, and summarized the status and trends of a particular resource; (4) executive summaries and annual resource status reports; and (5) assorted administrative reports, summaries, and checklists of past resource program activities. Resource assessors also determined how the condition of a resource could best be assessed and gathered appropriate references and documentation that would support the metrics and reference conditions chosen to complete their assessment. As a result of this process, focal natural resources and their assessment categories were identified for inclusion in this report; they are listed and summarized in Table 5.

Each resource assessment is generally structured as follows: (1) Introduction; (2) Approach; (3) Reference Conditions and Comparison Metrics; (4) Results and Assessment; (5) Emerging Issues; (6) Data Needs; and (7) Literature Cited. The introduction subsection introduces a specific resource by providing background information about the resource, places the resource in the context of its importance to the park, and summarizes the primary objectives of the resource-specific assessment. The approach subsection outlines the methods used to conduct the assessment. The reference and comparison metrics subsection summarizes the conditions and metrics used to make a determination as to the overall condition of the resource. The results and assessment subsection presents details of the outcome of the analysis of resource-specific data used to complete the assessment, and the overall condition assessment of the resource. The emerging issues subsection is designed to identify present or future potential stressors of a resource. The data needs subsection is used to identify gaps in presently available data as well as suggest additional sampling and data collection that could be useful for better assessing the condition of a resource. The overall objective of this approach is to assess and articulate the present condition of each focal resource based on a reasonably thorough review of available information (e.g., data, publications, and reports) generated by park staff, and by research and monitoring cooperators. This condition assessment provides a "snap-shot in time" evaluation of the conditions of a select set of MORA natural resources.

Table 5. Focal Mount Rainier National Park resources and their assessment categories.

Resource	Assessment Elements
Air Quality	Ozone; Visibility; Nitrogen-Sulfur deposition; PBT deposition
Lake Water Quality	Trophic status: chlorophyll *a*; nitrogen; phosphorus; N:P; cation and anion concentrations; acid neutralizing capacity; conductivity; pH; dissolved oxygen concentrations; zooplankton and macroinvertebrate occurrence and distributions; lakes of management concern
Stream Water Quality	Variability of 12 physical habitat attributes; use of benthic macroinvertebrate model for predicting level of impairment; wadeable streams of management concern
Vegetation	Landscape-scale vegetation dynamics; Forest Health – disturbance regime; Forest Health – Whitebark Pine and blister rust; Forest Health – air quality; Fire ecology; Biodiversity – exotic plants; Biodiversity – wetlands; Biodiversity – alpine-subalpine vegetation; Biodiversity – sensitive vegetation species
Amphibians	Park occurrence and distributions; species management and conservation status
Fish	Park occurrence and distributions in rivers, streams, and lakes; species management and conservation status; hybridization among trout species; Skagit River Bull Trout genetics; Salmon-Steelhead stock assessments and spawning; Puyallup River Bull Trout Recovery Unit
Land Birds	Park occurrence and distributions; species management and conservation status
Mammalian Fauna	General presence and management status
Mammalian Carnivores	In-park status and distributions (19 species)
Elk	Estimate of abundance and population trends
Bats	Presence, distributions, and frequency of capture/detection
Glaciers	Total glacial area (extent); surface mass balance of 4 indicator glaciers
Soundscapes	Acoustical monitoring; ambient sound levels; intensity, duration, and distribution of sound
Dark Night Skies	Sky luminance, sky quality, and anthropogenic light

3.3 Literature Cited

Aubry, C., W. Devine, R. Shoal, A. Bower, J. Miller, and N. Maggiuli, N. 2011. Climate change and forest biodiversity: A vulnerability assessment and action plan for national forests in western Washington. U.S. Department of Agriculture, Forest Service, Pacific Northwest Region. Olympia, Washington.

Coops, N. C., and R. H. Waring. 2011. Estimating the vulnerability of fifteen tree species under changing climate in Northwest North America. Ecological Modeling 222:2119–2129.

Hemstrom, M. A., and J. F. Franklin. 1982. Fire and other disturbances of the forests in Mount Rainier National Park. Quaternary Research 18:32–51.

Lynch, E., D. Joyce, and K. Fristrup. 2011. An assessment of noise audibility and sound levels in U.S. National Parks. Landscape Ecology 26:1297–1309.

McKenney, D. W., J. Pedlar, M. Hutchinson, K. Lawrence, and K. Campbell. 2007. Potential impacts of climate change on the distribution of North American trees. BioScience 57:939–948.

Rehfeldt, G. E., N. L. Crookston, M. V. Warwell, and J. S. Evans. 2006. Empirical analyses of plant-climate relationships for the western United States. International Journal of Plant Sciences 167:1123–1150.

Stoddard, J. L., D. P. Larsen, C. P. Hawkins, R. K. Johnson, and R. H. Norris. 2006. Setting expectations for the ecological condition of streams: The concept of reference condition. Ecological applications 16:1267–1276.

Shafer, S. L., P. J. Bartlein, and R. S. Thompson. 2001. Potential changes in the distributions of western North America tree and shrub taxa under future climate scenarios. Ecosystems 4:200–215.

Chapter 4 Natural Resource Condition Assessments

4.1 Air Quality and Air Quality-Related Values

(Tonnie Cummings, Pacific West Region Air Resources Specialist, NPS; Barbara Samora, Biologist, MORA, NPS)

4.1.1 Introduction

Visitor enjoyment, the health of park ecosystems, and the integrity of cultural resources depend upon clean air. To foster clean air in parks, the National Park Service (NPS) monitors air quality; assesses effects on resources; communicates information about air quality issues; advises and consults with regulatory agencies; partners with stakeholders to develop air pollution management strategies; and promotes pollution prevention practices (NPS Management Policies 2006).

Several laws provide the basis for air quality protection in units of the National Park System, including the Organic Act, Wilderness Act, and Clean Air Act. The 1977 Clean Air Act amendments have a requirement to "preserve, protect, and enhance the air quality" in Class I national parks and wilderness areas (42 U.S.C. 7470 et seq.). Mount Rainier National Park (MORA) is 1 of the 48 Class I air quality areas managed by the NPS. The 1977 Clean Air Act amendments give federal land managers an "affirmative responsibility" to protect the air quality related values (AQRVs) in Class I areas. Air quality related values are resources sensitive to air quality, including visibility, lakes, streams, vegetation, soils, and wildlife. Congress directed the NPS to "err on the side of protecting air quality-related values for future generations" (Senate Report No. 95-127, 95th Congress, 1st Session, 1977).

Air Pollution Sources

Most human activities, including manufacturing and industrial processes, agricultural practices, land disturbance, and fossil fuel combustion, produce air pollution. MORA is downwind of Seattle and Tacoma, Washington; and the only coal-fired power plant in the state, located near Centralia, is 80 km west of the park. Washington Department of Ecology's (WDOE) 2011 stationary source emissions inventory (Stephanie Summers, WDOE, personal communication) provides insight on the types of facilities that affect air quality at MORA. Sources within 100 km of the park included an aluminum smelter, a cement plant, power plants, wood products manufacturers, and other manufacturing facilities (Figure 4). Significant sources of area emissions were construction, road dust, residential woodburning, on-road vehicles, recreational boats and commercial marine vessels, non-road vehicles (e.g., forklifts, tractors, and snowmobiles), solvents, and livestock (WDOE website 2014). Air pollutants of concern include sulfur (S) and nitrogen (N) compounds, ground-level ozone, and persistent bioaccumulative toxics (PBTs), such as mercury (Hg).

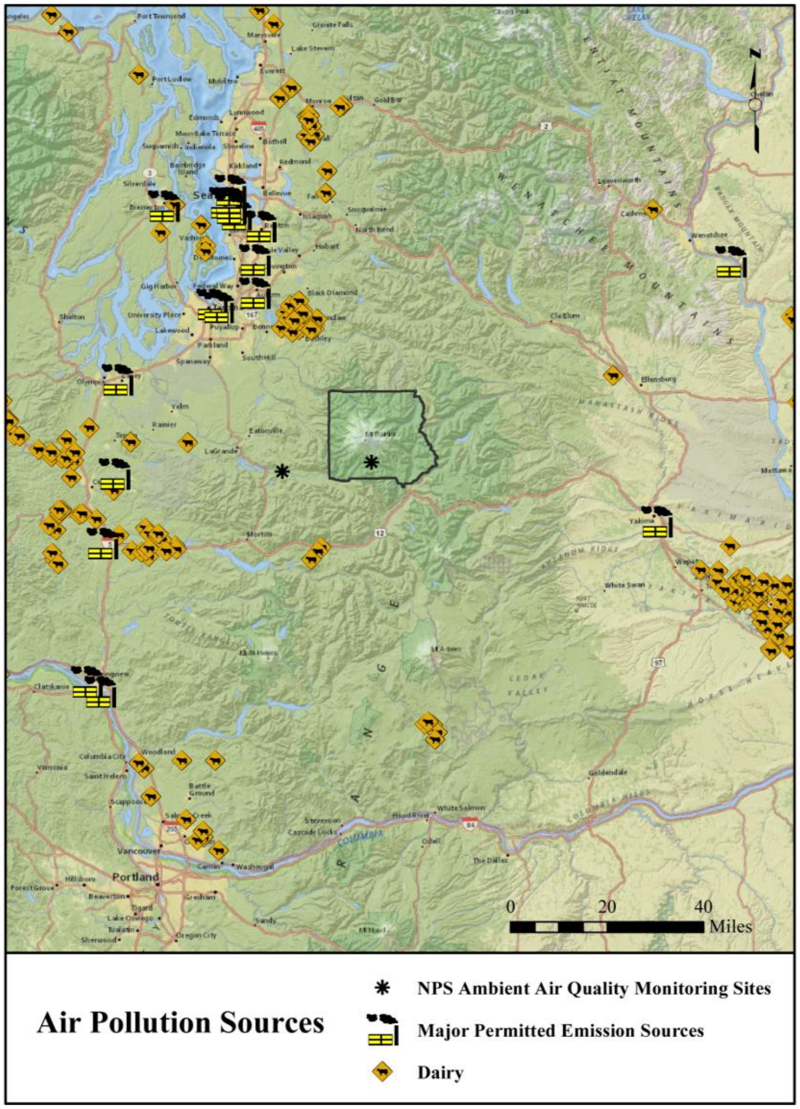

Figure 4. Pollution sources near Mount Rainier National Park

The main source of S pollution is coal combustion at power plants and industrial facilities. Oxidized N compounds (i.e., nitrogen oxides) result from fuel combustion by vehicles, power plants, and industry. Reduced N compounds (e.g., ammonia and ammonium) are the result of agricultural activities, fires, vehicle emissions, and other sources. Ozone is formed when nitrogen oxides and volatile organic compounds from vehicles, solvents, industry and vegetation react in the atmosphere in the presence of sunlight, usually during the warm summer months. Persistent bioaccumulative toxics include heavy metals and organic compounds such as pesticides. Coal combustion, incinerators, mining processes, and other industries emit Hg.

Air Pollution Effects

Fine particles of S and N compounds, and other pollutants in the atmosphere, absorb or scatter light, causing haze and reducing visibility (Hand et al. 2011). There are 2 size-range categories of particulate matter typically measured by air quality monitoring networks, i.e., particles smaller than 10 µm (PM_{10}) and particles smaller than 2.5 µm ($PM_{2.5}$). These smaller particles are of most concern for human, and possibly wildlife, health because they can easily pass through the nose and throat, enter the lungs, and cause serious health problems. Primary threats to visual resources, i.e., expansive scenic views of iconic park landscapes, come from development outside the park boundaries and pollutants that degrade visibility (NPS 2013b). Sulfur and N pollutants are eventually deposited as either wet deposition (e.g., via rain, snow, clouds, and fog) or dry deposition (e.g., via settling, impaction or adsorption). These pollutants change water and soil chemistry, which in turn, affects algae, aquatic invertebrates, and soil microorganisms, and can lead to impacts higher in the food chain (Sullivan et al. 2011a, 2011b; Greaver et al. 2012). Because N is an essential plant nutrient, N compounds may cause unwanted fertilization or eutrophication, with subsequent changes in soil nutrient cycling and plant community structure and composition. Deposition can acidify lakes and streams that have low buffering capacity.

Ozone is a respiratory irritant and can trigger a variety of health problems including chest pain, coughing, throat irritation, and congestion. Ozone also affects vegetation, causing significant harm to sensitive plant species (USEPA 2013). Ozone enters plants through leaf openings called stomata and oxidizes plant tissue, causing visible injury (e.g., stipple and chlorosis) and growth effects (e.g., premature leaf loss; reduced photosynthesis;, and reduced leaf, root, and total size).

After Hg is deposited, it can be transformed by ecosystem processes into the very toxic form, methylmercury, which biomagnifies in the food chain and can reach harmful levels in fish, wildlife, and humans. Biological effects of PBTs include impacts on reproductive success, growth, behavior, disease susceptibility, and survival (Moran et al. 2007, Landers et al. 2008).

The NPS and others have monitored air quality and AQRVs at MORA since the early 1980s (Figure 5). In 1994, the NPS published a review of the status of air quality and air pollution-related ecological effects in 5 Class I parks in the Pacific Northwest, including MORA (Eilers et al. 1994); a 2003 addendum summarized visibility data collected at the 5 parks through 1999 (Air Resource Specialists 2003). Cummings (2014) provided an updated summary of air pollution monitoring and research conducted at MORA through early 2014. Because a comprehensive discussion of air quality at MORA is beyond the scope of this condition assessment, the overview reports should be consulted for additional information.

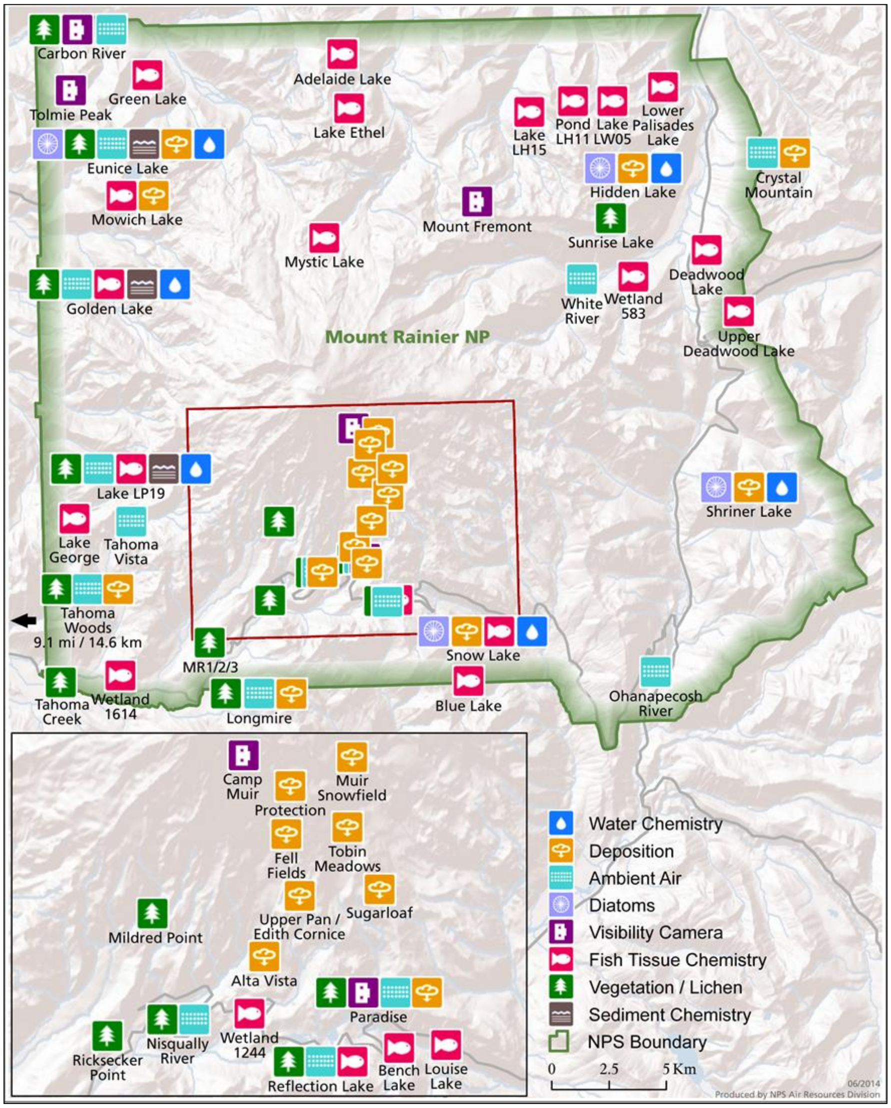

Figure 5. Locations of some of the air quality-related monitoring and research that has been conducted at Mount Rainier National Park (from Cummings 2014).

4.1.2 Approach

Visibility – Sources and Methods

The NPS began monitoring visibility at MORA in the 1980s. To provide qualitative documentation of visual conditions, pictures were taken with a 35-mm camera (1985–1995), and a digital camera (2003–present). In 1995, an historical photographic archive was developed to show representative regional haze visibility conditions (Figure 6), including each slide's estimated standard visual range (i.e., the distance at which one can barely make out the presence of a large, dark object).

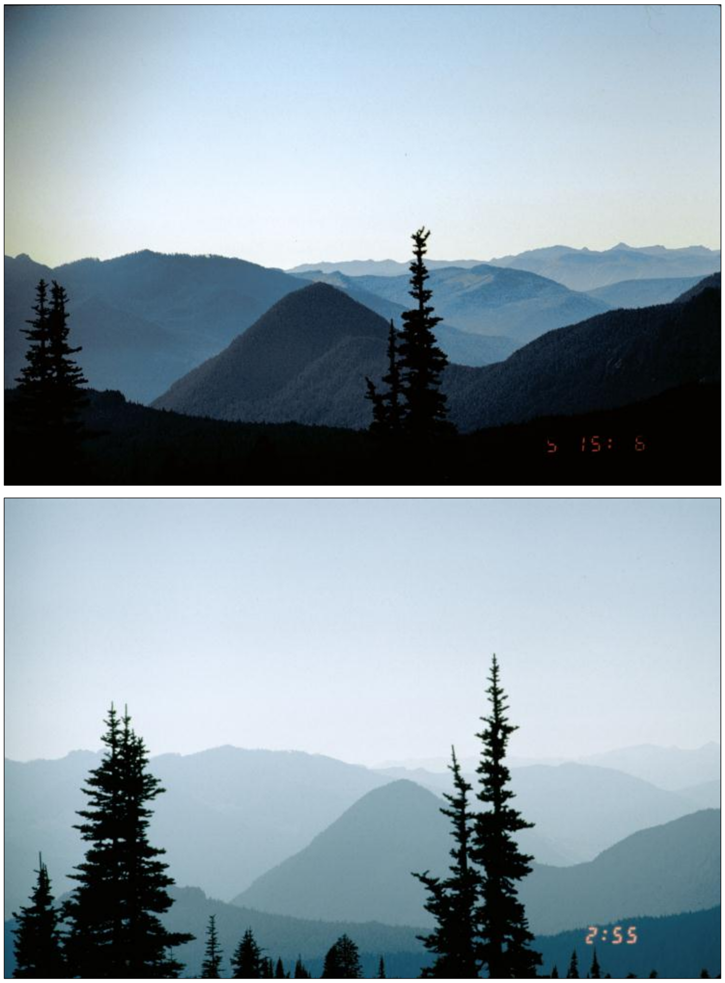

Figure 6. Representative photographs of the view from Paradise at Mount Rainier National Park (from Cummings 2014). The top picture, with a standard visual range of 280 km, illustrates the clearest days. The bottom picture, with a standard visual range of 60 km, illustrates the haziest days.

Since 1988, an Interagency Monitoring of Protected Visual Environments (IMPROVE) Program particle monitor has been operating at Tahoma Woods; the monitor gives quantitative measurements of mass, chemical elements, sulfate, nitrate, organics, and elemental carbon. Particle monitoring allows for identification of the chemical species and sources of human-caused visibility impairment in the park, and is used to document long-term visibility trends (IMPROVE website 2014). Particles were also monitored in the Ohanapecosh Campground, located in the southeast corner of the park, during the summers of 2009, 2010, and 2013. Monitoring was conducted in response to visitor and employee complaints regarding respiratory effects from campfire smoke (Lofgren and Samora 2010).

Nitrogen and Sulfur Deposition – Sources and Methods—There are 2 national deposition chemistry monitoring programs. The National Atmospheric Deposition Program (NADP) monitor at Tahoma Woods, 16 km outside of MORA's southwest entrance, has monitored wet deposition of sulfate, nitrate, and ammonium since 1984 (NADP website 2014). The Clean Air Status and Trends Network (CASTNET) site, at Tahoma Woods from 1995 to 2013, measured atmospheric concentrations of particles and gases including sulfate, nitrate, ammonium, sulfur dioxide, and nitric acid (CASTNET website 2014). Monitoring of bulk (wet plus dry) deposition has been conducted at Paradise since 1989 (Agren et al. 2013) and throughfall deposition sampling (i.e., collected under the forest canopy) was conducted in the park from 2005–2007 (Fenn et al. 2013). Given the limited number of CASTNET, bulk, and throughfall deposition monitoring sites, the NPS Air Resources Division (ARD) currently relies on the more widespread NADP wet deposition data to assess and compare conditions and trends in parks throughout the country (NPS 2013a).

The U.S. Environmental Protection Agency (EPA) has not established air quality standards or thresholds for S and N deposition. In lieu of regulatory standards, the NPS and other federal land managers are increasingly using critical loads to assess the threat of air pollutants to AQRVs. A critical load is the amount of pollution below which significant harmful effects are not expected to occur. At this time, information about acceptable pollution levels and resource sensitivity is limited. As more studies are completed, critical loads will be developed for more pollutants and more ecosystem components. Critical loads for S deposition have not been identified for the western U.S., where S deposition is low, and of lesser concern, than N deposition. Pardo et al. (2011) identified critical loads of N deposition for a number of ecoregions across the U.S. Cummings et al. (2014) summarized the current state of knowledge about N deposition, effects, and critical loads in Idaho, Oregon, and Washington. While Cummings et al. (2014) identified cumulative potential adverse ecological effects in the region (Figure 7), they determined that with the exception of lichens N critical loads have not been well established for the Pacific Northwest.

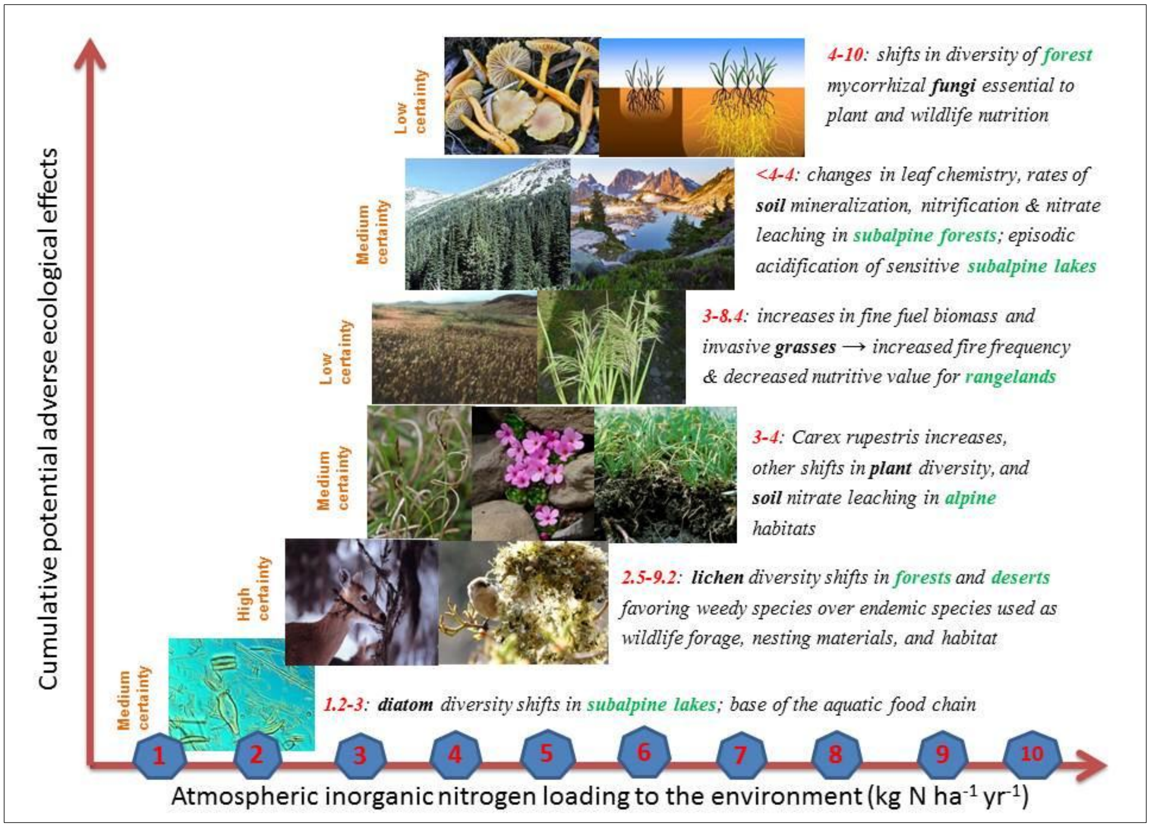

Figure 7. Cumulative potential adverse ecological effects associated with atmospheric N deposition in the Pacific Northwest (from Cummings et al. 2014). The reliability assessments are as follows: High Certainty when a number of published papers of various studies show comparable results, Medium Certainty when the results of some studies are comparable, and Low Certainty when very few or no data are available in the Pacific Northwest so the applicability is based on expert judgment.

Ozone – *Sources and Methods*

Ozone was monitored year round from1991 to 2013 at Tahoma Woods (NPS website 2014), and seasonally at the Jackson Visitor Center since 2000 (MORA, unpubl. records). A portable monitor was used at Tahoma Vista in 2004 and 2005. In addition, summertime ozone concentrations were monitored with passive samplers at many locations in the park from 1999–2005.

The EPA has established a primary National Ambient Air Quality Standard (NAAQS) for ozone that is designed to protect public health. The NAAQS is based on the 3-yr average of the annual fourth highest 8-hr ozone concentration and is currently set at 75 parts per billion (ppb). In January 2010, EPA proposed to lower the primary ozone NAAQS to a value in the range of 60–70 ppb ("National Ambient Air Quality Standard for Ozone, EPA-HQ-OAR-2005-0172; Notice of Proposed Rulemaking", 75 F.R. 11 [19 January 2010], p. 2938–3052). At the same time, EPA proposed a new secondary ozone NAAQS to protect vegetation. The secondary standard would be based on a metric called W126, which is a cumulative sum of hourly ozone concentrations, with hourly values weighted according to their magnitude. The EPA proposed to set the secondary NAAQS in the range of 7 to 15 parts per million-hours (ppm-hr).

PBTs – Sources and Methods

It was once thought that remote locations, such as high elevation parks with headwater streams, were safe from the threat of PBTs. It has been found that, as with S and N, toxic contaminants are atmospherically transported around the globe and often deposited in high elevation and high latitude locations. Hageman et al. (2010) correlated pesticide concentrations in snowpack from several national parks, including MORA, with nearby cropland intensity and wind patterns and concluded that for all studied parks, <25% of the pesticide contribution was from pesticide use within 150 km of the park. After Hg is emitted, it has the potential for long-range transport and joins the "global Hg pool" (i.e., Hg that cycles continuously between the atmosphere, ocean, soil, and living organisms). Modeling indicates 0 to 10% of the Hg deposited in the Pacific Northwest is from local anthropogenic sources, approximately 20% is from Asia and the rest is from the global pool (National Research Council 2009).

The NADP Mercury Deposition Network (MDN) monitors the amount of Hg deposited in precipitation. There are currently 2 MDN sites in Washington: 1 at the Makah National Fish Hatchery on the northwestern tip of the Olympic Peninsula and 1 in Seattle (NADP website 2014). Continued operation of the Makah MDN site is threatened by lack of funding. It is unlikely that either of the sites adequately represent Hg deposition at MORA. In 2002–2003, concern about potential deposition of PBTs in Washington's Class I national parks prompted a U.S. Geological Survey (USGS) study of occurrence and concentration of Hg and organochlorine compounds in fish collected from park lakes (Moran et al. 2007). In 2002, the NPS spearheaded a multi-agency study, the Western Airborne Contaminants Assessment Project (WACAP), to determine the risk from airborne contaminants to ecosystems and food webs in 20 national parks in the western U.S., including MORA (Landers et al. 2008). More recently, Eagles-Smith et al. (2014) analyzed Hg concentrations in fish collected between 2008 and 2012 from 21 western national parks. Samples included fish taken from 17 sites at Mount Rainier in 2012 as part of a focused study to examine a range of food web components (Eagles-Smith, In prep). A study of mercury concentrations in birds at 6 of these sites was also conducted by Adams and others (2013).

4.1.3 Reference Conditions and Comparison Metrics

Visibility

The 1977 Clean Air Act amendments set a National Visibility Goal for "the prevention of any future, and the remedying of any existing, impairment of visibility" in Class I areas (42 U.S.C. 7491). Therefore, the reference condition for visibility is natural conditions (i.e., no human-caused visibility impairment). Visibility is typically reported using a haze index called the deciview (dv). The dv scale is near zero for a pristine, clean atmosphere and increases as visibility degrades.

Nitrogen and Sulfur Deposition

The NPS ARD classifies park condition of significant concern if wet deposition of S or N exceeds 3 kilograms/hectare/year (kg/ha/yr), or if wet N deposition is 1 to 3 kg/ha/yr and the park contains N-sensitive ecosystems (NPS 2013a). Based on over 1,400 study plots, Geiser et al. (2010) recommended a total (wet plus dry) N critical load to protect lichens in western Oregon and Washington. That critical load is 2.7 to 9.2 kg/ha/yr with the critical load increasing as precipitation increases. Pardo et al. (2011) recommended a critical load of 1.5 kg/ha/yr of wet N deposition to protect high elevation aquatic ecosystems in the Rocky and Sierra Nevada Mountains. A USGS study examined diatom assemblages in a total of 11 lakes in MORA, North Cascades, and Olympic National Parks to look for species changes associated with N deposition (Sheibley et al. 2014). Only 1 lake, Hoh Lake at Olympic, had the known N-sensitive diatom species that formed the basis for establishing aquatic critical loads in the Rocky and Sierra Nevada Mountains. Sheibley et al. (2014) determined the critical load for Hoh Lake was1.2 kg/ha/yr of wet N.

Ozone

The NPS ARD uses the values at the low end of the ranges EPA proposed in 2010 for the primary and secondary standards as the reference conditions for ozone (i.e., 60 ppb to protect human health and 7 ppm-hr to protect vegetation; NPS 2013a). Parks with a 3-yr average of the annual fourth highest 8-hr ozone concentrations of 61–75 ppb are considered to be in a condition of moderate concern for ozone.

PBTs

Because there are no ambient air quality standards for PBTs, NPS ARD relies on literature values indicating the concentrations of pollutants in fish tissue that are known to be a threat to fish health or to the health of humans and wildlife that eat fish. For example, for Hg, the EPA has established a guideline of 300 ppb for safe human consumption of fish. The Washington Department of Health recently lowered the state’s Hg consumption criteria to 100 ppb in fish fillets (Dave McBride, Washington Department of Health, personal communication). Recommended mercury thresholds for wildlife are much lower, e.g., 90 to 270 ppb (Eagles-Smith et al., 2014). Consuming fish that have pollutant concentrations below the respective thresholds is not known to be a threat to wildlife or human health.

4.1.4 Results and Assessment

Visibility

The NPS ARD produces an annual report that provides condition and trend information for visibility, deposition, and ozone in parks, monuments, and other areas managed by the NPS. The most recent report (NPS 2013a), covering 2000–2009, indicates a significant improvement in visibility at MORA on both the clearest and the haziest days (Figure 8).

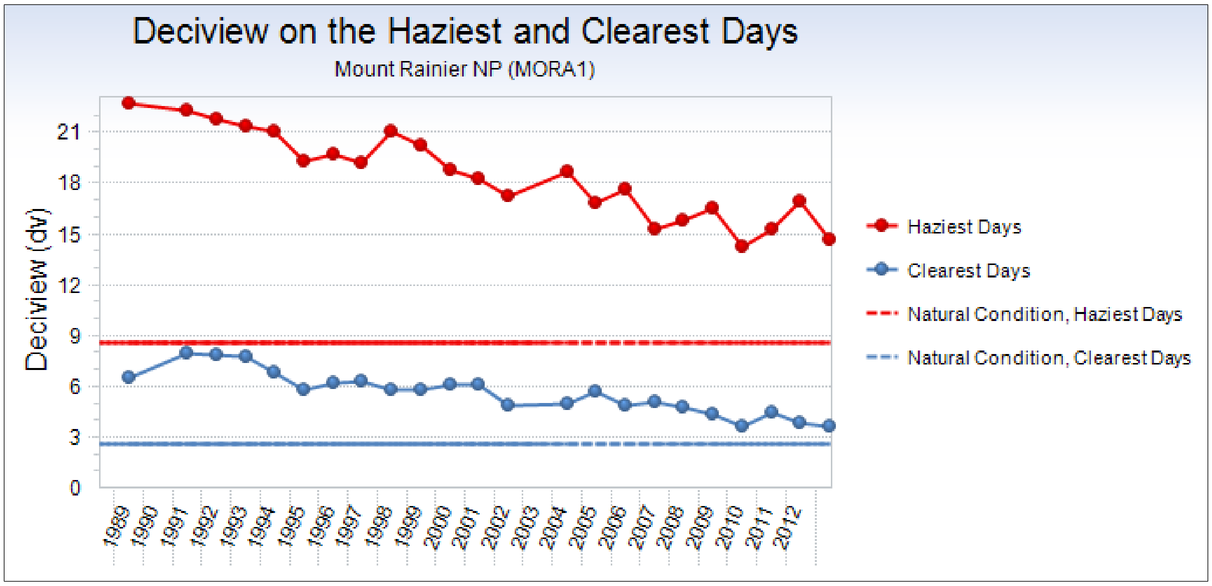

Figure 8. Deciview trends compared to natural conditions on the haziest and clearest days at Mount Rainier National Park (from Cummings 2014).

To quantify the amount of visibility impairment at a site, IMPROVE determines the dv difference between monitored visibility and calculated natural conditions, i.e., the visibility that would exist without human-caused impairment. The 2008–2012 average visibility difference at MORA was 4.21 dv, indicating current visibility is 42% hazier than natural conditions (NPS website 2014). Parks with estimates ranging 2 to 8 dv higher than natural visibility were considered by the NPS ARD to be in a condition of moderate concern for visibility impairment (NPS 2013a).

During sample periods at the Ohanapecosh campground, no exceedances of the particulate matter NAAQS occurred; however, high hourly concentrations were recorded on the weekends during evening hours (Lofgren and Samora 2010). In 2013, the number of campfires and weather conditions were correlated with $PM_{2.5}$ levels. Results indicated concentrations of particulate matter in the Ohanapecosh area do not necessarily increase with an increase in campfire activity. High concentrations were found to be more related to the presence of campfires in combination with inversions occurring on clear, cold nights and mornings in the Ohanapecosh valley (Johnson and Lofgren, In prep.).

Nitrogen and Sulfur Deposition

Based on 2000–2009 NADP wet deposition data, there were improving trends in both N and S concentrations in precipitation at MORA's Tahoma Woods site (Figure 9; NPS 2013a). Agren et al. (2013) reported improving trends in sulfate and nitrate concentrations, but a deteriorating trend in ammonium concentrations, at the Paradise bulk deposition site from 1989 to 2012.

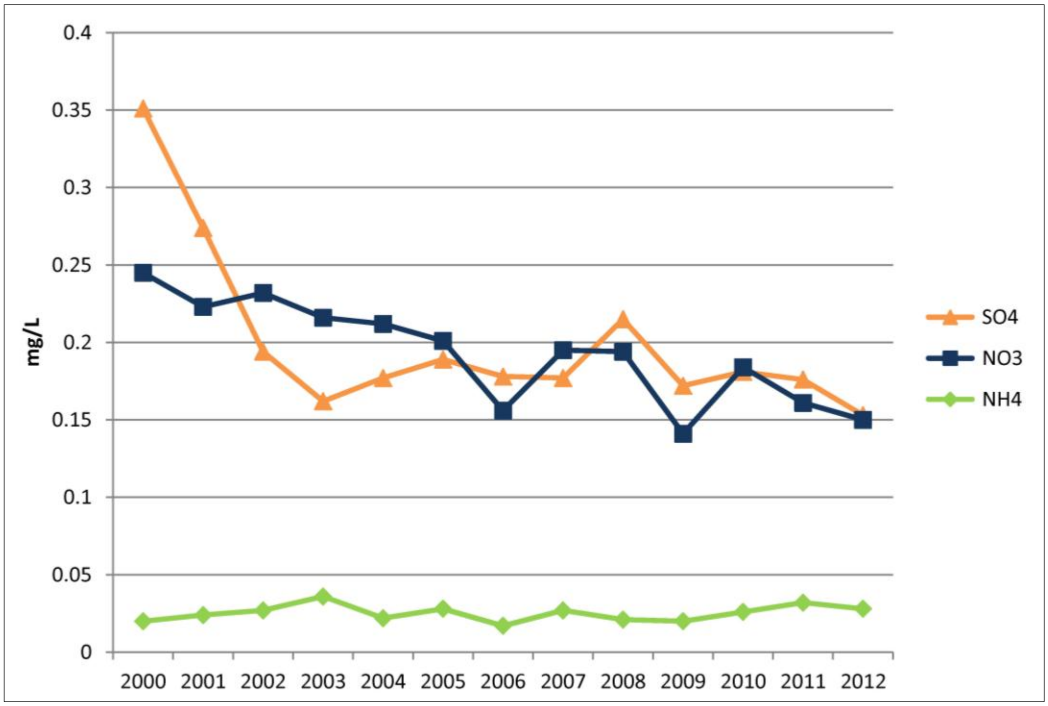

Figure 9. Trends in annual concentrations of sulfate, nitrate, and ammonuim at the Tahoma Woods NADP site at Mount Rainier National Park (from Cummings 2014).

High elevation ecosystems in western Washington are thought to be very sensitive to atmospheric deposition of S and N pollutants due to a limited ability to neutralize acid deposition and to absorb excess N. Sullivan et al. (2011c, 2011d) evaluated the relative sensitivity of NPS Inventory and Monitoring (I&M) Networks and all 79 associated park units larger than 100 mi^2 to surface water acidification and N enrichment. MORA was ranked in the highest risk category for both assessments. Clow and Campbell (2008) found evidence of episodic acidification associated with spring snowmelt at Eunice Lake. They concluded rain-on-snow events and spring snowmelt could cause episodic acidification of high-elevation lakes and streams in the Cascade Mountains.

It appears that, in some years, wet N deposition at MORA exceeds 1.5 kg/ha/yr, which is the possible threshold for effects on aquatic resources. According to Geiser et al. (2010), the N critical load for lichens has likely not yet been exceeded at MORA, based on the limited samples collected from the park. Given the suspected sensitivity of AQRVs in the park and possible underestimation of deposition due to coarse-scale monitoring and modeling and the park's complex terrain, MORA is in a condition of significant concern for atmospheric deposition.

Ozone

2000–2009 data from Tahoma Woods showed an improving trend in ozone concentration (NPS 2013a); ozone levels at Paradise are also decreasing (Figure 10). The reason for the decline is unclear; while it might be due to a change in weather patterns, it is more likely due to a reduction in emissions of ozone precursors throughout the region (Brian Lamb, Washington State University, pers. comm.). The 1999–2005 passive sampling data showed ozone concentrations were typically greater at higher elevations and in the northwest corner of the park (Cummings 2014).

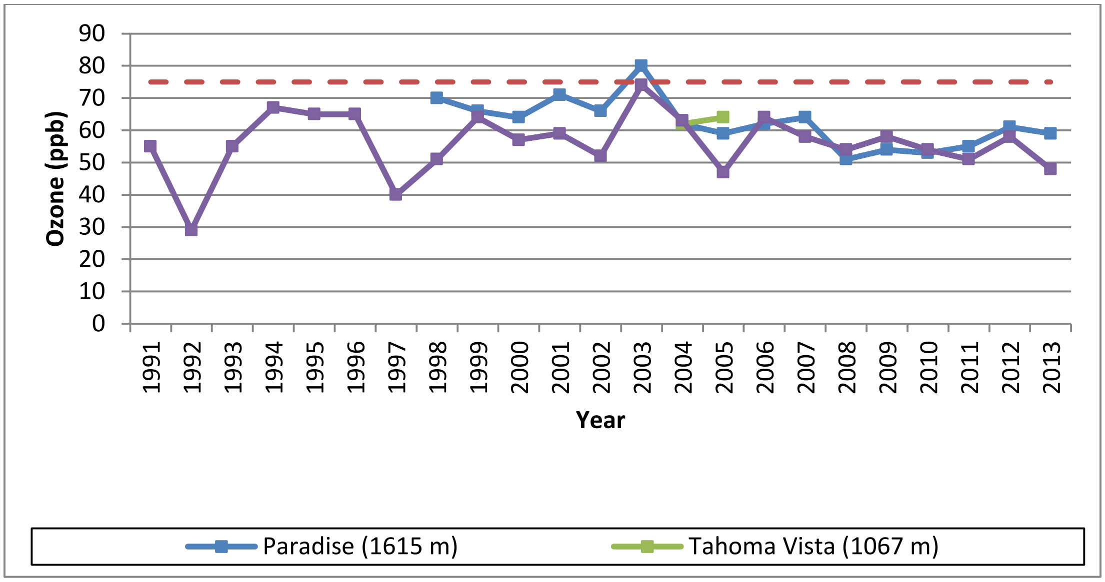

Figure 10. Annual 4th highest daily maximum 8-hr ozone concentrations (in ppb) measured with continuous and portable monitors at Mount Rainier National Park between 1991 and 2013 (from Cummings 2014).

Kohut (2004) assessed the risk of ozone-induced foliar injury at MORA based on species sensitivity, ozone concentrations, and soil moisture (which influences ozone uptake). Kohut concluded there was low risk of ozone injury at the park. NPS vegetation surveys from 1999–2005, and U.S. Forest Service (USFS) Forest Inventory and Analysis surveys in 1998 (Campbell et al. 2000) and 2000–2009 (Sarah Jovan, USFS Pacific Northwest Research Station, pers. comm.), found no signs of ozone injury. While the Tahoma Woods W126 values did not exceed EPA's proposed secondary standard, because both the Tahoma Woods and the Paradise sites exceeded the annual fourth highestdaily maximum 8-hr concentration of 61 ppb during some years, the park is in a condition of moderate concern for ozone.

PBTs

Moran et al. (2007) collected Cutthroat Trout (*Salmo clarkii*) from 4 lakes in MORA, 5 lakes in North Cascades National Park, and 5 lakes in Olympic National Park, in 2002–2003. Mercury was detected in trout from all of the sampled lakes. The highest fish tissue Hg concentration from MORA was 100 ppb, which did not exceed the human health threshold but did exceed wildlife health thresholds. Moran et al. (2007) also detected low concentrations of 2 organochlorine compounds in fish from all sampled lakes in MORA.

As part of the WACAP study (Landers et al. 2008), passive air sampling devices, snow, conifer needles, lichens, lake water, lake sediments, and fish from MORA were sampled in 2003–2005. All fish collected from the MORA lakes exceeded the Hg health threshold for fish-eating birds, and some exceeded the health threshold for humans. Landers et al. (2008) also detected a number of other PBTs in the MORA samples including current- and historic-use pesticides, combustion by-products, industrial chemicals and metals (Figure 11). Concentrations of flame retardant chemicals in fish from

Golden Lake were the highest detected in any of the WACAP parks. Dieldrin concentrations in 9 out of 20 MORA fish exceeded the human health threshold.

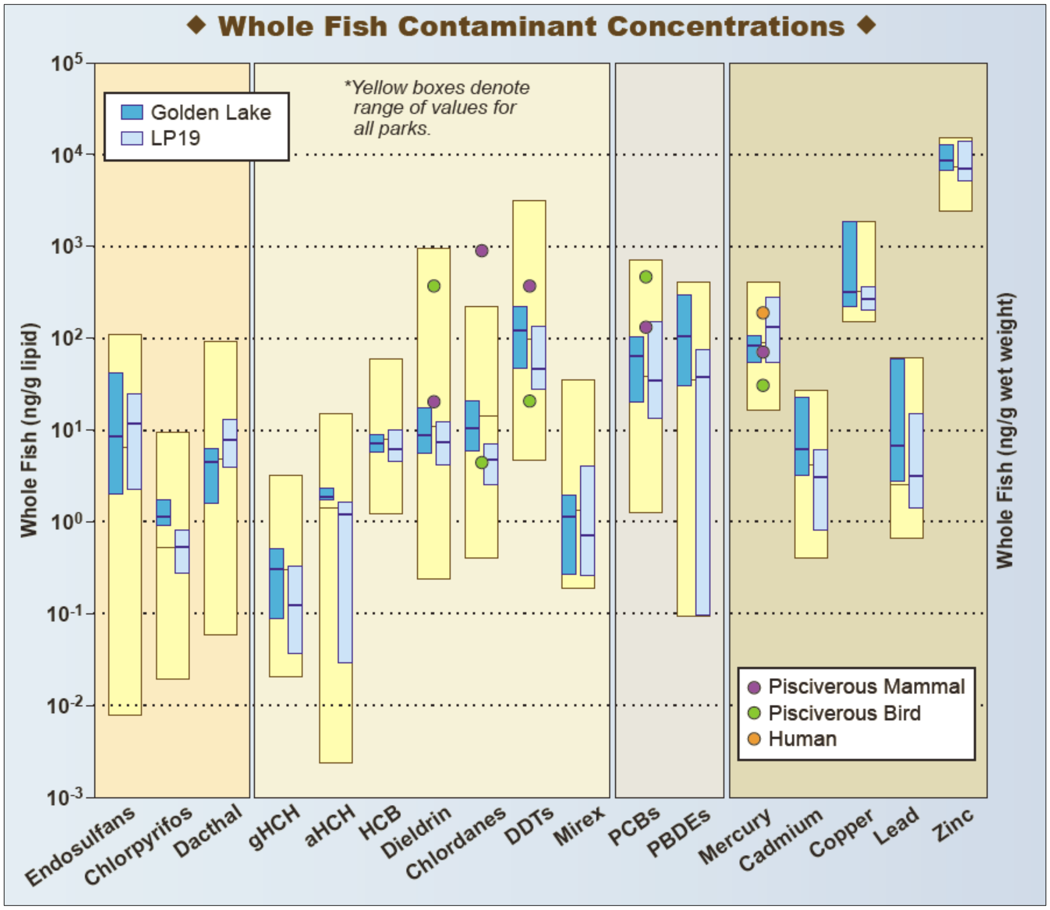

Figure 11. Concentrations of PBTs detected in fish collected from Golden Lake and Lake LP19 in Mount Rainier National Park in 2005 as part of the WACAP study (from Landers et al., 2008). Horizontal lines in boxes indicate median values. From left to right, pollutant categories represented by large shaded boxes are Current-Use Pesticides, Historic-Use Pesticides, Industrial Compounds, and Metals.

To enable a better spatial comparison of the fish samples collected from 21 western parks, Eagles-Smith et al. (2014) normalized Hg concentrations to control for the influence of size and species. Based on the normalized concentrations, fish were assigned to 1 of 3 size classes, i.e., 50 mm, 200 mm, or 400 mm. Results for the 200 mm size class at MORA showed the site with the highest average Hg concentration was nearly 23-fold higher than the site with the lowest average Hg concentration. Eagles-Smith (In prep.) found that Hg exposure in park invertebrates, fish, and amphibians varied among habitat types, and could be at toxicologically significant levels. Adams and others (2013) found that Hg levels at 4 of the park sample sites was higher than the highest sites in 2 other parks included in the study (Yosemite and Grand Teton National Parks), and that wet meadow habitat in the park had higher levels of mercury than wet meadows in the other parks. Mercury levels were highest in Varied Thrush, Hermit Thrush, Audubon's Warbler, and Pacific-slope Flycatcher, and significantly higher than Hg levels measured at the other parks. Given the detection of many PBTs in snow, sediment, and vegetation samples, and concentrations of Hg and other contaminants in fish samples that exceed human and wildlife health thresholds, MORA is in a condition of serious concern for PBTs.

4.1.5 Information and Data Needs–Gaps

Visibility

Each state was required to develop a Regional Haze Plan to improve visibility in Class I areas, with the goal of returning visibility to natural conditions by 2064 Washington's plan indicates it is not possible to achieve natural visibility conditions by 2064; the plan proposes a glide path to reach natural conditions at MORA by 2092. Visibility monitoring at MORA needs to continue so that NPS can track progress in achieving the goals of the Regional Haze Program. Campfire smoke monitoring should also be conducted in Cougar Rock and White River Campgrounds. In addition, sensitive vista points should be identified in the park that include views extending beyond NPS boundaries. For each of these vista points it would be beneficial to: (1) assess the existing and desired future conditions of the visual setting; and (2) prepare a visibility analysis including photo documentation and a description of the view, surrounding land use (existing and planned), the general level of visitor use, and importance to the visitor experience.

Nitrogen and Sulfur Deposition

The Cummings et al. (2014) report summarized N critical loads information applicable to the Pacific Northwest and identified and prioritized additional data needs. In order to improve critical load estimates for MORA, more information is needed about both the amount of deposition and the sensitivity of AQRVs. Most of the deposition data for the Pacific Northwest are from low elevation NADP monitors. There is a need for fine-scale estimates of total deposition in complex terrain, particularly at higher elevations. A NADP subcommittee is addressing the nationwide need for better total deposition estimates; they are producing new maps of total deposition and providing recommendations for improving existing datasets (NADP website 2014).

At present, there are only enough Pacific Northwest-specific AQRV data to establish critical loads for lichens. Current studies at MORA are investigating the effects of N deposition on soils, biogeochemical processes, and alpine and subalpine vegetation (Darlene Zabowski and Anna Simpson, University of Washington; Justin Poinsatte and David Evers, Washington State University). Results are expected in 2015. A 2013–2015 nutrient enrichment experiment (Jason Williams and Marc Beutel, Washington State University) is following up on the Sheibley et al. (2014) critical loads study to investigate phosphorus versus N limitation in park lakes, identify levels of N that cause changes in diatom species composition, and determine if there are phytoplankton species unique to high elevation Pacific Northwest lakes that may be indicators of nutrient enrichment effects.

Ozone

Given that ozone concentrations at MORA sometimes exceed the lower limit of the revised primary ozone standard proposed by EPA in 2010, ozone monitoring should continue at the park. The Tahoma Woods monitor was removed in 2013 due to a lack of funds. The Paradise monitor operated in cooperation with WDOE should continue because it is the only ozone monitor remaining in the park and represents the highest elevation site being monitored in the State of Washington.

PBTs

More information is needed about the amount of and trends in deposition of Hg and other PBTs at MORA. To better understand the extent of PBT occurrence and bioaccumulation, data should be collected from numerous locations throughout the park. Additional information is needed about wildlife health thresholds and sensitive life stages for a number of pesticides and other PBTs; at present, information is limited to a handful of chemicals and species. Studies to evaluate the risk of Hg methylation in different habitats and measurement of Hg concentrations in fish, amphibians, aquatic invertebrates, and songbirds should continue. Adams and others (2013) suggest that Hg monitoring of songbirds would be a reasonable way to develop a better understanding of the geographic regions, climates, and habitats that are at risk from Hg exposure. Eagles-Smith (In prep.) concludes that future alterations in wetland hydrology and structure associated with climate change could result in enhanced risk to some communities in the park. He recommends quantifying the landscape factors that influence Hg levels in aquatic and terrestrial indicator species, evaluating the potential effects of climate change on Hg availability and subsequent exposure in park wildlife, and investigating whether current wildlife exposure to Hg in the park is causing toxicological responses to sensitive hormones associated with endocrine disruption. By identifying areas in the park where Hg risk is greatest and assessing the important factors controlling Hg bioaccumulation managers will be able to target mitigation efforts in a more precise and efficient fashion.

Climate Change

It is critical to better understand the interaction between air pollution and climate change in the Pacific Northwest. It is not clear how climate change will affect air pollutant concentration and deposition in MORA. A recent comparison of 1993–2001 and 2003–2009 plot surveys indicates that increasing temperature and lower relative humidity have already changed Pacific Northwest lichen communities (Linda Geiser, USFS Air Program, unpubl. data). Changes in precipitation amount and timing could affect deposition and concentrations of S, N, and PBTs. Increased temperatures might change the rate of Hg methylation, resulting in increased bioaccumulation in fish and other species. Changes in agricultural practices in response to weather patterns or pests could result in additional pesticide deposition in the park. Increased summertime temperatures may lead to higher ozone levels (USEPA 2009).

Black carbon, a component of soot particles, contributes to global warming by absorbing sunlight, thereby heating the atmosphere. When black carbon is deposited on snow and ice, melting accelerates. Black carbon's effects are particularly strong in the Arctic and other alpine regions (USEPA 2012). A current study is measuring black carbon concentrations in snowpack and snowmelt at MORA (Susan Kaspari, Central Washington University). Further research is needed regarding the effects of black carbon on snowpack and glaciers in the park.

NPS ARD also provided specific recommendations for this condition assessment: (1) provide management direction that emphasizes cooperative conservation to protect air quality, scenic views and resources sensitive to air pollution; and (2) seek continued support for existing air quality monitoring through partnerships and cooperative efforts and a need to re-initiate monitoring that was discontinued in October 2013 due to budget shortfalls (i.e., ozone and dry deposition monitoring at Tahoma Woods).

4.1.6 Literature Cited

Adams, E., A. Jackson, and D. Evers. 2013. Songbirds as indicators of mercury in national park ecosystems: A preliminary evaluation of mercury availability in Yosemite, Grand Teton and Mount Rainier National Parks. Biodiversity Research Institute, Gorham, Maine.

Agren, J., C. Johnson, and A. M. Johansen. 2013. Precipitation chemistry at Mount Rainier (Paradise Ranger Station) collection site: Final Report for data collected between June 2, 2010 and June 1, 2011. Chemistry Department, Central Washington University, Ellensburg, Washington.

Air Resource Specialists. 2003. Addendum to the status of air quality and effects of atmospheric pollutants on ecosystems in the Pacific Northwest Region of the National Park Service. Report to the National Park Service, Air Resources Division, Denver, Colorado.

Campbell, S., G. Smith, P. Temple, J. Pronos, R. Rochefort, and C. Anderson. 2000. Monitoring for ozone injury in west coast (Oregon, Washington, California) forests in 1998. Gen. Tech. Rep. PNW-GTR-495.U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station, Portland, Oregon.

[CASTNET] Clean Air Status and Trends Network. 2014. CASTNET web site. http://www.epa.gov/castnet.

Clow, D. W., and D. H. Campbell. 2008. Atmospheric deposition and surface-water chemistry in Mount Rainier and North Cascades National Parks, U.S.A., water years 2000 and 2005–2006. Scientific Investigations Report 2008–5152. U.S. Geological Survey, Denver, Colorado.

Cummings, T. 2014. Air quality overview: Mount Rainier National Park. Natural Resource Report NPS/PWRO/NRR—2014/848. National Park Service, Fort Collins, Colorado.

Cummings, T., T. Blett, E. Porter, L. Geiser, R. Graw, J. McMurray, S. Perakis, and R. Rochefort. 2014. Thresholds for protecting Pacific Northwest ecosystems from atmospheric deposition of nitrogen: State of knowledge report. Natural Resource Report NPS/PWRO/NRR—2014/823. National Park Service, Fort Collins, Colorado.

Eagles-Smith, C. In prep. Mercury cycling and ecological risk across habitats in Mount Rainier National Park.

Eagles-Smith, C. A., J. J. Willacker, and C. M. Flanagan Pritz. 2014. Mercury in fishes from 21 national parks in the western United States – inter and intra-park variation in concentrations and ecological risk. U.S. Geological Survey Open File Report 2014-1051.

Eilers, J. M., C. L. Rose, and T. J. Sullivan. 1994. Status of air quality and effects of atmospheric pollutants on ecosystems in the Pacific Northwest Region of the National Park Service. National Park Service, Air Resources Division, Denver, Colorado.

Fenn, M. E., C. S. Ross, S. L. Schilling, W. D. Baccus, M. A. Larrabee, and R. A. Lofgren. 2013. Atmospheric deposition of nitrogen and sulfur and preferential canopy consumption of nitrate in forests of the Pacific Northwest, USA. Forest Ecology and Management 302:240–253.

Geiser, L. H., S. E. Jovan, D. A. Glavich, and M. K. Porter. 2010. Lichen-based critical loads for atmospheric nitrogen deposition in western Oregon and Washington forests, USA. Environmental Pollution 158:2412–2421.

Greaver, T. L., T. J. Sullivan, J. D. Herrick, M. C. Barber, J. S. Baron, B. J. Cosby, M. E. Deerhake, R. L. Dennis, J. B. Dubois, C. L. Goodale, A. T. Herlihy, G. B. Lawrence, L. Liu, J. A. Lynch, and K. J. Novak. 2012. Ecological effects of nitrogen and sulfur air pollution in the US: What do we know? Frontiers in Ecology and the Environment 10:365–372.

Hageman, K. J., W. D. Hafner, D. H. Campbell, D. A. Jaffe, D. H. Landers, and S. L. Massey Simonich. 2010. Variability in pesticide deposition and source contributions to snowpack in western U.S. national parks. Environmental Science and Technology 44:4452–458.

Hand, J. , S. A. Copeland, D. E. Day, A. M. Dillner, H. Indresand, W. C. Malm, C. E. McDade, C. T. Moore, M. L. Pitchford, B. A. Schichtel, and J. G. Watson. 2011. Spatial and seasonal patterns and temporal variability of haze and its constituents in the United States. Report V. ISSN 0737-5352-87. Cooperative Institute for Research in the Environment, Colorado State University. Fort Collins, Colorado.

[IMPROVE] Interagency Monitoring of Protected Visual Environments. 2014. IMPROVE website: http://vista.cira.colostate.edu/improve.

Johnson, J., and R. A. Lofgren. In prep. Ohanapecosh Campground smoke 2013. Internal National Park Service report. Mount Rainier National Park, Ashford, Washington.

Kohut, R. 2004. Assessing the risk of foliar injury from ozone on vegetation in parks in the North Coast and Cascades Network. Available at http://www.nature.nps.gov air/Pubs/pdf/03Risk/nccnO3RiskOct04.pdf.

Landers, D. H., S. L. Simonich, D. A. Jaffe, L. H. Geiser, D. H. Campbell, A. R. Schwindt, C. B. Schreck, M. L. Kent, W. D. Hafner, H. E. Taylor, K. J. Hageman, S. Usenko, L. K. Ackerman, J. E. Schrlau, N. L. Rose, T. F. Blett, and M. M. Erway. 2008. The fate, transport, and ecological impacts of airborne contaminants in western national parks (USA). EPA/600/R-07/138. U.S. Environmental Protection Agency, Office of Research and Development, NHEERL, Western Ecology Division, Corvallis, Oregon.

Lofgren, R., and B. A. Samora. 2010. Campfire wood smoke impacts in campgrounds at Mount Rainier National Park. Internal National Park Service report. Mount Rainier National Park, Ashford, Washington.

Moran, P. W., N. Aluru, R. W. Black, and M. M. Vijayan. 2007. Tissue contaminants and associated transcriptional response in trout liver from high elevation lakes of Washington. Environmental Science and Technology 41:6591–6597.

[NADP] National Atmospheric Deposition Program. 2014. NADP web site: http://nadp.sws.uiuc.edu.

[NPS] National Park Service. 2013a. Air quality in national parks: Trends (2000–2009) and conditions (2005–2009). Natural Resource Report NPS/NRSS/ARD/NRR—2013/683. Air Resources Division, National Park Service, Denver, Colorado.

[NPS] National Park Service. 2013b. Scenic resources briefing paper. Mount Rainier National Park. Natural Resource Stewardship and Science, Air Resources Division. August, 2013.

[NPS] National Park Service. 2014. Air Resources Division website: http://www.nature.nps.gov/air/monitoring/index.cfm.

National Research Council. 2009. Global sources of local pollution: an assessment of long-range transport of key air pollutants to and from the United States. The National Academies Press, Washington, D.C.

Pardo, L. H., M. J. Robin-Abbott, and C. T. Driscoll, editors. 2011. Assessment of nitrogen deposition effects and empirical critical loads of nitrogen for ecoregions of the United States. Gen. Tech. Rep. NRS-80. U.S. Department of Agriculture, Forest Service, Northern Research Station, Newtown Square, Pennsylvania.

Sheibley, R. W., M. Enache, P. W. Swarzenski, P. W. Moran, and J. R. Foreman. 2014. Nitrogen deposition effects on diatom communities in lakes from 3 national parks in Washington state. Water, Air and Soil Pollution 225:1857.

Sullivan, T. J., T. C. McDonnell, G. T. McPerson, S. D. Mackey, and D. Moore. 2011a. Evaluation of the sensitivity of inventory and monitoring national parks to nutrient enrichment effects from atmospheric nitrogen deposition. Main report. Natural Resource Report NPS/NRPC/ARD/NRR—2011/313. National Park Service, Denver, Colorado.

Sullivan, T. J., G. T. McPherson, T. C. McDonnell, S. D. Mackey, and D. Moore. 2011b. Evaluation of the sensitivity of inventory and monitoring national parks to acidification effects from atmospheric sulfur and nitrogen deposition: main report. Natural Resource Report NPS/NRPC/ARD/NRR—2011/349. National Park Service, Denver, Colorado.

Sullivan, T. J., T. C. McDonnell, G. T. McPerson, S. D. Mackey, and D. Moore. 2011c. Evaluation of the sensitivity of inventory and monitoring national parks to nutrient enrichment effects from atmospheric nitrogen deposition. North Coast and Cascades Network (NCCN). Natural Resource Report NPS/NRPC/ARD/NRR—2011/319. National Park Service, Denver, Colorado.

Sullivan, T. J., T. C. McDonnell, G. T. McPerson, S. D. Mackey, and D. Moore. 2011d. Evaluation of the sensitivity of inventory and monitoring national parks to acidification effects from atmospheric sulfur and nitrogen deposition. North Coast and Cascades Network (NCCN). Natural Resource Report NPS/NRPC/ARD/NRR—2011/365. National Park Service, Denver, Colorado.

[USEPA] U.S. Environmental Protection Agency. 2009. Assessment of the impacts of global change on regional U.S. air quality: A synthesis of climate change impacts on ground-level ozone. An Interim Report of the U.S. EPA Global Change Research Program. National Center for Environmental Assessment, Washington, DC; EPA/600/R-07/094F. Available from the National Technical Information Service, Springfield, Virginia.

[USEPA] U.S. Environmental Protection Agency. 2012. Our nation's air: Status and trends through 2010. EPA-454/R-12-001. Office of Air Quality Planning and Standards, Research Triangle Park, North Carolina.

[USEPA] U.S. Environmental Protection Agency. 2013. Integrated science assessment of ozone and related photochemical oxidants (final report). EPA/600/R-10/076F. Washington, D.C.

[WDOE] Washington Department of Ecology. 2014. Air Emissions Inventory website: http://www.ecy.wa.gov/programs/air/EmissionInventory/AirEmissionInventory.html.

4.2 Lake Water Quality

(Robert L. Hoffman, USGS FRESC)

4.2.1 Introduction

Lakes are prominent features of many montane landscapes. Functioning as downstream catchment basins, they integrate many of the properties and characteristics of their surrounding watersheds and are influenced by varying conditions of the local and regional environment (Larson et al. 1994, 1999, Allan and Johnson 1997, Kling et al. 2000). Lakes, therefore, can be useful indicators of ecosystem stability or change at the local and landscape level. The physical, chemical, and biological characteristics of lakes (water quality) can be affected by natural disturbances such as fires, catchment vegetation succession, increases in inputs of sediment and detritus, and species invasions. They also can be susceptible to disturbances of human origin including atmospheric deposition of nutrients and pesticides (Carpenter et al. 1998); the presence or introduction of invasive aquatic biota (Boersma et al. 2006); climate change (McKnight et al. 1996, Williams et al. 1996, Murdoch et al. 2000); and other anthropogenic stressors such as timber harvest, road building, livestock grazing, and recreational activities (Schindler 1987, Spencer 1991).

Documenting and monitoring the status and trends in the water quality of lakes in protected landscapes such as wilderness areas and national parks is important because these landscapes often comprise ecosystems least affected and modified by anthropogenic disturbances (Cole and Landres 1996). Since 1988, Mount Rainier National Park (MORA) resource management personnel have inventoried lakes, sampled, and monitored the water quality of many lakes within the park, and have recently implemented the monitoring of 6 MORA lakes as part of a North Coast and Cascades Network program for the long-term monitoring of mountain lakes in parks of the network (Glesne et al. 2012.). There have been 406 lakes inventoried in MORA. Of these, we grouped 404 lakes based on their area and elevation (Table 6). Most of these lakes (88%) could be placed into 2 groups of small lakes (Group 1: $\bar{x}$ = 0.33 ha, n = 205; Group 2: $\bar{x}$ = 0.35 ha, n = 150) that occur at average elevations of 1546 (Group 1) and 1820 m (Group 2). When grouped by depth, 80% of 235 lakes with reliable depth data (Table 6) have an average maximum depth of 1.5 m. MORA lakes, based on these results, can be generally characterized as being relatively small and shallow.

Table 6. Area, elevation, and maximum depth of listed lakes, Mount Rainier National Park, Washington.

Parameters	*n*	Mean	Mode	Range
Area (ha)	404	0.7	0.03	0.0004 – 45.4
Elevation (m)	404	1611	1459	670 – 2510
Maximum depth (m)	235	3.8	1.0	0.05 – 60.0

The primary objectives of this lake water quality assessment are to: (1) estimate the overall general trophic status of MORA lakes; (2) determine average concentrations of cations, anions, alkalinity, conductivity, pH, and dissolved oxygen; and (3) describe the relative distributions of zooplankton and macroinvertebrates that inhabit MORA lakes. In addition, the water quality of Ethel Lake will be examined, and the results of recent reports concerning potential impacts of atmospheric deposition on 2 MORA lakes, and lake ice-out will be summarized. The results reported in Rawhouser et al.

(2012:Appendix D) for MORA lakes of management concern ranked relative to their potential level of risk to impairment will also be summarized.

4.2.2 Approach

Trophic Status

A database containing concentrations of chlorophyll *a* (CHLA µg/L), total nitrogen (TN mg/L), and total phosphorus (TP µg/L) was created for lakes sampled June–September, 1988 through 2009 (n = 139; Figure 12). The database comprised 208 CHLA measurements (representing 48 lakes); 385 TN measurements (137 lakes); and 390 TP measurements (137 lakes). Descriptive statistics (mean, standard deviation, median, and range) were determined for each parameter. Nitrogen-phosphorus ratios were also calculated for 136 lakes. CHLA, TP, and TN concentrations of 8 lakes sampled during the month of August for 8 to 18 yrs (1988–2009) were analyzed to illustrate trends for each parameter (Trend lakes in Figure 12).

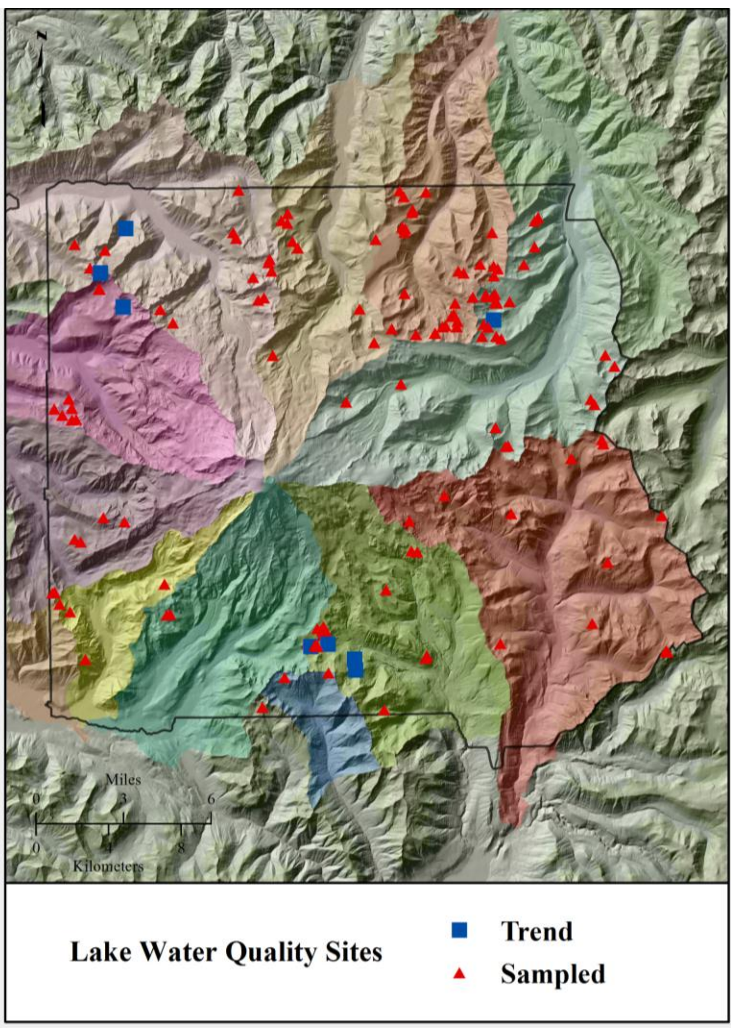

Figure 12. Distribution of MORA lakes sampled 1988–2009 (Colors in this figure represent 6th field HUC 13 MORA watershed boundaries; see Figure 13, 4.3.1, for watershed names and their associated colors).

Cations and Anions

A database containing the concentrations (μeq/L) of 5 cations (Ca^{2+}, K^+, Mg^{2+}, Na^+, NH_4^+) and 3 anions (Cl^-, NO_3^-, SO_4^{2-}) was created for lakes sampled June–September, 1988 through 2008. The database comprised 242 to 348 measurements completed during the sampling period 1988–2008 and representing 92 to 118 lakes, with the number of measurements and lakes varying by parameter. Descriptive statistics (mean, standard deviation, median, and range) were determined for each parameter in 2 categories: near lake surface and near lake bottom. Cation and anion concentrations of 8 lakes sampled during the month of August for 4 to 15 yrs (1988–2008) were analyzed to illustrate trends for each parameter.

Alkalinity, Conductivity, pH, and Dissolved Oxygen

A database was created for measurements of alkalinity (ALKA, μeq/L), conductivity (COND, μS/cm), pH, and dissolved oxygen (DO, mg/L) for lakes sampled predominantly in August, 1988–2001. Descriptive statistics were determined for near surface and near bottom measurements for each parameter. The database comprised 30 to 45 near surface measurements representing 21 to 27 lakes; and 28 to 45 near bottom measurements representing 21 to 24 lakes.

Zooplankton and Macroinvertebrates

Analysis of zooplankton species occurrence and distribution was based on summaries of the results of Larson et al. (2009) and the 2009 Field Season Report for North Coast and Cascades Network core mountain lake study sites (Fradkin et al. 2012). Analysis of macroinvertebrates was based on interpretation of species occurrence and distribution in 24 MORA lakes sampled in 2004 and 2007.

Additional Assessments

Clow and Campbell (2008) was used to summarize potential impacts of atmospheric deposition on MORA lakes. Ethel Lake water chemistry was examined to determine if the lake is an outlier relative to other MORA lakes. An unpublished 2011 MORA draft report on lake water temperatures was used to summarize the ice-out characteristics of MORA lakes. Resuts of the ranking of lakes of management concern in Appendix D of the NCCN Water Quality Monitoring Protocol (Rawhouser et al. 2012) were summarized to elucidate the potential level of risk of MORA lakes to impairment.

4.2.3 Reference Conditions and Comparison Metrics

Trophic Status

The trophic status of a lake is defined as “the total weight of living biological material (biomass) in a waterbody at a specific location and time” (Carlson and Simpson 1996), and is indicative of the biological productivity of the waterbody. Carlson (1977) created a trophic state index (TSI) for lakes, which is typically calculated using water clarity as determined by Secchi disk depth, and concentrations of CHLA and TP. Kratzer and Brezonik (1981) also developed a TSI for TN. Trophic classes associated with the index include oligotrophic (low productivity), mesotrophic (intermediate productivity), eutrophic (high productivity), and hypereutrophic (very high productivity). The estimated trophic status of MORA lakes was assessed by comparing the concentrations of CHLA, TP, and TN with concentrations determined for 30 Washington lakes as part of a collaborative national lakes assessment (Bell-McKinnon 2010). It is important to note that the Bell-McKinnon lakes sample was limited to 30 lakes within the State and none of the lakes sampled were within the Cascades Ecoregion where MORA is located; most of the lakes in that study were located in lower elevation areas. Nitrogen and phosphorus limitation in MORA lakes were assessed using the ratio of the concentrations of dissolved inorganic nitrogen (DIN: nitrate-nitrite + ammonia) to total dissolved phosphorus (DTP; Morris and Lewis 1988, Sickman et al. 2003, McMaster and Schindler 2005, Bergström 2010, Murphy et al. 2010). According to Morris and Lewis (1988), DIN:DTP is 1 of 2 best indices for estimating nitrogen and phosphorus limitation in lakes because DIN and DTP represent the fractions of N and P most available to phytoplankton. Lakes with a ratio of <1 were classified as nitrogen limited; lakes with a ratio of >4 were classified as phosphorus limited; and lakes with a ratio of 1 to 4 were classified as co-limited (i.e., either nitrogen or phosphorus limited or both; Murphy et al. 2010).

Cations and Anions

The chemical composition of lake water is fundamentally a function of climate and basin geology. This composition comprises, in part, 5 major cations (Ca^{2+}, K^{+}, Mg^{2+}, Na^{+}, NH_4^{+}) and 3 major anions (Cl^{-}, NO_3^{-}, SO_4^{2-}), which are essential for the occurrence and persistence of lake biota. Concentrations of these ions in a lake are generally the result of watershed soil erosion and weathering, atmospheric deposition, and the geological composition of the lake basin. As such, the concentrations of ions can be relatively good predictors of the level of natural and human-caused disturbance within a lake watershed or of potential causes of perturbation (such as atmospheric deposition of pollutants) from more remote locations. The assessment of cation and anion concentrations in MORA lakes was accomplished by comparing them to concentrations reported by Bell-McKinnon (2010) and Clow et al. (2002).

Alkalinity, Conductivity, pH, and Dissolved Oxygen

Alkalinity, conductivity, pH, and dissolved oxygen are also important constituents of lake water quality and useful indicators of lake condition and health. Their assessment was accomplished by comparing the August, 1988–2001 results with results reported in Turney et al. (1986; COND, pH, DO), Larson et al. (1994; ALKA, pH), and Clow et al. (2002; ALKA, COND, pH).

Zooplankton and Macroinvertebrates

Zooplankton and macroinvertebrate species and assemblages are known to be useful predictors of water quality impairment (Reynoldson et al. 1997), and the biological integrity (Hawkins et al. 2000, Hawkins and Carlisle 2001) and ecological quality (Clarke et al. 2003) of freshwater ecosystems. Zooplankton condition was based on 2 past assessments of zooplankton assemblages in up to 103 MORA lakes by Larson et al. (1999, 2009), and a recent NPS report (Fradkin et al. 2012) on zooplankton assemblages in 6 MORA lakes that are part of the North Coast and Cascades Network Mountain Lake Monitoring Protocol. The assessment of macroinvertebrates was accomplished using comparisons with other studies such as Hoffman et al. (1996), Lafrancois et al. (2003), Füreder et al. (2006), and Oertli et al. (2008).

Lakes of Management Concern

As part of the development of the NCCN Water Quality Monitoring Protocol (Rawhouser et al. 2012), a ranking process was developed to estimate the level of risk of MORA lakes <50 ha (<124 ac) to impairment. Initially, a list of lakes of management concern was created based on professional opinion as well as any lakes that were 303d listed under the Clean Water Act (CWA). The ranking metrics were: (1) waters classified as impaired (Category 4, 4a, 4b or 5) from the 303(d) report that are within or drain into MORA (Rawhouser et al. 2012, Table 1.12, p. 26); (2) streams that drain from watersheds classified as being at a high risk of impairment during the watershed assessment (Rawhouser et al. 2012, p. 23–24); (3) waters ranked at a high risk level in the informed risk assessment (Rawhouser et al. 2012, Table 1.24, p. 43); and (4) water bodies within MORA that receive water from any of the above sources, even if those sources are outside park boundaries.

4.2.4 Results and Assessment

Trophic Status

Trophic state class concentration thresholds for CHLA, TN, and TP (Table 7) were used to assign MORA lakes sampled at least once between 1988 and 2009 to 1 to 4 trophic state classes. Based on concentrations of CHLA and TN, MORA lakes can be classified predominantly as oligotrophic (CHLA = 96% of lakes sampled; TN = 86%), and as oligotrophic–mesotrophic (59 and 34%, respectively) based on TP concentrations (Table 8). Compared to values for the 3 indices calculated for the 30 non-MORA Washington lakes (Bell-Mckinnon 2010), the mean concentration of CHLA in MORA lakes is 15 times lower than the mean concentration of CHLA in the non-MORA lakes; 3 times lower for TN; and 2 times lower for TP (Table 9). This result indicates that MORA lakes, in general, are relatively low in productivity compared to the 30 non-MORA lakes. Of the MORA lakes analyzed using their CHLA concentrations, 58% were relatively larger-deeper lakes (n = 28; mean area = 5.5 ha; mean maximum depth = 15.1 m) and 42% were relatively smaller-shallow lakes (n = 20; mean area = 0.4 ha; mean maximum depth = 1.5 m). Only 2 MORA lakes could be classified as mesotrophic ($\bar{x}$ = 3.2 μg/L, range: 2.3–4.8 μg/L) based on their CHLA concentrations (Table 8), indicating a somewhat increased level of algal productivity in these lakes. No lakes were classified as eutrophic or hypereutrophic. This is a relatively important result because CHLA concentration is considered to be a better predictor of algal biomass, and by proxy productivity, than TN or TP (Carlson and Simpson 1996). Four lakes could be classified as eutrophic based on their TN concentrations ($\bar{x}$ = 0.81 mg/L, range: 0.76–0.89 mg/L) (Table 8). These lakes were small and shallow ($\bar{x}$ surface area: 0.08 ha; maximum depth: < 1 m). Ten MORA lakes were classified as eutrophic (n = 8) or hypereutrophic (n = 2) based on their TP concentrations (Table 8). The mean TP concentration for the eutrophic lakes was 52 μg/L (range: 33–99 μg/L), and 116 μg/L (range: 113–119 μg/L) for the hypereutrophic lakes. These lakes were also small and shallow ($\bar{x}$ surface area: 0.1 ha; maximum depth: <1.5 m).

The condition of MORA lakes could also be assessed using 3 condition classes for concentration thresholds of CHLA, TN, and TP determined for lakes in the Western Mountains Nutrient Ecosystem (Bell-McKinnon 2010:Table 2). The results of this assessment are reported in Table 10. Based on CHLA concentrations, 96% of the MORA lakes analyzed were determined to be in Good condition; 77% of the analyzed lakes were determined to be in Good condition based on TN concentrations; and 79% of the analyzed lakes were determined to be Good condition based on TP concentration.

Lake productivity can also be expressed as the ratio of nitrogen and phosphorus concentrations (N/P) in lake water samples. Nitrogen and phosphorus are necessary elements that promote and support algal growth, and each can be limiting. A limiting element is one that is present in a waterbody, but at quantities insufficient for promoting continued or expansive algal growth. Once a limiting element is exhausted, algal growth ceases; however, algal growth and expansion would resume if additional amounts of the limiting element were added to the waterbody. Of 127 MORA lakes for which DIN:DTP ratios were calculated, 58 (46%) were determined to be nitrogen limited ($\bar{x}$ ratio: 0.5; range: 0–0.9); 8 (6%) were phosphorus limited ($\bar{x}$ ratio: 7.8; range: 4.3–14.5); and 61 (48%) were co-limited ($\bar{x}$ ratio: 1.9; range: 1.0–3.8).

Trends in the concentrations of CHLA, TP, and TN (1988–2009) were examined for 8 MORA lakes (Table 11). These lakes were selected because they had 8 to 18 yrs of data for August samples. August was selected as the month for analysis because lake productivity is relatively well established in MORA lakes during August. Focusing on a single month also limited potential confounding effects of intra-seasonal variation. All of the lakes, based on trophic state thresholds for each parameter, were determined to be oligotrophic. There were no significant trends for each parameter in 3 of the lakes (LM01, LW20, and LZ27); a significant positive trend for TN was determined for 2 lakes (LC07, LM04); a significant negative trend for TP was determined for 2 lakes (LN19, LZ29); and 1 lake (LZ21) showed a significant positive trend for TN and a significant negative trend for TP. The mean concentrations for TP and TN in these lakes were from 2 to 3 and 8 to 12 times lower than the oligotrophic threshold maximum for each parameter, respectively, indicating that the changes in TP and TN in the lakes were relatively minimal over the 8 to 18 yrs of data. There was no significant trend for CHLA in any of the lakes, and the mean concentrations for CHLA in the lakes were 6 to 15 times lower than the oligotrophic threshold maximum for this parameter.

Table 7. Index thresholds for trophic state classes.

Trophic State	**Chlorophyll *a* (µg/L)**	**Total Nitrogen (mg/L)**	**Total Phosphorus (µg/L)**
Oligotrophic	<2	<0.35	<10
Mesotrophic	2 – <7	0.35 – <0.75	10 – <25
Eutrophic	7 – <30	0.75 – <1.4	25 – <100
Hypereutrophic	≥30	≥1.4	≥100

Table 8. Number of MORA lakes in each of 4 lake trophic classes based on measurements for chlorophyll *a* (CHLA), total nitrogen (TN), and total phosphorus (TP) concentrations (1988–2009).

Class	**CHLA (*n* = 48)**	**TN (*n* = 137)**	**TP (*n* = 137)**
Oligotrophic	46	118	81
Mesotrophic	2	15	46
Eutrophic		4	8
Hypereutrophic			2

Table 9. Descriptive statistics: concentrations of chlorophyll a (µg/L), total nitrogen (mg/L), and total phosphorus (µg/L) in MORA lakes, 1988–2009, and Washington (WA) lakes, 2007[a].

Parameter	Metric	MORA Lakes	WA Lakes
chlorophyll a	*n* lakes	48 (208[b])	30
	$\bar{x}$ (SD)	0.39 (0.53)	5.86 (6.1)
	median	0.21	1.91
	minimum	0.005	0.15
	maximum	4.78	26.08
total nitrogen	*n* lakes	137 (385[b])	30
	$\bar{x}$ (SD)	0.12 (0.15)	0.41 (0.38)
	median	0.07	0.21
	minimum	0	0.03
	maximum	1.24	2.62
total phosphorus	*n* lakes	137 (390[b])	30
	$\bar{x}$ (SD)	8.5 (14.7)	18.4 (25.02)
	median	5	7
	minimum	0	1
	maximum	195	190

[a] Bell-McKinnon, Maggie. 2010. An assessment of Washington lakes – National Lake Assessment Results. Department of Ecology, State of Washington, Publication No. 10-03-029. 57 p.

[b] Number of measurements

Table 10. Number of MORA lakes in each of 3 condition class thresholds for chlorophyll-a (CHLA µg/L), total nitrogen (TN mg/L), and total phosphorus (TP µg/L). Thresholds[1] are based on values determined for the Western Mountains Nutrient Ecoregion and reported in Table 2 of Bell-Mckinnon (2010).

Parameter	*n*	Good	Fair	Poor
CHLA	48	46	1	1
TN	137	105	15	17
TP	137	108	11	17

[1]CHLA: Good = <1.8, Fair = 1.8–2.7, Poor = >2.7; TN: Good = <0.27, Fair = 0.27–0.38, Poor = >0.38; TP: Good = <15, Fair = 15–19, Poor = >19.

Table 11. August values for chlorophyll *a* (CHLA – µg/L), total phosphorus (TP – µg/L), and total nitrogen (TN – mg/L) for 8 MORA lakes sampled for 8 to 18 yrs, 1988–2009. Oligotrophic threshold maximums: CHLA < 2.0 µg/L; TP < 10 µg/L; TN < 0.35 mg/L. * = Regression returned significant result.

Lake	Index	Years Sampled	Mean	Mode	Range	Overall Change
LC07 (Green)	CHLA	12	0.153	0.055	0.055 – 0.365	
	TP	13	3.5		0 – 7	
	TN *	13	0.041	0.03	0.02 – 0.09	+0.06
LM01 (Eunice)	CHLA	9	0.128	0.075	0.075 – 0.188	
	TP	10	2.1	0.0	0 – 6	
	TN	10	0.042		0.02 – 0.06	
LM04 (Mowich)	CHLA	15	0.218	0.005	0.005 – 0.825	
	TP	18	3.3		0 – 5	
	TN *	18	0.035	0.03	0.018 – 0.06	+0.012
LN19 (Reflection)	CHLA	10	0.360	0.058	0.058 – 0.993	
	TP *	11	4.8	5	0 – 9	–5
	TN	11	0.061		0.03 – 0.09	
LW20 (Clover)	CHLA	8	0.153	0.017	0.017 – 0.325	
	TP	8	4.1	3.0	3 – 6	
	TN	8	0.054	0.04	0.04 – 0.08	
LZ21 (Louise)	CHLA	9	0.239	0.021	0.021 – 0.745	
	TP *	11	3.0	3.0	0 – 9	–6
	TN *	11	0.028	0.03	0.015 – 0.04	+0.025
LZ27 (Bench)	CHLA	8	0.302	0.136	0.136 – 0.8	
	TP	9	4.3	3.0	0 – 7	
	TN	9	0.083	0.08	0.05 – 0.11	
LZ29 (Snow)	CHLA	9	0.324	0.058	0.058 – 1.12	
	TP *	10	4.8		0 – 13	–6
	TN	10	0.021	0.02	0.01 – 0.03	

Cations and Anions

Near surface and near bottom mean concentrations of cations and anions were calculated for between 92 and 118 MORA lakes (depending on ion) sampled at least once, June–September, 1988 through 2008, and compared to mean concentrations calculated for 30 non-MORA Washington lakes (Bell-McKinnon 2010) (Table 12). The near surface mean values for all ions except NH_4^+ in MORA lakes were from 4 to 40 times lower (depending on ion) than mean concentrations for ion concentrations in the non-MORA lakes; the mean values for NH_4^+ in MORA and non-MORA lakes were similar. Similar results were determined for near bottom samples. When compared to mean ion concentrations in 6 national parks in the western United States (Clow et al. 2002), MORA lake near surface and near bottom mean concentrations were within the range of values for lakes sampled in the other parks: (1) K^+, NH_4^+, and NO_3^- mean concentrations in MORA lakes were similar to the other park mean concentrations; (2) SO_4^{2-} was in the lower range of values; and (3) MORA lakes Ca^{2+}, Mg^{2+}, Na^+, and Cl^- mean concentrations were within the mid-range of mean values determined for the other parks (Table 12).

Trends in the concentrations of cations and anions were examined for August samples of 8 MORA lakes (Table 13). No significant trends were determined for Mg^{2+}, NH_4^+, and NO_3^-, and no significant trends were calculated for any of the ions in the near surface samples of 2 lakes (LM01, LZ27). There was a significant negative trend for Cl^- in LN19; the trend for K^+ was negative in LW20 and positive in LZ21; the trend for Na^+ was positive in LC07, LM04, LN19, LZ21, and LZ29; the trend for Ca^{2+} was positive in LM04, LZ21, and LZ29; and the trend for SO_4^{2-} was positive in LN19 and LZ21. Significant trends in near bottom samples were limited, with Na^+ positive in LC07 and LM04, and Cl^- positive in LZ21. Determination of the potential reasons for these trends was beyond the scope of this assessment. Although there were significant trends for 5 of the ions, the highest concentrations recorded for each ion in MORA lakes where a significant trend was determined were much lower than the mean concentrations calculated for the 30 non-MORA lakes, and well within the range of median concentrations for the 6 national parks (Table 14).

Alkalinity, Conductivity, pH, and Dissolved Oxygen

Near surface and near bottom mean values for ALKA, COND, and pH of 21 to 27 MORA lakes (depending on parameter) sampled at least one time, predominantly in August, 1988–2001 (Table 15), were compared to mean values of 13 MORA lakes sampled in 1983 (Turney et al. 1986), 23 to 27 MORA lakes sampled in 1988 (Larson et al. 1994), and mean values determined by Clow et al. (2002) for 6 national parks in the western United States. Mean values for each parameter were each similar among the 3 groups of MORA lake samples: (1) ALKA ranged from 122 to 141.8 μeq/L; (2) COND ranged from 15.5 to 22.9 μS/cm; and (3) pH increased from 6.3 in 1983 to 6.7–7.0 in the 1988–2001 samples (Table 13). All MORA lake ALKA and COND mean values were within the mid-range of mean values calculated for the other 6 western U.S national parks; pH was circum-neutral ranging from 6.3 to 7.4 (Table 15).

Near surface and near bottom mean concentrations of DO in 24 to 27 MORA lakes sampled at least 1 time, predominantly in August, 1988–2001, were compared to mean concentrations in 13 MORA lakes sampled in 1983 (Table 15). The mean values were similar and ranged from 7.2 to 8.3 mg/L. Lowest minimum concentrations (1.8 and 2.2 mg/L) occurred in near bottom samples for both groups of lakes.

Table 12. Descriptive statistics: near surface (ns) and near bottom (nb) concentrations of cations and anions (μeq/L) in Mount Rainier National Park lakes (1988–2008), Washington (WA) lakes (2007)[a], and 6 national parks[b] in the western United States sampled in the fall of 1999.

Ion	Metric	MORA ns (1988–2008)	MORA nb (1988–2008)	WA (2007)	GLAC	LAVO	ROMO	SEKI	YELL	YOSE
Ca^{2+}	*n* lakes	110 (332[c])	110 (332[c])	30	4	7	22	20	6	9
	$\bar{x}$ (SD)	69.9 (65.1)	90.8 (70.9)	373.3 (392.7)	307.6	26.2	67.3	57.8	453.2	29.1
	median	48.9	78.8	184.6	239.3	10.4	62.3	55.4	319.8	26.9
	range	0.96–432.6	12.0 – 430.6	27–1785	26.4–725.5	5.9–82.8	28.4–140.2	11.4–177.1	99.8–1196.6	6.4–61.8
K^{+}	*n* lakes	110 (333[c])	110 (333[c])	30	4	7	22	20	6	9
	$\bar{x}$ (SD)	4.6 (5.4)	3.9 (3.1)	43 (216.9)	3.0	4.4	3.6	3.3	203.8	3.7
	median	2.8	3.1	10	3.0	4.4	3.1	3.0	47.5	2.8
	range	0–48.4	1.2 – 19.7	2.6–2034.4	2.2–3.7	1.5–8.9	2.0–8.4	1.8–6.4	4.1–908.6	2.2–8.4
Mg^{2+}	*n* lakes	110 (333[c])	110 (333[c])	30	4	7	22	20	6	9
	$\bar{x}$ (SD)	14.9 (13.01)	18.6 (15.8)	321.7 (497)	157.5	20.4	16.9	5.5	135.6	4.8
	median	12.4	15.6	101.2	129.6	15.6	15.6	3.7	74.0	4.1
	range	0–101.6	5.6 – 96.9	74.9–2893.2	20.5–350.5	5.7–56.7	8.2–46.9	1.6–13.9	26.3–428.7	1.6–9.8
Na^{+}	*n* lakes	110 (333[c])	110 (333[c])	30	4	7	22	20	6	9
	$\bar{x}$ (SD)	30.8 (23.5)	35.4 (32.2)	603.3 (3720)	10.4	15.1	25.9	19.2	301.4	17.6
	median	28.01	27.4	114	10.5	8.4	10.5	19.4	110.3	16.4
	range	2.7 – 264.9	13.1 – 250.1	35.2 – 34654	4.2–16.6	6.7–36.4	7.9–97.3	4.3–48.2	11.7–925.6	6.3–27.5
NH_4^{+}	*n* lakes	118 (348[c])	118 (348[c])	30	4	7	22	20	6	9
	$\bar{x}$ (SD)	0.85 (2.09)	0.97 (1.5)	0.55 (1.11)	≤0.5	0.6	≤0.5	0.6	0.7	≤0.5
	median	0.43	0.57	0.55	≤0.5	≤0.5	≤0.5	≤0.5	≤0.5	≤0.5
	range	0 – 23.9	0 – 10.8	0.55 – 3.9	≤0.5–1.1	≤0.5–1.8	≤0.5–3.9	≤0.5–4.2	≤0.5–2.4	≤0.5–4.0
Cl^{-}	*n* lakes	92 (242[c])	92 (242[c])	30	4	7	22	20	6	9
	$\bar{x}$ (SD)	12.4 (5.8)	13.9 (5.02)	226.8 (1052.4)	1.8	2.5	2.2	1.9	403.6	1.7
	median	12.1	13.6	54.4	1.7	2.6	1.9	1.4	16.8	1.7
	range	1.1 – 41.7	3.7 – 26.8	10.7 – 9787.9	1.0–2.8	1.7–2.9	1.3–6.9	0.9–6.2	3.3–1938.6	0.7–2.5

Table 12. Descriptive statistics: near surface (ns) and near bottom (nb) concentrations of cations and anions (µeq/L) in Mount Rainier National Park lakes (1988–2008), Washington (WA) lakes (2007)[a], and 6 national parks[b] in the western United States sampled in the fall of 1999 (continued).

Ion	Metric	MORA ns (1988–2008)	MORA nb (1988–2008)	WA (2007)	GLAC	LAVO	ROMO	SEKI	YELL	YOSE
NO_3^-	*n* lakes	118 (346[c])	118 (346[c])	30	4	7	22	20	6	9
	$\bar{x}$ (SD)	0.2 (0.7)	0.96 (3.6)	0.8 (4.03)	2.0	≤0.3	4.3	0.9	1.4	0.7
	median	0.0	0.07	0.16	1.7	≤0.3	1.9	≤0.3	0.5	≤0.3
	range	0 – 7.8	0 – 37.9	0.16 – 35.9	≤0.3–4.6	≤0.3	≤0.3–15.4	≤0.3–8.3	≤0.3–5.1	≤0.3–6.53
SO_4^{2-}	*n* lakes	92 (243[c])	92 (243[c])	30	4	7	22	20	6	9
	$\bar{x}$ (SD)	6.96 (6.72)	6.68 (7.2)	281.5 (1979.7)	21.8	4.0	25.7	9.1	646.9	5.8
	median	5.2	3.7	28.1	17.2	2.3	21.9	6.7	30.3	3.8
	range	0 – 51.8	0.42 – 44.1	2.71 – 18727	4.3–48.6	0.6–16.4	12.8–65.9	1.2–41.1	4.1–2937.3	1.7–13.2

[a]Bell-McKinnon (2010)

[b]Clow et al. (2002); water samples were collected from the epilimnion

[c]Number of measurements

Table 13. Significant trends in the near surface and near bottom concentrations of cations and anions in 6 of 8 MORA lakes with 4 to 15 yrs of August samples collected from 1988 through 2008. Overall change units = μeq/L.

Sample Location	Lake	Ion	Overall Change	Number of Years
Near Surface	LC07 (Green)	Na^+	+11.2	10
	LM04 (Mowich)	Na^+	+10.01	14
		Ca^+	+12.3	14
	LN19 (Reflection)	$Cl^–$	–2.45	5
		$SO_4^–$	+4.82	5
		Na^+	+1.04	10
	LW20 (Clover)	K^+	–1.28	8
	LZ21 (Louise)	$SO_4^–$	+7.19	6
		Na^+	+18.84	11
		K^+	+3.78	11
		Ca^+	+17.85	11
	LZ29 (Snow)	$SO_4^–$	+5.82	5
		Na^+	+14.62	9
		Ca^+	+37.22	9
Near Bottom	LC07 (Green)	Na^+	+9.14	9
	LM04 (Mowich)	Na^+	+7.57	11
	LZ21 (Louise)	$Cl^–$	+2.82	4

Table 14. Maximum concentrations (μeq/L) for Ca^{2+}, K^+, Na^+, Cl^-, and SO_4^{2-} in 6 MORA lakes where significant trends for each index were determined (near surface / near bottom).

Lake	Ca^{2+}	K^+	Na^+	$Cl^–$	$SO_4^{2–}$
LC07 (Green)			48.3 / 59.6		
LM04 (Mowich)	84.6		33.5 / 31.5		
LN19 (Reflection)			41.3	11.6	7.7
LW20 (Clover)		5.9			
LZ21 (Louise)	48.9	5.3	36.7	12.7	10.3
LZ29 (Snow)	82.1		35.9		9.8
Non-MORA WA lakes mean	373.3	43.0	603.3	226.8	281.5
6 national parks range of medians	10.4–319.8	2.8–47.5	8.4–110.3	1.7–16.8	2.3–30.3

Table 15. Descriptive statistics: values for alkalinity (µeq/L), conductivity (µS/cm), pH, and dissolved oxygen (mg/L) in MORA lakes sampled August 1988–2001, MORA lakes sampled in August 1983[a], MORA lakes sampled July–September 1988[b], and in 6 national parks[c] in the western United States sampled in the fall of 1999. ns: near surface; nb: near bottom.

Index	Metric	MORA ns (1988–2001)	MORA nb (1988–2001)	MORA ns (1983)	MORA nb (1983)	MORA ns (1988)	MORA nb (1988)	GLAC	LAVO	ROMO	SEKI	YELL	YOSE
alkalinity	*n* lakes	27 (45[d])	24 (45[d])	13		26	23	4	7	22	20	6	9
	$\bar{x}$ (SD)	140.7 (105.5)	141.8 (104.2)	139.5 (128.9)		122.0	162.0	457.2	61.7	76.3	63.5	685.4	41.7
	median	117.8	112.8	104.0				31.5	38.6	14.7	59.0	533.7	32.2
	minimum	15.2	21.8	42.0		10.0	26.0	39.1	13.8	14.7	7.2	–38.8	13.7
	maximum	439.6	482.8	540.0		458.0	1002.0	1154.7	165.4	175.1	151.9	1621.1	75.3
conductivity	*n* lakes	21 (30[d])	21 (28[d])	13	13	24	22	4	7	22	20	6	9
	$\bar{x}$ (SD)	22.9 (16.6)	22.5 (16.6)	15.5 (13.6)	20.9 (20.8)	15.2	21.3	44.4	7.0	12.2	9.0	201.3	6.2
	median	19.1	16.5	12.0	13.0			30.9	4.4	12.2	8.8	127.1	5.6
	minimum	5.4	4.8	4.1	5.9	4.0	4.2	6.1	3.1	6.3	3.1	21.0	2.9
	maximum	70.2	73.7	58.0	72.0	57.9	80.3	109.7	17.0	23.9	21.0	711.0	10.3
pH	*n* lakes	25 (43[d])	24 (44[d])	13	13	27	23	4	7	22	20	6	9
	$\bar{x}$ (SD)	7.0 (0.53)	6.7 (0.68)	6.3 (0.24)	6.3 (0.17)	6.7	6.4	7.4	6.7	6.9	6.8	7.2	6.6
	median	6.95	6.53	6.4	6.3			7.4	6.7	6.8	6.9	7.8	6.6
	minimum	5.77	5.37	5.8	5.9	6.0	5.6	6.7	6.3	6.3	6.0	4.3	6.2
	maximum	9.14	9.10	6.5	6.5	7.8	7.3	8.1	7.2	7.2	7.3	8.4	6.9
dissolved oxygen	*n* lakes	27 (45[d])	24 (45[d])	13	13								
	$\bar{x}$ (SD)	8.3 (0.97)	7.2 (2.2)	8.1 (0.52)	8.0 (2.2)								
	median	8.0	7.6	8.0	8.3								
	minimum	7.1	1.8	7.0	2.2								
	maximum	11.1	10.6	8.7	10.2								

[a] Turney et al. (1986)

[b] Larson et al. (1994)

[c] Clow et al. (2002); water samples were collected from the epilimnion

[d] Number of measurements

Zooplankton

The occurrence of zooplankton (rotifers and crustaceans) in MORA lakes has been documented by Larson et al. (2009), Fradkin et al. (2012), and a significant amount of unpublished data from 2006–2013 (B. Samora, pers. comm.).

Larson et al. (*2009*)—Rotifer and crustacean assemblages were elucidated for 103 MORA lakes sampled 1988–2005. They identified 45 rotifer and 44 crustacean taxa in the lakes and determined that total zooplankton species distribution was generally limited: 56% of taxa were present in 1 to 4 lakes; 19% were present in 5 to 10 lakes; and 25% were present in 11 to 72 lakes. They also identified 4 rotifer taxa (*Conochilus unicornis, Kellicottia longispina, Keratella cochlearis,* and *Keratella taurocephala*) and 7 crustacean taxa (*Daphnia ambigua, Daphnia rosea, Hesperodiaptomus franciscanus, Hesperodiaptomus kenai, Leptodiaptomus signicauda, Holopedium gibberum,* and *Microcyclops varicans)* as indicator species of unique zooplankton assemblages. The 11 species were so identified because of their broad niche breadths, which suggested that they have wide tolerances to the physical and chemical gradients present in MORA lakes.

Fradkin et al. (*2012*)—Fradkin et al. (2012) reported results of the analysis of zooplankton data collected from 18 North Coast and Cascades Network (NCCN) lakes from 3 parks (6 MORA, 6 North Cascades, 6 Olympic) during August and September, 2009 as part of the NCCN Lake Monitoring Program. They recorded 20 taxa (8 rotifer and 12 crustaceans) from 6 MORA lakes, with 13 taxa (6 rotifers and 7 crustaceans) present in only 1 or 2 of the lakes. They found that assemblage structure among the parks was significantly different. Zooplankton assemblages in MORA lakes had the highest diversity gradient among the parks based on the presence of more taxa (11.2 MORA > 9.0 NOCA > 7.2 OLYM), higher richness (2.55 MORA > 2.32 NOCA > 1.92 OLYM), and a higher Shannon's Diversity Index (2.21 MORA > 2.03 NOCA > 1.79 OLYM). They also found that 2 rotifer taxa (*Conochilus unicornis, Keratella cochlearis*) and 4 crustacean taxa (*Daphnia rosea, Hesperodiaptomus arcticus, Holopedium gibberum, Microcyclops varicans*) contributed the most to community structure.

Macroinvertebrates

Macroinvertebrate samples were collected from 15 MORA lakes in 2004 and 12 lakes in 2007 (24 lakes in both years). A total of 97 taxa were collected in 2004, and 59 taxa were collected in 2007, representing 18 taxonomic groups. Occurrence was limited: 73% of 2004 taxa were present in 1 to 5 lakes (45% in 1 to 2 lakes), and 32% were restricted to individual lakes; 80% of 2007 taxa were present in 1 to 5 lakes (58% in 1 to 2 lakes), and 21% were restricted to individual lakes. Twelve taxa with the widest distributions in both years were present in 11 to 15 lakes in 2004 and 8 to 12 lakes in 2007 (Table 16).

Table 16. The most widely distributed macroinvertebrate taxa in MORA lakes, 2004 and 2007.

		Number of Lakes	
Taxa	**Order: Family**	**2004 (*n* =15)**	**2007 (*n* = 12)**
Ablabesmyia	Diptera: Chironomidae	12	
Acari	Arachnida (Class)	15	8
Aeshna	Odonata: Aeshnidae	11	
Callibaetis	Ephemeroptera: Baetidae	13	
Dytiscidae	Coleoptera: Dytiscidae	13	11
Halesochila taylori	Trichoptera: Limnephilidae	11	
Oligochaeta	Clitellata (Class)	15	11
Paratanytarsus	Diptera: Chironomidae	11	
Procladius	Diptera: Chironomidae	13	12
Psectrocladius	Diptera: Chironomidae	11	8
Sphaeriidae	Veneroida: Sphaeriidae	12	
Tanytarsus	Diptera: Chironomidae	14	12

Lake Ice-Out

Unpublished surface water temperature data collected at 9 MORA lakes from 2004 through 2011 was used as a proxy to access potential changes in estimated lake ice-out dates. The 9 lakes selected for this analysis had from 4 to 7 yrs of estimated lake ice-out dates. Ice-out date was defined as the day, in Julian Days, when the lake hourly surface water temperature rose rapidly to above 4.5°C, and did not fall below 4.0°C after ice-out (MORA 2011). Based on simple regression analysis of the 9 lakes (Table 17), 4 lakes showed no significant change in estimated ice-out date, while 5 lakes showed a significant positive change, with ice-out occurring later in the season (mid-May through mid-August). ANOVA showed that between the 2 groups of lakes (i.e., lakes with no significant trend [ns] and lakes with a significant [s] trend) there was no significant correlation with lake elevation (F = 3.46, P = 0.10; $\bar{x}_{[ns]}$ = 1608 m, $\bar{x}_{[s]}$ = 1453 m) or maximum depth (F = 0.79, P = 0.40; $\bar{x}_{[ns]}$ = 12.1 m, $\bar{x}_{[s]}$ = 17.8 m); however, the numbers of years of collected data appeared to be a significant factor between the 2 groups (F = 21.75, P = 0.002; $\bar{x}_{[ns]}$ = 4.2 yrs, $\bar{x}_{[s]}$ = 6.6 yrs). This outcome suggests that identifying changes in estimated lake ice-out times requires the collection of data over time periods of at least 7 yrs; however, this result could simply be due to the small sample size used in this analysis.

Table 17. Regression outcomes for unpublished ice-out date data for 9 MORA lakes with ≥4 yrs of measurements. Zmax = maximum depth; * indicates significant increase.

GIS Code	Name	Elevation (m)	Zmax (m)	No. Years	Ice-out Range Julian Days	Ice-out Range Date	R^2	*P*
LC35	Crescent	1697	29	5	183–224	2 July – 11 August	0.21	0.433
LF04	Ethel	1326	29.5	5	132–187	12 May – 6 July	0.88	0.019*
LM01	Eunice	1635	20	7	147–222	27 May – 10 August	0.58	0.046*
LM30	Unnamed	1496	9	4	175–206	24 June – 24 July	0.60	0.227
LN19	Reflection	1479	11.5	7	144–208	24 May – 27 July	0.62	0.036*
LO12	Shriner	1490	3.5	4	127–171	7 May –20 June	0.04	0.796
LW26	Sunrise	1750	7	4	150–184	30 May – 3 July	0.32	0.431
LZ21	Louise	1401	17.2	7	130–196	10 May – 15 July	0.60	0.041*
LZ29	Snow	1426	10.7	7	144–208	24 May – 6 July	0.77	0.009*

Lakes of Management Concern

Twenty-five MORA lakes were identified as being of management concern (Rawhouse et al. 2012:Appendix D). None of these lakes were 303d listed under the CWA. Based on informed risk criteria (Rawhouser et al. 2012, Table 1.24, p. 43), 16 lakes (64%) were ranked as being at minor risk of impairment (stressors are dispersed over a large area and resources would return to reference conditions without implementing restoration activities if stressors ceased); and 9 lakes (32%) were ranked as being at moderate (stressors are readily apparent and measureable, but with limited spatial extent) or high (stressors are substantial and measureable, highly noticeable and affect a large area) risk of impairment. Four lakes (LW40, Mowich, Reflection, and Tipsoo) were ranked as threatened.

Assessment

Examination of the trophic state of MORA lakes based on concentrations of CHLA, TN, and TP shows that lakes in the park are relatively low in productivity with low nutrient concentrations and are, therefore, predominantly oligotrophic. This outcome is similar to results determined for MORA lakes by Clow and Campbell (2008). Further, examination of CHLA, TN, and TP concentrations in the 8 lakes with multiple years of data also showed that although there were significant positive trends for TN and negative trends for TP in 5 of the lakes, temporal changes in productivity and nutrient concentrations are relatively benign. Analysis of DIN:DTP ratios also indicated that 94% of the 127 MORA lakes analyzed are either nitrogen limited or co-limited in nitrogen or phosphorus.

Concentrations of cations and anions in mountain lakes are typically low, influenced by basin and catchment geology and vegetation associated with low rates of weathering, thin soils, high water fluxes, and relatively sparse vegetation (Baron 1983, Marchetto et al. 1995, Skjelkvåle and Wright 1998). Because of their low ion concentrations, mountain lakes are generally considered to be sensitive to atmospheric inputs and acidification (Skjelkvåle and Wright 1998, Clow and Campbell 2008). MORA lakes, based on their ion concentrations in this assessment, are no exception to this widely-accepted view (Turney et al. 1986, Larson et al. 1994, Clow and Campbell 2008). Although MORA lakes at present show conflicting limited shifts in concentrations of ions (Nieber et al. 2011, and the results of this report), the lakes in the park remain susceptible to potential future changes due to atmospheric deposition of pollutants, precipitation acidity and acidified snowmelt runoff (Samora and Clow 2002, Clow and Campbell 2008), and changes in local and regional climate (Hauer et al. 1997, Murdoch et al. 2000, Parmesan 2006).

Measuring alkalinity, conductivity, and pH is one way to characterize the acid sensitivity of poorly buffered surface waters (Ontario Ministry of the Environment 1979, NRCC 1981, Turney et al. 1986, Radtke et al. 1998). Lakes with ALKA <200 μeq/L, COND <35 μS/cm, and pH <6.0 are considered to be sensitive to acidification (NRCC 1981, Turney et al. 1986). Six of the 27 MORA lakes examined in this analysis had mean ALKA and COND values above the threshold for each parameter, indicating that 21 of the lakes surveyed are likely sensitive to acidification based on their ALKA and COND levels. Conversely, 25 of the lakes had pH values above the pH threshold for acid sensitivity.

Dissolved oxygen concentration is an important water quality parameter integral for biotic productivity in freshwater ecosystems and a primary indicator of the capacity of surface waters to support aquatic life. In surface waters not naturally intended for salmonid production, such as the MORA lakes in this analysis, DO concentrations ≥6 mg/L for aquatic organisms other than invertebrates and ≥8 mg/L for invertebrates indicate no discernable production impairment; DO concentrations ≥5 mg/L to below the upper threshold (6.0 and 8.0 mg/L, respectively) indicate some production impairment (Chapman 1986). In general, the near surface and near bottom DO concentrations in MORA lakes are most often above the upper threshold limits and are therefore adequate for supporting aquatic biota. Low DO concentrations (e.g. 1.8 to 4.8 mg/L), as occurred in 8 of 45 near bottom measurements recorded for MORA lakes between 1988 and 2001, are typically episodic and probably due, in part, to increased organic oxygen demand near the lake bottom. No near surface measurements recorded for MORA lakes were <7 mg/L.

A total of 108 zooplankton taxa (55 rotifers and 53 crustaceans) have been identified from MORA lake samples. The results of Larson et al. (2009) and Fradkin et al. (2012) indicate that the distribution of zooplankton in MORA lakes is relatively limited with 56 (Larson et al. 2009) to 65% (Fradkin et al. 2012) of taxa present in only 1 to 4 or 1 to 2 lakes, respectively. Both studies did, however, identify 6 (Fradkin et al. 2012) to 12 (Larson et al. 2009) species that contributed most to and were indicators of MORA lake zooplankton community structure and assemblages. The 4-indicator rotifer species in MORA lakes are known to be common members of zooplankton assemblages in other western North American mountain lakes; whereas the 8-indicator crustacean species in MORA lakes are more similar to dominant taxa in lakes of the Sierra Nevada in California than to dominant taxa in lakes in the Canadian Rockies, Yukon, and Northwest Territories (Larson et al. 2009). According to Larson et al. (1994, 1999), zooplankton taxa and assemblages (especially crustaceans) vary spatially and temporally in MORA lakes, although the common-dominant species reported in 1994 and 1999 are similar to taxa reported by Larson et al. (2009) and Fradkin et al. (2012). This indicates that the species primarily contributing to zooplankton assemblage structure in MORA lakes are relatively stable. Three broad categories associated with landscape characteristics, zooplankton assemblages, and water quality, have also been tentatively identified that contribute to variability in assemblage composition and distribution in MORA lakes (Thomas and Torgersen, In Prep.). Landscape characteristics include 2 groups: (1) lower temperature and higher solar radiation; and (2) higher temperature and lower solar radiation, as well as precipitation. Zooplankton assemblages were classified by distinct communities of rotifers, communities of mixed rotifers and crustaceans, and various communities of rotifers and crustaceans. Water quality characteristics could also be grouped based on either high, intermediate, or low levels of conductivity, alkalinity, and pH, as well as high dissolved oxygen and low temperature. These categories and their relationships are indicative of broad environmental conditions in MORA lakes and ponds.

The limited distribution of macroinvertebrates in MORA lakes is similar to their distribution in other relatively undisturbed and pristine mountain lakes. In North Cascades National Park Service Complex, Washington, Hoffman et al. (1996) sampled 41 lakes, 1989–1991. They identified 88 taxa representing 16 taxonomic groups, with 72% of taxa present in 8 or fewer lakes, and 25% restricted to individual lakes. Lafrancois et al. (2003) also recorded the limited distribution of macroinvertebrates in 22 lakes in Rocky Mountain National Park and the Indian Peaks Wilderness Area, Colorado. They identified 48 taxa of which 70% were present in 6 or fewer lakes, and 22%

were restricted to 1 or 2 lakes. This distribution pattern is similar in lakes of the Austrian, Italian, and Swiss Alps. Füreder et al. (2006) sampled 55 alpine lakes in a large watershed comprising the 3 countries and identified 144 taxa; 67% were present in 3 or fewer lakes, and 39% were restricted to individual lakes. Likewise, Oertli et al. (2008) sampled 25 cirque ponds in the Swiss National Park, Switzerland, identified 47 taxa, and found that the macroinvertebrate assemblages in these ponds were species poor compared to lower elevation ponds. The results of these studies indicate that the limited distribution of macroinvertebrates in MORA lakes is not unique, and that mountain lakes and ponds act as refugia for macroinvertebrates of limited distribution across these higher elevation landscapes. This pattern of distribution is associated, in part, with (1) variability in the dispersal ability of taxa; (2) the distance and connectivity (or discontinuity) among lakes; (3) physical characteristics of the lake-basin terrestrial environment; and (4) the adaptation of many taxa inhabiting these lakes to cold-stenothermal and oligotrophic environments (Hoffman et al. 1996; Lafrancois et al. 2003; Catalan et al. 2006; Füreder et al. 2006; Oertli et al. 2008).
Clow and Campbell (2008) examined potential effects of the atmospheric deposition of inorganic nitrogen and sulfur on 2 MORA lakes, Eunice Lake (LM01) and Lake Louise (LZ21). Potential effects include episodic or chronic acidification, and, with respect to nitrogen, possible lake eutrophication or increased productivity. MORA receives air pollution from local, regional, and possibly global sources (NPS 2002), including emissions from Seattle, Tacoma, and Vancouver in Washington, and Portland, Oregon. The primary influence on lake acidity appears to be melting seasonal snow-pack containing dilute, slightly acidic water, and episodic acidification is possible during rain-on-snow events, primarily in late spring and early summer (Clow and Campbell 2008). The scale of these episodes, however, is not known. Historical lake-survey data indicates that nitrate concentrations have been very low in MORA lakes, with the annual volume-weighted concentration of inorganic nitrogen at the MORA National Atmospheric Deposition Program/National Trends Network site at Tahoma Woods averaging 5.1 μeq/L, 2000–2005 (Clow and Campbell 2008). Sulfate concentrations have decreased significantly at Eunice Lake, which is the site nearest upwind from a power plant in Centralia, Washington, where emission controls were added in 2001; the wet deposition of sulfate at Tahoma Woods averaged 4.6 μeq/L, 2000–2005 (Clow and Campbell 2008).

There has been concern that water quality conditions in Lake Ethel (LF04) are changing relative to conditions in other MORA lakes. Analysis of values for 16 water quality parameters determined from Lake Ethel samples collected 2004–2009 indicates that all Lake Ethel parameter values fall well within the range of values calculated for each parameter for other MORA lakes sampled, 1988–2009 (Table 18). Based on these data, Lake Ethel is, on average, a nitrogen-limited oligotrophic system with the mean values of Cl^-, SO_4^-, DO, and pH in Lake Ethel equivalent to their mean values determined for other MORA lakes; the mean values of TN, N:P ratio, NH_4^+, and NO_3^+ in Lake Ethel each somewhat lower than their mean values determined for other MORA lakes; and the mean values of CHLA, TP, Ca^{2+}, K^+, Mg^{2+}, Na^+, ALKA, and COND somewhat higher in Lake Ethel than in other MORA lakes. Based on these data, the water quality characteristics of Lake Ethel generally appear to be quite similar to the characteristics of other MORA lakes.

Analysis of surface water temperature used as a proxy for the date of lake ice-out indicated that in 5 of 9 MORA lakes the estimated ice-out date showed a significant trend toward occurring later in the open water season. This change was not significantly related to lake elevation or maximum depth, but was significantly related to the number of years of estimated ice-out dates. This result suggests that longer-term temporal data collection may better reveal this trend (Magnuson 1990). It is not presently specifically known what factors contribute to this later occurrence of ice-out in MORA lakes, but the trend may be attributed, in part, to possible short-term changes in local and regional environmental conditions affected by climate (Murdoch et al. 2000, Parmesan 2006). It is instructive to note that the present trend in MORA lakes to later-occurring ice-out is opposite of what has been found in lakes of the Great Lakes region (Jensen et al. 2007) and New England (Hodgkins et al. 2002). Jensen et al. (2007) found that lake freeze and break-up dates during 1975–2004 have been occurring more rapidly than historical rates (1846–1995), and that average ice duration and the average number of days with snow have decreased. Hodgkins et al. (2002) found that ice-out dates in New England lakes have become significantly earlier since 1850. Although these results are conflicted, it is likely that change in climate is affecting the ice-out dynamics of the lakes in these regions and at MORA (Murdoch et al. 2000).

Conclusion

MORA lakes are generally low in productivity and nutrient concentrations, and tend to be either nitrogen limited (58 of 127 lakes analyzed) or co-limited (nitrogen-phosphorus; 61 of 127 lakes). The lakes have low ion concentrations and tend to be poorly buffered, which makes them susceptible to acidification and atmospheric deposition of nutrients and pollutants. Zooplankton and macroinvertebrates are limited in occurrence and distribution, and many individual taxa tend to each be present in a relatively small number of lakes, which act as refuges for numerous localized taxa occurring across the MORA landscape. Finally, although the temporal length of surface water temperature measurements is short (i.e., maximum 7 yrs), the timing of ice-out in some MORA lakes appears to be changing. Overall, MORA lakes are predominantly oligotrophic and identified changes in water quality parameters occur below the upper threshold for this trophic state. At present, most MORA lakes can be rated as being minimally disturbed by non-stochastic natural perturbations or human activities. However, 25 lakes have been identified as being of management concern, and 9 of these lakes have been ranked as being at moderate to high risk of impairment due to non-stochastic natural perturbations or human activities; 4 lakes are considered threatened.

Table 18. Comparison of mean values and ranges for water quality indices: Lake Ethel (LF04) and MORA lakes data (1988–2009). Cations, anions, alkalinity, conductivity, dissolved oxygen, and pH values are all for near surface samples. H = Lake Ethel mean higher than MORA lakes mean; L = Lake Ethel mean lower than MORA lakes mean; E = Lake Ethel mean equivalent to MORA lakes mean.

Index	Lake Ethel mean	MORA Lakes mean	Lake Ethel range	MORA Lakes range	Lake Ethel average condition
Chlorophyll *a*	1.07	0.39	0.18–2.68	0.005–4.8	Oligotrophic; H
Total Phosphorus	11.5	8.5	9–14	>0–195	Mesotrophic; H
Total Nitrogen	0.06	0.12	0.02–0.17	>0–1.2	Oligotrophic; L
N:P Ratio	5.1	17.8	2–12	2–43	Nitrogen limited
Ca^{2+}	89.6	69.9	81.8–100.2	0.96–432.6	H
K^{+}	11.9	4.6	10.5–13.4	>0–48.4	H
Mg^{2+}	24.9	14.9	23.0–28.9	>0–101.6	H
Na^{+}	51.6	30.8	48.9–54.7	2.7–264.9	H
NH_4^{+}	0.05	0.85	>0–0.38	>0–23.9	L
Cl^{-}	11.8	12.4	10.4–13.9	1.1–41.7	E
NO_3^{-}	0.03	0.2	>0–0.21	>0–7.8	L
SO_4^{-}	8.4	7.0	7.7–8.9	>0–51.8	E
Alkalinity	180.6	140.7	134.8–218.9	15.2–439.6	H
Conductivity	39.7	22.9	23.3–56.0	5.45–70.2	H
Dissolved Oxygen	8.95	8.3	8.5–9.3	7.1–11.1	E
pH	6.8	7.0	6.3–7.5	5.8–9.1	E

4.2.5 Emerging Issues

There are 3 basic issues that have the potential of affecting the present status and health of MORA lakes. Climate change continues to be a global, regional, and local threat to aquatic ecosystems, with the potential of leading to chronically degraded water quality due to episodes of climate-induced stress related to changes in precipitation and temperature regimes (Hauer et al. 1997, Murdoch et al. 2000). Lake biotic species and assemblages will also most likely change in response to climate change; however the mechanisms and types of changes are relatively complex and, at present, not well understood (although see Vinnebrooke and Leavitt 1999 and Messner et al. 2013). Atmospheric deposition of nutrients (e.g., nitrogen, phosphorus, and carbon) and pollutants (e.g., sulfate, mercury, and other airborne contaminants), from nearby urban locations (e.g., Vancouver, BC; Puget Sound, WA; Portland, OR) and global sources, also have the potential of degrading MORA lake water quality (Carpenter et al. 1998, Mast et al. 2003). Because of their overall low buffering capacity, MORA lakes tend to be susceptible to acidification; and increased inputs of nutrients such as nitrogen and phosphorus could, in time, cause changes in the trophic status of some lakes. The Washington State Department of Ecology, for example, has developed action values for establishing nutrient criteria for Cascades Ecoregion lakes based on the concentration of ambient TP (Table 230[1], p. 24; WDOE 2012). Lakes with TP concentrations ≤10 μg/L are considered oligotrophic (>4–10 μg/L) or ultraoligotrophic (0–4 μg/L); whereas in lakes with concentrations >10 μg/L it is recommended that lake specific studies be initiated to evaluate lake characteristics for identifying potential sources of threat or impairment (if any). Of the 137 MORA lakes with documented TP measurements, 47 (34%) have TP concentrations >10 μg/L. The atmospheric deposition of mercury in MORA lakes is also a concern. Recent research has shown that fish sampled from a few small park lakes have exceeded mercury health thresholds for fish-eating animals as well as for humans. A study begun in 2012 is designed to determine the magnitude and extent of this contamination. Although a relatively minor issue, the introduction of invasive aquatic species (e.g., Brazilian Elodea, Eurasian Watermilfoil, New Zealand Mudsnail, Zebra Mussel, and various fish species) into MORA lakes is a potential threat to lake water quality. The primary avenue for introduction is most likely accidental, with deliberate introduction being least likely.

MORA has implemented a limited lake monitoring program as part of the North Coast and Cascades Network natural resources monitoring program. Six core MORA lakes are included as part of this monitoring effort. These lakes should continue to be monitored by measuring parameters that are useful indicators of ecosystem change due to each of the issues identified above. Additional lakes should be added to this core group of lakes should monitoring indicate any changes in the status or trends of water quality or the presence of invasive aquatic species in any of the core lakes being monitored.

Rawhouser (unpubl. data) applied the River Invertebrate Prediction and Classification System (RIVPACS) to benthic macroinvertebrate data collected from Mount Rainier lakes from 2004–2005. RIVPACS is a statistical model which enables the user to estimate the macroinvertebrate community expected at high quality reference sites using information on their environmental characteristics (Wright et al. 2000). The model consists of categorizing the reference sites in the model database into a number of discrete community types. By measuring the environmental characteristics for a new site of interest, a user can predict the probability of membership of each community type, and the overall reference condition. The model generates a list of taxa expected in a lake given certain environmental conditions in the absence of human activity. Rawhouser developed a model for MORA lakes based on collected data, and compared expected to observed species richness values. He developed Impairment Thresholds based on these data and found that out of 43 sites of concern, 33% were below expected values indicating potential water quality and habitat impairment; 5% of these sites were well below reference conditions indicating substantial impairment of water quality and habitat. Additional analyses, however, is needed to further verify the model.

Wetlands are considered the most sensitive ecosystems to climate change because wetland hydrology, and structure and function each respond dynamically to changes in temperature and precipitation, such as those predicted for the coming century (Carpenter et al. 1992, Poiani et al. 1996, Burkett and Kusler 2000, IPCC 2001, 2007, Erwin 2009). Near-coastal areas of the Pacific Northwest are among the most sensitive regions in the western U.S. to climate change, amplifying consequences for wetlands in our region (Cayan et al. 2001, Mote 2003, Hamlet et al. 2005, Mote et al. 2005, Nolin and Daly 2006, Hamlet et al. 2007). Warming in all seasons, increasing precipitation in fall, winter, and spring, and decreasing precipitation in summer may all contribute to shifting patterns of wetland hydrology and resulting changes in ecological function (Mote and Salathé 2010; Lee et al., In prep.). Five wetland dependent Federal and State listed Species of Concern inhabit park wetlands. Developing projections for how wetlands may change in coming decades and identifying opportunities for climate adaptation action are key steps in preserving these sensitive resources.

4.2.6 Information and Data Needs–Gaps

An on-going attempt should be made to collect data from MORA lakes to examine the possible presence of air-borne contaminants and pollutants of local, regional, and global origin (see also 4.1 Air Quality and Air Quality-Related Values). For example, mercury (Hg) contamination of aquatic ecosystems poses considerable risks to human and wildlife health (Scheuhammer et al. 2007). Recently completed research on contaminant deposition throughout Western National Parks (Landers et al. 2008) identified surprisingly elevated Hg concentrations in fish collected from isolated lakes in MORA. In fact, Hg concentrations in fish exceeded criteria developed for the protection of both human and wildlife health. However, only 2 MORA lakes were included in the study, which prohibited any detailed assessment to evaluate the extent of contamination, or the watershed, landscape, and ecological factors that might be influencing Hg concentrations. Thus, additional high-resolution efforts focusing on the magnitude of Hg contamination, factors controlling contamination, and potential effects to human and ecosystem health are needed to help guide future management efforts.

In addition to continuing to collect water quality data from the 6 core monitoring lakes, it would be advantageous to continue to measure air and water temperatures and water level at those lakes, expanding to additional lakes whenever possible.

Lake riparian disturbance surveys have also been conducted at several lakes over multiple years; data collection includes survey plot impact descriptions and qualitative shore-nearshore disturbance scores. These data should be analyzed in the future using multivariate analysis. Results can be used to establish indicators and standards to address user capacity concerns at lakes with heavy recreational use.

The Rawhouser study initiated in 2004, titled Use of Invertebrates for the Assessment of Impairment of Water Quality and Biological Integrity in Mount Rainier National Park Lakes, with emphasis on developing potential NPS VERP (Visitor Experience and Resource Protection) framework indicators for recreational use, should be completed and published. Data will be useful for monitoring recreational use and other anthropogenic stresses to park lakes.

Approximately 678 MORA wetlands have been inventoried (1986–1999), and a subset of the wetlands (from 91 to 543) have been sampled for pH, maximum depth, presence of wildlife (including amphibians, fish, and invertebrates), primary vegetation and qualitative estimate of cover, and soil composition. All parameters except pH and maximum depth were qualitatively assessed. It would be beneficial for MORA to more intensively sample and monitor a representative subset of wetlands in the future given that these shallow aquatic ecosystems are sensitive indicators of climate change.

The MORA aquatic resources program has collected a significant amount of data for numerous lake water quality parameters. It would be most expedient if these data were organized and consolidated into a single database with categories or components for physical, chemical, and biological characteristics that could be linked for analysis. It would also be useful for all site and sample labels to be consistent for all years, and for the metrics of all measurements and concentrations to be clearly identified and defined. Once organized and annotated, the 20+ yrs of data should be published in the Natural Resources Data Report series to facilitate future scientific work on park lakes, provide data for supporting the anti-degradation regulations, as well as support efforts to designate Outstanding Natural Resource waters in the park.

4.2.7 Literature Cited

Allan, J. D., and L. B. Jonhson. 1997. Catchment-scale analysis of aquatic ecosystems. Freshwater Biology 37:107–111.

Baron, J. 1983. Comparative water chemistry of four lakes in Rocky Mountain National Park. Water Resources Bulletin 19:897–902.

Bell-McKinnon, M. 2010. An assessment of Washington lakes: National lake assessment results. Publication No. 10-03-029, Washington State Department of Ecology, Olympia, Washington.

Bergström, A-K. 2010. The use of TN:TP and DIN:TP ratios as indicators for phytoplankton nutrient limitation in oligotrophic lakes affected by N deposition. Aquatic Sciences 72:277–281.

Boersma, P. D., S. H. Reichard, and A. N. Van Buren, editors. 2006. Invasive species in the Pacific Northwest. University of Washington Press, Seattle, Washington.

Burkett, V., and J. Kusler. 2000. Climate change: Potential impacts and interactions in wetlands of the United States. Journal of the American Water Resources Association 36:313–320.

Carlson, R. E. 1977. A trophic state index for lakes. Limnology and Oceanography 22:361–369.

Carlson R. E., and J. Simpson. 1996. A coordinator's guide to volunteer lake monitoring methods. North American Lake Management Society.

Carpenter, S. R., S. G. Fisher, and N. B. Grimm. 1992. Global change and freshwater ecosystems. Annual Review of Ecology and Systematics 23:119–139.

Carpenter, S. R., N. F. Caraco, D. L. Correll, R. W. Howarth, A. N. Sharpley, and V. H. Smith. 1998. Nonpoint pollution of surface waters with phosphorus and nitrogen. Ecological Applications 8:559–568.

Catalan, J., L. Camarero, M. Felip, S. Pla, M. Ventura, T. Buchaca, and others. 2006. High mountain lakes: Extreme habitats and witnesses of environmental changes. Lemnetica 25:551–584.

Cayan D. R., S. A. Kammerdiener, M. D. Dettinger, and others. 2001. Changes in the onset of spring in the western United States. Bulletin of the American Meteorological Society 82:399–415.

Chapman, G. 1986. Ambient water quality criteria for dissolved oxygen. EPA 440/5-86-003. U.S. Environmental Protection Agency, Office of Research and Development, Environmental Research Laboratories, Duluth, MI and Narragansett, Rhode Island.

Clarke, R. T., J. F. Wright, and M. T. Furse. 2003. RIVPACS models for predicting the expected macroinvertebrate fauna and assessing the ecological quality of rivers. Ecological Modelling 160:219–233.

Clow, D. W., and D. H. Campbell. 2008. Atmospheric deposition and surface-water chemistry in Mount Rainier and North Cascades National Parks, U.S.A., water years 2000 and 2005–2006. U.S. Geological Survey Scientific Investigations Report 2008–5152.

Clow, D. W., R. G. Striegl, L. Nanus, M. A. Mast, D. H. Campbell, and D. P. Krabbenhoft. 2002. Chemistry of selected high-elevation lakes in seven national parks in the western United States. Water, Air, and Soil Pollution: Focus 2:139–164.

Cole, D. N., and P. B. Landres. 1996. Threats to wilderness ecosystems: Impacts and research needs. Ecological Applications 6:168–184.

Erwin, K. L. 2009. Wetlands and global climate change: The role of wetland restoration in a changing world. Wetlands Ecology and Management 17:71–84.

Fradkin, S. C., W. Baccus, R. Glesne, C. Welch, B. Samora, and R. Lofgren. 2012. Zooplankton assemblages from core mountain lake study sites in the North Coast and Cascades Network: 2009 Field Season Report. Natural Resource Technical Report NPS/NCCN/NRTR–2012/629.

Füreder, L., R. Ettinger, A. Boggero, B. Thaler, and H. Thies. 2006. Macroinvertebrate diversity in alpine lakes: Effects of altitude and catchment properties. Hydrobiologia 562:123–144.

Glesne, R. S., S. C. Fradkin, B. A. Samora, J. R. Boetsch, R. E. Holmes, and B. Christoe. 2012. Protocol for long-term monitoring of mountain lakes in the North Coast and Cascades Network: Version July 9, 2012. Natural Resource Report NPS/NCCN/NRR–2012/549. National Park Service, Fort Collins, Colorado.

Hamlet, A. F., P. W. Mote, M. P. Clark, and others. 2005. Effects of temperature and precipitation variability on snowpack trends in the western U.S. Journal of Climate 19:4545–4561.

Hamlet, A. F., P. W. Mote, M. P. Clark, and others. 2007. Twentieth-century trends in runoff, evapotranspiration, and soil moisture in the western United States. Journal of Climate 20:1468–1486.

Hauer, F. R., J. S. Baron, D. H. Campbell, K. D. Fausch, S. W. Hostetler, G. H. Leavesley, P. R. Leavitt, D. M. McKnight, and J. A. Stanford. 1997. Assessment of climate change and freshwater ecosystems of the Rocky Mountains, USA and Canada. Hydrological Processes 11:903–924.

Hawkins, C. P., and D. M. Carlisle. 2001. Use of predictive models for assessing the biological integrity of wetlands and other aquatic habitats. In: Rader, R. B., D. P. Batzer, and S. A. Wissinger, editors. Bioassessment and management of North American freshwater wetlands. JohnWiley and Son, New York, New York. p. 59–83.

Hawkins, C. P., R. H. Norris, J. N. Hogue, and J. W. Feminella. 2000. Development and evaluation of predictive models for measuring the biological integrity of streams. Ecological Applications 10:1456–1477.

Hodgkins, G. A., I. C. James II, and T. G. Huntington. 2002. Historical changes in lake ice-out dates as indicators of climate change in New England, 1850–2000. International Journal of Climatology 22:1819–1827.

Hoffman, R. L., W. J. Liss, G. L. Larson, E. K. Deimling, and G. A. Lomnicky. 1996. Distribution of nearshore macroinvertebrates in lakes of the North Cascades Mountains, Washington, USA. Archiv Fur Hydrobiologie 136:363–389.

[IPCC] Intergovernmental Panel on Climate Change. 2001. Climate change 2001: Impacts, adaptation, and vulnerability. Contribution of Working Group II to the Third Assessment Report of the Intergovernmental Panel on Climate Change, J. J. McCarthy, O. F. Canziani, N. A. Leary, D. J. Dokken, and K. S White, editors. World Meteorological Organization and the United Nations Environmental Programme: Cambridge University Press.

[IPCC] Intergovernmental Panel on Climate Change. 2007. Ecosystems, their properties, goods, and services. Climate change 2007: Impacts, adaptation and vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. M. L. Parry, O. F. Canziani, J. P. Palutikof, P. J. van der Linden, and C. E. Hanson, editors. Cambridge, UK: Cambridge University Press. p. 211–272.

Jensen, O. P., B. J. Benson, J. J. Magnuson, V. M. Card, M. N. Futter, P. A. Soranno, and K. M. Stewart. 2007. Spatial analysis of ice phenology trends across the Laurentian Great Lakes region during a recent warming period. Limnology and Oceanography 52:2013–2026.

Kling, G. W., G. W. Kipphut, M. M. Miller, and W. J. O'Brien. 2000. Integration of lakes and streams in a landscape perspective: The importance of material processing on spatial patterns and temporal coherence. 2000. Freshwater Biology 43:477–497.

Kratzer, C. R., and P. L. Brezonik. 1981. A Carlson-type trophic state index for nitrogen in Florida lakes. Water Resources Bulletin 17:713–715.

Lafrancois, B. M., D. M. Carlisle, K. R. Nydick, B. M. Johnson, and J. S. Baron. 2003. Environmental characteristics and benthic invertebrate assemblages in Colorado mountain lakes. Western North American Naturalist 63:137–154.

Landers, D. H., S. L Simonich, D. A. Jaffe, L. H. Geiser, D. H. Campbell, A. R. Schwindt, C. B. Schreck, M. L. Kent, W. D. Hafner, H. E. Taylor, and others. 2008. The fate, transport, and ecological impacts of airborne contaminants in western National Parks (USA). EPA/600/R-07/138. U.S. Environmental Protection Agency, Office of Research and Development, NHEERL, Western Ecology Division, Corvallis, Oregon.

Larson, G. L., A. Wones, C. D. McIntire, and B. Samora. 1994. Integrating limnological characteristics of high mountain lakes into the landscape of a natural area. Environmental Management 18:871–888.

Larson, G. L., C. D. McIntire, R. W. Jacobs, and R. Truitt. 1999. Temporal variations of water quality and the taxonomic structure of phytoplankton and zooplankton assemblages in mountain lakes, Mount Rainier National Park, USA. Journal of Lake and Reservoir Management 15:148–158.

Larson, G. L., R. Hoffman, C. D. McIntire, G. Lienkaemper, and B. Samora. 2009. Zooplankton assemblages in montane lakes and ponds of Mount Rainier National Park, Washington State, USA. Journal of Plankton Research 31:273–285.

Lee, S., A. F. Hamlet, M. E. Ryan, and W. J. Palen. In prep. Modeling the effects of climate change on Pacific Northwest wetlands.

Magnuson, J. J. 1990. Long-term ecological research and the invisible present: Uncovering the processes hidden because they occur slowly or because effects lag years behind causes. BioScience 40:495–501.

Marchetto, A., R. Mosello, R. Psenner, G. Bendetta, A. Boggero, D. Tait, and G. A. Tartari. 1995. Factors affecting water chemistry of alpine lakes. Aquatic Sciences 57:81–89.

Mast, M. A., D. H. Campbell, G. P. Ingersoll, W. T. Foreman, and D. P. Krabbenhoft. 2003. Atmospheric deposition of nutrients, pesticides, and mercury in Rocky Mountain National Park, Colorado, 2002. U.S. Geological Survey Water Resources Investigations Report 03-4241.

McKnight, D., D. F. Brakke, and P. J. Mulholland, editors. 1996. Freshwater ecosystems and climate change in North America. Limnology and Oceanography 41:815–1149.

McMaster, N. L., and D. W. Schindler. 2005. Planktonic and epipelic algal communities and their relationship to physical and chemical variables in alpine ponds in Banff National Park, Canada. Arctic, Antarctic, and Alpine Research 37:337–347.

Messner, J. S., M. M. Maclennan, and R. D. Vinebrooke. 2013. Higher temperatures enhance the effects of invasive sportfish on mountain zooplankton communities. Freshwater Biology 58:354–364.

[MORA] Mount Rainier National Park. 2011. Lake temperatures at Mount Rainier National Park. Unpublished draft report.

Mote, P. W. 2003. Trends in temperature and precipitation in the Pacific Northwest during the twentieth century. Northwest Science 77:271–282.

Mote, P. W., A. F. Hamlet, M. P. Clark, and others. 2005. Declining mountain snowpack in western North America. Bulletin of the American Meteorological Society 86:39–49.

Mote, P. W., and E. P. Salathé. 2010. Future climate in the Pacific Northwest. Climatic Change 102: 29–50.

Morris, D. P., and W. M. Lewis, Jr. 1988. Phytoplankton nutrient limitation in Colorado mountain lakes. Freshwater Biology 20:315–327.

Murdoch, P. S., J. S. Baron, and T. L. Miller. 2000. Potential effects of climate change on surface-water quality in North America. Journal of the American Water Resources Association 36:347–366.

Murphy, C. A., P. L. Thompson, and R. D. Vinebrooke. 2010. Assessing the sensitivity of alpine lakes and ponds to nitrogen deposition in the Canadian Rocky Mountains. Hydrobiologia 648:83–90.

Nieber, A., C. Johnson, and A. M. Johansen. 2011. Lake and stream water chemistry in Mount Rainier National Park; Report for data collected in summer and fall 2010 and trend analysis for 2003–2010. Central Washington University Chemical Analysis Laboratory, Ellensburg, Washington.

Nolin, A. W., and C. Daly. 2006. Mapping "at risk" snow in the Pacific Northwest. Journal of Hydrometeorology 7:1164–1171.

[NPS] National Park Service. 2002. Air quality in the National Parks, 2nd edition. National Park Service, no. D–2266. Lakewood, Colorado.

[NRCC] National Research Council of Canada. 1981. Acidification in the Canadian aquatic environment: Scientific criteria for assessing the effects of acidic deposition on aquatic ecosystems. Publication NRCC No. 18475, Environmental Secretariat, Ottawa.

Oertli, B., N. Indermuehle, S. Angélibert, H. Hinden, and A. Stoll. 2008. Macroinvertebrate assemblages in 25 high alpine ponds of the Swiss National Park (Cirque of Macun) and relation to environmental variables. Hydrobiologia 597:29–41.

Ontario Ministry of the Environment. 1979. Determination of the susceptibility to acidification of poorly buffered surface waters. Limnology and Toxicity Section, Water Resources Branch, Rexdale, Ontario.

Parmesan, C. 2006. Ecological and evolutionary responses to recent climate change. Annual Review of Ecology, Evolution, and Systematics 37:637–669.

Poiani, K. A., W. C. Johnson, G. A. Swanson, and T. C. Winter. 1996. Climate change and northern prairie wetlands: Simulations of long-term dynamics. Limnology and Oceanography 41:871–881

Radtke, D. B., F. D. Wilde, J. V. Davis, and T. J. Popowski. 1998. Alkalinity and acid neutralizing capacity, In: National field manual for the collection of water quality data. U.S. Geological Survey Techniques of Water Resources Investigations Book 9, Chapter 6.6.

Rawhouser, A. K., L. P. Grace, R. A. Lofgren, R. S. Glesne, J. R Boetsch, C. A. Welch, B. A. Samora, P. Crain, and R. E. Holmes. 2012. North Coast and Cascades Network water quality monitoring protocol. Natural Resource Report NPS/NCCN/NRR—2012/571. National Park Service, Fort Collins, Colorado.

Reynoldson, T. B., R. H. Norris, V. H. Resh, K. E. Day, and D. M. Rosenberg. 1997. The reference condition: A comparison of multimetric and multivariate approaches to assess water-quality impairment using benthic macroinvertebrates. Journal of the North American Benthological Society 16:833–852.

Samora, B. A., and D. Clow. 2002. Episodic acidification of Eunice Lake, Mount Rainier National Park, Washington. Unpublished report.

Scheuhammer, A. M., M. W. Meyer, M. B. Sandheinrich, and M. W. Murray. 2007. Effects of environmental methylmercury on the health of wild birds, mammals, and fish. Ambio 36:12–18.

Schindler, D. W. 1987. Detecting ecosystem responses to anthropogenic stress. Canadian Journal of Fisheries and Aquatic Sciences 44 (Suppl.):6–25.

Sickman, J. O., J. M. Melack, and D. W. Clow. 2003. Evidence for nutrient enrichment of high-elevation lakes in the Sierra Nevada, California. Limnology and Oceanography 48:1885–1892.

Skjelkvåle, B. L., and R. F. Wright. 1998. Mountain lakes; Sensitivity to acid deposition and global climate change. Ambio 27:280–286.

Spencer, C.N. 1991. Study Module B: Evaluation of historical sediment deposition related to land use through analysis of lake sediments. In: Flathead Basin Forest Practices Water Qulaity and Fisheries Cooperative Program, Final Report. p. 19–39.

Thomas A., and C. Torgersen. In prep. Relationships of landscape characteristics to multivariate classifications of zooplankton assemblages and water quality of lentic systems in Mount Rainier National Park, WA, USA.

Turney, G. L., N. P. Dion, and S. S. Sumioka. 1986. Water quality of selected lakes in Mount Rainier National Park, Washington, with respect to lake acidification. U.S. Geological Survey Water Resources Investigations Report 85-4254.

Vinebrooke, R. D., and P. R. Leavitt. 1999. Phytobenthos and phytoplankton as bioindicators of climate change in mountain lakes and ponds: An HPLC-based approach. Journal of the North American Benthological Society 18:14–32

[WDOE] Washington Department of Ecology. 2012. Water quality standards for surface waters of the State of Washington, Chapter 173-201A-WAC. Publication no. 06-10-091 (revised). 117 p.

Williams, M. W., M. Losleben, N. Caine, and D. Greenland. 1996. Changes in climate and hydrochemical responses in a high-elevation catchment in the Rocky Mountains, USA. Limnology and Oceanography 41:939–946.

Wright, J. F., D. W. Sutcliffe, and M. T. Furse. 2000. Assessing the biological quality of fresh waters: RIVPACS and other techniques. Freshwater Biological Association, Ambleside, Cumbria, U.K.

4.3 Stream Water Quality

(Robert L. Hoffman, USGS FRESC)

4.3.1 Introduction

Streams and rivers are an integral part of the landscape of Mount Rainier National Park (MORA). Their characteristics express variations in local conditions associated with geology, geomorphology, hydrology, climate, and environmental stochasticity, and are useful indicators of watershed vitality and health (Naiman et al. 1992). Water quality comprises physical, chemical, and biological constituents that express the overall health and condition of streams and rivers. In the Pacific Northwest, streams and rivers are generally oligotrophic relative to nutrient status, low in acid neutralizing capacity, high in chemical quality, and typically cool in temperature (Welch et al. 1998). There are approximately 470 mapped MORA streams and rivers present in 10 major and 3 relatively minor watersheds (Figure 13), and the tributaries of all but 2 watersheds (Huckleberry Creek, Ohanapecosh River) are glacially influenced.

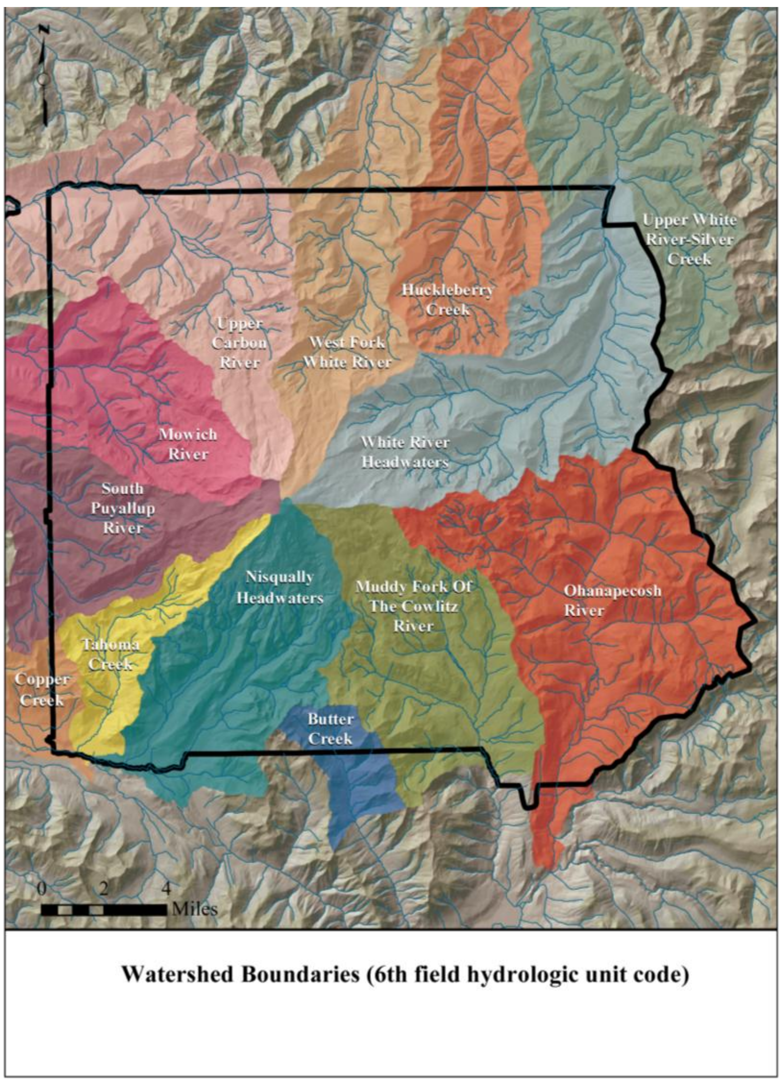

Figure 13. 6th field HUC watershed boundaries, Mount Rainier National Park.

4.3.2 Approach

Several sources of information and data were used to complete the assessment of the water quality of MORA streams and rivers. Assessment of trends in anions and cations was accomplished by summarizing the results of an analysis completed using data collected from 6 sites, 2003–2010 (Nieber et al. 2011). Descriptive statistics (i.e., mean, SD, median, and range) were calculated for concentrations of 13 water quality parameters measured at 29 sites, 1985–1995 (MORA, unpublished data). The occurrence and distributions of macroinvertebrates were assessed based on samples collected from 13 stream and river sites, 2005–2007, and these results were used to evaluate stream condition at each of the sites. Macroinvertebrates in 80 streams were also sampled, 2004–2006, and preliminary observed versus expected (O/E) scores based on these samples were used to predict the condition of 45 of the streams (A. Rawhouser, NOCA, unpubl. data). Resuts of the ranking of wadeable steam and river catchments of management concern identified in Appendix B and D of the NCCN Water Quality Monitoring Protocol (Rawhouser et al. 2012) were summarized to elucidate the potential level of risk of MORA steams and rivers to impairment.

4.3.3 Reference Conditions and Comparison Metrics

The condition of MORA streams and rivers were assessed using results and criteria from the following sources and programs. Concentrations of anions and cations in MORA streams and rivers were compared to concentrations measured at 5 western USGS Hydrologic Benchmark Network water quality stations in Colorado, Idaho, Oregon, and Washington. Washington surface water quality standards (WDOE 2012) for dissolved oxygen, pH, and water temperature were used to assess the condition of these parameters in MORA streams and rivers. Conductivity, total nitrogen, and total phosphorus in MORA streams and rivers were compared to disturbance thresholds determined for these parameters as part of the EMAP assessment of western streams and rivers (Stoddard et al. 2005). The general conditions of the 13 MORA stream and river sites were assessed using the Level II assessment indices developed as part of the Oregon Department of Environmental Quality stream macroinvertebrate protocol (ORDEQ 1999). The indices included: (1) taxa richness (total number of families); (2) mayfly richness (total number of families); (3) stonefly richness (total number of families); (4) caddisfly richness (total number of families); (5) % Chironomidae (total number of chironomids divided by the total number of organisms sorted); and (6) % dominance (total number of the 3 most abundant taxa divided by total number of organisms sorted).

As part of the development of the NCCN Water Quality Monitoring Protocol (Rawhouser et al. 2012), a ranking process was developed to estimate the level of risk of MORA wadeable stream and river catchments to impairment due to human activities and changes associated with water quality. Initially, a list of streams and rivers of management concern was created based on professional opinion as well as any streams and rivers that were 303d listed under the Clean Water Act (CWA). The human activity metrics included trail density, road density, road crossings/stream km, % developed area, and number of mines within a watershed. Water quality associated metrics included: (1) waters classified as impaired (Category 4, 4a, 4b or 5) from the 303(d) report that are within or drain into MORA (Rawhouser et al. 2012, Table 1.12, p. 26); (2) streams that drain from watersheds classified as being at a high risk of impairment during the watershed assessment (Rawhouser et al. 2012, p. 23–24); (3) waters ranked at a high risk level in the informed risk assessment (Rawhouser et al. 2012, Table 1.24, p. 43); and (4) water bodies within MORA that receive water from any of the above sources, even if those sources are outside park boundaries.

4.3.4 Results and Assessment

Nieber et al. (2011) analyzed and summarized trends in 3 anions and 5 cations for 6 MORA stream and river sites that were sampled 2003–2010. Of the 48 cases (6 sites x 8 ions), they found 18 cases of significant positive trends in ion concentrations, 6 cases of significant negative trends, and 24 cases with null trends (Table 19). Most of the 18 positive trends (50%) were associated with increases in concentrations of NH_4^+ (5 of 6) and K^+ (4 of 6). Mean concentrations for the 8 ions in samples collected from the 6 sites are summarized in Table 20.

Between 137 and 332 measurements were completed at 29 MORA stream and river sites between 1985 and 1995 for 13 water quality parameters (Table 21). Mean nutrient concentrations were relatively low (0.005–0.04 mg/L), as were alkalinity, conductivity, and water temperature. Mean dissolved oxygen concentration was relatively high at 10.5 mg/L, and pH ranged from 5.5 to 8.3.

Twelve macroinvertebrate groups comprising 100 taxa were identified in MORA stream and river samples collected 2004–2007 (Table 22). Forty-six percent of taxa were in the orders Plecoptera and Trichoptera, and an additional 46% were in the orders Ephemeroptera, Diptera (Chironomidae), and Diptera (not-Chironomidae). Most taxa were relatively limited in distribution with 52% present at only 1or 2 sites (31 and 21 taxa, respectively). Only 15 taxa (Table 23) were present at >50% of sites (7 to 9) and 40% of these taxa were in the order Ephemeroptera.

Table 19. Trend analysis (2003–2010) for 3 anions and 5 cations at 6 locations in MORA (from Nieber et al. 2011). (+ = positive trend; - = negative trend; 0= no trend).

Location	Obs.	Cl^-	NO_3^-	SO_4^{2-}	Na^+	NH_4^+	K^+	Mg^{2+}	Ca^{2+}
Chinook Ck at Ohanapecosh R	7	0	0	0	0	+	+	+	0
Nisqually R below Longmire	9	+	0	0	+	+	+	+	+
Nisqually R at Sunshine Point	9	–	0	+	–	+	0	0	–
Nisqually R at Glacier Bridge	8	–	0	0	–	0	0	0	–
Ohanapecosh R at Campground	9	0	0	+	0	+	+	+	0
Ohanapecosh R at Chinook Ck	8	+	0	0	0	+	+	0	0

Table 20. Anions and cations (µeq/L) for 6 MORA stream sites — 2007 Descriptive statistics. (Rybka et al. 2008; Nieber and Johansen 2010; and Nieber et al. 2011)

Ion	Mean	Median	SD	Range
Chloride	49.7	31.4	49.8	10.4–193.3
Nitrate	0.30	0.299	0.24	0.01–0.89
Sulfate	53.7	40.1	41.0	13.4–177.4
Sodium	123.2	111.6	66.1	53.2–293.3
Ammonium	2.10	1.77	1.32	0.52–5.34
Potassium	10.1	9.3	5.0	4.2–21.9
Magnesium	76.2	63.1	51.4	21.9–203.3
Calcium	227.9	215.2	112.1	64.3–379.5

Table 21. Descriptive statistics for 29 MORA stream and river sites sampled 1985–1995 (MORA, unpubl. data).

Parameter	*n*[1]	Mean	SD	Median	Range
Water Temperature (°C)	326	6.9	3.1	6.8	1–19.5
Conductivity (µS/cm)	286	61.7	71.5	41.7	5.7–518.3
Dissolved Oxygen (mg/L)	137	10.5	1.3	10.8	2–13
pH (standard units)	309	7.4	0.4	7.4	5.5–8.3
Alkalinity (µeq/L)	283	186.8	176.1	114.2	16–984
Turbidity	301	32.4	55.4	3.2	0.09–330
Suspended Solids	332	324.5	733.9	36.6	0–6171.7
Dissolved Solids	264	52.1	30.8	45.0	0–214
Total Nitrogen (mg/L)	263	0.029	0.049	0.016	0.001–0.52
Ammonia (mg/L)	274	0.005	0.009	0.002	0–0.066
Nitrate-Nitrite (mg/L)	284	0.017	0.017	0.015	0–0.17
Total Phosphorus (mg/L)	283	0.04	0.03	0.034	0.001–0.185
Orthophosphate (mg/L)	283	0.022	0.02	0.017	0–0.119

[1]total number of measurements completed at the 29 sites

Table 22 Taxa Groups collected from 13 MORA stream and river sites, 2004–2007.

Group	Level of Identification	# Taxa
Arachnida	Class	1
Coleoptera	Family - Genus	3
Diptera – Chironomidae	Complex - Genus	17
Diptera – not Chironomidae	Family – Genus	12
Ephemeroptera	Genus – Species	17
Gastropoda	Family	1
Nematoda	Phylum	1
Oligochaeta	Subclass	1
Ostracoda	Class	1
Plecoptera	Family – Species	24
Trichoptera	Group – Species	21
Turbellaria	Class	1

Table 23. Taxa collected from >50% (7 to 9) of the 13 MORA stream and river sites from which macroinvertebrates were collected, 2005–2007.

# Sites	Taxon	Order - Family
9	*Baetis bicaudatus*	Ephemeroptera - Baetidae
	Dicranota spp.	Diptera - Tipulidae
	Drunella doddsi	Ephemeroptera - Ephemerellidae
	Epeorus grandis	Ephemeroptera - Heptageniidae
	Oligochaeta	
	Rhyacophila brunnea/vemna Group	Trichoptera - Rhyacophilidae
8	Chloroperlidae	Plecoptera
	Megarcys spp.	Plecoptera - Perlodidae
	Rhithrogena spp.	Ephemeroptera - Heptageniidae
7	*Ameletus* spp.	Ephemeroptera - Ameletidae
	Cinygmula spp.	Ephemeroptera - Heptageniidae
	Eukiefferiella spp.	Diptera - Chironomidae
	Rhyacophila hyalinata Group	Trichoptera - Rhyacophilidae
	Simulium spp.	Diptera - Simuliidae
	Zapada cinctipes	Plecoptera - Nemouridae

Forty-five MORA wadeable stream and river catchments of management concern were ranked relative to risk of impairment based on the human activity metrics listed in 4.3.3. For an explanation of this process see Rawhouser et al. (2012:Appendix B). Of these catchments, 23 (51%) were ranked as being of moderate (stressors are readily apparent and measureable, but with limited spatial extent) to high (stressors are substantial and measureable, highly noticeable and affect a large area) risk of impairment (Rawhouser et al. 2012:Appendix B). Thirty-three catchments were ranked based on water quality associated mertrics also listed in 4.3.3. Of these catchments, 21 (64%) were ranked as being of moderate to high risk of impairment, with 14 of these also ranked as threatened (Rawhouser et al. 2012:Appendix D). None of the wadeable stream and river catchments of management concern were 303d listed under the CWA.

Assessment—The median concentrations of the 3 anions and 5 cations measured at the 6 MORA stream and river sites (Table 20) were determined to be relatively comparable to the median concentrations of ions measured at the 5 western USGS Hydrologic Benchmark Network water quality stations (Table 24). This result indicates that ion concentrations at the MORA sites fit well within the overall variability of ion concentrations among all of the sites. Of the 8 ions, the concentrations of Ca^{2+}, K^{+}, Mg^{2+}, and SO_4^{2-} at the MORA sites tended to be the lowest among all of the sites.

Water quality standards for surface waters developed by Washington State (WDOE 2012) have been grouped into 4 criteria classes: extraordinary, excellent, good, and fair. Three of the parameters used as part of the assessment of water quality based on these criteria classes include dissolved oxygen, pH, and water temperature. The 29 MORA stream and river sites sampled 1985–1995 had measurements for 2 or all of these parameters. Based on their mean values, all of the sites could be classified as extraordinary: (1) DO > 9.5 mg/L; (2) pH = 6.5–8.5; and (3) temperature < 16°C.

Disturbance thresholds for concentrations of conductivity, total nitrogen, and total phosphorus that were developed as part of the EMAP assessment of western streams and rivers (Stoddard et al. 2005) were also used to assess the condition of the 29 MORA stream and river sites sampled 1985–1995 (Table 25). The primary disturbance categories are most-disturbed and least-disturbed. Based on the thresholds for mountain systems for each category and parameter, each of the MORA streams with conductivity and total nitrogen concentration measurements could be categorized as least-disturbed; whereas for sites with total phosphorus concentration measurements, 3 sites could be categorized as least-disturbed, 8 sites could be categorized as moderately-disturbed, and 11 sites could be categorized as most-disturbed (Table 25). According to Binkley et al. (2002), streams can naturally acquire substantial quantities of phosphate from minerals in bedrock and subsoil. Additionally, the concentration of phosphate in streams and rivers can be influenced by rates of erosion and organic matter input (Hayslip et al. 2004). Therefore, phosphorus concentration levels in streams and rivers in protected areas such as National Parks are typically a result of local, naturally occurring processes. Although there presently are no State criteria for phosphorus concentration thresholds (Hayslip et al. 2004), the EPA recommendation is that phosphorus be limited to 100μg/L for streams that do not flow into lakes (MacDonald et al. 1991); none of the mean phosphorus concentrations measured at the MORA stream and river sites were ≥100μg/L. So, although 11 of the MORA sites could be categorized as most-disturbed based on their total phosphorus mean concentrations, these higher levels are derived naturally and naturally occurring phosphorus concentrations are rarely acutely or chronically toxic (MacDonald et al. 1991).

The mean alkalinity of the 29 MORA stream and river sites sampled 1985–1995 was 186.8 μeq/L (median = 114.2 μeq/L; range = 16–984 μeq/L). Omernik and Griffith (1986) and Omernik et al. (2005) determined that the range for alkalinity in the Washington Cascades was <50–200 μeq/L, and Henderson (1988) found that the range of alkalinities at 49 Oregon Cascades sites was 28–720 μeq/L (median = 370 μeq/L). Based on these values, the range of alkalinities for the MORA sites are comparable to the general ranges of alkalinities in the Cascade Range.

Aquatic macroinvertebrates can also be used as indicators of the condition of water quality in streams and rivers. The Oregon Department of Environmental Quality used macroinvertebrate-based criteria for developing several assessment levels for determining stream and river water quality as part of a stream macroinvertebrate protocol (ORDEQ 1999). Level II comprised 6 criteria whose total sum determined to which of 3 condition classes a site would be assigned (Table 26). This process was applied to the 13 MORA stream and river sites for which macroinvertebrates were collected 2005–2007. This assessment revealed that 5 sites could be assigned to the no impairment group; 6 sites could be identified as having moderate impairment; and 2 sites (North Puyallup River and Tahoma Creek) could be categorized as being severely impaired (Table 26). An important caveat to these results is that the occurrence and distribution of macroinvertebrates in streams and rivers is greatly dependent on local environmental conditions such as water temperature; substrate composition; water level, current, and discharge; levels of suspended sediment and turbidity; and dissolved oxygen concentration (Ward 1992). So, although a site can be classified as impaired based on the macroinvertebrate taxa present at or absent from the site, that condition may actually be an expression of the site's naturally occurring environmental conditions and associated limitations, and, therefore, not a result of some form of anthropogenic disturbance. This is most likely true for streams and rivers in protected areas like MORA. However, anthropogenic disturbance cannot be ruled out; the Tahoma Creek site has been significantly altered by attempts to protect the adjacent West Side Road, and dredging has occurred in the Carbon and Nisqually Rivers and in Tahoma Creek. Additional information concerning the condition of MORA streams and rivers will be available when the results of the analysis of macroinvertebrate presence in 63 additional MORA streams are available (A. Rawhouser, NOCA, pers. comm.).

In 2004–2006, 80 streams were sampled for macroinvertebrates, and used to develop a preliminary impairment prediction model based on macroinvertebrate O/E scores (A. Rawhouser, NOCA, unpubl. data). Twenty streams were used to generate reference O/E scores, 45 streams were used as assessment sites, and 15 streams were used as QA/QC sites. Model analysis determined that all of the streams were potentially impaired. However, the O/E scores for 21 streams (47%) were below the range of O/E scores for the reference streams; scores for 19 streams (42%) were within the range of reference stream scores; and the scores of 5 streams (11%) were above the range of reference stream scores. Although these results are preliminary, they show that only a small percent of the streams evaluated by this model appear to be impaired beyond the baseline calculated for the reference streams.

Overall, it appears that the MORA streams and rivers that have been used in this assessment are generally in good condition relative to the environmental characteristics of the watersheds and landscape within which they are embedded. However, channel changes appear to be occurring in some rivers due to an increase in shoreline protection projects undertaken in response to increasing river aggradation, and the hyporheic zone of some rivers is also being affected by road maintenance and shoreline protection activities, which could be contributing to an increase in the frequency of impairment of MORA streams and rivers. In addition, ≥51% of wadeable stream and river catchments of management concern have been ranked as being of moderate to high risk of impairmanet based on human activity and water quality associated metrics, and 14 of these catchments have been ranked as threatened.

Table 24. Anions and cations (μeq/L): Descriptive statistics for 5 western US Hydrologic Benchmark Network water quality stations.

Station	**Location**	**Years**	***n***	**Statistic**	**Cl^-**	**NO_2^-–NO_3^-**	**SO_4^{2-}**	**Na^+**	**NH_4^+**	**K^+**	**Mg^{2+}**	**Ca^{2+}**
Andrews Creek[1]	Mazama, WA	1971–1995	75–165	Range	<2.8–68	0.7–15	<2.1–150	35–320	<0.7–13	2.6–38	16–200	90–460
				Median	8.5	5	380	96	1.4	13	82	340
Minam River[1]	Oregon	1966–1995	81–204	Range	<2.8–76	<0.7–31	<2.1–210	35–150	<0.7–14	10–54	25–190	120–440
				Median	14	5.7	33	100	1.4	28	120	300
Big Jacks Creek[1]	Bruneau, ID	1967–1995	41–111	Range	39–210	<0.7–86	6–290	170–700	<0.7–12	72–170	110–350	310–950
				Median	130	7.1	150	480	2.9	97	230	600
Vallecito Creek[2]	Bayfield, CO	1963–1995	74–234	Range	<2.8–280	<0.7–50	35–540	4.4–160	<0.7–12	5.1–62	40–420	180–800
				Median	16	7.9	170	48	2.1	15	160	500
Halfmoon Creek[2]	Malta, CO	1965–1995	100–256	Range	<2.8–70	2.1–24	6.2–270	26–130	<0.7–16	3–36	96–540	220–750
				Median	14	9.3	110	65	1.4	15	300	500

[1]Mast and Clow (2000)

[2]Mast and Turk (1999)

Table 25. Range of means for concentrations of conductivity (μS/cm), total nitrogen (μg/L), and total phosphorus (μg/L) in MORA streams and rivers sampled 1985–1995; and concentration thresholds for mountain systems used in EMAP assessments of western streams and rivers (Stoddard et al. 2005).

Parameter	**MORA**	**Most-Disturbed Threshold**	**Least-Disturbed Threshold**
Conductivity (*n* = 28)	15.6–196.6	>1000	≤500
Total Nitrogen (*n* = 22	7.7–71.2	>200	≤125
Total Phosphorus (*n* 22)	8.2–95.5	>40	≤10

Table 26. Condition of 13 MORA stream sites sampled 2005–2007, based on Oregon Department of Environmental Quality Stream Macroinvertebrate Protocol Level II Assessment criteria (OR DEQ 1998).

Site	Taxa Richness	Mayfly Richness	Stonefly Richness	Caddisfly Richness	Percent Chironomidae	Percent Dominance	Score[7]	Condition[8]
Chinook Creek	5	5	5	5	5	1	26	No impairment
Frying Pan Creek	3	3	3	3	5	1	18	Moderate impairment
Nisqually River[1]	3	3	5	1	5	1	18	Moderate impairment
N. Puyallup River	1	1	1	1	3	1	8	Severe impairment
Ohanapecosh River[2]	3	3	5	3	5	1	20	Moderate impairment
Ohanapecosh River[3]	5	5	5	3	5	1	24	No impairment
Ohanapecosh River[4]	5	5	5	3	5	1	24	No impairment
Ohanapecosh River[5]	3	3	5	3	5	1	20	Moderate impairment
Panther Creek	5	5	5	3	5	1	24	No impairment
Tahoma Creek	1	3	1	1	1	1	8	Severe impairment
Twin Falls Creek	5	5	5	3	5	3	26	No impairment
West Fork White River	3	3	3	3	5	1	18	Moderate impairment
White River at CG[6]	3	3	5	3	5	1	20	Moderate impairment

[1]Below Longmire;

[2]At oil spill site near Visitor Center;

[3]Downstream of oil spill site

[4]Upstream of oil spill site;

[5]At Chinook Creek;

[6]Campground

[7]Sum of the 6 criteria;

[8]No impairment: >23; moderate impairment: 17–23; severe impairment: <17

4.3.5 Emerging Issues
There are a number of issues that have the potential of affecting lotic ecosystems (Malmqvist and Rundle 2002). Climate change will alter precipitation patterns and the variability of precipitation events; intensify the impacts of floods and droughts; and increase uncertainty in water quality, quantity, availability, and the capacity for sustaining natural lotic ecosystem services (Covich 2009). Altered flow regimes and the impact of climate change on glaciers and snow precipitation will affect the overall availability of water, potentially increasing demands for water and conflicts related to its use; as well as complicating the ability of resource agencies such as the NPS in managing aquatic ecosystems (Everest et al. 2004). Climate change will also likely affect water quality due to perturbations such as glacier recession, increases in debris flow events and sedimentation, and changes in the timing of snowmelt and runoff. Any future increase in the atmospheric deposition of nutrients into lotic ecosystems will also alter water quality and the trophic status of streams and rivers, even in protected reserves such as national parks and wilderness areas (Cole and Landres 1996; Malmqvist and Rundle 2002). Finally, the accidental or intentional introduction of exotic and nonnative species into lotic ecosystems could result in the loss of native species and altered biotic assemblages (Cole and Landres 1996), which could lead to changes in the biodiversity and water quality characteristics of streams and rivers (Allan and Flecker 1993; Malmqvist and Rundle 2002).

4.3.6 Information and Data Needs–Gaps
At present, MORA has compiled water quality data for a limited number of streams and rivers in the park. Data collection covers the periods 1985–1995 and 2003–2010. The data for these 2 collection periods should be combined into a single database and published as a Natural Resource Data Series report.

MORA will also participate in the NCCN water quality monitoring program. The program sampling design includes up to 35 eligible wadeable streams in MORA (14 of which have been designated as of highest priority) from which will be collected samples for 10+ water quality parameters (Rawhouser et al. 2012). However, current funding only supports 6 high priority sites in MORA. Benthic macroinvertebrates will be sampled as part of the monitoring effort, and this will help increase the MORA benthic macroinvertebrate database and enhance the park’s ability to elucidate the distribution and occurrence of these invertebrates in MORA streams and rivers. Ultimately, if more funding becomes available to implement a larger program beyond the 6 potentially impacted sites, the monitoring effort would standardize the park’s sampling effort, enhance consistency in data collection, and eventually create a database that can be used for inferring the condition of streams and rivers throughout the park.

Data concerning the hyporheic zone of MORA streams and rivers is limited, and an effort should be made to increase the available information for this important lotic habitat. The placement of continuous temperature data loggers in selected MORA streams and rivers would also contribute useful information about the potential effects of climate change on the temperature environment of these lotic systems.

4.3.7 Literature Cited

Allan, J. D., and A. S. Flecker. 1993. Biodiversity conservation in running waters. BioScience43:32–43.

Binkley, D., G. G. Ice, J. Kaye, and C. A. Williams. 2004. Nitrogen and phosphorus concentrations in forest streams of the United States. Journal of the American Water Resources Association 40:1277–1291.

Cole, D. N., and P. B. Landres. 1996. Threats to wilderness ecosystems: Impacts and research needs. Ecological Applications 6:168–184.

Covich, A. P. 2009. Emerging climate change impacts in freshwater resources: A perspective on transformed watersheds. Resources for the Future (RFF) Report.

Everest, F. H., D. J. Stouder, C. Kakoyannis, L. Houston, G. Stankey, J. Kline, and R. Alig. 2004. A review of scientific information on issues related to the use and management of water resources in the Pacific Northwest. General Technical Report PNW-GTR-595. USDA Forest Service, Pacific Northwest Research Station, Corvallis, OR.

Hayslip, G. A., L. G. Herger, and P. T. Leinenbach. 2004. Ecological condition of Western Cascades ecoregion streams. EPA 910-R-04-005. U.S. Environmental Protection Agency, Region 10, Seattle, WA.

Henderson, S. 1988. Regional patterns of alkalinity in Oregon streams: An overview of ecological regionalization [thesis]. Oregon State University, Corvallis, Oregon.

MacDonald, L. H., A. W. Smart, and R. C. Wissmar. 1991. Monitoring guidelines to evaluate effects of forestry activities on streams in the Pacific Northwest and Alaska. EPA 910-9-91-001. U.S. Environmental Protection Agency, Region 10, Water Division, Nonpoint Source Section, Seattle, Washington.

Malmqvist, B., and S. Rundle. 2002. Threats to the running water ecosystems of the world. Environmental Conservation 29:134–153.

Mast, M. A., and D. W. Clow. 2000. Environmental characteristics and water-quality of Hydrologic Benchmark Network stations in the Western United States. U.S. Geological Survey Circular 1173–D. 115 p.

Mast, M. A., and J. T. Turk. 1999. Environmental characteristics and water-quality of Hydrologic Benchmark Network stations in the West-Central United States, 1963–95. U.S. Geological Survey Circular 1173–C. 105 p.

Naiman, R. J., T. J. Beechie, L. E. Benda, D. R. Berg, P. A. Bisson, L. H. MacDonald, M. D. O’Connor, P. L. Olson, and E. A. Steel. 1992. Fundamental elements of ecologically healthy watersheds in the Pacific Northwest coastal ecoregion. In: Naiman, R. J., editor. Watershed management: Balancing sustainability and environmental change. Springer-Verlag, New York, New York.

Nieber, A., and A. M. Johansen. 2010. Lake and stream water chemistry in Mount Rainier National Park; Report for data collected in summer and fall 2009 and trend analysis for 2003–2009. Central Washington University Chemical Analysis Laboratory, Ellensburg, WA.

Nieber, A., C. Johnson, and A. M. Johansen. 2011. Lake and stream water chemistry in Mount Rainier National Park; Report for data collected in summer and fall 2010 and trend analysis for 2003–2010. Central Washington University Chemical Analysis Laboratory, Ellensburg, WA.

Omernik, J. M., and G. E. Griffith. 1986. Total alkalinity of surface waters: A map of the western region. Journal of Soil and Water Conservation41:374–378.

Omernik, J. M., G. E. Griffith, J. T. Irish, and C. B. Johnson. 2005. Total alkalinity of surface waters. Western Ecology Division, U.S. Environmental Protection Agency, Corvallis, Oregon.

[ORDEQ] Oregon Department of Environmental Quality. 1999. Water quality monitoring technical guidebook, Oregon plan for salmon and watersheds. Oregon DEQ Laboratory, Portland, Oregon.

Rawhouser, A. K., L. P. Grace, R. A. Lofgren, R. S. Glesne, J. R. Boetsch, C. A. Welch, B. A. Samora, P. Crain, and R. E. Holmes. 2012. North Coast and Cascades Network water quality monitoring protocol. Natural Resource Report NPS/NCCN/NRR–2012/571. National Park Service, Fort Collins, Colorado.

Rybka, S., M. Sorey, and A. M. Johansen. 2008. Lake and stream water chemistry in Mount Rainier National Park; Report for data collected in summer 2007 and trend analysis for 2003–2007. Central Washington University Chemical Analysis Laboratory, Ellensburg, Washington.

Stoddard, J. L., D. V. Peck, S. G. Paulson, J. Van Sickle, C. P. Hawkins, A. T. Herlihy, R. M. Hughes, P. R. Kaufmann, D. P. Larsen, G. Lomnicky, A. R. Olson, S. A. Peterson, P. L. Ringold, and T. R. Whittier. 2005. An ecological assessment of western streams and rivers. EPA 620/R-05/005, U.S. Environmental Protection Agency, Washington D.C.

Ward, J. V. 1992. Aquatic insect biology 1. Biology and habitat. John Wiley and Sons, New York, New York.

[WDOE] Washington Department of Ecology. 2012. Water quality standards for surface waters of the State of Washington, Chapter 173-201A-WAC. Publication no. 06-10-091 (revised).

Welch, E. B., J. M. Jacoby, and C. W. May. 1998. Stream quality. In: R. J. Naiman, and R.E. Bilby, editors. River ecology and management: Lessons from the Pacific coastal region. Springer-Verlag, New York, New York. p. 69–94.

4.4 Landscape-scale Vegetation Dynamics

(Andrea Woodward and Patricia Haggerty, USGS FRESC)

4.4.1 Introduction

Mountainous terrain, with more than 3600 m relief (11,811 ft), along with glacier-carved topography creates large- and small-scale climatic variation in Mount Rainier National Park (MORA). Climatic variation coupled with volcanism, glacier activity, large-scale disturbances, and a variety of geologic substrates and soil types, have resulted in rich vegetation diversity over relatively short distances (Franklin et al. 1988, Crawford et al. 2009). Approximately 58% of the park is forested, with temperature, moisture and disturbance regimes strongly determining distribution of forest types (Franklin et al. 1988). The distribution of forest zones, in particular, is driven by temperature regime, which is determined by elevation. Specifically, the Western Hemlock (*Tsuga heterophylla*) zone occurs below 900 m (2953 Ft) elevation, the Silver Fir (*Abies amabilis*) zone occurs from approximately 900 to 1500 m (2953–4921 ft), and the Mountain Hemlock (*Tsuga mertensiana*) zone occurs from approximately 1500 to 2200 m (2953–7218 ft), including subalpine parklands. Communities within zones depend on moisture regime, specifically depth and duration of snowpack at high-elevations and summer moisture regime at lower elevations, as well as local patterns due to aspect and topography. For the park as a whole, the mountain creates a rainshadow from southwest to northeast with half as much snow falling at Sunrise compared with Paradise (Biek 2000). However, at low elevations, the northwest quadrant receives the highest precipitation, the southeast quadrant is comparatively dry and warm, the northeast quadrant is the most continental, and the southwest is intermediate between the northwest and southwest. These differences are mostly manifest in understory vegetation, but the White River drainage in the northeast includes the continental species Engelmann Spruce (*Picea engelmanii*), Lodgepole Pine (*Pinus contorta*), and Subalpine Fir (*Abies lasiocarpa*); while Sitka Spruce (*Picea sitchensis*), a coastal species, is found in the northwest part of the park. Subalpine meadow types reflect snowpack and are classed into 2 groups: shrub dominated (heather [*Phyllodoce, Cassiope*]; huckleberry [*Vaccinium* spp.]) or herbaceous. Herbaceous meadows are further classed as lush herbaceous meadows (Sitka Valerian [*Valeriana sitchensis*], Indian Hellebore [*Veratrum viride*], Showy Sedge [*Carex spectabilis*], Arctic Lupine [*Lupinus arcticus*]); low herbaceous meadows (High Mountain Cinquefoil [*Potentilla flabellifolia*], pussytoes [*Antennaria* spp.], Black Alpine Sedge [*Carex nigricans*]); or dry grasslands (Vasey Greenleaf Fescue [*Festuca viridula*], Arctic Lupine [*Lupinus arcticus*]). The alpine environment occurs above the subalpine parklands where available substrate is inhabited by fell-field and snowbed plant communities and dwarf-heath shrublands, including primarily heathers. Various wetlands such as fens, marshes, wet meadows, aquatic beds, and riparian forests and shrublands are found throughout the park. Although they occupy a very small portion of the landscape, wetlands often support a disproportionately high percentage of landscape biodiversity (Apostol and Sinclair 2006, Flynn et al. 2008, Van Dyke 2008, Crawford et al. 2009). Age-structure of forests is determined by disturbance regime, which in MORA includes fire, windthrow, avalanches, insects, diseases, and lahars (volcanic mudflows) (Crawford et al. 2009).

In consulation with park staff, we chose to focus on landscape-scale vegetation dynamics, forest health, and plant biodiversity from the wealth of potential indicators of condition and trend of park vegetation. To assess landscape-scale vegetation dynamics, we used maps of nationally defined vegetation classes from several sources. To evaluate forest health, we assessed data regarding tree mortality due to biological and physical agents, fire regime, effects of blister rust on Whitebark Pine, and potential air quality effects. To describe the status and trend of biodiversity, we report what is known about the spread of exotic plant species, the condition of wetlands and subalpine-alpine areas, and the status of sensitive species. We conducted these analyses using the relevant ecological boundaries for each topic rather than restrict the analyses to administrative boundaries.

Vegetation distribution has been responsive to climate change over geologic time-scales (Davis and Shaw 2001) and is expected to respond as contemporary climate change accelerates (Peterson et al. 1997, Shafer et al. 2001). Shifts in vegetation distribution may be especially dramatic in mountainous areas where steep environmental gradients create closely spaced ecoclines and ecotones (Guisan et al. 1995, Peterson et al. 1997, Beniston 2003). Moreover, the island-like distribution of subalpine and alpine plant communities may limit the potential for migration to suitable areas. Changes in distribution will result from direct effects of climate on plant physiology, as well as indirectly though changes in snowpack, flow regime, soil moisture, phenology, competition and disturbance regime (Mote 2003, McKenzie et al. 2004, Littell et al. 2008, Raffa et al. 2008, van Mantgem et al. 2009). Changes in plant distribution will accordingly affect other biotic components of ecosystems through alteration of habitat conditions. Finally, vegetation change has the potential to alter climate change through feedback relationships (Levis et al. 1999, Bonan 2008).

4.4.2 Approach

We used metrics developed from the newly completed vegetation map of MORA (Nielsen and Copass, In prep.) to evaluate current status of landscape-scale vegetation distribution. This map classifies vegetation consistent with the Federal Geographic Data Committee national standards for vegetation classification (FGDC 2008). We also used a crosswalk of MORA vegetation to Ecological Systems (Comer et al. 2003) provided by NatureServe as part of a contract to support this project. ES units are mapped nationally and assessed relative to their global conservation status.

Predictions regarding the effect of climate change on vegetation are usually developed for biomes at the global scale (e.g., Nielson 2005) and for communities or individual species at national (e.g., McKenney et al. 2007), regional (e.g., Rehfeldt et al. 2006), or sub-regional scales (e.g., Shafer et al. 2001). Biome models are generally too coarse to be informative at the park scale and were not considered. Methods to predict changes in species distributions are often based on correlations between current distribution (e.g., Shafer et al. 2001, Rehfeldt and others 2006) or growth (Littell et al. 2010) and biophysical variables. Other models include a process-based component to describe presence or absence of a particular species (e.g., Coops and Waring 2011). Alternatively, species and communities at risk due to climate change in the Pacific Northwest have been identified by ranking species according to a list of attributes and threats (Aubry et al. 2011, Devine et al. 2012).

We also used regionally relevant literature to identify species and vegetation communities thought to be vulnerable to continuing climate change. These assessments indicate whether changes seen in the twentieth century are likely to continue and whether new shifts can be expected.

4.4.3 Reference Conditions and Comparison Metrics

We have no historic vegetation map that could be used as a reference condition. The USDA Forest Service LANDFIRE Program (Landscape Fire and Resource Management Planning Tools, http://landfire.gov/vegetation.php, accessed November 2012) provides a Biophysical Settings map layer to represent the vegetation that may have been dominant on the landscape prior to Euro-American settlement. However, this layer is constructed using quantitative state-and-transition models describing succession and fire regime but not changes in climate.

The metrics we used to summarize current vegetation include: (1) current areal extent and map of MORA vegetation classes to describe current status of landscape-scale vegetation pattern; (2) proportion that each ES class contributes to total park area to identify classes that are significant to the park; and (3) the global conservation status of each ES class to indicate its global significance. We also provided an ESRI file geodatabase with the land cover rasters that were used by NatureServe to develop the crosswalks.

4.4.4 Results and Assessment

Current Condition

The diversity of MORA vegetation is evident in the environmental range encompassed by the 31 vegetated map classes found in the park (Table 27, Figure 14; bare classes have <10% vegetative cover). Classes include maritime to Rocky Mountain forest types, low elevation Douglas-fir forests to subalpine forests and meadows, and alpine meadows. The vegetation also includes a variety of wetland and rocky habitat types. None of the park vegetation classes are globally threatened, but 4 riparian-swamp associated classes are ranked between vulnerable (G3) and apparently secure (G4) based on the status of the corresponding Ecological Systems classification for each.

Several forest types are rare in the park and may therefore be of management concern. Western Hemlock-Douglas-fir forest, both wet and dry (M043 and M044), Dry Subalpine Forest and Woodland (M012), Conifer Shrubland (M015), and Subalpine Fir–Whitebark Pine Woodland (M017) all cover less than 3% of the park. Moreover, all grassland, meadow and wetland classes are also relatively rare (<3.3% of park area). Wetlands and subalpine meadows have enough significance that they are addressed in subsequent chapters (wetlands, 4.10; subalpine-alpine, 4.11).

Trend

We have no park-wide information to describe trends in vegetation pattern. Consequently, the recently completed vegetation map can serve as a baseline for assessing future changes. Trend could possibly be described by revisiting plots used to delineate the Franklin et al. (1988) vegetation map or by determining the correspondence between the vegetation classes in the 1988 map compared with the new map. The new map potentially could also be compared with the subalpine vegetation map developed by Henderson (1973).

Predicted Changes

The most consistent conclusions drawn from projections of changes in spatial distributions and vulnerability of plant communities and species due to changing climate agree that subalpine, alpine and tundra communities and species will decline or disappear (Shafer et al. 2001, Nielson et al. 2005, Rehfeldt et al. 2006, Aubry et al. 2011, Coops and Waring 2011) (Table 28). Aubry et al. (2011) also predict that wetland communities are vulnerable to climate change. Results are less consistent for lower elevation species. Shafer et al. (2001) predict that the ranges of Douglas-fir, Pacific Yew (*Taxus brevifolia*), Red Alder (*Alnus rubra*), and maybe Western Hemlock will shift from west to east of the Cascade Range due to an increase in the mean temperature of the coldest month. Other predictions for Douglas-fir include a decline west of the Cascades (Littell et al. 2010), low potential for expansion in the Pacific Northwest (Coops and Waring 2011) or low vulnerability (Rehfeldt et al. 2006, Aubry et al. 2011). These mixed results are typical of most other species that were studied. Although predictions for individual species are variable and difficult to interpret at the spatial scale of the park, the conclusion of Rehfeldt et al. (2006) that by 2090 most of the park will have a different biotic community than today may be general enough to be accurate, although this may be truer for understory communities rather than the long-lived overstory forest component.

Table 27. Areal extent of Mount Rainier National Park vegetation map classes, the corresponding Ecological Systems (ES) vegetation class, and the global status of the ES.

	MORA Code	MORA Vegetation Class Name	MORA area (ha)	Park (% area)	ES	Global Status[1]
Forests	M007	Silver Fir-Western Hemlock Warm Forest	13,650.73	14.4	4229	G5
	M042	Western Hemlock-Douglas Fir Mesic Forest	2,818.03	3.0	4224	G4
	M043	Western Hemlock-Douglas Fir Dry Forest	2,323.18	2.4	4224	G4
	M044	Western Hemlock-Douglas Fir Wet Forest	1,550.64	1.6	4224	G4
	M901	Western Hemlock-Douglas Fir Successional Depauperate Forest	3,163.28	3.3	4224	G4
	M006	Mesic Subalpine Forest and Woodland	4,865.08	5.1	4225	G5
	M008	Silver Fir-Western Hemlock Cold Forest	8,255.60	8.7	4225	G5
	M046	Mountain Hemlock-Silver Fir Forest and Woodland	11,758.25	12.4	4228	G5
	M047	Subalpine Mixed Woodland and Shrubland	5,449.51	5.7	4225	G5
	M012	Dry Subalpine Forest and Woodland	1,127.02	1.2	4242	G5
	M015	Conifer Shrubland	577.06	0.6	4233,4225	G5,G5
	M017	Subalpine Fir-Whitebark Pine Woodland	1,132.94	1.2	4233	G5
Grasslands & shrublands	M021	High Elevation Deciduous Tall Shrubland	2,555.88	2.7	5261	G5
	M063	Crowberry-Kinnikinnick-Juniper Dwarf Shrubland	178.27	0.2	5261	G5
	M077	Non-vascular Bald	123.68	0.1	7162	G4
	M052	Mixed Forb/Graminoid Herbaceous Meadow	358.63	0.4	5205	G5
	M060	Showy Sedge Mesic Subalpine Meadow	125.67	0.1	5205	G5
	M073	Talus, Scree, Snowbed and Fellfield Vegetation	1,533.59	1.6	5205	G5
	M074	Subalpine Mountain Heather Dwarf Shrubland	3,165.00	3.3	5205	G5
	M085	High Elevation Dry Post-fire Shrubland	1,434.30	1.5	5205	G5
	M906	Alpine Mountain Heather Dwarf Shrubland	947.68	1.0	5205	G5
	M067	Green Fescue Dry Herbaceous Meadow	575.21	0.6	7118	G5
	M086	Valerian-Hellebore-Luzula Mesic Subalpine Meadow	296.95	0.3	7118	G5
Wetlands	M001	Deciduous Floodplain and Swamp Forest	1,020.65	1.1	9106,9190	G3G4, G3G4
	M005	Low Elevation Conifer Riparian and Swamp Forest	745.77	0.8	9106,9190	G3G4, G3G4
	M010	High Elevation Conifer Riparian Forest	1,609.56	1.7	9108,9171	G5,G5
	M018	High Elevation Deciduous Tall Shrubland and Forest	1,823.97	1.9	9106	G3G4
	M039	Riparian Deciduous Tall Shrubland	323.17	0.3	9106,5261	G3G4,G5
	M058	High Elevation Wet Meadow/Dwarf Shrubland	496.73	0.5	9166	GU
	M092	Montane Wet Meadow	49.46	0.1	9166	GU

Table 27. Areal extent of Mount Rainier National Park vegetation map classes, the corresponding Ecological Systems (ES) vegetation class, and the global status of the ES (continued).

	MORA Code	MORA Vegetation Class Name	MORA area (ha)	Park (% area)	ES	Global Status[1]
Bare	M981	Bare (Colluvial)	4,567.87	4.8	3118	G5
	M980	Bare (Alluvial)	1,146.13	1.2		
	M983	Bare (Bedrock)	4,702.58	4.9		
Other	M990	Flowing Water	365.29	0.4		
	M991	Impounded Water	248.39	0.3		
	M992	Snow and Ice	6,827.57	7.2		
	M993	Glacial Till	3,138.04	3.3		

[1]GU, unrankable due to lack of data; G1, critically imperiled; G2, imperiled; G3, vulnerable; G4, apparently secure; G5, secure; ranking attributed to ES

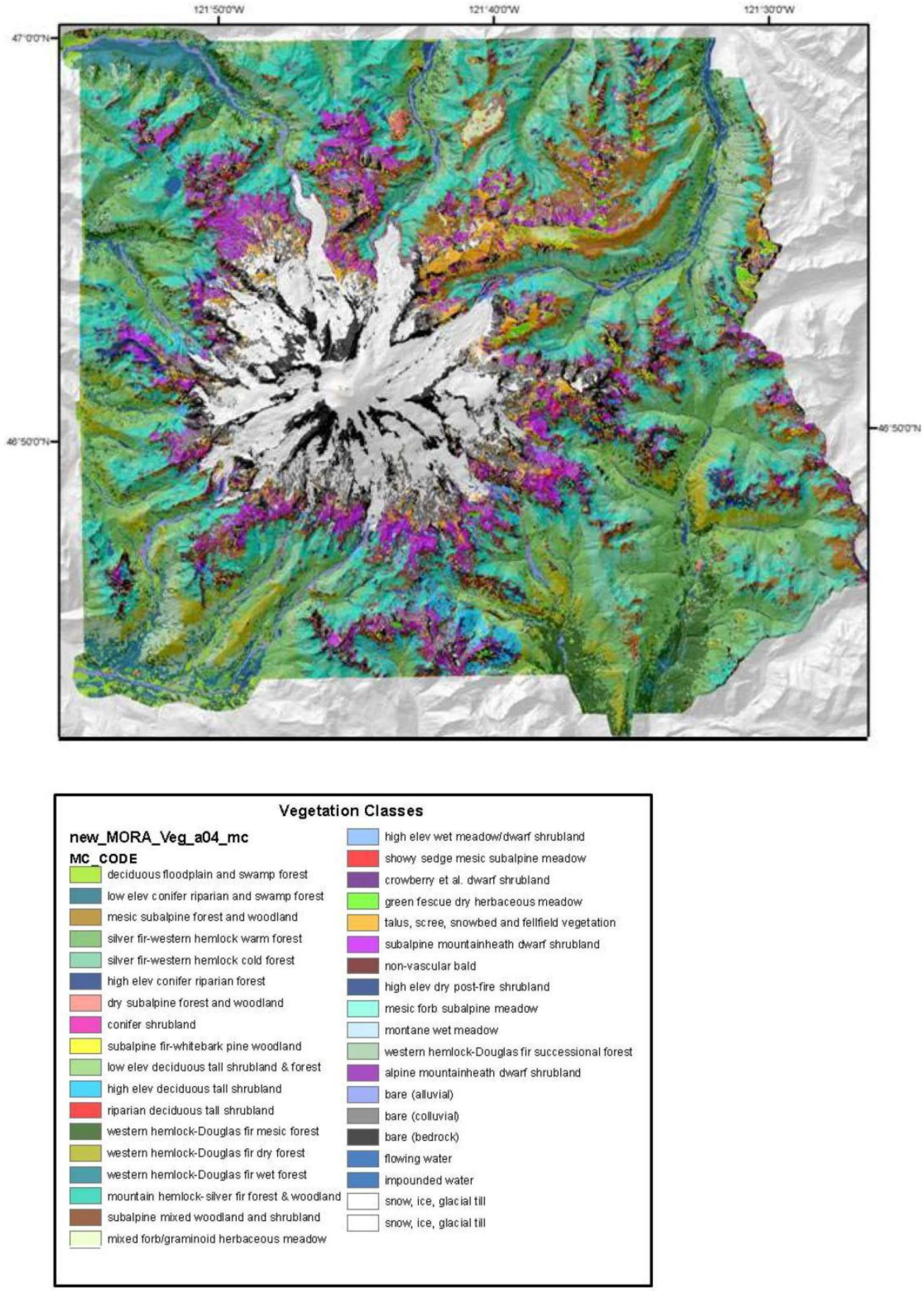

Figure 14. Map of Ecological Systems in Mount Rainier National Park.

Table 28. Predicted changes in tree species distribution by 2090–2100. Predictions of substantial change in species distribution are shown in bold. Terms in the column for Aubry et al. 2011 refer to vulnerability.The 'best' scenario for McKenney et al. (2007) assumes tree species can disperse from current locations while the'worst' scenario does not.

Geographic Extent	**Western Washington**		**Western United States**		**North America**	
Metric and Source	**Risk assessment (Aubry et al. 2011)**	**Range change (Shafer et al. 2001)**	**Percent range maintained – Coops and Waring 2011)**	**Percent area change (Rehfeldt et al. 2006)**	**Percent area loss- best scenario (McKenney et al. 2007)**	**Percent area loss- worst scenario (McKenney et al. 2007)**
Abies amabilis	**Higher**	**Contract**	>50		19.0	-42.7
Abies grandis	**Higher**		>50		8.2	-49.6
Abies lasiocarpa	**Higher**		**<50**		**-6.8**	-27.8
Abies procera	**Higher**		>50		**-1.8**	**-75.7**
Acer macrophyllum	Lower				20.0	-35.7
Alnus rubra	Lower	Move east			27.2	-45.1
Betula papyrifera					2.5	-28.7
Chamaecyparis nootkatensis	**Higher**		>50			
Cornus nuttallii					3.7	**-66.9**
Larix lyallii					**-1.8**	**-66.7**
Larix occidentalus			>50	**-63**	12.7	-48.8
Picea engelmannii	**Higher**		**<50**	**-72**		
Pinus albicaulus	**High**				29.1	-41.5
Pinus contorta			**<50**		**-5.5**	-29.0
Pinus monticola	Lower		**<50**		19.0	-33.9
Pinus ponderosa		Expand	**<50**	-13	10.7	-40.4
Populus balsamifera	Lower					
Pseudotsuga menziesii	Lower	Move east	>50	-2	12.4	-31.5
Sorbus sitchensis					24.1	-39.9
Taxus brevifolia		Move east			12.5	-37.9
Thuja plicata	Lower		>50		16.2	-26.5
Tsuga heterophylla	Lower		>50		12.5	-29.2
Tsuga mertensiana	**Higher**		**<50**		8.8	-32.3

4.4.5 Emerging Issues

- Using climate envelopes to predict future distributions of species is a useful first approximation (Pearson and Dawson 2003), but conservation of unique species would benefit from more accurate predictions. Predictions are needed that take more comprehensive consideration of factors affecting species survival such as physiological constraints at all critical life stages (Hampe 2004); processes occurring at the leading and trailing edges of shifting distributions such as dispersal and adaptation (Thuiller et al. 2008); and the effects of changing disturbance regimes. Predictions regarding potential refugia will help park staff plan for potential management actions.

- While predictions of habitat and species loss at coarse spatial scales can be fairly dire, predictions from models developed at local scales (25 x 25 m grid cells) indicate that suitable habitat may persist for most species (Randin et al. 2009).
- Park staff may consider describing desired future conditions consistent with NPS policy so that models can be built to identify strategies to achieve a desired state through backcasting (Sutherland 2006).

4.4.6 Information and Data Needs–Gaps

- Predictions on a spatial scale relevant to national parks are lacking. These include predictions regarding changes in distribution of species and communities as well as locations of potential refugia where species might be assisted to migrate. In addition to predicting species shifts with climate envelopes, it may also be productive to forecast changes in ecological processes that may affect species composition even in communities with long-lived species (e.g., fire regime which could eliminate fire sensitive species and reduce the carrying capacity of an area).
- Using remotely-sensed data is the most efficient means to analyze broad-scale changes in vegetation structure and composition in large national parks having challenging terrain. Opportunities to apply new tools and higher resolution datasets are constantly emerging, however, the costs of access to state of the art imagery and the technical and computing skills required to develop analysis tools may continue to be limiting factors for resource managers.

4.4.7 Literature Cited

Apostol, D., and M. Sinclair, editors. 2006. Restoring the Pacific Northwest, the art and science of ecological restoration in Cascadia. Island Press, Washington, D.C.

Aubry, C., W. Devine, R. Shoal, A. Bower, J. Miller, and N. Maggiuli, N. 2011. Climate change and forest biodiversity: A vulnerability assessment and action plan for national forests in western Washington. U.S. Department of Agriculture, Forest Service, Pacific Northwest Region. Olympia, Washington.

Beniston, M. 2003. Climatic change in mountain regions: A review of possible impacts. Climatic Change 59:5–31.

Biek, D. 2000. Flora of Mount Rainier National Park. Oregon State University Press, Corvallis, Oregon.

Bonan, G. B. 2008. Forest and climate change: Forcings, feedbacks, and the climate benefits of forests. Science 320:1444–1449.

Comer, P., D. Faber-Langendoen, R. Evans, S. Gawler, C. Josse, G. Kittel, S. Menard, M. Pyne, M. Reid, K. Schulz, K. Snow, and J. Teague. 2003. Ecological systems of the United States: A working classification of U.S. terrestrial systems. NatureServe, Arlington, Virginia.

Coops, N. C., and R. H. Waring. 2011. Estimating the vulnerability of fifteen tree species under changing climate in Northwest North America. Ecological Modeling 222:2119–2129.

Crawford, R. C., C. B. Chappell, C. C. Thompson, and F. J. Rocchio. 2009. Vegetation classification of Mount Rainier, North Cascades, and Olympic National Parks, plant association description and identification keys. National Park Service Natural Resource Technical Report NPS/NCCN/NRTR—2009/D-586.

Davis, M. B., and R. G. Shaw. 2001. Range shifts and adaptive responses to Quarternary climate change. Science 292:673–679.

Devine, W., C. Aubry, A. Bower, J. Miller, and A. N. Maggiulli. 2012. Climate change and forest trees in the Pacific Northwest: A vulnerability assessment and recommended actions for national forests. U.S. Department of Agriculture, Forest Service, Pacific Northwest Region, Olympia, Washington.

[FGDC] Federal Geographic Data Committee. 2008. National Vegetation Classification Standard. FGDC-STD-005-2008 (Version 2). Federal Geographic Data Committee–Vegetation Subcommittee, Reston, Virginia.

Flynn, D. R. B., M. Gogol-Prokurat, T. Nogeire, N. Molinari, B. T. Richers, B. B. Lin, N. Simpson, M. M. Mayfield, and F. DeClerck. 2008. Loss of functional diversity under land use intensification across multiple taxa. First published online October 2008. doi: 10.1111/j.1461-0248.2008.01255.x.

Franklin, J. F., W. H. Moir, M. A. Hemstrom, S. E. Greene, and B. G. Smith. 1988. The forest communities of Mount Rainier National Park. Scientific Monograph Series No. 19, U.S. Department of Interior, National Park Service, Washington, D.C.

Guisan, A., J. I. Holten, R. Spichiger, and L. Tessier, editors. 1995. Potential ecological impacts of climate change in the Alps and Fennoscandian Mountains .Conservatoire et Jardin botaniques, Geneva, Switzerland.

Hampe, A. 2004. Bioclimate envelope models: What they detect and what they hide. Global Ecology and Biogeography 13:469–476.

Henderson, J. A. 1973. Composition, distribution and succession of subalpine meadows in Mount Rainier National Park, Washington [thesis]. Oregon State University, Corvallis, Oregon.

Levis, S., J. A. Foley, and D. Pollard. 1999. Potential high-latitude vegetation feedbacks on CO_2-induced climate change. Geophysical Letters 26:747–750.

Littell, J. S., D. L. Peterson, and M. Tjoelker, 2008. Douglas-fir growth-climate relationships along biophysical gradients in mountain protected areas of the northwestern U.S. Ecological Monographs 78:349–368.

Littell, J. S., E. E. Oneil, D. McKenzie, J. A. Hicke, J. A. Lutz, R. A. Norheim, and M. M. Elsner. 2010. Forest ecosystems, disturbance, and climatic change in Washington State, USA. Climatic Change 102:129–158.

McKenney, D. W., J. Pedlar, M. Hutchinson, K. Lawrence, and K. Campbell. 2007. Potential impacts of climate change on the distribution of North American trees. BioScience 57:939–948.

McKenzie, D., Z. Gedlof, D. L. Peterson, and P. Mote. 2004. Climatic change, wildfire and conservation. Conservation Biology 18:890–902.

Mote, P. W. 2003. Trend in snow water equivalent in the Pacific Northwest and their climatic causes. Geophysical Research Letters 30. doi:10.1029/2003GL017258, 2003.

Mote, P. W., and E. P. Salathé. 2010. Future climate in the Pacific Northwest. Climatic Change 102:29–50.

Nielsen, R. P. and C. Copass. In prep. Vegetation inventory project for Mount Rainier National Park, 2007–2013 (MORA_Veg_Polys). Mount Rainier National Park. Geospatial Dataset-XXXXXXX.

Nielson, R. P., L. F. Pitelka, A. M. Solomon, R. Nathan, G. F. Midgley, J. M. V. Fragoso, H. Lischke, and K. Thompson. 2005. Forecasting regional to global plant migration in response to climate change. BioScience 55:749–759.

Pearson, R. G., and T. P. Dawson. 2003. Predicting the impacts of climate change on the distribution of species: Are bioclimate envelope models useful? Global Ecology and Biogeography 12:361–371.

Peterson, D. L., E. G. Schreiner, and N. M. Buckingham. 1997. Gradients, vegetation and climate: Spatial and temporal dynamics in the Olympic Mountains, U.S.A. Global Ecology and Biogeography Letters 6:7–17.

Raffa, K. F, B. H. Aukema, B. J. Bentz, A. L. Carroll, J. A. Hicke, M. G. Turner, and W. H. Romme. 2008. Cross-scale drivers of natural disturbances prone to anthropogenic amplification: The dynamics of bark beetle eruptions. BioScience 58:501–517.

Randin, C. F., R. Engler, S. Normand, M. Zappa, N. E. Zimmermann, P. B. Pearman, P. Vittoz, W. Thuiller, and A. Guisan. 2009. Climate change and plant distribution: Local models predict high-elevation persistence. Global Change Biology 15:1557–1569.

Rehfeldt, G. E., N. L. Crookston, M. V. Warwell, and J. S. Evans. 2006. Empirical analyses of plant-climate relationships for the western United States. International Journal of Plant Sciences 167:1123–1150.

Shafer, S. L., P. J. Bartlein, and R. S. Thompson. 2001. Potential changes in the distributions of western North America tree and shrub taxa under future climate scenarios. Ecosystems 4:200–215.

Sutherland, W. J. 2006. Predicting the ecological consequences of environmental changes: A review of methods. Journal of Ecology 43:599–616.

Thuiller, W., C. Albers, M. B. Araujo, P. M. Berry, M. Cabeza, A. Guisan, T. Hickler, G. F. Midgley, J. Paterson, F. M. Schurr, M. T. Sykes, and N. E. Zimmermann. 2008. Predicting global change impacts on plant species' distributions: Future challenges. Perspectives in Plant Ecology, Evolution and Systematics 9:137–152.

Van Dyke, F. 2008. Conservation biology, foundations, concepts, applications. Springer, Dordrecht, Netherlands.

van Mantgem, P. J., N. L. Stephenson, J. C. Byrne, L. D. Daniels, J. F. Franklin, P. Z. Fule, M. E. Harmon, A. J. Larson, J. M. Smith, A. H. Taylor, and T. T. Veblen. 2009. Widespread increase of tree mortality rates in the western United States. Science 323:521–524.

4.5 Forest Health: Disturbance Regime

(Andrea Woodward and Patricia Haggerty, USGS FRESC)

4.5.1 Introduction

The composition, structure and function of forest ecosystems are shaped by disturbances (Dale et al. 2001) in events that range in scale from extensive mortality over large areas (e.g., fire) to small patches (e.g., local wind throw events), or the widespread decline of individual species (e.g., insect infestation). Events in the Pacific Northwest include fires, windstorms, ice storms, drought, landslides, floods, insects and pathogens, and exotic species (Spies and Franklin 1989). Climate change is expected to change the severity, frequency, and magnitude of forest disturbances (Dale et al. 2001), which may accelerate alterations to tree species distribution expected from the direct effects of climate change (Littell et al. 2010).

Landscape-scale disturbances often have complicated dynamics, in some cases including critical thresholds, feedback loops, and cross-scale interactions (Raffa et al. 2008). Understanding the potential effects of changing climate on disturbance regimes adds another level of complexity. In the case of insects, predictions of irruptions depend on understanding the effects of climate on the physiology of insects, including growth rate and generation time, as well as the susceptibility and resistance of trees (Bentz et al. 2010) at seasonal to evolutionary time scales (Raffa et al. 2008). Moreover, interactions among disturbances can be affected by climate change such as when drought decreases tree vigor thereby increasing tree susceptibility to insects with consequences for fuel loads and subsequent intensity of fire (Dale et al. 2001) or when fire intensity affects tree susceptibility to insects (Youngblood et al. 2009). In other cases, multiple events may interact to cause a disturbance. For example, Douglas-fir Beetle (*Dendroctonus pseudotsugae*) outbreaks are triggered by a disturbance such as wind, fire, or ice storms to create breeding habitat in large dead or stressed and weakened trees (Greenland et al. 2003). Poor understanding of these and other composite and cumulative effects of multiple disturbances can lead to surprising future conditions (Paine et al. 1998).

Specific disturbances of particular importance to MORA are covered elsewhere in this document, including White Pine blister rust (section 4.6), fire ecology (section 4.8), and invasive species (section 4.9). This section is focused on the other potential disturbance agents.

4.5.2 Approach

The longest-term comprehensive description of the disturbance regime in MORA is provided by Aerial Detection Survey (ADS) data collected by the USDA Forest Service. These data have been collected annually since 1949 and describe the location of forest insects, disease, weather-related damage, and other forest health stressors (Johnson and Wittwer 2008). Using fixed-wing aircraft typically flying at 185 km/hr (115 mi/hr) and 500 m (1640 ft) elevation, observers evaluate a swath of 2.5 km (1.6 mi) and sketch the location of disturbances on topographic maps. Assessment of disturbance agents is based on the occurrence of pest-specific damage ‘signatures’ consisting of foliage color, canopy texture, tree species identity, and season (McConnell et al. 2000). In addition, observers estimate the severity of damage in 3 classes (high, moderate, and low), the number of trees affected or trees/ha affected. Aerial surveys are not effective at detecting root disease, dwarf mistletoe, or minor defoliation. Creating disturbance maps using the sketchmapping method is highly subjective and therefore variable among observers (Klein et al. 1983). Consequently, the data are best used for demonstrating trends rather than precisely identifying affected areas (Johnson and Wittwer 2008). Mapping accuracy improved with the advent of digital technology (digital aerial sketchmap system, DASM; Schrader-Patton 2002), including touch screens and integrated GPS. Nevertheless, remotely determining the cause of a disturbance will remain subjective for the foreseeable future. For example, damage polygons attributed to the Fir Engraver (*Scolytus ventralis*), which affects mainly Grand Fir (*Abies grandis*), are almost certainly due to Silver Fir Beetle (*Pseudohylesinus sericeus*) in the North Cascades area where Grand Fir is rare (Carlson 2013).

The study area for this analysis includes MORA and the buffer area around it defined for the landscape change monitoring protocol (Kennedy et al. 2007). This buffer was created to acknowledge that the park has porous boundaries relative to the spread of disturbance agents and other ecological processes. It is defined as a 16.1 km (10 mi) wide ring around the park, truncated a bit in the south to accommodate the geometry of available satellite imagery (Antonova et al. 2012).

As part of the NPS Inventory and Monitoring Program, NPS staff members are implementing a protocol to detect disturbance events using Landsat imagery (Kennedy et al. 2007). Initial use of the protocol indicated that the original approach would not meet park needs. However, the recently developed tools Landtrendr (Kennedy et al. 2010) and TimeSync (Cohen et al. 2010) may be effective at detecting disturbance events relevant to MORA (Antonova et al. 2010). Consequently a new protocol has been written (Antonova et al. 2012) and results from 1985 to 2009 for short-term disturbances (those whose signatures last <4 yrs) are available (Antonova et al. 2014). The 8 categories of disturbances tracked by this protocol are: avalanches, clearing, development, fire, mass movements, progressive defoliation, riparian and tree toppling.

4.5.3 Reference Conditions and Comparison Metrics

Abiotic and biotic disturbance agents are direct results of weather (e.g., wind and ice storms, floods, fire regime) or are influenced by weather (Dale et al. 2001), primarily by affecting the success of biotic agents or the susceptibility of hosts (Bentz et al. 2010); or by affecting the availability of fuel. Consequently, we investigated whether a shift in weather regime could explain trends in disturbance from a reference period to the present. Considering the time span of available ADS data (1949–2011), data from Washington State Climate Division 5 (monthly average of daily data from all weather stations in Division 5 region) indicate a notable change beginning in 1986 when average annual temperature (7.7°C) consistently and dramatically exceeded (2-tailed t-test, $P < 0.000$) the average of average temperature estimated since 1949 (6.4°C; Figure 15). Accordingly, we define the reference period to be from the beginning of the ADS record (1949) until 1985.

To describe status and trends of forest disturbance agents, we evaluated ADS data for the following metrics: (1) total area of MORA and surrounding buffer affected by disturbance agents through time, 1949–2011; (2) location of most severe occurrence; (3) location of most frequent occurrence; and (4) comparison pre- and post-1985 when annual temperature dramatically increased.

Predicted changes expected in disturbance agents were summarized from a literature review and by extrapolating changes observed in ADS data from 1986 to 2011 compared with 1949 to 1985. The complete digital data set including disturbance polygons and calculations of severity and disturbance agents for MORA and the buffer area will be provided to the park in a geodatabase.

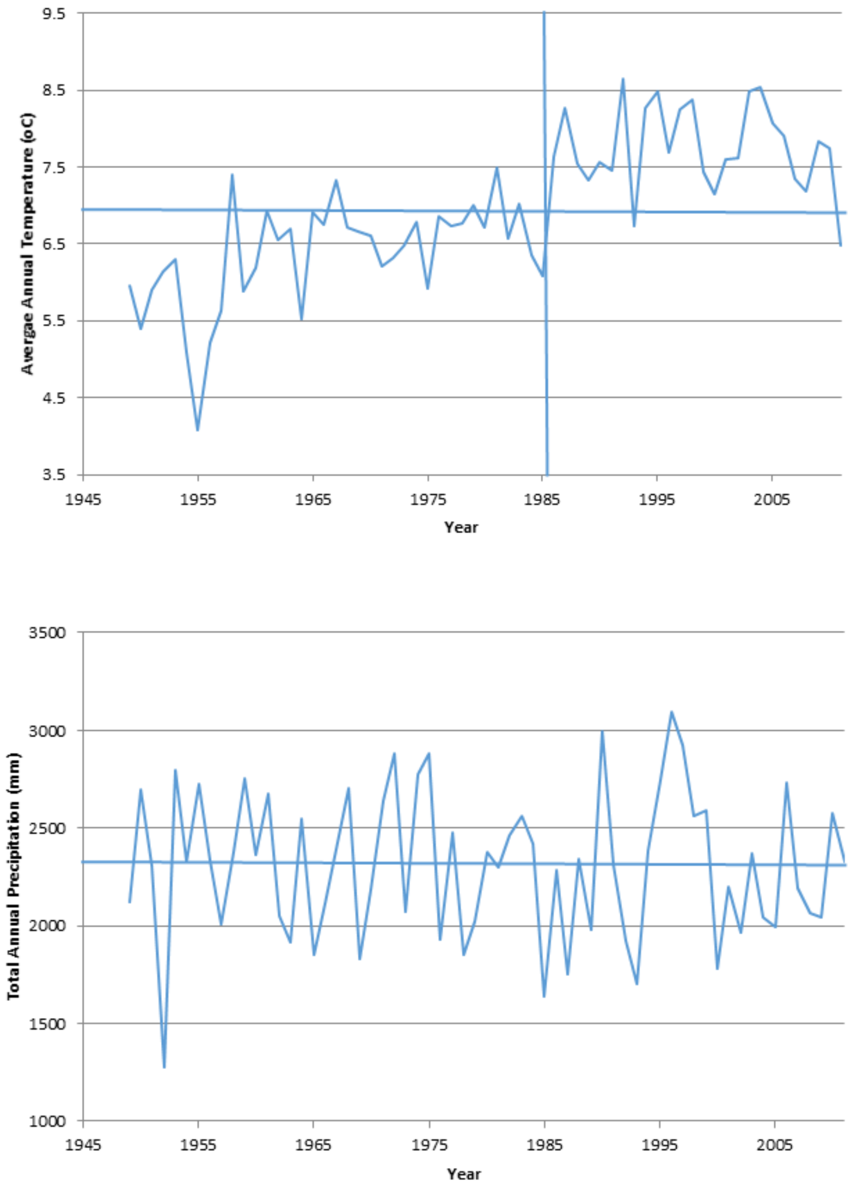

Figure 15. Time series of average annual temperature and total annual precipitation from 1949–2011 for Washington State Division 5, Cascade Mountains West. Horizontal lines indicate average for record; vertical line indicates 1985.

4.5.4 Results and Assessment

Current Condition (1986-2011)

Since 1985, forests in MORA and the surrounding buffer have experienced damage due to several native insects (Figure 16), but primarily by the introduced Balsam Woolly Adelgid. The native insect species include the Fir Engraver, Western Spruce Budworm (*Choristoneura occidentalis*), and Mountain Pine Beetle (*Dendroctonus ponderosae*). These insects are responsible for 83% (MORA) and 59.2% (buffer) of tree damage documented by ADS. Considering all agents, 95.1% (MORA) and 73.1% (buffer) of observed tree damage has been due to insects; 0.3% (MORA) and 1.5% (buffer) due to diseases; 4.3% (MORA) and 24.9% (buffer) due to physical disturbances (i.e., fire, bear damage, red belt, slides, water, wind, ice); and 0.3% (MORA) and 0.5% (buffer) due to unknown causes. The park and the buffer area differed in several ways. Insect damage in the park was primarily due to Balsam Woolly Adelgid (*Adelges piceae*) and secondarily to Fir Engraver while damage in the buffer was primarily due to Western Spruce Budworm. This may be due to a larger population of Subalpine Fir (*Abies lasiocarpa*), which is the chief host of Balsam Woolly Adelgid, inside the park than in the buffer. Also, the relative amount of physical damage was much greater in the buffer and was attributed to bear damage.

Disturbance is widespread within the park and the surrounding buffer during 1986 to 2011 (Figure 17). Balsam Woolly Adelgid has been active at high elevation throughout MORA (Figure 18), while Mountain Pine Beetle impact has been light and limited to the northeast (Figure 19). This contrasts with the buffer where Balsam Woolly Adelgid activity has been minor and Mountain Pine Beetles have affected significant amounts of area to the east. In addition, Western Spruce Budworm has been the dominant disturbance agent in the buffer, occurring mainly in the southeastern portion of MORA with some activity in the east (Figure 20). Fir Engraver has been more abundant in MORA than in the buffer, and activity has primarily occurred in the eastern portion of the park. Douglas-fir Beetle, Western Balsam Bark Beetle (Dryocoetes confusus), and the fungus White Pine blister rust (Cronartium ribicola) have each also disturbed at least 1000 ha (2471 ac) of the park since 1985.

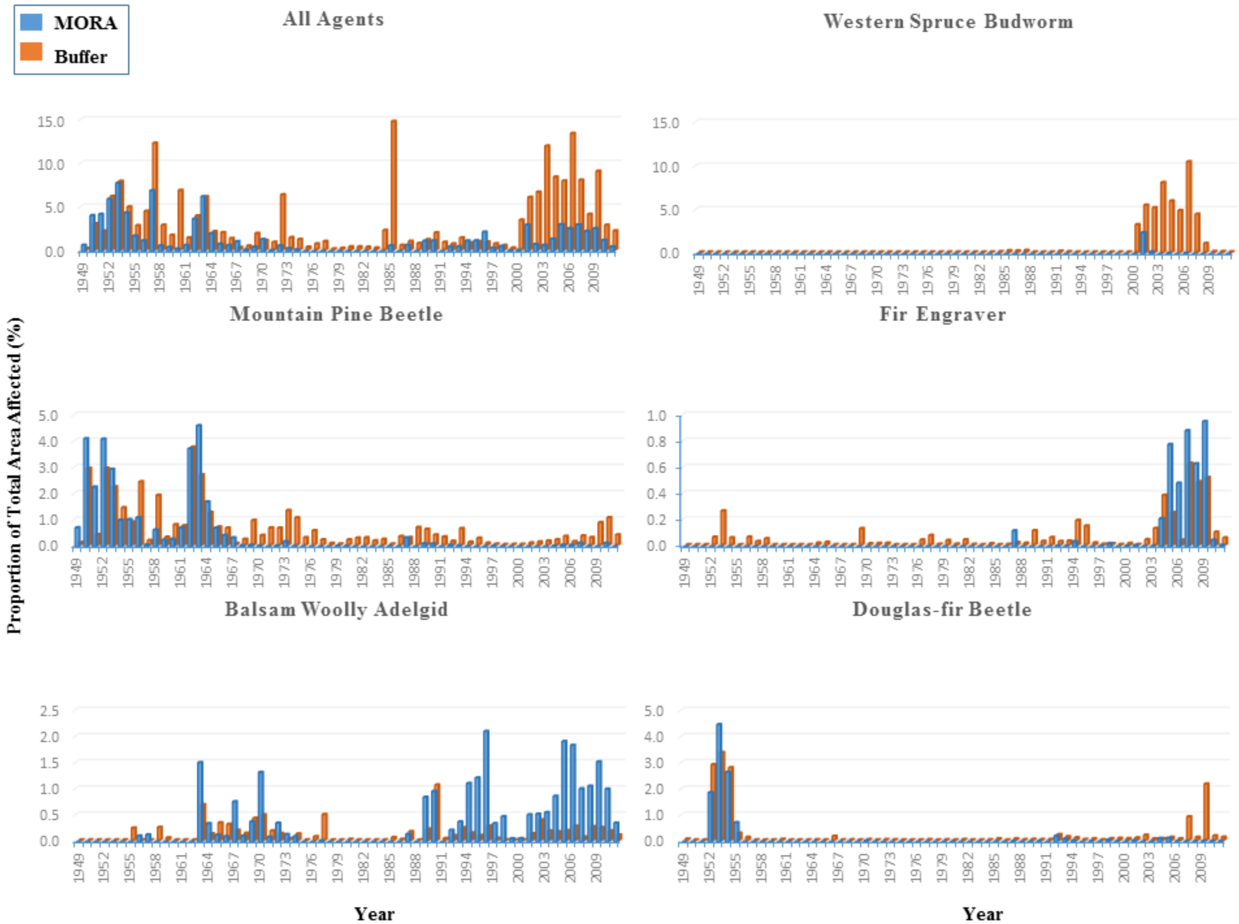

Figure 16. Aerial Detection Survey results describing area of park or buffer affected by various agents through time.

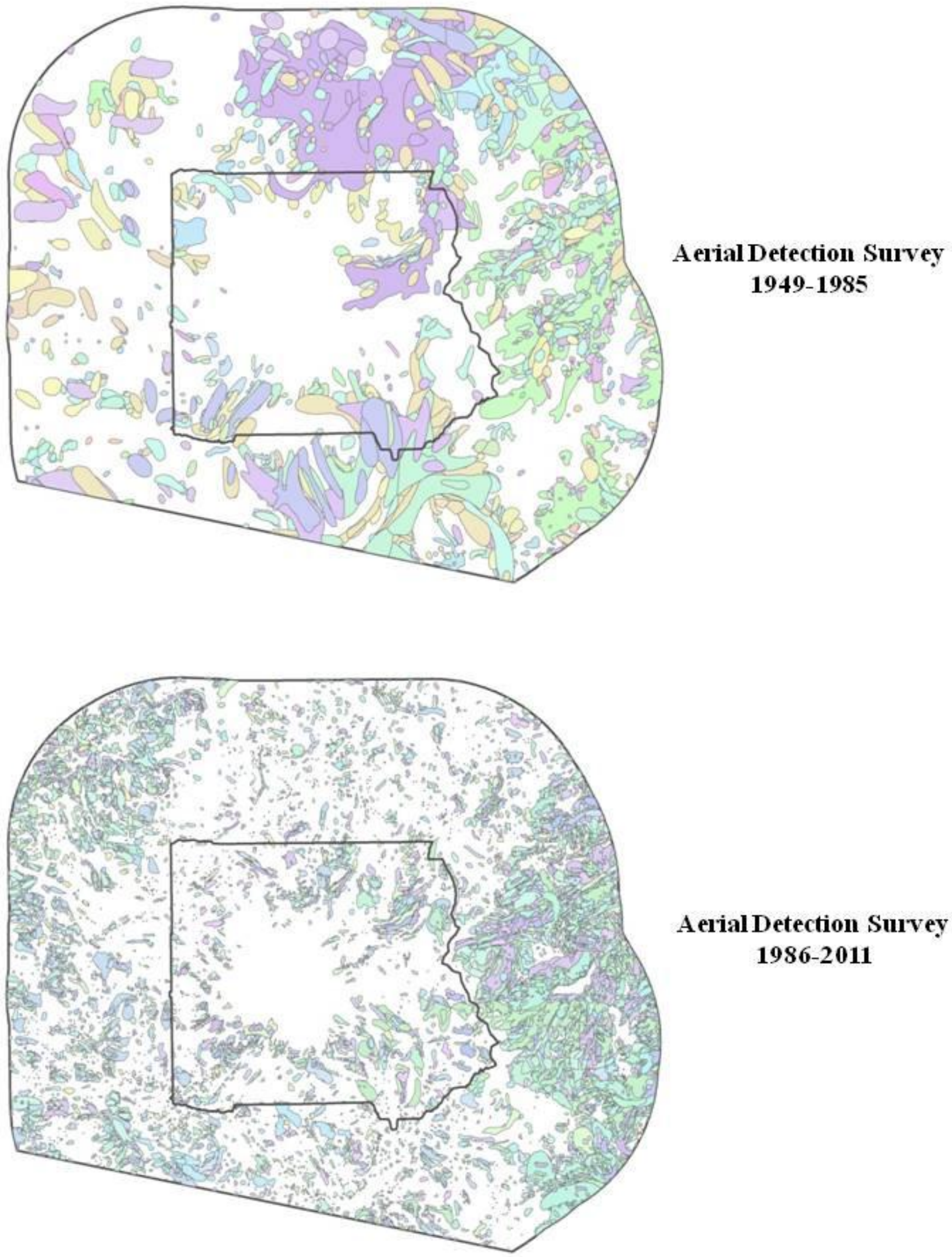

Figure 17. Spatial distribution of disturbance events during 2 time periods as detected by the Aerial Detection Survey in MORA and surrounding buffer. Colors vary by year. No legend is provided because the graphic conveys distribution and intensity of disturbances rather than temporal detail.

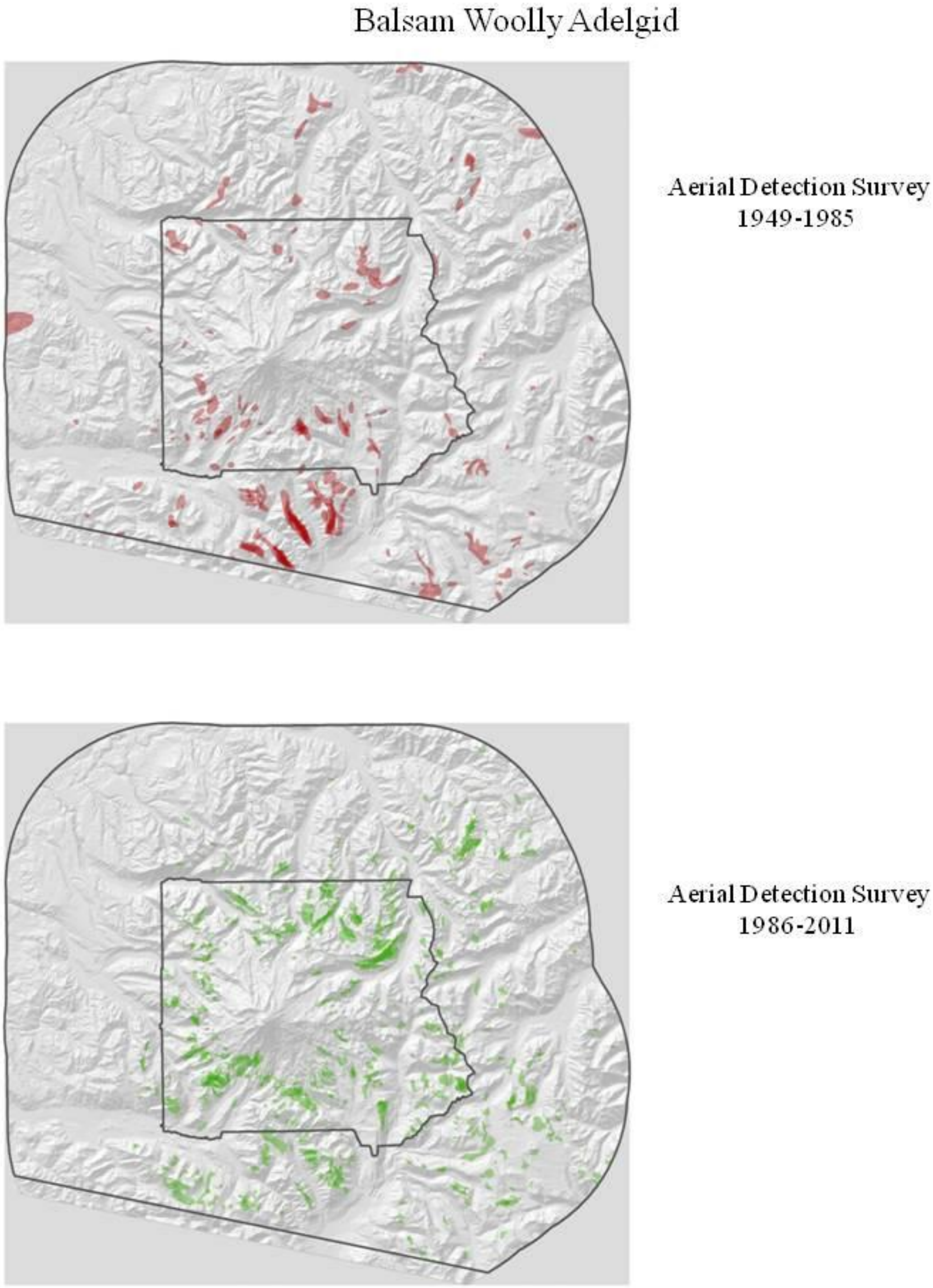

Figure 18. Balsam Woolly Adelgid pre- and post-1985. Darker colors indicate more years of impact.

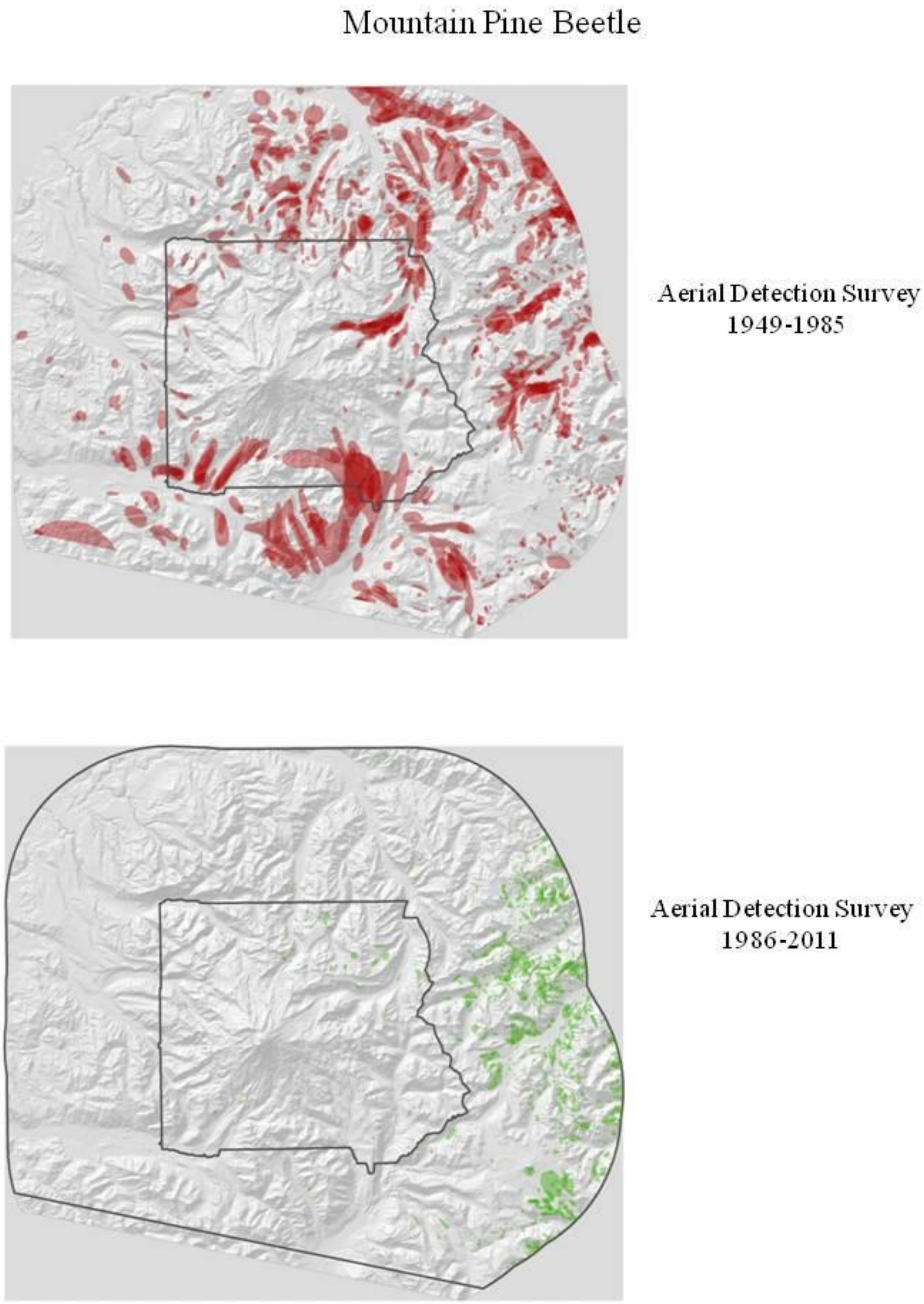

Figure 19. Distribution of Mountain Pine Beetle pre- and post-1985. Darker colors indicate greater number of years with presence.

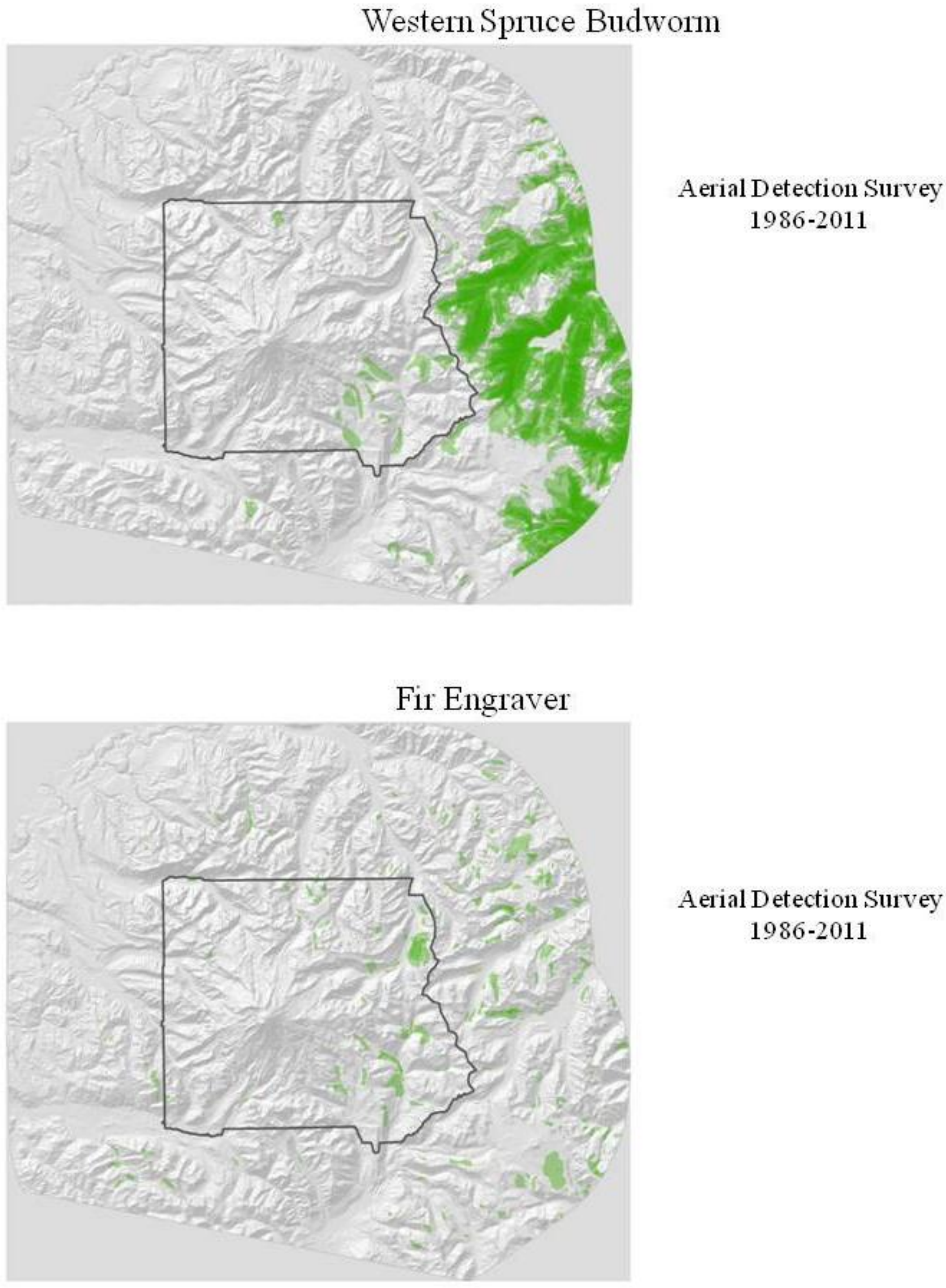

Figure 20. Distribution of Western Spruce Budworm and Fir Engraver post-1985. Darker colors indicate greater number of years with presence.

Trend

We compared the recent period (1986–2011), which shows dramatically higher temperatures, with the reference period (1947–1985) to describe trend (Table 29). In general, disturbance in the park was somewhat more prevalent in the eastern region during both periods but with relatively more impact in the western part of the park in recent years than during the reference period (Figure 16). In addition, both periods are dominated by disturbance due to insects compared with diseases and abiotic agents in the park and surrounding buffer, although physical damage mainly attributed to bears has increased considerably in the buffer (Table 29). Regarding specific insects, the reference period was dominated by Mountain Pine Beetle, while dominance has shifted toward Balsam Wooly Adelgid (MORA) and Western Spruce Budworm (buffer) more recently. Western Black-headed Budworm (*Acleris gloverana*) occurred in only 4 yrs, but caused the spikes in the buffer seen in 1957 and 1985 (Figure 16). Disturbance peaked during the 1950s in the reference period and during the 2000s in recent times (Figure 16), with no apparent relationship to climate. A trend towards smaller polygons through time is likely due to methodological refinement.

Table 29. Comparison of area disturbed by agents during 1947–1985 versus 1986–2011. Values reported as buffer do not include the park.

Agent	Time period: 1947-1985 % total disturbance		Time period: 1986-2011 % total disturbance		Change	
	MORA	**Buffer**	**MORA**	**Buffer**	**MORA**	**Buffer**
Mountain pine beetle	53.7	32.0	3.6	8.0	-50.1	-24.0
Balsam woolly adelgid	9.8	4.0	60.5	4.6	+50.7	+0.6
Douglas-fir beetle	16.8	9.3	3.4	4.9	-13.4	-4.4
Fir engraver	0.0	0.8	13.3	3.4	+13.3	+2.6
Western black-headed budworm	13.1	31.2	0.0	0.0	-13.1	-31.0
Western spruce budworm	0.0	0.2	9.2	51.2	+9.2	+51.0
Total insects	95.8	80.7	95.2	73.1	-0.6	-7.6
Total disease	3.4	2.4	0.3	1.5	-3.1	-0.9
Total Physical damage	0.8	10.1	4.3	24.9	+3.5	+14.8
Other	0.0	6.7	0.3	0.5	+0.3	-6.2
Total ha/yr	1,428	7,695	1,167	10,534	-261	+2,839
Area %/yr	1.58	2.80	1.23	3.64	-0.35	+0.84

Balsam Woolly Adelgid

This is an exotic pest of Subalpine Fir and Pacific Silver Fir (*Abies amabilis*) in MORA (Carlson 2011) that can cause branch stunting and topkill; death can result after several years of heavy infestation. Balsam Woolly Adelgid was evident in the park and buffer during the 1960s (Figure 16). Since 1986, it has affected over 18,000 ha (44,479 ac) of MORA, although some areas may be repeat observations in consecutive years. The lower relative impact outside of the park is likely due to the preference of Balsam Woolly Adelgid for high-elevation tree species.

Mountain Pine Beetle

Mountain Pine Beetle is a bark beetle that attacks and kills all species of pines. During the reference period it occurred in the northern and southern parts of the park and in all but the western part of the buffer (Figure 19) and primarily affected Western White Pine (*Pinus monticola*) everywhere, plus some Lodgepole (*Pinus contorta*), Ponderosa (*Pinus ponderosa*), and Whitebark Pines in the buffer. Since 1985, Mountain Pine Beetle activity has been relatively low, but it has been attacking Whitebark Pine in the northeastern part of MORA (7 yrs since 1996) and east of the park in the buffer (10 yrs since 1986) (Figure 19). Usually Mountain Pine Beetle moves from other pines to Whitebark Pine, but this does not seem to be happening in MORA (Carlson 2011). Instead, the greatest mortality in MORA has been in Whitebark Pine, with less in Lodgepole Pine and very little in Western White Pine (Carlson 2011). This unusual pattern may be due to the small population size of Lodgepole Pine in MORA and significant mortality of Western White Pine during intial outbreaks of blister rust in the 1930s and 1940s (Regina Rochefort, written communication). Although Mountain Pine Beetle outbreaks seem to be increasing in recent decades and expanding into previously unaffected areas such as western Canada and Alaska (Logan et al. 2003, Carroll et al. 2004), its incidence has remained relatively low in MORA and the buffer. However, the small outbreak that has occurred has been associated with years having low showpack and low rainfall during the hottest part of the year (Carlson 2011).

Western Spruce Budworm

Western Spruce Budworm defoliates Douglas-firs, true firs and Engelmann Spruce (*Picea englemannii*) over multiple years. Trees that are defoliated for 5 to 10 yrs are likely to have dead tops or be killed while surviving trees are more vulnerable to bark beetles. Western Spruce Budworm was absent during the reference period but has repeatedly affected a significant part of the buffer to the east of the park (Figure 20). It has had some impact inside MORA, especially in the southeastern sector of the MORA. In fact, it was detected on the most acres in a single year of any insect and is predicted to occur again in this sector because the stand composition is favorable and the budworm continues to be active in the buffer (Carlson 2011).

Fir Engraver Beetle

Fir Engraver Beetles primarily feed on Grand Fir and occasionally Subalpine Fir. The beetles especially attack trees that have been weakened, for example by root disease or Balsam Woolly Adelgid. Fir Engraver Beetles have been active in the eastern part of the park (Figure 20). This activity has been attributed to higher than average temperatures and lower than average precipitation during 2007–2009 near Sunrise, and since 2002 measured in Ohanapecosh (Carlson 2011). The coincidence with Balsam Woolly Adelgid activity may also be significant.

Douglas-fir Beetle

Douglas-fir Beetle kills large diameter trees that have been weakened by drought, fire, flood, root disease, defoliating insects, or windthrow; many of these disturbances may increase with climate change. This insect was active in the park and buffer early in the reference period and has been evident in the buffer more recently (Figure 16). It has been detected in the western part of the park in relatively small areas associated with flood damage (Carlson 2011).

Two trends in the ADS data are particularly notable because they involve high elevation species with necessarily limited distribution. In these cases, the significance of the damage is perhaps under-represented by the number of affected hectares because these data do not express the proportion of vulnerable area affected. First, there are indications that warmer climate may be beginning to enable Mountain Pine Beetles to affect Whitebark Pine, a high-elevation species also susceptible to Whitebark Pine blister rust (Carlson 2011). Second, Balsam Woolly Adelgid is an exotic insect that affects true firs, and is primarily affecting Subalpine Fir and Pacific Silver Fir in MORA (Carlson, 2011). Subalpine Fir also has limited distribution because it occurs at high elevations, hence the relatively small number of hectares affected may not fully express the significance of the damage. Balsam Woolly Adelgid has caused severe damage to Fraser Fir (*Abies fraseri*) following introduction to Great Smoky Mountains National Park (Allen and Kupfer 2001) and may have potential to do great harm in the Pacific Northwest. At sites in Washington and Oregon it has been shown to cause 40 to 79% decline of Subalpine Fir forests in a 35- to 45-yr period (Mitchell and Buffam 2001).

Because disturbance due to insects, disease, and physical agents are natural ecological processes, although some disease agents and insects are introduced, we are most interested in whether climate change might increase their natural range of variation (Dale et al. 2000). Based on a 63-yr time series of ADS records, it appears that the natural range of variation has not remarkably increased to date. While there may be a trend toward greater synchronization of agents including a non-native insect, and a different mix of agents, the total area affected and duration of outbreaks are not greater than past events (Figure 16). Given the difficulty of assigning causes to damage from the air, this conclusion is probably more robust than conclusions regarding individual agents and is subject to unknown effects of changes in accuracy through time. Moreover, this analysis has not shown a clear relationship between recent climate change and disturbance patterns; hence the park may still be experiencing conditions that could be considered reference relative to climate.

Predicted Changes

In general, warming climate is predicted to increase the effects of forest insects (Dale et al. 2001, Bentz et al. 2010) and diseases (Sturrock et al. 2011) primarily through climate-induced increase in host stress, decreased limitations on pest survival, or both. Duration of Western Spruce Budworm outbreaks is predicted to increase in a warmer climate due to higher over-winter survival and longer growing season (Campbell et al. 2006; Thomson et al. 1984). The life-cycle of Mountain Pine Beetle is primarily controlled by temperature (Logan and Bentz 1999, Logan et al. 2003, Powell and Logan 2005) and this insect has been observed to have advanced to higher elevations and more northern latitudes than in past records (Raffa et al. 2008). Migration to higher elevations corresponds to predictions of Littell et al. (2010) showing the future (2080) distribution of Mountain Pine Beetle to correspond with the current distribution of Whitebark Pine. While the obligatory winter diapauses of Douglas-fir Beetle may be disrupted by warmer winters, the insect does prefer stressed and injured trees (Furniss and Carolin 1977), which may be more abundant due to climate change (Bentz et al. 2010). The limitation posed by warm winters for Balsam Woolly Adelgid (Antonelli 1992) is expected to be less frequent in the future.

Currently, forest diseases are minor causes of tree mortality in MORA, at least as detected in ADS surveys (but see Section 4.7 for detailed treatment of White Pine blister rust). The role of pathogens is expected to increase in general due to climate change because most disease agents will adapt faster than their hosts (Sturrock et al. 2011). However details will vary depending on whether the agents are affected directly or indirectly by climate. Additionally, changing climate is expected to produce a higher frequency of extreme events and consequently abiotic disturbance effects. Floods, high winds, and fire may kill trees outright or make them more vulnerable to pests (see section 4.8 for detailed treatment of fire). Finally, the complex interactions among biotic and abiotic environmental conditions, climatic limitations on insects and diseases, stress level of hosts, the potential for range shifts in hosts, insects and pathogens, and stochastic introduction of exotic organisms may create novel and surprising outcomes (Paine et al. 1998).

Predicted changes are perhaps supported by some observations of trend in MORA. Specifically, throughout the record, the most severe disturbance has occurred in the warmest and driest parts of the park. Disturbance has increased on the west side of the park since temperatures dramatically warmed in 1985. Finally, the high elevation species Subalpine Fir and Whitebark Pine have experienced increasing levels of disturbance in recent years (Carlson 2011).

4.5.5 Emerging Issues

- Predicting future disturbance regimes depends on better understanding of the interactions among climate change, disturbance agents/regimes, and vulnerability of tree species, including which disturbance agents might be able to expand their range or increase in prominence into MORA. There may be unexpected consequences from the compounded effects of multiple disturbances (Paine et al. 1998).
- Improved tools are needed to detect and identify disturbances using Landsat and other public domain remotely-sensed imagery. While the LendTrendr-based protocol is an improved tool, the time delay to delivery of results still renders it less useful for detection if immediate management action is required.
- Changes in forest composition are likely to occur most rapidly in areas of severe stand-replacing disturbance following outbreaks of insects and pathogens or catastrophic fire. Patterns of regeneration within these areas, especially along the edges of species' ranges, may provide a first indication of future changes in forest composition.

4.5.6 Information and Data Needs–Gaps

- The accuracy and resolution of available data and climate projections are inadequate to forecast changes within an area the size of MORA. In particular, responses to climate change may vary by region within the park and by elevation zone (Littell et al. 2009). Both patterns are relevant to the distribution of forest insects and diseases.
- Mechanistic models describing the effects of climate changes on disturbance agents and tree physiology are needed to predict changes in future consequences of agents (Bentz et al. 2010).

4.5.7 Literature Cited

Allen, T. R., and J. A. Kupfer. 2001. Specral response and spatial pattern of Fraser Fir mortality and regeneration, Great Smoky Mountains, USA. Plant Ecology 156:59–74.

Antonelli, A. L. 1992. Balsam Woolly Adelgid: A pest of true firs. Bulletin 11456. Washington State Extension, Olympia, Washington.

Antonova, N. V., K. Beirne, and C. Thompson. 2010. Implementation of landscape dynamics monitoring at the North Coast and Cascades Network: Initial assessment of change detection methods. Natural Resource Technical Report NPS/NCCN/NRTR—2010/328. National Park Service, Fort Collins, Colorado .

Antonova, N., C. Copass, R. K. Kennedy, Z. Yang, J. Braaten, and W. Cohen. 2012. Protocol for Landsat-based monitoring of landscape dynamics in North Coast and Cascades Network Parks: Version 2. Natural Resource Report NPS/NCCN/NRR—2012/601. National Park Service, Fort Collins, Colorado.

Antonova, N., C. Copass, and S. Clary. 2014. Landsat-based monitoring of landscape dynamics in the North Cascades National Park Service Complex: 1985–2009. Natural Resource Data Series NPS/NCCN/NRDS—2013/532. National Park Service, Fort Collins, Colorado.

Bentz, B. J., J. Regniere, C. J. Fettig, M. Hansen, J. L. Hayes, J. A. Hicke, R. G. Kelsey, J. F. Negron, and S. J. Seybold. 2010. Climate change and bark beetles of the western United States and Canada: direct and indirect effects. BioScience 60:602–613.

Campbell, R., D. J. Smith, and A. Arsenault. 2006. Multicentury history of Western Spruce Budworm outbreaks in interior Douglas-fir forests near Kamloops, British Columbia. Canadian Journal of Forest Research 36:1758–1769.

Carlson, D. 2011. Mount Rainier National Park twenty year forest insect damage patterns and risks. Report prepared for Mount Rainier National Park by USDA Forest Service.

Carlson, D. 2013. North Cascades National Park twenty year forest insect damage pattern and risk assessment. Report prepared for North Cascades National Park Complex by USDA Forest Service.

Carroll, A. L., S. W. Taylor, J. Régnière, and L. Safranyik, L. 2004. Effects of climate change on range expansion by the Mountain Pine Beetle in British Columbia. In: Shore, T. L., J. E. Brooks, and J. E. Stone, editors. Mountain Pine Beetle Symposium: Challenges and Solutions, October 30-31, 2003, Kelowna, British Columbia, Canada. Natural Resources Canada, Canadian Forest Service, Pacific Forestry Centre, Victoria, British Columbia, Information Report BC-X-399. p. 223–232.

Cohen, W. B., Z. Yang, and R. Kennedy. 2010. Detecting trends in forest disturbance and recovery using yearly Landsat time series: 2. TimeSync — Tools for calibration and validation. Remote Sensing of Environment 12:2911–2924.

Dale, V. H., L. A. Joyce, S. McNulty, and R. P. Nielson. 2000. The interplay between climate change, forests, and disturbances. Science of the Total Environment 262: 201–204.

Dale, V. H., L. A. Joyce, S. McNulty, R. P. Neilson, M. P. Ayres, M. D. Flannigan, P. J. Hanson, L. C. Irland, A. E. Lugo, C. J. Peterson, D. Simberloff, F. J. Swanson, B. J. Stocks, and B. M. Wotton. 2001. Climate change and forest disturbances. BioScience 51:723–734.

Furniss, R. L., and V. M. Carolin. 1977. Western forest insects. Miscellaneous Publication No. 1339. U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station, Portland, Oregon.

Greenland, D., F. Bierlmaier, M. Harmon, J. Jones, A. McKee, J. Means, F. J. Swanson, and C. Whitlock, C. 2003. Climate variability and ecosystem response at the H. J. Andrews Long-term Ecological Monitoring site. In: Greenland, D., and D. G. Goodin, editors. Climate variability and ecosystem response at Long-term Ecological Research sites. Oxford University Press, New York, New York.

Johnson, E. W., and D. Wittwer. 2008. Aerial detection surveys in the United States. Australian Forestry 71:212–215.

Kennedy, R. E., W. B. Cohen, A. A. Kirshbaum, and E. Haunreiter. 2007. Protocol for Landsat-based monitoring of landscape dynamics at North Coast and Cascades Network parks. Techniques and Methods 2-G1, US Geological Survey, Reston, Virginia.

Kennedy, R. E., Z. Yang, and W. B. Cohen, W.B. 2010. Detecting trends in forest disturbance and recovery using yearly Landsat time series: 1. LandTrendr — Temporal segmentation algorithms. Remote Sensing of Environment 12:2897–2910.

Klein, W. H., S. Tunnock, J. G. D. Ward, and J. A. E. Knopf. 1983. Aerial sketchmapping. Forest Insect and Disease Survey Methods Manual, Chapter 1.1.1. USDA Forest Service, Forest Pest Management, Methods Application Group, Fort Collins, Colorado.

Littell, J. S., D. McKenzie, D. L. Peterson, and A. L. Westerling. 2009. Climate and wildfire area burned in western U.S. ecoprovinces, 1916–2003. Ecological Applications 19:1003–1021.

Littell, J. S., E. E. Oneil, D. McKenzie, J. A. Hicke, J.A. Lutz, R. A. Norheim, and M. M. Elsner. 2010. Forest ecosystems, disturbance, and climatic change in Washington State, USA. Climatic Change 102:129–158.

Logan, J. A., and B. J. Bentz. 1999. Model analysis of Mountain Pine Beetle (Coleoptera: Scolytidae) seasonality. Enviromental Entomology 28:924–934.

Logan, J. A., J. Regniere, and J. A. Powell. 2003. Assessing the impacts of global warming on forest pest dynamics. Frontiers in Ecology and the Environment 3:130–137.

McConnell, T., E. Johnson, and B. Burns. 2000. A Guide to conducting aerial sketchmap surveys. FHTET 00-01, USDA Forest Service, Forest Health Technology Enterprise Team, Fort Collins, Colorado.

Mitchell, R. G., and P. E. Buffam. 2001. Patterns of long-term Balsam Woolly Adelgid infestations and effects in Oregon and Washington. Western Journal of Applied Forestry 16:121–126.

Paine R. T., M. J. Tegner, and A. E. Johnson. 1998. Compounded perturbations yield ecological surprises: Everything else is business as usual. Ecosystems 1:535–545.

Powell, J. A., and J. A. Logan. 2005. Insect seasonality: Circle map analysis of temperature-driven life cycles. Theoretical Population Biology 3:161–179.

Raffa, K. F., B. H. Aukema, B. J. Bentz, A. L. Carroll, J. A. Hicke, M. G. Turner, and W. H. Romme. 2008. Cross-scale drivers of natural disturbances prone to anthropogenic amplification: The dynamics of bark beetle eruptions. BioScience 58:501–517.

Schrader-Patton, C. 2002. Digital aerial sketchmapping. RSAC-LSP-3400-RPT2, USDA Forest Service Remote Sensing Application Center publication, Salt Lake City, Utah.

Spies, T. A., and J. F. Franklin. 1989. Gap characteristics and vegetation response in coniferous forests of the Pacific Northwest. Ecology 70:543–545.

Sturrock, R. N., S. J. Frankel, A. V. Brown, P. E. Hennon, J. T. Kliejunas, K. J. Lewis, J. J. Worrall, and A. J. Woods. 2011. Climate change and forest diseases. Plant Pathology 60:133–149.

Thomson, A. J., R. F. Shepherd, J. W. E. Harris, and R. H. Silversides. 1984. Relating weather to outbreaks of Western Spruce Budworm, *Choristoneura occidentalis* (Lepidoptera: Tortrididae), in British Columbia. Canadian Entomologist 116:375–381.

Youngblood, A., J. B. Grace, and J. D. McIver. 2009. Delayed conifer mortality after fuel reduction treatments: Interactive effects of fuel, fire intensity, and bark beetles. Ecological Applications 19:321–337.

4.6 Forest Health: Whitebark Pine and White Pine Blister Rust

(Andrea Woodward, USGS FRESC)

4.6.1 Introduction

Whitebark Pine (*Pinus albicaulis*) grows on cold, dry sites above 1524 m (5000 ft) in the northeast corner of MORA and in small, disjunct populations on the west side of the park. Often the first tree species to establish in subalpine meadows or alpine ridges, it influences snowmelt patterns, soil development, and provides important micro-sites for establishment of other plants. In these areas it sometimes functions as a pioneer species, taking the lead in meadow invasion (Franklin and Mitchell 1967). Whitebark Pine seeds are a valuable food source for birds, squirrels, and bears. Clark's Nutcrackers (*Nucifraga columbiana*), Red Squirrels (*Tamiasciurus hudsonicus*) and Douglas' Squirrels (*Tamiasciurus douglasii*) extract seeds from the closed cones and then cache them in subalpine meadows for future retrieval (Tomback et al. 2001).

In 2011, the U.S. Fish and Wildlife Service determined that Whitebark Pine warrants protection under the Endangered Species Act (ESA), but that adding the species to the Federal List of Endangered and Threatened Wildlife and Plants was precluded by the need to address other listing actions having higher priority. Threats to the Whitebark Pine include habitat loss and mortality from White Pine blister rust (*Cronartium ribicola*), Mountain Pine Beetle (*Dendroctonus ponderosae*), catastrophic fire and fire suppression, environmental effects resulting from climate change, and the inadequacy of existing regulatory mechanisms.

4.6.2 Approach

We summarized the results of surveys of Whitebark Pine in 19 plots that were conducted in MORA from 1994 to 1998 which had the objectives of: (1) assessing the rates of blister rust infections and morality in trees and saplings; (2) determining whether Mountain Pine Beetles were present and contributing to mortality; (3) determining spatial patterns of rates of infection and mortality; and (4) providing data to assist in the development of a long-term monitoring program (Rochefort 2008). Permanent monitoring plots were subsequently established in 2004 and reassessed in 2009 (NCCN Inventory and Monitoring, undated). We also report long-term trends predicted by the U.S. Fish and Wildlife Service in the finding regarding a petition to list Whitebark Pine under the Endangered Species Act (Sattelberg 2011).

4.6.3 Reference Conditions and Comparison Metrics

Because White Pine blister rust is an introduced disease, the reference condition for assessing trend is the absence of blister rust. Assessment metrics included extent of mapped vegetation classes that include Whitebark Pine since 1936 and change in infection rate and mortality from the 1990s to 2009.

4.6.4 Results and Assessment

Current Condition

The recently completed vegetation map of MORA (Nielsen and Copass, In prep.) indicates that Subalpine Fir (*Abies lasiocarpa*)-Whitebark Pine woodland covers 1133 ha (2800 ac) or 1.2% of the park (Table 27). It occurs at high elevation on all aspects of the park, but is most dense in the northeastern region. Based on field data collected from permanent plots in 2009, less than a quarter of mature trees are uninfected and mortality is 52%, while 43% of saplings are infected. Mountain Pine Beetle occurs at <1% of sites (NCCN Inventory and Monitoring, undated).

Trend

A vegetation map for MORA from 1936 shows 66 stands of Whitebark Pine covering approximately 1193 ha (2948 ac) in 5 plant associations: Subalpine Fir dominant; subalpine parkland; Whitebark Pine dominant; Mountain Hemlock (*Tsuga mertensiana*) dominant; and Yellow Cedar (*Chamaecyparis nootkatensis*) dominant (Rochefort 2008). This compares well with the estimate of 1133 ha (2800 ac) in the latest vegetation map. However, both of these maps have potentially large errors with respect to an individual, relatively rare species. The map from 1936 was dependent on field surveys; the recent map is dependent on detecting the reflectance signature that characterizes vegetation classes as determined by plot samples and ground-truthing.

White Pine blister rust was introduced to North America in 1910 (Keane and Arno 1993) and first appeared in Mount Rainier in 1928, but not in Whitebark Pine until 1937 (Rochefort 2008). Studies show that infection rate of adult trees (>2.54 cm (1 in) diameter at breast height, dbh) and saplings (individuals taller than 50 cm (20 in) but <2.54 cm dbh) has increased since the 1990s, especially in the most recent interval (Rochefort 2008, North Coast and Cascades Network Inventory and Monitoring undated; Table 30). Perhaps due to the small size of Whitebark Pine stands in MORA, Mountain Pine Beetles were rarely observed in the 1990s (Rochefort 2008) and in <1% of sites in the 2000s (NCCN Inventory and Monitoring undated).

Predicted Changes

According to the U.S. Fish and Wildlife Service finding regarding listing of Whitebark Pine under the Endangered Species Act, the species is experiencing an overall long-term pattern of decline, even in areas originally thought to be mostly immune from White Pine blister rust, Mountain Pine Beetles, and fire suppression (Sattelberg 2011). “Recent predictions indicate a continuing downward trend within the majority of its range. While individual trees may persist, given current trends the USFWS anticipates Whitebark Pine forests will likely become extirpated and their ecosystem functions will be lost in the foreseeable future. On a landscape scale, the species appears to be in danger of extinction, potentially within as few as 2 to 3 generations. The generation time of Whitebark Pine is approximately 60 yrs.”

Table 30. Infection and mortality rates of Whitebark Pine due to White Pine blister rust.

		Percent of trees		
		1990s	**2004**	**2009**
Infected	Mature trees	13.5	15	26
	Saplings	24.3	25	43
Mortality	Mature trees	33.4	48	52
	Saplings	8.6	na	na

4.6.5 Emerging Issues

- Resistant genotypes may exist that could be used for restoration in the future. A project in collaboration with the USDA Forest Service Dorena Genetic Resource Center has shown that some Whitebark Pine parent trees in MORA have among the highest levels of resistance yet seen (Richard Sniezko, personal communication).

4.6.6 Information and Data Needs–Gaps

- Continuing to monitor blister rust infection rates and the prevalence of Mountain Pine Beetles will describe the extent and trend of the infestation and potential exacerbation by Mountain Pine Beetles.
- Further collections from new locations in MORA could identify more resistant families of trees.
- Re-collections from rust-resistant trees could be used for future restoration or gene conservation.
- In 2010, 240 WBP seedlings were planted near Shadow Lake in an experimental design to evaluate genetic source and effectiveness of endophyte treatment on survival. Continued establishment and testing of restoration plantings such as this will inform effective restoration protocols.

4.6.7 Literature Cited

Franklin, J. F., and R. G. Mitchell. 1967. Successional status of Subalpine Fir in the Cascade Range. Pacific Northwest Forest and Range Experiment Station. USDA Forest Service Research Paper PNW-46. 16 p.

Keane, R. E., and S. F. Arno. 1993. Rapid decline of Whitebark Pine in western Montana: Evidence from 20-year remeasurements. Western Journal of Forestry 8:44–47.

Nielsen, R. P., and C. Copass. In prep. Vegetation inventory project for Mount Rainier National Park, 2007–2013 (MORA_Veg_Polys). Mount Rainier National Park. Geospatial Dataset-XXXXXXX. https://irma.nps.gov/App/Reference?Profile/2177201.

Rochefort, R. M. 2008. The influence of White Pine blister rust (*Cronartium ribicola*) on Whitebark Pine (*Pinus albicaulis*) in Mount Rainier National Park and North Cascades National Park Service Complex, Washington. Natural Areas Journal 28:290–298.

Sattelberg, R. M. 2011. 12-month finding on a petition to list *Pinus albicaulis* as endangered or threatened with critical habitat. Federal Register Doc 2011-17943 (Docket number FWS-R6-ES-2010-0047).

Tomback, D. F., S. F. Arno, and R. E. Keane, editors. 2001. Whitebark Pine communities, ecology and restoration. Island Press, Wahsington, D. C.

4.7 Forest Health: Air Quality Effects

(Andrea Woodward, USGS FRESC)

4.7.1 Introduction

Air quality is a concern of park resource managers because MORA is downwind from the urban and agricultural areas of the Puget Sound, Vancouver, Washington, and Portland, Oregon, metropolitan areas. Moreover, the Pacific Northwest receives pollutants in air masses from Asia (Jaffe et al. 1999, Fiore et al. 2002, Jaffe et al. 2005, Weiss-Penzias 2007). Pollutants potentially arriving at MORA include nitrogen and sulfur compounds, ozone, semi-volatile organic compounds (SOCs; current and historic-use pesticides, combustion by-products and industrial-urban use compounds), and toxic metals, notably mercury (Landers et al. 2008). Ozone in particular is often at higher concentrations downwind of urban source areas than in the source areas of the precursors (Brace et al. 1999).

Pollutants have a variety of potential impacts on forest ecosystems. Nitrogen (N) is a critical plant nutrient and consequently, elevated N may affect a variety of vegetative components and processes such as soil microbes and mycorrhizal fungi (Eilers et al. 1994), resistance of plants to insects and pathogens, winter injury in conifers (Fenn et al. 2003a), as well as plant growth. Over the longer term, N fertilization may affect ecosystem structure and diversity, as species adapted to higher nitrogen levels gain a competitive advantage. Nitrogen fertilization is especially influential in conditions typical of the Pacific Northwest, such as naturally low N availability, shallow soils, and snowmelt as a major component of run-off (Eilers et al. 1994). In addition, N deposition may be contributing to greater fuel loads and thus potentially altering the fire cycle in a variety of ecosystem types in concert with climate change, although much more study is needed to understand this effect (Fenn et al. 2003b). Nitrogen and sulfur compounds also contribute to the production of acid rain, which can have long-term effects on forest biogeochemistry and biomass accumulation (Likens et al. 1996, McLaughlin and Percy 1999). Ozone is a strong oxidant that is toxic at relatively low concentrations to sensitive species, including several species of vascular plants and lichens that are abundant in Pacific Northwest forests (Brace et al. 1999, Geiser et al. 2010). While mercury is highly toxic to animals, its direct effects on plants are unclear (Azevedo and Rodriguez 2012).

High elevation areas are potentially at higher risk than other areas due to long-range transport of pollutants being deposited in the snowpack (Blais et al. 1998), and cold fractionation of lighter SOCs in the atmosphere, which may result in migration of these and other compounds to higher (colder) alpine areas (Wania and Mackay 1996). Significant changes in alpine species composition have been recorded over the past several decades in the high Rocky Mountains that may be a response to 6 decades of elevated N deposition (Fenn et al. 2003a).

A direct assessment of air pollution in MORA is covered in section 4.1 of Chapter 4 of this report and should be consulted for a detailed description of air quality status and trends. Here we focus on the effects of air quality on vegetation.

4.7.2 Approach

To assess the consequences of air quality on park vegetation we consulted 3 studies of the relationship between contaminant concentrations and vegetation change that incorporated data from

MORA. The first study included an evaluation of whether lichen communities described in plots in MORA exhibited effects of exposure to detrimental levels of nitrogen and sulfur compounds (Geiser and Neitlich 2007, Geiser et al. 2010). Results were based on modeling lichen community gradients in relation to air quality, climate, and other environmental variables. The model was developed using plots which could be described as 'polluted' and 'non-polluted' based on chemical analysis of lichens for N, sulfur (S), and lead. The second study was an assessment of airborne contaminants, including N, S, mercury, other metals, and SOCs in air and biota of 20 national parks of the western US, also known as the Western Airborne Contaminants Assessment Project (WACAP) (Landers et al. 2008). Finally, Brace and Peterson (1998) described spatial patterns of tropospheric ozone in the park using passive samplers in 4 drainages and along elevation gradients during the summers of 1994 and 1995. The USDA Forest Service also monitors ozone damage to vegetation in MORA as part of the FIA plot network. Potential effects of future changes in air quality are assessed based on a literature review.

4.7.3 Reference Conditions and Comparison Metrics

With the exception of extremely rare events (e.g., volcanic eruptions), impaired air quality results from human activities. Consequently, the reference condition for the effects of air pollution on vegetation is pre-industrial air quality levels. However, in recognition that pre-industrial levels are unlikely to be re-established, the NPS Air Resources Division uses EPA guidelines (ozone and pesticides) and critical loads (N and S) known to harm aquatic and terrestrial resources as standards for impairment (see Chapter 4.1).

4.7.4 Results and Assessment

Current Condition

Nitrogen and Sulfur Compounds

Based on lichen samples taken widely on U.S. Forest Service land in western Washington and Oregon and interpolated to the entire area, lichen communities in MORA fell in an area mapped as 'best' on a 6-step scale. This means that all sensitive species were expected to be present and the sites were expected to be in the 75% quantile for a measure describing pollution concentration (Geiser and Neitlich 2007). This conclusion is substantiated by chemical analysis of 5 collections of lichen samples on an elevational gradient showing that N and S concentrations were not elevated above background levels typical of remote areas (Landers et al. 2008).

Ozone

Ozone concentrations in MORA exceeded what are considered elevated levels (>80 ppb) at various times, especially in the late 1980s and early 1990s, at Longmire, Carbon River, the southwestern section and Tahoma Woods, and Paradise which has seen the highest ozone levels recorded in the state (http://www.nps.gov/mora/naturescience/airquality.htm). Brace and Peterson (1998) determined that ozone concentrations increase with elevation and are higher on the west side of the park. Even though ozone levels higher than 60 ppb have been known to harm vegetation, systematic evaluation of *Abies lasiocarpa* and *Populus trichocapra* in MORA led to no evidence of damage (Brace et al. 1999). However, damage to *Pinus ponderosa* has been observed in Pack Forest, just outside of the park, and is hypothesized to have been caused by an ozone-sulfur dioxide synergism (http://www.nps.gov/mora/ naturescience/airquality.htm). Eleven ozone-sensitive vascular plant species occur in the park (Porter 2003): Red Alder (*Alnus rubra*), Saskatoon (*Amelanchier alnifolia*), Spreading Dogbane (*Apocynum androsaemifolium*), Douglas's Sagebrush (*Artemisia douglasiana*), Pacific Ninebark (*Physocarpus capitatus*), Ponderosa Pine (*Pinus ponderosa*), Quaking aspen (*Populus tremuloides*), Thimbleberry (*Rubus parviflorus*), Scouler's Willow (*Salix scouleriana*), Common Snowberry (*Symphoricarpos albus*), and Black Huckleberry (*Vaccinium membranaceum*).

Semi-volatile Organic Compounds

Concentrations of all SOCs measured in samples of lichens and conifer needles from MORA were at or above the median values for the 20 western national parks sampled by WACAP (Landers et al. 2008). SOCs included polycyclic aromatic hydrocarbons (PAHs); current-use pesticides: endosulfans, dacthal, chloropyrifos and trifluralin; historic-use pesticides: hexachlorbenzene (HCB), a-HCH, g-HCH, chlordanes, dieldrin, and dichlorodiphenyltrichloroethanes (DDTs); and industrial-urban-use compound polychlorinated biphenyls (PCBs) (Table 31). These values were similar to those in other PNW parks (CRLA, NOCA, OLYM). Typical of results across all parks, pesticide and PCB concentrations in the lichens sampled in MORA increased with elevation. Because needle productivity is high, the ecological effects of cumulate SOCs contributed by needle litterfall are a potential concern (Landers et al. 2008).

Table 31. Mean concentration of semi-volatile organic compounds in lichen and conifer needles.

	Concentration (ng SOC/g lipid)	
Compound Class	**Lichens**	**Conifer Needles**
Current-use pesticides	126.4	63.7
Historic-use pesticides	47.9	43.1
Polychlorinated biphenyls (PCBs)	6.18	0.84
Polycyclic aromatic hydrocarbons (PAHs)	764	826

Mercury

Mercury levels in MORA were at or well above the concentrations observed at the other western parks in the WACAP study (Landers et al. 2008). However, the WACAP parks did not have higher levels of mercury than expected of remote areas in the western United States. Meanwhile, lead levels in Common Witch's Hair (*Alectoria sarmentosa*) collected at Golden Lake declined from 5.45 ± s.d. 2.62 ppm in 1983 to 1.29 ± 0.12 ppm in 2005.

Trend

None of these pollutant chemicals were present under reference conditions. Especially for SOCs and mercury, we don't know the potential consequences for plant species and the ecosystem. The trend of increasing pollutant concentrations has not apparently impacted vegetation in MORA to date.

Predicted Changes

Despite improvements due to the Clean Air Act, atmospheric pollutants are predicted to increase due to a number of pressures. Increasing energy needs are likely to negate air quality gains regarding acidifying and oxidizing pollutants (Dahlgren 2000). Nitrogen emissions are expected to increase by 2020 due to population growth (Schary 2003), and both regional ozone and NOx are predicted to increase with populations and standard of living increases in Asia through trans-Pacific transport (Bertschi et al. 2004). Meanwhile, ozone showed a statistically significant increase, 1996–2005, (http://www2.nature.nps.gov/ air/Pubs/pdf/gpra/GPRA_AQ_ConditionsTrendReport2006.pdf). The effect these changes will have on vegetation is unclear. However, ozone damage to sensitive species may eventually become evident and nitrogen deposition is expected to affect plant community composition (Fenn et al. 2003a). While nitrogen enrichment has ecosystem-wide consequences (Vitousek et al. 1997), it appears that vascular plants are more sensitive than soil and other processes (Bowman et al. 2006). Lichen communities are expected to shift to nitrophilous or pollution tolerant species (Fenn et al. 2003a, Geiser and Neitlich 2007) with consequent loss of species diversity. Biomagnification of SOCs and mercury may not directly affect the plants where they collect, but they may spread by leaching or burning to affect other parts of ecosystems (Friedli et al. 2003, Landers et al. 2008). Finally, we do not know what effect changing climate might have on the response of plants to pollutants.

4.7.5 Emerging Issues

- Increasing urban-industrial development and agriculture in the Seattle, Washington, and Vancouver, British Columbia, areas are expected to increase air pollutant concentrations and consequent risk to vegetation (Dahlgren 2000). Increasing agricultural and industrial development in Asia may also increase air pollution to harmful levels (Jaffe et al. 2005; Bertschi et al. 2004) and be more difficult to influence or regulate than domestic sources.
- Pacific coast parks have high contaminant concentrations in and on conifer needles and dense foliage in forest canopies, which contribute canopy leachates and needle litter to soils (Horstmann and McLachlan 1998, Weiss 2000, Nizzetto et al. 2006). In fact, western US coniferous forests have the capacity to annually accumulate amounts of pesticides in second-year needles that are comparable on a per hectare basis to a significant fraction of regional pesticide application rates (Landers et al. 2008). The relative importance of these pathways to affect understory contamination versus deposition from precipitation is unknown (Horstmann and McLachlan 1998, Weiss 2000, Nizzetto et al. 2006). Moreover, the potential negative effects of contaminants on understory and soil arthropods, fungi or microbial decomposers, or plant life is also unknown.
- Temporal dynamics of contaminant accumulation in conifer needles, which may persist for many years, is unknown (Landers et al. 2008). Even though mercury concentrations in conifer needles of western forests appear to be relatively low, the biomass of needles/ha is so high that forest fires can be a significant source of mercury release (Friedli et al. 2003).
- Increases in nitrogen levels will competitively favor species adapted to higher nitrogen levels and select against species adapted to low nitrogen levels, which will lead to a long-term change in species composition and relative abundance. In addition, many invasive plant species may also gain a competitive advantage with altered nutrient regimes, especially increased nitrogen (Fenn et al. 2003a).

4.7.6 Information and Data Needs–Gaps

- Ozone monitoring only occurred for a brief period in the 1990s, yet Puget Sound air quality has significantly degraded since that time; therefore direct monitoring of ozone would be beneficial.
- Acquisition of FIA monitoring data to follow trends in ozone damage should be continued.
- Impaired air quality is expected to have the most detrimental effects at high elevations (Blais et al. 1998, Wania and Mackay 1996), yet there is no routine monitoring of contaminants in air or vegetation there.
- Relationships among contaminant levels in air with levels in plants due to bioaccumulation and biomagnifications and consequences for plants and ecosystems need study.
- Critical and target loads for N have been identified for lichens (Geiser et al. 2010), but still need to be identified for vascular plants. Determining critical loads must include consideration of interactions between N deposition and warmer temperatures.

4.7.7 Literature Cited

Azevedo, R., and E. Rodriguez. 2012. Phytotoxicity of mercury in plants: A review. Journal of Botany Article ID 848614.

Bertschi, I. T., D. A. Jaffe, L. Jaegle, H. U. Price, and J. B. Dennison. 2004. PHOEBE/ITCT 2002 airborne observations of transpacific transport of ozone, CO, volatile organic compounds, and aerosols to the northeast Pacific: Impacts of Asian anthropogenic and Siberian boreal fire emissions. Journal of Geophysical Research 109: D23S12.

Blais J. M., D. W. Schindler, D. C. G. Muir, L. E. Kimpe, D. B. Donald, and B. Rosenberg. 1998. Accumulation of persistent organochlorine compounds in mountains of western Canada. Nature 395:585–588.

Bowman, W.D., J.L. Gartner, K. Holland, and M. Wiedermann. 2006. Nitrogen critical loads for alpine vegetation and terrestrial ecosystem response – Are we there yet? Ecological Applications 16:1183–1193.

Brace, S., and D. L. Peterson. 1998. Spatial patterns of tropospheric ozone in the Mount Rainier region of the Cascade Mountains, U.S.A. Atmospheric Environment 32:3621–3637.

Brace, S., D. L. Peterson, and D. Bowers. 1999. A guide to ozone injury in vascular plants of the Pacific Northwest. General Technical Report PNW-GTR-466. USDA Forest Service, Pacific Northwest Research Station, Portland, Oregon.

Dahlgren, T. 2000. 1999 air quality trends in Washington. Publications No. 00-02-011. State of Washington, Department of Ecology, Seattle, Washington.

Eilers, J. M., C. L. Rose, and T. J. Sullivan. 1994. Status of air quality and effects of atmospheric pollutants on ecosystems in the Pacific Northwest region of the National Park Service. Technical Report NPS/NRAQD/NRTR-94/160. National Park Service, Fort Collins, Colorado.

Fenn, M. E., J. S. Baron, E. B. Allen, H. M. Rueth, K. R. Nydick, L. Geiser, W. D. Bowman, J. O. Sickman, T. Meixner, D. W. Johnson, and P. Neitlich. 2003a. Ecological effects of nitrogen deposition in the western United States. BioScience 53:404–420.

Fenn, M. E., R. Haeuber, G. S. Tonnesen, J. S. Baron, S. Grossman-Clarke, D. Hope, D. E. Jaffe, S. Copeland, L. Geiser, H. M. Rueth, and J. O. Sickman. 2003b. Nitrogen emissions, deposition, and monitoring in the western United States. BioScience 53:1–13.

Fiore, A. M., D. J. Jacob, I. Bey, R. M. Yantosca, B. D. Field, A. C. Fusco, and J. G. Wilkinson. 2002. Background ozone over the United States in summer: Origin, trend, and contribution to pollution episodes. Journal of Geophysical Research 107(D15): 4275.

Friedli, H. R., L. F. Radke, J. Y. Lu, C. M. Banic, W. R. Leaitch, and J. I. MacPherson. 2003. Mercury emissions from burning of biomass from temperate North American forests: Laboratory and airborne measurements. Atmospheric Environment 37:253–267.

Geiser, L., and P. Neitlich. 2007. Air pollution and climate gradients in western Oregon and Washington indicated by epiphytic macrolichens. Environmental Pollution 145:203–218.

Geiser, L., S. E. Jovan, D. A. Glavich, and M. K. Porter. 2010. Lichen-based critical loads for atmospheric nitrogen deposition in western Oregon and Washington forests, USA. Environmental Pollution 158:2412–2421.

Horstmann, M., and M. S. McLachlan. 1998. Atmospheric deposition of semivolatile organic compounds to two forest canopies. Atmospheric Environment 32:1799–1809.

Jaffe, D., E. Prestbo, P. Swartzendruber, P. Weiss-Penzias, S. Kato, A. Takami, S. Hatakeyama, and Y. Kajii. 2005. Export of atmospheric mercury from Asia. Atmospheric Environment 39:3029–3038.

Jaffe, D., T. Anderson, D. Covert, R. Kotchenruther, B. Trost, J. Danielson, W. Simpson, T. Bernsten, S. Karlsdottir, D. Blake, J. Harris, G. Carmichael, and I. Uno. 1999. Transport of Asian air pollution to North America. Geophysical Research. Letters 26:711–714.

Landers, D. H., S. L. Simonich, D. A. Jaffe, L. H. Geiser, D. H. Campbell, A. R. Schwindt, C. B. Schreck, M. L. Kent, W. D. Hafner, H. E. Taylor, and others. 2008. The fate, transport, and ecological impacts of airborne contaminants in western National Parks (USA). EPA/600/R-07/138. U.S. Environmental Protection Agency, Office of Research and Development, NHEERL, Western Ecology Division, Corvallis, Oregon.

Likens, G. E., C. T. Driscoll, and D. C. Buso. 1996. Long-term effects of acid rain: Response and recovery of a forest ecosystem. Science 272:244–246.

McLaughlin, S., and K. Percy. 1999. Forest health in North America: Some perspectives on actual and potential roles of climate and air pollution. Water, Air and Soil Pollution 116:151–197.

Nizzetto, L., C. Cassani, and A. Di Guardo. 2006. Deposition of PCBs in mountains: The forest filter effect of different forest ecosystem types. Ecotoxicology and Environmental Safety 63:75–83.

Porter, E. 2003. Ozone sensitive plant species on National Park Service and U.S. Fish and Wildlife Service Lands: Results of a June 24–25, 2003 workshop, Baltimore, Maryland. Natural Resource Report NPS/NRARD/NRR-2003-01, National Park Service Air Resources Division, Denver, Colorado.

Schary, C. 2003. Future trends impacting air quality in the Pacific Northwest. Available online: http://yosemite.epa.gov/r10/homepage.nsf/3061430ee8351cae88256cdb005af493/ec3990566baac3d888256cd30075ed08/$FILE/Future%20Trends.ppt (accessed 20 March 2003).

Vitousek, P. M., J. D. Aber, R. W. Howarth, G. E. Likens, P. A. Matson, D. W. Schindler, W. H. Schlesinger, and D. G. Tilman. 1997. Human alteration of the global nitrogen cycle: Sources and consequences. Ecological Applications 7:737–750.

Wania, F., and D. Mackay. 1996. Tracking the distribution of persistent organic pollutants. Enviromental Science and Technology 30:A390–A396.

Weiss, S. B. 2000. Vertical and temporal distribution of isolation in gaps in an old-growth coniferous forest. Canadian Journal Forest Research 30:1953–1964.

Weiss-Penzias, P., D. A. Jaffe, P. Swartzendruber, W. Hafner, D. Chand, and E. Prestbo. 2007. Quantifying Asian and biomass burning sources of mercury using the Hg/CO ratio in pollution plumes observed at the Mount Bachelor Observatory. Atmospheric Environment 41:4366–4379.

4.8 Fire Ecology

(Karen Kopper, NPS NOCA)

4.8.1 Introduction

Forests and other vegetation types are greatly influenced by fire regime properties. The frequency and severity of a fire regime influence horizontal and vertical structure, species composition, and the relative abundance of species (Agee 1993, Turner et al. 1994, Sugihara et al. 2006). Fire intervals can be altered by fire suppression, which lengthens the time between fires and prolongs the accumulation of dead and downed fuels (Brown 1983, Graham et al. 2004). They can also be shortened by warmer and drier conditions currently associated with climate change, which increase the number of acres burned (Littell et al. 2009).

Fire has been identified as the most important disturbance agent at MORA, followed by avalanches and lahars, whereby relatively infrequent, large stand-replacing fires have shaped the current forest and subalpine mosaic (Hemstrom and Franklin 1982, Stueve et al. 2009). Hemstrom and Franklin (1982) performed a comprehensive stand reconstruction for the forests of MORA from which they have made the following conclusions: (1) south aspects and higher elevations have burned more frequently; (2) major fire episodes have corresponded with periods of prolonged drought; and (3) modern human influence has probably had little impact on the natural fire regime, although it may have limited the growth of fires during the 1917–1934 drought.

4.8.2 Approach

We examined and mapped the recent fire history (1930–2009) for MORA using the NPS fire records that are archived at the Wildland Fire Management Information (WFMI) website (USDI 2013). We assessed the recent fire history, extending the record that Hemstrom and Franklin (1982) examined to include fires from 1978 to 2009.

4.8.3 Reference Condition and Comparison Metrics

Hemstrom and Franklin's (1982) interpretation of the recent fire history (1930–1978) at MORA is the reference condition for our assessment (1930–2009). Neither their assessment nor ours are long enough to compare to the historical fire regime at MORA. Hemstrom and Franklin (1982) identified the time required for an area equal to the size of the park to burn (the natural fire rotation [NFR]) for the pre-settlement era (1200–1850) as 465 yrs. They cautioned that the MORA fire regime, characterized by infrequent stand-replacing fires, is not well represented by any NFR calculation, especially those based on shorter time periods (such as ours) that could miss large fire events.

4.8.4 Results and Assessment

Current Condition

The NPS fire records document a total of 356 fires that burned 5003 ac (2025 ha) of all vegetation types between 1930 and 2009 (Table 32, Figure 21). Typical of high severity, long interval fire regimes, the majority of fires were <1 ac in size. Only 4 fires were more than 100 ac, and only 1 of these 4 was >1000 ac.

The majority of fires (73%) occurring between 1930 and 2009 were lightning caused compared to 27% caused by humans. During this same time period, the majority of fires were suppressed (82%) compared to 17% that went out naturally. Less than 1% of fires were managed for resource benefit (previously referred to as "prescribed natural fire" or "wildland fire use"). Fire suppression may have been effective after the time-period reported by Hemstrom and Franklin (1982); although 53% of all the fires in the 1930 to 2009 record occurred after 1978, and only 11% of the total acres burned were consumed after 1978.

There are 444 (180) fewer burned acres (hectares) recorded by Hemstrom and Franklin (1982) between 1900 and 1978 than recorded by the park in the forested area between 1930 and 1978. The discrepancy may be partially due to fires that Hemstrom and Franklin (1982) omitted due to their small size, but larger fires that started outside of their study area do not account for the remainder of the excluded acres. We surmise that some of the additional burned acres recorded by the park may have been from lower severity fires that were not captured by Hemstrom and Franklin's (1982) stand reconstruction, which used stand ages to detect stand replacing events.

Trend

Hemstrom and Franklin (1982) surmise that the fires during the droughts of 1917–1934 may have gotten larger if they were not suppressed. Average annual precipitation rates since 1934 do not indicate comparable periods of drought (PRISM Climate Group 2013); however, fire suppression may have been more effective in the recent record (since 1978). Fires suppressed after 1978 make up 36% of the total number of fire occurrences, but only 11% of the total acres burned.

Fire suppression may have reduced the number of acres burned; however, it has not, and will not cause an unnatural accumulation of dead and downed fuel in the majority of forest types at MORA. The natural fire rotation (465 yrs) is sufficiently long to accumulate and maintain large quantities of coarse woody debris with little to no additional effect due to fire suppression (Hemstrom and Franklin 1982). This may not hold true for the eastern-most forests of the park, however, because these forests are drier and may have missed some lower severity fires.

Predicted Changes

In the future, MORA may experience an increase in the area burned by wildfires due to climate change. The fire season will be longer, given that summer temperatures are expected to increase and snowpack levels decrease with climate change (Mote et al. 2005). Climate is the primary driver for wildfire area burned (WFAB), explaining an average of 64% (33–87%) of area burned between 1977 and 2003 in the western U.S. (Littell et al. 2009). Sensitivity to climate drivers depends on climate-fire interactions in ecosystem provinces; increases in WFAB will be greatest in ecosystems such as MORA, where climate (not fuel) is the limiting factor (Hemstrom and Franklin 1982, Agee 1993, Littell et al. 2009). Forests on the east-side of MORA (in the rain shadow) are somewhat drier than on the west-side, and therefore, may experience a more rapid increase in WFAB with climate change.

Table 32a. Number of fires (by fire type) burned at MORA per decade. Table constructed from the NPS fire records archived in the Wildland Fire Management Information database. MRB = managed for resource benefit.

Decade	Human	Natural	Suppressed	Natural out	MRB	Total no. of fires
1930	16	18	33	0	1	34
1940	11	48	59	0	0	59
1950	14	8	22	0	0	22
1960	7	5	12	0	0	12
1970	5	36	41	0	0	41
1980	13	20	30	3	0	33
1990	12	72	53	31	0	84
2000	19	52	43	28	0	71
Total fires	97	259	293	62	1	356
Fires/Year	1.2	3.2	3.7	0.8	0.0	4.5
Relative %	27.2	72.8	82.3	17.4	0.3	100.0

Table 32b. Number of acres (by fire type) burned at MORA per decade. Table constructed from the NPS fire records archived in the Wildland Fire Management Information database. MRB = managed for resource benefit.

Decade	Human	Natural	Suppressed	Natural out	MRB	Total acres burned
1930	4135.3	16.6	4145.9	0	6	4151.9
1940	28.8	209.4	238.2	0	0	238.2
1950	8.1	0.8	8.9	0	0	8.9
1960	0.7	6.4	7.1	0	0	7.1
1970	3.3	38.7	42	0	0	42.0
1980	48	51.6	52	47.6	0	99.6
1990	1.2	18.4	16.5	3.1	0	19.6
2000	2.8	432.4	429.7	5.5	0	435.2
Acres burned	4228.2	774.3	4940.3	56.2	6	5002.5
Relative %	84.5	15.5	98.8	1.1	0.1	100.0

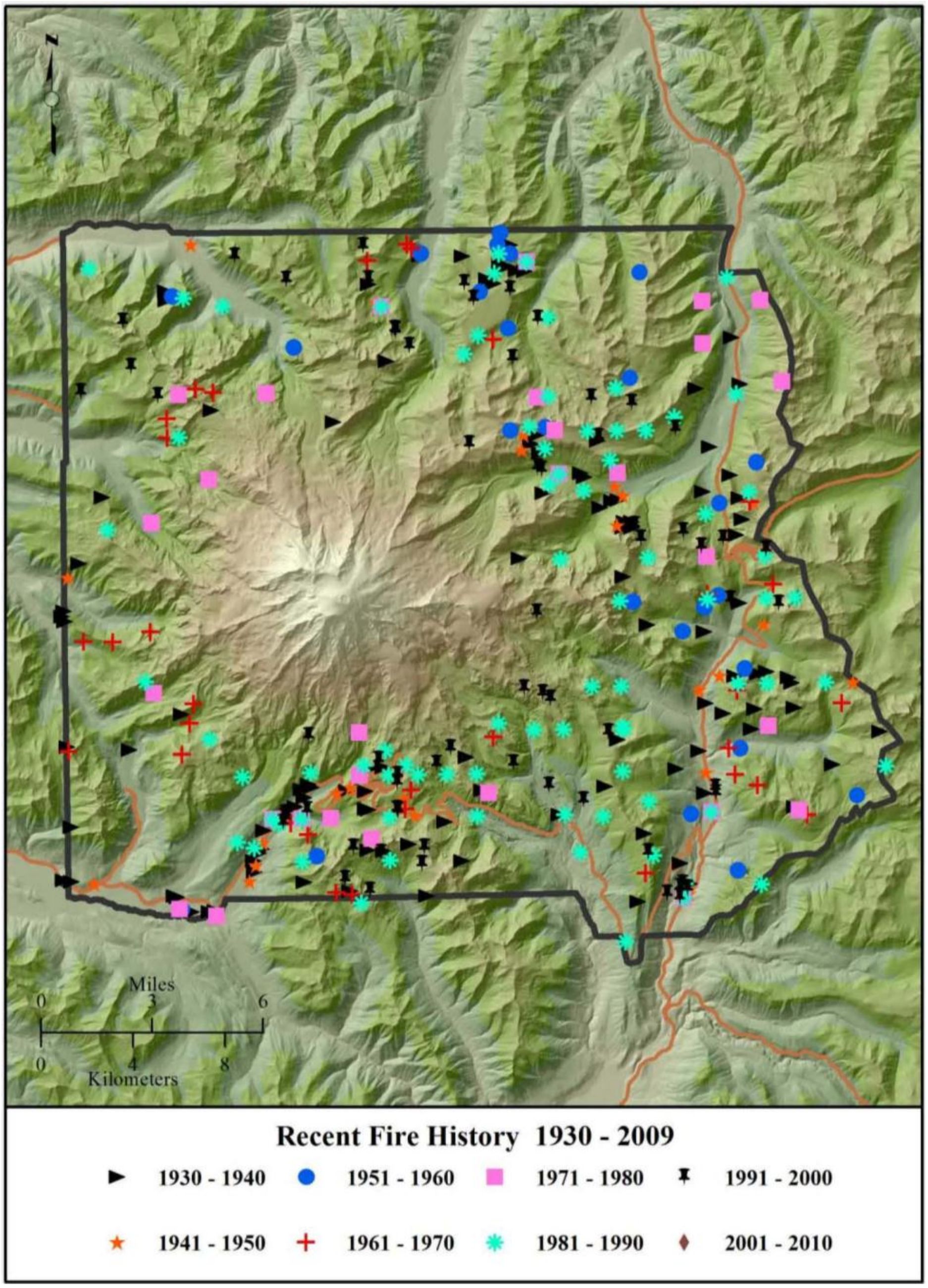

Figure 21. Map of all fire occurrences at MORA between 1930 and 2009, from the NPS fire records in the Wildland Fire Management Information database.

4.8.5 Emerging Issues

The effects of feedbacks and interactions between climate, fire and insect infestations are complex and still relatively uncertain (Field et al. 2007). Drought stress could increase tree mortality due to fires (fire severity) and insect infestations more rapidly than anticipated. Fuel could become a limiting factor in more areas of the park after 1 or more severe wildfires.

Novel species interactions due to shifts in climate conditions may alter post-fire regeneration. Non-native plant species, such as cheatgrass, may invade burned areas, displace natives, and alter fuel and fire regime properties (e.g., increase fire frequency) (Brooks et al. 2004). Restoration objectives for forest and fire regime properties should focus on resiliency (e.g. managing for fire-adapted species and stand characteristics in forests that are experiencing increased fire frequencies and severities) and ecosystem function rather than historical conditions which may no longer be suitable with climate change (Churchill et al. 2013).

4.8.6 Information and Data Needs–Gaps

We have identified 2 categories of relatively important future data requirements for MORA: (1) development of models for climate, fire, and insect interactions that include frequency of ignition and predictions of fuel availability within and adjacent to the park; and (2) development of climate adaptation strategies (e.g. fire and fuel treatments that promote high spatial variability in surface fuels and forest structure; Stephens et al. 2010), especially for dry-forests on the east-side of MORA.

4.8.7 Literature Cited

Agee, J. K. 1993. Fire ecology of Pacific Northwest forests. Island Press, Washington, D.C.

Brooks, M. L., C. M. D'Antonio, D. M. Richardson, J. B. Grace, J. E. Keeley, J. M. DiTomaso, R. J. Hobbs, M. Pellant, and D. Pyke. 2004. Effects of invasive alien plants on fire regimes. BioScience. 54:677–688.

Brown, J. K. 1983. Unnatural fuel buildup issue. In: Lotan, J.E. et al., editors. Proceedings – Symposium and workshop on wilderness fire. USDA Forest Service Intermountain Forest and Range Experiment Station, General Technical Report INT-128, Ogden, Utah.

Churchill, D. J., A. J. Larson, M. C. Dahlgreen, J. F. Franklin, P. F. Hessburg, and J. A. Lutz. 2013. Restoring forest resilience: From reference spatial patterns to silvicultural prescriptions and monitoring. Forest Ecology and Management 291:442–457.

Field, C. B., D. B. Lobell, H. A. Peters, and N. R. Chiariello. 2007. Feedbacks of terrestrial ecosystems to climate change. Annual Review of Environmental Resources 32:1–29.

Graham, R. T., S. McCaffrey, T. B. Jain, technical editors. 2004. Science basis for changing forest structure to modify wildfire behavior and severity. USDA Forest Service, General Technical Report, RMRS GTR-120, Rocky Mountain Research Station, Fort Collins, Colorado.

Hemstrom, M. A., and J. F. Franklin. 1982. Fire and other disturbances of the forests in Mount Rainier National Park. Quaternary Research 18:32–51.

Littell, J., D. McKenzie, D. L. Peterson, and A. L. Westerling. 2009. Climate and wildfire area burned in western U.S. ecoprovinces, 1916–2003. Ecological Applications 19:1003–1021.

Mote, P. W., A. F. Hamlet, M. P. Clark, and D. P. Lettenmaier. 2005. Declining mountain snowpack in western North America. Bulletin of the American Meteorological Society 86:39–49.

PRISM Climate Group. 2013. Oregon State University, Available online: http://prism.oregonstate.edu. Accessed 29 March 2013.

Stephens, S. L., C. I. Millar, and B. M. Collins. 2010. Operational approaches to managing forests of the future in Mediterranean regions within a context of changing climates. Environmental Research Letters 5:024003.

Stueve, K. M., D. L. Cerney, R. M. Rochefort, and L. L. Kurth. 2009. Post-fire tree establishment patterns at the alpine treeline ecotone: Mount Rainier National Park, Washington, USA. Journal of Vegetation Science 20:107–120.

Sugihara, N. G., J. W. Van Wagtendonk, K. E. Shaffer, J. Fites-Kaufman, and A. E. Thode. 2006. Fire in California's ecosystems. University of California Press, Berkeley, California.

Turner, M. G., W. W. Hargrove, R. H. Gardner, and W. H. Romme. 1994. Effects of fire on landscape heterogeneity in Yellowstone National Park, Wyoming. Journal of Vegetation Science 5:731–742.

[USDI] United States Department of the Interior. 2013. Wildland Fire Management Information website. https://www.nifc.blm.gov/cgi/WfmiHome.cgi. Accessed June 2012.

4.9 Biodiversity: Exotic Plants

(Andrea Woodward, USGS FRESC)

4.9.1 Introduction

While terminology varies by agency and through time, it is generally recognized that human activities have transported species to new places where they are described as non-native, exotic, alien, or introduced. Of these species, some are considered invasive because they can spread widely without the aid of human cultivation in a new environment. Invasive species that are recognized by federal, state, or local governments to threaten agricultural crops, local ecosystems, or fish and wildlife habitat are given the legal designation 'noxious weed' (Washington State Noxious Weed Control Board, http://www.nwcb.wa.gov/) and are subject to regulations concerning control measures.

In general, most non-native plant species have minor effects on natural ecosystems (Hiebert and Stubbendieck 1993). For example, of the approximately 973 vascular plant species at MORA, 152 are non-native, of which 26 species are considered to be threatening to park resources (Rochefort 2010). However, some exotic species can be extremely disruptive, such as interfering with natural processes, including disturbance regimes and biogeochemical cycles, and threatening the survival of naturally evolved plant assemblages and individual native species (D'Antonio and Vitousek 1992, Hiebert and Stubbendieck 1993, Vitousek et al. 1996, 1997, Mack et al. 2000, Asner and Vitousek 2005, Strayer et al. 2006). Some consequences of long-term invaders are becoming apparent, such as the ability of knotweed (*Polygonum* spp.) to reduce the nutrient subsidy from riparian litterfall to aquatic systems after displacing higher quality native vegetation (Urgenson and Reichard 2007). In fact, invasive species are said to be one of the biggest threats to biodiversity, ecosystem function, and community interactions (Boersma et al. 2006). Moreover, exotic species can disrupt the accurate presentation of a historic scene and damage historic or archeological resources (Hiebert and Stubbendieck 1993). The National Park Service recognizes the need to address invasive, introduced species (NPS 2006) and has established teams of exotic plant management technicians (Exotic Plant Management Teams, EPMTs) to work throughout the national parks (Beard and Gibbons 2011).

4.9.2 Approach

Information regarding invasive plants was provided by park staff from surveys conducted throughout MORA in 2006 and for the road from the Nisqually entrance to Paradise in 2009. The data from 2009 are in a geospatial database, and pdf files of maps by species have been made. The database containing the 2006 data may be incomplete because there are no data for 5 of the 12 areas and 17 species listed in the tables. Lists of noxious weeds found on adjacent national forest lands were used to identify species that are in the vicinity but not currently included in geospatial data in the park. The assessment study area was MORA and the Gifford-Pinchot, Okanogan-Wenatchee, and Mount Baker-Snoqualmie National Forests.

4.9.3 Reference Conditions and Comparison Metrics

The appropriate reference condition for exotic plants is an absence of species transported to the park through human activities. While restoring park lands to the reference condition is likely impossible, it is nevertheless a baseline for evaluating trend. The assessment metric is distribution of exotic plants in the park.

4.9.4 Results and Assessment

Current Condition

An estimated 152 non-native species have been observed in MORA (Rochefort 2010); however, data regarding locations of only 51 species are readily available (Table 33). Seventeen species with location information are classed as noxious weeds in Washington State, meaning that they are considered to threaten agricultural crops, local ecosystems, or fish and wildlife habitat. Another 9 noxious weeds are included in the database without location information

Species which are most widespread include Spotted Knapweed (*Centaurea maculosa*), Canada Thistle (*Cirsium arvense*), Foxglove (*Digitalis purpurea*), Common St. John's Wort (*Hypericum perforatum*), Ox-eye Daisy (*Leucanthemum vulgare*), and Birdsfoot Trefoil (*Lotus corniculatus*) (Table 33); 3 are considered noxious by Washington State. Most of the documented sites are on the road from the Nisqually entrance to Paradise and this may reflect a greater effort at inventory conducted in anticipation of significant road work. In general, invasive species are restricted to frequently disturbed areas, such as roads, trails, and administrative areas.

Inventories of invasive species on national forest lands surrounding MORA identify species that are not included in the records of MORA. There are 2 such species in the Naches Ranger District of the Okanogan-Wenatchee National Forest to the east of the park; 39 species in the Gifford Pinchot National Forest to the south; and 26 species in the Mount Baker-Snoqualmie National Forest to the north (Table 34). Note that the records for Okanogan-Wenatchee are from the adjacent ranger district while other records are from entire national forests.

Trend

Compared to the reference condition of zero invasive species, the flora of MORA has experienced an increase in plant invasion resulting in over 152 non-native species (http://www.nps.gov/mora/), of which 51 have location data and 17 are designated as noxious weeds by Washington State. Nevertheless, while the trend is toward more invasive species, the park has been largely successful in extirpating some non-natives such as *Hieracium* species on the route from the Nisqually entrance to Paradise (Todd Neel, written communication).

Assessing short-term trends is not possible because many areas have not been surveyed more than once. Compared with the rest of North America, the Pacific Northwest has been settled relatively recently by descendants of Europeans. Consequently, there have been fewer plant invasions and greater opportunity to protect still relatively pristine wilderness areas (Harrington and Reichard 2007). Successful integrated management programs by NPS are needed to make this possible.

Predicted Changes

Invasive non-native species together with habitat loss and climate changes are considered to be the major drivers of global environmental change (Pejchar and Mooney 2009). These forces also have the potential to interact with one another such that climate change and other drivers, for example increasing amounts and different pathways of global trade and travel (Pejchar and Mooney 2009), will affect the distribution, spread, abundance, and impact of invasive species (Gritti et al. 2006). While climate change could conceivably inhibit invasive species as expected for natives, case studies indicate that climate change is not likely to substantially decrease the impact of current invasives because many already span a large environmental range (Qian and Ricklefs 2006). Effects of invasive species are challenging to foresee, partly because climate is expected to affect all phases of transport, establishment, survival, and spread (Hellman et al. 2008). Changes may include greater potential for transport due to more frequent disturbance events; innocuous non-native species becoming invasive; greater competitive advantage of invasive species as some resources (e.g., water) become more limited and disturbance regimes are altered; and altered effectiveness of control strategies if, for example, higher atmospheric CO2 levels confer greater tolerance to herbicides (Hellman et al. 2008). Climate change is also expected to affect native plants such that ecological structure may be so profoundly altered in unanticipated ways that certain invasive species may actually be valued because, for example, they fill a role vacated by a native species (Walther et al. 2009) or the impact of particular invasive species could lessen as the rest of the ecosystem changes (Strayer et al. 2006).

Table 33. Invasive plant species by region of MORA.

			Park Region											
			Northwest		Northeast		Southeast			Southwest				
Species name	**Common name**	**Class[1]**	**Carbon River**	**Mowich**	**Highway 410**	**White River – Sunrise Rd.**	**Highway 123**	**Ohanapecosh**	**Stevens Canyon**	**Cougar Rock**	**Kautz**	**Longmire**	**Nisqually-Paradise Rd.**	**Westside Rd.**
Agropyron repens	Quack Grass	--											X	X
Agrostis stolonifera	Creeping Bentgrass	--											X	
Agrostis tenuis	Bentgrass	--												
Anthoxanthum odoratum	Sweet Vernal Grass	--												
Arctium minus	Lesser Burdock	--											X	
Bellis perennis	Lawn Daisy	--											X	
Bromus inermis	Smooth Brome	--											X	
Bromus rigidus	Rip-gut Brome	--												
Bromus tectorum	Cheatgrass	--												
Centaurea diffusa	Diffuse Knapweed	B												
Centaurea maculosa	Spotted Knapweed	--			X	X	X		X				X	
Cerastium viscosum	Sticky Chickweed	--											X	
Chondrilla juncea	Rush Skeleton Weed	B												
Cichorium intybus	Chicory	--							X					
Cirsium arvense	Canada Thistle	C		X			X		X				X	X
Cirsium vulgare	bull thistle	C		X	X				X				X	
Crataegus monogyna	Single-seeded Hawthorn	--											X	
Cynosurus cristatus	Crested Dog's-tail Grass	--											X	
Cytisus scoparius	Scot's Broom	B			X	X			X				X	
Dactylis glomerata	Orchard Grass	--			X									
Daucus carota	Queen Anne's Lace	C			X	X	X						X	
Digitalis purpurea	Foxglove	--		X	X		X		X				X	
Epipactis helleborine	Broad-leaved Helleborine	--											X	
Euphrasia officinalis	eyebright	--											X	

Table 33. Invasive plant species by region of MORA (continued).

			Park Region											
			Northwest		Northeast		Southeast			Southwest				
Species name	**Common name**	**Class**[1]	**Carbon River**	**Mowich**	**Highway 410**	**White River – Sunrise Rd.**	**Highway 123**	**Ohanapecosh**	**Stevens Canyon**	**Cougar Rock**	**Kautz**	**Longmire**	**Nisqually-Paradise Rd.**	**Westside Rd.**
Festuca pratensis	English or Meadow Fescue	--												
Glechoma hederacea	Ground Ivy	--											X	
Geranium robertianum	Herb Robert	B					X						X	
Hieracium atratum	Polar Hawkweed	C			X	X							X	
Hieracium aurantiacum	Orange Hawkweed	B												
Hieracium caespitosum	Meadow Hawkweed	B												
Hieracium floribundum	Yellow Devil Hawkweed	A			X									
Hieracium murorum	Wall Hawkweed	C												X
Hieracium pilosella	Mouse Ear Hawkweed	B												
Holcus lanatus	Velvet Grass	--												
Hypericum perforatum	Common St. John's Wort	C		X	X	X	X		X				X	X
Hypochaeris radicata	Hairy Cat's Ear	C												
Lathyrus sylvestris	Flat Pea	--											X	
Lepidium campestre	Field Pepperweed	--											X	
Leucanthemum vulgare	Ox-eye Daisy	C		X	X	X	X		X				X	X
Linaria dalmatica	Dalmatian Toadflax	B			X								X	
Linaria vulgaris	Butter and Eggs	C												
Lotus corniculatis	Bird's Foot Trefoil	--			X	X	X		X					X
Matricaria matricoides	Mayweed	--											X	
Melilotus alba(officinalis)	Yellow Sweet Clover	--											X	
Petasites japonicus	Japanese Sweet Coltsfoot	--												
Phalaris arundincea	Reed Canary Grass	C			X								X	X
Phleum pratense	Timothy	--											X	X
Plantago lanceolata	English Plantain	--											X	

Table 33. Invasive plant species by region of MORA (continued).

			Park Region											
			Northwest		Northeast		Southeast			Southwest				
Species name	**Common name**	**Class[1]**	**Carbon River**	**Mowich**	**Highway 410**	**White River – Sunrise Rd.**	**Highway 123**	**Ohanapecosh**	**Stevens Canyon**	**Cougar Rock**	**Kautz**	**Longmire**	**Nisqually-Paradise Rd.**	**Westside Rd.**
Plantago major	Common Plantain	--											X	
Poa annua	Annual Bluegrass	--												
Poa bulbosa	Bulbous Bluegrass	--												
Poa pratensis	Perennial Bluegrass	--												
Polygonum aviculare	Common Knotgrass	--											X	
Polygonum cuspidatum	Japanese Knotweed	B												
Potentilla norvegica	Norvegian Cinquefoil	--											X	
Potentilla recta	Sulfur Cinquefoil	B				X			X					
Prunus sp.		--											X	
Ranunculus repens	Creeping Buttercup	--			X		X						X	X
Rubus discolor (armeniacus)	Himalayan Blackberry	C												
Rubus laciniatus	Cut-leaved Blackberry	C					X		X					
Senecio jacobaea	Tansy Ragwort	B			X		X						X	X
Sonchus asper (arvensis)	Perennial Sowthistle	C											X	
Tanacetum vulgare	Common Tansy	C		X	X		X						X	
Trifolium hybridum	Alsike Clover	--											X	
Tragopogon dubius	Yellow Salsify	--							X					
Verbascum thapsus	Common Mullein	--		X	X	X			X					
Veronica officinalis	Common Speedwell	--											X	
Vicia sativa	Common Vetch	--					X							

[1]Washington State noxious weed classes: A, eradicate all, not widespread; B, control where not widespread, contain elsewhere; C, species is widespread or of agricultural interest, control or provide public education

Table 34. Noxious weeds found in USDA Forest Service Ranger Districts (RD) adjacent to MORA. Large X's indicate the species is not currently documented in MORA.

Species name	Common name	WA Noxious Weed Class[1]	Okanogan-Wenatchee NF, Naches RD[2]	Gifford Pinchot NF[3]	Mount Baker-Snoqualmie NF[3]
Ailanthus altissima	Tree of Heaven	C		X	
Alliaria petiolata	Garlic Mustard	A		X	
Amorpha fruticosa	Desert False Indigo	B		X	
Arctium minus	Lesser Burdock	--		x	
Artemisia absinthium	Absinth Wormwood	C			X
Berteroa incana	Hoary Alyssum	B		X	
Buddleja davidii	Butterfly Bush	B		x	x
Carduus acanthoides	Spiny Plumeless Thistle	B		X	
Centaurea biebersteinii	Spotted Knapweed	--		X	X
Centaurea debeauxii	Meadow Knapweed	--		X	
Centaurea diffusa	Diffuse Knapweed	B	x	x	x
Centaurea jacea	Brown Ray Knapweed	B		X	X
Centaurea maculosa	Spotted Knapweed	--	x	x	
Centaurea montana	Perennial Cornflower	--		x	
Centaurea nigra	Lesser Knapweed	B		X	
Centaurea nigrescens	Vochin Knapweed	A		X	
Centaurea pratensis	Tyrol Knapweed	--		X	
Centaurea solstitialis	Yellow Star-thistle	B		X	
Centaurea stoebe	Spotted Knapweed	B	X	X	X
Centaurea triumfettii	Squarrose Knapweed	--		X	
Cichorium intybus	Chicory	--	x	x	
Cirsium arvense	Canada Thistle	C	x	x	
Cirsium vulgare	Bull Thistle	C	x	x	x
Conium maculatum	Poison Hemlock	B			X
Convolvulus arvensis	Field Bindweed	C			X
Cynoglossum officinale	Gypsy Flower	B	X		X
Cyperus esculentus	Yellow Nutsedge	B		X	
Cytisus scoparius	Scot's Broom	B	x	x	x
Daphne laureola	Spurge Laurel	B		X	
Darmera peltata	Indian Rhubarb	--			X
Daucus carota	Queen Anne's Lace	C		x	x
Dipsacus fullonum	Common Teasel	C			X
Geranium robertianum	Herb Robert	B		x	x
Hedera helix	English Ivy	C		X	X
Heracleum mantegazzianum	Giant Hogweed	A			X
Hieracium aurantiacum	Orange Hawkweed	B		x	x
Hieracium caespitosum	Meadow Hawkweed	B		x	x
Hieracium glomeratum	Queen-devil Hawkweed	B		X	

Table 34. Noxious weeds found in USDA Forest Service Ranger Districts (RD) adjacent to MORA. Large X's indicate the species is not currently documented in MORA (continued).

Species name	Common name	WA Noxious Weed Class[1]	Okanogan-Wenatchee NF, Naches RD[2]	Gifford Pinchot NF[3]	Mount Baker-Snoqualmie NF[3]
Hieracium lachenalii	Common Hawkweed	C		X	X
Hieracium laevigatum	Smooth Hawkweed	B			X
Hieracium murorum	Wall Hawkweed	C		x	
Hieracium pilosella	Mouseear Hawkweed	B		x	
Hieracium pratense	Meadow Hawkweed	C		X	
Hieracium vulgatum	Common hawkweed	C		X	
Hypericum perforatum	St. John's Wort	C	x	x	x
Hypochaeris radicata	Spotted Cat' Ear	C	x	x	x
Ilex aquifolium	English Holly	--		X	X
Impatiens capensis	Jewelweed	--			X
Iris pseudacorus	Yellowflag Iris	C			X
Kochia scoparia	Burning Bush	B		X	
Lamiastrum galeobdolon	Yellow Archangel	B		X	X
Lathyrus latifolius	Perennial Pea	--		X	
Lathyrus sylvestris	Flat Pea	--		x	
Leucanthemum vulgare	Oxeye Daisy	C	x	x	x
Linaria dalmatica ssp. macedonica	Dalmatian Toadflax	B	x	x	x
Linaria vulgaris	Butter and Eggs	C		x	
Lotus corniculatus	Bird's Foot Trefoil	--		x	x
Lythrum salicaria var. vulgare	Purple Loosestrife	B		X	
Onopordum acanthium	Scotch Cottonthistle	B		X	
Petasites japonicas	Japanese Sweet Coltsfoot	--			x
Phalaris arundinacea	Reed Canary Grass	C		x	x
Phytolacca americana	American Pokeweed	--		X	
Polygonum cuspidatum	Japanese Knotweed	B		x	x
Polygonum x bohemicum	Bohemian Knotweed	B		X	X
Polygonum sachalinense	Giant Knotweed	B		X	X
Potentilla recta	Sulfur Cinquefoil	B			x
Robinia pseudoacacia	Black Locust	--		X	X
Rubus armeniacus	Himalayan Blackberry	C		x	x
Rubus laciniatus	Cut-leaf Blackberry	C		x	x
Rubus lasiococcus	Roughfruit Berry	--			X
Senecio jacobaea	Tansy Ragwort	B	x	x	x
Senecio vulgaris	Common Groundsel	C			X
Silene csereii	Balkan Catchfly	--		X	
Silene latifolia	Bladder Campion	C			
Solanum dulcamara	Climbing Nightshade	--			X
Solanum rostratum	Buffalobur Nightshade	A		X	
Sonchus arvensis	Field Sowthistle	C		x	

Table 34. Noxious weeds found in USDA Forest Service Ranger Districts (RD) adjacent to MORA. Large X's indicate the species is not currently documented in MORA (continued).

Species name	Common name	WA Noxious Weed Class[1]	Okanogan-Wenatchee NF, Naches RD[2]	Gifford Pinchot NF[3]	Mount Baker-Snoqualmie NF[3]
Symphytum officinale	Common Comfrey	--			X
Tanacetum vulgare	Common Tansy	C		x	x
Taraxacum officinale	Tommon Dandelion			X	
Ulex europaeus	Common Gorse	B		X	
Verbascum thapsus	Common Mullein	--	x	x	
Vinca major	Bigleaf Periwinkle			X	
Vinca minor	Common Periwinkle	--		X	X

[1]Washington State noxious weed classes: A, eradicate all, not widespread; B, control where not widespread, contain elsewhere; C, species is widespread or of agricultural interest, control or provide public education

[2]Source: Rod Clausnitzer, pers. comm. 2012

[3]Source: Shawna Bautista, USDA Forest Service PNW Regional Invasive Coordinator, personal communication

4.9.5 Emerging Issues

- The potential for effects of invasive species to be modulated over time by processes such as evolutionary changes, shifts in species composition, accumulation of materials and interactions with abiotic variables necessitates using a long-term perspective to assess the consequences of invasive species (Strayer et al. 2006, Walther et al. 2009).
- While most invasive plant species are currently restricted to developed areas, there is evidence that they are spreading more widely within those areas, partly due to management practices such as sidecasting. (Todd Neel, written communication).
- Currently most of the exotic species in MORA are found at lower elevations, but increasing temperatures may allow exotics to move to higher elevations (Pauchard et al. 2009).
- There are species in adjacent Forest Service lands that have not been recorded in MORA and therefore may pose imminent threats.
- Existing populations of invasive plants may potentially move from frequently disturbed areas (roads, trails, administrative areas) to more pristine areas of the park, including alpine meadows, and sensitive riparian areas.
- Climate change is predicted to influence invasion dynamics and ecosystem consequences of invasive species (Hellman et al. 2008, Pejchar and Mooney 2009, Walther et al. 2009).

4.9.6 Information and Data Needs–Gaps

- The park has many records of invasive species locations that have not been digitized. Having these data combined into a single spatial database would provide context to help determine an effective strategy for integrated management of invasive species.
- Frequent and comprehensive inventory and monitoring of at least front-country areas would help the park understand the extent of invasive species distribution, effectiveness of control and prevention efforts, and would provide the basis for studies of potential long-term consequences and climate change effects. This effort would also require resources to summarize and integrate data from monitoring and exotic plant management as well as conduct analyses.
- Surveys of higher elevations for new exotic invasions are currently inadequate to understand the dynamics of spread to these areas.

4.9.7 Literature Cited

Asner, G. P., and P. M. Vitousek. 2005. Remote analysis of biological invasion and biogeochemical change. Proceedings of the National Academy of Sciences of the United States of America 102:4383–4386.

Beard, R., and L. Gibbons. 2011. Exotic Plant Management Team Program: 2010 annual report. Natural Resource Report NPS/NRSS/NRR—2011/459. National Park Service, Fort Collins, Colorado.

Boersma, P. D., S. H. Reichard, and A. N. Van Buren, editors. 2006. Invasive species in the Pacific Northwest. University of Washington Press, Seattle, Washington.

D'Antonio, C. M., and P. M. Vitousek. 1992. Biological invasions by exotic grasses, the grass/fire cycle, and global change. Annual Review of Ecology and Systematics 23:63–87.

Gritti, E. S., B. Smith, and M. T. Sykes. 2006. Vulnerability of Mediterranean Basin ecosystems to climate change and invasion by exotic plant species. Journal of Biogeography 33:145–157.

Harrington, T. B., and S. A. Reichard. 2007. Meeting the challenge: Invasive plants in Pacific Northwest ecosystems. General Technical Report PNW-GTR-694. USDA Forest Service, Portland, Oregon.

Hellman, J. J., J. E. Byers, B. G. Bierwagen, and J. S. Dukes. 2008. Five potential consequences of climate change for invasive species. Conservation Biology 22:534–543.

Hiebert, R. D., and J. Stubbendieck. 1993. Handbook for ranking exotic plants for management and control. Natural Resources Report NPS/NRMWRO/NRR-93/08. National Park Service, Denver, Colorado.

Mack, R. N., D. Simberloff, W. M Lonsdale, H. Evans, M. Clout, and F. A. Bazzaz. 2000. Biotic invasions: Causes, epidemiology, global consequences and control. Ecological Applications. 10:689–710.

[NPS] National Park Service. 2006. Management Policies 2006. Government Printing Office, Washington, D.C.

Pauchard, A., C. Kueffer, H. Dietz, C.C. Daehler, J. Alexander, P.J. Edwards, J.R. Arevalo, L.A. Cavieres, A. Guisan, S. Haider, G. Jakobs, K. McDougall, C.I. Millar, B.J., Naylor, C.G. Parks, L.J. Rew, and T. Seipel. 2009. Ain't no mountain high enough: Plant invasions reaching new elevations. Frontiers in Ecology and the Environment 7:479–486.

Pejchar, L., and H. A. Mooney. 2009. Invasive species, ecosystem services and human well-being. Trends in Ecology and Evolution 24:497–504.

Qian, H., and R. E. Ricklefs. 2006. The role of exotic species in homogenizing the North American flora. Ecology Letters 9:1293–1298.

Rochefort, R. M. 2010. Vascular plant inventory of Mount Rainier National Park. Natural Resource Technical Report NPS/NCCN/NRTR—2010/347. National Park Service, Fort Collins, Colorado.Washington Natural Heritage Program. 2002. Endangered, threatened and sensitive vascular plants of Washington (20 October 2002). Washington State Department of Natural Resources, WA.

Strayer, D. L., V. T. Eviner, J. M. Jeschke, and M. L. Pace. 2006. Understanding the long-term effects of species invasions. Trends in Ecology and Evolution 21:645–651.

Urgenson, L., and S. H. Reichard. 2007. The ecological consequences of giant knotweed invasion into riparian forests. In: Harrington, T.B., and S.A. Reichard, editors. Meeting the challenge:

Invasive plants in Pacific Northwest ecosystems. General Technical Report PNW-GTR-694, USDA Forest Service, Portland, OR. p. 63–64.

Vitousek, P. M., C. M. D'Antonio, L. L. Loope, and R. Westbrooks. 1996. Biological invasions as global environmental change. American Scientist 84:468.

Vitousek, P. M., C. M. D'Antonio, L. L. Loope, M. Rejmanek, M., and R. Westbrooks. 1997. Introduced species: A significant component of human-caused global change. New Zealand Journal of Ecology 21:1–16.

Walther, G. R., A. Roques, P. E. Hulme, M. T. Sykes, P. Pysek, I. Kuhn, M. Zobel, S. Bacher, Z. Botta-Dukat, H. Bugmann, and others. 2009. Alien species in a warmer world: Risks and opportunities. Trends in Ecology and Evolution 24:686–693.

4.10 Biodiversity: Wetlands

(Andrea Woodward and Patricia Haggerty, USGS FRESC)

4.10.1 Introduction

Wetlands are perhaps the most biodiverse of ecosystems. While wetlands only represent approximately 2% of Washington's landscape, 30% of the native flora has facultative or obligate wetland indicator status (Roccio, written communication), 66% of terrestrial vertebrates utilize wetlands (Sheldon et al. 2005), and 45% of the plant species considered Endangered, Threatened, or Sensitive by the Washington Natural Heritage Program (WNHP) are associated with wetland or riparian areas. Factors contributing to the potential for wetlands to support a wide variety of species include the combination of aquatic and terrestrial conditions, high productivity, and changing water levels, which provide a range of habitats through the seasons (Halls 1997).

The park includes palustrine (marshes, swamps, fens) and deepwater wetlands, plus riverine wetlands along 363 km (226 mi) of rivers and streams (NPS 2006). These wetlands are quite species diverse, occurring in forest, subalpine, and alpine environments. Subalpine wetlands are often dominated by Black Sedge (*Carex nigricans*) in association with Showy Sedge (*Carex spectabilis*), Alpine Aster (*Aster alpigenus*), and Woolly Pussytoes (*Antennaria lanata*) (Henderson 1974). Low elevation riparian wetlands usually include Red Alder (*Alnus rubra*) and perhaps Big-leaf Maple (*Acer macrophyllum*), Black Cottonwood (*Populus balsamifera* ssp. *trichocarpa*), Sitka Spruce (*Picea sitchensis*), and Oregon Ash (*Fraxinus latifolius*) in the canopy. Salmonberry (*Rubus spectabilis*), Devil's Club (*Oplopanax horridus*), Skunk Cabbage (*Lysichiton americanum*), and a variety of ferns are found in the understory. At mid-elevations, wetland flora includes several alders (*Alnus viridis* spp. *sinuata, A. incana* ssp. *tenuifolia*), willows (*Salix boothii, S. commutata*), and huckleberries (*Vaccinium deliciosum, V. uliginosum*) (Crawford et al. 2009).

Besides containing a variety of flora and fauna, park waters provide habitat for 8 fish or amphibian species that are listed as threatened, endangered or species of concern (http://nps.mora.gov). The integrity of wetlands inside the park contrasts with wetlands outside the park on public and private lands which have been extensively modified by logging (NPS 2010), and other human uses (e.g., development, grazing).

Climate change is predicted to have dramatic effects on hydrologic processes and water conditions due to increasing temperature and changes in the timing and amount of precipitation. In the Pacific Northwest, recent increases in summer and winter air temperature, decreasing summer precipitation, increasing winter precipitation, and consequent changes in the hydrograph are expected to be more frequent (Mote and Salathé 2010). As integrated elements of the hydrologic system, wetlands and their inhabitants will certainly be affected.

4.10.2 Approach

We assessed status of wetlands in MORA using wetland maps produced by the National Wetlands Inventory (NWI) program of the U.S. Fish and Wildlife Service. This program has been producing wetland maps and geospatial data for the U.S since 1974 based on analysis of aerial imagery (http://www.fws.gov/wetlands) and the Cowardin wetland classification system (Cowardin et al.

1979). These maps are based on imagery from the 1980s and were validated in the late 1990s by MORA staff members (Samora et al. 2000). More recently, wetlands along the Carbon and Nisqually Rivers were mapped and classified as part of Environmental Assessments regarding road rehabilitation (NPS 2010, 2012). While NWI assesses trend in wetland area, this has only been done on a national basis and for selected areas not including the Pacific Northwest. We also compared the NWI map with areas mapped as wetland vegetation in the recently completed vegetation map of MORA (Nielsen and Copass, In prep.) to evaluate the correspondence of map classes.

4.10.3 Reference Conditions and Comparison Metrics

There is no evidence to date that total extent and general water quality of wetlands is changing in MORA, although the location of individual wetlands is dynamic, and no studies have been specifically conducted to assess wetland quality. Consequently, the current inventory of wetlands extent can serve as the baseline for identifying future changes in spatial extent, and there is no baseline for wetland quality.

4.10.4 Results and Assessment

Current Condition

The MORA wetland map (Figure 22) based on NWI data identifies 1636.6 ha (4045 ac) of wetlands including 279 ha (689 ac) of lakes and ponds. Wetland types include riverine wetlands, freshwater emergent wetlands, and freshwater forested-shrub wetlands. However, results of validation surveys by MORA staff (Samora et al. 2000) show that of 533 wetlands assessed, only 44% were correct to system. Also, 165 unmapped wetlands were encountered, of which 91% were above 1219 m (3999 ft) elevation and most had high forest cover.

Wetland area determined by NWI, compares with 4245.3 ha (10,490 ac) of wetland vegetation mapped by the MORA vegetation map (Figure 23). The 2 maps differ in that the NWI description of wetlands is more limited to fluvial areas and impoundments while the wetland vegetation classes describe a wider riparian influence and palustrine areas (Figure 24). Also the MORA vegetation map extends slightly outside of the park boundary in places to include 5.9 ha (15 ac) of recently acquired lands and possibly to complete a polygon that starts inside the park (Lou Whiteaker, pers. comm.). Detailed comparison of corresponding wetland classes (Table 35) indicates that the greatest deficit in wetland area mapped by NWI is in classes of forested wetlands (those that should be included as freshwater forested-shrub wetland). The fact that forested wetlands are the most difficult for NWI to photointerpret and that they are conservatively mapped has been long acknowledged (Tiner 1997).

Comparison among the NWI (1980s) wetland map, the MORA vegetation map (2012), and a wetland survey of the Carbon River road area (NPS 2010) further exemplify the differences between the NWI and park vegetation maps. This comparison indicates that points identified as wetlands during the ground survey are generally included in areas classified as the wetland type “low elevation conifer riparian and swamp forest” in the MORA vegetation map and are missed by NWI.

Table 35. Comparison of area mapped as corresponding wetland types by the National Wetland Inventory (NWI) and the MORA vegetation map within the MORA boundary.

National Wetland Inventory Wetland Class	Area (ha)	Mount Rainier National Park Vegetation Map Wetland Class	Area (ha)
Freshwater emergent wetland	210.0	High elevation wet meadow/dwarf shrubland Montane wet meadow	496.7 49.5
Freshwater forested/shrub wetland	368.6	Deciduous floodplain and swamp forest Low elevation conifer riparian and swamp forest High elevation conifer riparian forest Riparian deciduous tall shrubland	1009.9 748.2 1612.2 322.7
Riverine Lake Pond Other	755.9 92.3 186.7 5.1	(Not mapped)	

Trend

At present there is no information to describe wetland trends in MORA. Nationally, factors causing losses in wetlands include agriculture, forested plantations, rural development, urban development, and other land uses, while restoration and conservation have resulted in wetland improvement (Dahl 2011). None of these factors are especially relevant to MORA. However, there has likely been historic alteration of wetlands near roads and trails and in administrative areas of the park (Barbara Samora, written communication). For example, Longmire Meadow, despite being a very unique calcareous fen, is primarily comprised of weedy native species or species indicative of past disturbance (i.e. *Juncus arcticus* var. *littoralis*) (Joe Rocchio, written communication). Also, many roads and trails were established in the bottom of drainages for ease of construction. Associated wetlands are likely affected by resulting changes in hydrology as well as run-off from roads (Lou Whiteacker, written communication). Moreover, with continual river aggradation and flooding, wetlands adjacent to roads and trails will no doubt continue to be altered as park staff try to maintain access.

Predicted Changes

Climate change projections forecast warmer winters and summers, higher winter precipitation and lower summer precipitation (Mote and Salathe 2010). These changes have already resulted in declining snowpack, earlier snowmelt runoff, and earlier soil moisture recession (Hamlet et al. 2007) and are predicted to cause longer and more frequent summer droughts (Hamlet et al. 2005). As evidence, the Palmer Hydrologic Drought Index (PHDI, http://www.ncdc.noaa.gov), which describes long-term hydrologic departures from normal ground-water conditions (Guttman 1991), has been negative in 15 of 27 yrs since temperatures rose dramatically beginning in 1985 (Figure 25). The net effect of these changes is difficult to predict, but modeled montane wetlands show earlier and more rapid drawdown, lower water levels, and a longer dry season in summer (Lee et al. in review) in response to projected climate change. The effects are expected to be greatest for intermediate wetlands (those that dry in late summer or early fall in years with low precipitation) because they are shallow and are highly sensitive to summer water availability. Modeled results show that the majority of intermediate montane wetlands will become ephemeral wetlands (meaning they dry in most years, usually soon after snowmelt) by the 2080s (Lee et al. in review). More immediate effects may be shifts in the zonation of soil moisture and vegetation found around wetland basins. Ecosystem effects of these changes include loss of habitat provided by intermediate but not ephemeral wetlands for fast-developing amphibians, drought resistant invertebrates, migratory birds, and meso-predators (Ryan et al. 2014, Lee et al. in review). Intermediate wetlands are also important for preserving meta-population dynamics of animals and plants and therefore beta-diversity (Semlitsch and Brodie 1998) while also being difficult to survey and monitor.

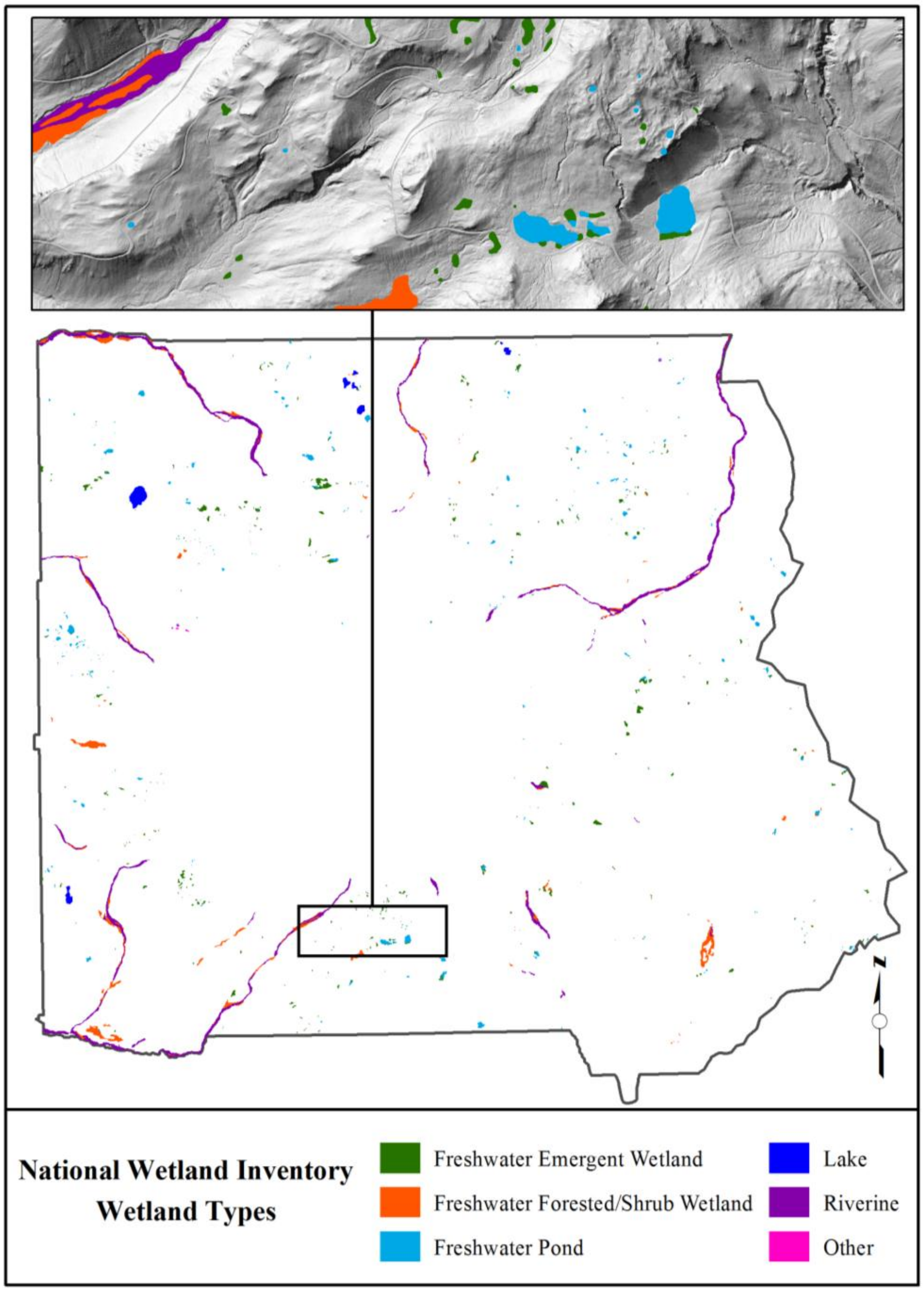

Figure 22. Wetland map for MORA based on National Wetland Inventory data (inset is a magnification of a representative area of wetlands in the park).

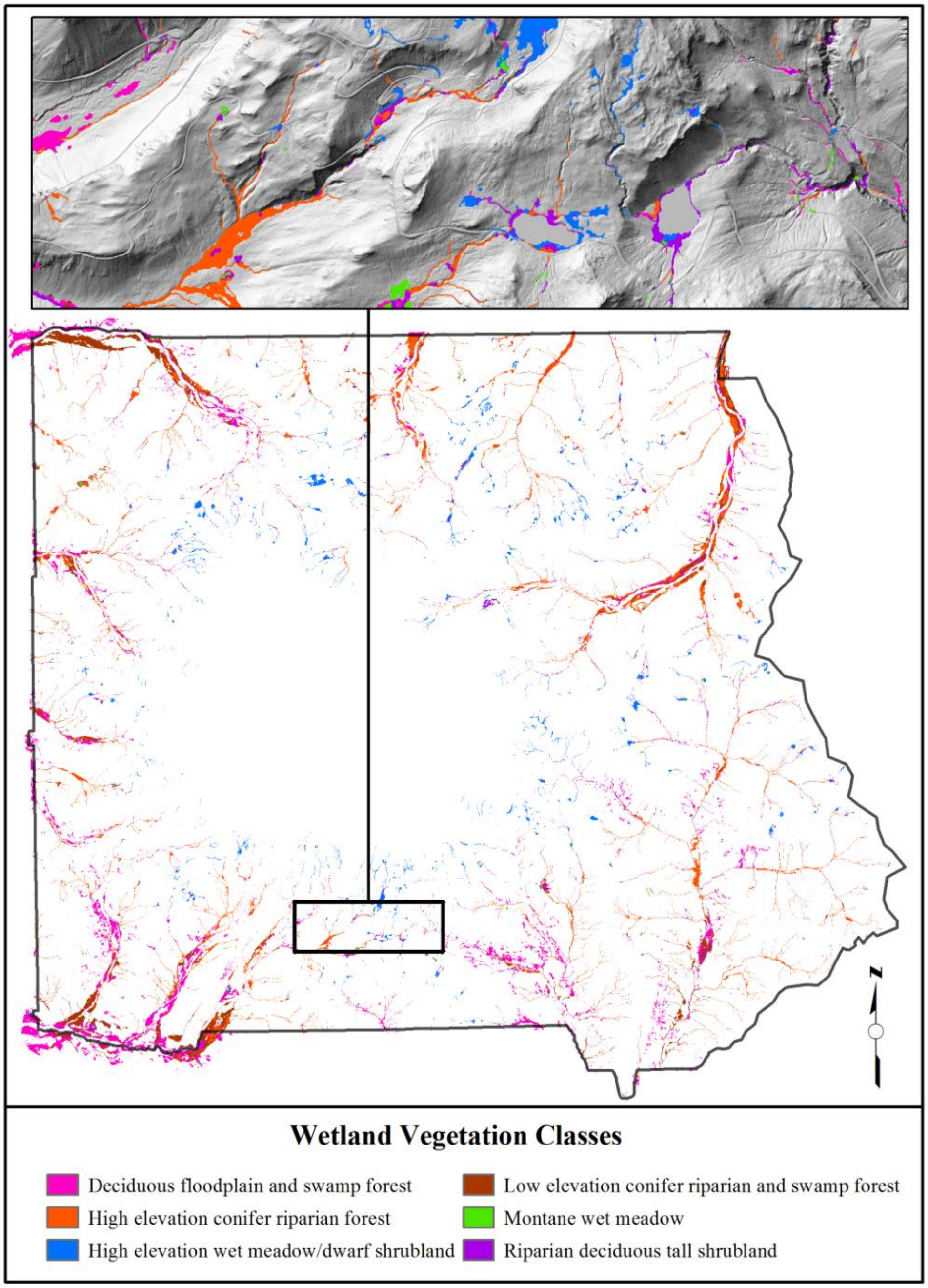

Figure 23. Distribution of wetland vegetation classes in MORA (inset is a magnification of a representative area of wetlands in the park).

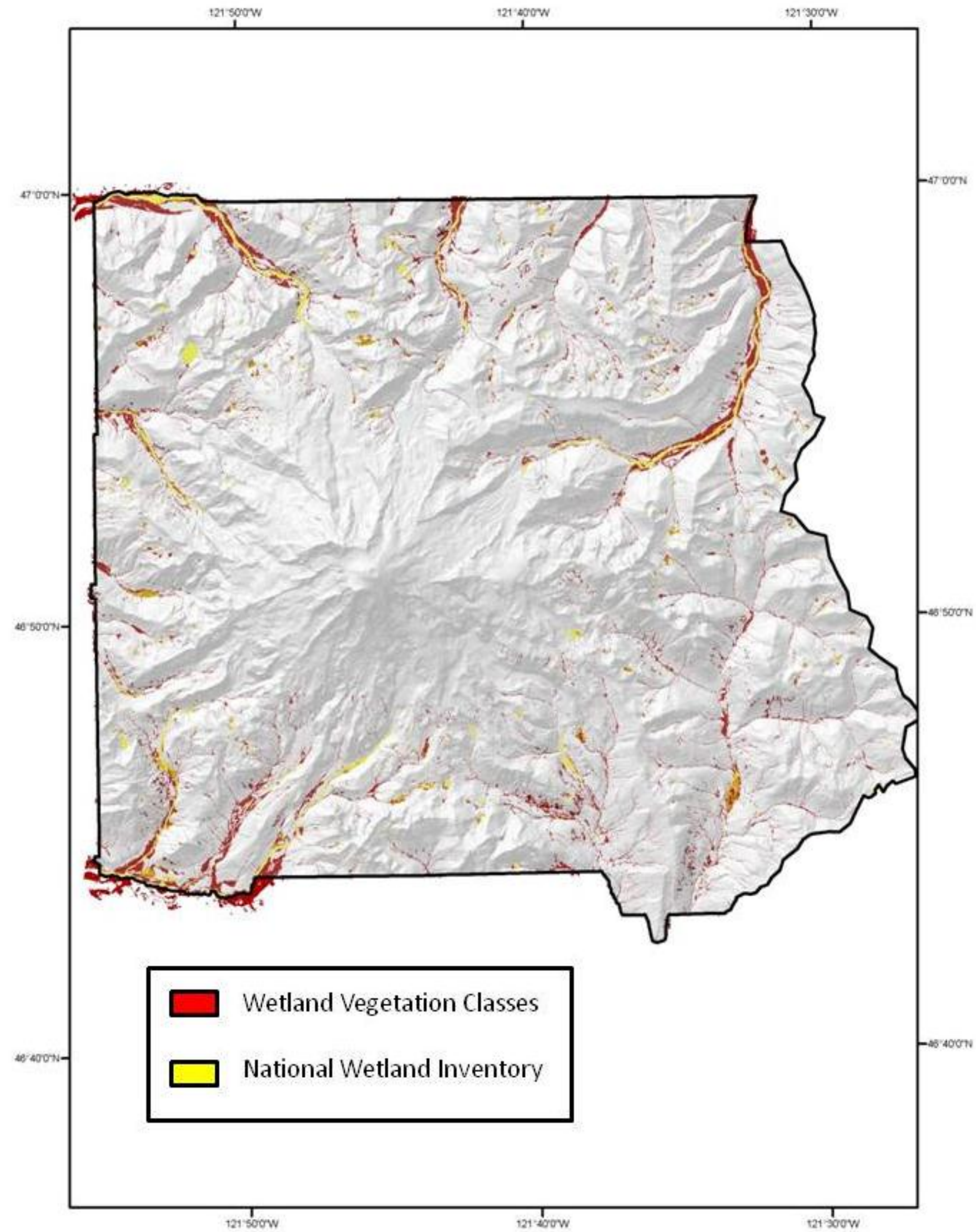

Figure 24. Wetlands mapped by the National Wetland Inventory and Wetland Vegetation Classes mapped for MORA.

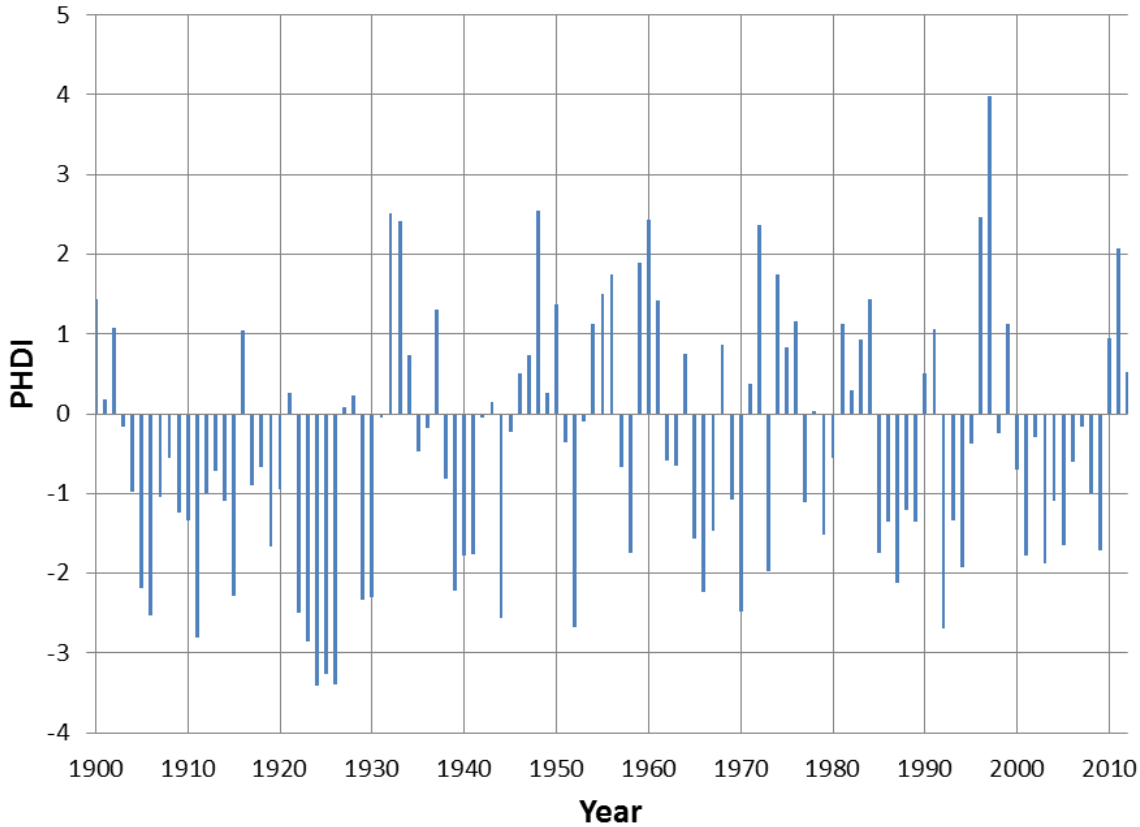

Figure 25. Palmer Hydrologic Drought Index for Climate Division 5 of Washington State (Cascade Mountains West), 1900–2012. Negative numbers indicate drought conditions.

4.10.5 Emerging Issues

- While climate change may have the greatest impact on precipitation-dependent wetlands (Burkett and Keusler 2000; Winter 2000), these types (bogs and vernal pools) are rare to absent in MORA. Instead, wetland types present in MORA are primarily fed by surface and groundwater inputs. These inputs are expected to change over the longer term due to climate change, although changes are already being seen in the PHDI (Figure 25). Climate change will likely affect water quality, particularly temperature, as well as quantity. Perhaps most importantly, climate change will likely change hydrodynamics including the timing of maximum and minimum water levels.
- Increasing levels of air pollutants from local and global sources may affect wetland water quality in the future. Many wetlands in MORA are especially sensitive because they are oligotrophic and have low acid-neutralizing capacity (Clow and Campbell 2008). However, some may be more resilient because they are nutrient rich, such as Longmire Meadow, forested swamp and fens near the confluence of Tahoma Creek and the Nisqually River, and many riparian areas (Joe Rocchio, written communication).

4.10.6 Information and Data Needs–Gaps

- Repeated inventories of wetland resources are warranted given the importance of wetlands to support park biodiversity and the potential for climate change to dramatically alter wetlands. This probably cannot be done in conjunction with NWI because so many wetlands in MORA are forested and are not described by NWI. However, monitoring of wetland extent alone will give limited insight into changes in wetland biodiversity. Ideally, creating a wetland profile (extent of wetland types so that shifts among types can be tracked) and ecological conditions within each wetland type would allow a powerful assessment of wetland resource conditions. This can be done using rapid assessment techniques developed by WNHP or others using a random sample design within discrete basins. It is also important to describe the distribution of rare wetland types (those tracked by WNHP).
- While extent may have greater potential to be monitored remotely on a parkwide basis, more intensive monitoring of hydroperiods and vegetation composition of a few sentinel sites could be informative for analyzing, predicting, and mitigating the effects of climate change on wetlands (Conly and Van der Kamp 2001). A study presently being conducted in MORA is developing models of MORA wetland ecosystem response to climate change as part of a broader effort to forecast impacts of climate change on wetland ecosystems in the Pacific Northwest (Lee et al., In prep), and to develop climate adaptation strategies for vulnerable wetland types and assemblages. Follow-up studies should integrate newly collected ecological and hydrologic data to update preliminary hydrologic models of climate impacts to wetlands, complete a vulnerability assessment of climate impacts on 3 classes of montane wetland (ephemeral, semi-permanent, and permanent wetlands), and collect data on wetland dependent plant and animal species.

4.10.7 Literature Cited

Burkett, V., and J. Keusler. 2000. Climate change: Potential impacts and interactions in wetlands of the United States. Journal of the American Water Resources Association 36:313–320.

Clow, D. W., and D. H. Campbell. 2008. Atmospheric deposition and surface-water chemistry in Mount Rainier and North Cascades National Parks, U.S.A., water years 2000 and 2005–2006. U.S. Geological Survey Scientific Investigations Report 2008–5152.

Conly, F. M., and G. Van der Kamp. 2001. Monitoring the hydrology of Canadian prairie wetlands to detect the effects of climate change and land use change. Environmental Monitoring and Assessment 67:195–215.

Cowardin, L. M., V. Carter, F. C. Golet, and E. T. LaRoe. 1979. Classification of wetlands and deepwater habitats of the United States. FWS/OBS-79/31, U.S. Fish and Wildlife Service, Washington, D.C.

Crawford, R. C., C. B. Chappell, C. C. Thompson, and F. J. Roccio. 2009. Vegetation classification of Mount Rainier, North Cascades, and Olympic National Parks, plant association descripition and identification keys. National Park Service Natural Resource Technical Reprot NPS/NCCN/NRTR – 2009/D-586.

Dahl, T. E. 2011. Status and trends of wetlands in the conterminous United States 1998 to 2009. U.S. Department of Interior Fish and Wildlife Service, Washington, D.C.

Guttman, N. B. 1991. A sensitivity analysis of the Palmer Hydrologic Drought Index. Water Resources Bulletin 27:797–807.

Halls, A. J., editor. 1997. Wetlands, biodiversity and the Ramsar Convention: The role of the Convention on wetlands in the conservation and wise use of biodiversity. Ramsar Convention Bureau, Gland, Switzerland.

Hamlet, A.F., P. W. Mote, M.P. Clark, and D.P Lettenmaier. 2005. Effects of temperature and precipitation variability on snowpack trends in the western US. Journal of Climate 19:4545–4561.

Hamlet, A.F., P.W. Mote, M.P.Clark, and D.P. Lettenmaier. 2007. Twentieth-century trends in runoff, evapotranspiration, and soil moisture in the western United States. Journal of Climate 20:1468–1486.

Henderson, J. A. 1974. Composition, distribution, and succession of subalpine meadows in Mount Rainier National Park [dissertation]. Oregon State University, Corvallis, Oregon.

Lee, S., A. F. Hamlet, M. E. Ryan, and W. J. Palen. In prep. Modeling the effects of climate change on Pacific Northwest wetlands.

Lee, S.-Y., M.E. Ryan, A.F. Hamlet, W. Palen, and M. Halabisky. In review. Forecasting climate change impacts on the hydrology of montane wetlands. PLoS ONE.

Mote, P. W., and E. P. Salathé. 2010. Future climate in the Pacific Northwest. Climatic Change 102:29–50.

Nielsen, R. P., and C. Copass. In prep. Vegetation inventory project for Mount Rainier National Park, 2007–2013 (MORA_Veg_Polys). Mount Rainier National Park. Geospatial Dataset-XXXXXXX.

[NPS] National Park Service. 2006. Mount Rainier National Park Final General Management Plan/Environmental Impact Statement. Mount Rainier National Park, Ashford, Washington.

[NPS] National Park Service. 2010. Carbon River area access management environmental assessment. Mount Rainier National Park, Ashford, Washington.

[NPS] National Park Service. 2012. Nisqually to Paradise Road rehabilitation environmental assessment. Mount Rainier National Park, Ashford, Washington.

Ryan, M.E., W.J. Palen, M.J. Adams, and R.M. Rochefort. 2014. Amphibians in the climate vice: Loss and restoration of resilience of montane wetland ecosystems in the western US. Frontiers in Ecology and the Environment 12:232–240.

Samora, B. A., R. Rochefort, and D. Swinney. 2000. Mount Rainier National Park wetlands inventories, draft final report. Unpublished NPS report, on file at MORA.

Semlitsch, R. D., and J. R. Brodie. 1998. Are small, isolated wetlands expendable? Conservation Biology 12:1129–1133.

Sheldon, D., T. Hruby, P. Johnson, K. Harper, A. McMillan, T. Granger, S. Stanley, and E. Stockdale. 2005. Wetlands in Washington State – Vol. 1: A synthesis of the science. Washington State Department of Ecology, Publications # 05-06-006, Olympia WA.

Tiner, R. W. 1997. NWI maps: What they tell us. National Wetlands Newsletter 19:7–12.

Winter, T. C. 2000. The vulnerability of wetlands to climate change: A hydrological landscape perspective. Journal of the American Water Resources Association 36:305–311.

4.11 Biodiversity: Subalpine Vegetation

(Andrea Woodward and Patti Haggerty, USGS FRESC)

4.11.1 Introduction

The subalpine zone constitutes the ecotone between continuous forest and treeless alpine meadows, reflecting increasingly harsh growing conditions with elevation. While it consists of a broad band of vegetation graduating from tree islands through krummholz, it is nevertheless a dramatic physiognomic transition that is predicted to be especially sensitive to climate change (Walther et al. 2005). Summer temperature and the duration of snowpack are the primary climatic factors controlling establishment and survival of subalpine vegetation (Rochefort and Peterson 1996). However, specific climatic limiting factors vary at microsite, local, and regional scales (Woodward et al. 1995, Peterson et al. 2002, Millar et al. 2004), primarily driven by topography. Effects of biota, such as determining seed sources and altering snow distribution, also influence subalpine plant distribution. Consequently, subalpine vegetation pattern reflects interactions among climatic, topographic, and biotic factors at multiple spatial scales (Zald et al. 2012). High levels of fragmentation and a unique flora not adapted to other environments cause these areas to contribute significantly to park biodiversity and habitat variety, including summer habitat for migratory birds. Subalpine areas are also important for recreation (Franklin et al. 1971), and are the most heavily visited areas in the park, are valued for scenic views, seasonal wildflower displays, and wildlife sightings.

4.11.2 Approach

We used the area classified as subalpine and alpine vegetation by the MORA vegetation map (Nielsen and Copass, In prep.) to assess current status of subalpine vegetation in MORA. To describe trend, we summarized the research studies describing trends in subalpine meadows conducted in MORA. Finally, we acquired times series of aerial photographs and imagery to look for dramatic changes at sites recommended by park staff. Thorough, quantitative geospatial analysis that might detect subtle changes was beyond the scope of this project.

4.11.3 Reference Conditions and Comparison Metrics

Defining a reference condition for treeline and subalpine meadows is complicated by the fact that treeline has moved to higher and lower elevations in response to millennial trends in climate (Rochefort et al. 1994), and there is a delay between conditions favoring tree establishment and a noticeable change. For example, tree invasion observed in the 1960s at Mount Rainier was attributed to warmer climate during 1920–1940 (Franklin et al. 1971). Moreover, the period of record for MORA is very short relative to decadal-scale climate fluctuations. Consequently, the present condition may simply serve as the reference for future change.

4.11.4 Results and Assessment

Current Condition

According to the newly created vegetation map, 23.4% of MORA comprises vegetation classes that span the ecotone from the upper edge of continuous forest, through tree clumps and krummholz, to alpine meadows. Subalpine forests occur at 1200 m (3937 ft.) to 1500 m (4921 ft.) all around the park and include moister associations with *Abies amabilis* (Mesic Subalpine Forest and Woodland, M006), and drier associations dominated by *Abies lasiocarpus* (Dry Subalpine Forest and Woodland, M012) or *Pinus albicaulis* (Subalpine Fir-Whitebark Pine Woodland), especially in the northeast sector. Areas with tree islands among meadows also occur all around the park and may be dominated by *Abies lasiocarpa*, *Tsuga mertensiana*, and *Cupressus nootkatensis* (Subalpine Mixed Woodland and Shrubland, M047). Subalpine meadows in dry areas feature *Fescue viridula* and occur on slopes throughout the park (Mixed Forb/Graminoid Herbaceous Meadow, M052) and on flatter areas, especially in Grand Park and Sunrise (Green Fescue Dry Herbaceous Meadow, M067). Moister sites might be dominated by *Carex spectabilis* (M060), *Valeriana sitchensis*, and other herbs (Valerian-Hellebore-Luzula Mesic Subalpine Meadow, M086) or ericaceous shrubs (Subalpine Mountain Heather Dwarf Shrubland, M074). The wettest meadows are dominated by *Carex nigricans* (High Elevation Wet Meadow/Dwarf Shrubland, M058), and *Vaccinium* spp. are characteristic of meadows that are early successional following fires in subalpine areas (High Elevation Dry Post-fire Shrubland, M085). At higher elevation windswept areas with shallow soils and subalpine trees take a krummholz form (Conifer Shrubland, M015). Alpine meadows on well-drained, moderately steep slopes are dominated by *Empetrum nigricans* (Crowberry-Kinnikinnick-Juniper Dwarf Shrubland, M063), *Carex spectabilis*, *Lomatium martindalei*, and other herbs on talus and scree (Talus, Scree, Snowbed and Fellfield Vegetation, M073); and *Cassiope mertensiana* or *Phyllodoce empetriformis* on mesic, rocky areas, especially in the north part of the park (Alpine Mountain Heather Dwarf Shrubland, M906).

Trend

We detected no dramatic changes in tree distribution upon examining time series of aerial photography and satellite imagery for 2 subalpine meadows on the west side of MORA over the period 1959 to present (Spray Park and Mist Park). However, new tree patches and in-filling of meadows were apparent in Van Trump Park from 1951 to present, and near Golden Lakes from 1955 to 2003 (Stueve et al. 2009). The images from Van Trump Park and results from Golden Lakes correspond to the study of Rochefort and Peterson (1996) showing continuous recruitment in west-side meadows since 1930, attributed to warm dry summers, which lengthen the growing season in this area characterized by high annual snowpack. They found establishment to occur in short, discrete periods in east-side meadows, coincident with cool, wet summers (especially 1980s), which alleviate summer drought in areas with lower annual snowpack. This contrasts with earlier studies showing establishment during 1923 to 1944 with a peak in the 1930s in Paradise Meadow (Franklin et al. 1971), considered a west-side site by Rochfort and Peterson (1996), and other sites throughout the park (Henderson 1974). As with Rochefort and Peterson (1996), Henderson (1974) and Franklin et al. (1974) concluded that the snow-free period is the most critical factor affecting tree establishment, but they did not draw different conclusions about east-side meadows. All 3 studies agree that tree recruitment is most dense in heath-shrub communities dominated by *Phyllodoce empetriformis*. These results correspond to other studies showing increasing tree establishment in subalpine meadows elsewhere in the Pacific Northwest (Franklin et al. 1971, Woodward et al. 1995, Rochefort and Peterson 1996, Zolbrod and Peterson 1999), and the observation that increases in tree density are a potential impact of climate change (Camarero and Gutierrez 2004). Conclusions about the importance of cool, wet summers to tree establishment in relatively dry areas have also been found following fire at sites just northeast of MORA (Little et al. 1994).

Predicted Changes

Summer temperature is predicted to increase in the Pacific Northwest during the 21st century, and the extent and duration of snowpack are predicted to decrease (Mote et al. 2005). These changes will mean earlier onset of spring conditions and longer growing seasons. A decrease in subalpine meadow habitat as conifers advance is a documented effect of climate change (Woodward et al. 1995, Rochefort and Peterson 1996, Zolbrod and Peterson 1999, Peterson et al. 2002, Millar et al. 2004, Holtmeier and Broll 2005, Zald et al. 2012). However, while climate models can predict generalized trends, local responses to climate change will vary (Malanson et al. 2007). Consequently, predicted upward migration of tree species may be ameliorated if the high degree of fine-scale variability in mountain ecosystems provides some localized conditions that are unfavorable for tree establishment (Randin et al. 2009). Nevertheless, subalpine vegetation is expected to exhibit increased habitat fragmentation and to experience increased competition from lower elevation species due to climate change (Walther et al. 2005). In addition to impacts of changing climate, subalpine vegetation may experience greater effects of insects and pathogens (Dale et al. 2010). For example, the spread of Mountain Pine Beetle to Whitebark Pine has been attributed to warmer temperatures (Logan et al. 2003). Changes to other ecosystem processes such as phenology of flower bloom may also alter subalpine ecosystem function (Dunne et al. 2003). The consequences of meadow loss or impairment include the loss of genetic diversity, habitat, and overall alpine diversity (Malanson et al. 2007), and may affect water and nutrient budgets of mountain watersheds (Seastedt et al. 2004).

4.11.5 Emerging Issues

- Changes in treeline position are more complex than trees simply establishing at higher elevations due to warming climate. Fine-scale constraints such as micro-topography, distance from mature trees as sources of shelter and seed, and characteristics of meadow vegetation will limit the ability of trees to establish in meadows (Holtmeier and Broll 2007, Malanson et al. 2007, Randin et al. 2009, Zald et al. 2012). Perhaps subalpine-alpine vegetation will be squeezed between the advance of trees at lower elevations as they increase upslope with climate change and the slow process of alpine pedogenesis at upper elevations.
- In addition to potential loss in areal extent, climate change may alter ecological processes in subalpine meadows such as phenology (Dunne et al. 2003), disturbance due to native and non-native insects and pathogens (Dale et al. 2001), and fire if fuels become more available due to longer warm-dry periods during summer.
- Changes in air quality may interact with warming temperatures and reduced snowpack to accelerate changes in composition of herbaceous vegetation communities (Bowman et al. 1993, 1995, Adams 2003).

4.11.6 Information and Data Needs–Gaps

- Many years may elapse between when trees begin to establish in meadows and when they can be detected in remotely sensed data because the harsh subalpine environment significantly limits tree growth. Therefore, ground-based monitoring is required to provide early warning of changes. LiDAR may be useful for early detection of tree establishment over large areas, especially as it becomes less costly.

- Current climate models are at resolutions too coarse to be useful in complex high-elevation topography with important small-scale variation in habitat characteristics. Monitoring the duration and extent of annual snowpack would provide valuable information to supplement temperature and precipitation for understanding subalpine responses to climate change (Aubry et al. 2011).
- Recreational use of subalpine areas in the park is significant. Current levels of recreational use have resulted in adverse changes to biological resources and visitors' experiences (VandeKamp and Zweibel 2004, Rochefort and Swinney 2000). Informal social trails and campsites can fragment plant communities or wildlife habitat into smaller patches reducing habitat connectivity and ecosystem resilience. Moderate to high levels of fragmentation can influence and alter wildlife movement patterns and alter patterns of gene flow. A project is presently underway to investigate the use of spatial statistical metrics to evaluate the influence of recreational use trails and campsites on park ecosystems (Rochefort In prep.). Results of this project should be integrated into management of sensitive areas such as subalpine and alpine habitats and long-term monitoring instituted using spatial metrics, should the methodology prove to be useful for assessing habitat fragmentation and ecosystem resilience.

4.11.7 Literature Cited

Adams, M. B. 2003. Ecological issues related to N deposition to natural ecosystems: Research needs. Environment International 29:189–199.

Aubry, C., W. Devine, R. Shoal, A. Bower, J. Miller, J., and N. Maggiuli. 2011. Climate change and forest biodiversity: A vulnerability assessment and action plan for national forests in western Washington. U.S. Department of Agriculture, U.S. Forest Service, Pacific Northwest Region, Olympia, Washington.

Bowman, W. D., T. A. Thodose, J. Schardt, and R. T. Conant. 1993. Constraints of nutrient availability on primary production of two alpine tundra communities. Ecology 74:2085–2097.

Bowman, W. D., T. A Theodose, and M. C. Fisk. 1995. Physiological and production responses of plant growth forms to increases in limiting resources in alpine tundra: Implications for differential community response to environmental change. Oecologia 101:217–222.

Camarero, J., and E. Gutierrez. 2004. Pace and pattern of recent tree line dynamics: Response of ecotones to climatic variability in the Spanish Pyrenees. Climate Change 63:181–200.

Dale, V. H., L. A. Joyce, S. Mcnulty, R. P. Neilson, M. P. Ayres, M. D. Flannigan, P. J. Hanson, L. C. Irland, A. E. Lugo, C. J. Peterson, D. Simberloff, F. J. Swanson, B. J. Stocks, and B. M. Wotton. 2001. Climate change and forest disturbances. BioScience 51:723–734.

Dunne, J. A., J. Harte, and K. J. Taylor. 2003. Subalpine meadow flowering phenology responses to climate change: Integrating experimental and gradient methods. Ecological Monographs 73:69–86.

Franklin, J. F., W. H. Moir, G. W. Douglas, and C. Wiberg. 1971. Invasion of subalpine meadows by trees in the Cascade Range, Washington. Arctic and Alpine Research 3:215–224.

Henderson, J. A. 1974. Composition, distribution and succession of subalpine meadows in Mt. Rainier National Park [dissertation]. Oregon State University, Corvallis, Oregon.

Holtmeier, F.-K., and G. Broll. 2005. Sensitivity and response of northern hemisphere altitudinal and polar treelines to environmental change at landscape and local scales. Global Ecology and Biogeography 14:395–410.

Holtmeier, F.-K., and G. Broll. 2007. Treeline advance – driving processes and adverse factors. Landscape Online 1:1–33.

Little, R. L., D. L. Peterson, and L. L. Conquest. 1994. Regeneration of Subalpine Fir (*Abies lasiocarpa*) following fire: Effect of climate and other factors. Canadian Journal or Forest Research 24:934–944.

Logan, J. A., J. Regniere, and J. A. Powell. 2003. Assessing the impacts of global warming on forest pest dynamics. Frontiers in Ecology and Environment. 1:130–137.

Malanson, G. P., D. R. Butler, D. B. Fagre, S. J. Walsh, D. F. Tomback, L. D. Daniels, L. M. Resler, W. K. Smith, D. J. Weiss, D. L. Peterson, and others. 2007. Alpine treeline of western North America: Linking organism-to-landscape dynamics. Physical Geography 28:378–396.

Millar, C. I., R. D. Westfall, D. L. Delany, J. C. King, and L. J. Graumlich. 2004. Response of subalpine conifers in the Sierra Nevada, California, USA, to 20th-century warming and decadal variability. Arctic, Antarctic, and Alpine Research. 36:181–200.

Mote, P. W., A. F. Hamlet, M. P. Clark, and D. P. Lettenmaier. 2005. Declining mountain snowpack in western North America. Bulletin of the American Meteorological Society 86:39–49.

Nielsen, R. P., and C. Copass. In prep. Vegetation inventory project for Mount Rainier National Park, 2007–2013 (MORA_Veg_Polys). Mount Rainier National Park. Geospatial Dataset-XXXXXXX.

Peterson, D. W., D. L. Peterson, and G. J. Ettl. 2002. Growth responses of subalpine fir to climatic variability in the Pacific Northwest. Canadian Journal of Forest Research 32:1503–1517.

Randin, C.F., R. Engler, S. Normand, M. Zappa, N. E. Zimmermann, P. B. Pearman, P. Vittoz, W. Thuiller, and A. Guisan. 2009. Climate change and plant distribution: Local models predict high-elevation persistence. Global Change Biology 15:1557–1569.

Rochefort, R. M., and D. L. Peterson. 1996. Temporal and spatial distribution of trees in subalpine meadows of Mount Rainier National Park, Washington, U.S.A. Arctic and Alpine Research 28:52–59.

Rochefort, R. M,. and D. D. Swinney. 2000. Human impact surveys in Mount Rainier National Park: Past, present, and future. Proceedings–Wilderness Science in a Time of Change Conference. (Volume 5: p. 165–171). USDA Forest Service, RMRS-P-15-VOL-5.

Rochefort, R. M., R. M. Little, A. Woodward, and D. L. Peterson. 1994. Changes in subalpine tree distribution in Western North America: A review of climatic and other causal factors. The Holocene 4:89–100.

Rochefort, R. M. In prep. Identifying spatial metrics to evaluate the influence of recreational impacts on ecosystems in Mount Rainier National Park.

Seastedt, T. R., W. D. Bowman, T. N. Caine, D. McKnight, A. Townsend, and M. W. Williams. 2004. The landscape continuum: A model for high-elevation ecosystems. BioScience 54:111–121.

Stueve, K. M., D. L. Cerney, R. M. Rochefort, and L. L. Kurth. 2009. Post-fire establishment patterns at the alpine treeline ecotone: Mount Rainier National Park, Washington, USA. Journal of Vegetation Science 20:107–120.

Vande Kamp, M. E., and B. R. Zweible. 2004. A regression-based model of visitor use in the Paradise developed area of Mount Rainier National Park. Technical Report PNW/CESUY, College of Foerest Resources, University of Washington. Seattle, Washingotn.

Walther, G.-R., S. Beiβner, and R. Pott. 2005. Climate change and high mountain vegetation shifts. In: Broll, G., and B. Keplin, editors. Mountain ecosystems: Studies in treeline ecology. Springer, New York, New York.

Woodward, A., E. G. Schreiner, and D. G. Silsbee. 1995. Climate, geography, and tree establishment in subalpine meadows of the Olympic Mountains, Washington, USA. Arctic and Alpine Research. 27:217–225.

Zald, H. S., T. A. Spies, M. Huso, and D. Gatziolis. 2012. Climatic, landform, microtopographic, and overstory canopy controls of tree invasion in a subalpine meadow landscape, Oregon Cascades, USA. Landscape Ecology 27:1197–1212.

Zolbrod, A. N., and D. L. Peterson. 1999. Response of high-elevation forests in the Olympic Mountains to climate change. Canadian Journal of Forest Research 29:1966–1978.

4.12 Biodiversity: Sensitive Vegetation Species

(Andrea Woodward, USGS FRESC)

4.12.1 Introduction

National parks strive to minimize the effects of human development on the ecosystems they protect. One of the desired results is reduced risk of extinction for native species and preservation of biodiversity. Besides protecting biodiversity for its intrinsic value, areas having relatively unimpaired complements of species provide opportunities to study natural ecologic processes and they serve as benchmarks against which developed areas can be compared. Moreover, the process and consequences of federal listing can be minimized for sensitive species that have sufficient populations in protected areas.

4.12.2 Approach

The status of sensitive species was assessed using lists of vascular and non-vascular plant species and fungi, compiled by Rochefort (2010), Glew (2002, and undated Mount Rainier records), Harpel (2010), and the adjacent national forests (http://www1.dnr.wa.gov/nhp/refdesk/fguide/htm/f sfgabc.htm). The range of each species in North America was extracted from the Plant Profiles website (USDA NRCS 2010 available at http://www.nrcs.usda.gov/wps/portal/nrcs/site/national/ home). Documented occurrences of sensitive species in Washington State were obtained from the Washington Natural Heritage Program (WNHP 2002, http://www1.dnr.wa.gov/nhp/ refdesk/fguide). Trend in sensitive species was determined by assessing change in species status in Washington State since 1997. The assessment study area was MORA plus adjacent parts of Gifford-Pinchot, Okanogan-Wenatchee, and Mount Baker-Snoqualmie National Forests.

4.12.3 Reference Conditions and Comparison Metrics

The WNHP has published changes in the conservation status of plant species since 1997. Consequently we will use 1997 as the reference condition. The assessment metric is number of species changing WNHP status.

4.12.4 Results and Assessment

Current Condition

There are currently 8 species having a state conservation rank of 'vulnerable' (state rank S3) or higher among species documented to occur in MORA (Table 36). Six have state sensitive status while the other 2 have watch status. One other species is apparently rare but more field studies are needed to determine its status (Table 36). In addition, of the 8 species, 2 are considered globally vulnerable to imperiled (*Castilleja crypthantha*, *Pedicularis rainierensis*). Both of these species occur in subalpine areas and were thought to be endemic to MORA, but have also been documented outside of the park boundary (Biek 2000). *Castilleja crypthantha* occurs in dryish meadows on pumice-derived soils in the northern part of the park; *Pedicularis rainierensis* has been seen in various parts of the park on north-facing slopes.

Numerous additional sensitive species occur in adjacent national forests (Table 37). While many of these species could occur in MORA, those that have been observed near the park boundary and in appropriate habitats seem most likely to also have populations in the park. Candidates include

Botrychium ascendens, *Carex comosa*, *Corydalis aquae-gelidae*, *Fritillaria camschatcensis*, *Gentiana douglasiana*, *Heterotheca oregona* var. *oregona*, *Juncus howellii*, *Lycopodiella inundatum*, *Microseris borealis*, *Montia diffusa*, *Ranunculus populago*, *Sidalcea hirtopes*, and *Utricularia intermedia*.

Several surveys of non-vascular plants and macrofungi have been conducted in localized areas of MORA. Although these efforts are limited, surveys discovered several lichen species that are listed by Washington, are globally vulnerable, or were identified as rare by Katherine Glew (i.e., *Allantoparmelia almquistii*, *Lecidella carpathica*, *Stereocaulon nivale* and *Tephromela armeniaca*) (Table 38). More work on non-vascular plants and fungi is clearly warranted.

There are 5 additional species besides those in Table 36 that are considered to be species of management concern for MORA (spreadsheet SOMCPlantsMORA.xls, on file at MORA). *Agoseris elata* is listed as sensitive by WNHP and there is an historic record of it in MORA (WNHP website). Although it was targeted with field surveys in 2011, it has not been relocated. *Carex atrosquama* (syn *Carex atrata* var. *atrosquama* (Mackenzie) Cronq.) is no longer listed by WNHP, and Biek (2000) indicates that the voucher for this species from the park actually misapplied the name to *Carex spectabilis*. It was not located during the survey conducted in 2011. *Dryopteris cristata* is on the species list for the park, but is unlikely to occur there (Biek 2000). *Poa nervosa* is currently considered to be a rare plant of the lower Columbia gorge. The 2 vouchers from MORA were collected in the 1890s and are of *Poa wheeleri* (Biek 2000), which is not listed by WNHP. *Pinus albicaulis* has been proposed for listing under the federal Endangered Species Act and is also subject to White Pine blister rust. Finally, *Thuja plicata* and *Xerophyllum tenax* are of concern because they are both of cultural importance to tribes for basketry.

Trend

Among the sensitive species documented as occurring in MORA, none have been elevated in status since 1997, while 2 have been downgraded from ‘sensitive’ to ‘watch’ (*Botrychium lanceolatum* and *B. pinnatum*) and 1 (*Saxifraga rivularis*) has been removed from the list (Table 36). Improved status is most commonly due to the location of previously unknown populations. There is insufficient information to describe trends in non-vascular plants and macrofungi.

Predicted Changes

Threats to sensitive species include changes in air quality, climate change, and invasive species. The effects of all of these factors are expected to accelerate over time and their effects on vegetation are discussed in other sections of this chapter. Species that may deserve particular attention (NatureServe 2012) because of their relative rarity, they are at the edge of their range, or may be in the park but have not been documented include:

1. *Castilleja cryptantha* – a nearly MORA endemic that is globally vulnerable to threatened (G2G3) and SS, S2S3 in Washington;
2. *Heterotheca oregona var. oregona* – ST, S1 in Washington and occurs near the eastern boundary of MORA;

3. *Juncus howellii* – ST, S1 in Washington and occurs near the park and is at the northern edge of its range;
4. *Lycopodiella inundatum* – SS, S1 in Washington and occurs just west of MORA;
5. *Oxytropis monticola* – SS, S2 in Washington, and occurs in MORA, but most of its range is intermountain west;
6. *Pedicularis rainierensis* – a nearly MORA endemic that is globally vulnerable to threatened (G2G3), and SS, S2S3 in Washington;
7. *Ranunculus populago* – SS, S2 in Washington, and occurs near the western boundary of MORA (see Tables 35 and 36 for definitions of codes).

Table 36. Sensitive species of Mount Rainier National Park.

Species name	Common name	Global Rank[1]	State status (rank) 2012 [2]	Change since 1997[2]	Range in North America[1]
Botrychium lanceolatum	Triangle Grapeleaf	G5	SW(S3)	↓S-W	Can:AB,BC,LB,NB,NF,NS,ON,PE,SK,YT USA:AK,AZ,CA,CO,CT,ID,KY,MA,MD,ME,MI,MN,MT,NC,NH,NJ ,NM,NV,NY,OH,OR
Botrychium pinnatum	Northern Moonwort	G4?	SW(S3)	↓S-W	Can:AB,BC,NF,NT,QC,SK,YT USA:AK,AZ,CA,CO,ID,MT,NV,OR, UT, WA
Castilleja cryptantha	Obscure Indian-Paintbrush	G2G3	SS(S2S3)		USA: WA
Luzula arcuata ssp. unalaskensis	Curved Woodrush	G5T3T5	SS(S1)		Can:AB,BC,YT USA:AK,OR,WA
Microseris borealis	Northern Microseris	G5	SS(S2)		Can: BC USA:AK,CA,OR,WA
Oxytropis monticola	Slender Crazyweed	G5?	SS(S2)		Can:AB,BC,MB,SK USA:CO,ID,MT,ND,SD,WA,WY
Pedicularis rainierensis	Mount Rainier Lousewort	G2G3	SS(S2S3)		USA: WA
Polemonium viscosum	Skunk Polemonium	G5	SS(S1S2)		Can:AB,BC USA:AZ,CO,ID,MT,NM,OR,UT,WA,WY
Saxifraga rivularis	Pygmy Saxifrage	G5?		↓S-off[3]	Can:AB,BC,LB,MB,NF,NT,NU,ON,QC,YT USA:AK,AZ,CA,CO,ID,MT,NH,NM,NV,OR,UT,WA,WY
Whipplea modesta	Modest Whipple-vine	G4	SR1(SNR)		USA:CA,OR,WA

[1]Codes and source (NatureServe); G1, globally critically imperiled; G2, globally imperiled; G3, globally vulnerable; G4, globally apparently secure; G5, globally secure; T# indicates same categories for varieties and subspecies

[2]http://www1.dnr.wa.gov/nhp/refdesk, accessed December 2012; State status: SE, state endangered; ST, state threatened; SS, state sensitive; SW, watch; SR1, additional fieldwork needed before status can be assigned; State rank: S1, state critically imperiled; S2, state imperiled; S3, state vulnerable; SNR, state not ranked

[3]Biek (2000)

Table 37. Sensitive species documented in adjacent national forests but not in MORA.

Species name	Common name	Global Rank[1]	WNHP State status[2]	WNHP WDFW State Rank[3]	MBS[4]	OW[4]	GP[4]	Nearest record since 1980[5]
Allium campanulatum	Sierra Onion	G4	ST	S1		D		Columbia Co.
Antennaria parvifolia	Nuttall's Pussy-toes	G5	SS	S2		D		Stevens Co.
Astragalus arrectus	Palouse Milk-vetch	G2G4	ST	S2		D		Klickitat Co.
Astragalus microcystis	Least Bladdery Milk-vetch	G5	SS	S2		S		Olympic peninsula
Bolandra oregana	Oregon Bolandra	G3	SS	S2			D	Skamania Co.
Botrychium ascendens	Upward-lobed Moonwort	G2G3	SS	S2	D	D		Near park eastern boundary
Botrychium crenulatum	Crenulate Moonwort	G3	SS	S3		D		unknown
Botrychium lineare	Slender Moonwort	G2?	ST	S1		S		Ferry Co.
Calochortus longebarbatus var. longebarbatus	Long-bearded Mariposa Lily	G4	SS	S2S3			S	Yakima Co.
Carex chordorrhiza	Cordroot Sedge	G5	SS	S1		D		Okanogan Co.
Carex comosa	Bristly Sedge	G5	SS	S2	S	D		Pierce Co. west of MORA
Carex densa	Dense Sedge	G5	ST	S1			D	Wahkiakum Co.
Carex gynocrates	Yellow Bog Sedge	G5	SS	S1		D		Eastern Okanogan Co.
Carex macrochaeta	Long-awned Sedge	G5	ST	S1				Skamania Co.
Carex media/norvegica	Intermediate Sedge	G5?	SS	S2		D	S	North-central Okanogan Co.
Carex pauciflora	Few-flowered Sedge	G5	SS	S2	D	S		King Co.
Carex proposita	Smokey Mountain Sedge	G4	ST	S2		D	D	Wenatchee mountains
Carex scirpoidea var. scirpoidea	Canadian Single-spike Sedge	G5T5	SS	S2	D	D		Olympic peninsula
Carex stylosa	Long-styled Sedge	G5	SS	S1S2	D	S		Border King and Chelan Co.s
Carex sychnocephala	Many-headed Sedge	G4	SS	S2		D		Okanogan Co.
Carex tenuiflora	Sparseflower Sedge	G5	ST	S1		D		Central Okanogan Co.
Carex vallicola	Valley Sedge	G5	SS	S2		D		Eastern Dougla Co.
Chaenactis thompsonii	Thompson's Chaenactis	G2G3	SS	S2S3	D	D		Chelan, Whatcom Co.; serpentine soil
Chrysolepis chrysophylla var chrysophylla	Golden Chinquapin	G5	SS	S2			D	Mason, Skamania Co.s
Chrysosplenium tetrandrum	Northern Golden-carpet	G5	SS	S2		D		Eastern Okanogan Co.
Cicuta bulbifera	Bulb-bearing Water-hemlock	G5	SS	S2			S	Chelan Co.
Collinsia sparsiflora var. bruceae	Few-flowered Collinsia	G4	SS	S1S2			S	Klickitat Co.

Table 37. Sensitive species documented in adjacent national forests but not in MORA (continued).

Species name	Common name	Global Rank[1]	WNHP State status[2]	WNHP WDFW State Rank[3]	MBS[4]	OW[4]	GP[4]	Nearest record since 1980[5]
Coptis aspleniifolia	Spleenwort-leaved Goldthread	G5	SS	S2	D	S	S	Snohomish Co.
Corydalis aquae-gelidae	Cold-water Corydalis	G3	SS	S2S3			D	Skamania Co.
Cryptantha flaccida	Beaked Cryptantha	G4	ST	S2			S	unknown
Cryptogamma stelleri	Steller's Rockbrake	G5	SS	S1S2		D		Northern Chelan Co.
Cypripedium parviflorum	Yellow Lady's Slipper	G5	ST	S2		D		Western Okanogan Co.
Damasonium californicum	Fringed Waterplantain	G4	SE	S1			S	Klickitat Co.
Delphinium viridescens	Wenatchee Larkspur	G2	ST	S2		D		Southern Chelan Co.
Draba cana	Lance-leaved Draba	G5	SS	S1S2		D		Northwestern Okanogan Co.
Dryas drummondii var. drummondii	Drummond's Mountain-avens	G5T5	SS	S2	D	S		Jefferson, Snohomish Co.s
Erigeron howellii	Howell's Daisy	G2	ST	S2			S	Skamania Co.
Erigeron oreganus	Oregon Daisy	G3	ST	S2			S	Skamania Co.
Eriophorum viridicarinatum	Green Keeled Cotton-grass	G5	SS	S2			D	Lincoln Co.
Eritrichium nanum var. elongatum	Pale Alpine Foret-me-not	G5T4	SS	S1		D		Border Okanogan, Chelan Co.s
Eryngium petiolatum	Oregon Coyote-thistle	G4	ST	S1			S	Klickitat Co.
Fritillaria camschatcensis	Black Lily	G5	SS	S2	D		S	King Co.
Gaultheria hispidula	Creeping Snowberry	G5	SS	S2	S			Central Snohomish Co.
Gentiana douglasiana	Swamp Gentian	G4	SS	S2	D	D		King Co., north of MORA
Geum rivale	Water Avens	G5	SS	S2S3		D		Western Okanogan Co.
Geum rossii var. depressum	Ross' Avens	G5T1	SE	S1		D		Southern Chelan Co.
Hackelia hispida var. disjuncta	Sagebrush Stickseed	G4T2T3	SS	S2S3		D		Grant Co.
Hedysarum occidentale var. occidentale	Western Hedysarum	G5	SS	S1			D	Skamania Co.
Heterotheca oregona var. oregona	Oregon Goldenaster	G4T4?	ST	S1		D	D	Yakima Co. near MORA
Juncus howellii	Howell's Rush	G4	ST	S1		D	D	Skamania Co.
Leptosiphon bolanderi	Baker's Linanthus	G4G5	SS	S2			S	Klickitat Co.
Lomatium suksdorfii	Suksdorf's Desert Parsley	G3	SS	S3			D	Klickitat Co.
Lycopodiella inundatum	Bog Club-moss	G5	SS	S1			S	Pierce Co., just west of MORA

Table 37. Sensitive species documented in adjacent national forests but not in MORA (continued).

Species name	Common name	Global Rank[1]	WNHP State status[2]	WNHP WDFW State Rank[3]	MBS[4]	OW[4]	GP[4]	Nearest record since 1980[5]
Mecronella oregano	White Fairypoppy	G2G3	ST	S1			S	Lewis Co., west of MORA
Microseris borealis	Northern Microseris	G4?	SS	S2	S		D	Northern Skamania Co.
Mimulus pulsiferae	Pulsifer's Monkey-flower	G4?	SS	S2		D	D	Central western Skamania Co.
Mimulus suksdorfii	Suksdorf's Monkey-flower	G4	SS	S2		D	S	Kittitas Co.
Montia diffusa	Branching Montia	G4	SS	S2S3			D	Northern Skamania Co.
Navarretia tagetina	Marigold Navarretia	G5	ST	S1			S	Klickitat Co.
Nicotiana attenuata	Coyote Tobacco	G4	SS	S2		D		Yakima, Klickitat Co.s
Ophiglossum pusillum	Adder's Tongue	G5	ST	S1S2			S	Klickitat Co.
Pellaea brachyptera	Sierra Cliffbrake	G4G5	SS	S2		D		Northeastern Chelan Co.
Pellaea breweri	Brewer's Cliff-brake	G5	SS	S2	S	D		Kittitas Co.
Penstemon barrettiaw	Barrett's Penstemon	G2	ST	S2			D	Skamania Co.
Penstemon eriantherus var. whitedii	Whited's Penstemon	G4T2	SS	S2		D		Southern Chelan Co.
Penstemon wilcoxii	Wilcox's Penstemon	G4	SS	S1			D	Eastern Spokane Co.
Petrophytum cinerascens	Chelan Rockmat	G1	SE	S1		D		Eastern Chelan Co.
Phacelia minutissima	Dwarf Phacelia	G3	SE	S1		D		North-central Kittitas Co.
Physaria didymocarpa var. didymocarpa	Common Twinpod	G5T4	ST	S1		D		Northwestern Kittitas Co.
Pilularia americana	American Pillwort	G5	ST	S1S2		D		Central eastern WA
Platanthera chorisiana	Choris' Bog-orchid	G3G4	ST	S2	D	S		Northern King Co.
Platanthera sparsiflora	Canyon Bog-orchid	G4G5	ST	S1	D	D	S	Southern Skamania Co.
Polemonium carneum	Great Polemonium	G4	ST	S1S2			S	Southern Skamania Co.
Potentilla nivea	Snow Cinquefoil	G5	SS	S2		D		Northwestern Okanogan Co.
Pyrrocoma hirta var. sonchifolia	Sticky Goldenweed	G4G5	SS	S1		D		Kittitas Co.
Ranunculus cooleyae	Cooley's Buttercup	G4	SS	S1S2	D			Northern King Co.
Ranunculus populago	Mountain Buttercup	G4	SS	S2			D	Western border MORA
Ranunculus triternatus	Dalles Mt. Buttercup	G2	Se	S1			S	Southern Klickitat Co.
Ribes oxyacanthoides ssp. irriguum	Idaho Gooseberry	G5T3T4	ST	S2		D		Eastern WA
Rorippa columbiae	Columbia Cress	G3	SE	S1S2			S	Southern Skamania Co.
Rotala ramosior	Lowland Toothcup	G5	ST	S1		D		Grant Co.

Table 37. Sensitive species documented in adjacent national forests but not in MORA (continued).

Species name	Common name	Global Rank[1]	WNHP State status[2]	WNHP WDFW State Rank[3]	MBS[4]	OW[4]	GP[4]	Nearest record since 1980[5]
Rubus arcticus ssp. acaulis	Nagoonberry	G5T5	ST	S1		D		Central Okanogan Co.
Salix glauca ssp. glauca var. villosa	Glaucus Willow	G5T5?	SS	S1S2		D		North-central Okanogan Co.
Salix maccalliana	Maccall's Willow	G5?	SS	S1		D		Northeastern WA
Sanicula marilandica	Black Snake-root	G5	SS	S2		D		North-central Okanogan Co.
Saxifraga cernua	Nodding Saxifrage	G4	SS	S1S2		D		Western Okanogan Co.
Saxifagopsis fragarioides	Joint-leaved Saxifrage	G3?	ST	S1		D		Southern Chelan Co.
Scribneria bolanderi	Scribner's Grass	G4	SS	S1			D	Klickitat Co.
Sidalcea hirtipes	Bristly-stemmed Sidalcea	G2	ST	S1			D	Central Lewis Co.
Sisyrinchium sarmentosum	Pale Blue-eyed Grass	G1G2	ST	S1S2		S	D	Central-eastern Skamania Co.
Spiranthes porrifolia	Western Ladies-tresses	G4	SS	S2		D		Eastern Kittitas Co.
Sullivantia oregana	Oregon Sullivantia	G2	SE	S1			S	Southern Skamania Co.
Trifolium thompsonii	Thompson's Clover	G2	ST	S2		D		Southeastern Chelan Co.
Utricularia intermedia	Flat-leaved Bladerwort	G5	SS	S2			S	Northern King, central Skamania Co.s
Vaccinium myrtilloides	Velvet-leaf Blueberry	G5	SS	S1		D		Eastern Okanogan Co.
Viola renifolia	Kidney-leaved Violet	G5	SS	S2		D		Northeastern WA

[1]G1, globally critically imperiled; G2, globally imperiled; G3, globally vulnerable; G4, globally apparently secure; G5, globally secure; T# indicates same categories for varieties and subspecies

[2]SE, state endangered; ST, state threatened; SS, state sensitive

[3]S1, state critically imperiled; S2, state imperiled; S3, state vulnerable

[4]Documented (D) and suspected (S) occurrence of species in Mount Baker-Snoqualmie (MBS) and Okanogan-Wenatchee (OW) National Forests (http://www.fs.fed.us/r6/sfpnw/isssp/agency-policy/ accessed 12/2012)

[5]Source: http://www1.dnr.wa.gov/nhp/refdesk/fguide/htm/fsfgabc.htm; most species descriptions were updated in 2003.

Table 38. Sensitive non-vascular plants and macrofungi found in MORA.

	Species (MORA surveys)	Global Rank[2]	State Rank[3]
Mosses[1]	*Thamnobryum neckeroides*	G4	S2
	Anthoceros fusiformis	G3	none
Lichens[4]	*Allantoparmelia almquistii*	GNR	none
	Buellia notabilis	G3	none
	Lecidella carpathica	G5	SNR
	Rhizocarpon jemtlandicum	G3G5	SNR
	Sporastatia polyspora	G3G5	SNR
	Stereocaulon nivale	GNR	SNR
	Tephromela armeniaca	G5	none
	Umbilicaria decussata	G3?	S1
	Umbilicaria havaasii	G3G4	S1
Macrofungus[5]	*Bridgeporus nobilissimus*	G3	S2

[1]Source: Final Mt. Rainier Phase 1 Bryophyte Survey Report ver2.doc, Judith Harpel 2010

[2]G1, globally critically imperiled; G2, globally imperiled; G3, globally vulnerable; G4, globally apparently secure; G5, globally secure; NR, not yet ranked

[3]S1, state critically imperiled; S2, state imperiled; S3, state vulnerable; NR, not yet ranked

[4]Sources: MountRainierRareLickensKGlew.doc, Katherine Glew, undated; Rare Alpine Lichens Camp Muir_Glew.doc, Katherine Glew 2002

[5]Source: 2009_12_29_Report_BRNO_final.doc, Matt Gordon 2009

4.12.5 Emerging Issues

- Climate change is likely to affect the abundance and location of habitats of sensitive species.
- Species that are on the edge of their distribution may be genetically distinct from the main populations and have traits that contribute to long-term survival (Gaston 2012).

4.12.6 Information and Data Needs–Gaps

- Surveys of relevant habitats for species that have been reported in the park but not relocated in the NPS inventory effort, or that are known to occur in adjacent national forests but have not been located in the park would help confirm their absence.
- An opportunity exists for MORA staff to participate in establishing a formal classification method for NPS of species of management concern that could be cross-referenced to the classifications of surrounding federal agencies.
- Forecasts of where relevant habitats may migrate due to changing climate would provide valuable infomation for considering potential management interventions.
- Characterization of genetic composition and adaptations of species on the edge of their distribution may indicate whether these populations can contribute to the long-term survival of these species.
- More extensive and systematic surveys for non-vascular plants and fungi are needed to adequately describe their status to serve as a baseline for eventually detecting trends. These

surveys should include an indication of total area surveyed as well as where populations were found.

4.12.7 Literature Cited

Biek, D. 2000. Flora of Mount Rainier National Park. Oregon State University Press, Corvallis, Oregon. 506 p.

Gaston, K. J. 2012. The importance of being rare. Nature 487:46–47.

NatureServe. 2012. NatureServe Explorer: An online encyclopedia of life [web application]. Version 7.1. NatureServe, Arlington, VA. Available: http://www.natureserve.org/explorer. Accessed 12 December 2012.

Rochefort, R. M. 2010. Vascular plant inventory of Mount Rainier National Park. Natural

Resource Technical Report NPS/NCCN/NRTR—2010/347. National Park Service, Fort Collins, Colorado.Washington Natural Heritage Program. 2002. Endangered, threatened and sensitive vascular plants of Washington (20 October 2002). Washington State Department of Natural Resources, Washington.

[WNHP] Washington Natural Heritage Program. 2002. Endangered, threatened and sensitive vascular plants of Washington (20 October 2002). Washington State Department of Natural Resources, Olympia, Washington.

Additional Resources

Glew, K. A. undated. Mount Rainier RareLichens KGlew.doc.

Glew, K. A. 2002. Rare Alpine Lichens Camp Muir_Glew.doc.

Gordon, M. 2009. 2009_12_29_Report_BRNO_final.doc.

Harpel, J. 2010. Final Mt. Rainier Phase 1 Bryophyte Survey Report ver2.doc.

SOMCPlantsMORA.xls on file at MORA

4.13 Amphibians

(Michael J. Adams, USGS FRESC)

4.13.1 Introduction

Amphibians are a class of vertebrate defined by moist glandular skin. Some species have complex life cycles and rely on both aquatic and terrestrial habitats for different parts of their life history. It is convenient, however, to categorize amphibians according to their breeding habitat: pond, stream, and terrestrial. Fourteen species (4 frogs, 1 toad, and 9 salamanders) have been identified as present in MORA (Figure 26; Table 39). Three species are federally listed as Species of Concern (Larch Mountain Salamander, Van Dyke's Salamander, and Western Toad). Larch Mountain and Van Dyke's Salamanders are also listed by Washington State as sensitive species; the Western Toad is a candidate for listing in Washington; and the Cascades Frog, Coastal Tailed Frog, and Cope's Salamander are each species recommended for monitoring. All but 4 of the species (Cope's Salamander, Larch Mountain Salamander, Northern Red-legged Frog, and Van Dyke's Salamander) have wide distributions within the park (Table 40). Within their respective ranges, the statuses of all but 4 species are classified as stable (Table 40). Cascades Frog, Ensatina, and Western Toad are classified as decreasing within their ranges, and the status of the Coastal Tailed Frog is unknown.

4.13.2 Approach

This assessment relied predominantly on a previous report that compiled all amphibian records for the National Parks in Washington State (Galvan et al. 2005). The report covered the bulk of inventory work that was completed 1984–2005; however, we also consulted Samora et al. (2013) and a few unpublished inventories that have more recently been completed.

4.13.3 Reference Conditions and Comparison Metrics

Each of the amphibian species documented as present in MORA have attributed to them management status designations (Table 39), as well as global trend and within park and regional distribution information (Table 40). This information can be used to indirectly attribute some level of conservation or management importance to the presence of these species in MORA habitats. The designations or listings for each species were gathered from several sources including NatureServe, US ESA Listing (Federal), International Union for Conservation of Nature, and the Washington State Species of Concern List available from the WDFW.

Table 39. MORA amphibian species and their management status. G = global conservation status rank: 3 = vulnerable, 4 = apparently secure, 5 = secure; NL = not listed.

		Management Status			
Scientific name	**Common name**	**Washington**	**Federal**	**IUCN**	**NatureServe**
Ambystoma gracile	Northwestern Salamander	NL	NL	Least Concern	G5
Ambystoma macrodactylum	Long-toed Salamander	NL	NL	Least Concern	G5
Ascaphus truei	Coastal Tailed Frog	Monitor	NL	Least Concern	G4
Anaxyrus boreas	Western Toad	Candidate	Species of Concern	Near Threatened	G4
Dicamptodon tenebrosus	Coastal Giant Salamander	NL	NL	Least Concern	G5
Dicamptodon copei	Cope's Giant Salamander	Monitor	NL	Least Concern	G3G4
Ensatina eschscholtzii	Ensatina	NL	NL	Least Concern	G5
Pseudacris regilla	Northern Pacific Treefrog	NL	NL	Least Concern	G5
Plethodon larselli	Larch Mountain Salamander	Sensitive	Species of Concern	Near Threatened	G3
Plethodon vandykei	Van Dyke's Salamander	Sensitive	Species of Concern	Least Concern	G3
Plethodon vehiculum	Western Red-backed Salamander	NL	NL	Least Concern	G5
Rana aurora	Northern Red-legged Frog	NL	NL	Least Concern	G4
Rana cascadae	Cascades Frog	Monitor	NL	Near Threatened	G3G4
Taricha granulosa	Rough-skinned Newt	NL	NL	Least Concern	G5

Table 40. Global trends and distributional extent of amphibians present in Mount Rainier National Park. IUCN = International Union for Conservation of Nature; PNW = Pacific Northwest.

		Trends	Extent	
Scientific name	**Common name**	**IUCN**	**Inside Park**	**Outside Park**
Ambystoma gracile	Northwestern Salamander	stable	wide	PNW
Ambystoma macrodactylum	Long-Toed Salamander	stable	wide	PNW
Ascaphus truei	Coastal Tailed Frog	unknown	wide	PNW
Anaxyrus boreas	Western Toad	decreasing	wide	western US
Dicamptodon tenebrosus	Coastal Giant Salamander	stable	wide	PNW
Dicamptodon copei	Cope's Giant Salamander	stable	limited	sub PNW
Ensatina eschscholtzii	Ensatina	decreasing	wide	western US
Pseudacris regilla	Northern Pacific Treefrog	stable	wide	PNW
Plethodon larselli	Larch Mountain Salamander	stable	limited	sub PNW
Plethodon vandykei	Van Dyke's Salamander	stable	limited	sub PNW
Plethodon vehiculum	Western Red-Backed Salamander	stable	wide	PNW
Rana aurora	Northern Red-Legged Frog	stable	limited	PNW
Rana cascadae	Cascades Frog	decreasing	wide	PNW
Taricha granulosa	Rough-Skinned Newt	stable	wide	PNW

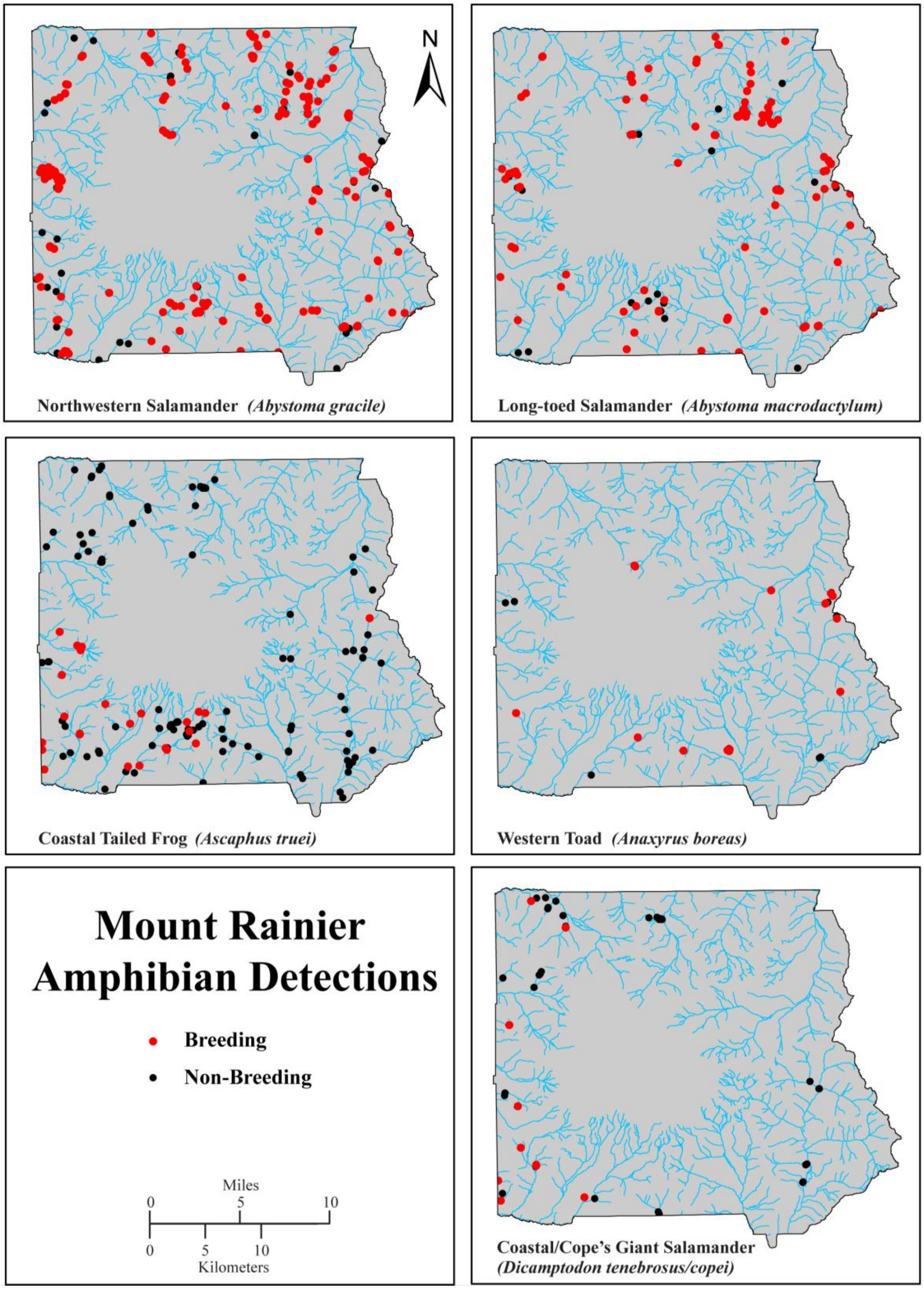

Figure 26. Distribution of amphibian species in Mount Rainier National Park. Distribution maps revised from maps originally published in Galvan et al. (2005).

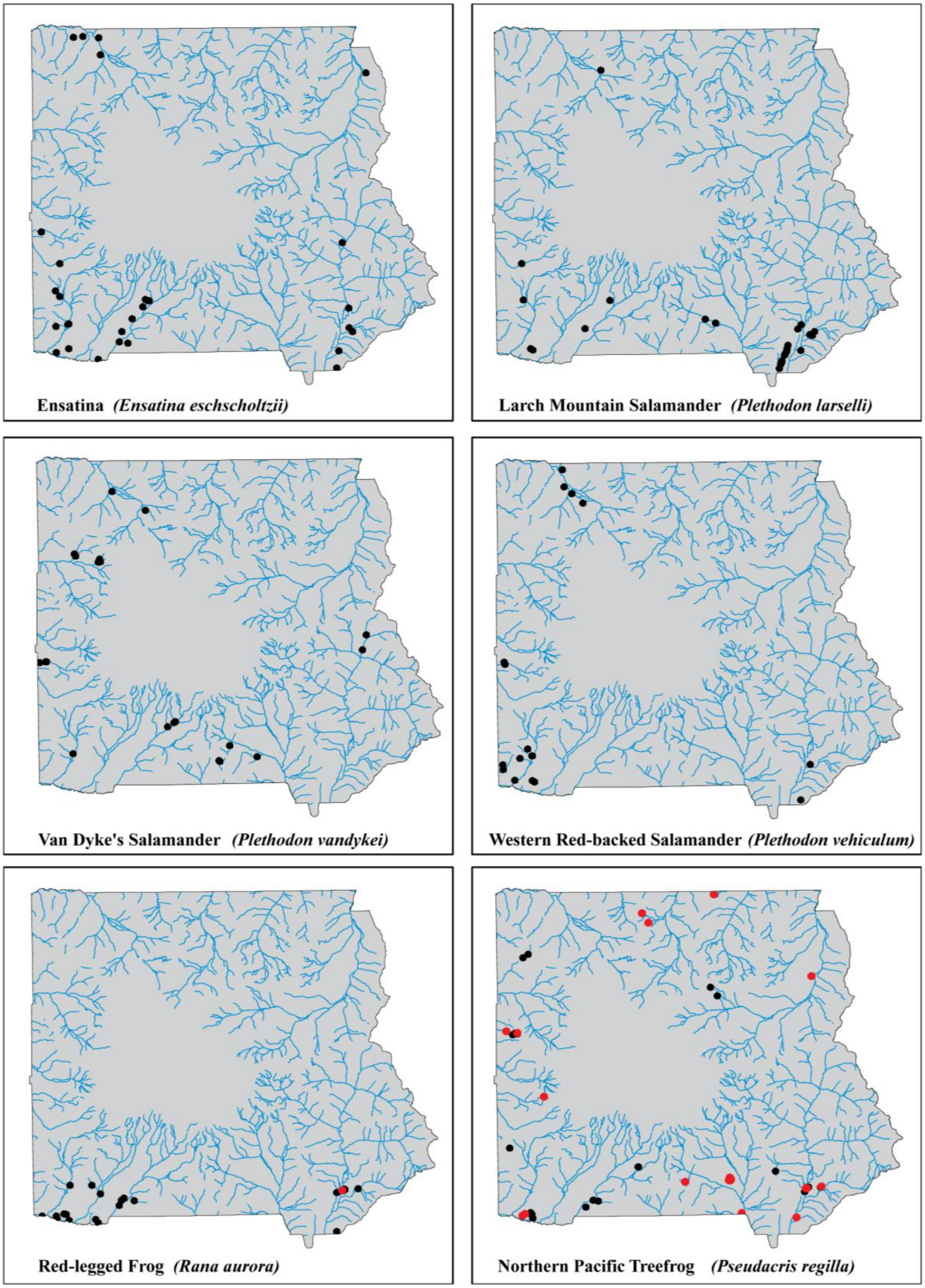

Figure 26. Distribution of amphibian species in Mount Rainier National Park. Distribution maps revised from maps originally published in Galvan et al. (2005) (continued).

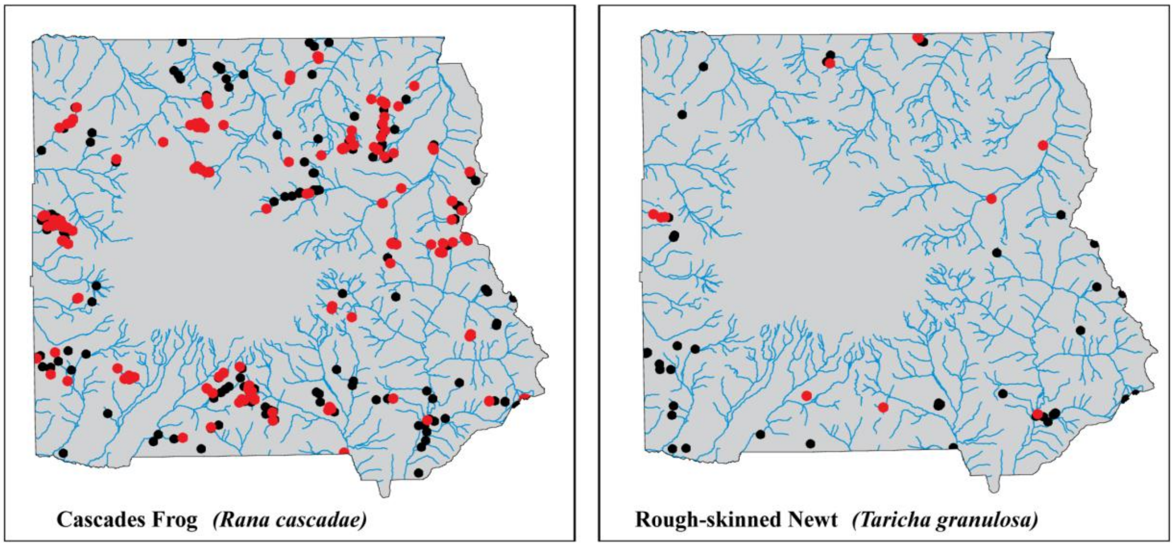

Figure 26. Distribution of amphibian species in Mount Rainier National Park. Distribution maps revised from maps originally published in Galvan et al. (2005) (continued).

4.13.4 Results and Assessment

All amphibians with a reasonable potential to occur in MORA have been detected in the park with perhaps 1 exception, the Cascade Torrent Salamander (*Rhyacotriton cascadae*). This species is found to the southwest of the park, and although stream surveys have been thorough, not enough of them have been conducted to allow us to determine with complete certainty that the species does not occur in the park.

Because of the relatively low mobility of amphibians compared to other vertebrates, all species found in MORA complete all aspects of their life history within the park. There are 4 species (Table 39) that have relatively limited distributions within MORA, with the majority of their distributions outside of the park. No species present in MORA is endemic to the park. Within park trend information for species is currently not available, although some monitoring of pond breeding species is ongoing by park staff and NCCN, with the potential of providing trend information at very long time intervals (decades).

Aquatic breeding amphibian inventories have been thorough and pond (1996–2003) and stream (1996–1999) inventories with good spatial coverage have been completed by park staff and the USGS. Nearly all lentic habitats have been surveyed for amphibians and a large number of streams have been sampled. Terrestrial surveys have been completed, including some targeted at the rare Van Dyke's and Larch Mountain Salamanders. These surveys, however, have been associated with NEPA compliance projects that are in developed areas (e.g., roadsides, trailsides, locations where stream alteration have been proposed), which limits the information available concerning the distributions of terrestrial species.

A large portion of the amphibian locality data (20 databases spanning 1984–2005) have been aggregated in a single database (NCCN amphibian database.mdb) and report (Galvan et al. 2005). The report has dot maps for all species and all parks in the network.

The main species for which there is some concern regarding their conservation status are Cascades Frogs and Western Toads. The concern for these species is due to declines in other parts of their range rather than any information that they are declining in MORA. However, only 13 breeding sites for these 2 species have been documented in the park. Cascades Frogs are fairly widespread in the Klamath Mountains of northern California, but extremely rare in the California southern Cascades. In the southern Cascades, 11 populations are known to occur on private and state-owned lands, and the species has been extirpated form Lassen Volcanic National Park (Pope et al. 2014). There is weak evidence of declines in the Oregon Cascades. No information is available for Washington. Western Toads have declined severely in Colorado. There is weak evidence of decline in eastern Oregon and in the Oregon Cascades. No information is available for Washington. There is also reason for concern about the conservation status of Van Dyke's Salamanders and, especially, Larch Mountain Salamanders due to their limited distributions inside and outside of the park. Because of potential declines or limited range, these 4 species might be a higher priority for monitoring.

4.13.5 Emerging Issues

Activities associated with the construction and maintenance of roads and trails that could disrupt or destroy habitat are probably the most obvious threat to certain amphibians. Some of the best known habitat for Van Dykes and Larch Mountain salamanders is within meters of roads. Other threats to consider are aerial deposition of contaminants, introduced species, and disease transmission. There are several emerging diseases that have been associated with die offs of amphibians including chytridiomycosis (see below), *Rana* virus, and a disease associated with a perkensis-like organism (such as protozoans in the genus *Perkensis*). Salmonids have been widely introduced to formerly fishless mountain lakes and are thought to reduce or displace some species of amphibians (Knapp 2005). Species of amphibian that rely on permanent lakes seem particularly vulnerable. Western Toads and Rough-skinned Newts are exceptions that seem to coexist well with fish.

Worldwide amphibian declines are thought to be driven by multiple factors. For example, Blaustein and Wake (1995) hypothesized that exposure to ultraviolet (UV) radiation might be an important contributor to the decline of amphibian populations. Results of several recent field and laboratory studies (Palen et al. 2002, 2005, Calfee et al. 2010), however, indicate that aquatic breeding amphibians in the Cascade Range of the Pacific Northwest are likely minimally affected by exposure to UV radiation due, in part, to the physical and chemical characteristics of the habitats they occupy. The more enigmatic declines in amphibian populations observed in protected areas (e.g., MORA) seem to be better explained by a disease called chytridiomycosis, and perhaps by interactions between this disease and climate or contaminants. Chytridiomycosis is caused by the fungal pathogen *Batrachochytrium dendrobatidis* (Bd). This species was discovered in 1999 (Longcore et al. 1999) and is the only chytrid known to specialize on amphibians, killing amphibians by dehydration. Susceptibility is highly variable and not well understood. Peptides produced by immune response and by bacteria that live on the skin of amphibians play a role in resistance. Environmental factors like temperature also play a role. The pathogen is present in many pond-breeding populations in the Pacific Northwest without clear effect. The pathogen may be having low-level effects that are not as obvious as the waves of decline and extinction seen in other parts of the world; or declines in the Pacific Northwest may have already occurred and we now have relatively resistant populations. It is also possible that severe declines occur during particular environmental conditions that happen intermittently. We also need to consider that the pathogen may not be a problem for species present in or occupying certain locations and habitats.

4.13.6 Information and Data Needs–Gaps

Long-term monitoring of Western Toad breeding sites is conducted through a MORA Citizen Science program (B. Samora, unpubl. data). Amphibians inhabiting the 6 lakes being monitored as part of the NCCN mountain lakes monitoring program should continue and expand if additional funds become available. The focus of additional monitoring should be on sensitive habitats such as wetlands and shallow ponds where alterations as a result of climate change are expected.

Amphibian data should continue to be entered into the existing parkwide database. Associated habitat data should be entered into a single database. Park data should be periodically published as Natural Resources Data Series reports to facilitate access by scientists.

Additional surveys for Van Dyke's and Larch Mountain Salamanders should be conducted due to their cryptic nature and limited distribution within the park.

Additional inventory work targeting the genus *Dicamptodon* might be useful to differentiate Coastal Giant Salamanders (*D. tenebrosus*) from Cope's Salamanders (*D. copei*). These species are difficult to identify, and because much of the stream amphibian work occurred prior to the discovery of Cope's Salamander in the park, it was assumed that any *Dicamptodon* observed in MORA were Coastal Giant Salamanders. Random samples using genetic analyses could help confirm the distribution of the 2 species within the park. MORA represents the northern most localities in the Cascade Range for Cope's Salamanders, Van Dyke's Salamanders, and Larch Mountain Salamanders.

Finally, unexplained die-offs of amphibians such as observed at Crystal Lake will require additional investigation to determine the cause of these apparent episodic declines.

4.13.7 Literature Cited

Blaustein, A, R., and D. B. Wake. 1995. The puzzle of declining amphibian populations. Scientific American (April):52–57.

Calfee, R. D., E. E. Little, C. A. Pearl, and R. L. Hoffman. 2010. Effects of simulated solar UVB radiation on early developmental stages of the Northwestern Salamander (*Ambystoma gracile*) from three lakes. Journal of Herpetology 44:572–580.

Galvan, S. K., M. J. Adams, B. Samora, R. E. Holmes, S. Stonum, P. J. Happe, R. S. Glesne, and A. Rawhouser. 2005. North Coast and Cascades Network consolidated amphibian database and mapping project. U. S. Geological Survey, Unpublished Report.

Knapp, R. A. 2005. Effects of nonnative fish and habitat characteristics on lentic herpetofauna in Yosemite National Park, USA. Biological Conservation 121:265–279.

Longcore, J. E., A. P. Pessier, and D. K. Nichols. 1999. *Batrachochytrium dendrobatidis* General. et sp. nov., a chytrid pathogenic to amphibians. Mycologia 91:219–227.

Palen, W. J., C. E. Williamson, A. A. Clauser, and D. E. Schindler. 2005. Impact of UV-B exposure on amphibian embryos: Linking species physiology and oviposition behaviour. Proceedings of the Royal Society B 272:1227–1234.

Palen, W. J., D. E. Schindler, M. J. Adams, C. A. Pearl, R. B. Bury, and S. A. Diamond. 2002. Optical characteristics of natural waters protect amphibians from UV-B in the U.S. Pacific Northwest. Ecology 83:2951–2957.

Pope, K., C. Brown, M. Hayes, G. Green, and D. Macfarlane, techical coordinators. 2014. Cascades Frog conservation assessment. Gen. Tech. Rep. PSW-GTR-244. Albany, CA: U.S. Department of Agriculture, Forest Service, Pacific Southwest Research Station. 116 p.

Samora, B., M. Layes, and R. Lofgren. 2013. Mount Rainier National Park amphibian inventory 2001–2003. NPS/NCCN/NRTR–2013/696. National Park Service, Fort Collins, Colorado.

4.14 Fish Species in Streams and Lakes

(Robert L. Hoffman, USGS FRESC)

4.14.1 Introduction

Fourteen fish species have been confirmed as present in Mount Rainier National Park (MORA) streams and lakes (Table 41). These species include 2 sculpins (Cottidae), 1 stickleback (Gasterosteidae), and 11 salmonids (Salmonidae). Many species are native to park streams; however, all fish in park lakes have been introduced. Two species, Yellowstone Cutthroat Trout (*Oncorhynchus clarkii bouvieri*) and Eastern Brook Trout (*Salvelinus fontinalis*), have been introduced to the park from outside of their native ranges. Westslope Cutthroat Trout (*Oncorhynchus clarkii lewisi*) is a native Washington State species, but was introduced to MORA streams and lakes. In addition, Threespine Sticklebacks (*Gasterosteus aculeatus*) were recently discovered at Deadwood Lake where they have been introduced.

Several species have been identified as species of special conservation or management concern at the federal and state levels (Table 41, Table 42). Bull Trout (*Salvelinus confluentus*), Chinook Salmon (*Oncorhynchus tshawytscha*), Coho Salmon (*Oncorhynchus kisutch*), Sockeye Salmon (*Oncorhynchus nerka*), and Steelhead (*Oncorhynchus mykiss*) have all been identified as threatened or endangered, at least partially within their ranges, by the US Fish and Wildlife Service, and as state candidates of special concern by the Washington Department of Fish and Wildlife (Table 42). Potential threats for these species include habitat modification and degradation–loss, barriers to upstream passage (e.g., dams, culverts), competition with introduced fish species, and hybridization (Table 42).

According to unpublished park records, the first officially recorded stocking of MORA streams and lakes occurred in 1915. In that year, 2500 Cutthroat Trout (subspecies not identified) and 1500 Eastern Brook Trout were stocked into Chenuis and Ipsut Creeks, respectively; and 5000 Cutthroat Trout were stocked into Mowich Lake. Between 1951 and 1964, 5 salmonid species were stocked into 39 MORA streams (MORA, unpubl. data). Over 3 million fish were stocked during this 50-yr period (Table 43). The same 5 salmonid species were also stocked into at least 40 park lakes between 1915 and 1972 (MORA, unpubl. data). Over 6 million fish were stocked (Table 43). Stocking was discontinued at MORA after 1972.

Table 41. Distributions, occurrences, habitation, and status of fish species confirmed to be present in Mount Rainier National Park. (I = Introduced nonnative; In = Introduced native; M = Migratory; N= Native; NA = Not applicable).

		Range-wide	Park		Conservation Status [5]	
Scientific Name	**Common Name**	**Distribution** [3]	**Occurrence**	**Habitation**	**Range-wide**	**Washington**
Cottus asper	Prickly Sculpin	AK, CA, OR, WA, AB, BC	Lake	In	N4 – N5	S5
Cottus confusus	Shorthead Sculpin	ID, NV, OR, WA, BC	Streams	N	N2 – N3	S5
Cottidae (species unknown)	Sculpin	NA	Streams, Lakes	NA	NA	NA
Gasterosteus aculeatus	Threespine Stickleback	USA (17); Canada (13)	Lake	In	N5	S5
Oncorhynchus clarkii bouvieri [1]	Yellowstone Cutthroat Trout	ID, MT, NM, NV, UT, WY	Stream	I	N2	Rare
Oncorhynchus clarkii clarkii	Coastal Cutthroat Trout	AK, CA, OR, WA, BC	Streams, Lakes[4]	N, In	N3 – N4	SNR
Oncorhynchus clarkii lewisi	Westslope Cutthroat Trout (WCT)	CO, ID, MT, OR, WA, WY, AB, BC	Streams, Lakes	In, In	N3	SNR
Oncorhynchus mykiss [2]	Rainbow Trout (RBT) – Steelhead	USA (48); Canada (12)	Streams, Lakes	N [M], In	N5	S5
Oncorhynchus hybrids (Trout)	RBT x WCT	NA	Streams	NA	NA	NA
Oncorhynchus gorbuscha	Pink Salmon	AK, CA, MI, NY, OR, PA, WA, WI, BC, ON, QC	Streams	N [M]	N5	S2
Oncorhynchus kisutch	Coho Salmon	USA (22); Canada (6)	Streams	N [M]	N4	S3
Oncorhynchus nerka	Sockeye Salmon - Kokanee	USA (18); Canada (6)	Streams, Lake	N [M], In	N4	S2 – S3
Oncorhynchus tshawytscha	Chinook Salmon	USA (16); Canada (4)	Streams	N [M]	N4	S3 – S4
Prosopium williamsoni	Mountain Whitefish	CA, CO, ID, MT, NV, OR, UT, WA, WY, AB, BC, NT, YT	Streams	N	N5	S5
Salvelinus confluentus	Bull Trout	AK, CA, ID, MT, NV, OR, WA, AB, BC, NT, YT	Streams	N [M?]	N4	S3
Salvelinus fontinalis	Eastern Brook Trout	USA (42); Canada (13)	Streams, Lakes	I	N5	SNA

[1] According to Wydoski and Whitney (2003), this subspecies was extensively stocked as early as 1895; however, at present the subspecies is quite scarce beyond its native range.

[2] Represents the subspecies Coastal Rainbow Trout (*Oncorhynchus mykiss irideus*), Columbia Redband Trout (*Oncorhynchus mykiss gairdneri*), and Steelhead (the anadromous form of both subspecies).

[3] Number of States and Provinces are in parentheses.

[4] Many of the stocking records for Cutthroat Trout do not identify the subspecies stocked, so it is possible that this subspecies may have been stocked in lakes at some point during the park's stocking history.

[5] N: national rank; S: subnational rank; 2: imperiled; 3: vulnerable; 4: apparently secure; 5: secure; NA: not applicable; NR: unranked (from NarureServe accessed July–August 2012)

Table 42. Mount Rainier National Park fish species information: Management status and threats.

	Management Status[1]			
Species	**US ESA**	**COSEWIC**	**WA**	**Major Threats (NatureServe)**
Prickly Sculpin	None	None	None	No known threats – Introduced in MORA lake
Shorthead Sculpin	None	SC	None	Coal mining in southeastern BC; otherwise none
Yellowstone Cutthroat Trout	None	None	None	Habitat degradation; pollution; siltation; movement barriers; genetic introgression – Introduced in MORA stream
Coastal Cutthroat Trout	PS	None	None	Habitat degradation; overfishing; dam passage; introduction of hatchery stock Introduced in MORA lakes
Westslope Cutthroat Trout	None	SC	None	Hybridization; habitat degradation and loss; fishing pressure; competition with introduced fish species – Introduced in MORA streams and lakes
Rainbow Trout – Steelhead	PS(FT)	C	C	Habitat degradation; competition with introduced fish species; siltation; water flow – Introduced in MORA lakes
Pink Salmon	None	C	None	Habitat degradation and loss; water flow; overharvest
Coho Salmon	PS(FT)	C	None	Habitat degradation and loss; water temperature; poor ocean conditions; genetic effects-hatchery stock
Sockeye Salmon-Kokanee	PS(FT, FE)	C	C	Dams; overharvest; habitat modification and degradation – Introduced in MORA lake
Chinook Salmon	PS(FT, FE)	C	C	Resource extraction activities; dams; habitat modification and degradation
Mountain Whitefish	None	None	None	No known threats
Bull Trout	PS(FT)	None	C	Hybridization; competition with introduced fish species; siltation; habitat fragmentation and degradation
Eastern Brook Trout	None	PS	None	In eastern USA: habitat degradation and loss; competition with introduced fish species – Introduced in MORA streams and lakes
Threespine Stickleback	PS	None	None	No major range-wide threats; Introduced in MORA lake

[1]C: Candidate; FE: Federal Endangered; FT: Federal threatened; PS: Partial Status in range; SC: Special Concern; WA: Washington.

Table 43. Number of fish/species stocked in MORA streams (1915–1964) and lakes (1915–1972).

Species	Streams	Lakes
Cutthroat Trout	316,597	641,738
Westslope Cutthroat Trout	1,667,364	1,430,947
Rainbow Trout	254,039	1,925,568
Steelhead	50,000	491,600
Steelhead eggs	15,000	0
Eastern Brook Trout	749,200	1,586,060
Total	3,052,200	6,075,913

4.14.2 Approach

Several sources of information and data were used to complete the assessment of fish in MORA streams and lakes. Summaries of range-wide distributions, conservation and management status, and potential major threats to the 13 fish species present in MORA streams and lakes were derived from information available on the NatureServe website (http://www.natureserve.org/); with additional information from Wydoski and Whitney (2003) and the Washington Department of Fish and Wildlife (WDFW; http://wdfw.wa.gov/conservation/endangered/; http://wdfw.wa.gov/conservation/endangered/esa/federally_listed_esa_fish.pdf). The MORA Stocking Records MS Excel spreadsheet was used for summarizing park stocking activities. The presence and occurrence of fish species in MORA streams was summarized from inventory information reported by Samora et al. (2013). The MORA unpublished data were used to report the presence and occurrence of fish species in MORA lakes. Native char surveys conducted during the summer of 2000 (Samora and Marks 2000) were used to describe the presence of Bull Trout in MORA. The presence of potential fish diseases was assessed based on National Wild Fish Health Survey case reports completed by the U.S. Fish and Wildlife Service (USFWS) at the Olympia (Washington) Fish Health Center laboratory in 2007.

4.14.3 Reference Conditions and Comparison Metrics

Each of the fish species documented as present in MORA have attributed to them both conservation and management status designations (Table 41, Table 42). These designations or listings can be used to indirectly attribute some level of conservation or management importance to the presence of these species in MORA stream and river habitats. The designations or listings for each species were gathered from several sources including NatureServe (National and Subnational), US ESA Listing (Federal; NatureServe), and the Washington State Species of Concern List available from the WDFW.

4.14.4 Results and Assessment

Streams and Rivers

There are approximately 470 mapped streams and rivers in MORA. Samora et al. (2013) reported the results of an inventory of a subset of these streams and rivers comprising 148 surveys of 138 stream segments in 8 river watersheds (Carbon, Cowlitz, Huckleberry, Mowich, Nisqually, Ohanapecosh, Puyallup, and White) 2001 through 2003. Gradients of the segments ranged from 1% to 35% with fish primarily present in segments with gradients <10%. The survey results identified trout (species not differentiated) as being present in the greatest number of stream segments and the most abundant

(Table 44), followed by cutthroat trout (subspecies not identified), unidentified sculpin (including Shorthead Sculpin), and Eastern Brook Trout. Four anadromous salmonid species (Chinook Salmon, Coho Salmon, Pink Salmon, and Sockeye Salmon) are also known to be present in some MORA watersheds, due, in part, to improved downstream access to streams and rivers originating within the park. There were no fish present in 27 stream segments surveyed.

Table 44. Results of fish surveys in MORA streams and lakes conducted 2001–2003 (Samora et al. 2013). Stream data are for individuals >100 mm total length.

	Streams		Lakes
Taxon	**Segments**	**Individuals**	**Number**
Brook Trout	14	130	9
Bull Trout	7	15	
Chinook Salmon	1	3	
Cutthroat Trout (subspecies not identified)	47	453	3
Kokanee			1
Prickly Sculpin			1
Rainbow Trout	7	56	13
Shorthead Sculpin	11	57	
Trout (species not differentiated)	55	700	
Unidentified Char species	4	5	
Unidentified Salmonids (Trout or Salmon)	16	75	
Unidentified Sculpin species	11	189	1

Tissue samples were collected from 43 trout captured during the 2001 through 2003 surveys. Most of the samples were collected from the Ohanapecosh watershed (all but 2) because at least 2 cutthroat trout subspecies and hybrids were thought to be present (Samora et al. 2013). DNA analysis determined that 22 individuals were Westslope Cutthroat Trout, 11 were Coastal Cutthroat Trout (*Oncorhynchus clarkii clarkii*), 9 were Rainbow Trout–Westslope Cutthroat Trout hybrids, and 1 individual was a Yellowstone Cutthroat Trout collected from an above-waterfall population in 1 stream in the Ohanapecosh watershed. The Yellowstone Cutthroat Trout is of particular interest because although this subspecies was widely stocked in Washington as early as 1895, it is presently extremely rare in the state and scarce outside of its native range (Wydoski and Whitney 2003; Table 41).

Fin clips were also collected from 11 char in 3 streams in the Carbon and White River watersheds during the 2001 through 2003 surveys to help determine the species of native char (Bull Trout or Dolly Varden [*Salvelinus malma*]) present in these streams. DNA analysis determined that 10 individuals were Bull Trout and 1 individual was an Eastern Brook Trout. No Dolly Varden were identified as part of this analysis. Bull Trout were also observed in a segment of the Paradise River in the Nisqually watershed; and during a native char survey conducted in 2000 (Samora and Marks 2000), 22 Bull Trout were observed in 9 streams of the Mowich, West Fork, and White watersheds. Subsequent surveys from 2001 through 2013 have documented Bull Trout in several streams in these watersheds and in the Carbon watershed.

Lakes

All fish species present in MORA lakes were originally stocked, and the populations that remain in 37 of the lakes after stocking was discontinued after 1972 represent populations that were able to establish some level of natural reproduction. Five salmonid species were predominantly stocked including cutthroat trout (subspecies not identified), Westslope Cutthroat Trout, Rainbow Trout–Steelhead, and Eastern Brook Trout (Table 43). In addition, Kokanee were stocked into Mowich Lake in 1961 (Larson et al. 2002), and sculpin were introduced into Mowich Lake (species not determined) and Lake George (Prickly Sculpin), most likely as bait fish. Recently, Threespine Stickleback were introduced into Deadwood Lake.

Fish Disease

In 2007, 59 fish (58 cutthroat trout and 1 Eastern Brook Trout) were collected from 3 MORA streams (Ohanapecosh River, $n = 6$; Paradise River, $n = 43$; Panther Creek, $n = 10$) for fish disease analysis at the USFWS Olympia Fish Health Center. Only 1 cutthroat trout was found to be infected with the kidney disease bacterium *Renibacterium salmoninarum*, which is a gram positive intracellular bacterium that causes Bacterial Kidney Disease (BKD) in salmonids (*Oncorhynchus*, *Salmo*, and *Salvelinus*). BKD is a chronic disease that can cause mortality in juvenile fish and pre-spawning adults. Pacific salmon species appear to be most susceptible to the disease.

Assessment

Bull Trout—Bull Trout are 1 of 2 char species (the other being Dolly Varden) native to the western US. They can be either resident or migratory, and have relatively narrow habitat requirements including cold water temperature; pristine water quality; clean stream substrates for spawning and rearing; complex habitat structure; and high connectivity of movement corridors. During the 2001 through 2003 surveys (Samora et al. 2013), only a small number of individuals ($n = 15$) were observed in 7 stream segments in 3 MORA watersheds. This low number of observations occurred it was hypothesized, because Bull Trout vary their use of MORA stream habitats seasonally, and that the pattern of use may not have coincided with the scheduled sampling visits of survey crews. It is believed that the 2001 through 2003 survey results do not realistically represent the actual presence of Bull Trout in MORA streams and rivers. The 2 Bull Trout distinct population segments (DPS) in Washington are federally listed as threatened, and the species is listed as vulnerable at the state level (as it is in Oregon). Bull Trout are listed as imperiled in Montana, critically imperiled in Nevada, and presumed extirpated in California. Because of the threatened and imperiled status of Bull Trout, the relatively pristine streams and rivers of MORA may serve as important habitat refugia for sustaining populations of this increasingly challenged species. However, the presence of Eastern Brook Trout and their capacity to hybridize with Bull Trout as well potentially out-compete them for habitat and resources, remains an important concern associated with Bull Trout management at MORA.

Cutthroat Trout—According to results of the 2001 through 2003 surveys, cutthroat trout are the predominant trout species in MORA streams and rivers (Samora et al. 2013). There are 3 subspecies present in the park: Yellowstone Cutthroat Trout, Westslope Cutthroat Trout, and Coastal Cutthroat Trout. One population of introduced Yellowstone Cutthroat Trout has been documented in 1 park stream. This is a rare and unique population outside of its native range. The Westslope Cutthroat

Trout, although native to parts of Washington, were introduced into MORA streams and lakes. This subspecies has been shown to readily hybridize with Rainbow Trout, which is considered detrimental to Westslope Cutthroat Trout by causing a marked reduction in fitness and reproductive success (Muhlfeld et al. 2009). Coastal Cutthroat Trout are present in all park watersheds except the Cowlitz, and no hybrids have been documented. Because this subspecies has diverse and complex life history attributes (i.e., migratory and resident life forms), there has been some concern that 1 or more of these attributes might decline or be lost due, in part, to human-caused environmental change. At present, Coastal Cutthroat Trout have a partial status listing as a Species of Concern in California and Oregon. However, after reviews in 1999, 2002, and 2010, the USFWS has determined that Coastal Cutthroat Trout, at present, do not warrant listing in Washington under the U.S. Endangered Species Act (US ESA). Even so, if this subspecies were to begin (or continue) to experience declines within its native range, MORA streams and rivers would most likely be relatively undisturbed refuges for resident populations.

Eastern Brook Trout—Brook Trout are native to a wide area of eastern North America and have been extensively stocked outside of their native range, including many MORA streams and lakes. Brook Trout are a very successful nonnative species in the western U.S., and are known to displace and hybridize with native salmonid species (Krueger and May 1991). One dominant concern in streams is the potential hybridization of Brook Trout and Bull Trout. During the 2001 through 2003 MORA surveys, however, no Brook Trout–Bull Trout hybids were observed or identified using genetic analysis (Samora et al. 2013). Introduced Brook Trout also have the potential of disrupting lake food webs and affecting or eliminating native amphibian species that use mountain lakes for reproduction and larval rearing. For example, Larson and Hoffman (2002) documented that the abundances of native Northwestern Salamanders (*Ambystoma gracile*) in MORA lakes with introduced Brook Trout were significantly lower than in lakes without fish, and Hoffman et al. (2004) found that Northwestern Salamanders also altered their behavior in response to the presence of fish, affecting their diel pattern of activity and reproductive effort. Brook Trout have no conservation status in Washington because they are an introduced species.

Mountain Whitefish—Although Mountain Whitefish were not observed during the 2001 through 2003 surveys, they have been documented as being present in the Carbon River within the park boundary (Wildman 1989).This species is presently identified as secure in Washington State.

Rainbow Trout–Steelhead—Rainbow Trout and Steelhead are the same species of fish exhibiting different life history forms. Rainbow Trout are non-anadromous and Steelhead are anadromous. Both forms are present in MORA streams and rivers. Only a small number of Rainbow Trout were observed during the 2001 through 2003 surveys, but this may be due, in part, to the small size (<100 mm TL) of many of the trout observed, making them hard to identify to species, especially during snorkel surveys. Non-hybrid Rainbow Trout were present in the Cowlitz, Huckleberry, and White watersheds, although these individuals were not differentiated as to whether they were of native or hatchery stock. Rainbow Trout–West Slope Cutthroat Trout hybrids were present in the Nisqually and Ohanapecosh watersheds. The conservation status of Rainbow Trout is identified as secure by NatureServe and Washington State.

Steelhead are thought to be present in the Carbon, Mowich, West Fork, and White watersheds; however, this life form has not recently been distinctly identified from the non-anadromous life form in the park. The Muckleshoot Tribe and WDFW (1993) have reported that in past years Steelhead redds and spawning were observed in the Carbon and White watersheds. There are no barriers to Steelhead movement in the Carbon River of the Carbon watershed, but Steelhead are transported around 2 dams that block their passage to streams and rivers of the 3 other watersheds. Five of 7 Steelhead DPS present in Washington are listed as threatened under the US ESA. The Steelhead being transported above the 2 dams belong to 1 of the 5 DPS (Puget Sound). Because of their overall threatened status in Washington, MORA Steelhead populations could be important contributors to the future status of this anadromous life form in the state.

Salmon—MORA streams and rivers are included as "essential fish habitat" (EFH), as defined by the Magnuson-Stevens Act, for Chinook, Coho, and Pink Salmon.

Spring Chinook Salmon have been documented as present in the White watershed, with in-park individuals typically <100 mm TL (Samora et al. 2013). Adult Chinook Salmon are transported upstream of the Mud Mountain Dam, and the White River in MORA is spawning and rearing habitat for this species. It is also possible that Puyallup River fall Chinook Salmon are present in the park, but this has not been documented. There are 8 Chinook Salmon "evolutionarily significant units" (ESUs) in Washington. Of these, 4 are federally listed as threatened (including the Puget Sound and Lower Columbia ESUs) and 1 is listed as endangered.

Coho Salmon have been documented as present in the Carbon and White Rivers and their tributaries, although none were observed or collected during the 2001 through 2003 surveys (Samora et al. 2013). These MORA streams and rivers are used as spawning and rearing habitat by this species. There are 4 Coho Salmon ESUs in Washington: the Lower Columbia River ESU is federally listed as threatened; the Puget Sound/Strait of Georgia ESU is listed as a Species of Concern; the Southwest Washington ESU is undetermined; and listing of the Olympic Peninsula ESU is considered to be not warranted.

Although not historically considered to be present in MORA streams and rivers, Pink Salmon have been increasingly observed in the park (White watershed) since 2006 (Samora et al. 2013). Like Chinook and Coho Salmon, Pink Salmon adults are transported upstream of the Mud Mountain Dam. Listing for both Pink Salmon ESUs in Washington is considered not warranted.

Anadromous Sockeye Salmon were not observed or collected during the 2001 through 2003 surveys, and this life form does not appear to typically use park streams or rivers for spawning or rearing (Samora et al. 2013); although they have been documented as present in the White River drainage on a few occasions. Kokanee (non-anadromous Sockeye Salmon) have been stocked in Mowich Lake (Mowich watershed), and that population continues to reproduce and survive in the lake.

Sculpin—Sculpin were observed in the Carbon, Cowlitz, Huckleberry, Nisqually, and White watersheds during the 2001 through 2003 surveys (Samora et al. 2013). The only species identified was the Shorthead Sculpin based on genetic analysis by WDFW. Sculpin, however, are relatively difficult to identify to species, especially when observed during snorkel surveys, and so the possibility remains that additional species (e.g., Mottled Sculpin, *Cottus bairdi*; Paiute Sculpin, *Cottus beldingi*; Reticulate Sculpin, *Cottus perplexus*; Riffle Sculpin, *Cottus gulosus*; and Torrent Sculpin, *Cottus rhotheus*) may be present in park streams and rivers. Wydoski and Whitney (2003), however, indicate that the known distributions of these additional sculpin species may exclude them from being present in MORA. Introduced Prickly Sculpin are documented as being present in Lake George, and an unidentified species is known to be present in Mowich Lake. According to NatureServe, the national conservation status for the Shorthead Sculpin is Vulnerable, primarily because of the species' Critically Imperiled listing in Nevada. In Washington, the Shorthead Sculpin is identified as Secure.

Threespine Stickleback—Threespine Stickleback have recently been introduced into Deadwood Lake. It is widely distributed throughout The United States and Canada. According to NatureServe, the global, national, and subnational conservation status for this species is Secure. However, because of its introduced status in Deadwood Lake, this species should be considered an exotic species whose short- and long-term effects on this lake ecosystem is presently unknown.

4.14.5 Emerging Issues

There are 4 basic issues that have the potential of affecting the continued viability and survival of native and nonnative fish species and populations in MORA streams, rivers, and lakes. They include: (1) habitat alteration due to changing climate, especially decreasing water availability and increasing air and water temperatures; (2) loss of habitat and stream corridor passage and connectivity due to human activities in and near the park; (3) atmospheric deposition with an increase in the concentrations of nutrients and pollutants in park watersheds; and (4) continued presence or future introduction of nonnative fish species; especially the potential for hybridization of Eastern Brook Trout with Bull Trout, and decline or loss of 1 or more native amphibian species. Future survey and research activities should include a design element useful for tracking and documenting any impacts to MORA fish species and populations due to these potential environmental-ecosystem changes and perturbations.

4.14.6 Information and Data Needs–Gaps

MORA has created a useful baseline database for fish species occurrence and distribution in park streams, rivers, and lakes (e.g., Samora et al. 1999, Samora and Marks 2000, Samora et al. 2013). The park should continue to expand the scope of the database by surveying additional park streams, rivers, and lakes; by conducting focused-surveys of potentially sensitive species, such as Bull Trout and anadromous salmon; and initiating surveys for detecting species for which occurrence and distribution are relatively unknown, such as Mountain Whitefish. Also useful would be surveys designed to identify species potentially present in the park but not confirmed, such as lamprey (*Lampetra* spp.) and dace (*Rhinicthys* spp.). Continued genetic analysis of Bull Trout tissue would be useful for confirming the absence (or presence) of Dolly Varden in park streams and rivers, as well as identifying any potential hybridization between Bull Trout and Eastern Brook Trout. Genetic analysis of Rainbow Trout and Westslope Cutthroat Trout will further document the extent of hybridization between these 2 species, and analysis of Rainbow Trout tissue can help elucidate the extent of occurrence of native and hatchery stocks in park streams and rivers. Sculpin-focused surveys should also be conducted so that additional sculpin species, if any, in the park can be identified and their distributions documented. All efforts should also include: (1) a habitat-survey component for the purpose of documenting and monitoring the present condition and potential future changes to the health and integrity of park stream, river, and lake habitats; and (2) an estimate of the potential impact of introduced nonnative species on native aquatic biota.

4.14.7 Literature Cited

Hoffman, R. L., G. L. Larson, and B. Samora. 2004. Responses of *Ambystoma gracile* to the removal of introduced nonnative fish from a mountain lake. Journal of Herpetology 38:578–585.

Krueger, C. C., and B. May 1991. Ecological and genetic effects of salmonid introductions in North America. Canadian Journal of Fisheries and Aquatic Sciences 48 (Suppl. 1):66–77.

Larson, G. L., and R. L. Hoffman. 2002. Abundances of Northwestern Salamander larvae in montane lakes with and without fish, Mount Rainier National Park, Washington. Northwest Science 76:35–40.

Larson, G. L., R. L. Hoffman, and C. D. McIntire. 2002. Persistence of an unusual pelagic zooplankton assemblage in a clear, mountain lake. Hydrobiologia 468:163–170.

Muhlfeld, C. C., S. T. Kalinowski, T. E. McMahon, M. L. Taper, S. Painter, R. F. Leary, and F. W. Allendorf. 2009. Hybridization rapidly reduces fitness of a native trout in the wild. Biology Letters 5:328–331.

Samora, B. A., and E. Marks. 2000. Native char surveys, Mount Rainier, Summer 2000. Mount Rainier National Park, Unpublished Report.

Samora, B. A., J. Feola, and B. Brokes. 1999. Survey of salmonid species in streams of Mount Rainier National Park, 1999, Unpublished Report.

Samora, B. A., H. Moran, and R. A. Lofgren. 2013. An inventory of fish in streams in Mount Rainier National Park, 2001–2003. Natural Resource Technical Report NPS/NCCN/NRTR—2013/717N. National Park Service, Fort Collins, Colorado.

[WDFW] Washington Department of Fisheries and Wildlife. 1993. Washington State salmon and steelhead stock inventory. Olympia, Washington.

Wildman, R. 1989. Letter to Mount Rainier national Park on one day sampling conducted on the Carbon River during near flood conditions in fall, 1989. Department of Fisheries and Wildlife, Oregon State University, Corvallis, Oregon.

Wydoski, R. S., and R. R. Whitney. 2003. Inland fishes of Washington, second edition. University of Washington Press, Seattle, Washington.

4.15 Land Birds

(Joan Hagar, USGS FRESC)

4.15.1 Introduction

The avifauna of MORA is characteristic of conifer forests and alpine habitats of the west slope of the Cascade Range. Dense, moist forests at lower elevations in the park support species that are representative of old-growth in the region, including the threatened Marbled Murrelet and Northern Spotted Owl. Several passerine species which are strongly associated with mature and closed-canopy conifer forests, and have been experiencing regional population declines, are among the most abundant species at MORA. Two species in this category, the Varied Thrush and Chestnut-backed Chickadee, have large proportions of their geographic ranges restricted to the Pacific Northwest, giving the region principal responsibility for their conservation. Alpine and subalpine habitats at MORA also are important for some species of regional conservation concern, such as the White-tailed Ptarmigan and American Pipit.

Information on bird species occurrence, abundance, and status within the park is available from multiple sources. In particular, systematic bird surveys conducted through the NPS Inventory & Monitoring Program are yielding high quality data that will be capable of tracking changes in distribution and abundance for at least 20 land bird species. Data from intensive studies are available for assessing population status and trends of some special status species, such as the Northern Spotted Owl and Marbled Murrelet. However, the status of many species of conservation concern within the park is difficult to determine because of rarity or a lack of data.

4.15.2 Approach

We focused this assessment on 48 bird species of management concern because of the large number of species that occur in the park (>175 bird species in NPSpecies database), and because management and monitoring of each species is logistically infeasible. The scientific and common names of all birds assessed are listed in Table 45. We included species listed as Management Priority in NPSpecies (15 species), and those identified as focal species for conservation strategies developed by Partners In Flight (PIF) and the North American Bird Conservation Initiative (NABCI). NABCI uses Bird Conservation Regions (BCRs) as a framework for landscape-scale bird conservation in North America. BCRs are ecologically distinct regions with similar bird communities, habitats, and resource management issues. MORA is located in BCR 5, the Northern Pacific Rainforest, which is located from the western Gulf of Alaska south through British Columbia and the Pacific Northwest to northern California (http://www.nabci-us.org/bcr5.html). Strategies developed by PIF nest within and coordinate with the BCR framework at smaller spatial scales. Within BCR 5, PIF conservation strategies cover coniferous forests in western Oregon and Washington (Altman 1999) and PIF Physiographic Area 93 (Southern Pacific Rainforest). PIF Physiographic Area 93 extends from the Pacific coastline of Washington and Oregon inland to the crest of the Cascade Range, and south to the coastal ranges of northwestern California (http://www.partnersinflight.org/bcps/pl_93sum.htm). Although these 3 conservation strategies all include MORA because they overlap in western Washington and Oregon, and they share many of the same focal species, each contributes some unique species, reflecting variation in conservation concern from different geographical perspectives (Table 46).

Table 45. Distributions, occurrences, habitation, and conservation status of bird species in Mount Rainier National Park.

		Range-wide Distribution		Park		Conservation Status	
Scientific Name	**Common Name**	**Breeding**	**Wintering**	**Occurrence**	**Habitation**	**U.S.**	**Washington**
Histrionicus histrionicus	Harlequin Duck	USA: AK, ID, MT, OR, WA, WY; CAN: AB, BC, NB, NL, NT, QC, YT	Coastal ME and coast of NE Canada; In w NA, along coasts of BC and s AK, coastal OR, WA, n CA	Common	N [M]	N4B, N4N	S2B, S3N
Lagopus leucura	White-tailed Ptarmigan	USA: AK, CA, CO, MT, NM, OR, UT, WA, WY; CAN: AB, BC, NT, YT	Resident throughout range	Uncommon	N [YR]	N5	S3
Dendragapus fuliginosus	Sooty Grouse	USA: AK, CA, NV, OR, WA; CAN: BC	Resident throughout range	Common	N [YR]	N5	SNR
Cathartes aura	Turkey Vulture	USA (32); CAN: AB, BC, MB, ON, SK, QC	On west coast (California), winters north to northern CA.	Present in Park	N [M]	N5B, N5N	S4B
Pandion haliaetus	Osprey	USA (33); CAN (13)	Coastal s CA, south to coasts of Baja and Mexico, east to TX and LA, year-round resident in coastal AL, MS, GE, FL, SC, NC.	Uncommon	N [M]	N5B, N4N	S4B
Haliaeetus leucocephalus	Bald Eagle	USA (50); CAN (13)	Majority of wintering population located in lower 48 states, coastal Canada and Alaska	Present in Park	N [M]	N5B, N5N	S4B, S4N
Accipiter gentilis	Northern Goshawk	USA (22); CAN(13)	Resident throughout breeding range; a portion of the population regularly winters south to central eastern and mid-western states, and in sw US to Mexico.	Uncommon	N [YR]	N4B, N4N	S2S3B,S3N
Aquila chrysaetos	Golden Eagle	USA (18 western states); CAN (10)	Western NA from s BC, SK, AL south to central Mexico	Uncommon	N [E]	N5B, N5N	S3
Falco peregrinus	Peregrine Falcon	USA (41); CAN (12)	In NA, winters mainly south of Canadian/US border	Uncommon	N [E]	N4B, N4N	S2B,S3N

Table 45. Distributions, occurrences, habitation, and conservation status of bird species in Mount Rainier National Park (continued).

		Range-wide Distribution		Park		Conservation Status	
Scientific Name	**Common Name**	**Breeding**	**Wintering**	**Occurrence**	**Habitation**	**U.S.**	**Washington**
Brachyramphus marmoratus	Marbled Murrelet	USA: AK, CA, OR, WA; CAN: BC	Present near breeding sites year-round in most areas. Also, wintering populations extend along southern CA coast	Uncommon	N [M]	N3, N4	S3
Patagioenas fasciata	Band-tailed Pigeon	USA: AZ, CA, CO, NM, OR, TX, UT, WA; CAN: BC	Southern CA, Baja MX; Mexico	Common	N [M]	N4B,N 4N	S3S4B, S4N
Strix occidentalis caurina	Northern Spotted Owl	USA: CA, OR, WA; CAN: BC	Resident throughout range	Uncommon	N [YR]	N1	S1
Strix varia	Barred Owl	USA (39); CAN (10)	Resident throughout range	Common	I [YR]	N5	S5
Strix nebulosa	Great Gray Owl	USA: AK, CA, ID, MN, MT, OR, WA, WI, WY; CAN: AB, BC, MB, NT, ON, QC, SK, YT	Resident throughout range	Unconfirmed	N [YR]	N4	S2B
Asio otus	Long-eared Owl	USA (25); CAN: AB, BC, NB, NS, NT, MB, ON, SK, YK	From s. Canada and n New England south, occasionally to Gulf states and Jalisco, Michoacan, Guerrero, and Oaxaca in the interior of Mexico	Occasional	N[E]	N5B, N5N	S3B, S4N
Aegolius funereus	Boreal owl	USA: AK, CO, ID, MN, MT, NM, OR, WA, WY; CAN (11)	Mostly the same as breeding range	Probably Present	N [YR]	N4	S3
Cypseloides niger	Black Swift	USA: AZ, CA, CO, ID, MT, NM, OR, UT, WA; CAN: AB, BC	South America	Present in Park	N [M]	N4B	S3B
Chaetura vauxi	Vaux's Swift	USA: CA, ID, MT, OR, WA; CAN: BC	Central Mexico to South America	Present in Park	N [M]	N4B	S3S4B
Selasphorus rufus	Rufous Hummingbird	USA: AK, CA, ID, MT, NV, OR, WA; CAN: AB, BC, YT	Extreme southern US, Mexico	Present in Park	N [M]	N5B	S4B
Melanerpes lewis	Lewis' Woodpecker	USA (13 western states); CAN: BC	Winters in southern portion of breeding range, as far north as sw OR	Rare	N[E]	N4B, N4N	S2S3

Table 45. Distributions, occurrences, habitation, and conservation status of bird species in Mount Rainier National Park (continued).

		Range-wide Distribution		Park		Conservation Status	
Scientific Name	**Common Name**	**Breeding**	**Wintering**	**Occurrence**	**Habitation**	**U.S.**	**Washington**
Sphyrapicus ruber	Red-breasted Sapsucker	USA: AK, CA, OR, WA; CAN: BC	Southwestern BC south through most of CA to northern Baja California	Unknown	N [YR]	N5	S4S5
Picoides dorsalis	American Three-toed Woodpecker	USA (18); CAN (13)	Resident throughout range	Uncommon	N[YR]	N5	S3
Picoides arcticus	Black-backed woodpecker	USA (15); CAN (13)	Resident throughout range	Rare	N[YR]	N5	S3
Dryocopus pileatus	Pileated Woodpecker	USA (38); CAN: AB, BC, MB, NB, NS, ON, SK, QC	Resident throughout range	Uncommon	N[YR]	N5	S4
Contopus cooperi	Olive-sided Flycatcher	USA (23); CAN (13)	Central and, primarily, South America	Uncommon	N [M]	N4B	S3B
Empidonax traillii	Willow Flycatcher	USA (40); CAN: AB, BC, MB, NB, ON, SK, QC	Mexico and Central America	Rare	N [M]	N5B	S4B
Empidonax hammondii	Hammond's Flycatcher	USA (12 western states); CAN: AB, BC, YT	Mexico and Central America	Rare	N [M]	N5B	S5B
Empidonax difficilis	Pacific-slope Flycatcher	USA: CA, OR, WA; CAN: BC	Mexico	Uncommon	N [M]	N5B	S4S5B
Vireo cassinii	Cassin's Vireo	USA: CA, ID, MT, OR, WA; CAN: AB, BC	Mexico	Uncommon	N [M]	N5B	S4B
Vireo huttoni	Hutton's Vireo	USA: AZ, CA, NM, OR, TX, WA; CAN: BC	Resident throughout range	Uncommon	N[YR]	N5	S5
Poecile rufescens	Chestnut-backed Chickadee	USA: AK, CA, ID, MT, OR, WA; CAN: BC	Resident throughout range	Abundant	N [YR]	N5	S5
Certhia americana	Brown Creeper	USA (31); CAN (9)	Resident throughout much of range; also winters central NA from south-central Canada to Gulf Region and Atlantic coast, and in western US, central CA and from e WA south to AZ	Common	N [YR]	N5	S4S5B, S5N

Table 45. Distributions, occurrences, habitation, and conservation status of bird species in Mount Rainier National Park (continued).

		Range-wide Distribution		Park		Conservation Status	
Scientific Name	**Common Name**	**Breeding**	**Wintering**	**Occurrence**	**Habitation**	**U.S.**	**Washington**
Troglodytes pacificus	Pacific Wren	USA: AK, AZ, CA, ID, MT, NV, OR, UT, WA; CAN: AB, BC, YT	Resident throughout much of range, except interior BC, YK, AB; also winters outside of breeding range in central and east WA, and central OR	Abundant	N [YR]	NNR	S5
Regulus satrapa	Golden-crowned Kinglet	USA (27); CAN (11)	Throughout lower 48 states, north into south central and sw Canada, and along Pacific coast to southern AK	Abundant	N [YR]	N5	S4S5B, S4S5N
Sialia mexicana	Western Bluebird	USA (12 western states); CAN: BC	Includes the breeding range (typically at lower elevations) in southern BC, western OR, CA, Baja, southwestern NV, and from central UT and portions of central CO and NM south. Also winter outside the breeding range in CA, Baja, AZ, NM, westernmost TX, and throughout northern Mexico	Present in Park	N[E]	N5	S3B
Catharus ustulatus	Swainson's Thrush	USA (23); CAN (13)	Mexico and northern South America	Common	N [M]	N5B	S5B
Ixoreus naevius	Varied Thrush	USA: AK, CA, OR, WA; CAN: AB, BC, NT, YT	Southern AK, southern BC and northern ID south through WA, OR, and CA to northern Baja	Abundant	N[R]	N5	S5B, S5N
Sturnus vulgaris	European Starling	USA (49); CAN (13)	Resident throughout range	Present in Park	I	NNA	SNA
Anthus rubescens	American Pipit	USA (14); CAN (13)	Migrates throughout North America to lower altitudes and latitudes	Common	N [M]	N5B, N5N	S3B, S3N
Oreothlypis celata	Orange-crowned Warbler	USA (13); CAN (9)	Southern US, Mexico, and Central America	Uncommon	N [M]	N5B, N5N	S4B

Table 45. Distributions, occurrences, habitation, and conservation status of bird species in Mount Rainier National Park (continued).

		Range-wide Distribution		Park		Conservation Status	
Scientific Name	**Common Name**	**Breeding**	**Wintering**	**Occurrence**	**Habitation**	**U.S.**	**Washington**
Geothlypis tolmiei	MacGillivray's Warbler	USA (13); CAN: AB, BC, SK, YT	Southern Baja, central Mexico, Central America	Common	N [M]	N5B	S4S5B
Setophaga nigrescens	Black-throated Gray Warbler	USA (10); CAN: BC	Mexico	Uncommon	N [M]	N5B	S5B
Setophaga occidentalis	Hermit Warbler	USA: CA, OR, WA	Mexico and Central America	Common	N [M]	N4N5B	S4B
Cardellina pusilla	Wilson's Warbler	USA (15); CAN (13)	Gulf coast of LA and TX; central Mexico south to Panama	Common	N [M]	N5B	S5B
Melospiza lincolnii	Lincoln's Sparrow	USA (19); CAN (12)	Coastal WA, OR, CA, southern CA, AZ, NM, and Gulf states to s AL, as far north as s MO and sw NE; through Mexico to sw Honduras	Uncommon	N [M]	N5B, N5N	S4B,S4N
Pheucticus melanocephalus	Black-headed Grosbeak	USA (15); CAN: AB, BC, SK	Mexico	Common	N [M]	N5B	S5B
Loxia curvirostra	Red Crossbill	USA (23); CAN (11)	Resident throughout range	Uncommon	N[YR]	N5	S4B
Passer domesticus	House Sparrow	USA (49); CAN (10)	Resident throughout range	Probably Present	I	NNA	SNA

Distribution: Number of States and Provinces are in parentheses

Habitation: N: native; M: migratory; E: erratic occurrence in park; YR: year-round resident; I: Introduced or recent range expansion

Conservation Status: N: national rank; S: subnational rank; 2: imperiled; 3: vulnerable; 4: apparently secure; 5: secure; NA: not applicable; NR: unranked; B: Breeding population; N: nonbreeding population (from NarureServe accessed July–August 2012

Table 46. Bird species and conservation plans.

Common name	MORA Management Priority	N.A. Bird Conservation Initiative BCR5	Partners In Flight: Physiographic Area 93	Partners In Flight: Oregon and Washington	Washington Department of Fish & Wildlife: Priority Species	Washington Department of Fish & Wildlife: State Monitor List	BCR 5 Short-term Trend (% / year, 95% CI)	Within Park Trend
Harlequin Duck	X				X		.	.
White-tailed Ptarmigan		X					.	.
Sooty Grouse		X	X		X		-1.25 (-4.22, 1.73)	possible decrease
Turkey Vulture						X	2.01 (-0.40, 4.26)	rare in Park
Osprey	X						4.05 (1.37, 6.68)	rare in Park
Bald eagle	X				X		3.23 (0.25, 7.76)	.
Northern Goshawk	X				X		.	.
Golden eagle	X				X		.	.
Peregrine Falcon	X						.	.
Marbled Murrelet	X						.	stable (Dhundale 2009)
Band-tailed Pigeon			X	X	X		-0.11 (-2.47, 3.45)	.
Northern Spotted Owl	X		X				.	probable decrease
Barred Owl	X						.	increase (Forsman et al 2011)
Great Gray Owl	X						.	rare in Park
Long-eared Owl	X						.	rare in Park
Boreal owl						X	.	.
Black Swift			X	X			-6.83 (-12.68, 1.21)	.
Vaux's Swift			X	X	X		0.49 (-2.47, 4.04)	stable (NCCN)
Rufous Hummingbird			X	X			-2.25 (-3.56, -0.34)	stable (NCCN); decrease (BBS-R)
Lewis's Woodpecker	X		X		X		.	rare in Park
Red-breasted Sapsucker		X					0.37 (-2.69, 3.48)	
American Three-toed Woodpecker						X	.	.
Black-backed Woodpecker					X	X	.	rare in Park
Pileated Woodpecker	X			X			1.04 (-1.32, 3.70)	.
Olive-sided Flycatcher				X			-3.44 (-5.17, -1.77)	.
Willow Flycatcher			X				-2.51 (-3.76, -1.23)	rare in Park
Hammond's Flycatcher			X	X			3.36 (-0.36, 7.10)	stable (NCCN, BBS-R)
Pacific-slope Flycatcher			X	X			-1.65 (-3.39, 0.07)	decrease (NCCN, BBS-R)
Cassin's Vireo			X				0.15 (-1.66, 2.35)	rare in Park

Table 46. Bird species and conservation plans (continued).

Common name	MORA Management Priority	N.A. Bird Conservation Initiative BCR5	Partners In Flight: Physiographic Area 93	Partners In Flight: Oregon and Washington	Washington Department of Fish & Wildlife: Priority Species	Washington Department of Fish & Wildlife: State Monitor List	BCR 5 Short-term Trend (% / year, 95% CI)	Within Park Trend
Hutton's Vireo			X	X			-1.38 (-4.10, 1.18)	rare in Park
Chestnut-backed Chickadee			X				-1.83 (-4.15, 0.40)	stable (NCCN, BBS-R)
Brown Creeper				X			-0.26 (-3.16, 1.74)	stable (NCCN, BBS-R)
Pacific Wren				X			-6.06 (-7.87, -4.42)	possible decrease (BBS-R)
Golden-crowned Kinglet			X				-3.19 (-6.06, -0.37)	possible decrease (BBS-R, NCCN)
Western Bluebird				X			-1.86 (-6.48, 2.37)	rare in Park
Swainson's Thrush			X				-0.74 (-1.52, 0.00)	stable (NCCN, BBS-R)
Varied Thrush				X			-2.04 (-4.56, -0.09)	possible decrease (BBS-R)
European Starling	X						-2.17 (-4.25, -0.52)	rare in Park
American Pipit				X			.	.
Orange-crowned Warbler				X			-2.57 (-3.86, -0.96)	rare in Park
MacGillivray's Warbler			X				-1.15 (-2.50, 0.96)	.
Black-throated Gray Warbler			X	X			-0.01 (-2.09, 2.49)	possible decrease (BBS-R)
Hermit Warbler			X	X			-0.67 (-2.48, 0.70)	rare in Park
Wilson's Warbler				X			-1.72 (-2.75, -0.58)	decrease (BBS-R)
Lincoln's Sparrow				X			2.89 (-1.25, 9.28)	.
Black-headed Grosbeak			X				1.20 (0.32, 2.20)	rare in Park
Red Crossbill				X			0.62 (-8.22, 10.21)	.
House Sparrow	X						0.17 (-1.85, 2.24)	rare in Park

BCR5 (North American Bird Conservation Initiative); the Northern Pacific Rainforest stretches from the western Gulf of Alaska south through British Columbia and the Pacific Northwest to northern California (http://www.nabci-us.org/bcr5.html); PIF Physiographic Area 93 (Southern Pacific Rainforest) extends from the Pacific coastline of Washington and Oregon inland to the crest of the Cascade Mountains, and south to the coastal ranges of northwestern California (http://www.partnersinflight.org/ bcps/pl_93sum.htm).

We evaluated several sources of information to assess the status of each species in the park. First, we used information from the North Coast and Cascades Network Landbird Monitoring (NCCN). As a part of the NCCN, MORA hosts a rigorous monitoring program designed to provide sufficiently robust sample sizes to allow detection of population changes for some avian species that regularly occur within the park (Holmgren et al. 2012). A standard survey protocol for land birds was developed and piloted in 2005–2006, and implemented 2007–2012 (Siegel et al. 2007). The protocol is designed to sample diurnal, territorial passerines, near-passerines (e.g., woodpeckers), and galliformes during the breeding season. Other species are only incidentally sampled. Sampling is stratified to distribute surveys equally over 3 elevation bands, from <650 m to >1350 m. Information on avian population dynamics resulting from the monitoring program can be used to guide decisions about management issues in the parks, including visitor impacts, fire management, and the effects of introduced species. Furthermore, because National Parks represent relatively pristine habitats, a comparison of avian population trends within and outside of park boundaries can provide insights on potential causes of population declines and suggest directions for region-wide conservation strategies. The results of the first detailed trend analyses have not yet been completed.

In addition to the NCCN surveys, a park-wide inventory of land birds was conducted in 2003–2004 by the Institute for Bird Populations in collaboration with MORA personnel (Wilkerson et al. 2009). This intensive effort sampled birds at 134 point count transects that were well distributed in vegetated habitats throughout the park. Information on species associations with habitats within MORA is also presented in this report.

The North American Breeding Bird Survey (BBS; Sauer et al. 2012) also provides data on diurnal breeding birds that are systematically monitored using roadside surveys. MORA has 1 BBS route that has been surveyed for a total of 14 yrs between 1991 and 2010. The Mount Rainier route (Route 89061; Longitude: 121° 47' 35" West; Latitude: 46° 45' 59" North) runs 24.5 mi (39 km) along Hwy 706 between 600 and 1475 m (1969–4839 ft) in elevation, from the southwest boundary of the park to the Nickel Creek crossing of the Stevens Canyon Road (Figure 27). Seventy-seven percent of the route runs through conifer forest (http://www.mbr-pwrc.usgs.gov/cgi-bin/rtena33.pl?89061). Data from single routes should be interpreted with caution because the BBS was designed to monitor bird populations at the scale of species' geographic ranges by sampling a large number of routes for each region. However, single routes contain information about species presence, and accumulation of annual surveys can reveal changes in abundance of frequently detected species.

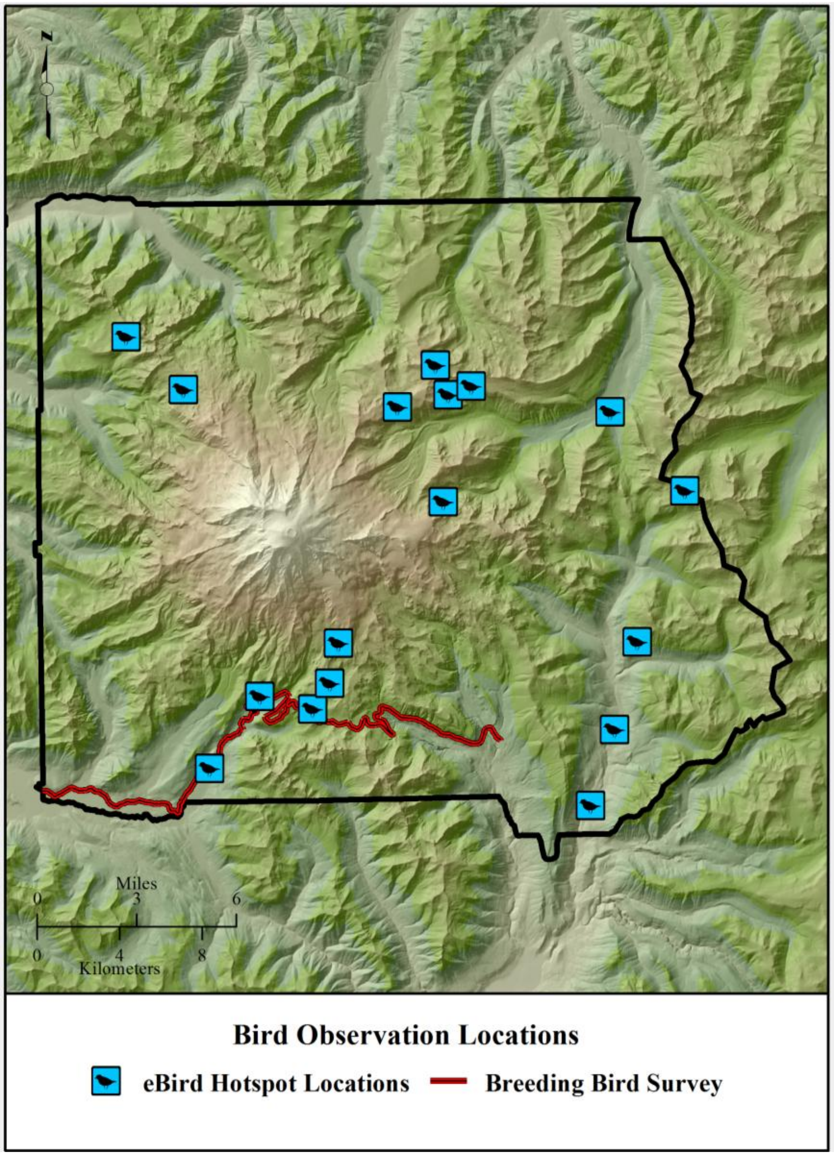

Figure 27. Mount Rainier National Park North American Breeding Bird Survey Route and eBird Hotspot locations.

Bird species that are not territorial during the early summer, are not diurnal, have large home ranges, or are otherwise difficult to detect are not well sampled by the NCCN or BBS surveys. Such species include the federally threatened Marbled Murrelet and Northern Spotted Owl. To asses these species, we used information available from species specific survey and monitoring efforts:

1. Marbled Murrelet surveys have been conducted in Mount Rainier National Park since the 1990s (Schaberl and Myers 2003). All surveys were conducted using standard protocol developed by the Pacific Seabird Group (Evans Mack et. al. 2003), or using marine radar (ABR 2011). Survey data were used to determine occupancy status of surveyed stands, but did not provide information on population status or trends. Population trends have been estimated using data from surveys of murrelets in near-shore marine waters (Miller et al. 2012).

2. Spotted Owl surveys at MORA have been conducted annually since 1997, and irregularly since 1983. These surveys track annual occupancy rates of historic nest sites and territories by Spotted and Barred Owls. Incidental observations of Great-horned Owls and Northern Goshawks also are documented during Spotted Owl surveys. The most recent available results were summarized in an annual report for the 2013 breeding season (Bagnall 2013). In addition, a significant proportion (40%) of the Rainier Spotted Owl Demographic Study Area (DSA) overlaps MORA (Forsman et al. 2011). Data from the DSA allows evaluation of the rate and possible causes of population change in Spotted Owls on the west slope of the Washington Cascades. Results are available from analysis of data from 1992–2008 for the Rainier DSA in Forsman et al. (2011:Table 1).
3. Surveys for Spotted Owls within and adjacent to MORA also are the best source of information on the location and population trends of Barred Owls in the park. Although Barred Owls are not specifically targeted in the surveys, the dates and locations of detections of all owl species are recorded (Forsman et al. 2011).

For the remainder of bird species that are difficult to detect and have not been monitored with species-specific surveys, we obtained information on presence within the park and distribution of predicted habitat from eBird (http://ebird.org/content/ebird/about) and the Washington GAP Analysis Program (Smith et al. 1997), respectively. eBird is an online checklist that collects and integrates bird observations contributed by recreational and professional bird watchers. The resulting bird distribution data are available via interactive queries. eBird registers 9 birding “Hotspots” at MORA, with aggregated data available for bird observations made from these specific locations by multiple observers. Sightings reported on eBird are useful mainly for recording the occurrence of rare or uncommon bird species, and in the long run may serve to help track species range expansions, contractions, and shifts.

The Washington GAP Analysis Progam (http://wdfw.wa.gov/conservation/gap) developed models predicting species’ distribution by combining information on range limits from known locations (primarily from the Washington Breeding Bird Atlas) with maps of appropriate habitat based on a composite of actual vegetation, vegetation zone, and ecoregion. The resulting maps show the predicted (not actual) potential distribution of breeding habitat for each species. We used these maps to help assess the potential for a species to occur in MORA.

Kitchin (1939) compiled information on historical occurrences for many species in MORA from the early 1900s. Although based on anecdotal observations, we used this check-list to provide a qualitative historical perspective of land birds occurrence, distribution, and abundance in the park. Finally, a database of wildlife observations managed by MORA provided additional information on the current status and occurrence of uncommon species within the park.

4.15.3 Reference Conditions and Comparison Metrics
Conservation plans developed by PIF provide a context for establishing management goals and targets for landbird populations that can be used in place of a reference condition. The mission of PIF includes both helping species at risk and preventing species endangerment, and associated costly

recovery efforts, by retaining healthy populations of common native birds throughout their natural ranges. Conservation plans focus on species that are designated as priorities for conservation ("priority species"), either because they are most in need of conservation actions or because they represent habitats that are important in supporting native biodiversity. An underlying assumption of this approach is that priority species represent the habitat conservation needs of a broader suite of species (Lambeck 1997). Many common and locally abundant species are PIF priority species because of their close association with a regionally important vegetation type; for example, the Chestnut-backed Chickadee is one of the most abundant birds in Pacific Northwest conifer forests, but its geographic range is limited to this region. Furthermore, some common bird species are currently experiencing steep population declines (e.g., Sooty Grouse, Rufous Hummingbird, Wilson's Warbler; PIF Species Assessment Database, http://pif.rmbo.org/).

4.15.4 Results and Assessment

We categorized the 48 bird species (Table 45) of potential conservation concern into 4 groups, based on frequency of occurrence in the park and the data available for assessing the status of each: (1) regularly occurring, well sampled species; (2) species that occur but are difficult to detect and not well sampled; (3) detectable species that occur infrequently in the park; and (4) species unlikely to occur regularly in the park.

Regularly Occurring – Well Sampled Species (n = 15)

Data that are available from formal surveys and monitoring programs will make it possible to detect significant changes in the status of these species within the park and to assess long-term trends. Trend results from the first phase of land birds monitoring are pending statistical analyses that are being conducted under the NPS Inventory & Monitoring Program. However, we used the preliminary results from the land birds surveys conducted from 2003 to 2011 in conjunction with other data sources (primarily from the single BBS route in MORA) to make provisional interpretations of the current status and trends for some of the most abundant, well sampled species. Pending availability of results of formal analyses to provide inferences about population trends, detection rates from the raw data were assessed. Detection rates are the number of individuals of a species observed each year and used as an index to abundance. Detection rates were summarized across all transects surveyed for each of 7 yrs of the monitoring program (2005–2011; Holmgren et al. 2012:Figure 6) and for 14 yrs of BBS surveys on the single route within the Park. Based on degree of consistency of results between these 2 independent surveys, this preliminary assessment suggests that 8 of these species may be declining within the park, 6 are apparently stable, and 1 is likely increasing.

Species with Evidence of Decline—Of the 45 native landbird species included in this assessment, 11 have experienced regional population declines over the last decade (Table 46). Primary, range-wide threats to these species include loss and fragmentation of large patches of naturally regenerated mature and old growth forests, alpine, meadow, wetland and riparian habitats due to forest management, urbanization, recreation, and intensification of agriculture (Table 47; Partners in Flight 2006).

Sooty Grouse—This species was historically considered common by Kitchin (1939), and is still common in the park currently, as evidenced by numerous sightings registered on eBird on a regular basis. It has been detected in low numbers in every year of NCCN surveys, so this monitoring effort should provide information on within-park trends. The preliminary numbers indicate a possible decreasing trend in the detection rate at MORA and throughout the NCCN.

Spotted Owl—The Northern Spotted Owl (NSO) is experiencing population declines within MORA and throughout its geographic range. Populations in Washington exhibited a long, gradual decline after the mid-1990s, and have declined 40−60% over the last 15 yrs. An increase in fecundity of NSO in the Rainier DSA between 1992 and 2008 was off-set by high annual variability (no young produced at all in some years) and precipitous declines in survival during the last 5 yrs (2004 – 2008) of the demographic study (Forsman et al. 2011). The population was estimated to be declining in the Rainier DSA at a rate of 7.1%/yr between 1992 and 2008. Decreased survival was associated with higher proportions of territories where Barred Owls were detected for Rainier, suggesting that the negative effects of Barred Owls may be the prominent cause of population declines of the NSO in the Rainier DSA. Monitoring surveys at MORA also document an increase in Barred Owl occupancy within the park, and a 45% decrease in NSO occupancy rates from peak levels recorded in 1998 (Bagnall 2013).

Historic and recent loss of nesting and roosting habitat is a major factor to which population declines of Spotted Owls have been related. Wildfire has been the leading cause of habitat loss since implementation of the Northwest Forest Plan (Davis et al. 2011), but large fires occur infrequently at MORA (Hemstrom and Franklin 1982). However, although estimated rates of population decline were highest for study areas in Washington, estimated habitat loss has been only 0.4% in the western WA Cascades where average habitat suitability remains relatively high (Davis et al. 2011). MORA is estimated to have approximately 32,375 ha (80,000 acres) of NSO habitat (Bagnall 2013).

In addition to loss of habitat, unfavorable weather conditions and climate change may also be contributing factors to population declines of Spotted Owls by lowering demographic rates (Glenn et al. 2010). Low temperatures during the early nesting season in some years of the last 2 decades were associated with low fecundity in the Rainier DSA and elsewhere (Forsman et al. 2011). Most climate change models predict warmer, wetter winters and hotter, drier summers for the Pacific Northwest. These conditions have been associated with lower population growth rates, survival, and recruitment of Spotted Owls, suggesting that future climate conditions may be less favorable for them. Prolonged summer drought may cause declines in populations of Northern Flying Squirrels, woodrats, and other small mammal prey species, ultimately affecting survival, recruitment, and population growth rates of owls.

Rufous Hummingbird—Raw data from NCCN surveys suggest a relatively stable population throughout the NCCN as a whole for this species, but annual variation is fairly high in MORA. Data from the MORA BBS route suggest a decline in the number of detections from 1991 to 2010 (trend estimate = –6.7, P = 0.02).

Pacific-slope Flycatcher—This species is well-sampled by the NCCN surveys, and data suggest a decrease in the rate of detection over the last 3 yrs of monitoring (Holmgren et al. 2012). The BBS route-level trend estimate for 1991–2010 also suggests declining detections: (Trend Estimate –5.00

(*P* = 0.003). The highest densities of Pacific-slope Flycatchers in MORA occur in Western Redcedar and Conifer Deciduous Mix forest types (Wilkerson et al. 2009) at elevations from 583–1393 m (1913–4570 ft) (Siegel et al. 2012).

Pacific Wren, Varied Thrush, Golden-crowned Kinglet—These species are among the most abundant birds at MORA, and are well-sampled by NCCN surveys. Route-level BBS data show a decline in number of detections of Pacific Wren and Varied Thrush over the last 2 decades, but analyses currently being conducted on NCCN survey data (Holmgren et al. 2012, Siegel et al 2012) will provide robust estimates of changes in local populations of these species. Single route analyses should be interpreted with caution, but declines in Golden-crowned Kinglet detections on the MORA BBS route (Trend Estimate: –4.44, *P* = 0.08) are consistent with the decrease in number of detections recorded on NCCN surveys from 2005–2011.

American Pipit—Although well-sampled by NCCN surveys, American Pipits are not detected on the BBS route, probably because they occur mainly at higher elevations (average elevation: 1957 m [6421 ft]; range: 1704–2198 m [5591–7212 ft]; Siegel et al. 2012). The trend analyses currently being conducted (Holmgren et al. 2012, Siegel et al 2012) will provide robust estimates of changes in local populations of this species. The first year that Pipits were not detected in the NCCN survey at MORA was 2011.

Table 47. Management status and major threats to bird species present in MORA.

Species	Management Status			Major Threats (NatureServe and BNA accounts)
	US ESA	COSEWIC	WA	
Harlequin Duck	NL	PS		habitat degradation; pesticides; recreational disturbance; over-harvesting; pollution (oil spills)
White-tailed Ptarmigan	NL	None		habitat degradation, especially land management practices that negatively affect willow; over-hunting
Sooty Grouse	NL	None		habitat degradation, primarily from forestry practices and grazing
Turkey vulture	NL	None	SM	eggshell thinning resulting from ingestion of contaminated food
Osprey	NL	None	SM	pesticides; shooting and trapping; powerline electrocution
Bald Eagle	NL	None	SS	habitat loss, disturbance by humans, biocide contamination, decreasing food supply, and illegal shooting
Northern Goshawk	SC	PS (T)	SC	habitat loss and degradation, primarily from timber harvest
Golden eagle	NL	None	C	powerline electrocution; poisoning; wind/solar energy development
Peregrine Falcon	NL	SC	SS	habitat loss and degradation; poaching; shooting; pesticides
Marbled Murrelet	PS (FT)	T	ST	habitat loss and degradation; gillnet fisheries; pollution (oil spills)
Band-tailed Pigeon	NL	SC	None	Habitat degradation and destruction; overhunting
Northern Spotted Owl	FT	E	SE	Habitat degradation and destruction; barred owl range expansion
Barred Owl	NL	None		Habitat degradation and destruction, primarily from timber harvest
Great Gray Owl	NL	None	SM	Habitat loss through logging; overgrazing of meadow habitat
Long-eared Owl	NL	None		Habitat degradation and destruction, primarily loss of riparian and grassland habitats
Boreal owl	NL	None	SM	Habitat degradation and destruction, primarily from timber harvest
Black Swift	NL	C		Disturbance from recreationists at nest and roost sites
Vaux's Swift	NL	None		Habitat degradation and destruction, primarily from timber harvest
Rufous Hummingbird	NL	None		None identified
Lewis' Woodpecker	NL	T	SC	Habitat degradation and destruction, primarily from timber management; fire suppression
Red-breasted Sapsucker	NL	None		Unstudied
American Three-toed Woodpecker	NL	None	SM	Habitat degradation and destruction, primarily from timber harvest;
Black-backed woodpecker	NL	None	SC	Habitat degradation and destruction, primarily from timber harvest and salvage logging
Pileated Woodpecker	NL	None	SC	Habitat degradation and destruction, primarily from timber harvest
Olive-sided Flycatcher	SC	T		Habitat degradation and destruction, on breeding and wintering grounds; fire suppression
Willow Flycatcher	PS (FE)	None		Habitat degradation and destruction, especially of riparian habitat
Hammond's Flycatcher	NL	None		Unstudied
Pacific-slope Flycatcher	NL	None		Unstudied
Cassin's Vireo	NL	None	None	Habitat degradation; cowbird nest-parasitism
Hutton's Vireo	NL	None	None	None identified

Table 47. Management status and major threats to bird species present in MORA (continued).

	Management Status			
Species	**US ESA**	**COSEWIC**	**WA**	**Major Threats (NatureServe and BNA accounts)**
Chestnut-backed Chickadee	NL	None	None	None identified
Brown Creeper	NL	None	None	Habitat degradation and destruction, primarily from timber harvest;
Pacific Wren	NL	None	None	Habitat degradation and destruction, primarily from timber harvest;
Golden-crowned Kinglet	NL	None	None	Habitat degradation and destruction, primarily from forest management
Western Bluebird	NL	None	SM	Habitat degradation and destruction, primarily from loss of nesting habitat (snags) and competition from invasive species (e.g., starlings, house sparrows)
Swainson's Thrush	NL	None	None	Habitat degradation (breeding and wintering); Collisions with windows, towers, etc.
Varied Thrush	NL	None		Habitat degradation and destruction, primarily from timber harvest; Collisions with windows
European Starling	NL	None	None	NA
American Pipit	NL	None	None	Habitat degradation (grazing, draining wetlands)
Orange-crowned Warbler	NL	None	None	Habitat degradation (breeding and wintering), primarily timber harvest and grazing
MacGillivray's Warbler	NL	None	None	Habitat degradation (breeding and wintering), primarily forest management
Black-throated Gray Warbler	NL	None	None	Unknown
Hermit Warbler	NL	None	None	Habitat degradation (breeding and wintering), primarily timber harvest
Wilson's Warbler	NL	None	None	Habitat degradation and destruction, primarily from forest management and grazing in riparian areas; Collisions with windows, towers, etc.
Lincoln's Sparrow	NL	None	None	Unstudied
Black-headed Grosbeak	NL	None	None	None identified
Red Crossbill	NL	PS:E		habitat degradation, primarily from forestry practices; competition from introduced species
House Sparrow	NL	None		NA

US ESA Status: PS=partial status (species has status in a portion of the range), E=endangered, T=Threatened, C=Candidate, XN=Experimental Nonessential, NL=not listed

Committee on the Status of endangered Wildlife in Canada (COSEWIC): PS=Partial Status, XT=Extirpated, E=Endangered, T=Threatened, SC=Special Concern, NAR=Not at Risk, DD=Data deficient, --- = no record

Washington State Status: SE=state endangered; ST=state threatened; SC=state candidate; SS= State sensitive; SM=state monitored

Species which are Apparently Stable within MORA—The Park represents an important stewardship opportunity for maintaining the characteristic avifauna of mature coniferous forests because MORA supports some of the largest remaining tracts of late-seral coniferous forest habitat in the region and is not subject to many of anthropogenic disturbances associated with resource extraction. Species that are representative of and reliant on this type of habitat include the federally threatened Marbled Murrelet and many range-limited species and subspecies unique to western North America (e.g., Chestnut-backed Chickadee, Varied Thrush, Pacific-slope Flycatcher). There is some indication that at least 3 forest-associated species (Marbled Murrelet, Chestnut-backed Chickadee, and Swainson’s Thrush; Table 45) with regional population declines have stable detection rates within the park.

Marbled Murrelet—Surveys for Marbled Murrelets conducted in MORA between 1995 and 2009 have documented behavior indicative of nesting in the northwest corner of the park (Dhundale 2009). Evidence of occupancy has been documented in every survey year for the Carbon River drainage. Murrelet occupancy also has been documented by both audio-visual and radar surveys in drainages of the South Puyallup and Mowich Rivers. Presence in the Nisqually River drainage also is based on radar detections, but needs to be confirmed with audio-visual surveys. Outside of MORA, populations of Marbled Murrelets have been declining throughout the region, with the steepest declines in Washington (Miller et al. 2012), where loss of older forest habitat has also been the greatest (Raphael et al. 2011). Data from Murrelet surveys cannot be used to determine trends within the park because of the variability in locations of survey effort and stations among years. However, the data are useful for tracking the occupancy status of specific locations that have been consistently surveyed using the standard protocol (Evans Mack et. al. 2003). Murrelets have consistently been detected on the Carbon River throughout all survey years, indicating the importance of this drainage as nesting habitat within the park.

Vaux's Swift—The breeding range of the Vaux’s Swift comprises an area limited to a few states and provinces in the Pacific Northwest (Table 45). This species has a low but consistent detection rate on NCCN surveys, but has been detected on the MORA BBS route in only 3 of 15 yrs. It is frequently reported in the park on eBird. Raw data from NCCN surveys suggest a relatively stable rate of detection within the park.

Hammond’s Flycatcher—Within MORA, this species is found in highest densities in Red Alder and Conifer Deciduous Mix forest types (Wilkerson et al. 2009), from 580–1235 m (1903–4052 ft) elevation (Siegel et al. 2012). Although relatively uncommon at MORA, Hammond’s Flycatchers have stable or increasing population trends both throughout the region (Table 45) and within the park according to NCCN surveys and BBS route-level data.

Chestnut-backed Chickadee—This species is one of the most abundant birds at MORA, and in coniferous forests throughout the region, but its global geographic range is limited to the Pacific Northwest. Because it is so abundant, the species is well-sampled by NCCN and BBS Surveys. Data from both surveys suggest stable detection rates.

Brown Creeper—This species is well-sampled by NCCN and BBS surveys; the trend analyses currently being conducted (Holmgren et al. 2012, Siegel et al 2012) will provide robust estimates of changes in local populations of these species. No obvious trend in within-park detection rate is evident within the park for the Brown Creeper from either data set.

Swainson's Thrush—This species is well sampled on the MORA BBS route, with an average detection rate of 10.9 birds/route (Sauer et al. 2012). It was detected on a relatively small subset of transects in the NCCN surveys, but data may still be sufficient for trend analyses. The highest densities of Swainson's Thrush in MORA occur in Red Alder and Conifer Deciduous Mix forest types (Wilkerson et al.2009) at elevations from 617–1268 m (2024–4160 ft) (Siegel et al. 2012).

Species with Evidence of Increase—
Barred Owl—The Barred Owl is a native species to North America that has expanded its range from east to west, and continues to expand throughout the Pacific states from north to south. Barred Owls began appearing in Washington in noticeable numbers in the mid-1980s, and by 2008, nearly 30% of the Spotted Owl territories on the Rainier DSA had Barred Owl detections (Forsman et al. 2011:Appendix B). For the past 5 breeding seasons (2009–2013), the proportion of monitored sites at MORA occupied by Barred Owls (50%) has been greater than the proportion occupied by NSO (41%; Bagnall 2013).

Species That Occur At MORA But Are Not Well Sampled (n = 12)

The species in this group are difficult to sample for a variety of reasons. Many of them occur at low densities, either because they are extremely wide-ranging (e.g., Golden Eagle, Peregrine Falcon, and Northern Goshawk), or they are associated with unique, localized, or remote habitat patches (e.g., Harlequin Duck, Black Swift, White-tailed Ptarmigan). Some species are not amenable to sampling with the point count methodology used for other passerines because they are non-territorial and occur in flocks (e.g., Red Crossbills, Band-tailed Pigeons), or have large territories (woodpeckers). MORA may represent important habitat for most or all of these species, but an assessment of status and trends within the park would require special survey efforts. Regional data that are accumulated over a broader geographical area by existing surveys may be most useful in providing information on the status for some of these species. For example, BBS data has been collected over sufficiently long periods of time to provide robust regional trend analyses for populations of some species that are infrequently detected on any single route.

Harlequin Duck—Harlequin Ducks use fast-flowing streams and rivers during the breeding season, but are sensitive to human disturbance and can be difficult to observe. A few observations between May and September were collected from eBird: Sunrise and White River Road at Shaw Creek on northeast side of park, and along the Paradise Road E below Cougar Rock Campground on the southwest side of the park. Reported as a "rare visitor" in Mount Rainier Nature News Notes (1925:Vol II, no. 21). Surveys for Harlequin Duck have been performed annually at MORA by park volunteers, from late April through July, since 2001 (MORA unpubl. data). Breeding is regularly documented on the Ohanapecosh River and Stevens Creek, with additional birds being located on the Nisqually River, Cowlitz River, Chinook Creek, and Nickel Creek.

White-tailed Ptarmigan—White-tailed Ptarmigan breed exclusively in rocky alpine habitats, typically between 1524 and 2286 m (5000–7500 ft) (Smith et al. 1997), therefore there is a low probability of encounter on either NCCN surveys (highest elevation point count was at 2248 m [7376 ft]; Siegel et al. 2012) or on BBS survey route. In fact, only 1 detection was made during NCCN surveys (during pilot surveys in 2003–2004; Wilkerson et al. 2009). The frequently reported sightings of this species in MORA on eBird mark the southern extent of detections in the Cascade Range. Because of its association with high elevation habitats, climate change may pose a threat to White-tailed Ptarmigan, although investigations of the effects of warming temperatures on this species have demonstrated effects on breeding phenology but not on population dynamics (Wann et al. 2002, Wilson and Martin 2011, Wann 2012). The U.S. Fish and Wildlife Service is currently reviewing the listing status for this species.

Bald Eagle—Following historic population lows in the last century, Bald Eagles have been experiencing a recovery in populations in Washington and throughout North America since the early 1980s (Sauer et al. 2012, Stinson et al. 2001). BBS data indicate that Bald Eagle populations increased 3.6%/yr (95% CI: 0.3, 8.6) from 2001 to 2011 in the Pacific Northwest (Sauer et al. 2012). However, Bald Eagles are observed too infrequently at MORA to determine within-park trends in abundance. No documented nesting records exist for the park, although Kitchin (1939) stated that Bald Eagles "formerly bred on all sides of the mountain", and were "fairly common during the salmon run at Ohanapecosh." Core habitat for Bald Eagles occurs along lakes, estuaries, and large rivers at low elevations, excluding much of MORA and the Cascade Range in Washington (Smith et al. 1997, Stinson et al. 2001).

Northern Goshawk—Kitchin (1939) listed goshawks as uncommon but regular in the northern and eastern portions of the park, but more recently they have rarely been observed in MORA. Observations of goshawks reported on eBird for MORA from scattered locations across the park amount to <1 sighting/yr. This species has not been detected during the NCCN surveys, although they have occasionally been incidentally observed in the park by survey crew members. A survey conducted in 2005 in conjunction with an assessment for Federal Lands Highway projects planned for MORA recorded 2 Goshawk sightings. Additional sightings are noted in the park Wildlife Observation database.

Golden Eagle—In spite of long-term population declines throughout the western U.S. (Kochert and Steenhof 2002), the status of occurrence of this species in MORA as rare but regular apparently has not changed over the last 7 decades (Kitchin 1939). Sightings in the park are registered several times each year on eBird, usually in the late summer and fall. Golden Eagles, when sighted, are typically observed foraging in rocky areas and alpine parkland at high elevations. MORA is within the zone of potential core habitat for breeding, although no evidence of eagles breeding in the park has been documented. Kitchin (1939) hypothesized that "a few pair may breed on the north or east sides [of Mount Rainier]." Observations of this species are too few to provide an estimate of within-park trends in abundance; the park likely represents a small proportion of suitable habitat for this species relative to its geographic distribution and large home range size (up to 250 km^2/pair (97 mi^2/pair); Kochert et al. 2002).

Peregrine Falcon—Peregrines have been rarely observed in MORA. They were not detected during the NCCN surveys, and <10 observations have been recorded on eBird. A survey conducted in 2005 in conjunction with an assessment for Federal Lands Highway projects planned for MORA did not record any Peregrines. Since 2006, park staff has been monitoring a pair of Peregrine Falcons using a cliff face 1.25 km southwest of Tumtum Peak. Standard 4 hr observation protocol has been employed and records kept on FWS Form 3-2307. In 2011 and 2012, copulation was observed in late April and early May, suggesting potential nesting, but no young or fledglings were detected (MORA unpubl. data). Visibility of the cliff used by the falcons is severely obstructed by thick forest, making observations and location of any eyrie challenging.

Band-tailed Pigeon—This species may have been more abundant in the park historically. Kitchin (1939) reported that Band-tailed Pigeons were especially abundant in MORA in the fall, when ripe huckleberries and Mountain Ash berries were available as food. Grater (1951) reported observing flocks of approximately 100 individuals early in the breeding season in 1947. In recent surveys, this species has occasionally been detected on NCCN point counts and on the BBS route in MORA, but numbers are too low and variable to assess trends. Three or fewer birds were detected per year on the NCCN surveys during the first 4 yrs (2005–2008), but none were detected on surveys from 2009–2011 (Holmgren et al. 2012). Observations have been reported to eBird from May–September for consecutive years from 2008–2012, and for several years in the 1970s–1990s. Based on a sample of 10 observations in 2003–2004, Band-tailed Pigeons occurred at elevations between 616–1561 m (2021–5122 ft) (Siegel et al. 2012).

Boreal Owl—MORA is on the western edge of the species range, and near the southern edge of the range for this longitude. This species breeds in high elevation forests (Subalpine Fir, Engelmann Spruce, Lodgepole pine), and are rarely found below 1220 m (4000 ft; Smith et al. 1997). Approximately 40 observations are reported in eBird between 2000 and 2012, all recorded at Sunrise Birding Hotspot in the months of September and October. Survey efforts for diurnal birds (e.g., NCCN, BBS) are not effective for detecting this and other nocturnal species.

Black Swift—Black Swifts nest on steep cliff faces behind waterfalls. Because of this unique habitat association, they are patchily distributed and not amenable to monitoring with standard multiple-species survey techniques such as the NCCN and BBS. Historically, Black Swifts have been observed on the eastern slopes of the mountain, near Indian Bar and the Cowlitz Chimneys where it was presumed to breed (Kitchin 1939). This species was recorded on the MORA BBS route in 4 yrs between 1991 and 2000, but not since. Numerous records on eBird likely reflect special effort by birders to add this species to their lists. The Washington Cascades are the southern extent of the largest patch of contiguous breeding range for this species in the U.S. and Canada. Special survey methods are needed for monitoring Black Swift populations.

Three-toed Woodpecker—Three-toed Woodpeckers are generally found in dense, closed-canopy forests, and lower elevation forests at MORA constitute habitat within their core distribution zone (Smith et al. 1997). A few have been recorded on NCCN and BBS surveys, but the species is uncommon.

Pileated Woodpecker—Although Pileated Woodpeckers are detected on the NCCN and BBS surveys, they are detected only irregularly and in low numbers because of their large home ranges.

This species uses mid- to late successional conifer forest mainly between 652–1542 m (2139–5059 ft) in elevation at MORA (Siegel et al. 2012).

Red Crossbill—Although regularly detected at MORA by birders (eBird records), Red Crossbills are not well detected on NCCN or BBS surveys. Red Crossbills were recorded in highest densities in Mixed Douglas-fir/Western Hemlock and Noble Fir forest types at MORA (Wilkerson et al. 2009).

Detectable Species That Occur Infrequently (n = 6)

Point count methodology used by the NCCN land bird survey is effective for sampling these species, but they occur in low abundances at MORA. MORA is within the geographic range of all 6 species, but may provide only small amounts of suitable habitat. It is possible that local abundances of these species within the park could change in the event of large scale disturbance, such as wild fire.

Red-breasted Sapsucker—Infrequently detected on NCCN surveys and only 1 time on the BBS survey route. This species has likely never been abundant in the park (Kitchin 1939), perhaps because of its association with deciduous trees below 2900 m (9515 ft) elevation.

Olive-sided Flycatcher—This species has a low and variable detection rate on both NCCN (detected in 6 of 7 yrs) and BBS (11 of 15 yrs) surveys, so trend analysis in MORA will be difficult. Raw data from NCCN surveys suggest a relatively stable rate of detection throughout the NCCN as a whole.

MacGillivray's Warbler, Wilson's Warbler—These are focal species for the PIF Oregon and Washington conservation strategy because they represent deciduous vegetation in early seral (MacGillivray's Warblers), and young and mature forest (Wilson's Warbler). These species are experiencing significant long-term and recent population declines throughout much of the PNW portion of their ranges. Deciduous vegetation is an important element of biodiversity in PNW conifer forests with which both species are strongly associated. MORA lacks significant amounts of suitable habitat for these species because low elevation (<1200 m [<3937 ft]; Altman 1999), early seral forest is scarce. Detections of both species in MORA by NCCN surveys are too few and variable to indicate trend. However, the Wilson's Warbler is well sampled on the MORA BBS route, with a trend estimate indicating a declining detection rate since the early 1990s (Trend Estimate: –5.2; P = 0.001). The MacGillivray's Warbler was recorded in most (13 of 15) years on the MORA BBS route, but evidence of a declining trend in detection rate is inconclusive.

Black-throated Gray Warbler—Historically, this species has been rare in the park (Grater 1951), and was not detected every year in NCCN surveys. In recent surveys, it was detected from 647 to1159 m (2123–3803 ft) elevation (n = 12; Siegel et al. 2012), with highest densities (0.22 birds /ha) in Grand Fir and mid-elevation shrub habitats (Wilkerson et al. 2009). Detections on the BBS route at MORA dropped to zero for the latest 6 consecutive years of the survey.

Lincoln's Sparrow—A close association with high elevation wetland habitats creates a patchy, local distribution of this species. This could be why the Lincoln's Sparrow was not detected on NCCN surveys, and was detected only once in 15 yrs of BBS surveys. The few sporadic observations registered on eBird also indicate that this species is uncommon in MORA. A few detections of

Lincoln's Sparrows were made in Sedge Meadow (4 detections) and Subalpine Fir (1 detection) habitats during the 2003–2004 intensive surveys for land birds inventory (Wilkerson et al. 2009).

Species Unlikely To Occur (*n* = 15)

MORA is peripheral to the current geographic ranges of or lacks suitable habitat for species in this group. These species were not detected on the NCCN surveys, and few, if any, records of occurrence in the park exist. However, given the potential for range shifts to occur as plant communities respond to climate change, these species should not be completely discounted as irrelevant to park management. Monitoring of the 2 invasive species in this group, the European Starling and House Sparrow, may be of particular importance.

Turkey Vulture—The status and distribution of Turkey Vultures is monitored by the state of Washington because of concern over their well-being in the state (WDFW State Monitor List 2013). Regular sightings of vultures in MORA are reported on eBird, but this species has not been detected on NCCN surveys, or on the BBS route. Vultures are not included on historic (Kitchin 1939) or current check-lists for the park. Even the lowest elevation forests within the park boundaries are above the predicted zone of core habitat for vultures, and are too dense to be considered suitable habitat (Smith et al. 1997).

Osprey—Following historic population lows in the last century, Ospreys have been experiencing a recovery in populations in Washington and throughout North America since the early 1980s (Sauer et al. 2012). BBS data indicate that Osprey populations increased 4.5%/yr (95% CI: 1.5, 7.4) from 2001 to 2011 in the Pacific Northwest (Sauer et al. 2012). Although Osprey regularly nest and reproduce on the Ohanapecosh River north of the Grove of the Patriarchs and south of Panther Creek (MORA unpubl. data), they are observed too infrequently at MORA to determine within-park trends in abundance. Kitchin (1939) did not include Osprey on a check-list of birds of MORA. Core habitat for Ospreys occurs along lakes, estuaries, and large rivers at low elevations, excluding much of MORA and the Cascade Range in Washington (Smith et al. 1997, Stinson et al. 2001).

Great Gray Owl—There are no confirmed records of this species at MORA, nor any detections reported on eBird. This species is considered rare in Washington, with only a few records from the northeastern part of the state. Conifer forest associated with meadow systems up to 2800 m (9187 ft) elevation offer suitable nesting habitat for this species (Bull and Duncan 1993).

Long-eared Owl—This species is rare in western Washington, although it has occasionally been detected in MORA. Suitable habitat for Long-eared Owls includes open forest types and forest edges.

Lewis' Woodpecker—This species is common in open forest habitats in eastern Washington. It was historically fairly common in lowland savannah habitats in western Washington, and Kitchin (1939) reported some Lewis' Woodpeckers breeding in a burned area near the southern boundary at lower Nickel Creek. This species may colonize burned areas at MORA if they were to become available, but the current prevalence of dense mature forest does not offer suitable habitat. It has not been detected on the BBS route nor in the NCCN surveys; eBird has just 1 observation of a Lewis' Woodpecker documented at Sunrise in September 2012.

Black-backed Woodpecker—MORA is peripheral to distribution of the Black-backed Woodpecker (Smith et al. 1997), which is most frequently found in recent burns and stands of diseased conifers. Few park records exist for this species, and it has not been recorded by NCCN and BBS surveys.

Willow Flycatcher—This flycatcher is restricted to relatively low elevations within the park. Only 1 observation in MORA from NCCN surveys. Only 6 records were included on eBird; all observations made in June; most recent was 2011. The relatively high elevation, mature forest at MORA is outside of the zone of core habitat predicted for this species (Smith et al. 1997). Therefore, MORA probably does not currently make an important contribution to habitat for this species.

Cassin's Vireo—This species is associated with dry forests at low and moderate elevation, and therefore has rarely been detected at MORA. It was not detected on NCCN surveys, nor has it ever been detected on the BBS route. Only 3 sightings of Cassin’s Vireos in MORA have been recorded in eBird.

Hutton's Vireo—This resident species is rare in MORA (detected once on the BBS route; 2 sightings in eBird), which is outside of its predicted zone of core habitat. Hutton’s Vireos are most often found in hardwood or mixed second-growth forest with a strong hardwood component (Smith et al. 1997). The relatively high elevation mature forest at MORA is not considered suitable habitat for this species.

Western Bluebird—This species is uncommon in western Washington in general, and does not use closed-canopy moist conifer forest habitats. It has not been recorded on the NCCN surveys or on the BBS route in MORA. Very few, sporadic observations have been recorded in eBird. The predominance of mature, closed-canopy conifer forest at MORA precludes regular use of the park by this species.

European Starling—Starlings occur irregularly at the park; they have only been detected twice on the MORA BBS route and are occasionally recorded on eBird. The park is well outside the zone of core habitat for this species (Smith et al. 1997). Starling populations decreased by 2.4%/yr between 2001and 2011 in the Pacific Northwest (Sauer et al. 2012).

Orange-crowned Warbler—Like MacGillivray’s Warblers, Orange-crowned Warblers are focal species for the PIF Oregon and Washington conservation strategy because they represent deciduous vegetation in early seral forest. This species also is experiencing significant long-term and recent population declines throughout much of the PNW portion of the range. Orange-crowned Warblers were only detected in 3 out of 15 yrs on the BBS route, and are rarely detected on NCCN surveys. Habitat at MORA is probably unsuitable for this species because of a lack of low elevation (<1200 m [<3937 ft]; Altman 1999), early seral forest.

Hermit Warbler—MORA is near the northern limits of this species’ geographical range, and it was uncommon in the park historically (Grater 1951). Although predictions of effects of climate change might suggest a northward and upslope shift in the range of this species, competitive displacement by the Townsend’s Warbler (*S. townsendi*) may be causing the opposite trend: a shrinkage of range downward in latitude and elevation (Krosby and Rohwer 2010). Hermit Warblers have not been detected on the BBS route since 1995, were detected only once on the park-wide intensive surveys in 2003–2004 (Wilkerson et al. 2009), and were not detected on NCCN surveys. Hybridization of Hermit Warblers with Townsend's Warblers causes confusion with identification, so reports from casual observers need verification.

Black-headed Grosbeak—This species has only rarely been detected on land birds inventory surveys at MORA (Wilkerson et al. 2009, Holmgren et al. 2012), and has not been detected on the BBS route. Core habitat for this species occurs in low elevation hardwood forests (Smith et al. 1997). BBS data for the region suggest a recent population increase for this species (Sauer et al. 2012).

House Sparrow—Although MORA is remote from the urban and agricultural habitats that primarily support this introduced species, park structures may provide nesting habitat. House Sparrows have not been detected by NCCN surveys or on the BBS route, but detections at the park are occasionally reported on eBird.

4.15.5 Emerging Issues

Declining populations of forest-associated birds, including both rare and common species, is an overarching issue for bird conservation efforts in the Pacific Northwest. Habitat loss and degradation, often in the form of forest fragmentation, are major threats implicated in many population declines (Table 46). MORA represents an important refuge and stewardship opportunity for forest-associated bird species because it supports large tracts of unmanaged, late-seral, coniferous forest habitat which has become increasingly rare in the region as a result of intensive forest management. However, other threats are likely to transcend park boundaries.

Climate change is a major emerging issue that is likely to impact whole ecological communities within the park. Both direct and indirect effects on birds can be expected, although predictability of specific effects is currently low because of the complexity of interacting factors (Halofsky et al. 2011, Tingley et al. 2012). Changes in temperature and precipitation regimes are expected to cause changes in distribution and structure of plant communities that provide important food and cover. Thus, a major effect of climate change is expected to be changes in bird distributions. Species at the margins of their geographic ranges may be most susceptible to changes in status within the park. Such species include Harlequin Duck, White-tailed Ptarmigan, Boreal Owl, and Black Swift. Other species with already restricted ranges (e.g., Sooty Grouse, Vaux's Swift, and Red-breasted Sapsucker) may also be vulnerable to climate change effects, especially those that have declining population trends (e.g., Marbled Murrelet, Rufous Hummingbird, Chestnut-backed Chickadee, Varied Thrush). The White-tailed Ptarmigan is an iconic high elevation species that reaches the southern edge of its contiguous range in the Washington Cascades. Climate change threatens this species with further population fragmentation.

As addressed in chapter 4.1, mercury and other contaminants are also of concern. A recent study on mercury contamination in songbirds found high levels of mercury in the Varied Thrush and in wet meadow habitat in MORA (Adams et al. 2013). In addition, a study by the Western Airborne Contaminants Assessment Project (WACAP) found levels of contaminants in fish (dieldrin, chlordanes, PCBs, and mercury) that may pose threats to piscivorous birds (Landers et al. 2008).

Invasive species, including vertebrates, plants, insect pests, and diseases, comprise ongoing threats to natural communities in the park. Of immediate concern is the range expansion of the native Barred Owl because of its negative effect on survival of Spotted Owls. This threat may be increasing as Barred Owls continue to colonize and become more abundant throughout the region. Negative impacts of other invasive species may be exacerbated by climate change. Warming temperatures and changing plant communities may facilitate the colonization of habitats in MORA by non-native bird species, such as the European Starling and House Sparrow, which are probably already present in the park. Similarly, changes in the distribution or abundance of native nest-parasites (i.e., Brown-headed Cowbird) and nest-predators (e.g., corvids, small mammals), could affect productivity of many bird species, including the threatened Marbled Murrelet.

Finally, some species may be highly influenced by threats outside park boundaries because a significant portion of their annual life cycle is spent elsewhere. This includes migratory birds that may encounter sources of mortality on their wintering grounds or along their migration routes. Also, wide-ranging species (e.g., Golden Eagle, Peregrine Falcon) may be highly influenced by threats outside park boundaries (e.g., contaminants, including lead) because the park represents a small proportion of the area these species use on an annual basis.

4.15.6 Information and Data Needs–Gaps

The well-established avian inventory and monitoring program in the North Coast and Cascades Network is a tremendous asset that provides critical information about the status of many land bird species to park managers. However, data are lacking for species that are difficult to detect or occur too infrequently to monitor effectively at the spatial scale of the park. Therefore, population trends are unknown for most diurnal raptors, owls, alpine- and meadow-associated species, and woodpeckers. Assessments of population and productivity trends for these species require specially designed monitoring programs for each group.

Monitoring information may be particularly useful for management of some special status species within the park such as:

Marbled Murrelet

Continued surveys for Marbled Murrelets will be critical for tracking the status of this species in the park over time. Dhundale (2009) recommended that intensive surveys continue along the Nisqually River drainage to confirm nesting occupancy by murrelets.

Harlequin Duck

This species is unique among North American waterfowl for its use of montane rivers and streams for breeding. Because Harlequin Ducks require pristine, productive streams and are sensitive to human disturbance during the nesting season (Lewis and Kraege 2004), the remote wilderness breeding habitat available at MORA may be particularly important in maintaining populations at the southern end of the species' range, especially in consideration of potential climate change effects. However, Harlequin Ducks are not well-sampled by landbird survey methods, and require a special survey effort for inventory and monitoring. The only currently existing records are the informal surveys by park volunteers for the Ohanapecosh River area, and a handful of observations from eBird.

4.15.7 Literature Cited

ABR, Inc. 2011. Radar surveys for marbled murrelets in Mt. Rainier National Park, Washington, 2011. Unpublished report. ABR, Inc. Forest Grove, Oregon.

Adams, E., A. K. Jackson , and D. C. Evers. 2013. Songbirds: Indicators of mercury in national park ecosystems. Biodiversity Research Institute, Gorham, Maine. Science Communication Series BRI 2013-15.

Altman, B. 1999. Conservation strategy for landbirds in coniferous forests of western Oregon and Washington. Oregon-Washington Partners in Flight.

Bagnall, K. 2013. Spotted owl monitoring in Mount Rainier National Park: 2013 Annual Report. Unpublished.

Bull, E. L., and J. R. Duncan. 1993. Great Gray Owl (*Strix nebulosa*). In: Poole, A. editor. The birds of North America online. Cornell Lab of Ornithology, Ithaca, New York. Retrieved from The birds of North America online: http://bna.birds.cornell.edu/bna/species/041.

Davis, R. J., K. M. Dugger, S. Mohoric, L. Evers, and W. C. Aney. 2011. Northwest Forest Plan—the first 15 years (1994–2008): Status and trends of northern spotted owl populations and habitats. Gen. Tech. Rep. PNW-GTR-850. U. S. Department of Agriculture, Forest Service, Pacific Northwest Research Station, Portland, Oregon.

Dhundale, J. 2009. Marbled murrelet 2009 progress report. Unpublished report submitted to Mount Rainier National Park.

Evans Mack, D., W. P. Ritchie, S. K. Nelson, E. Kuo-Harrison, P. Harrison, and T. E. Hamer. 2003. Methods for surveying Marbled Murrelets in forests: A revised protocol for land management and research. Pacific Seabird Group, Marbled Murrelet Technical Committee. January 2003.

Forsman, E. D., R. G. Anthony, K. M. Dugger, E. M. Glenn, A. B. Franklin, G. C. White, C. J. Schwarz, K. P. Burnham, D. R. Anderson, J. D. Nichols, and others. Population demography of Northern Spotted Owls: 1985–2008. Studies in Avian Biology 40. Cooper Ornithological Society.

Glenn, E. M., R. G. Anthony, and E. D. Forsman. 2010. Population trends in Northern Spotted Owls: Associations with climate in the Pacific Northwest. Biological Conservation 143:2543–2552.

Grater, R. K. 1951. Recent bird records from Mount Rainier National Park. Condor 53:156–157.

Halofsky, J. E., D. L. Peterson, M. J. Furniss, L. A, Joyce, C. I. Millar, and R. P. Neilson. 2011. Workshop approach for developing climate change adaptation strategies and actions for natural resource management agencies in the United States. Journal of Forestry 109:219–225.

Hemstrom, M. A., and J. F. Franklin. 1982. Fire and other disturbances of the forests in Mount Rainier National Park. Quaternary Research 18:32–51.

Holmgren, A. L., R. L. Wilkerson, R. B. Siegel, and R. C. Kuntz II. 2012. North Coast and Cascades Network landbird monitoring: Report for the 2011 field season. Natural Resource Technical Report NPS/NCCN/NRTR—2012/605. National Park Service, Fort Collins, Colorado.

Kitchin, E. A. 1939. A distributional check-list of the birds of Mount Rainier National Park. The Murrelet 20:27–37.

Kochert, M. N., and K. Steenhof. 2002. Golden Eagles in the U.S. and Canada; status, trends, conservation challenges. Journal of Raptor Research 36(supplement):33–41.

Kochert, M. N., K. Steenhof, C. L. McIntyre, and E. H. Craig. 2002. Golden Eagle (Aquila chrysaetos). In: Poole, A., editor. The birds of North America online. Cornell Lab of Ornithology, Ithaca, New York. Retrieved from The birds of North America online: http://bna.birds.cornell.edu/bna/species/684.

Krosby, M., and S. Rohwer. 2010. Ongoing movement of the Hermit Warbler X Townsend's Warbler hybrid zone. PLoS ONE 5:e14164.

Lambeck, R. J. 1997. Focal species: A multi-species umbrella for nature conservation. Conservation Biology 11:849–856.

Landers, D. H., S. L. Simonich, D. A. Jaffe, L. H. Geiser, D. H. Campbell, A. R. Schwindt, C. B. Schreck, M. L. Kent, W. D. Hafner, H. E. Taylor, and others. 2008. The fate, transport, and ecological impacts of airborne contaminants in western national parks (USA). EPA/600/R-07/138. U.S. Environmental Protection Agency, Office of Research and Development, NHEERL, Western Ecology Division, Corvallis, Oregon.

Lewis, J. C., and D. Kraege. 2004. Harlequin Duck. In: Larsen, E., J. M. Azerrad, N. Nordstrom, editors. Management recommendations for Washington’s priority species, Volume IV: Birds. Washington Department of Fish and Wildlife, Olympia, Washington. Available online: http://wdfw.wa.gov/publications/ 00026/wdfw00026.pdf.

Miller, S. L., M. G. Raphael, G. A. Falxa, C. Strong, J. Baldwin, T. Bloxton, B. M. Galleher, M. Lance, D. Lynch, S. F. Pearson, C. J. Ralph, and R. D. Young. 2012. Recent population decline of the Marbled Murrelet in the Pacific Northwest. The Condor 114:771–781.

Partners In Flight. 2006. Available at: http://www.pifbcyukon.org/3e.html.

Raphael, M. G., G. A. Falxa, K. M. Dugger, B. M. Galleher, D. Lynch, S. L. Miller, S. K. Nelson, and R. D. Young. 2011. Status and trend of nesting habitat for the Marbled Murrelet. U. S. Department of Agriculture, Forest Service, Pacific Northwest Research Station, Corvallis, Oregon.

Sauer, J. R., J. E. Hines, J. E. Fallon, K. L. Pardieck, D. J. Ziolkowski Jr., and W. A. Link. 2012. The North American breeding bird survey, results and analysis 1966–2011. Version 12.13.2011. USGS Patuxent Wildlife Research Center, Laurel, Maryland.

Schaberl, J., and E. Myers. 2003. Mount Rainier National Park Marbled Murrelet 2002 Progress Report. Unpublished report for MORA, NCR division.

Siegel, R. B., R. L. Wilkerson, R. C. Kuntz, J. F. Saracco, and A. L. Holmgren. 2012. Elevation ranges of birds at Mount Rainier National Park, North Cascades National Park Complex, and Olympic National Park, Washington. Northwestern Naturalist 93:23–39.

Smith, M. R., P. W. Mattocks Jr., and K. M. Cassidy. 1997. Breeding birds of Washington State. Volume 4. In: Cassidy, K. M., C. E. Grue, M. R. Smith, and K .M. Dvornich, editors. Washington State Gap Analysis - Final Report. Seattle Audubon Society Publications in Zoology No. 1, Seattle, Washington.

Stinson, D. W., J. W. Watson, and K. R. McAllister. 2001. Washington State status report for the Bald Eagle. Washington Department of Fish and Wildlife, Olympia, Washington.

Tingley, M. W., M. S. Koo, C. Moritz, A. C. Rush, and S. R. Beissinger. 2012. The push and pull of climate change causes heterogeneous shifts in avian elevational ranges. Global Change Biology 18:3279–3290.

Wann, G. T. 2012. Long-term demography of a White-tailed Ptarmigan (*Lagopus leucura*) population in Colorado [thesis]. Colorado State University, Fort Collins, Colorado.

Wann , G., N. T. Hobbs, H. Galbraith, and K. M. Giesen. 2002. Signatures of large-scale and local climates on the demography of White-tailed Ptarmigan in Rocky Mountain National Park, Colorado, USA. International Journal of Biometereorology 46:197–201.

WDFW State Monitor List. 2013. Available at: http://wdfw.wa.gov/conservation/endangered/status/SM.

Wilkerson, R. L, R. B. Siegel, and J. Schaberl. 2009. Landbird inventory for Mount Rainier National Park (2003–2004). Natural Resource Technical Report NPS/NCCN/NRTR—2009/164. National Park Service, Fort Collins, Colorado.

Wilson, S., and K. Martin. 2011. Life-history and demographic variation in an alpine specialist at the latitudinal extremes of the range. Population Ecology 53:459–471.

4.16 Mammalian Fauna

(Paul Griffin and Kurt Jenkins, USGS FRESC)

4.16.1 Introduction

MORA anchors an important network of protected lands in the southern Washington Cascades. Although MORA is a relatively small park compared to the surrounding federal land holdings, the subalpine parklands, lower elevation forests, and extensive riparian habitats in MORA serve as important habitat in the conservation of many mammalian species in Washington's southern Cascades. MORA is reknowned for its expansive alpine and subalpine habitats, which sustain several high-elevation mammal species such as the Cascade Red Fox, Hoary Marmot, Pika, and migratory ungulates such as Elk. At lower elevations, late-seral coniferous forests in MORA are associated with higher abundance of tree-roosting bat species (Thomas 1988), as well as Northern Flying Squirrels, Red-backed Voles, and other small mammals (Carey 1995, Aubry et al. 1991), which support diverse communities of both avian and mammalian carnivores. Although several species of the larger mammalian carnivores have been extirpated within MORA (reviewed below), the connectivity of MORA to other large federally protected holdings is critically important to long-range population recovery goals for some species (e.g., Fisher), and for the long term viability and conservation of others (e.g., Cascade Red Fox).

4.16.2 Approach

We consulted park records, historical documents, museum records, websites, and primary sources to assess the current status of mammalian fauna in MORA. Unfortunately, recent site-specific primary information was lacking, precluding us from assessing current status and trends for most species and faunal groups. Therefore, we conducted a 2-tiered appraisal. First, we assessed the status of mammalian biodiversity, based on reviewing the occurrence, management status, and threats associated with all mammalian species found in MORA. Second, we conducted more in-depth reviews of the current status for species and assemblages that have been recently inventoried or monitored in MORA; including the mammalian carnivores, bats, and elk populations.

Mammalian Biodiversity

Our assessment of biodiversity status relied heavily on previous summaries contained in NPSpecies, NatureServe, the Committee on the Status of Endangered Wildlife in Canada (COSEWIC), and the International Union of Conservation and Nature (IUCN), as well as Federal and State listing status (Tables 48–50).

Table 48. Distributions, occurrences, habitation, and status of mammal species present, historically present, or potentially present in Mount Rainier National Park.

Species (common name, scientific name)	Range-wide Distribution (NatureServe)	Occurrence In-Park (NPSpecies)	Abundance In-Park (NPSpecies)	Habitation In-Park (NPSpecies)	Significance of Park to Species	Range-wide Short-term Trend (NatureServe)	Within Park Short-term Trend
Mountain Goat *Oreamnos americanus*	AK, CO, ID, MT, NV, OR, SD, UT, WA, WY; AB, BC, NT, YT	Present in Park	Common	Native	Resident year round to seasonal resident (e.g. migratory)	Not assessed	Unknown
Elk *Cervus elaphus* (syn. *C. canadensis*)	AR, AZ, CA, CO, IL, IN, KS, KY, MI, MN, MT, NC, ND, NE, NM, NN, NV, OR, PA, SD, TX, UT, WA, WI, WY; AB, BC, MB, NT, ON, SK, YT	Present in Park	Abundant	Native	Seasonal resident	Not assessed	Unknown, although probably increasing
Black-tailed Deer *Odocoileus hemionus*	AK, AZ, CA, CO, ID, KS, MT, ND, NE, NM, NN, NV, OK, OR, SD, TX, UT, WA, WY; AB, BC, MB, NT, SK, YT	Present in Park	Abundant	Native	Resident year round to seasonal resident (e.g. migratory)	Not assessed	Unknown
Coyote *Canis latrans*	AK, AL, AR, AZ, CA, CO, CT, DE, FL, GA, IA, ID, IL, IN, KS, KY, LA, MA, MD, ME, MI, MN, MO, MS, MT, NC, ND, NE, NH, NJ, NM, NN, NV, NY, OH, OK, OR, PA, RI, SC, SD, TN, TX, UT, VA, VT, WA, WI, WV, WY; AB, BC, LB, MB, NB, NF, NS, NT, ON, PE, QC, SK, YT	Present in Park	Common	Native	Resident year round	Not assessed	Unknown
Gray Wolf *Canis lupus*	AK, AZ, ID, IL, ME, MI, MN, MT, NM, NV, OR, WA, WI, WY; AB, BC, LB, MB, NT, NU, ON, QC, SK, YT	Unconfirmed	NA	Native	Historically present; now extirpated	Increasing, but rate is not known	Increasing in the North Cascades region, in Okanogan NF. Packs (Wenatchee, Teanaway) expanding near north boundary
Cascade Red Fox *Vulpes vulpes cascadensis*	OR, WA †	Present in Park	Common	Native	Resident year round; MORA contains a significant proportion of habitat	Not assessed	Unknown
Canada Lynx *Lynx canadensis*	AK, CO, ID, ME, MI, MN, MT, ND, NH, OR, UT, VT, WA, WY; AB, BC, LB, MB, NB, NF, NS, NT, NU, ON, QC, SK, YT	Historic	NA	Native	Historically present; now extirpated	Short-term trend unknown; may be regionally variable	Unknown

Table 48. Distributions, occurrences, habitation, and status of mammal species present, historically present, or potentially present in Mount Rainier National Park (continued).

Species (common name, scientific name)	Range-wide Distribution (NatureServe)	Occurrence In-Park (NPSpecies)	Abundance In-Park (NPSpecies)	Habitation In-Park (NPSpecies)	Significance of Park to Species	Range-wide Short-term Trend (NatureServe)	Within Park Short-term Trend
Bobcat *Lynx rufus*	AL, AR, AZ, CA, CO, CT, DC, DE, FL, GA, IA, ID, IL, IN, KS, KY, LA, MA, MD, ME, MI, MN, MO, MS, MT, NC, ND, NE, NH, NJ, NM, NN, NV, NY, OH, OK, OR, PA, RI, SC, SD, TN, TX, UT, VA, VT, WA, WI, WV, WY; AB, BC, MB, NB, NS, ON, PE, QC, SK	Present in Park	Uncommon	Native	Resident year round	Relatively Stable	Unknown
Mountain Lion *Puma concolor*	AZ, CA, CO, CT, FL, GA, ID, IN, LA, MD, ME, MI, MN, MS, MT, NC, ND, NE, NH, NJ, NM, NN, NV, OK, OR, PA, RI, SC, SD, TX, UT, VA, VT, WA, WV, WY; AB, BC, MB, NB, NS, ON, QC, SK, YT	Present in Park	Rare	Native	Resident year round	Short-term trend unknown; may be regionally variable)	Unknown
Striped Skunk *Mephitis mephitis*	AL, AR, AZ, CA, CO, CT, DC, DE, FL, GA, IA, ID, IL, IN, KS, KY, LA, MA, MD, ME, MI, MN, MO, MS, MT, NC, ND, NE, NH, NJ, NM, NN, NV, NY, OH, OK, OR, PA, RI, SC, SD, TN, TX, UT, VA, VT, WA, WI, WV, WY ; AB, BC, MB, NB, NS, NT, ON, PE, QC, SK	Present in Park	Rare	Native	Occasional use by individuals	Not assessed	Unknown
Western Spotted Skunk *Spilogale gracilis*	AZ, CA, CO, ID, MT, NM, NN, NV, OK, OR, TX, UT, WA, WY; BC	Present in Park	Uncommon	Native	Resident year round	Not assessed	Unknown
Wolverine *Gulo gulo*	AK, CA, CO, ID, MT, NH, NV, OR, UT, WA, WY; AB, BC, LB, MB, NT, NU, ON, QC, SK, YT	Historic	NA	Native	Historically present; now possibly extirpated	Relatively stable to decline of 30%	Unknown
River Otter *Lontra canadensis*	AK, AL, AR, AZ, CA, CO, CT, DC, DE, FL, GA, IA, ID, IL, IN, KS, KY, LA, MA, MD, ME, MI, MN, MO, MS, MT, NC, ND, NE, NH, NJ, NM, NN, NV, NY, OH, OK, OR, PA, RI, SC, SD, TN, TX, UT, VA, VT, WA, WI, WV, WY; AB, BC, LB, MB, NB, NF, NS, NT, NU, ON, QC, SK, YT	Present in Park	Rare	Native	Resident year round	Relatively Stable	Unknown

Table 48. Distributions, occurrences, habitation, and status of mammal species present, historically present, or potentially present in Mount Rainier National Park (continued).

Species (common name, scientific name)	Range-wide Distribution (NatureServe)	Occurrence In-Park (NPSpecies)	Abundance In-Park (NPSpecies)	Habitation In-Park (NPSpecies)	Significance of Park to Species	Range-wide Short-term Trend (NatureServe)	Within Park Short-term Trend
American Marten *Martes americana*	AK, CA, CO, ID, ME, MI, MN, MT, NH, NM, NN, NV, NY, OR, SD, UT, VT, WA, WI, WY; AB, BC, LB, MB, NB, NF, NS, NT, NU, ON, QC, SK, YT	Present in Park	Uncommon	Native	Resident year round	Relatively stable	Unknown
Fisher *Pekania pennanti*	CA, CT, ID, MA, MD, ME, MI, MN, MT, ND, NH, NJ, NY, OR, PA, RI, TN, VA, VT, WA, WI, WV, WY; AB, BC, MB, NB, NS, NT, ON, QC, SK, YT	Unconfirmed	NA	Native	Historically present; now possibly extirpated	Relatively stable to decline of 30% (West Coast population segment)	Unknown; reintroduction planned as early as 2016
Ermine *Mustela erminea*	AK, CA, CO, CT, IA, ID, MA, ME, MI, MN, MT, ND, NH, NJ, NM, NV, NY, OH, OR, PA, RI, SD, UT, VT, WA, WI, WY; AB, BC, LB, MB, NB, NF, NS, NT, NU, ON, PE, QC, SK, YT	Present in Park	Uncommon	Native	Resident year round	Unknown; Ermine populations fluctuate with vole abundance	Unknown
Long-tailed Weasel *Mustela frenata*	AL, AR, AZ, CA, CO, CT, DC, DE, FL, GA, IA, ID, IL, IN, KS, KY, LA, MA, MD, ME, MI, MN, MO, MS, MT, NC, ND, NE, NH, NJ, NM, NN, NV, NY, OH, OK, OR, PA, RI, SC, SD, TN, TX, UT, VA, VT, WA, WI, WV, WY; AB, BC, MB, NB, ON, QC, SK	Present in Park	Uncommon	Native	Resident year round	Not assessed	Unknown
American Mink *Mustela vison* (syn. *Neovison vison*)	AK, AL, AR, CA, CO, CT, DC, DE, FL, GA, IA, ID, IL, IN, KS, KY, LA, MA, MD, ME, MI, MN, MO, MS, MT, NC, ND, NE, NH, NJ, NM, NN, NV, NY, OH, OK, OR, PA, RI, SC, SD, TN, TX, UT, VA, VT, WA, WI, WV, WY; AB, BC, LB, MB, NB, NF, NS, NT, NU, ON, PE, QC, SK, YT	Present in Park	Rare	Native	Resident year round	Not assessed	Unknown
Raccoon *Procyon lotor*	AL, AR, AZ, CA, CO, CT, DC, DE, FL, GA, IA, ID, IL, IN, KS, KY, LA, MA, MD, ME, MI, MN, MO, MS, MT, NC, ND, NE, NH, NJ, NM, NN, NV, NY, OH, OK, OR, PA, RI, SC, SD, TN, TX, UT, VA, VT, WA, WI, WV, WY; AB, BC, MB, NB, NS, ON, PE, QC, SK	Present in Park	Common	Native	Resident year round	Not assessed	Unknown

Table 48. Distributions, occurrences, habitation, and status of mammal species present, historically present, or potentially present in Mount Rainier National Park (continued).

Species (common name, scientific name)	**Range-wide Distribution (NatureServe)**	**Occurrence In-Park (NPSpecies)**	**Abundance In-Park (NPSpecies)**	**Habitation In-Park (NPSpecies)**	**Significance of Park to Species**	**Range-wide Short-term Trend (NatureServe)**	**Within Park Short-term Trend**
Black Bear *Ursus americanus*	AK, AL, AR, AZ, CA, CO, CT, FL, GA, ID, KY, LA, MA, MD, ME, MI, MN, MO, MS, MT, NC, NH, NJ, NM, NN, NV, NY, OH, OK, OR, PA, RI, SC, SD, TN, TX, UT, VA, VT, WA, WI, WV, WY; AB, BC, LB, MB, NB, NF, NS, NT, NU, ON, QC, SK, YT	Present in Park	Common	Native	Resident year round	Populations have increased recently in the northeastern US and in Oklahoma	Unknown
Grizzly Bear *Ursus arctos*	AK, ID, MT, WA, WY; AB, BC, NT, NU, YT	Unconfirmed	NA	Native	Historically present; now extirpated	Decline of 10 to 30%	Unknown
Townsend's Big-eared Bat *Corynorhinus townsendii* (syn *Plecotus townsendii*)	AR, AZ, CA, CO, ID, KS, KY, MT, NC, NE, NM, NN, NV, OK, OR, SD, TN, TX, UT, VA, WA, WV, WY; BC	Present in Park	Rare	Native	Resident year round	Not assessed	Unknown
Big Brown Bat *Eptesicus fuscus*	AK, AL, AR, AZ, CA, CO, CT, DC, DE, FL, GA, IA, ID, IL, IN, KS, KY, LA, MA, MD, ME, MI, MN, MO, MS, MT, NC, ND, NE, NH, NJ, NM, NN, NV, NY, OH, OK, OR, PA, RI, SC, SD, TN, TX, UT, VA, VT, WA, WI, WV, WY; AB, BC, MB, NB, ON, QC, SK	Present in Park	Uncommon	Native	Resident year round to seasonal resident (e.g., migratory)	Unknown	Unknown
Silver-haired Bat *Lasionycteris noctivagans*	AK, AL, AR, AZ, CA, CO, CT, DC, DE, FL, GA, IA, ID, IL, IN, KS, KY, LA, MA, MD, ME, MI, MN, MO, MT, NC, ND, NE, NH, NJ, NM, NN, NV, NY, OH, OK, OR, PA, RI, SC, SD, TN, TX, UT, VA, VT, WA, WI, WV, WY; AB, BC, MB, NB, NS, ON, QC, SK	Present in Park	Common	Native	Resident year round to seasonal resident (e.g., migratory)	Not assessed	Unknown
Hoary Bat *Lasiurus cinereus*	AL, AR, AZ, CA, CO, CT, DC, DE, FL, GA, HI, IA, ID, IL, IN, KS, KY, LA, MA, MD, ME, MI, MN, MO, MS, MT, NC, ND, NE, NH, NJ, NM, NN, NV, NY, OH, OK, OR, PA, RI, SC, SD, TN, TX, UT, VA, VT, WA, WI, WV, WY; AB, BC, MB, NB, NF, NS, NT, ON, PE, QC, SK	Present in Park	Rare	Native	Seasonal resident (e.g., migratory)	Not assessed	Unknown

Table 48. Distributions, occurrences, habitation, and status of mammal species present, historically present, or potentially present in Mount Rainier National Park (continued).

Species (common name, scientific name)	Range-wide Distribution (NatureServe)	Occurrence In-Park (NPSpecies)	Abundance In-Park (NPSpecies)	Habitation In-Park (NPSpecies)	Significance of Park to Species	Range-wide Short-term Trend (NatureServe)	Within Park Short-term Trend
California Myotis *Myotis californicus*	AK, AZ, CA, CO, ID, MT, NM, NN, NV, OR, TX, UT, WA; BC	Present in Park	Uncommon	Native	Resident year round - seasonal resident (e.g., migratory)	Not assessed	Unknown
Western Long-eared Bat *Myotis evotis*	AZ, CA, CO, ID, MT, ND, NM, NN, NV, OR, SD, UT, WA, WY; AB, BC, SK	Present in Park	Rare	Native	Resident year round - seasonal resident (e.g., migratory)	Relatively stable	Unknown
Little Brown Bat *Myotis lucifugus*	AK, AL, AR, CA, CO, CT, DC, DE, FL, GA, IA, ID, IL, IN, KS, KY, MA, MD, ME, MI, MN, MO, MS, MT, NC, ND, NE, NH, NJ, NM, NV, NY, OH, OK, OR, PA, RI, SC, SD, TN, UT, VA, VT, WA, WI, WV, WY; AB, BC, LB, MB, NB, NF, NS, NT, ON, PE, QC, SK, YT	Present in Park	Common	Native	Resident year round- seasonal resident (e.g., migratory)	Not assessed	Unknown
Long-legged Myotis *Myotis volans*	AK, AZ, CA, CO, ID, MT, ND, NE, NM, NN, NV, OR, SD, TX, UT, WA, WY; AB. BC	Present in Park	Rare	Native	Resident year round - seasonal resident (e.g., migratory)	Relatively stable	Unknown
Yuma Myotis *Myotis yumanensis*	AZ, CA, CO, ID, MT, NM, NN, NV, OK, OR, TX, UT, WA, WY; BC	Present in Park	Rare	Native	Resident year round - seasonal resident (e.g., migratory)	Unknown	Unknown
Virginia Opossum *Didelphis virginiana*	AL, AR, AZ, CA, CO, CT, DC, DE, FL, GA, IA, ID, IL, IN, KS, KY, LA, MA, MD, ME, MI, MN, MO, MS, NC, ND, NE, NH, NJ, NM, NY, OH, OK, OR, PA, RI, SC, SD, TN, TX, UT, VA, VT, WA, WI, WV, WY; BC, ON, QC	Present in Park	Rare	Non-Native	Resident year round - Occasional use by individuals	Not assessed	Unknown
Snowshoe Hare *Lepus americanus*	AK, CA, CO, CT, ID, MA, MD, ME, MI, MN, MT, ND, NH, NM, NV, NY, OR, PA, RI, UT, VA, VT, WA, WI, WV, WY; AB, BC, LB, MB, NB, NF, NS, NT, NU, ON, PE, QC, SK, YT	Present in Park	Common	Native	Resident year round	Not assessed	Unknown
American Pika *Ochotona princeps*	CA, CO, ID, MT, NM, NN, NV, OR, UT, WA, WY; AB, BC	Present in Park	Common	Native	Resident year round	Not assessed	Unknown

Table 48. Distributions, occurrences, habitation, and status of mammal species present, historically present, or potentially present in Mount Rainier National Park (continued).

Species (common name, scientific name)	Range-wide Distribution (NatureServe)	Occurrence In-Park (NPSpecies)	Abundance In-Park (NPSpecies)	Habitation In-Park (NPSpecies)	Significance of Park to Species	Range-wide Short-term Trend (NatureServe)	Within Park Short-term Trend
Mountain Beaver *Aplodontia rufa*	CA, NV, OR, WA; BC	Present in Park	Common	Native	Resident year round	Not assessed	Unknown
Beaver *Castor canadensis*	AK, AL, AR, AZ, CA, CO, CT, DC, DE, FL, GA, IA, ID, IL, IN, KS, KY, LA, MA, MD, ME, MI, MN, MO, MS, MT, NC, ND, NE, NH, NJ, NM, NN, NV, NY, OH, OK, OR, PA, RI, SC, SD, TN, TX, UT, VA, VT, WA, WI, WV, WY; AB, BC, LB, MB, NB, NF, NS, NT, NU, ON, PE, QC, SK, YT	Present in Park	Rare	Native	Resident year round	Increase of 10 to >25%	Unknown
Pacific Jumping Mouse *Zapus trinotatus*	CA, OR, WA; BC	Present in Park	Common	Native	Resident year round	Not assessed	Unknown
Porcupine *Erethizon dorsatum*	AK, AZ, CA, CO, CT, ID, KS, MA, MD, ME, MI, MN, MT, ND, NE, NH, NJ, NM, NN, NV, NY, OK, OR, PA, RI, SD, TX, UT, VT, WA, WI, WV, WY;	Present in Park	Rare	Native	Resident year round	Not assessed	Unknown
Western Pocket Gopher *Thomomys mazama*	CA, OR, WA; BC	Unconfirmed	NA	Native	Unlikely to occur; not historically or now present	Not assessed	Unknown
Northern Pocket Gopher *Thomomys talpoides*	AZ, CA, CO, ID, MN, MT, ND, NE, NM, NN, NV, OR, SD, UT, WA, WY; AB, BC, MB, SK	Present in Park	Unknown	Native	Resident year round	Not assessed	Unknown
Southern Red-backed Vole *Clethrionomys gapperi* (syn. *Myodes gapperi*)	AK, AZ, CO, CT, GA, IA, ID, KY, MA, MD, ME, MI, MN, MT, NC, ND, NH, NJ, NM, NY, OH, OR, PA, RI, SC, SD, TN, UT, VA, VT, WA, WI, WV, WY; AB, BC, LB, MB, NB, NF, NS, NT, NU, ON, PE, QC, SK, YT	Present in Park	Uncommon	Native	Resident year round	Not assessed	Unknown
Long-tailed Vole *Microtus longicaudus*	AK, AZ, CA, CO, ID, MT, NM, NN, NV, OR, SD, UT, WA, WY; AB, BC, NT, YT	Present in Park	Uncommon	Native	Resident year round	Not assessed	Unknown
Montane Vole *Microtus montanus*	AZ, CA, CO, ID, MT, NM, NV, OR, UT, WA, WY; BC	Unconfirmed	NA	Native	Resident year round	Not assessed	Unknown
Creeping Vole *Microtus oregoni*	CA, OR, WA; BC	Present in Park	Common	Native	Resident year round	Not assessed	Unknown

Table 48. Distributions, occurrences, habitation, and status of mammal species present, historically present, or potentially present in Mount Rainier National Park (continued).

Species (common name, scientific name)	Range-wide Distribution (NatureServe)	Occurrence In-Park (NPSpecies)	Abundance In-Park (NPSpecies)	Habitation In-Park (NPSpecies)	Significance of Park to Species	Range-wide Short-term Trend (NatureServe)	Within Park Short-term Trend
Water Vole *Microtus richardsoni*	ID, MT, OR, UT, WA, WY; AB, BC	Present in Park	Uncommon	Native	Resident year round	Not assessed	Unknown
Townsend's Vole *Microtus townsendii*	CA, OR, WA; BC	Present in Park	Unknown	Native	Resident year round	Not assessed	Unknown
House Mouse *Mus musculus*	AL, AR, AZ, CA, CO, CT, DC, DE, FL, GA, IA, ID, IL, IN, KS, KY, LA, MA, MD, ME, MI, MN, MO, MS, MT, NC, ND, NE, NH, NJ, NM, NN, NV, NY, OH, OK, OR, PA, RI, SC, SD, TN, TX, UT, VA, VT, WA, WI, WV, WY; AB, BC, LB, MB, NB, NF, NS, NT, ON, PE, QC, SK, YT	Historic	NA	Non-Native	Unknown	Not assessed	Unknown
Bushy-tailed Woodrat *Neotoma cinerea*	AK, AZ, CA, CO, ID, MT, ND, NE, NM, NN, NV, OR, SD, UT, WA, WY; AB, BC, NT, SK, YT	Present in Park	Unknown	Native	Resident year round	Not assessed	Unknown
Muskrat *Ondatra zibethicus*	AK, AL, AR, AZ, CA, CO, CT, DC, DE, GA, IA, ID, IL, IN, KS, KY, LA, MA, MD, ME, MI, MN, MO, MS, MT, NC, ND, NE, NH, NJ, NM, NN, NV, NY, OH, OK, OR, PA, RI, SC, SD, TN, TX, UT, VA, VT, WA, WI, WV, WY; AB, BC, LB, MB, NB, NF, NS, NT, NU, ON, PE, QC, SK, YT	Historic	NA	Native	Resident year round	Not assessed	Unknown
Keen's Mouse *Peromyscus keeni*	AK, WA; BC, YT	Present in Park	Unknown	Native	Resident year round	Unknown	Unknown
Deer Mouse *Peromyscus maniculatus*	AK, AR, AZ, CA, CO, CT, GA, IA, ID, IL, IN, KS, KY, MA, MD, ME, MI, MN, MO, MS, MT, NC, ND, NE, NH, NJ, NM, NN, NV, NY, OH, OK, OR, PA, SC, SD, TN, TX, UT, VA, VT, WA, WI, WV, WY; AB, BC, LB, MB, NB, NF, NS, NT, ON, PE, QC, SK, YT	Present in Park	Abundant	Native	Resident year round	Not assessed	Unknown
Heather Vole *Phenacomys intermedius*	CA, CO, ID, MT, NM, OR, UT, WA, WY; AB, BC, LB, SK	Present in Park	Common	Native	Resident year round	Unknown	Unknown

Table 48. Distributions, occurrences, habitation, and status of mammal species present, historically present, or potentially present in Mount Rainier National Park (continued).

Species (common name, scientific name)	Range-wide Distribution (NatureServe)	Occurrence In-Park (NPSpecies)	Abundance In-Park (NPSpecies)	Habitation In-Park (NPSpecies)	Significance of Park to Species	Range-wide Short-term Trend (NatureServe)	Within Park Short-term Trend
Norway Rat *Rattus norvegicus*	AK, AL, AR, AZ, CA, CO, CT, DC, DE, FL, GA, IA, ID, IL, IN, KS, KY, LA, MA, MD, ME, MI, MN, MO, MS, MT, NC, ND, NE, NH, NJ, NM, NV, NY, OH, OK, OR, PA, RI, SC, SD, TN, TX, UT, VA, VT, WA, WI, WV, WY; AB, BC, LB, MB, NB, NF, NS, ON, PE, QC, SK	Historic	NA	Non-Native	Unknown	Not assessed	Unknown
Northern Flying Squirrel *Glaucomys sabrinus*	AK, CA, ID, MA, ME, MI, MN, MT, NC, ND, NH, NJ, NV, NY, OH, OR, PA, SD, TN, UT, VA, VT, WA, WI, WV, WY; AB, BC, LB, MB, NB, NS, NT, ON, PE, QC, SK, YT	Present in Park	Common	Native	Resident year round	Not assessed	Unknown
Hoary Marmot *Marmota caligata*	AK, ID, MT, WA; AB, BC, NT, YT	Present in Park	Common	Native	Resident year round	Not assessed	Unknown
Cascade Golden-mantled Ground Squirrel *Spermophilus saturatus*	WA; BC	Present in Park	Common	Native	Resident year round	Relatively stable	Unknown
Yellow-pine Chipmunk *Tamias amoenus* (syn. *Neotamias amoenus*)	CA, ID, MT, NV, OR, UT, WA, WY; AB, BC	Present in Park	Abundant	Native	Resident year round	Not assessed	Unknown
Townsend's Chipmunk *Tamias townsendii* (syn. *Neotamias townsendii*)	OR, WA; BC	Present in Park	Abundant	Native	Resident year round	Not assessed	Unknown
Douglas's Squirrel *Tamiasciurus douglasii*	CA, NV, OR, WA; BC	Present in Park	Abundant	Native	Resident year round	Not assessed	Unknown
Bendire's Water Shrew *Sorex bendirii*	CA, OR, WA; BC	Present in Park	Uncommon	Native	Resident year round	Population in BC is rare and thought to be declining	Unknown
Masked Shrew *Sorex cinereus*	AK, CO, CT, DE, GA, IA, ID, IL, IN, KY, MA, MD, ME, MI, MN, MT, NC, ND, NH, NJ, NM, NY, OH, PA, RI, SC, SD, TN, UT, VA, VT, WA, WI, WV, WY; AB, BC, LB, MB, NB, NF, NS, NT, NU, ON, PE, QC, SK, YT	Probably Present	NA	Native	Resident year round	Not assessed	Unknown

Table 48. Distributions, occurrences, habitation, and status of mammal species present, historically present, or potentially present in Mount Rainier National Park (continued).

Species (common name, scientific name)	Range-wide Distribution (NatureServe)	Occurrence In-Park (NPSpecies)	Abundance In-Park (NPSpecies)	Habitation In-Park (NPSpecies)	Significance of Park to Species	Range-wide Short-term Trend (NatureServe)	Within Park Short-term Trend
Montane Shrew *Sorex monticolus*	AK, AZ, CA, CO, ID, MT, NM, NN, NV, OR, UT, WA, WY; AB, BC, MB, NT, SK, YT	Present in Park	Common	Native	Resident year round	Not assessed	Unknown
Water Shrew *Sorex palustris*	AK, AZ, CA, CO, CT, GA, ID, MA, MD, ME, MI, MN, MT, NC, NH, NJ, NM, NV, NY, OR, PA, RI, SC, SD, TN, UT, VA, VT, WA, WI, WV, WY; AB, BC, LB, MB, NB, NS, NT, ON, PE, QC, SK, YT	Present in Park	Uncommon	Native	Resident year round	Relatively stable to decline of 30%	Unknown
Trowbridge's Shrew *Sorex trowbridgii*	CA, NV, OR, WA; BC	Present in Park	Common	Native	Resident year round	Unknown	Unknown
Vagrant Shrew *Sorex vagrans*	CA, ID, MT, NN, NV, OR, UT, WA, WY; AB, BC	Present in Park	Common	Native	Resident year round	Not assessed	Unknown
American Shrew Mole *Neurotrichus gibbsii*	CA, OR, WA; BC	Present in Park	Common	Native	Resident year round	Not assessed	Unknown
Pacific Mole *Scapanus orarius*	CA, ID, OR, WA; BC	Present in Park	Unknown	Native	Resident year round	Not assessed	Unknown
Townsend's Mole (syn. Snow Mole) *Scapanus townsendii*	CA, OR, WA; BC	Probably Present	NA	Native	Resident year round	Not assessed	Unknown

Table 49. Management status of mammals present or potentially present in MORA.

					NatureServe					
Common name	**US ESA**	**COSEWIC**	**WA**	**BC Status and SARA**	**Global (G)**	**US (N)**	**WA (S)**	**IUCN**	**MORA**	**Comments**
Mountain Goat	No listing	No listing			5	5	2,3	LC	Management priority; Exploitation concern	
Elk	No listing in USA	No listing			5	5	5	LC	Management priority; Exploitation concern	No listing in USA. Some Eurasian subspecies are LE
Black-tailed Deer	No listing in USA	No listing			5	5	5	LC		No listing in USA. The *O. h. cedrosensis* subspecies in Mexico is LE
Coyote	No listing	No listing			5	5	5	LC		
Gray Wolf	PS: LE	NAR	SE		4	4	1	LC	Management priority	LE in coterminous states, except in MN, WI, MI, eastern SD, and northern IA, portions of IL, ON, and OH – XN in AZ, NM, TX; MT, ID, WY. All Canadian populations were NAR, except that the arctic subspecies in NT and NU were DD
Cascade Red Fox	No listing	No listing	SC		*	*	*	*	Management priority; Exploitation concern	*Status of the subspecies is not considered (by NatureServe) – lowland introduced species *V. vulpes* is 5, 5, 5, LC
Canada Lynx	LT: lower 48	NAR	ST		5	4	1	LC	Management priority	
Bobcat	No listing in USA	No listing			5	5	5	LC		The Mexican subspecies (*L. r. escuinape*) was listed as LE as of 2005, but delisting has been proposed
Mountain Lion	PS	PS			5	5	4,5	LC	Management priority; Exploitation concern	The Florida Panther (*P. c. coryi*) and Eastern Puma (*P. c. cougar*) are LE – outside the USA, *P. c. costaricensis* is LE – in Canada, no listing for western population; eastern population listed as DD
Striped Skunk	No listing	No listing			5	5	5	LC		
Western Spotted Skunk	No listing	No listing			5	5	4	LC		
Wolverine	C: lower 48	SC, E	SC	Red* Blue*	4	4	1	LC	Management priority	In Canada, western population listed as SC, and the eastern population listed as E – Vancouver Island subspecies is listed Red and the mainland subspecies is listed Blue in BC

Table 49. Management status of mammals present or potentially present in MORA (continued).

					NatureServe					
Common name	**US ESA**	**COSEWIC**	**WA**	**BC Status and SARA**	**Global (G)**	**US (N)**	**WA (S)**	**IUCN**	**MORA**	**Comments**
River Otter	No listing	No listing			5	5	4	LC		
American Marten	No listing	PS			5	5	4	LC		Subspecies in Newfoundland (*M.a. atrata*) listed as threatened
Fisher	C in WA, OR, CA	No listing	SE		5	5	SH	LC	Management priority; Reintroduction planned	Western population segment is a candidate for ESA listing
Ermine	No listing	PS			5	5	5	LC		In BC, the subspecies on Haida Gwaii islands (*M.e. haidarum*) is listed as threatened
Long-tailed Weasel	No listing	PS			5	5	5	LC		In Canada, the populations in AB, SK, and MB were found to be not at risk; other populations have no status in Canada
American Mink	No listing	PS			5	5	5	LC		Exotic species in Newfoundland
Raccoon	No listing	No listing			5	5	5	LC		
Black Bear	PS	NAR			5	5	5	LC	Management priority; Exploitation concern	Louisiana Black Bear population (*U. a. luteolus*) is LT in LA, MS, and TX
Grizzly Bear	PS	XT, SC	SE	Blue	4	3,4	1	LC		LT in the coterminous states, except where it is XN in portions of ID and MT – in Canada, prairie population extirpated from AB, MB and SK; special concern for NW population in AB, BC, NU, NT, YT – LE in Mexico, Italy, and parts of China
Townsend's Big-eared Bat	PS, SC	No listing	SC	Blue	4	4	2,3	LC	Management priority; Habitat concern	Federal SC in WA – subspecies *C. t. ingens* is LE in AR, MO, and OK – subspecies *C. t. virginianus* is LE in KY, NC, VA, and WV
Big Brown Bat	No listing	No listing			5	5	5	LC		
Silver-haired Bat	No listing	No listing			5	5	3,4	LC		
Hoary Bat	PS	No listing			5	5	3,4	LC		The Hawaiian subspecies *L. c. semotus* is LE
California Myotis	No listing	No listing			5	5	3,4	LC		
Western Long-eared Bat	SC	No listing	SM		5	5	4	LC		
Little Brown Bat	No listing	No listing			5	5	4,5	LC		
Long-legged Myotis	SC	No listing	SM		5	5	3,4	LC		

Table 49. Management status of mammals present or potentially present in MORA (continued).

					NatureServe					
Common name	**US ESA**	**COSEWIC**	**WA**	**BC Status and SARA**	**Global (G)**	**US (N)**	**WA (S)**	**IUCN**	**MORA**	**Comments**
Yuma Myotis	No listing	No listing			5	5	5	LC		
Virginia Opossum	No listing	No listing			5	5	NA	LC		
Snowshoe Hare	No listing	No listing		Red*	5	5	5	LC		Subspecies *L. a. washingtonii* in the Fraser Valley is listed Red in BC
American Pika	No listing	No listing			5	5	5	LC	Management priority	
Mountain Beaver	PS	SC		Blue: 1*	5	5	5	LC		The Point Arena subspecies *A. r. nigra* in Mendocino County, CA, is LE – subspecies *A. r. rufa* Blue Schedule 1 in BC
Beaver	No listing	No listing			5	5	5	LC		
Pacific Jumping Mouse	No listing	No listing			5	5	5	LC		
Porcupine	No listing	No listing			5	5	5	LC		
Western Pocket Gopher	No listing	No listing	ST		4	4	2	LC		This species is not now, and was not historically, present in MORA
Northern Pocket Gopher	No listing	No listing		Red*	5	5	5	LC		Subspecies *T. t. segregatus* from near Wyndell, BC, is listed Red
Southern Red-backed Vole	No listing	No listing		Red*	5	5	5	LC		Subspecies *M. g. occidentalis* at the west edge of the Fraser Valley is listed Red in BC
Long-tailed Vole	No listing	No listing			5	5	5	LC		
Montane Vole	No listing	No listing			5	5	5	LC		
Creeping Vole	No listing	No listing			5	5	4	LC		
Water Vole	No listing	No listing			5	5	5	LC		
Townsend's Vole	No listing	No listing		Red*	5	5	5	LC		Subspecies *M. t. cowani* from Triangle Island off the northern tip of Vancouver Island is listed Red in BC
House Mouse	No listing	No listing			5	NA	NA	LC		
Bushy-tailed Woodrat	No listing	No listing			5	5	5	LC		
Muskrat	No listing	No listing			5	5	5	LC		
Keen's Mouse	No listing	No listing			5	5	4	LC		
Deer Mouse	No listing	No listing			5	5	5	LC		
Heather Vole	No listing	No listing			5	5	5	LC		
Norway Rat	No listing	No listing			5	NA	NA	LC	Presence in park questionable	

Table 49. Management status of mammals present or potentially present in MORA (continued).

					NatureServe					
Common name	**US ESA**	**COSEWIC**	**WA**	**BC Status and SARA**	**Global (G)**	**US (N)**	**WA (S)**	**IUCN**	**MORA**	**Comments**
Northern Flying Squirrel	PS	No listing			5	5	4,5	LC		Appalachian subspecies *G. s. coloratus* is LE
Hoary Marmot	No listing	No listing			5	5	4,5	LC		
Cascade Golden-mantled Ground Squirrel	No listing	NAR			5	4	5	LC		
Yellow-pine Chipmunk	No listing	No listing			5	5	5	LC		
Townsend's Chipmunk	No listing	No listing			5	5	5	LC		
Douglas's Squirrel	No listing	No listing			5	5	5	LC		
Bendire's Water Shrew	No listing	E	SM	Red: 1	4	4	4	LC		
Masked Shrew	No listing	No listing			5	5	4,5	LC		
Montane Shrew	No listing	No listing			5	5	4	LC		
Water Shrew	No listing	No listing		Red*	5	5	4	LC		Vancouver Island subspecies *S. p. brooksi* is listed Red in BC
Trowbridge's Shrew	No listing	No listing		Blue	5	5	5	LC		
Vagrant Shrew	No listing	No listing			5	5	5	LC		
American Shrew Mole	No listing	No listing			5	5	5	LC		
Pacific Mole	No listing	No listing			5	5	5	LC		
Townsend's Mole	No listing	E		Red: 1	5	5	5	LC		

1. US ESA: LE–Listed Endangered; LT–Listed Threatened; C–Candidate; SC–Species of Concern; PS–Partial Status; XN–Experimental Nonessential

2. COSEWIC: E–Extirpated; SC–Special Concern; XT–Extirpated; PS–Partial Status; NAR–Not at Risk; DD–Data Deficient

3. WA (Washington): SE¬–Sate Endangered; ST–State Threatened; SC–State Candidate; SM–State Monitored

4. BC Status and Species at Risk Act (SARA): Blue–Special Concern; Red–Extirpated, Endangered, Threatened; 1–Schedule 1, Extirpated, Endangered, Threatened, or of Special Concern; *–Listing for only part of Province

5. NatureServe: 1–Critically Imperiled; 2–Imperiled; 3–Vulnerable; 4–Apparently Secure; 5–Secure; SH–Possibly Extirpated; NA–Not Suitable Species for Conservation Activities

6. IUCN: LC–Least Concern

Table 50. Mammals present or potentially present in MORA having threats listed by NatureServe. In most cases, the threat types listed in NatureServe are general, applying to some unspecified portion(s) of the species range, and do not apply specifically to MORA.

Common name	Threats (NatureServe)
Black-tailed Deer	Habituated deer are at elevated risk of collisions with vehicles; Hunting is not a threat, per se, because it is regulated
Cascade Red Fox	Habituated foxes are at elevated risk of collisions with vehicles; Food handouts from visitors may be leading foxes to use roads, and risking vehicular collision; Climate change may influence this high-elevation obligate subspecies
Canada Lynx	Climate change may reduce snowpack, changing the distribution of preferred Engelmann Spruce habitats (leading to fragmentation) and Snowshoe Hare populations
Bobcat	Coyotes compete with Bobcats for prey
Mountain Lion	Loss of remote, undisturbed habitats is a problem in some areas
Wolverine	Risk due to climate change is due to strong association with snow cover
Black Bear	Locally threatened by habitat loss and interference by humans; Black market value of gall bladder and paws has led to an increase in the illegal harvest of this species; Gall bladder and paws are of great value in the Asian black market; Management Requirements: Adults (e.g., "problem bears") must be moved at least 64 km to assure that less than 50% return to original location; No increase in natural mortality occurs in translocated bears of age 2 yr or older
Townsend's Big-eared Bat	Closure or reclamation of abandoned mines may lead to roosting habitat loss unless mitigation measures are taken; Recreational caving, and mine and cave surveys may disturb bats; In this species, gates can reduce this threat. There is threat potential if mine and cave surveys are conducted during breeding periods and winter hibernation; This species is a colonial hibernator in cool, moist caves, therefore, if White Nose Syndrome (WNS) spreads to the Pacific Northwest, species may be particularly at risk
Big Brown Bat	Grazing and associated loss of riparian habitat value could affect big brown bats; Species may roost in large-diameter snags; Recreational caving, and mine and cave surveys may disturb bats; This species is colonial where adequate roost sites are available, and it hibernates. If WNS spreads to the Pacific Northwest, this hibernating species would likely be susceptible
Silver-haired Bat	Sometimes roost in trees and under bark – clusters of snags appear to be important; If White Nose Syndrome spreads to the Pacific Northwest, it may pose a risk to all bats in the region; Silver-haired Bats generally migrate long-distances, not hibernating, and so might be somewhat protected from WNS. Some individuals, though, do hibernate in the region and may be predominantly juveniles, so species may still face high risk of WNS
Hoary Bat	Pesticide use on forest lands may affect the bats directly, and their insect prey; Species roosts in trees; If WNS spreads to the Pacific Northwest, all bats in the region may be at risk; Hoary Bats, though, are long-distance migrants, do not hibernate and are rather solitary, and so may be somewhat protected from WNS
California Myotis	Species could be affected by loss of large-diameter snags; Recreational caving, and mine and cave surveys may disturb bats; If WNS spreads to the Pacific Northwest, hibernating bat species such as this will be particularly at risk
Western Long-eared Bat	Affected by developments that impact cliff faces or rock outcrops; Recreational caving, and mine and cave surveys may disturb bats; If WNS spreads to the Pacific Northwest, hibernating bat species such as this will be particularly at risk; In 1998, WA natural heritage program staff indicated to NatureServe that this species is not very threatened in the state

Table 50. Mammals present or potentially present in MORA having threats listed by NatureServe. In most cases, the threat types listed in NatureServe are general, applying to some unspecified portion(s) of the species range, and do not apply specifically to MORA (continued).

Common name	Threats (NatureServe)
Little Brown Bat	Cyanide use in hard rock mining poses some risks to the species; This forest-associated species is affected by logging, especially loss of snags; Recreational caving, and mine and cave surveys may disturb bats; If WNS spreads to the Pacific Northwest, hibernating bats species such as this will be particularly at risk; Populations of this once common species have collapsed in the eastern US due to WNS; Hibernation sites in the west are poorly known
Long-legged Myotis	Closure or reclamation of abandoned mines may lead to roosting habitat loss unless mitigation measures are taken; Habitat loss due to logging; Recreational caving, and mine and cave surveys may disturb bats; If WNS spreads to the Pacific Northwest, cave-hibernating bats species such as this will be particularly at risk
Yuma Myotis	Species frequently roosts in human structures, so it may be at risk of pest control activities; Closure or reclamation of abandoned mines may lead to roosting habitat loss unless mitigation measures are taken; Recreational caving, and mine and cave surveys may disturb bats; Some riparian management practices may lead to loss of roost sites; If WNS spreads to the Pacific Northwest, hibernating bats species such as this will be particularly at risk
Snowshoe Hare	Loss of understory forest cover as second growth forests mature; Changes in snow pack may expose hares to higher predation rates if the timing of molt does not match the timing of snowfall
Beaver	Logging of deciduous trees
Western Pocket Gopher	Species is not now, and was not historically, present in the park
Cascade Golden-mantled Ground Squirrel	Finding of no threats in Canada is based on a 1992 COSEWIC report
Bendire's Water Shrew	Threats due to runoff and storm water management associated with urban and exurban development
Water Shrew	Logging may pose a threat due to water quality degradation; Climate change may isolate and fragment populations

Mammalian Carnivores

We reviewed available published literature, museum records, and any unpublished reports provided to us, including a database of available geo-referenced wildlife observations reported by the public or park staff. We considered mapping the locations of wildlife observations recorded in the park's database, but the locations sampled by observers were obviously biased in favor of roads, trails, and park facilities. This database is the result of unquantified detection, reporting, and recording rates, so we opted to not evaluate these observations graphically. For historical context, we relied heavily on the early work of Taylor (1922), who described wildlife presence and distribution patterns in the first decades following the park's establishment.

The park conducted the first park-wide effort to document carnivore species presence with a statistically valid sample in the winters of 2000–2001 and 2001–2002 (Reid et al. 2010). Baited, motion-triggered cameras were placed within systematically located 4 square miles sampling blocks. Detections of species established occupancy within sampling blocks. For logistical reasons, slightly more than half of the park was not included in the sampling frame, including much of the mid-elevation and subalpine habitats. We acknowledge that the relationship between any index of detection and abundance is probably non-linear, and dependent on unquantified effects of detection bias, body size, and other factors, but patterns of occupancy are often related to population size (MacKenzie and Nichols 2004). We also acknowledge that widespread detection patterns provide no information on population trends, nor any guarantee of population resilience in the face of future stressors, such as climate change.

Bats

We reviewed a baseline survey conducted in MORA (Petterson 2009), an inventory for bats conducted at 60 buildings and 2 bat boxes in MORA (Myers 2010), and available literature and reports pertinent to the surrounding area. We reviewed available surveys of bat evidence conducted by Washington DNR in abandoned and inactive mines within approximately 10 km of MORA. Species detection data collected by the interagency Bat Grid Inventory and Monitoring Group (Pat Ormsbee, USFS, Oregon, pers. comm.) on nearby U.S. Forest Service lands were not yet available for us to review; that group does not currently survey NPS lands.

One-third of the study sites in Petterson (2009) were randomly located within 3 elevational strata, while the other two-thirds of the study sites in each stratum were selected intentionally. Petterson (2009) used mist nets to survey for bats at 43 sites in MORA, and used passive acoustic sampling at 18 of those sites. Sites were in 3 habitat types (riparian backwater, low elevation forest, and subalpine). Elevations sampled ranged from 540 to 1820 m (1772 to 5971 ft). The methods were appropriate for documenting presence and relative frequency of the bats detected, but not population abundance. The acoustic sampling detected echolocation calls in 5 frequency classes: 1 frequency class was specific to Hoary Bats; 1 class was specific to Long-eared Myotis; 3 classes were specific to pairs of species (California Myotis or Yuma Myotis; Little Brown Bat or Long-legged Myotis; Big Brown Bat or Silver-haired Bat).

Elk

We reviewed the results of aerial surveys of Elk that have been conducted during late summer or early autumn (as funding has permitted) since 1974 on subalpine summer ranges in MORA. All surveys have been conducted through cooperation of the National Park Service, Washington Department of Fish and Wildlife, Muckleshoot Indian Tribe, and the Puyallup Tribe of Indians. Population trends have been estimated as an average of 4 indices multiplied by a factor of 2 to account for detection biases. The index is called the E4 index and is described in detail by Griffin et al. (2012). The E4 metric does not have an estimate of uncertainty and does not account for detection bias, but it probably reflects real trends in past Elk abundance. Recently, use of the E4 metric has been replaced with a direct estimate of abundance (Griffin et al. 2012), but the trend analysis of those estimates will not be published until 2014.

4.16.3 Reference Conditions and Comparison Metrics

Based on the reference conditions identified and defined by Stoddard et al. (2006), we judged the appropriate reference condition for mammalian fauna to be the 'Minimally Disturbed Condition' which refers to the condition of a resource in a landscape with minimum human disturbance (i.e., natural disturbance regimes are excluded from consideration). In general, the Minimally Disturbed Condition is judged relative to conditions first reported early in the park's history. This would include viable populations of all of the mammalian carnivore species that were historically present in the park, as part of regionally connected populations in the southern Washington Cascades.

Although this concept applies generally to most mammalian taxa in the park, it is difficult to assign a reference condition for Elk populations based on historical conditions because the park as first seen by early explorers may not represent prehistoric conditions. There is evidence of widespread contraction of Elk range and abundance during the 1800s throughout eastern Washington and the Cascade Range, based on limited archeological and anthropological records (Gustavson 1983, Schullery 1984). It appears that there were very few Elk present in the area that is now MORA when it was first glimpsed by early Euro-American explorers and settlers. The causes and extent of population reductions from pristine conditions are poorly understood; hence, it is not known whether low densities that occurred at the time of Euro-American contact represent a reasonable reference condition against which to compare contemporary conditions. The reference condition for Elk in MORA has been managed over the last decades as the 'Best Attainable Condition' (*sensu* Stoddard et al. (2006)). Although summer Elk habitat conditions in the park are of high quality, the surrounding region is altered. Elk populations are influenced by silviculture outside the park, by the state wildlife agency (WDFW), and by Native American tribes that exercise their sovereign hunting rights. The desirable condition is for Elk that summer in the park to be at a moderate density: high enough to recover from severe weather or disease outbreaks that may occur, yet low enough as to not adversely affect vegetation and soils through grazing, browsing, and trampling. The range of observed densities from approximately the 1960s to today has not been shown to have lasting negative impacts on other park resources, although high Elk densities reached during the 1980s caused considerable concern over the potential impacts of Elk trampling on the amount of bare soil (Bradley 1983) and trailing (Ripple et al. 1988) in subalpine meadows. Therefore, the range of densities of Elk using the subalpine meadows in MORA over the last decades, with the possible exception of high densities during the 1980s, sets a reasonable standard for the range of acceptable densities in the future.

4.16.4 Results and Assessment

Mammalian Biodiversity

Up to 58 native mammal species may currently reside during some or all of the year in MORA (Table 48), based on documentation in NPSpecies and the published literature we reviewed. Since the park was designated, 5 species (Canada Lynx, Fisher, Gray Wolf, Grizzly Bear, and Wolverine) appear to have been extirpated from the park and surrounding area. Three species of non-native mammals (House Mouse, Norway Rat, and Virginia Opossum) may also be present in the park. One species (Western Pocket Gopher) mistakenly listed on NPSpecies as present in MORA has no valid record in MORA.

All 5 of the extirpated carnivores listed above are federally or state listed or are candidates for listing as threatened or endangered (Table 49). In this geographic area, the Gray Wolf is federally listed as endangered, the Grizzly Bear and Canada Lynx are federally listed as threatened, and the Wolverine and Fisher are candidates for federal listing. Three bats that occur in MORA (Long-legged Myotis, Townsend's Big-eared Bat, and Western Long-eared Bat) are federal species of special concern. The Gray Wolf, Grizzly Bear, and Fisher are state listed as endangered in Washington; the Canada Lynx is state listed as threatened; the Cascade Red Fox, Wolverine, and Townsend's Big-eared Bat are state candidate species; and 3 species (Bendire's Water Shrew, Long-legged Myotis, and Western Long-eared Bat) are state listed as of interest for monitoring. British Columbian populations of 2 species (Bendire's Water Shrew and Townsend's Mole) are listed as endangered and 3 species (Grizzly Bear, Mountain Beaver, and Wolverine) are of special concern under the Committee on the Status of Endangered Wildlife in Canada. International conservation efforts will continue to be important in the Cascade Range. Populations of Fisher, Gray Wolf, Lynx, and Wolverine from Canada and the North Cascades may be sources for natural immigration and human-aided reintroductions into the MORA region of the United States while, conversely, Bendire's Water Shrew, Mountain Beaver, and Townsend's Mole all have robust populations in the United States that could augment populations in British Columbia, Canada, in the future.

The non-native Virginia Opossum was documented at Kautz Creek (Reid et al. 2010) in MORA, but its prevalence in the park is unknown. The non-native House Mouse and Norway Rat may be present near buildings, but they were not documented in materials we reviewed, suggesting that neither is currently widespread in MORA.

We conclude that with the exception of several of the larger carnivores, elaborated below, the mammalian fauna in MORA is intact, and there are negligible known populations of exotic mammalian species. We conclude that the current status of mammalian biodiversity is close to the Minimally Disturbed reference condition, but that the loss of the extirpated carnivores has very likely affected populations of the remaining mammalian species. In addition, we note that there are several emerging issues that potentially threaten future trends in biodiversity (see 4.16.5 this report).

Mammalian Carnivores

Mammalian carnivore species diversity in MORA is high today compared to much of the United States, but it is lower compared to the reference condition. Mindful of the limitations of the data sources, we can still make some provisional interpretations of current population status of some species in 'recent' ecological time (i.e., the last few generations of the larger predators). Because mammalian carnivores have been monitored by at most 1 study with park-wide sampling effort (Reid et al. 2010), we cannot make any firm conclusions about trend. We find 5 species that have been extirpated, 1 extant species that appears to be in a recent decline, 5 species that may be recently stable or increasing, and 7 species for which we cannot make any inference about status or trend.

Apparently Extirpated Species

Fisher—Before Fishers were reintroduced to Olympic National Park in 2008, the Washington Department of Fish and Wildlife concluded in 1998 that they no longer occurred in Washington (Lewis and Stinson 1998). That conclusion was partially based on 1990–1997 sampling that included survey points in MORA. Newmark (1995) reported that the last Fisher sighting in MORA was in 1935. No fishers were detected by Reid et al. (2010). The NPS and the State have plans and funding to reintroduce Fisher into the Cascades, including MORA, as early as 2014.

Gray Wolf—Once common in Washington, wolves were last seen in MORA in 1937 (Newmark 1995) and were gone from the southern Washington Cascades by 1941, other than occasional sightings (Wiles et al. 2011). Wolves have, since then, naturally recolonized the state at low numbers, and the 'Teanaway' pack in Kittitas County is the closest to MORA. The state recovery plan for wolves calls for at least 4 wolf packs in the southern Washington Cascades and Coast Region (Wiles et al. 2011).

Grizzly Bear—There are no confirmed recent or historic records of Grizzly Bears occurring in the park, but MORA is within their historic range (Schwartz et al. 2003). MORA is south of the area covered by the North Cascades Ecosystem recovery plan for the species (Servheen 1982). Grizzly Bear tracks were found west of the park in 1993 (Mount Rainier National Park 2002).

Canada Lynx—Individual transient Canada Lynx may occasionally wander through MORA, but the nearest current population is in Okanogan County (Stinson 2001). Hair samples from the Gifford Pinchot National Forest that were identified in 1999 as lynx (Weaver and Amato 1999) were later shown to not be lynx, and no lynx hairs were detected in widespread sampling in the southern Oregon Cascades (Stinson 2001). In 2000, there was sampling at 25 sites to attempt to snag lynx hair for genetic analysis (J. Petterson, NPS, letter to Gary Hanvey, USFS, Missoula, MT), with methods modeled after the national interagency lynx detection protocol (McKelvey et al. 1999). Of the 11 hair samples collected as part of the project, none were identified as Canada Lynx.

Wolverine—Vagrant Wolverines may use MORA on rare occasion. The species was listed as present by Taylor (1922). A Wolverine was recorded in MORA in 1979, but the wide-ranging species was more recently photographed in Goat Rocks Wilderness, and on Mount Adams (Cascades Carnivore Project 2009).

Species with Some Evidence Suggesting Recent or Historical Population Decline

Red Fox—Cascade Red Foxes are a native subspecies (Aubry et al. 2009) that was once distributed through the Cascade Range and high mountains of Washington (Aubry 1984). The non-native lowland subspecies of Red Fox was introduced to the Pacific Northwest and is now widespread in low elevations (Aubry 1984). In the last decade, Cascade Red Foxes have been detected repeatedly in MORA, and the Goat Rocks and Mt. Adams Wilderness areas of the Gifford Pinchot National Forest (Jocelyn Akins and Ben Sacks, UC Davis, pers. comm.). Ongoing genetic studies aim to clarify the degree of population connectivity between foxes in MORA and those along the Cascades crest (Jocelyn Akins, UC Davis, pers. comm.). Foxes were detected in surveys conducted in 2000 at the White River and Grand Park sampling blocks, and in the vicinity of Paradise and the Tatoosh Range (Reid et al. 2010). In the winter of 2011–2012, Mason Reid (MORA Wildlife Ecologist) recorded Red Fox tracks in the White River and Sunrise areas. Fox habituation to visitors poses risks to the foxes and to visitors. Cascade Red Foxes readily beg for food from visitors in the road, parking lots, and at high elevation camps. Foxes have denned close to the Paradise road. A fox pup was found dead in 2009, apparently struck by a vehicle (Herr 2009). Three radio-collared individuals were the subject of a recent study (Jenkins et al., In prep.) in the Longmire-Paradise area, assessing their behavior in relation to seasonal and temporal patterns of visitor use.

Species for Which Some Evidence Suggests Population is Stable or Increasing

Black Bear—Black Bears have a large and productive population in Washington State, including in the Southern Cascades (Anderson 2011). Visitors report numerous bear sightings every year; there were 204 in 9 mo of 2010 (Herr 2010). A perennial focus of activity for the wildlife program at MORA has been reducing the risks associated with bears that become habituated to humans. Activities have included installing bear-proof trash storage containers, hazing problem bears, and education programs for visitors, staff, and concession workers.

American Marten—This species was detected at the greatest number of survey sites in MORA; Martens were detected at 14 of 20 4 square mile sampling blocks (Reid et al 2010). Martens were detected across the range of sampled elevations.

Bobcat, Spotted Skunk, Coyote—Reid et al. (2010) detected these species across large areas of MORA; they were recorded at 8, 6, and 5 of the twenty 4 square mile sampling blocks of the carnivore inventory, respectively. Bobcats and Spotted Skunks were detected at low and mid-elevations in the Carbon River, Ohanapecosh River, Tahoma Creek, and Kautz Creek watersheds. Bobcats were also detected in the White River drainage. Coyotes were found at low and mid-elevations in the White River, Ohanapecosh River, Tahoma Creek, and Kautz Creek watersheds, and also at higher elevations, near Paradise and in the Tatoosh Range.

Species for Which Evidence of any Change in Status is Ambiguous

Mountain Lion—Mountain Lions using MORA are undoubtedly part of a larger population connected by movements throughout Washington's southern Cascades. There are no reliable estimates for Mountain Lion abundance or trend in Washington, but some evidence suggests that populations are stable statewide (Martorello 2011). In recent years, the Muckleshoot Indian Tribe wildlife program has fostered a tribal Mountain Lion harvest north of MORA to increase Elk populations in the North Rainier Elk herd (Vales 2005).

Raccoon—Reid et al. (2010) did not detect Raccoons in winter surveys. Raccoon sightings are common in Longmire and not uncommon along roads and in campgrounds, but abundance and trend cannot be assessed from sightings**.**

Ermine (Short-tailed Weasel), Long-tailed Weasel—Taylor (1922) reported that these 2 small weasels are widely distributed in the park, notably in forested and subalpine habitats. Reid et al. (2010), however, detected no Ermine and only detected the Long-tailed Weasel in the Carbon River drainage and one in the Ohanapecosh River drainage. Weasel populations are probably affected by abundance of their prey, including small mammals, birds, and amphibians.

River Otter—Otters are present in at least some MORA river systems, but park-wide information about their distribution is lacking. They were observed in 2000 and 2001 at Green Lake, in the Carbon River drainage (NPSpecies 2012), and at Lake George, Mowich Lake, the Carbon River, and the upper White River in 2011–2012 (M. Reid, NPS, pers. comm.).

Mink—Mink are seldom recorded in MORA, though they appear to be present. One Mink collected in 1981 from the upper Carbon River drainage is at the University of Washington Burke Museum.

Striped Skunk—Striped Skunks are associated with low elevation habitats and are a common human commensal in suburban and exurban areas. Striped Skunks are not well documented in the park, and may only occasionally be present; there were 2 observations in the 1990s.

Non-native Species

Virginia Opossum—Reid et al. (2010) detected Virginia Opossum from a low-elevation site along the Nisqually River. This species can take advantage of human structures and food sources to persist where it would otherwise be limited by cold winter temperatures (Kanda et al. 2009).

Bats

Because MORA has extensive old growth forests close to lakes, streams, and rivers, it provides valuable habitat for bats. Nocturnal, cryptic, and difficult to detect and distinguish, bats need safe roost sites that have appropriate microclimates and that are close to water and foraging areas. In the Pacific Northwest, high bat abundance and diversity have been associated with mature forests (FEMAT 1993; Hayes 2003); some species are closely associated with late seral stage forests, including Long-eared Myotis and Long-legged Myotis (FEMAT 1993, Taylor 1999, Weller 2008). Crevices and cavities in snags and large trees in older forests often serve as roost sites, but bats tend to feed more over open areas and water features, where flying insects are abundant and where bats can readily drink (Hayes 2003).

Nine bat species are thought to inhabit MORA, some seasonally and some year-round (Table 48). During baseline surveys in 2000, all 9 bat species were detected, with Little Brown Bat being the most frequently detected and captured (Petterson 2009). Townsend's Big-eared Bats were found hibernating in an abandoned mine in the park.

At 43 sites where mist nets were set, Petterson (2009) found a consistent pattern of highest capture rates for the Little Brown Bat in 3 habitat types. Yuma Myotis, which can be difficult to distinguish from the Little Brown Bat in the hand, may have been the next most commonly captured species, but this could not have been confirmed without genetic analysis. Silver-haired Bats were the only other bat species captured in all 3 habitat types. There were more than twice as many captured male bats than captured female bats; these results are similar to results found in montane habitats east of Mount Rainier (Baker and Lacki 2004) and in North Cascades National Park Complex (NOCA; Christophersen and Kunz 2003).

For 18 sites with acoustic sampling, Petterson (2009) detected echolocation calls in the frequency class that included Little Brown Bats and Long-legged Myotis at the most number of sites in the 3 habitat types. Calls in the frequency class representing Big Brown Bat and Silver-haired Bat were recorded at only slightly fewer sites in the 3 habitat types. Calls in the frequency class representing California Myotis and Yuma Myotis were recorded at a majority of riparian and low elevation forest sites, but in only a quarter of the subalpine sites. Christophersen and Kunz (2003) noted a lack of California Myotis in subalpine habitats of NOCA. Based on recorded calls, Long-eared Myotis was detected at approximately 40% of sites in all habitats, while Hoary Bats were recorded at approximately 20% of riparian and forest habitat sites, and approximately 40% of subalpine sites.

Townsend’s Big-eared Bat was not captured or detected acoustically. Directed surveys documented 23 hibernating Townsend’s Big-eared Bats in the Eagle Peak mine within the park (Petterson 2009), but no bats at 2 other abandoned mines. The majority of surveyed buildings had no bat sign (Myers 2010), but maternity roosts of Little Brown Bats and Big Brown Bats were found in Nisqually House (Petterson 2009, Myers 2010), and Long-eared Myotis maternity roosts were found at Longmire Warehouse (Petterson 2009). Other buildings with bats or bat sign included W204 Dorm at White River, Ohanapecosh Ranger Station, Tahoma Woods Greenhouse Shed, L221 Generator Building, and L209 Boiler Room at Longmire (Myers 2010). Bat boxes were occupied at Ohanapecosh, but not at Longmire (Myers 2010). Washington DNR found no bats at the Copper King mine, which is about 4 km north of the Carbon River (Wolff et al. 2003), and did not survey at the other 2 inactive and abandoned mines within 10 km of MORA (John Fleckenstein, Washington Department of Natural Resources, unpubl. data).

The 9 bat species that may use MORA are insectivores that either hibernate near their summer range or migrate away from MORA in winter, when insect prey is not available. Most bat species in the Pacific Northwest hibernate where conditions are cold, but above freezing: under tree bark, in snags, tree cavities, wood piles, caves, mines, or crevices. Townsend’s Big-eared Bat, Big Brown Bat, and the 5 *Myotis* species are thought to be year-round residents, short-distance migrants, or elevational migrants. In the South Cascades there are relatively few natural caves where large numbers of bats could roost, except that there are dozens of lava tube caves around Mount St. Helens and Mount Adams, including some with known winter roosts (hibernacula) for Townsend’s Big-eared Bats (Perkins 1993). Bats that migrate long distances to and from wintering grounds include the Silver-haired Bat and Hoary Bat. Silver-haired Bats are generally long-distance migrants (Kunz 1982), but at least some in the Pacific Northwest hibernate (Nagorsen et al. 1993).

Elk

Elk were hunted by Native Americans in the Cascades prehistorically, but the early historical record suggests that Elk were rare in what is now Mount Rainier National Park at the time of first contact by European-Americans (Schullery 1984). Although the native Elk were largely, if not completely, eliminated from MORA at the time of the park's creation in 1899, Elk populations were reestablished through several translocations of Rocky Mountain Elk (*Cervus elaphus nelsoni)* from Yellowstone and Grand Teton National Parks to lands adjacent to the park in 1912–1915 and 1932–1933 (Bradley 1982). Elk numbers increased by the 1960s, and they established a migratory tradition of using subalpine meadows within the park as summer range and migrating to winter and spring ranges north and south of the park. Today, 2 primary herds, the North Rainier and South Rainier herds (Figure 28), use MORA seasonally.

The E4 index of Elk abundance (Figure 29) peaked in the 1980s to early 1990s, and declined during the 1990s and through much of the 2000s in the North Rainier herd. Data for the South Rainier herd, although less regularly recorded than for the North Rainier herd, also indicate a stable or slowly declining population trend from the 1970s until the early 2000s. The index appears to have begun increasing in about 2008 in both herds. Although the South Rainier herd index value was higher in 2010 than in any previous year, not too much credence should be lent to any 1 value. Individual values may be influenced by weather conditions, survey effort, and other factors that influence distribution and detectability of Elk on summer ranges. Indices of Elk population abundance have increased recently in both the North Rainier and South Rainier Herds. Currently, Elk use of MORA during summer is within the range of variation observed since the mid-1970s. The influences of expanding wolf populations in Washington's Cascades Range, and unforeseen wildlife disease issues have the potential to reduce populations in the future.

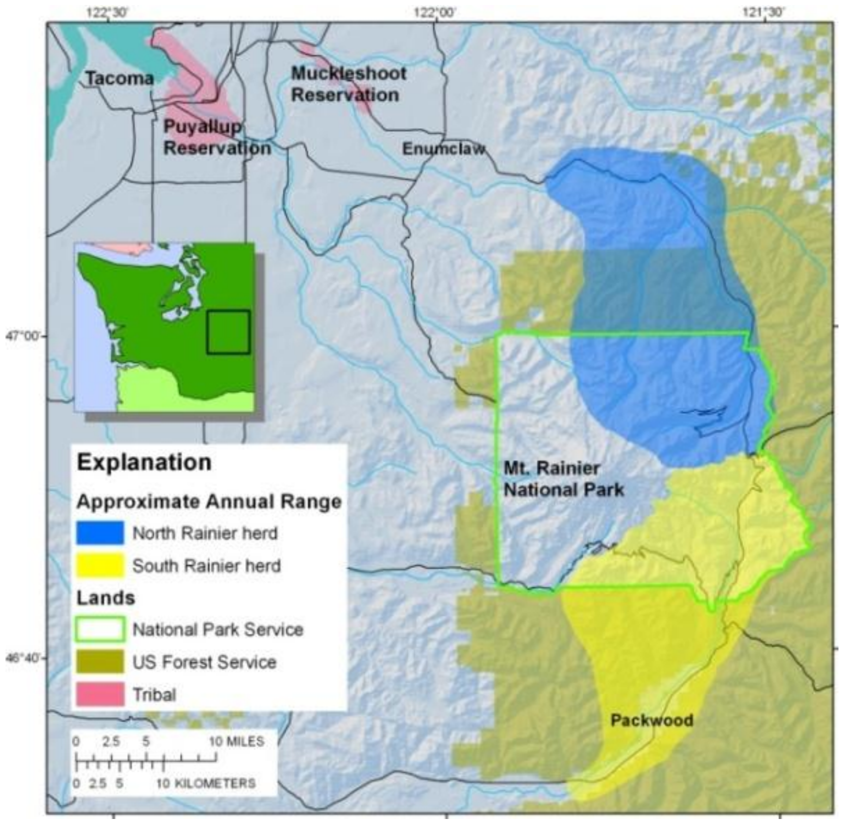

Figure 28. Approximate annual range of migratory elk from the North Rainier herd (blue) and South Rainier herd (yellow).

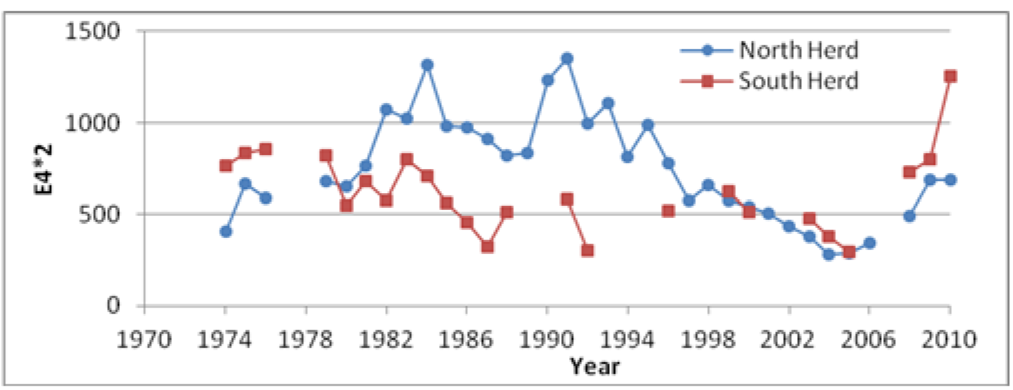

Figure 29. E4 indices of elk population abundance in the North Rainier (blue circles) and South Rainier herds (red squares), 1974–2010.

4.16.5 Emerging Issues

Primary range-wide threats to several of the mammal species in MORA are summarized in Table 49. The wilderness character of the park lands generally translates to a low level of direct human disturbance or habitat modification, and relatively high habitat quality for many of these species within the park. For example, range wide threats that are identified for several species in the form of logging, urban development, and resource extractions are generally not a concern within the park boundaries. Roads, facilities, and popular trails, however, may alter habitats in localized areas, and may influence distribution and behavioral patterns of species that are sensitive to human disturbance. For the majority of species, these impacts would seem to have little effect on population or community dynamics.

Human infrastructure and visitation may also, however, alter distributions and behaviors of mammals that become conditioned to seeking human foods and habituated to human presence. Food conditioned behaviors that lead to potentially dangerous human-wildlife interactions are a long-standing issue in the national parks, particularly as related to bear and coyote management (McCullough 1982, Bounds and Shaw 1994). Food–begging behavior is also well known among the Cascade Red Fox in MORA (M. Reid, Mount Rainier National Park, pers. comm.). In addition to concerns about human safety, food-conditioning and associated unnatural behaviors may pose a conservation concern in this small population through their potential connections to adult mortality. Food conditioning has led to a close association of Cascade Red Foxes to park developed areas in MORA (Jenkins et al., unpubl. data). Moreover, there are 5 known cases of foxes being struck by a vehicle, with 3 pups killed (M. Reid, Mount Rainier National Park, pers. comm.) since 2004. The NPS has been very proactive in securing garbage and educating the public not to feed wildlife or leave food unattended where food-conditioned behaviors may develop, but the problem has been difficult to address, particularly that of park visitors feeding wildlife.

Whether related to habitat changes around the parks, the elimination of competition from Wolves, or increased food supplies, Coyotes have increased in abundance in many park areas (Bounds and Shaw 1994). Coyotes have been linked to predation of the endemic Olympic Marmot in Olympic National Park (Griffin 2007, Witczuk et al. 2013), suggesting a mechanism by which unnatural population densities or concentrations of a generalist carnivore may have farther reaching effects on other mammal populations or communities. The incursion of Coyotes into the range of the Cascade Red Fox may be of particular concern because Coyotes are antagonistic and dominant toward Red Foxes, commonly killing them or usurping their range (Sargeant and Allen 1989, Gosselink et al. 2007).

Although large areas are protected within designated wilderness in the Southern Cascades (including MORA), habitat fragmentation and loss outside these wilderness areas, predominately at lower and middle elevations, may have several implications for mammalian populations within the park, particularly those that rely on genetic connectivity with other subpopulations outside the park, or those that range widely or migrate to use lands outside the park during part of the year. Low and mid-elevation forested habitats outside the park and adjoining wilderness areas are managed at varying levels of intensity, but under intensive management, logging creates a patchwork of early seral forests that may affect habitat qualities for species favoring landscapes with an abundance of late-seral forest structures (e.g., the Fisher; Raley et al. 2012). Fragmentation of preferred habitats by logging or roading may reduce connectivity among subpopulations, ultimately affecting the ability of landscapes to sustain some populations (Koehler et al. 2008). On the other hand, once forest lands have been harvested extensively and replanted, large contiguous areas of midseral regenerating forests may develop, reducing habitat qualities for species that depend on early-seral habitats as foraging areas. Elk population trends within MORA, for example, have been linked to forestry practices on the winter ranges outside the park (Jenkins and Starkey 1996). Elk populations increased dramatically following logging in the 1960-80s, heightening concerns over the effects of Elk trampling and grazing on subalpine ecosystems. Elk populations subsequently declined as midseral forests ensued following logging. Preliminary indications of another increase in the numbers of Elk using the park during summer may portend a new phase of population buildup in response to renewed logging outside the park.

Predation by top-level carnivores has the potential also to affect ungulate population trends in and around MORA. The recent expansion of Wolves into Washington State, for example, has the potential to increase predation-related mortality in ungulate populations. The approved plan for managing Wolves in Washington State calls for 15 or more packs statewide, including 4 packs in the southern Cascades and Northwest coast area, which includes MORA (Wiles et al. 2011). Cougar management practices outside the park appear to be linked to calf survival patterns in the North Rainier Elk herd during recent years (D. Vales, Muckleshoot Indian Tribe, pers. comm.); hence predator harvests outside the park also have the potential to influence the numbers of Elk using subalpine meadows in the park during summer.

Climate change presents a major concern for mammalian wildlife and their habitats, both within the park and more generally at larger spatial scales. Climate change is expected to cause warmer, drier summers in the Pacific Northwest (Mote et al. 2005). Climate change is especially likely to pose a threat to species that rely on high elevation habitats, such as Cascade Red Fox (Aubry et al. 2009), Mountain Goat (White et al. 2011), Hoary Marmot and Pika (Krajick 2004), or to those that require long snow pack duration, such as Snowshoe Hare (Rosner 2012), Canada Lynx, and Wolverine (McKelvey et al. 2011). Habitat loss and fragmentation due to climate change could decrease the likelihood that long-distance dispersing species such as Canada Lynx (Koehler et al. 2008) successfully reach MORA in high enough numbers to reestablish a population. Reduced snow pack and duration of snow may affect breeding and denning habitat for Wolverines (McKelvey et al. 2011), survival rates of Marmots (Armitage 2013) and Pikas (Beever et al. 2010), or forage quality for high altitude dependent species (Fox 1991). As the climate warms, heat and water stress may also affect bat reproduction (Adams and Hayes 2008). Species that are currently restricted to the Puget Sound lowlands and eastern foothills of the Cascade Range may increase in abundance or expand their range to higher elevations in MORA. Such changes could include exotic species such as Virginia Opossum, and native species such as Striped Skunk. Although it is difficult to predict how complex communities of interacting species will change in the future (Halofsky et al. 2011), models of climate/wildlife interactions suggest climate change has a great diversity of potential effects on montane wildlife communities (Lawler et al. 2009).

The emergence of new parasites and pathogens may also affect park mammal populations. White-nose syndrome (WNS), for example, is a new fungal pathogen apparently native to Eurasia that kills hibernating bats. WNS has severely reduced bat populations of many species in the northeast USA since about 2008, and it appears to be steadily spreading west (Blehert et al. 2011). WNS may cause regional population collapse and extinction of what were formerly the most common bat species (Frick et al. 2010). This disease, which has already been confirmed as far west as Missouri, will almost certainly kill high numbers of hibernating bats when it reaches the western U.S. WNS is caused by the fungus *Geomyces destructans*, which kills bats where many bats hibernate together in cool, damp conditions (USFWS 2012). Disease spread seems to be from bat to bat, or from cave to bat, and humans may carry the WNS fungus from cave to cave on clothing or gear used in caves where WNS is already present.

Wildlife diseases (e.g., chronic wasting disease, paratuberculosis, brucellosis) are also a growing national concern for wild ungulates (Daszak et al. 2000, Angers et al. 2006). Wild ungulate populations that move over wide areas may be more susceptible to pathogen spread than more sedentary mammal species. Certain diseases and pests pose known risks to Elk (e.g., Chronic Wasting Disease, and others), and Deer (e.g., Hair Loss Syndrome, Epizootic Hemorrhagic Disease, and others), and we can expect the emergence of new pathogens and pests in the future. For example, over the last decade a bacterial hoof disease caused by infectious treponeme bacteria has spread from the Cowlitz River basin south of MORA to infect the neighboring Mount St. Helens and Willapa Hills Elk herds (http://wdfw.wa.gov/conservation/health/hoof_disease; accessed 22 September 2014). Current research is aiming to determine the effects of this new bacterium on Elk populations and management options south of Mount Rainier.

Lastly, the recent increase in wind energy developments in the Colorado Plateau region of south-central Washington may also affect populations of long-distance migrating bats from MORA. Little is currently known about the specific migration paths of long-distance migrants such as the Hoary Bat or Silver-haired Bat that breed in MORA, but Hoary Bats are known to migrate hundreds of kilometers between summer breeding grounds and wintering areas (Cryan et al. 2014). These 2 species of tree roosting bats are the most common species found dead at wind turbine sites, potentially due to their attraction to turbines as roost sites (Kuntz et al. 2007, Arnett and Baerwald 2013).

4.16.6 Information and Data Needs–Gaps

With so much unknown about the current status and trends of mammal populations in MORA, it would be valuable to conduct additional research and monitoring that would improve our present level of knowledge on the status of most species. For the few species assemblages highlighted above, there has been a preliminary park-wide survey documenting status, or at least presence-absence during a narrow time period. For most species, however, there is no baseline information about the population status or park-wide distribution. Without baseline studies and repeated studies for those with baselines it would be difficult to diagnose future changes, or to assess the influence of management decisions on those species.

It would be useful to repeat and perhaps expand upon the carnivore detection surveys conducted previously (Reid et al. 2010) to test for temporal trends in the occupancy rate of mammalian carnivore species in MORA. Estimated changes in occupancy rates can correlate with changes in population abundance (MacKenzie and Nichols 2004), particularly for those species with relatively small home ranges. Moreover, repeat surveys would indicate local rates of site colonization or extinction (MacKenzie et al. 2003).

Population genetic studies would be useful to determine landscape connectivity and genetic indicators of population viability for subpopulations of forest carnivores in MORA and the southern Cascades. Ongoing studies of the population and landscape genetics of the Cascade Red Fox provide an example of conservation importance of such work (J. Akins, University of California, Davis, pers. comm.). Radio-telemetry based studies that identify corridors and important habitat features for carnivores at the regional scale would also be useful in focusing interagency conservation strategies.

Considering the current conservation concerns over the long-term viability of the Cascade Red Fox and the importance of MORA to the conservation of the subspecies overall, additional study is needed to verify current population status and trends of foxes within MORA, the effects of human visitation and infrastructure on Red Fox behavior and population characteristics, and to determine the effectiveness of management practices designed to reduce food conditioning and habitation to humans.

Based on the projected threats of climate warming to many subalpine and alpine mammal species, increased population monitoring of Hoary Marmots, Pikas, and Mountain Goats may be warranted. Although causes of regional population declines are poorly understood, Mountain Goats, in particular, have been declining in recent decades throughout most of the Cascades (Rice and Gay, 2010), but population trends remain poorly understood within MORA.

It will not be possible to detect any changes in bat resources unless there is an improved understanding of bat abundance in the Cascade Range. The interagency Bat Grid program, currently supported by the U.S. Forest Service, Bureau of Land Management, and Department of Defense, is the only existing program that is structured to gauge bat populations in the Pacific Northwest (Rodhouse et al. 2012). Cooperative sampling within MORA would extend inference to protected landscapes within the park, and provide a useful framework for monitoring trends in bats within the park compared to more modified landscapes.

Virtually any studies on the ecology of bats in MORA and the Southern Cascades would provide new information. Most bats in the region are dispersed widely, roosting in small numbers in forests. Annual bat counts at known nursery roost sites in structures could be an index to changes in bat numbers, but such counts could be misleading, as bats are known to sometimes change roost locations. Monitoring abundance of forest roost sites would not lead to reliable estimates of trend because roost site fidelity is low and the bats may be widely dispersed (Hayes 2003). Long distance migration routes for Hoary and Silver-haired Bats are not well known in this area, and it would be useful to know whether wind turbine facilities pose risks to migratory bat species that use MORA.

The NPS, USGS, WDFW, Muckleshoot Indian Tribe, and Puyallup Tribe of Indians recently collaborated in developing a standard protocol for monitoring trends in seasonal abundance of Elk using subalpine meadows in MORA during summer (Griffin et al. 2012). Initially, the plan was to conduct annual aerial surveys as the basis for monitoring trends in seasonal Elk abundance on MORA summer ranges. Due to budgetary considerations, however, the frequency of conducting such surveys was reduced to every other year and presently, due to even greater budgetary constraints, the future survey effort remains in question. If surveys occur as planned in the protocol (on an every other year basis), the data will provide good statistical power for the NPS to evaluate future trends in the seasonal abundance of Elk using subalpine meadows in the park during summer. Additional monitoring programs designed to measure ecosystem effects of Elk on species composition of subalpine vegetation, percent of bare soil, or the extent and characteristics of Elk trails would be useful in linking Elk numerical trends to changes in ecosystem structure or processes.

4.16.7 Literature Cited

Adams, R. A., and M. A. Hayes. 2008. Water availability and successful lactation by bats as related to climate change in arid regions of western North America. Journal of Animal Ecology 77:1115–1121.

Anderson, D. 2011. 2011 Black Bear status and trend report: region 5. In: Washington Department of Fish and Wildlife, 2011 game status and trend report. WDFW, Olympia, Washington. p. 211–213.

Angers, R. C., S. R. Browning, T. S. Seward, C. J. Sigurdson, M. W. Miller, E. A. Hoover, and G. C. Telling. 2006. Prions in skeletal muscles of deer with chronic wasting disease. Science 311:1117.

Armitage, K. B. 2013. Climate change and the conservation of Marmots. Natural Science 5:36–43.

Arnett, E. B., and E. F. Baerwald. 2014. Chapter 21: Impacts of wind energy development on bats: Implications for Conservation. In: Adams, R. A., and S. C. Pedersen, editors. Bat evolution, ecology, and conservation. Springer-Verlag, New York, New York. p. 435–456.

Aubry, K. B. 1984. The recent history and present distribution of the Red Fox in Washington. Northwest Science 58:69–79.

Aubry, K. B., M. J. Crites, and S. D. West. 1991. Regional patterns of small mammal abundance and community composition in Oregon and Washington. In: Ruggiero et al., editors. Wildlife and vegetation of unmanaged Douglas-fir forests. U.S. Forest Service General Technical Report PNW-GTR-285. p. 285–294.

Aubry, K. B., M. J. Statham, B. N. Sacks, J. D. Perrine, and S. M. Wisely. 2009. Phylogeny of the North American Red Fox: Vicariance in Pleistocene forest refugia. Molecular Ecology 18:2668–2686.

Baker, M. D., and M. J. Lacki. 2004. Forest bat communities in the east Cascade Range, Washington. Northwest Science 78:234–241.

Beever, E. A., C. Ray, P. W. Mote, and J. L. Wilkening. 2010. Testing alternative models of climate-mediated extirpations. Ecological Applications 20:164–178.

Blehert, D. S., J. M. Lorch, A. E. Ballmann, P. M. Cryan, and C. U. Meteyer. 2011. Bat white-nose syndrome in North America. Microbe 6:267–273.

Bounds, D. L., and W. W. Shaw. 1994. Managing Coyotes in U.S. National Parks: Human-Coyote interactions. Natural Areas Journal 14:280–284.

Bradley, W. 1982. History, ecology, and management in an introduced Wapiti population in Mount Rainier National Park, Washington [dissertation]. University of Washington, Seattle, Washington.

Carey, A.B. 1995. Sciurids in Pacific Northwest managed and old-growth forests. Ecological Applications 5:648–661.

Cascades Carnivore Project. 2009. September 14, 2009: Wolverine in Goat Rocks wilderness. Internet document: http://cascadescarnivoreproject.blogspot.com/2009/10/september142009-wolverine-in-goat-rocks.html (accessed 16 February 2011).

Christophersen, R. G., and R. C. Kuntz. 2003. A survey of bat species composition, distribution, and relative abundance in North Cascades National Park Service Complex, Washington. Technical Report NPS/NOCA/NRTR-2003/01.

Cryan, P. M., C. A. Stricker, and M. B. Wunder. 2014. Continental-scale, seasonal movements of a heterothermic migratory tree bat. Ecological Applications 24:602–616.

Daskaz, P., A. A. Cunningham, and A. D. Hyatt. 2000. Emerging infectious diseases of wildlife – threats to biodiversity and human health. Science 287:443–449.

[FEMAT] Forest Ecosystem Management Assessment Team. 1993. Forest ecosystem management: An ecological, economic, and social assessment. Report of the Forest Ecosystem Management Assessment Team.

Fox, J. L. 1991. Forage quality of *Carex macrochaeta* emerging from Alaskan alpine snowbanks through the summer. American Midland Naturalist 126:287–293.

Frick, W. F., J. F. Pollock, A. C. Hicks, K. E. Langwig, D. S. Reynolds, G. G. Turner, C. M. Butchoski, and T. H. Kunz. 2010. An emerging disease causes regional population collapse of a common North American bat species. Science 329:679–682.

Gosselink, T. E., T. R. VanDeelen, R. E. Wagner, and P. C. Mankin. 2007. Survival and cause-specific mortality of Red Foxes in agricultural and urban areas of Illinois. Journal of Wildlife Management 71:1862–1873.

Griffin, P. C., K. J. Jenkins, P. Happe, M. Reid, D. Vales, B. J. Moeller, S. McCorquodale, M. Tirhi, J. R. Boetsch, K. Beirne, and J. Schaberl. 2012. Elk monitoring protocol for Mount Rainier National Park and Olympic National Park. Natural Resource Report. NPS/ NCCN/NRR—2012/485. National Park Service, Fort Collins, Colorado.

Griffin, S. C. 2007. Demography and ecology of a declining endemic the Olympic Marmot [dissertation]. University of Montana. Missoula, Montana.

Gustafson, C. E. 1983. Wapiti populations in and adjacent to Mount Rainier National Park: Archeological and ethnographic evidence. Washington State University, Pullman, Washington.

Halofsky, J. E., D. L. Peterson, K. A. O'Halloran, and C. Hawkins Hoffman. 2011. Adapting to climate change at Olympic National Forest and Olympic National Park. US Forest Service PNW-GTR-844. Portland, Oregon.

Hayes, J. P. 2003. Habitat ecology and conservation of bats in western coniferous forests. In: Zabel C. J., and R. G. Anthony, editors. Mammal community dynamics: Management and conservation in the coniferous forests of western North America. University Press, Cambridge, UK. p. 81–119.

Herr, A. 2009. Mount Rainier National Park centennial "keep wildlife wild" season report 2009. Unpublished internal report to Mount Rainier National Park.

Herr, A. 2010. Centennial "keep wildlife wild" season report 2010 Mount Rainier National Park. Unpublished internal report to Mount Rainier National Park.

Jenkins, K. J., and E. E. Starkey. 1996. Simulating secondary succession of Elk forage values in a managed forest landscape, western Washington. Environmental Management 20:715–724.

Kanda, L. L., T. K. Fuller, P. R. Sievert, and R. L. Kellogg. 2009. Seasonal source-sink dynamics at the edge of a species' range. Ecology 90:1574–1585.

Koehler, G. M., B. T. Maletzke, J. A. VonKienast, K. B. Aubry, R. B. Wielgus, and R. H. Naney. 2008. Habitat fragmentation and the persistence of Lynx populations in Washington state. Journal of Wildlife Management 72:1518–1524.

Krajick, K. 2004. All downhill from here? Science 303:1600–1602.

Kunz, T. H. 1982. Lasionycteris noctivagans. Mammalian Species 172:1–5.

Kunz, T. H., E. B. Arnett, W. P. Erickson, A. R. Hoar, G. D. Johnson, R. P. Larkin, M. D. Strickland, R. W. Thresher, and M. D. Tuttle. 2007. Ecological impacts of wind energy development on bats: Questions, research needs, and hypotheses. Frontiers in Ecology and the Environment 5:315–324.

Lawler, J. J., S. L. Shafer, D. White, P. Kareiva, E. P. Maurer, A. R. Blaustein, and P. J. Bartlein. 2009. Projected climate-induced faunal change in the Western Hemisphere. Ecology 90:588–597.

Lewis, J. C., and D. W. Stinson. 1998. Washington state status report for the Fisher. Washington Department of Fish and Wildlife, Olympia, Washington.

MacKenzie, D. I., and J. D. Nichols. 2004. Occupancy as a surrogate for abundance estimation. Animal Biodiversity and Conservation 27:461–467.

MacKenzie, D. I., J. D. Nichols, J. E. Hines, M. G. Knutson, and A. B. Franklin. 2003. Estimating site occupancy, colonization and local extinction probabilities when a species is not detected with certainty. Ecology 84:2200–2207.

Martorello, D. A. 2011. Cougar status and trend report. In: Washington Department of Fish and Wildlife, 2011 game status and trend report. WDFW, Olympia, Washington.

McCullough, D. R. 1982. Behavior, bears, and humans. Wildlife society Bulletin 10:27–33.

McKelvey, K. S., J. J. Claar, G. W. McDaniel, and G. Hanvey. 1999. National Lynx detection protocol. Unpublished survey protocol. United States Forest Service, Rocky Mountain Research Station, Missoula, Montana.

McKelvey, K. S., J. P. Copeland, M. K. Schwartz, J. S. Littell, K. B. Aubry, J. R. Squires, S. A. Parks, M. M. Elsner, and G. S. Mauger. 2011. Climate change predicted to shift Wolverine distributions, connectivity, and dispersal corridors. Ecological Applications 21:2882–2897.

Mote, P., E. Salathé, and C. Peacock. 2005. Scenarios of future climate for the Pacific Northwest. Climate Impacts Group, University of Washington, Seattle, Washington.

Mount Rainier National Park. 2002. Final general management plan environmental impact statement. National Park Service.

Myers, E. 2010. Bat inventory summary 2010, Mount Rainier National Park. Unpublished internal report.

Nagorsen, D. W., A. A. Bryant, D. Kerridge, G. Roberts, A. Roberts, and M. J. Sarell. 1993. Winter bat records for British Columbia. Northwestern Naturalist 74:61–66.

Newmark, W. D. 1995. Extinction of mammal population in western North American national parks. Conservation Biology 9:512–526.

Perkins, M. 1993. Eruptive impacts of Mount St. Helens on local bat populations. In: Halladay, W. R., editor. Proceedings of the 3rd International Symposium on Vulcanospeleology, Bend, Oregon. p. 130–131.

Petterson, J. 2009. Bat inventory and monitoring program development for Mount Rainier National Park, Washington: 2000 final report. Natural Resource Technical Report NPS/NCCN/NRTR—2009/170. National Park Service, Fort Collins, Colorado.

Raley, C. M., E. C. Lofroth, R. L. Truex, J. S. Yaeger, and J. M. Higley. 2012. Habitat ecology of fishers in western North America: A new synthesis. In: Aubrey, K. B., W. J. Zielinski, M. G. Raphael, G. Proulz, and S. W. Buskirk, editors. Biology and conservation of artens, sables, and fishers: A new synthesis. Cornell University Press, Ithaca, New York.

Reid, M., J. Petterson, and J. Schaberl. 2010. A survey of forest carnivores in Mount Rainier National Park, Washington: National Park Service, North Coast and Cascades Network. Natural Resource Technical Report NPS/NCCN/NRTR—2010/412. National Park Service, Fort Collins, Colorado.

Rice, C. G., and D. Gay. 2010. Effects of Mountain Goat harvest on historic and contemporary populations. Northwestern Naturalist 91:40–57.

Ripple, W. J., E. E. Starkey, and B. J. Schrumpf. 1988. Assessing Elk trail and wallow impacts in Mount Rainier National Park. Final report. Oregon State University, Corvallis, Oregon.

Rodhouse, T. J., P. C. Ormsbee, K. M. Irvine, L. A. Vierling, J. M. Szewszak, and K. T. Vierling. 2012. Assessing the status and trend of bat populations across broad geographic regions with dynamic distribution models. Ecological Applications 22:1098–1113.

Rosner, H. 2012. Can Snowshoe Hares outrace climate change? High Country News, February 6.

Sargeant, A. B., and S. H. Allen. 1989. Observed interactions between Coyotes and Red Foxes. Journal of Mammalogy 70:631–633.

Schullery, P. 1984. A history of native Elk in Mount Rainier National Park. Mount Rainier National Park, Ashford, Washington. Available online at: http://www.nps.gov/history.

Schwartz, C. C., S. D. Miller, and M. A. Haroldson. 2003. Grizzly bear. In: Feldhammer, G. A., B. C. Thompson, and J. A. Chapman, editors. Wild mammals of North America: Biology, management, and conservation. Second edition. Johns Hopkins University Press. Baltimore, Maryland. p. 556–586.

Servheen, C. 1982. Grizzly Bear recovery plan; supplement: North Cascades ecosystem recovery plan chapter. U.S. Fish and Wildlife Service.

Stinson, D. W. 2001. Washington state recovery plan for the Lynx. Washington Department of Fish and Wildlife, Olympia, Washington.

Stoddard, J. L., D. P. Larsen, C. P. Hawkins, R. K. Johnson, and R. H. Norris. 2006. Setting expectations for the ecological condition of streams: The concept of reference condition. Ecological applications 16:1267–1276.

Taylor, W. P. 1922. A distributional and ecological study of Mount Rainier, Washington. Ecology 3:214–236.

Taylor, J. A. 1999. Habitat selection of the Long-legged Myotis (*Myotis volans*) in a managed landscape on the east-slopes of the Cascade Range [thesis]. Michigan State University, East Lansing, Michigan.

Thomas, D. W. 1988. The distribution of bats in different ages of Douglas-fir forests. Journal of Wildlife Management 52:619–626.

[USFWS] U.S. Fish and Wildlife Service. 2012. White Nose Syndrome. Available at: http://whitenosesyndrome.org. Accessed 16 December 2013.

Vales, D. J. 2005. Modeling prey and Cougar with an approach for managing Cougars to meet prey population objectives. Proceedings of the 8th Mountain Lion workshop, Leavenworth, Washington. Mountain Lion Workshop 8:170.

Weaver, J. L., and G. Amato. 1999. Lynx surveys in the Cascade Range, Washington and Oregon. Wildlife Conservation Society, with the USFS and USFWS.

Weller, T. J. 2008. Using occupancy estimation to assess the effectiveness of a regional multiple-species conservation plan: Bats in the Pacific Northwest. Biological Conservation 141:2279–2289.

White, K. S., G. W. Pendleton, D. Crowley, H. J. Griese, K. J. Hundertmark, T. McDonough, L. Nichols, M. Robus, C. A. Smith, and J. W. Schoen. 2011. Mountain Goat survival in coastal Alaska: Effects of age, sex, and climate. Journal of Wildlife Management 75:1731–1744.

Wiles, G. J., H. L. Allen, and G. E. Hayes. 2011. Wolf conservation and management plan for Washington. Washington Department of Fish and Wildlife, Olympia, Washington.

Witczuk, J., S. Pagacz, and L. S. Mills. 2013. Disproportionate predation on endemic Marmots by invasive Coyotes. Journal of Mammalogy 94:702–713.

Wolff, F. E., D. T. McKay, and D. K. Norman. 2003. Inactive and abandoned mine lands - United Copper Group mines, Chewelah mining district, Stevens County, Washington. Washington Division of Geology and Earth Resources Open File Report 2003-18.

4.17 Glaciers

(Jon Riedel, NOCA, NPS)

4.17.1 Introduction

Glaciers are significant features within the national parks of Washington State, and their condition is an important indicator of the status of park resources. Temperate glaciers at MORA are valuable as sensitive, dramatic indicators of climate change (Figure 30). The glaciers at this park are themselves ecosystems that are linked to larger alpine food webs (Hodson et al. 2008). They are the sole habitat for some species such as the ice worm (*Mesenchytraeus solifugus*), which is preyed upon by Rosy Finches (*Leucostitche arctoa*) and other alpine species. Glaciers are also valuable to park aquatic ecosystems, downstream municipalities, and regional ecosystems and industries because they provide vast quantities of cold, fresh melt-water during the hot, dry summer months.

Ice falls, sudden releases of glacial melt-water, and massive unstable piles of loose glacial sediment represent hazards to park staff and visitors. During extreme rain events and glacial outburst floods, streams incorporate this sediment to become debris flows. Several glaciers on Mount Rainier have been prone to past outburst floods, including Nisqually Glacier in the 1950s and 1960s (Richardson 1968) and Tahoma Glacier in the 1990s (Walder and Driedger 1993, 1994). One of the more memorable recent events occurred on Kautz Creek in October 1947, and covered the park's main entrance road in several meters of mud, rock, and debris.

There are 143 glaciers and permanent snowfields on Mount Rainier with a total area of 83.3 km^2 (32.2 mi^2) (Wilson and Fountain, 2014); 27 of these are named glaciers. Total ice volume on the volcano is an estimated 4.4 km^3 (1.1 mi^3) (Driedger and Kennard 1986). A number of glacier studies have been conducted in the park in the past century.

The following information is summarized from Driedger and Kennard (1986) and Heliker et al. (1984). The first description of Mount Rainier's glaciers was by A. Kautz in 1857 when he described the Nisqually Glacier. Geologists S. Emmons and A. Wilson collected information about the geology and location of glaciers on the mountain in 1870. The U.S. Geological Survey began studying the park's glaciers in 1896, when I. C. Russell suggested a Nisqually Glacier project that included photo stations, measurements indicating flow rates, and mapping of the glacier termini. In 1905, J. LeConte studied the flow rate of the Nisqually Glacier. F. Matthes of the USGS made the first accurate determination of glacier locations with his 1913 topographic map of the mountain. The NPS began making measurements of some changes in terminus position in the 1930s (Catton 1996). In 1931, the Tacoma City Light Department initiated measurements of surface elevation along profiles upon the lower Nisqually Glacier. Measurements were continued by the USGS until 1985, when the USGS could no longer support the project. The park reinstituted the surface elevation monitoring in 1991, and continues to support the effort as long as funding is available. Stevens (In prep.) is summarizing Nisqually Glacier surface elevation changes. Other shorter-term glaciological studies have included observations at the summit (1970), mapping of ice caves (1971), velocity and surface elevation measurements (1974), terminus mapping (1976), and ice thickness studies (1984).

Current studies include glacier mapping (Wilson and Fountain 2014), Nisqually Glacier velocities (Walkup et al., In prep.), and a summary of the Nisqually Glacier surface ice elevation surveys (Stevens et al., In prep.). Wilson and Fountain (2014) and Nylen (2004) have summarized MORA glacier areas (Table 51).

Because of the importance of glaciers as hazards, habitat, indicators of climate change, and timely providers of cold, fresh water, the National Park Service initiated a glacier monitoring program at MORA in 2003. The focus of this program is seasonal measurement of glacier accumulation and melt (mass balance) at 11 points on Nisqually and Emmons glaciers, and decadal measurement of the extent of glaciers park-wide (Figure 31). These measurements and complimentary research form the basis of this natural resource condition assessment.

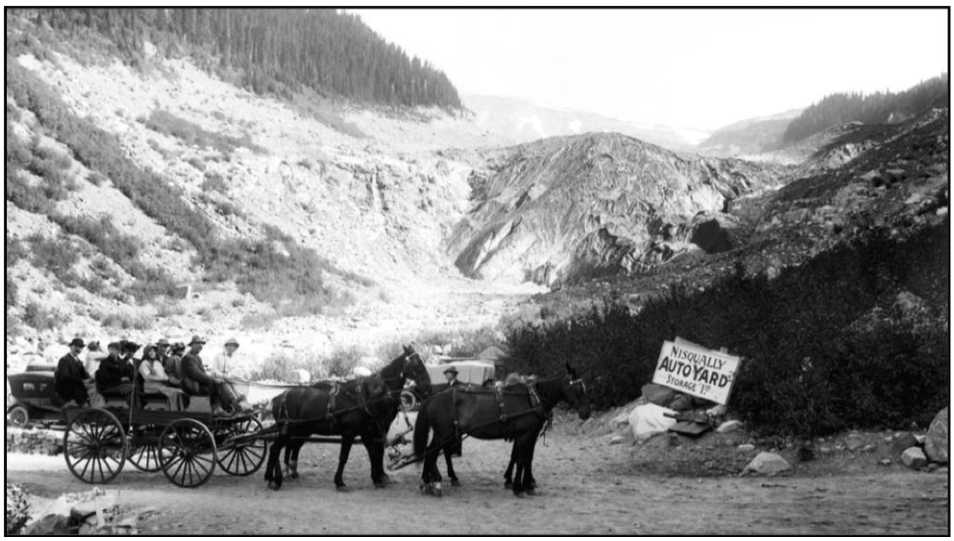

Figure 30. Terminus of Nisqually Glacier in 1914 near the present site of the State Highway 706 bridge. The glacier is no longer visible from this site, having retreated 2 km up valley. Photo 30965, Washington State Historical Society.

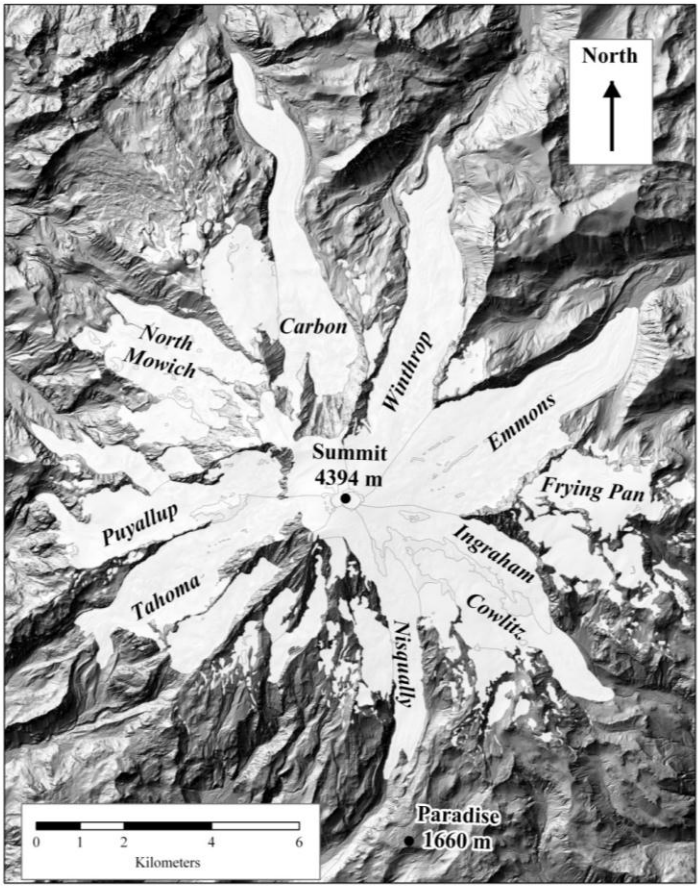

Figure 31. Major glaciers at Mount Rainier National Park. The National Park Service monitors the mass balance of Emmons and Nisqually Glaciers.

Table 51. Summary of glacier area from various inventories; all values are in square kilometers (from Wilson and Fountain 2014).

Glacier	1994 (Nylen 2004)	2007/2008 (Sisson et al. 2011)	2009 (Nylen, unpub.)	2011
Carbon	7.98 ± 0.08	7.65	7.40	7.39
Cowlitz	7.70 ± 0.10	7.28	7.05	7.03
Emmons	11.22 ± 0.08	11.23	10.99	10.98
Kautz	2.20 ± 0.04	2.06	2.08	2.07
North Mowich	6.11 ± 0.10	5.40	5.29	5.28
Puyallup	4.35 ± 0.05	3.51	3.52	3.52
South Mowich	4.06 ± 0.07	3.97	3.97	3.97
South Tahoma	2.23 ± 0.03	1.97	2.02	2.10
Tahoma	7.28 ± 0.08	6.95	6.83	7.15
Winthrop	9.95 ± 0.07	8.41	8.53	8.47

4.17.2 Reference Conditions and Comparison Metrics

Two primary reference condition indicators of glacier status and trends are used in this assessment: total glacier area and the mass balance of 2 indicator glaciers. Glacial extent was chosen because measurements of glacier area from aerial photographs and field surveys have been taken frequently. Surface mass balance measurements represent a global standard for assessing annual volume changes (Ostrem and Brugman 1991). The level of confidence with these indicators is high because methods for measurement are standardized, the length of records for both is relatively long, and identification of trends is clear because of the indicator's sensitivity to the primary climate stressors.

Changes in glacier extent were examined for the last century. Recent glacier area measurements are compared to air-photo based surveys in 1913, 1970, and 1994 (Nylen 2004; Riedel et al. 2010; Sisson et al. 2011).

Glacier accumulation and melt is measured annually at 11 points on the Nisqually and Emmons glaciers. Status and trends in mass balance were examined by plotting the cumulative net mass balance of Nisqually and Emmons glaciers since 2003. Cumulative net mass balance is based on standardized seasonal measurements of winter accumulation and summer melt at 4 or 5 fixed locations on each glacier (Riedel et al. 2010). Point measurements are averaged across the glacier surface to determine annual net mass balance, which is used to determine cumulative net mass balance. Nisqually and Emmons Glaciers were selected because they have different aspects, some history of past measurement, and access (Figure 30; Riedel et al. 2010). Melt stakes are also placed in debris covered ice to record the insulating effect of this extensive glacier surface cover.

4.17.3 Results and Assessment

Climate Change Stressors

Climate change stressors for glaciers include annual air temperature and winter precipitation. Glaciers are particularly sensitive to temperature because it affects the rate of summer melt, the length of the melt and accumulation seasons, and the form of precipitation. Decreased winter snowfall starves a glacier of mass, and warm autumn rains can result in greater melting, particularly near the terminus. Together, increased temperature and lower snowfall lead to a downward trend in cumulative net mass balance and, played out over decades, dramatic declines in the thickness and extent of glaciers.

Long climate records from near the elevation of glaciers are available from only 1 site at MORA. Paradise is at elevation 1670 m (5479 ft) and has a weather record that begins in 1916, but temperature measurements are missing for long periods in the 1940s. The Longmire record was started in 1914 and is more complete, but is more than 800 m (2625 ft) lower in elevation (Figure 32). During this period there is a slight trend toward increasing temperature of a few tenths of a degree. Low elevation sites in wet western Cascade Range valleys are relatively insensitive to climate change compared to glaciers because of the moderating influence of cold marine water.

Another measure of the impact of rising temperatures on glaciers is the 24-yr average annual elevation of the winter freezing level, which has risen 200 m (656 ft) since 1959, or about 4 m/yr (NOAA 2012). Further, the last 2 decades witnessed the first 2 winters when the average freezing level was above 1500 m (4921 ft; Figure 33).

Seasonal weather patterns in this region also play a strong role in the sensitive response of glaciers to climate change because above-normal winter accumulation is typically followed by lower summer melt due to the persistence of cool, cloudy weather in May and June. This pattern enhances annual glacier growth, just as the opposite pattern of dry winters followed by warm, dry summers accentuates annual glacier volume loss.

The sensitivity of glacier mass balance means that it responds to variability within the climate of this region (Bitz and Battisti 1999). Primary sources of climate variability include the temperature of the equatorial Pacific Ocean (El Nino-Southern Oscillation or ENSO) and the Pacific Decadal Oscillation (PDO). These events can be easily identified on longer records as 2- to 5-yr periods with a trend toward positive cumulative net mass balance.

Mount Rainier Reference Condition

Glacier area and cumulative net mass balance (volume) are decreasing rapidly at MORA due to increasing temperature and decreasing snowfall. Glacier area declined about 6.7% from 93.3 km2 (36 mi2) in 1970 to about 87.7 km2 (33.9 mi2) in 2007 (Table 50; Sisson et al. 2011). Over longer time scales, the amount of recession between 1913 and 2007 is approximately 24.3 km2 (9.4 mi2) or 21% (Table 51). However, the areal change pattern for the last century includes a brief, modest period of glacier growth in the middle part of the 20th century that slowed but did not reverse the long-term trend. Glacier advances at this time were due primarily to above normal precipitation and below normal melting associated with the cool phase of the PDO and strong La Nina events between 1948–1956 and 1970–1976 (Bitz and Battisti 1999).

Advances for the larger glaciers at MORA lag about 8 to 9 yrs behind actual changes in accumulation. Thus, some glaciers at MORA were continuing to grow until the mid-1990s. Since that time, most of the glaciers have retreated upslope. Exceptions include Emmons Glacier, which advanced 600 m (1969 ft) and Winthrop Glacier, which advanced 200 m (656 ft) between 1970 and 2007 (Sisson et al. 2011). Although both Emmons and Winthrop glaciers lost volume, each glacier advanced during the same time period. The pattern of retreat is dominated by down-wasting of the ice surface, with retreat of the glacier terminus (back-wasting) less perceptible.

The Nisqually Glacier has shown dramatic changes in dimension within the last century (Heliker et al. 1983). The Nisqually Glacier on Mount Rainier has one of the longest and most complete records in the Western hemisphere of terminus position observations and ice surface altitude measurements along specific profiles. Between 1857 and 1979, the glacier receded a total of 1945 m (6381 ft) and advanced a total of 294 m (965 ft). Advances occurred from 1963–1968 and from 1974–1979. Ice surface altitude changes of as much as 25 m (82 ft) occurred between 1944 and 1955. The climatic change of the late 1940's, which subsequently was found to have caused the advance of glaciers in many parts of the world, apparently was first detected in 1946 and 1947 in the Nisqually Glacier on Mount Rainier (Catton 1996). Figure 34 shows changes between 1930 and 2010 in the Nisqually Glacier ice surface altitude measurements. An analysis of changes from 1979 to 2012 is presently being conducted through a cooperative agreement with the University of Washington (Stevens, In prep.).

Decrease in the proportion of the park covered by glaciers at MORA over the last century is lower than for other glaciated mountain ranges in the region. For example, in the 20th century glacier area declined about 57% at Olympic National Park (Reidel and others, In prep.) and 44% at Garibaldi Provincial Park (Koch et al. 2007). The reasons for the lower apparent rate of glacial extent change at MORA are that the glaciers extend to more favorable climates above 3000 m (9843 ft) and have extensive debris cover, which slowed surface melting of parts of the glaciers by 75% between 2003 and 2010. Based on the mass balance trend, glaciers at MORA appear to be thinning more rapidly than they are decreasing in area (Riedel and Larrabee 2011).

Cumulative net mass balances since 2003 at MORA are –6.0 and –9.0 m (–20 and –30 ft) water equivalent (w.e.), respectively, for Nisqually and Emmons glaciers (Figure 35). Combined, this represents a net loss of water of 0.15 km3 (0.04 mi3) between the 2 glaciers in 9 yrs, with 70% (0.1 km3) from Emmons Glacier, which is nearly twice as large as the Nisqually-Wilson-Muir glacier complex (Table 48). Variability of mass balance between these 2 glaciers is due to extent and thickness of debris cover, aspect, and response time to climate change. For example, Nylen (2004) points out that the glaciers on the south face of Mount Rainier receive as much as 25% more solar radiation than those on the north face.

Park-wide volume loss since 2003, assuming an area of 87.4 km2 (33.7 mi2) and an average cumulative net mass balance of –7.5 m (–24.6 ft) w.e., is approximately –0.65 km3 (–0.16 mi3). This represents a loss of about 15% of the volcano's ice volume of 4.4 km3 (1.1 mi3) (Driedger and Kennard 1986). An independent study by Sisson et al. (2011) used remapping of glaciers to estimate the loss of volume between 1970 and 2007–2008 at –0.59 km3 (– 0.14 mi3). Given the strongly positive cumulative net mass balance observed at other sites in the Cascade Range between 1970–1976 and the late 1990s, and the 0.65 km3 (0.16 mi3) cumulative net mass balance estimate for the period 2003–2011, it is clear that most of the volume loss at MORA has occurred in the last 2 to 3 decades.

Most volume loss on Mount Rainier's glaciers has occurred, as expected, at lower elevation in the ablation zone (Figure 36). This simple pattern is complicated by shading, debris cover, and snow avalanching and drifting, and as a result the lowest balance is not at the glacier termini. Cumulative net balance of –34 m (–112 ft) w.e. at Nisqually Glacier occurred at 1770 m (5807 ft) elevation, while at Emmons Glacier the maximum net loss of –62 m (–203 ft) w.e. occurred at an elevation of about 1710 m (5610 ft; Figure 36). Debris cover at stake 4 on Emmons increased cumulative mass balance compared to an adjacent stake on ice with no debris cover by 15% (i.e., decreased melting).

While the 9-yr length of the MORA mass balance record is too short to discern variability associated with decadal weather patterns, it is likely that positive mass balance in water years 2010 and 2011 were due to the return of the La Nina phase of ENSO and the cold phase of the PDO (i.e., not a reversal of long term negative trend; Bitz and Battisti 1999). Longer cumulative net mass balance records at glaciers in the North Cascades have short-term, minor volume increases over 4- to 6-yr intervals that occur about every 10 to 15 yrs. Based on this pattern, it is likely the long-term trend will continue to be negative and the current 2 yr modest increase in volume will be short-lived, and will not lead to a glacial advance.

The strongly negative trend in cumulative net mass balance and the decrease in glacial extent at MORA are a result of warming temperatures, which have increased summer melting and resulted in less winter snowfall. Correlation of the mass balance data with the Paradise weather station temperature data is problematic due to the short mass balance record and the high variability of average annual air temperature at Paradise. However, the 4 m/yr (13 ft/yr) rise in the freezing level is an important manifestation of rising temperature that has a strong relationship to glacial mass balance.

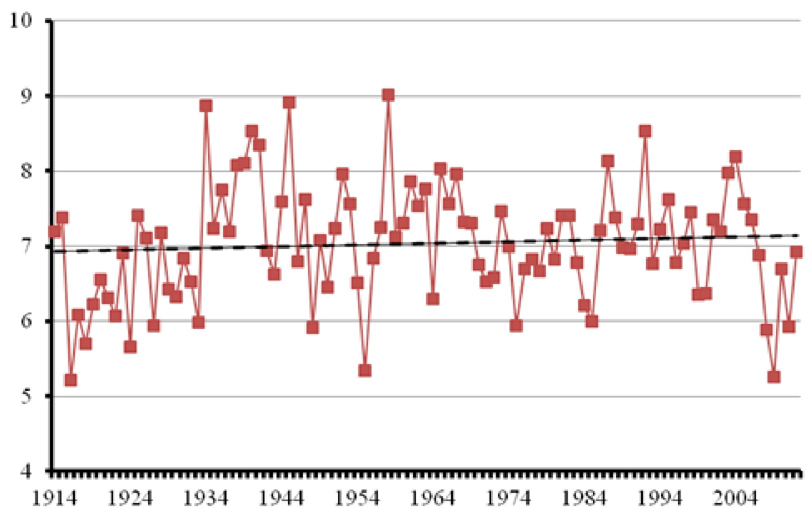

Figure 32. Average annual air temperature at Longmire, MORA (NOAA 2012). The period of record average is 7°C, minimum 5.2°C (1916), and maximum 9°C (1958). Dashed line is trend.

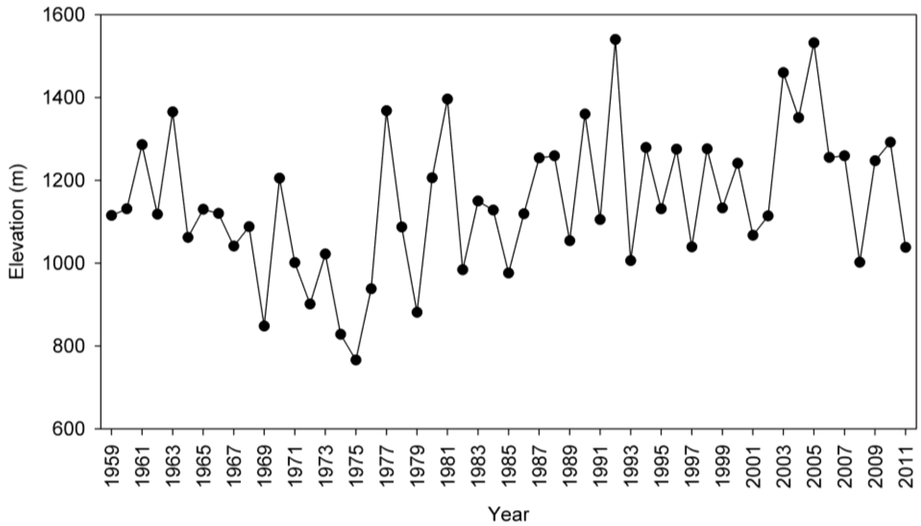

Figure 33. Average winter (November–April) elevation of the freezing level in the Cascade Range. Dashed line is trend, which has risen ~200 m since 1959 (NOAA 2012).

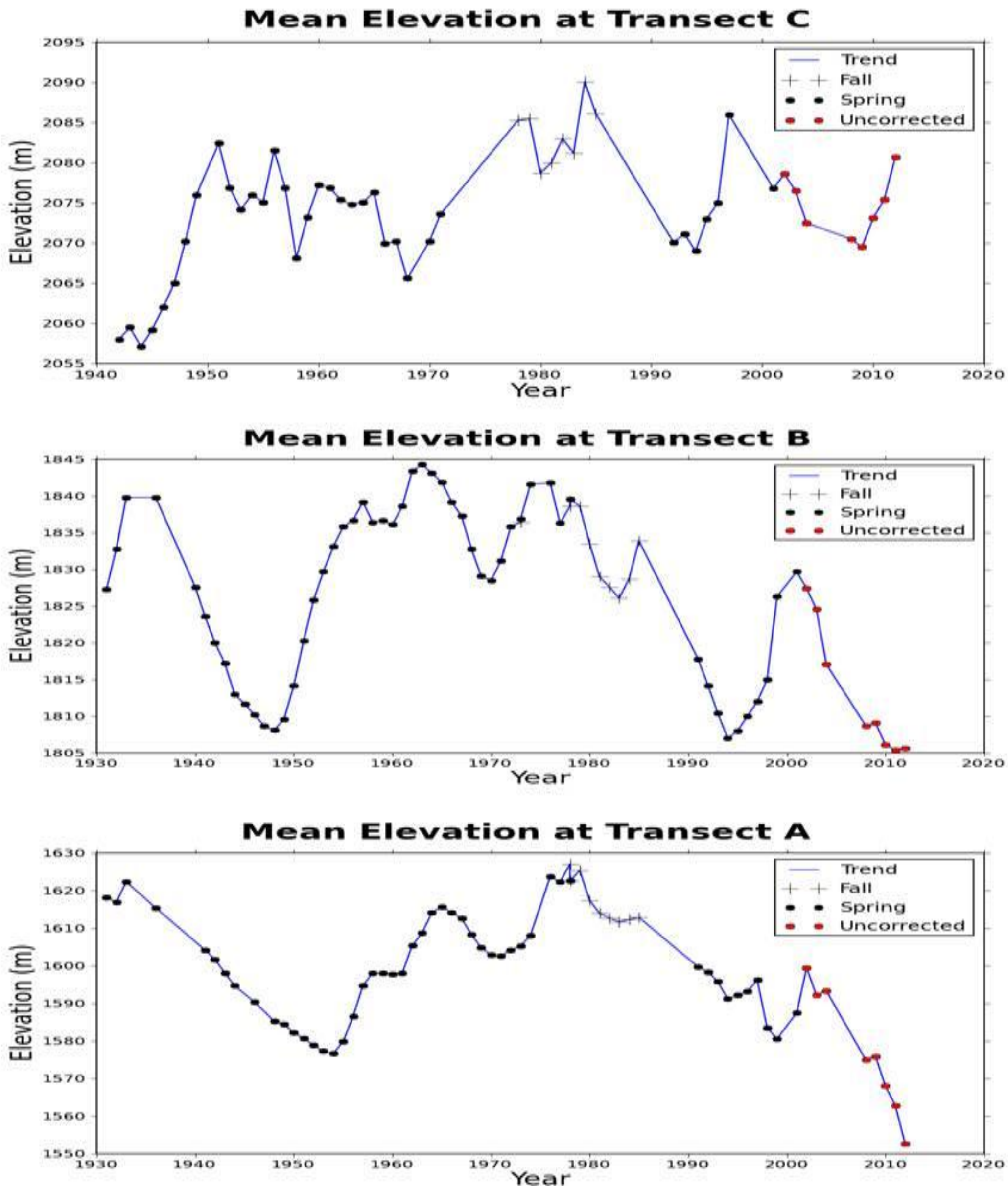

Figure 34. Nisqually Glacier ice surface elevations, 1930 to 2012 (Stevens, In prep.).

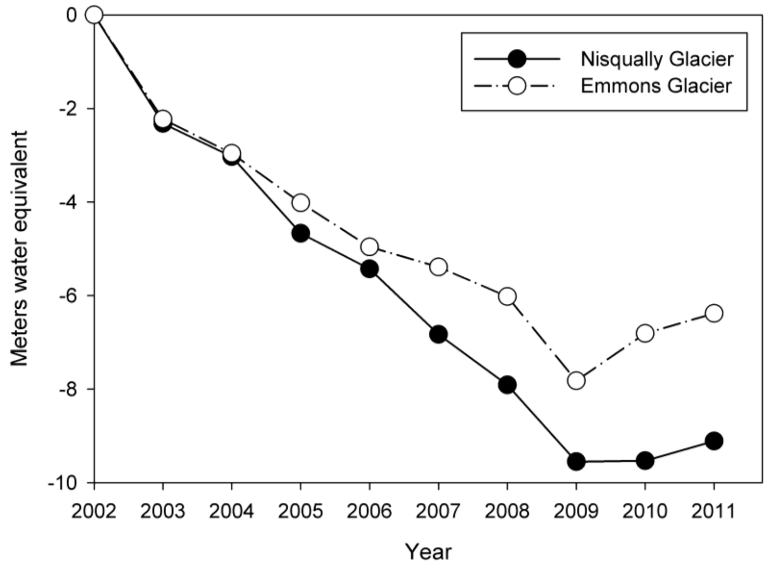

Figure 35. Cumulative net mass balance of 2 Mount Rainier glaciers. Values represent loss averaged across the entire glacier by water year.

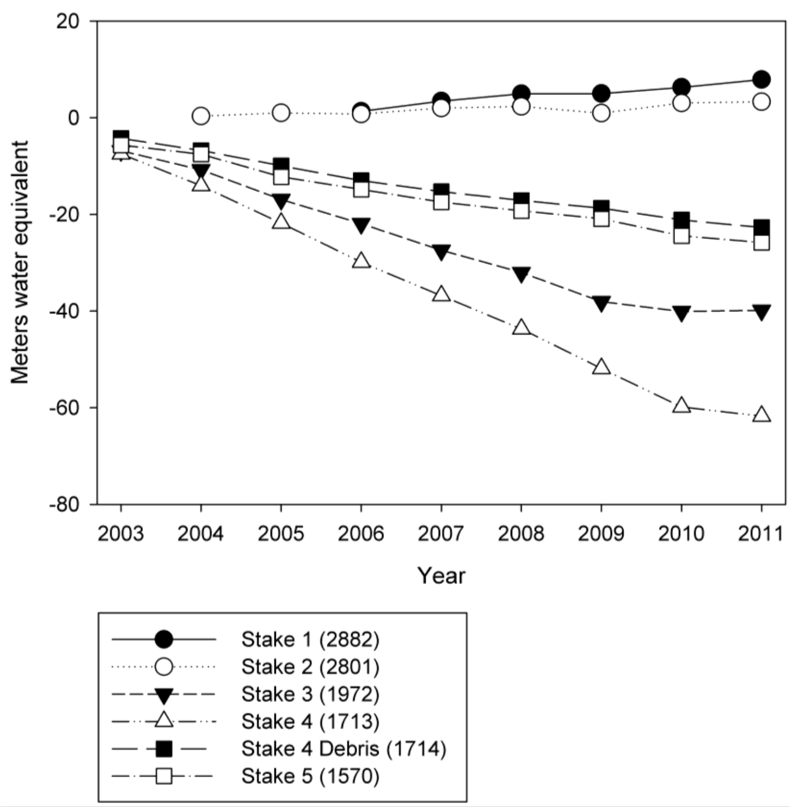

Figure 36. Cumulative mass balance by stake (elevation in meters) on Emmons Glacier, MORA.

4.17.4 Emerging Issues

There are several management implications for the observed recent and projected future decline of glaciers at MORA due to warming climate. The loss of glaciers impacts alpine and aquatic ecosystems, sustainability of water supplies, access, recreation, and visitor interpretation of climate change.

Glaciers are sensitive, unambiguous signals of warming climate that are invaluable public education assets (Figure 30). Glacier change data can help the public value parks as places to understand impacts from, and vulnerability to climate change. They are also sensitive enough to respond to climate variability at inter-annual to decadal time scales, which provides a clear context for assessing longer term climate change. For example, cold wet periods in the last 50 yrs led to short-term expansion of glaciers, but did not reverse the long-term trend of glacial retreat since 1913. Therefore the glaciers show that these periods are a natural feature of the climate, and do not represent evidence against climate warming. Strong climatic gradients in the Cascade Range mean that hydrologic changes in response to climate are occurring at different elevations and aspects. For example, cumulative net mass balance of Nisqually Glacier is 50% higher than Emmons Glacier primarily because of its south aspect.

Many popular climbing routes will continue to change due to thinning glaciers, particularly the main route to the Mount Rainier summit, which crosses the rapidly declining Muir Snowfield. In other areas, thinning ice may lead to ice and rock falls, such as the ice fall at Nisqually Glacier in 2011. Loss of ice also has direct impacts to aquatic ecosystem function through the loss of water to supplement summer base flow, increased sediment supply, and increases in stream temperature. Decline of glacier area means the loss of habitat for some species endemic to glaciers such as the ice worm, and likely has indirect effects on the larger alpine food web, which loses diversity as glaciers recede.

In a few cases the complete loss of glaciers will mean the creation of new alpine lakes at both parks. These lakes will provide opportunities to understand how lake ecosystems develop following glacial retreat. At sites where glaciers remain above newly formed shallow lakes, high sedimentation rates in the next century will convert them into wetlands.

Widespread exposure of unconsolidated sand, rock, and gravel exposed by glacial recession has created a massive new source of sediment for rivers. Stagnation of glacial ice and failure of glacial moraines will lead to outburst floods and debris flows on some streams, particularly those on steep slopes. Facilities and roads at Longmire and along Nisqually River, White River, and Tahoma Creek will continue to face high maintenance and reconstruction costs. The Upper Carbon River road was closed due to channel aggradation and flooding. Debris-covered lower Emmons and Carbon Glaciers also may be prone to future outburst activity.

Deposition of glacial gravel is widespread at MORA where movement of loose glacial debris off of the steep flanks of the volcano has led to aggradation of floodplains at lower elevations. Rates of gravel accumulation on the major rivers at MORA were about 0.3 m/decade (1 ft/decade) from the 1960s to 1990s (Riedel 1997). In the past decade these rates have tripled, and in some cases quadrupled (Beason 2007, Beason et al. 2011). Some parts of the Carbon, White, and Nisqually River beds are now several meters above major park roads. During flood stage, water spilling out of channels is causing significant damage to roads and other infrastructure. West side road was closed in the 1990s due to aggradation of the Tahoma Creek channel caused by outburst floods; however, Anderson (2013) suggests that Tahoma Creek has recovered and aggradation slowed. This issue may be accentuated in the future by continued glacial recession, stagnation, and outburst floods, as well as larger, more frequent precipitation events.

Glaciers currently supply a significant amount of water to all of the major streams at MORA at a critical time of year. Mass balance measurements at a wide range of elevations and GIS data on the distribution of glaciers by elevation are used to estimate glacial contribution to summer streamflow for Nisqually and Whiter River watersheds (Figure 37; Riedel and Larrabee 2011). These estimates represent melt from ice, firn, and snow on the glaciers' surfaces between 1 May and 30 September. Measurement of the ice-only component of the melt was not made due to the time-transgressive start of the melt season on glaciers spanning >1300 m (>4265 ft) in elevation, and only 3-measurement periods per glacier each year.

Total volume of the annual glacial contribution ranges from 47–69M m^3 on Nisqually River at National and 63–92M m^3 on White River at Mud Mountain Dam (Figure 37; Riedel and Larrabee 2011). The large annual variability in glacial input is due to the amount of snow melt in the basin, as well as the summer melt rate. This variability, combined with a short record and an increasing rate of melt, makes it difficult to discern a trend in glacial runoff since 2003. However, the proportion of summer runoff that could be lost due to future glacial retreat is summarized in Figure 37.

Decline in glacier area and volume in the past 30 yrs combined with lower winter snowpack are resulting in lower summer streamflow and higher summer stream temperature. The loss of snow and ice resources for summer streamflow has resulted in a trend toward increasing summer stream temperatures at some sites with long records in the region. This trend is likely due to the combined effect of loss of glaciers, decline in snowpack, and higher air temperatures; however, our current understanding of the glacial influence on stream temperature is limited by a lack of long records from sites distributed across the landscape.

Some aquatic organisms will likely adapt to the loss of glacial input and increasing stream temperatures in the next 100 yrs by migrating into cooler areas on north exposures, particularly those with glaciers, and upstream toward glaciers (Brittain and Milner 2001; Milner et al. 2001; Brown et al. 2007). Adaptation of benthic macroinvertebrates to the loss of glaciers has been examined at several sites in temperate latitudes, and deterministic models could serve as a useful tool for predicting future changes at MORA. Research and monitoring of the glacial influence on stream temperature and channel stability is needed to provide a framework for understanding ecosystem response to the loss of glaciers.

Some of the communities that are adapted to abundant glacial meltwater (low stream temperatures) will become extirpated in watersheds that will lose glaciers in the coming decades. At MORA, sensitive sites include watersheds with minimal glacial cover that are not sourced on Mount Rainier, particularly the Ohanapecosh River. In these areas, groundwater will play a key role in reaches that have extensive gravel deposits. Loss of glacial stream buffering may complicate efforts to sustain endangered species such as Bull Trout (*Salvelinus confluentus*) and summer-run Chinook Salmon (*Oncorhynchus tshawytscha*).

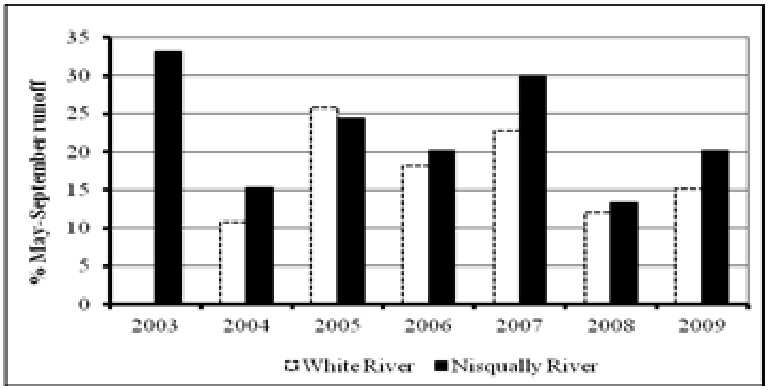

Figure 37. Total summer (May–September) glacial melt-water contribution to 2 watersheds at MORA. White River watershed is 2.4% glaciated above Mud Mountain Dam, while Nisqually River basin above National is 4.6% glaciated.

4.17.5 Information and Data Needs–Gaps

A number of data needs and gaps have been identified based on this assessment:

- Continue monitoring glacier mass balance, glacier extent, and changes in glaciers termini.
- Assess trends in ice surface elevations and continue monitoring established on the Nisqually glacier.
- Monitor stream bed elevations in glacial systems of the park.
- Monitor trends in summertime stream temperatures, glacier runoff, and overall discharge to gain a better understanding of the effects of glacier change on dependent aquatic ecosystems.
- Repeat LiDAR surveys of the topography of the mountain, particularly the upper mountain due to geothermal influences and uncertainty in winter balance measurements.
- Monitor changes in benthic macroinvertebrate communities in glacial streams.
- Research and monitor glacial influence on stream temperature and channel stability to provide a framework for understanding ecosystem response to loss of glaciers.
- Gain a better understanding of groundwater contribution in watersheds with minimal or no glacial cover.
- Gain a better understanding of the hyporheic zone of glacial and non-glacial systems and the relationship to habitat, especially for native and threatened and endangered species.
- Investigate the effects of rockfall on glaciers and identify past rockfalls (location, timing, magnitude)
- Investigate the effects of climate change on rockfall including on glacier velocities.
- Investigate how stagnant ice contributes to outburst floods.

- Monitor glacier change and debris flows on the Carbon Glacier.
- Investigate the role of non-volcanic rock controlling debris flows.
- Study the interaction between sediment and forests and effects on floodplains.
- Walkup et al. (2013) studied whether the surficial velocity field of the Nisqually Glacier is changing, They found that measurable glacial velocity changes do occur between subsequent summers and that their data supports Hodge's observation (Hodge 1974) of increased velocity in the vicinity of the ELA, concurrent with decreased velocity near the terminus prior to the occurrence of an outburst flood. Additional studies are needed to assess these measurements as a tool in the prediction of outburst flood hazards.

4.17.6 Literature Cited

Anderson, S. C. 2013. Sediment fluxes in a changing climate: Tahoma Creek over daily to centennial time-scales [thesis]. University of Colorado at Boulder, Boulder, Colorado.

Beason, S. R., P. M. Kennard, T. B. Abbe, and L. C. Walkup. 2011. Landscape response to climate change and its role in infrastructure protection and management at Mount Rainier National Park. Park Science 26:31–35.

Bitz, C. M., and D. S. Battisti. 1999. Interannual to decadal variability in climate and the glacier mass balance in Washington, western Canada, and Alaska. Journal of Climate 12:3181–3196.

Brittain, J. E., and A. M. Milner. 2001. Ecology of glacier-fed rivers: Current status and concepts. Freshwater Biology 46:1571–1578.

Brown, L. E., D. M. Hannah, and A. M. Milner. 2007 Vulnerability of alpine stream biodiversity to shrinking glaciers and snow packs. Global Change Biology 13:958–966.

Catton, T. 1996. Wonderland: An administrative history of Mount Rainier National Park. National Park Service, Cultural Resources Program. Seattle, Washington.

Driedger, C. L., and P. M. Kennard. 1986. Ice volume on Cascades volcanoes – Mount Rainier, Mount Hood, Three Sisters, and Mount Shasta. U.S. Geological Survey Professional Paper 1365:28.

Heliker, C. C., A. Johnson, and S. M. Hodge. 1983. The Nisqually Glacier, Mount Rainier, Washington, 1857–1979: A summary of long-term observations and a comprehensive bibliography, U. S. Geological Survey Open-File Report 84-541.

Hodge, S. M. 1974. Variations in the sliding of a temperate glacier. Journal of Glaciology. 13:349–369.

Hodson, A., A. M. Anesio, M. Tranter, S. F. Fountain, M. Osborn, J. Priscu, J. Layborn-Parry, and B. Sattler. 2008. Glacial ecosystems. Ecological Monographs 78:41–67.

Koch, J., J. J. Clague, and G. D. Osborn. 2007. Glacier fluctuations during the past millennium in Garibaldi Provincial Park, southern Coast Mountains, British Columbia. Canadian Journal of Earth Sciences 44:1215–1233.

Milner, A., J. E. Brittain, E. Castella, and G. Petts. 2001. Trends in macroinvertebrate community structure in glacier-fed rivers in relation to environmental conditions: A synthesis. Freshwater Biology 46:1833–1847.

National Oceanic and Atmospheric Administration (NOAA). 2012. National Climate Data Center. Available at: http://lwf.ncdc.noaa.gov/oa/ncdc.html.

Nylen, T. 2004. Spatial and temporal variation of glaciers on Mount Rainier between 1913–1994. Thesis. Portland State University, Portland, Oregon.

Ostrem, G., and M. Brugman. 1991. Glacier mass balance measurements: A manual for field and office work. NHRI Science Report No. 4, Environment Canada.

Richardson, D. 1968. Outburst floods in the Pacific Northwest. Geological Survey Research: D79–86.

Riedel, J. L. 1997. Geologic hazard and floodplain management. Unpublished report for the Mount Rainier General Management Plan.

Riedel, J. L., J. M. Wenger, and N. D. Bowerman. 2010. Long term monitoring of glaciers at Mount Rainier National Park: Narrative and standard operating procedures version 1.0. Natural Resource Report NPS/NCCN/NRR–2010/175. U.S. National Park Service, Fort Collins, Colorado.

Riedel, J. L., and M. A. Larrabee. 2011. Mount Rainier National Park glacier mass balance monitoring annual report, water year 2009: North Coast and Cascades Network. Natural Resource Technical Report NPS/NCCN/NRTR–2011/484. National Park Service, Fort Collins, Colorado.

Reidel, J. L., S. Wilson, B. Baccus, M. Larrabee, S. Dorsch, and S. Fountain. In prep. Glacial status and contribution to streamflow in the Olympic Mountains.

Sisson, T. W., J. E. Robinson, and D. D. Swinney. 2011. Whole-edifice ice volume change A.D. 1970 to 2007/2008 at Mount Rainier, Washington, based on LiDAR surveying. Geology 39:639–642.

Walder, J. S., and C. D. Driedger. 1993. Glacier-generated debris flows at Mount Rainier. U.S. Geological Survey Open File Report 91–242. U.S. Geological Survey Water Fact Sheet 2.

Walder, J. S., and C. D. Driedger. 1994. Rapid geomorphic change caused by glacial outburst floods and debris flows along Tahoma Creek, Mount Rainier, Washington, U.S.A. Arctic and Alpine Research 26:319–327.

Walkup, L. C., P. Kennard, J. Ohlschlager, and S. R. Beason. In Prep. Surficial Velocities of the Nisqually Glacier, Mount Rainier National Park, 2011 and 2012. Natural Resource Data Series NPS/XXXX/NRDS—20XX/XXX. National Park Service, Fort Collins, Colorado.

Walkup, L. C., S. R. Beason, P. M. Kennard, J. G. Ohlschlager, and A, C. Stifter. 2013. Surficial ice velocities of the lower Nisqually Glacier and their relationship to outburst flood hazards at Mount Rainier National Park, Washington, United States. Presentation at the 125th Anniversary Annual Meeting and Expo of the Geological Society of America, 27–30 October 2013, Denver, Colorado.

Wilson, S., and A. Fountain. 2014. Field mapping glacier extents at Mount Rainier for hazard recognition. Report to Mount Rainier National Park. Portland State University, Department of Geology, Portland, Oregon.

4.18 Soundscape

(Lelaina Marin, U.S. Fish and Wildlife Service)

4.18.1 Introduction

Our ability to see is a powerful tool for experiencing our world, but sound adds a richness that sight alone cannot provide. In many cases, hearing is the only option for experiencing certain aspects of our environment. An unimpaired acoustical environment is an important part of overall visitor experience and enjoyment as well as vitally important to overall ecosystem health.

Visitors to national parks often indicate that an important reason for visiting the parks is to enjoy the relative quiet that parks can offer. In a 1998 survey of the American public, 72% of respondents identified opportunities to experience natural quiet and the sounds of nature as an important reason for having national parks (Haas and Wakefield 1998). Additionally, 91% of NPS visitors “consider enjoyment of natural quiet and the sounds of nature as compelling reasons for visiting national parks” (McDonald et al. 1995).). Natural sounds at MORA include those made by insects, the vocalizations of frogs, birds, and mammals, as well as the sounds of wind, flowing water, falling rock, sliding shale, and snow avalanches. Despite this desire for quiet environments, anthropogenic noise continues to intrude upon natural areas and has become a source of concern. A report in Landscape Ecology, for example, determined that the median hourly percent time audible of human-caused noise across all sites (189 sites in 43 national parks) and hours is over 28% (Lynch et al. 2011).

Sound plays a critical role in intraspecies communication, courtship and mating, predation and predator avoidance, and effective use of habitat. Studies have shown that wildlife can be adversely affected by sounds and sound characteristics that intrude on their habitats. While the severity of the impacts varies depending on the species being studied and other conditions, research strongly supports the fact that wildlife can suffer adverse behavioral and physiological changes from intrusive sounds (noise) and other human disturbances. Documented responses of wildlife to noise include increased heart rate, startle responses, flight, disruption of behavior, and separation of mothers and young (Selye 1956, Clough 1982, USDA 1992, Anderssen et al. 1993, NPS 1994). Noise as used in this context can be defined as sounds that are created by humans and human activity (e.g., the mechanized sounds of vehicles, compressors, generators, etc.).

4.18.2 Approach

During 2006–2007 and 2009, staff from the NPS Natural Sounds and Night Skies Division (NSNSD) and Mount Rainier National Park (MORA) conducted acoustical monitoring at 8 sites within the park (Figure 38). Six acoustical monitoring systems (MORA001 through MORA006) were deployed during the summer and winter of 2006 and the summer of 2007. Two acoustical monitoring systems (MORA008 and MORA009) were deployed during summer of 2009. The primary goal of the site selection process was to identify the optimum number of field-measurement sites, which would allow for characterization of the ambient sound levels for different vegetation zones, management zones, and span different elevations and climate conditions (Table 52). In addition to the 8 sites discussed previously, another sound monitoring system was set up during the summer of 2011 by Resource Systems Group, Inc., in the Nisqually Corridor (Figure 38).

In characterizing natural and non-natural acoustic conditions in a park, knowledge of the intensity, duration, and distribution of the sound sources is essential. In order to collect this type of information at each site, sound pressure level (SPL) measurements were taken, along with digital audio recordings and meteorological data. For this resource assessment, key findings on natural and existing ambient sound levels and types of sound sources are summarized. Natural ambient sound level refers to the acoustical conditions that exist in the absence of human-caused noise and represents the level from which the NPS measures impacts to the acoustical environment. Existing ambient sound level refers to the current sound intensity of an area, including both natural and human-caused sounds. Some tables report sound levels for 2 frequency ranges: 20–1250 Hz and 12.5–20,000 Hz. It is useful to look at the low-frequency range (20–1250 Hz) because it includes most human-caused noise while excluding higher-frequency natural sounds like birds and insects. If we were to consider only the full frequency range, the sound levels may appear higher because of the inclusion of louder birds or insects. Although we have included levels for both frequency ranges in the tables, the levels we report in the text focus on the 20–1250 Hz frequency range. For further details on data collection and analysis see the full acoustical monitoring report (NPS 2011).

Characteristics of Sound

Humans perceive sound as an auditory sensation created by pressure variations that move through a medium such as water or air and is measured in terms of amplitude and frequency (Saunders et al. 1997, Harris 1998). Noise, essentially the negative evaluation of sound, is defined as extraneous or undesired sound (Morfey 2001). Sound pressure level is proportional to sound power and is measured in decibels (dB). Decibels constitute a logarithmic scale. The loudness of a sound as heard by the human ear is estimated by an A-weighted decibel scale, where the A-weighting provides a formula for discounting sounds at low (<1 kHz) and high (>6 kHz) frequencies. This adjustment for human hearing is expressed as dBA. For this discussion, A-weighted values are used to describe potential effects on the park’s acoustical environment and soundscape. Table 53 provides examples of A-weighted sound levels.

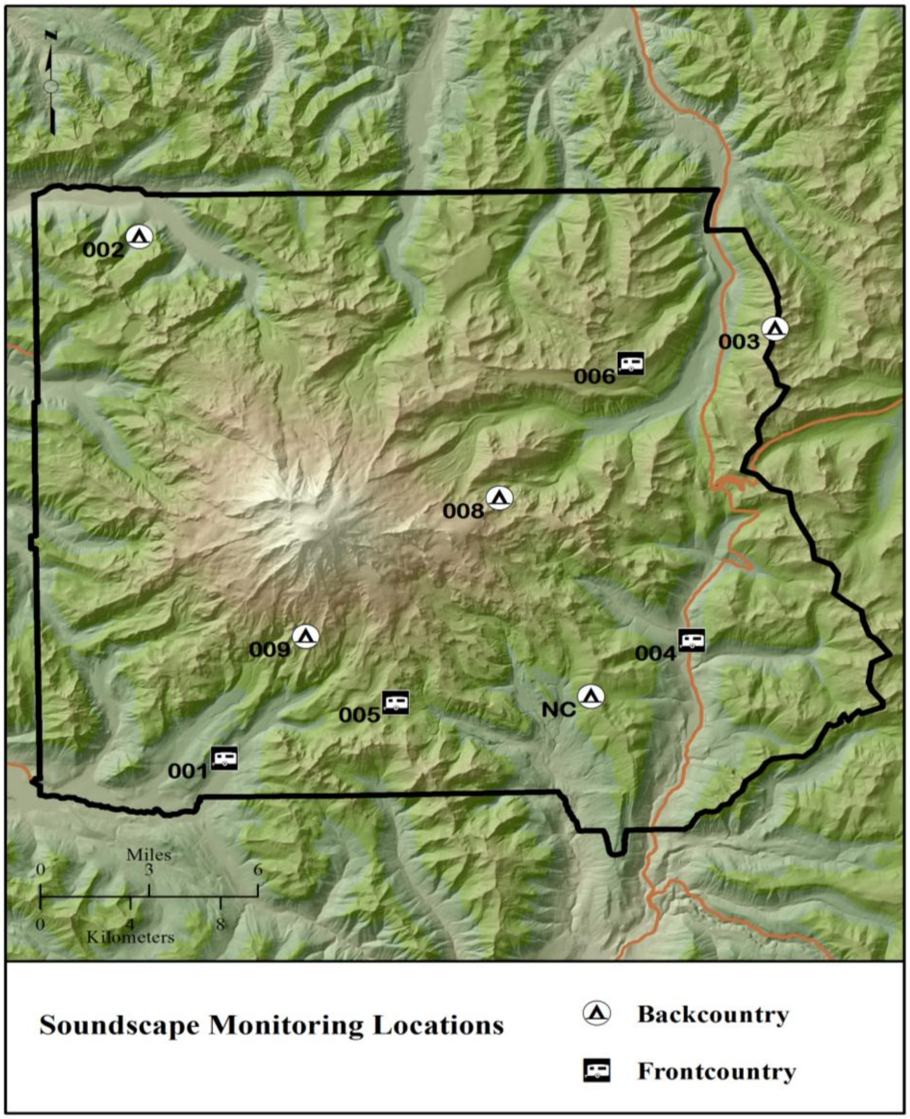

Figure 38. Soundscape measurement sites for Mount Rainier National Park.

Table 52. MORA measurement site locations, 2006–2007, 2009.

Site ID	Site Name	Location	# Days of Data	Habitat Type (NLCD[1] Classification)	Coordinates (latitude/longitude in decimal degrees)	Elevation (m)
MORA001	Trail of Shadows	Front Country	30	Moderately Wet Forest (Evergreen Forest)	46.752277° / -121.814901°	851 (2800 ft)
MORA002	Green Lake	Back Country	30	Wet Forest (Evergreen Forest)	46.97857° / -121.85757°	999 (3280 ft)
MORA003	Crystal Mountain	Back Country	30	Subalpine (Evergreen Forest)	46.93457° / -121.50273°	1951 (6400 ft)
MORA004	Shriner's Trail	Front Country	30	Dry Forest (Evergreen Forest)	46.80028° / -121.55295°	750 (2460 ft)
MORA005	Lake Trail	Front Country	30	Subalpine (Evergreen Forest)	46.77542° / -121.71903°	1,538 (5050 ft)
MORA006	Sunrise Ridge	Front Country	30	Subalpine (Evergreen Forest)	46.92060° / -121.58393°	1746 (5730 ft)
MORA008	Summerland	Back Country	34	Glacier/Alpine (Transitional)	46.863193° / -121.658732°	1865 (6120 ft)
MORA009	Van Trump	Back Country	38	Glacier/Alpine (Transitional)	46.804500° / -121.768369°	1,786 (5860 ft)

With the goal of potentially facilitating future data transferability between parks, all baseline acoustic data have been organized/classified in accordance with the National Land Cover Database (NLCD). Developed by the U.S. Geological Survey (USGS), the NLCD is the only nationally consistent land cover data set in existence and is comprised of 21 NLCD subclass categories for the entire U.S. (Vogelmann, J. E., S. M. Howard, L. Yang, C. R. Larson, B. K. Wylie, N. Van Driel. 2001. Completion of the 1990s National Land Cover Data Set for the Conterminous United States from Landsat Thematic Mapper Data and Ancillary Data Sources. Photogrammetric Engineering and Remote Sensing 67:650-652.)

Table 53. Examples of sound levels.

Reference Sound	dB(A) Level[1]
Normal breathing	10
Leaves rustling	20
Crickets (16 feet)	40
Normal conversation (5 feet)	60
2 stroke snowmobile (30 mph at 50 feet)	70
Helicopter landing at 200 feet	80
Heavy truck or motorcycle (25 feet)	90
Thunder	100
Military jet (110 feet)	120
Shotgun firing	130

[1]An increase of 10 dBA represents a perceived (to human hearing) doubling of sound pressure level; that means 20 dBA would be perceived as twice as loud as 10 dBA, 30 dBA would be perceived as 4 times louder than 10 dBA, etc.

4.18.3 Reference Conditions and Comparison Metrics

Various characteristics of sound can contribute to how noise may affect the park acoustical environment or wildlife. These characteristics may include rate of occurrence, duration, loudness, pitch, and predictive or sporadic nature of sounds. In order to capture these aspects, sound is measured using a number of different metrics including sound level (measure in decibels), percent time human-caused noise is audible, noise free interval, natural ambient sound level, existing sound level. If we are to develop a complete understanding of a park's acoustical environment, we must consider a variety of sound metrics. This can make selecting 1 reference condition difficult. For example, if we chose to use just the natural ambient sound level for our reference condition, we would focus only on loudness and overlook the other aspects of sound mentioned above. Although selecting a single reference condition for MORA would be difficult, we can consider referring to the results of a recent report that summarizes acoustical data collected at 189 sites in 43 national parks (Lynch et al. 2011). The report estimates that the median hourly percent time audible of human-caused noise across all sites and hours is over 28%. The median L_{90} across all sites and hours of the day was 21.8 dBA (between 20 and 800 Hz). L_{90} is the sound level that is heard 90% of the time; an estimate of the background against which individual sounds are heard. In the "Acoustical Conditions in the Park" section below, we will refer to the natural ambient sound level. This metric is comparable to L_{90}, which can be used as a proxy when natural ambient sound level is not available. So, we can use natural ambient values to compare with the 21.8 dBA level reported here.

4.18.4 Results and Assessment

Natural ambient sound levels measured at the 8 MORA sites ranged from 20.5–47.3 dBA during the day, and 14.1–48.4 dBA at night within the 20–1250 Hz frequency band, representing a very quiet acoustical environment (Table 54). Higher sound levels were heard at Summerland and Van Trump, as a result of running water sounds and occasional rain events. Louder levels during nighttime hours resulted from increased insect activity. Existing ambient sound levels ranged from 21.1–47.9 dBA during the day and 14.3–48.4 dBA at night (Table 54) within the 20–1250 Hz frequency band (NPS 2011).

The acoustical environment is vital to the function and character of the park. Natural sounds include those sounds upon which ecological processes and interactions depend. Examples of natural sounds in parks include sounds produced by: (1) birds, frogs, or insects to define territories or attract mates; (2) bats to navigate or locate prey; and (3) physical processes such as wind in trees, flowing water, or thunder. While listening to audio recordings, NPS staff identified numerous species such as woodpeckers at Trail of Shadows, Barred Owls and Red-tailed Hawks at Green Lake, Elk at Crystal Mountain, bears at Lakes Trail, Pika at Sunrise Ridge, and Hoary Marmots at Summerland. Park staff also collected recordings of a rock slide at Green Lake and shale sliding down the slope on Crystal Mountain. These recordings along with wind and flowing water are just a few of the many natural sounds which create the MORA acoustical environment.

Although natural sounds predominate throughout the park, human-caused noise has the potential to mask these sounds. Noise impacts the acoustical environment much like smog impacts the visual environment; obscuring the listening horizon for both wildlife and visitors. Examples of human-caused sounds heard in the park include aircraft (i.e., high-altitude and military jets, fixed-wing aircraft, and helicopters), vehicles, generators, and visitors. At backcountry sites aircraft were the most pervasive non-natural sound sources, audible between 3 and 23% of the day (07:00 to 19:00), mostly caused by high altitude or military jets, except at Sunrise Ridge and Crystal Mountain where fixed-wing aircraft and helicopters were heard more frequently. Air tours are currently allowed at MORA. At the frontcountry sites, Trail of Shadows and Nisqually Corridor, vehicles were the most pervasive non-natural summer sound source, audible 43 and 61.6% of the day, respectively (07:00 to 19:00). At Trail of Shadows in the winter, generators were the most commonly heard human-caused sound, audible 70% of the day (NPS 2009).

Despite the presence of various human-caused noise intrusions, natural sounds can be heard at all sites between 56 and 96% of the day (Table 55, Figure 39). The most common natural sounds are birds, water, wind, and insects. A useful way to study the amount of natural sounds heard in a park is to calculate the Noise Free Interval (NFI), which describes the length of time between extrinsic or human-caused events when only natural sounds are audible. The longest NFI of all of the MORA sites occurred at Green Lake, with a maximum NFI of approximately 57 min. The shortest NFI occurred at Trail of Shadows (approximately 3 min), which is consistent with the frontcountry nature of the site (Table 55). All of the MORA sites have a diversity of natural sounds that make for a rich and spectacular acoustical environment.

In determining the current conditions of an acoustical environment, it is also important to examine how often sound pressure levels exceed certain thresholds. Table 56 reports the percent of time that measured sound levels were above 4 key thresholds. The top value in each cell focuses on frequencies affected by transportation noise whereas the lower values use the conventional full frequency range. The first 35 dBA is designed to address the health effects of sleep interruption. Recent studies suggest that sound events as low as 35 dB can have adverse effects on blood pressure while sleeping (Haralabidis et al. 2008). The percent time above 35 dBA was highest at Summerland, Van Trump, and Green Lake due to the presence of running water and rain events. The lowest percent time above 35 dBA occurred at Crystal Mountain, Lakes Trail, and Sunrise Ridge (Table 56).

The second threshold addresses the World Health Organization's recommendations that noise levels inside bedrooms remain below 45 dBA (Berglund et al. 1999). With the exception of Van Trump, the rest of the sites had low percent time above 45 dBA within the 20–1250 Hz frequency band (0.3–1.5%; Table 56). The third threshold, 52 dBA, is based on the EPA's speech interference threshold for speaking in a raised voice to an audience at 10 m. This threshold addresses the effects of sound on interpretive programs in parks. The final threshold, 60 dBA, provides a basis for estimating impacts on normal voice communications at 1 m. Hikers and visitors viewing scenic vistas in the park would likely be conducting such conversations. Relative to the 52 and 60 dBA thresholds, all of the sites had very low percent time above these thresholds, at or very close to 0%. Overall, there are only a few sites that had higher percent time above 35 dBA or 45 dBA (greater than 50%), and this resulted from louder natural sounds (i.e., flowing water and rain) or was consistent with the frontcountry nature of the site (i.e. Trail of Shadows).

Table 54. Natural and existing ambient sound levels measured 2006–2007 and 2009.

		Daytime (7 am to 7 pm)		Nighttime (7 pm to 7 am)	
Site ID	**Site Name**	**Natural**	**Existing**	**Natural**	**Existing**
MORA001	Trail of Shadows	33.1[a]	35.1	32.1	32.4
		34.0[b]	35.9	33.1	33.3
MORA002	Green Lake	34.9	35.4	35.3	35.5
		35.9	36.3	36.6	36.7
MORA003	Crystal Mountain	21.1	21.7	22.3	22.4
		23.0	23.4	24.4	24.5
MORA003	Crystal Mountain	30.7	31.1	31.7	31.7
		31.3	31.7	32.5	32.5
MORA003	Crystal Mountain	26.5	27.0	26.6	27.2
		27.2	28.0	27.1	27.6
MORA004	Shriner's Trail	33.6	34.1	34.2	34.3
		34.2	34.6	35.2	35.3
MORA005	Lakes Trail	23.8	24.7	18.2	18.4
		24.9	25.8	22.6	23.7
MORA006	Sunrise Ridge	20.5	21.1	14.1	14.3
		22.4	23.2	20.4	21.2
MORA008	Summerland	41.9	41.9	41.6	41.6
		43.3	43.4	43.4	43.3
MORA009	Van Trump	47.8	47.9	48.4	48.4
		49.3	49.6	50.4	50.4
		24.8	25.1	22.3	22.4

[a] The top value in each cell focuses on frequencies affected by transportation, which approximately correspond to 20–1250 hertz. This range does not correspond to a specific vehicle or type of transportation.

[b] The bottom value in each cell uses the full frequency spectrum, from 12.5–20,000 hertz.

Table 55. Percent time audible for aircraft, human, and natural sounds.

		% Time Audible			
Site ID	**Site Name**	**Aircraft Sounds**	**Other Human Sounds**	**Natural Sounds**	**Noise Free Interval (maximum event)**
MORA001	Trail of Shadows	9.2	35.3	55.5	2:59
MORA002	Green Lake	22.3	3.4	74.4	57:06
MORA003	Crystal Mountain	12.2	4.9	82.9	28:10
MORA003	Crystal Mountain	7.1	14.4	N/A*	N/A*
MORA003	Crystal Mountain	5.1	18.2	N/A*	N/A*
MORA004	Shriner's Trail	10.5	3.2	86.3	15:25
MORA005	Lakes Trail	22.6	7.1	70.4	5:56
MORA006	Sunrise Ridge	18.7	6.1	75.2	8:37
MORA008	Summerland	2.9	1.3	95.8	N/A*
MORA009	Van Trump	10.8	0.7	88.5	N/A*

* N/A – Noise Free Interval was not calculated

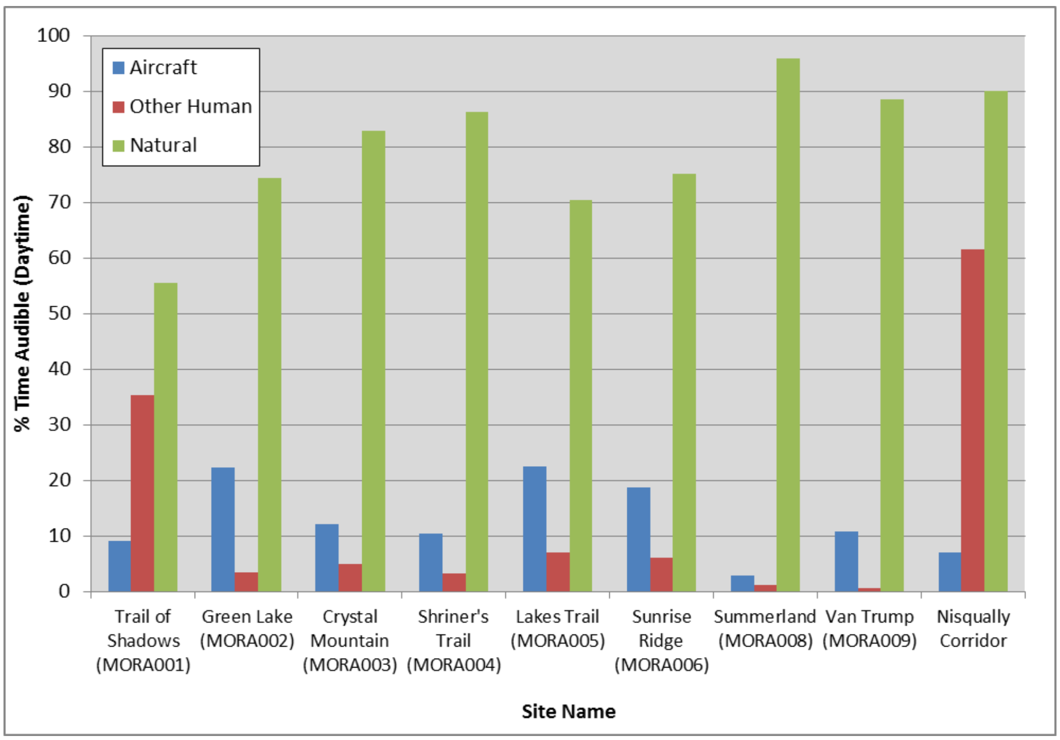

Figure 39. Percent time audible for aircraft, human, and natural sounds, MORA.

Table 56. Percent time above metrics for day and night.

		% Time above sound level: 7 am to 7 pm				% Time above sound level: 7 pm to 7 am			
Site ID	**Site Name**	**35 dBA**	**45 dBA**	**52 dBA**	**60 dBA**	**35 dBA**	**45 dBA**	**52 dBA**	**60 dBA**
MORA001	Trail of Shadows	52.8[a]	1.5	0.1	0.0	14.4	0.3	0.0	0.0
		62.4[b]	1.9	0.2	0.0	25.3	0.4	0.0	0.0
MORA002	Green Lake	73.7	0.3	0.1	0.0	89.6	0.1	0.0	0.0
		90.8	0.8	0.1	0.0	96.1	0.2	0.0	0.0
MORA003	Crystal Mountain	1.6	0.2	0.0	0.0	0.4	0.0	0.0	0.0
		2.0	0.3	0.1	0.0	5.3	0.1	0.0	0.0
MORA003	Crystal Mountain	3.98	0.15	0.01	0.00	0.54	0.02	0.00	0.00
		7.83	0.57	0.19	0.02	17.73	0.27	0.03	0.00
MORA003	Crystal Mountain	3.31	0.08	0.00	0.00	5.74	0.02	0.00	0.00
		12.68	0.31	0.01	0.00	9.29	0.07	0.00	0.00
MORA004	Shriner's Trail	44.9	0.8	0.0	0.0	29.6	0.1	0.0	0.0
		52.1	1.6	0.0	0.0	55.1	15.2	5.8	0.1
MORA005	Lakes Trail	4.1	0.5	0.1	0.0	0.6	0.1	0.0	0.0
		5.4	0.6	0.1	0.0	19.2	0.5	0.0	0.0
MORA006	Sunrise Ridge	0.8	0.1	0.0	0.0	0.1	0.0	0.0	0.0
		3.8	0.6	0.1	0.0	17.6	0.3	0.0	0.0
MORA008	Summerland	100.0	1.1	0.0	0.0	100.0	1.1	0.0	0.0
		100.0	18.8	1.3	0.1	100.0	18.3	1.5	0.2
MORA009	Van Trump	100.0	99.9	0.3	0.0	100.0	99.9	0.1	0.0
		100.0	98.6	9.8	0.0	100.0	98.2	24.6	4.4
		2.97	0.28	0.06	0.00	0.99	0.09	0.00	0.00

[a] The top value in each cell focuses on frequencies affected by transportation, which approximately correspond to 20-1250 Hz. This range does not correspond to a specific vehicle or type of transportation.

[b] The bottom value in each cell uses the full frequency spectrum, from 12.5–20,000 Hz.

4.18.5 Emerging Issues

Transportation noise (i.e., vehicles and aircraft) is the most common type of noise heard in MORA. Between 1970 and 2007, traffic on U.S. roads nearly tripled to almost 5 trillion vehicle km/yr (http://www.fhwa.dot.gov/ohim/tvtw/tvtpage.cfm). Most visitors who visit MORA do so by traveling to and through the park in various types of vehicles such as passenger cars, Recreational Vehicles, tour buses, and motorcycles. As the number of vehicles entering the park increases, so will the noise pollution they create. Aircraft traffic has grown by a factor of 3 or more between 1981 and 2007 (http://www.bts.gov/programs/airline_information/ air_carrier_traffic_statistics/airtraffic/annual/ 1981_present.html). The over-flight of commercial and military jets, non-commercial fixed-wing aircraft, and helicopters, contribute to the noise pollution affecting MORA. Air tours are also a continuing noise management issue at MORA. The park has started their Air Tour Management Plan, but it is currently on hold. As these noise sources increase throughout the United States, the ability to protect pristine and quiet natural areas will become more difficult (Mace et al. 2004). MORA management has begun and continues to explore ways to minimize the effects of these sources of human-created sound.

4.18.6 Information and Data Needs–Gaps

Although there is compelling evidence that wildlife can suffer adverse behavioral and physiological changes from intrusive sounds (noise) and other human disturbances, the ability to translate that evidence into quantitative estimates of impacts is presently limited. Several recommendations have been made for human exposure to noise, but no guidelines exist for wildlife and the habitats we share. The majority of research on wildlife has focused on acute noise events, so further research needs to be dedicated to chronic noise exposure (Barber et al. 2011) and impacts to wildlife related to alerting distance and listening area (Barber et al. 2009). In addition to the lack of guidelines for wildlife, standards have not yet been developed for assessing the quality of physical sound resources (the acoustical environment) separate from human or wildlife perception. Scientists are also working to differentiate between impacts to wildlife that result directly from the noise or the presence of the noise source. For example, if a low flying aircraft flies over a park and causes wildlife to leave the area, are they fleeing due to the resulting noise or because of the presence of the aircraft?

4.18.7 Literature Cited

Anderssen, S. H., R. B. Nicolaisen, and G. W. Gabrielsen. 1993. Autonomic response to auditory stimulation. Acta Paediatrica 82:913–918.

Barber, J. R., K. R. Crooks, and K. M. Fristrup. 2009. The costs of chronic noise exposure for terrestrial organisms. Trends in Ecology and Evolution 25:180–189.

Barber, J. R., C. L. Burdett, S. E. Reed, K. A. Warner, C. Formichella, K. R. Crooks, D. M. Theobald, and K. M. Fristrup. 2011. Anthropogenic noise exposure in protected natural areas: Estimating the scale of ecological consequences. Landscape Ecology 26:1281–1295.

Berglund, B., T. Lindvall, and D. H. Schwela, editors. 1999. WHO. Guidelines for community noise. World Health Organization, Geneva, Switzerland.

Clough, G. 1982. Environmental effects on animals used in biomedical research. Biological Reviews 57:487–523.

Haas, G., and T. Wakefield. 1998. National parks and the american public: A national public opinion survey on the national park system. National Parks and Conservation Association and Colorado State University, Washington, DC and Fort Collins, Colorado.

Haralabidis, A. S., and others. 2008. Acute effects of night-time noise exposure on blood pressure in populations living near airports. European Heart Journal Advance Access. Published online 12 February 2008.

Harris, C. 1998. Handbook of acoustical measurement and noise control. McGraw-Hill, New York, New York.

Lynch, E., D. Joyce, and K. Fristrup. 2011. An assessment of noise audibility and sound levels in U.S. National Parks. Landscape Ecology 26:1297–1309.

Mace, B. L., P. A. Bell, and R. J. Loomis. 2004. Visibility and natural quiet in national parks and wilderness areas: Psychological considerations. Environment and Behavior 36:5–31.

McDonald, C. D., R. M. Baumgartner, and R. Iachan. 1995. National Park Service aircraft management studies (U.S. Department of Interior Rep. No. 94-2). National Park Service, Denver, Colorado.

Morfey, C. 2001. Dictionary of acoustics. Academic Press–Elseveir, Waltham, Massachusetts.

[NPS] National Park Service. 1994. Report to Congress. Report on effects of aircraft overflights on the National Park System. 12 September 1994.

[NPS] National Park Service. 2009. Mount Rainier National Park. Draft Acoustical monitoring report. Natural Resource Report NPS/NRPC/NRTR—2009/001. National Park Service, Fort Collins, Colorado.

[NPS] National Park Service. 2011. Mount Rainier National Park: Acoustical monitoring report 2009. Natural Resource Technical Report NPS/NRSS/NRTR—2011/495. National Park Service, Fort Collins, Colorado.

Selye, H. 1956. The stress of life. McGraw-Hill, New York, New York.

Saunders, D., P. Mapp, P. Sacre, and D. Templeton. 1997. Acoustics in the built environment: Advice for the design team. 2nd Edition. Architectural Press, Oxford, United Kingdom.

US Department of Agriculture, Forest Service (USDA). 1992. Report to Congress. Potential impacts of aircraft overflights of National Forest System wildernesses. 9223 1208. U.S. Department of Agriculture, Forest Service, San Dimas Technology and Development Center, San Dimas, California:

4.19 Dark Night Skies

(Dan Duriscoe, Death Valley National Park, NPS)

4.19.1 Introduction

The resource of a dark night sky is important to the National Park Service for a variety of reasons. First, the preservation of natural lightscapes (the intensity and distribution of light on the landscape at night) will keep the nocturnal photopic environment within the range of natural variability. Excursions outside this natural range may result in a modification to natural ecosystem function, especially to systems involving the behavior and survival of nocturnal animals. The natural night sky is therefore one of the physical resources under which natural ecosystems have evolved. Second, the "scenery" of national park areas does not just include the daytime hours. A natural starry sky absent of anthropogenic light is one of their key scenic resources, especially large wilderness parks remote from major cities. Third, the history and culture of many civilizations are steeped in interpretations of night sky observations, whether for scientific, religious, or time-keeping purposes. As such, the natural night sky may be a very important cultural resource, especially in areas where evidence of aboriginal cultures is present. Fourth, the recreational value of dark night skies is important to campers and backpackers. Fifth, night sky quality is an important wilderness value, contributing to the ability to experience a feeling of solitude in a landscape free from signs of human occupation and technology.

Anthropogenic light in the night environment can be very significant, especially on moonless nights. Unshielded lamps mounted on tall poles have the greatest potential to cause light pollution, since light directly emitted by the lamp has the potential to follow an unobstructed path into the sky or the distant landscape. This type of light spill has been called glare, intrusive light, or light trespass (Narisada and Schreuder 2004). The dark-adapted human eye will see these individual light sources as extremely bright points in a natural environment. These sources also have the potential to illuminate the landscape, especially vertical surfaces aligned perpendicular to them, often to a level that approaches or surpasses moonlight. The brightness of such objects may be measured as the amount of light per unit area striking a detector or a measuring device, or entering the observer's pupil. This type of measure is called illuminance (Ryer 1997).

Anthropogenic light which results in an upward component will be visible to an observer as sky glow. This is because the atmosphere effectively scatters light passing through it. The sky is blue in daytime because of Rayleigh scattering by air molecules, which is more effective for light of shorter wavelengths. For this reason bluish light from outdoor fixtures will produce more sky glow than reddish light. Larger particles in the atmosphere (aerosols and water vapor droplets) cause Mie scattering and absorption of light, which is not as wavelength-dependent and more directional. This process gives clouds their white appearance, and produces a whitish glow around bright objects, like the sun and moon, when the air is full of larger particles. The pattern of sky glow as seen by a distant observer will appear as a dome of light of decreasing intensity from the center of the city on the horizon. As the observer moves closer to the source, the dome gets larger until the entire sky appears to be luminous (Garstang 1989).

The brightness or luminance of the sky in the region of the light domes may be measured as the number of photons per second reaching the observer for a given viewing angle, or area of the sky (such as a square degree, square arc minute, or square arc second). The National Park Service Night Skies Program (NSP) utilizes a digital camera with a large dynamic range monochromatic CCD (Charge Coupled Device) detector and an extensive system of data collection, calibration, and analysis procedures (Duriscoe et al. 2007). This system allows for the accurate measurement of both luminance and illuminance, since it is calibrated on standard stars that appear in the same images as the data, and the image scale in arc seconds per pixel is accurately known. High resolution imagery of the entire night sky reveals details of individual light domes that may be attributed to anthropogenic light from distant cities or nearby individual sources. These images and data may be used for both resource condition assessment and long term monitoring.

Mount Rainier National Park (MORA) is located in an area of central Washington that is relatively remote from cities and towns, but is generally within 97 km (60 mi) of the large metropolitan areas of Seattle, Tacoma, and Olympia. Therefore, this area is influenced by anthropogenic sky glow from the west (Figure 40). This leads to a significant gradient of expected night sky quality from northwest to southeast. The vast majority of the park is designated Wilderness; therefore it is particularly important that within-park sources of light be contained, eliminating light trespass and minimizing anthropogenic sky glow (Figure 41).

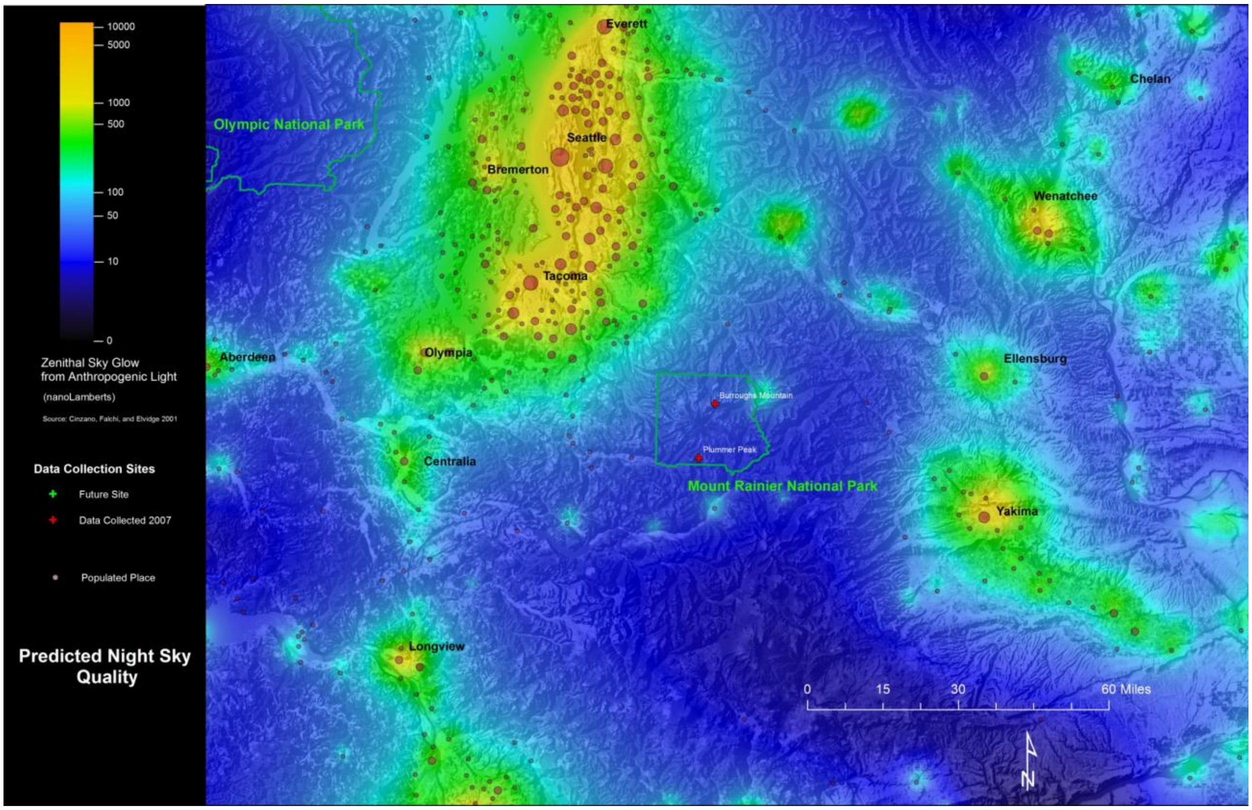

Figure 40. Model of sky quality from late 1990's satellite imagery at night and sky glow model by Cinzano et al. (2001). Note the logarithmic scale for the color ramp. The Milky Way would generally not be visible in areas appearing yellow or orange.

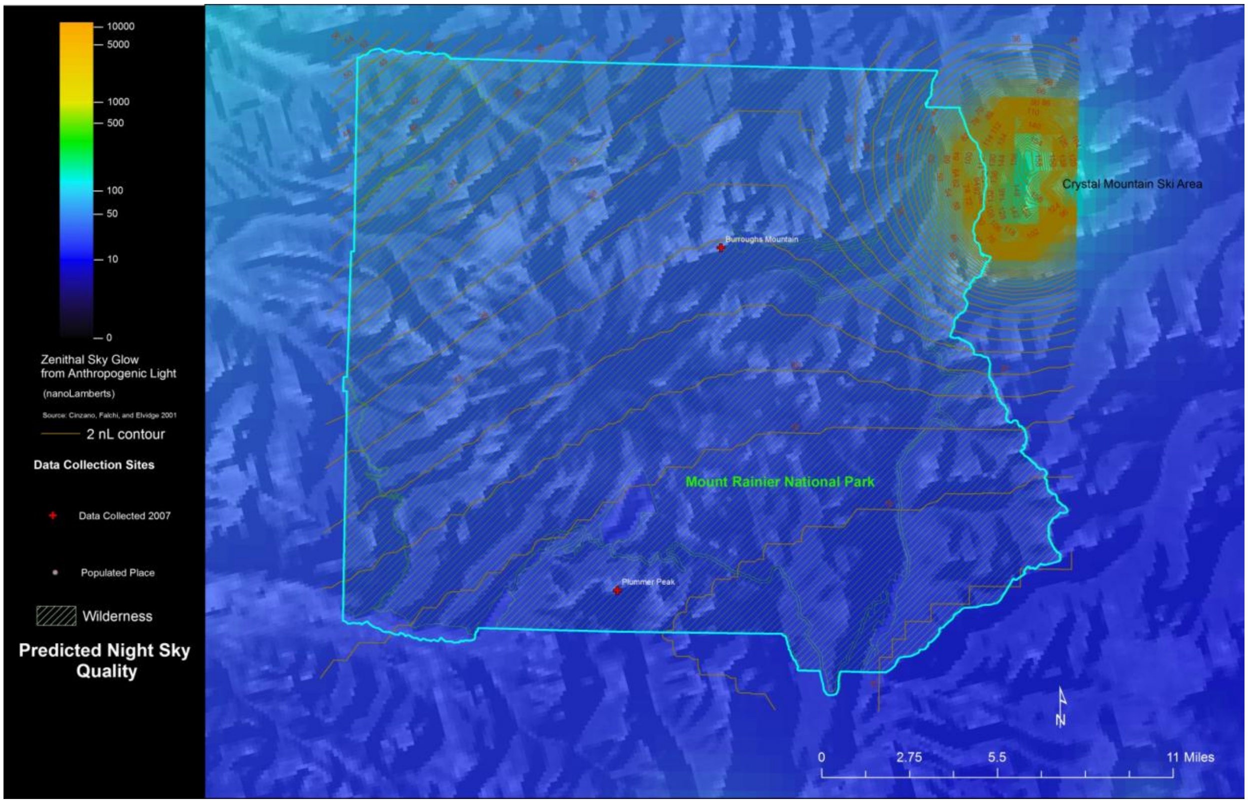

Figure 41. Close up of Mount Rainier National Park. The model, based upon satellite imagery, shows a situation where night skiing is underway at Crystal Mountain Resort, just east of the park boundary.

4.19.2 Approach

The following measures were used for this assessment:

1. Sky luminance over the hemisphere in high resolution (thousands of measures comprise a data set), reported in photometric luminance units (V magnitudes per square arc second, nanoLamberts, or milli-candela/m2), or relative to natural conditions (i.e., “Skies”, where 1 Sky = 22.0 V magnitudes/square arc second), which is often shown as a sky brightness contour map of the entire sky (Figures 42–46). Sky brightness maps are used extensively in reports by the NSP, which is part of the Natural Resource Stewardship and Science Directorate. The Sky Quality Index (SQI) is an experimental synthetic index of anthropogenic sky luminance measures and atmospheric transparency, intended to rate the aesthetic quality of the night sky as seen by a human with very good eyesight and no magnifying or intensifying optical aid. It has a range 0–100, where 100 indicates zero measured anthropogenic sky glow and air transparency equivalent to clean air at 3000 m (9843 ft) elevation. An SQI of 0 would indicate only the brightest 10 or 20 stars visible, while a value of 50 would indicate that the Milky Way would be barely visible;
2. Maximum vertical illuminance from anthropogenic sky glow, reported in milli-Lux or ratio of anthropogenic to average natural vertical illuminance;
3. Integration of the entire sky illuminance measures, reported either in milli-Lux of total hemispheric (or horizontal) illuminance, milli-Lux of anthropogenic hemispherical (or horizontal) illuminance, or ratio of anthropogenic illuminance to average natural illuminance;

4. Vertical illuminance from individual (or groups of) outdoor lighting fixtures at a given observing location (such as a Wilderness boundary), in milli-Lux;
5. Visual observations by a human observer, such as Bortle Class (Bortle 2001) and Zenithal limiting magnitude; visual observations are important in measuring sky quality, especially in defining the aesthetic character of night sky feature;
6. Integrated synthesized measure of the luminance of the sky within 50° of the Zenith, as reported by the Unihedron Sky Quality Meter, in V magnitudes per square arc second. V magnitude is a broadband photometric term in astronomy, meaning the total flux from a source striking a detector after passing through a "Johnson-Cousins V" filter (Bessell 1990).

The accurate measurement of both anthropogenic light in the night sky and the accurate prediction of the brightness and distribution of natural sources of light allows for the use of a very intuitive metric of the resource condition: a ratio of anthropogenic to natural light. Both luminance and illuminance for the entire sky or a given area of the sky may be described in this manner (Hollan 2009). This so-called light pollution ratio is unit-less and is always referenced to the brightness of a natural moonless sky under average atmospheric conditions, or, in the case of the NSP data, the atmospheric conditions determined from each individual data set.

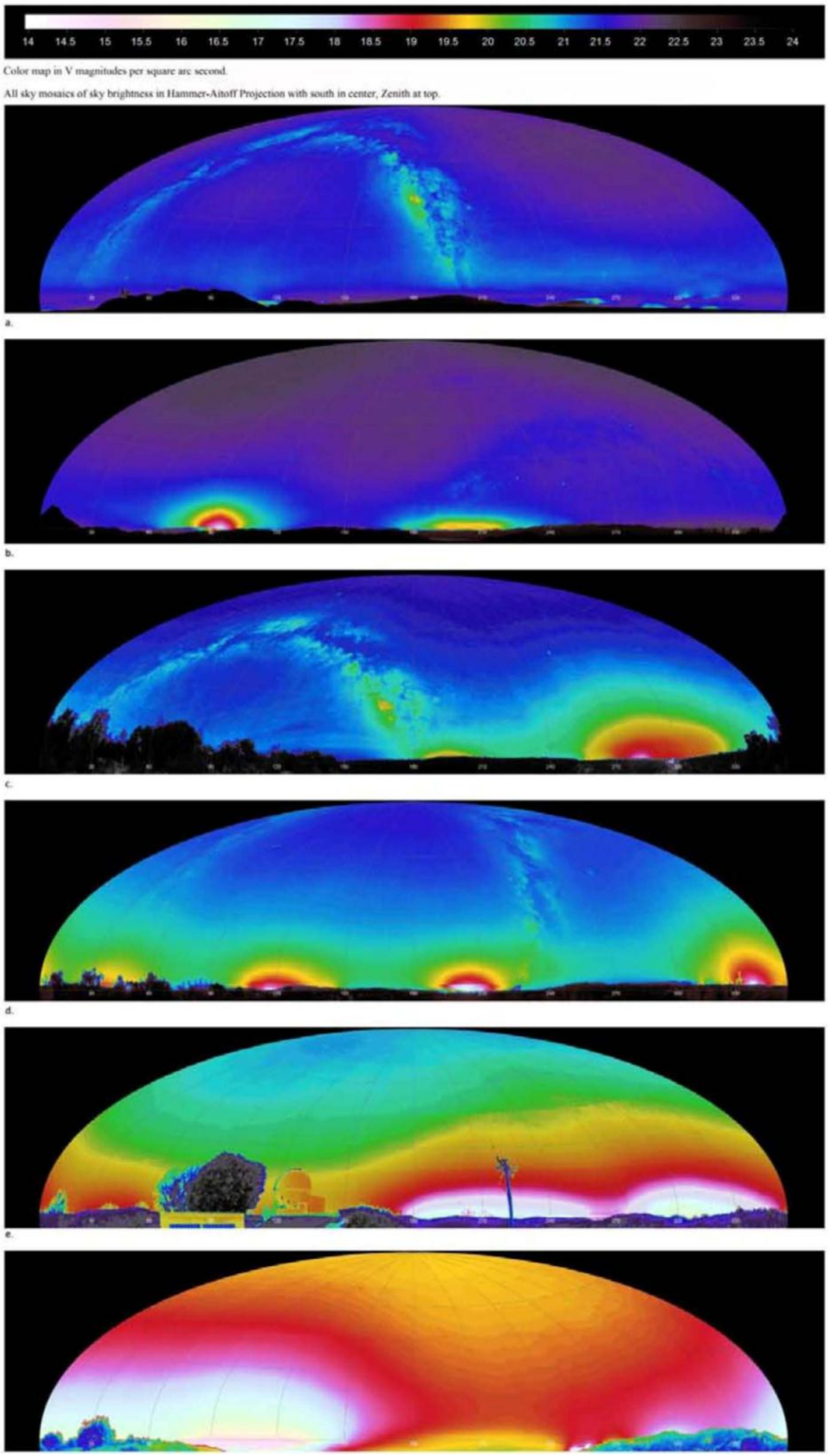

Figure 42. Example sky brightness maps from locations representing a wide range of sky quality: a) Puu Poliahu, Mauna Kea, Hawaii; b) Dantes View, Death Valley NP, California; c) Walnut Canyon NM, Arizona; d) Bandelier NM, New Mexico; e) Palomar Observatory, California; and f) Santa Monica Mountains NRA, California.

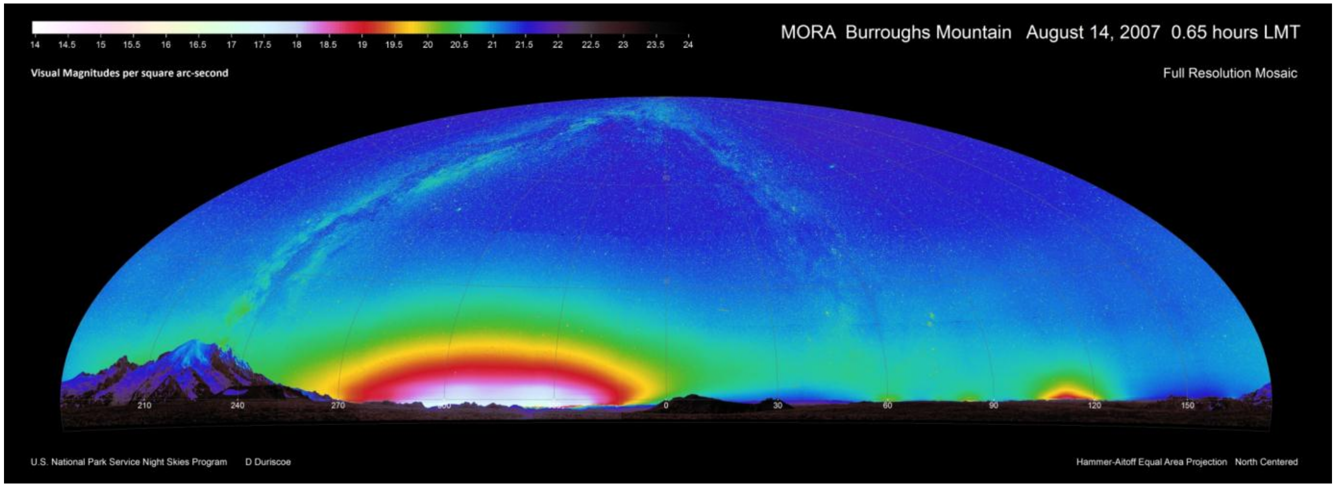

Figure 43. Contour map of night sky brightness in Hammer-Aitoff projection, Burroughs Mountain, 14 August 2007. The Milky Way is seen curving over the upper portion of the map. The Seattle-Tacoma-Olympia area produces a large bright light dome centered at about 310 azimuth and more than 90° wide.

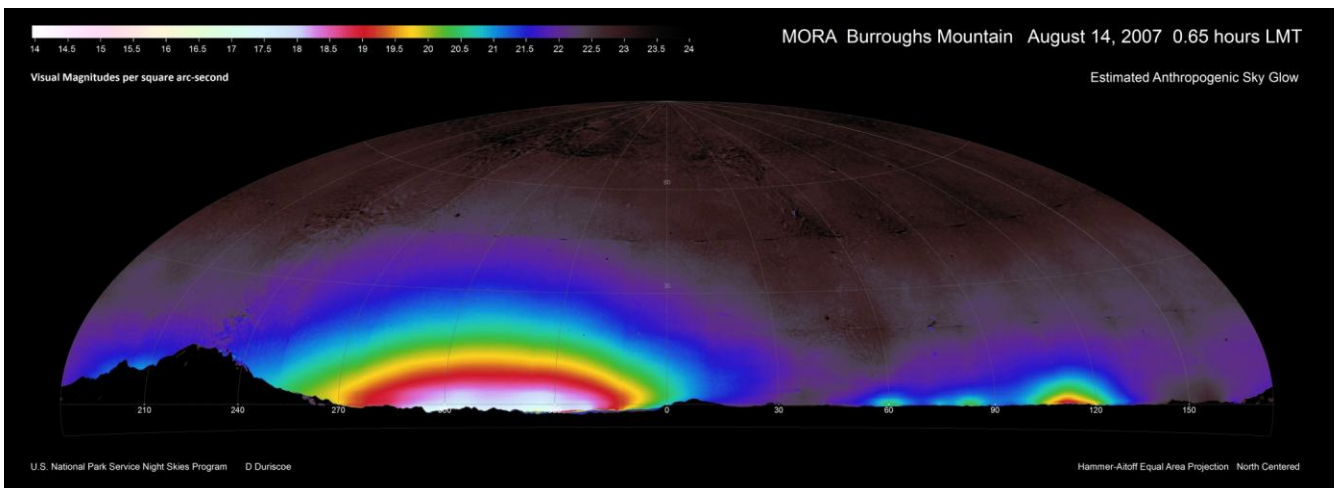

Figure 44. Same data as in Figure 43, but with the natural sources of sky brightness removed with the natural sky model. The core of the Seattle-Tacoma light dome is very bright near azimuth 330. Yakima is at azimuth 97, Olympia at azimuth 294. The brightest parts of the Seattle area light dome are more than 300 times the natural background.

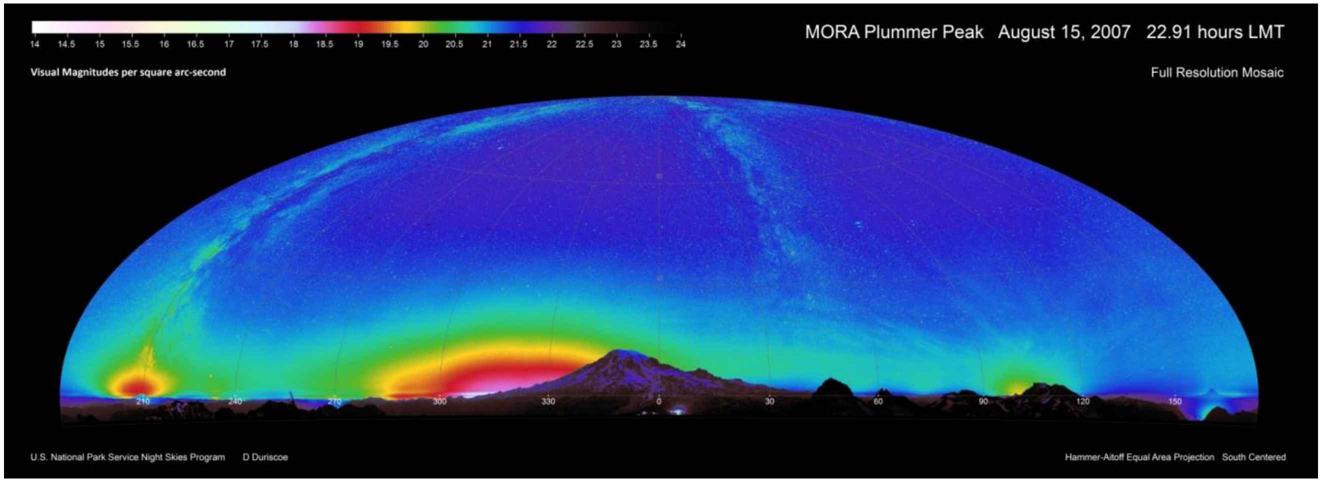

Figure 45. Contour map of night sky brightness in Hammer-Aitoff projection, Plummer Peak, 15 August 2007. Mount Rainier near center at azimuth 345, with much of the Seattle area light dome behind it. Portland, Oregon and Vancouver, Washington form the round light dome at the left. The natural airglow shows banded character on this night.

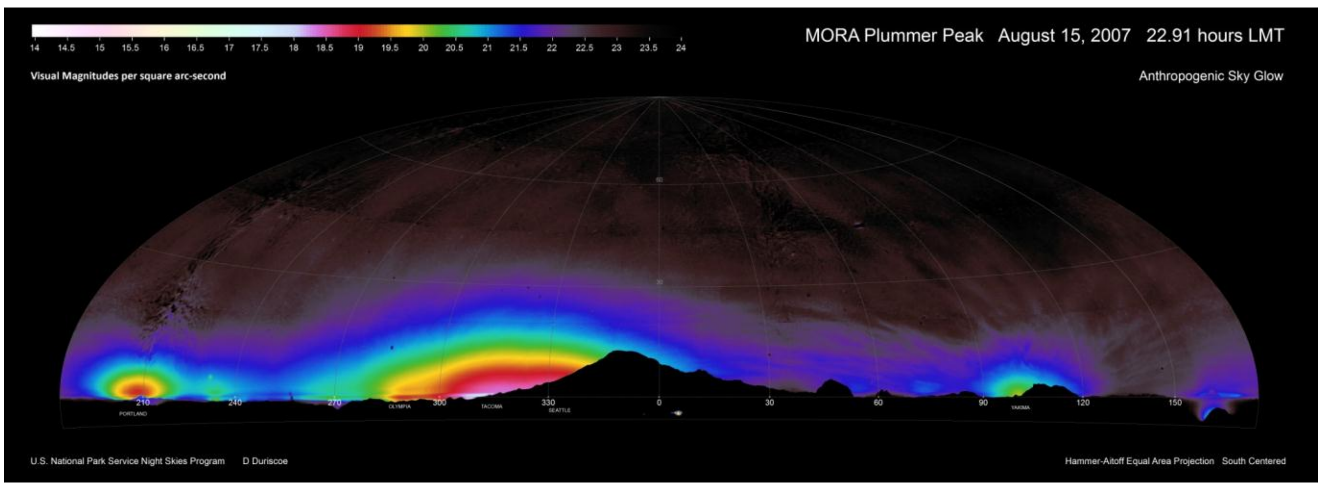

Figure 46. Same data as in Figure 45, but with the natural sources of sky brightness mostly removed with the natural sky model. Airglow artifacts are seen as faint bands, especially between 60 and 150 azimuth, features that the model cannot remove. The cores of the city light domes are fainter than at Burroughs Mountain.

4.19.3 Reference Conditions and Comparison Metrics

The reference condition for this resource is defined in terms of sky luminance and illuminance at the observer's location from anthropogenic sources as follows: no portion of the sky background brightness exceeds natural levels by more than 200%, and the sky brightness at the Zenith does not exceed natural Zenith sky brightness by more than 20% (NPS Night Skies Program, unpubl. data). The ratio of anthropogenic illuminance from sky glow to average natural illuminance from the moonless night sky does not exceed 20%. The observed light from a single visible anthropogenic source (light trespass) is not observed as brighter than the planet Venus (0.1 milli-Lux) when viewed from within any area of the park designated as the naturally dark zone (Garstang 1989, Jensen et al. 2006, NPS Night Skies Program, unpubl. data).

Natural Zenith sky brightness is defined as 22.0 V magnitudes per square arc second (0.171 milli-Candela/m^2 or 54 nano-Lamberts). Average natural illuminance is defined for moonless nights as: Hemispherical = 0.8 milli-Lux; Horizontal = 0.8 milli-Lux; Vertical = 0.4 milli-Lux.

Figure 47 displays a nomogram that compares some of the sky quality measures described above and indicates the reference condition on this graph.

Achieving this reference condition for preserving natural night skies is well summarized in the NPS Management Policies (NPS 2006), section 4.10: "The Service will preserve, to the greatest extent possible, the natural lightscapes of parks, which are natural resources and values that exist in the absence of human-caused light."

Implementing this directive in MORA requires that facilities within the park that utilize outdoor lighting, local communities, and distant cities meet outdoor lighting standards that provide for the maximum amount of environmental protection while meeting human needs for safety, security, and convenience. This means that outdoor lights within the park produce zero light trespass beyond the boundary of their intended use; be of an intensity that meets the minimum requirement for the task but does not excessively exceed that requirement; be of a color that is toward the yellow or orange end of the spectrum to minimize sky glow; and be controlled intelligently, preventing unnecessary dusk to dawn bright illumination of areas.

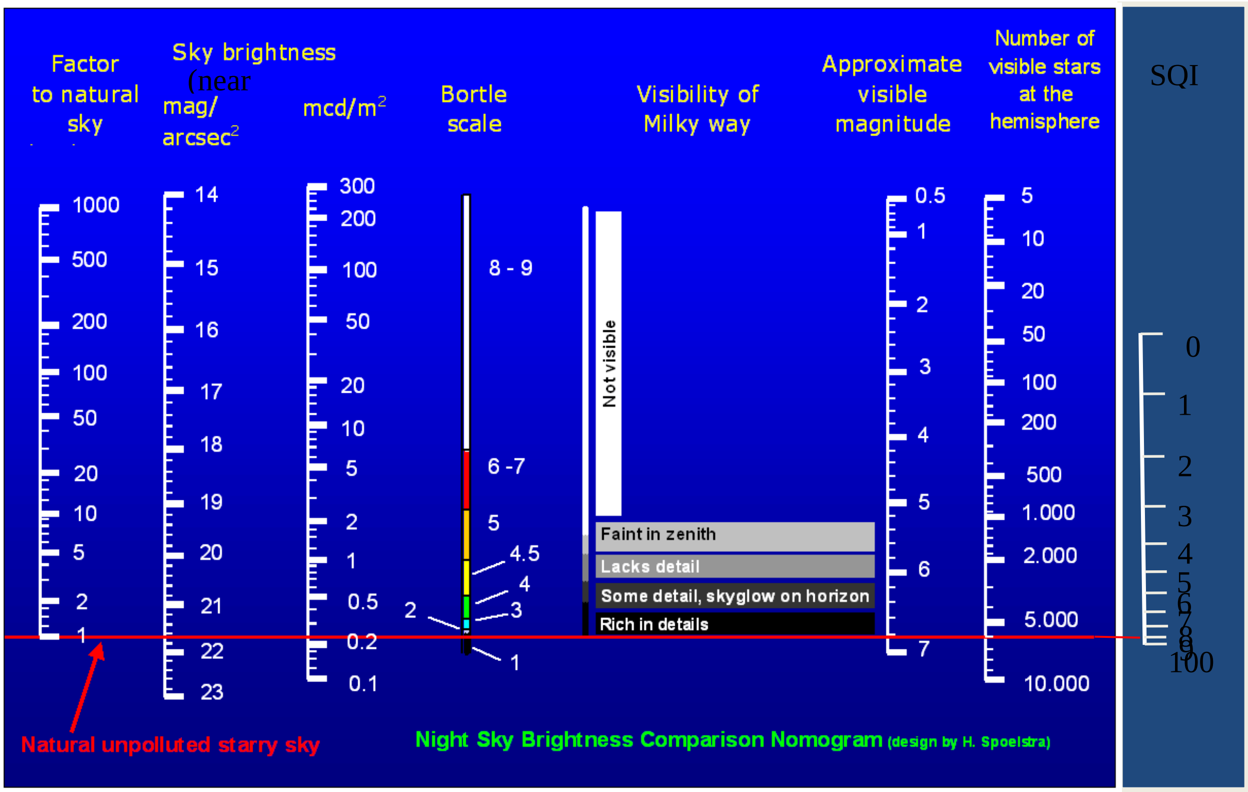

Figure 47. Nomogram comparing methods of measuring sky quality; a horizontal line drawn across the graph will cross measures that indicate approximately the same sky quality.

4.19.4 Results and Assessment

Current Condition and Trend

The night sky as seen from MORA is impaired by anthropogenic sky glow from distant cities. The National Park Service has conducted an inventory of night sky quality, with data collection beginning in 2007. Two locations for measuring sky luminance and light trespass have been visited including Burroughs Mountain and Plummer Peak (see Figure 40).

Important statistics from these data are presented in Tables 57–60. Illustrations of total sky brightness and anthropogenic sky glow are presented as false color maps of the sky hemisphere in Hammer-Aitoff projection in Figures 43–46. Tables 57 and 59 give information on the data collection sites, weather, and equipment, a narrative describing observing conditions and visual observations, and photometric calculations derived from the calibrated images before processing with the natural sky model. Tables 58 and 60 reveal measures of the estimated anthropogenic sky glow for each data set, including the brightest part of the sky, the Zenith, and illuminance from the entire sky, expressed both in milli-lux and as a light pollution ratio (LPR).

Sky luminance and illuminance from anthropogenic sources is seen to be about twice as high at Burroughs Mountain than at Plummer Peak. However, both are given Bortle Class 4, indicating that even at the darker site the impairment from city light domes is quite significant. Hemispherical illuminance from sky glow is the most unbiased indicator of the quality of the entire hemisphere of the sky; for this indicator Burroughs Mountain yielded a 1.33 (133%) ratio of anthropogenic to natural, while Plummer Peak yielded ratios of 0.72–0.76 (71–76%). Sky luminance from anthropogenic sky glow in the brightest portion of the sky (the core of the Seattle-Tacoma area light dome near the horizon) was observed to be extremely bright at both sites, reaching a maximum of more than 29,000 nl (540 skies) at Burroughs Mountain, and 2580–2678 nl (48–50 skies) at Plummer Peak. Anthropogenic sky glow measured at the Zenith appeared less severe than the other indicators, measuring 19.1 nl at Burroughs Mountain (LPR = 0.35 or 35%) and 13–15 nl at Plummer Peak (LPR 0.25–0.27 or 25–27%). These values are about 30% darker than the model presented in Figure 40. The extinction coefficient for each of these nights indicates very clear air, or air with few aerosols. Clean air will affect sky glow from anthropogenic sources in 2 ways. First, scattering by aerosols will be minimized, producing smaller and dimmer light domes above outdoor lights. Second, light domes from distant cities suffer less atmospheric extinction and therefore appear brighter to the observer.

In summary, here are the quantities from the Burroughs Mountain and Plummer Peak data nights for each of the metrics described in the Approach sub-section:

1. Sky luminance: Ratio of anthropogenic to natural: maximum = 540, minimum = 0.25; Sky Quality Index = 60–68;
2. Maximum vertical illuminance from anthropogenic sky glow: 1.46 mLux (Azimuth 265 at Burroughs Mountain); ratio of anthropogenic to natural = 3.64 or 346% above average natural conditions;
3. All-sky illuminance from anthropogenic sky glow as a ratio of anthropogenic to natural: Hemispherical: Burroughs Mountain = 1.33 (133%), Plummer Peak = 0.6 (60%); Horizontal: Burroughs Mountain = 0.56 (56%), Plummer Peak = 0.4 (40%);
4. Vertical illuminance from light trespass: Not measured;
5. Visual observations: Burroughs Mountain Bortle Class 4, ZLM not measured; Plummer Peak Bortle Class 4, ZLM not measured;
6. Sky quality meter: Not measured (synthetically derived as 21.36 for Burroughs Mountain and 21.5 for Plummer Peak).

Overall Condition

The night sky quality of MORA is impaired significantly, primarily from sky glow originating in major cities 50–150 km (31–93 mi) distant. All measures of sky quality exceed the reference condition for natural night skies. The unbiased measure of anthropogenic hemispherical illuminance is 3 to 7 times brighter than the proposed standard of 20% above average natural conditions, while the maximum anthropogenic sky luminance is up to 270 times the proposed standard of 200% above the average natural background sky luminance. While the Milky Way is clearly visible overhead throughout most of the park, light pollution dominates the sky when the observer looks toward the Seattle-Tacoma area. The recorded Bortle Class 4 visual sky quality measure can be described as mediocre at best, and indicates that visitors to MORA looking for a view of the natural night sky will be disappointed if they consider the entire celestial hemisphere.

Table 57. Data night attributes, NPS Night Skies Program, Burroughs Mountain, 14 August 14 2007.

PARK:	MORA		**EQUIPMENT:**	IMG 2, 50 mm f/2, 6084		
SITE NAME:	Burroughs Mountain		**OBSERVERS:**	R Lofgren, L Helzer, O Brenger		
LONGITUDE:	-121.67537		**AIR TEMP (°F):**	41.7		
LATITUDE:	46.911798		**REL HUMID (%):**	43		
ELEVATION (m):	2194		**WIND SP (mph):**	4.5		
DATE (UT):	August 14, 2007		**CCD TEMP (°C):**	-20		
TIME START (UT):	8:37:00		**EXP (seconds):**	10		
DATA QUALITY:	Good		**BORTLE CLASS:**	4	**ZLM:**	

NARRATIVE: None

Summary of all Sky Photometry for each Data Set

Data Set	Local Mean Time at middle (hours)	Extinction Coefficient (magnitudes / airmass ±0.01)	Std. Error of Y Extinction Regression (magnitudes)	Sky Quality Index	Synthetic SQM	Zenith Sky Brightness (magnitudes / sq arc sec ±0.04)	Brightest area of the Sky (magnitudes / sq arc sec ±0.04)	Hemispherical Illuminance (mLux ±0.01)	Horizontal Illuminance (mLux ±0.01)	Maximum Vertical Illuminance (mLux ±0.01)	Notes
1	0.66	0.13	0.04	59.75	21.36	21.34	15.16	1.71	1.17	1.85	

Table 58. Anthropogenic sky glow observed at Burroughs Mountain, 14 August 2007: Illuminance (mLux), Luminance (nL), and Ratio of Light Pollution to Natural Conditions (LPR).

Local Mean Time (hours)	Hemispherical Illuminance (±0.05 mLux)		Vertical Illuminance (±0.05 mLux) Maximum		Average		Minimum		Horizontal Illuminance (±0.05 mLux)		Sky Luminance Brightest		Zenith	
	mLux	LPR	mLux	LPR	mLux	LPR	mLux	LPR	mLux	LPR	nL (±10)	LPR (skies)	nLl(±5)	LPR (skies)
0.65	1.07	1.33	1.46	3.64	0.64	1.59	0.20	0.50	0.45	0.56	29,365	542.1	18	0.34

Table 59. Data night attributes, NPS Night Skies Program, Plummer Peak, 15–16 August 2007.

PARK:	MORA	**EQUIPMENT:**	IMG 2, 50mm f/2, 6084
SITE NAME:	Plummer Peak	**OBSERVERS:**	R Lofgren, H.Coolidge
LONGITUDE:	-121.73944	**AIR TEMP (°F):**	59
LATITUDE:	46.7535	**REL HUMID (%):**	50.2
ELEVATION (m):	1938	**WIND SP (mph):**	2.6
DATE (UT):	15-Aug-07	**CCD TEMP (°C):**	-20
TIME START (UT):	5:28:49	**EXP (seconds):**	10
DATA QUALITY:	Good	**BORTLE CLASS:**	4 **ZLM:**

NARRATIVE: None

Summary of all Sky Photometry for each Data Set

Data Set	Local Mean Time at middle (hours)	Extinction Coefficient (magnitudes / airmass ±0.01)	Std. Error of Y Extinction Regression (magnitudes)	Sky Quality Index	Synthetic SQM	Zenith Sky Brightness (magnitudes/ sq arc sec ±0.04)	Brightest area of the Sky (magnitudes / sq arc sec ±0.04)	Hemispherical Illuminance (mLux ±0.01)	Horizontal Illuminance (mLux ±0.01)	Maximum Vertical Illuminance (mLux ±0.01)	Notes
1	21.52	0.16	0.03	66.59	21.53	21.70	15.19	1.30	0.99	0.99	
2	22.22	0.15	0.03	68.46	21.49	21.46	15.19	1.31	1.01	0.97	
3	22.92	0.15	0.03	67.53	21.47	21.34	15.19	1.33	1.02	0.99	

Table 60. Anthropogenic sky glow observed at Plummer Peak, 15–16 August 2012: Illuminance (mLux), Luminance (nL), and Ratio of Light Pollution to Natural Conditions (LPR).

Local Mean Time (hours)	Hemispherical Illuminance (±0.05 mLux)		Vertical Illuminance (±0.05 mLux)						Horizontal Illuminance (±0.05 mLux)		Sky Luminance			
			Maximum		Average		Minimum				Brightest		Zenith	
	mLux	LPR	mLux	LPR	mLux	LPR	mLux	LPR	mLux	LPR	nL (±10)	LPR (skies)	nLl(±5)	LPR (skies)
21.52	0.60	0.76	0.62	1.55	0.35	0.89	0.19	0.48	0.32	0.40	2678	49.88	15	0.27
22.22	0.57	0.72	0.59	1.48	0.34	0.84	0.18	0.44	0.30	0.37	2635	49.06	14	0.27
22.92	0.60	0.75	0.62	1.55	0.35	0.88	0.18	0.45	0.31	0.39	2580	48.04	13	0.25

4.19.5 Emerging Issues

Sky glow from the large metropolitan areas of Seattle, Tacoma, and Olympia are significantly impairing the sky quality in the areas visited. Continued growth of these areas may cause a greater impact in the future. The possibility of growth in communities immediately adjacent to the park boundary also may pose an even greater threat.

4.19.6 Information and Data Needs–Gaps

Light trespass from within-park developments should be investigated. The impacts of the Crystal Mountain Ski Area in winter to adjacent wilderness areas should also be investigated.

4.19.7 Literature Cited

Bessell, C. M. 1990. UVBRI passbands. Publications of the Astronomical Society of the Pacific 102:1181–1199.

Bortle, J. 2001. Introducing the Bortle Dark-Sky Scale. Sky and Telescope (February):126–129. http://www.skyandtelescope.com/resources/darksky/3304011.html.

Cinzano, P., F. Falchi, and C. D. Elvidge. 2001. The first World Atlas of the artificial night sky brightness. Monthly Notices of the Royal Astronomical Society 328:689–707.

Duriscoe, D. M., C. B. Luginbuhl, and C. A. Moore. 2007. Measuring night-sky brightness with a wide-field CCD camera. Publications of the Astronomical Society of the Pacific 119:192–213.

Garstang, R. H. 1989. Night-sky brightness at observatories and sites. Publications of the Astronomical Society of the Pacific 101:306–329.

Hollan, J. 2009. What is light pollution and how do we quantify it? Workshop paper at Darksky 2007 conference, Brno, Czech Republic. Available at: http://amper.ped.muni.cz/hollan/light/lp_what_is.pdf. Accessed on 27 December 2010.

Jensen, H. W., F. Durand, J. Dorsey, M. M. Stark, P. Shirley, and S. Premoze. 2001. A physically-based night sky model. SIGGRAPH ’01 Proceedings of the 28th annual conference on computer graphics and interactive techniques, ACM, New York, NY. p. 399–408. http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.2.5532&rep=rep1&type=pdf. Accessed on 28 December 2010.

Narisada, K., and D. Schrueder. 2004. Light pollution handbook. Astrophysics and space sciences library volume 322, Springer.

[NPS] National Park Service. 2006. Management Policies 2006. Available at http://www.nps.gov/policy/mp2006.pdf.

Ryer, A. 1997. The light measurement handbook. International Light, Inc., Technical Publications Division, Newburyport, Massachusetts. Available at: http://homepages.inf.ed.ac.uk/rbf/CVonline/LOCAL_COPIES/LIGHTMEASUREMENT/handbook.pdf. Accessed 27 December 2010)

Chapter 5 Climate and Climate Change in MORA

This chapter is a contribution from the University of Washington Climate Impacts Group and the Office of the Washington State Climatologist prepared by Guillaume S. Mauger (UW Climate Impacts Group), Karin Bumbaco (UW Office of the Washington State Climatologist), and Jeremy S. Littell (DOI Climate Science Center, Alaska).

5.1 Introduction

Understanding the nature of past, current, and likely future climate variations and change is critical to the mission of the NPS because the physical and ecological state of each park is partially driven by its climatic history. Current stresses and changes in the physical and ecological environment are influenced by current climate variability and century-long trends. The future of a park's ability to meet the mandates of the NPS Organic Act (i.e., to ensure that scenery and the natural objects and wildlife will be unimpaired for the enjoyment of future generations) will be affected, perhaps completely altered, by future climate change.

Climate is the statistics of weather; that is, climate variables describe the long term (generally 30 yrs or greater) averages, variability, and probabilities associated with temperature variations, precipitation events, storms, snow accumulation and melt, drought and others. Temperature and precipitation variability (i.e., year-to-year and decade-to-decade, often referred to as "interannual" and "interdecadal" variability, respectively), affect the growth and seasonal timing (phenology) of plants and animals, glaciers, streamflow, aquatic systems, and the ways people interact with landscapes and ecosystems. On longer time scales, these variables affect the distribution of species and ecosystems and the susceptibility of landscapes to disturbance.

Climate varies significantly across the Pacific Northwest (PNW) with proximity to the Pacific Ocean and due to the influence of mountainous topography. Regionally, about 50% of annual precipitation falls between November and February, while only 15% of annual precipitation occurs in June, July, and August. West of the Cascade Range crest, the Pacific Ocean and Puget Sound moderate the climate, keeping winters relatively warm and summers relatively cool compared to the eastern side of the Cascades. On the west side there is also a narrower range between daily low and high temperatures (or diurnal temperature range) than east of the Cascades, where the diurnal temperature range tends to be larger. For precipitation, the Cascade Mountains divide the region into the wetter, western side and the drier, eastern side where precipitation is on average much lower. More specifically, precipitation falls in greater amounts on the windward sides of the mountains (typically the west, southwest, or south) than on the leeward sides of the mountains. Figure 48 shows that the southern portion of MORA receives higher precipitation on average, due to the predominance of southwesterly and southerly winds in the area that MORA is located among the Cascade Mountains. Figure 48 also shows that in the mountainous Cascades, precipitation and temperature also change with elevation: higher elevations tend to receive more precipitation, predominantly as snowfall, and experience lower temperatures than lower elevations, features that are characteristic of alpine or highland climates.

Area mean temperature and precipitation observations for the state of Washington are shown in Figure 49. The record shows substantial yearly and decadal variability. Despite this variability, a warming trend is evident in statewide-average temperatures. In contrast, precipitation changes are dominated by year-to-year variability, although a weak trend is detectable in the observed record, it is not statistically significant.

Annual and decadal variability is an important aspect of PNW climate. Climate variations result from a combination of warming due to the rise in atmospheric greenhouse gas concentrations and the natural variations such as the El Niño-Southern Oscillation (ENSO), the Pacific Decadal Oscillation (PDO; Mantua et al., 1997), and other climate oscillations. Year-to-year variations unassociated with ENSO or the PDO are not easily diagnosed, and could either be related to other large-scale climate patterns or to local weather influences. ENSO is associated with anomalous sea surface temperatures in the eastern tropical Pacific (warmer temperatures for El Niño, cooler for La Niña), while the PDO is associated with warming coastal ocean temperatures along the west coast of North America and a cooling of the interior north Pacific Ocean (positive phase of the PDO; the converse is true for the negative phase). In both cases, changes in sea surface temperatures influence PNW climate by altering atmospheric circulations, including the location of the storm tracks. El Niño and the positive phase of the PDO favor warmer, drier winters in the PNW, while La Niña and the negative phase of the PDO favor cooler, wetter winters. Although the global manifestation of each differs somewhat, the primary difference of relevance to the PNW is the time scale of the 2 oscillations: in the past century there was a 2 to 7 yr return period for El Niño and La Niña winters, while PDO oscillations are multi-decadal, ranging from approximately 20 to 30 yrs in length. Summer climate is generally unaffected by large-scale climate variations such as ENSO and the PDO. Although the climate of the PNW is clearly linked to ENSO and the PDO, and knowledge of the 2 provides some ability to forecast upcoming seasons, it is worth remembering that (a) ENSO and the PDO each explain only about 10–20% of the variance at MORA (as indicated by correlations with local climate), and (b) summer climate is generally unaffected by large-scale climate variations: neither ENSO, the PDO, nor other oscillations.

In the short term, climate variations are dominated by natural variability. Over longer time periods, steadily increasing temperatures can have large cumulative effects on the resources of National Parks. Average annual temperature increased 0.8°C in the Pacific Northwest between 1920 and 2000 (Mote 2003), and the first decade of the 21st century (2001–2010) was tied with the previous decade (1991–2000) for the warmest in the Pacific Northwest since comprehensive observations began around 1920. Furthermore, century-long increasing trends in PNW region temperature have been attributed at least partially to human emissions of greenhouse gases (Stott 2003). As greenhouse gas concentrations increase in the future, warming trends are expected to become increasingly distinct from past variability, though year-to-year variations in climate will continue to be superposed on these trends.

In recent years, PNW snowpack trends have been the topic of heated debate, and have thus received substantial attention in the research community. Hamlet et al. (2005) used simulations of snowpack to indicate that recent trends are primarily associated with recent warming trends; Mote (2006) drew similar conclusions using observational data. Nearly all studies of Cascade snowpack acknowledge the important role of year-to-year variability in influencing changes in snowpack and confounding efforts to estimate trends. Stoelinga et al. (2010) use a simple regression approach to estimate that 71% of the variance in Cascade snowpack can be explained by year-to-year variations in large-scale climate. Using a more objective approach, Smoliak et al. (2010) obtain a nearly identical estimate. Mote (2006) do not estimate the combined effect of all modes of variability, but find that indices of large-scale variability can individually be responsible for 10–60% of the variation in snowpack. Accounting for the influence of variability, Stoelinga et al. estimate that global warming led to a loss of 16% of snowpack between 1930 and 2007 and project a loss of 9% between 1985 and 2025. Casola et al. (2010) show that multiple different approaches such as direct and indirect observations, seasonal regressions, and hydrologic simulations yield similar estimates of snowpack loss. Accounting for the influence of natural variability, they estimate a loss of 8% to16% snowpack between 1977 and 2006, and a projected loss of 11–21% by 2050.

In this chapter, we present the record of 20th century observed climate in Mount Rainier National Park, and describe the climate projected for the region in the 21st century. We conclude with a brief summary describing the nature, quality, and gaps in the observation network and their implications for understanding climate impacts in the North Cascadia Region.

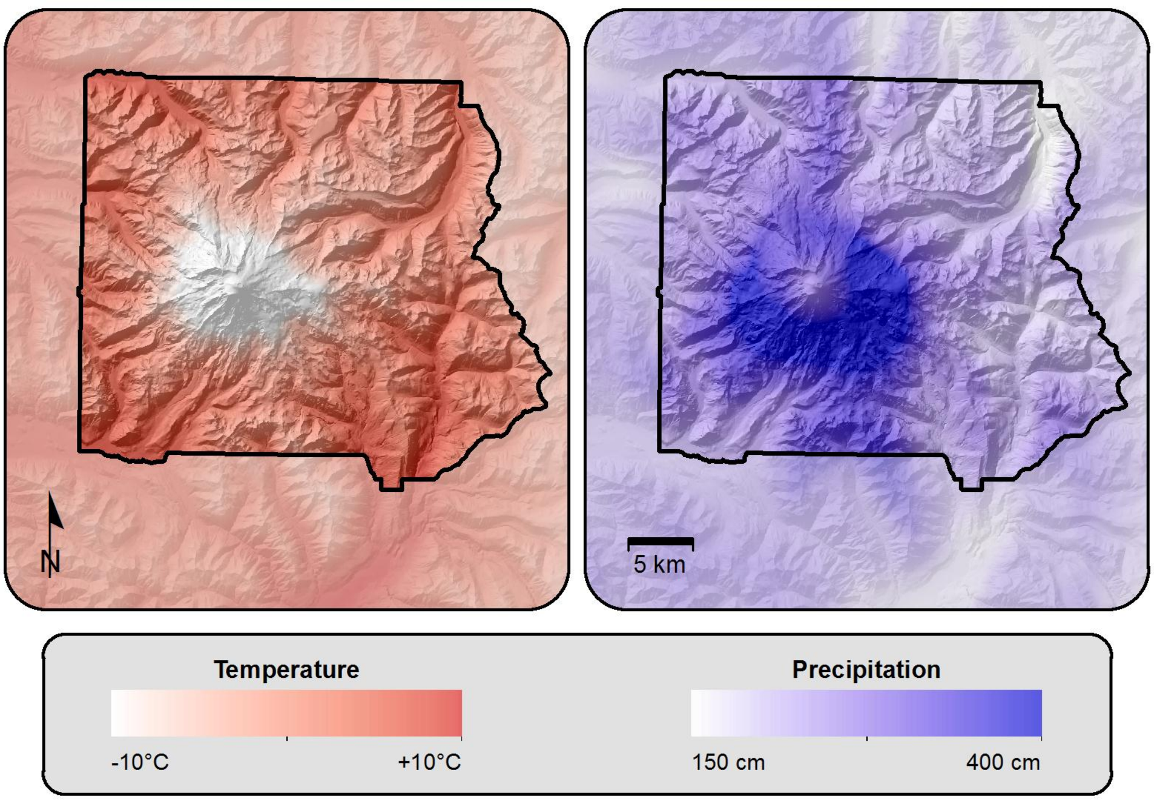

Figure 48. Map of climatological average (1971–2000) temperature and precipitation for Mt. Rainier National Park, obtained at 30 arc-second resolution from PRISM (Parameter Regressions on Independent Slopes Model; Daly et al., 2002). Note that the elevational gradients play a dominant role in climatic variations across the park.

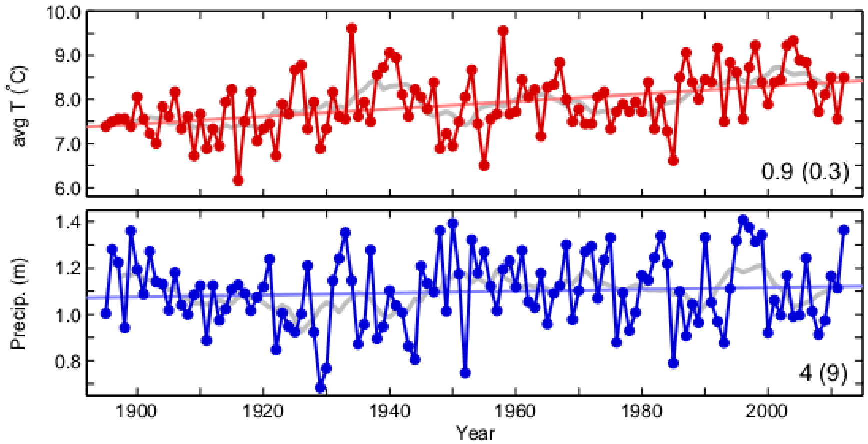

Figure 49. Annual average temperature (top) and annual total precipitation (bottom) for the state of Washington (1895–2012; data obtained from http://www.cefa.dri.edu/Westmap). The linear trend for the entire record is shown (straight red line for temperature, blue for precipitation), along with the 9-yr running average of each time series (grey lines). Trends (2σ value in parentheses) are listed in the bottom right corner of each panel, in units of °C/century for temperature and cm/century for precipitation.

5.2 Data and Methods

Weather monitoring is conducted in and around MORA by the NPS and several different agencies or networks (Figure 50, Table 61). This section describes each data source and its treatment (5.2.1), data continuity (5.2.2), and analysis methods (5.2.3).

5.2.1 Data Sources

Data from 12 stations in proximity to MORA were analyzed (Figure 50, Table 61). Data were aggregated as follows: Hourly data was aggregated to daily only if data was available for all hours of the day. Monthly values were only computed for months with at least 22 days of valid data (i.e., less than 9 days of missing data), except as noted below. Annual values were computed if at least 10 months of valid data are available for that year; all 3 months were required to be complete to compute seasonal values. All annual averages are for water years (October–September) instead of calendar years (January–December); i.e., water year 2011 goes from October 2010 to September 2011. The daily and monthly thresholds used for aggregation (22 days, 10 months) are standard for climate data analysis; tests showed that results are insensitive to the exact choice of these numbers. Temperature observations were averaged whereas totals were used for precipitation and the first of the month for snow.

COOP

The National Oceanographic and Atmospheric Administration's (NOAA) Cooperative Observer (COOP) Network includes thousands of stations across the conterminous U.S. Historically, volunteers recorded daily climate at each station at a fixed time of day that varied based on location and observer preference. There are 2 stations in the vicinity of MORA (in Table 60): Paradise Rainier and Longmire. The latter is designated as an USHCN station (see below).

Data for the Paradise Rainier (id: 456898) COOP temperature and precipitation records were obtained through NOAA's National Climatic Data Center (NCDC; http://www.ncdc.noaa.gov).

USHCN

A high quality subset of the COOP station data is archived as part of the US Historical Climate Network (USHCN; Karl et al. 1990). Selected for their longevity, completeness, and quality of data, USHCN data are also subjected to additional quality controls. The monthly version of the USHCN network includes adjustments for station moves, changes to the time of observation, and switches in the types of instrumentation (specifically, changes in temperature sensors throughout the 1980s), as well as other adjustments, and is considered to be a premiere dataset to use for long-term climate evaluation (Menne et al. 2009).

One USHCN station, Longmire (id: 454764), is located in the study area, the monthly temperature and precipitation data for which were obtained from http://cdiac.ornl.gov/epubs/ndp/ushcn/ushcn.html. Note that the USHCN record begins in 1895, which is earlier than measurements began at Longmire (1909); the USHCN data set has been infilled for missing data based on an optimal set of neighboring time series from other USHCN and COOP stations (Menne et al. 2009). Also note that the monthly precipitation and snow depth data has not been adjusted as described above, nor has the daily data for all variables for the USHCN stations has not been adjusted – these data do not differ from the COOP data for the same station, and are therefore less reliable for assessing trends.

SNOTEL and Snow Course

Snowpack observations stem from both the manual snow course measurements and the newer automated SNOwpack TELemetry (SNOTEL) stations. In addition to snow depth and snow water equivalent (SWE; the amount of water contained in the snowpack), SNOTEL stations also monitor temperature and precipitation. Since many SNOTEL stations are located at the sites of former snow course measurements and snowpack records, some snow-related records date back to the 1930s to 1950s. However, most SNOTEL stations were established between the 1970s and 2000s, so the record of snowpack varies significantly within the region.

The SNOTEL data was accessed in 2 ways: through the NRCS main site for daily temperature and precipitation (http://www.wcc.nrcs.usda.gov/snotel), and through a new NRCS report generating tool that is still in test mode for the monthly snow depth and SWE values (http://www.wcc.nrcs.usda.gov/reportGenerator).

Data for the Cayuse Pass (id: 1085), Mowich (id: 941), and Paradise (id: 679) SNOTEL sites were accessed using both of these portals. The daily temperature and precipitation data were aggregated into annual values using the same 22-d and 10-mo thresholds described above. For snow depth and SWE, the first of the month values were downloaded.

The first of the month snow depth and SWE observations for the Cayuse Pass (id: 21C06) snow course site were obtained through the new NRCS report generator (http://www.wcc.nrcs.usda.gov/reportGenerator).

RAWS

Remote Automated Weather Stations (RAWS) are primarily used for monitoring summer weather that assists land management agencies with a variety of projects such as monitoring air quality, rating fire danger, and providing information for research applications. RAWS observation records are usually hourly year round, but are of short duration: none start before 1985, and some were not established until the early 2000s.

Monthly average RAWS temperature and precipitation data were obtained from the Western Regional Climate Center (WRCC; http://www.raws.dri.edu) for the Ohanapecosh (id: 451119) RAWS site. WRCC aggregated the monthly data from the hourly data, and performed basic quality control (QC) on the data. If temperature is less than –62°C or greater than 77°C then WRCC flags the value as missing. Similarly, values are flagged as missing if precipitation is less than 0 in/hr or greater than 40 in/hr. For the present analyses the monthly values were only used if at least 75% of the daily data was available to make that monthly calculation, very similar to the alternative approach of requiring 22 d. RAWS sites do not record snow information.

CASTNET

The Clean Air Status and Trends Network (CASTNET) is an air quality monitoring network designed and maintained by the Environmental Protection Agency (EPA) and established under the 1991 Clean Air Act Amendments to assess trends in acid deposition (Baumgardner 1995). CASTNET observations are focused on long-term monitoring in rural areas and include hourly measurements of temperature and precipitation. CASTNET sites do not record snow information.

Data for the Mt. Rainier (id: MOR409) CASTNET site were downloaded through the EPA site (http://java.epa.gov/castnet).

NPS

The NPS data (Camp Muir [id: 288], Carbon River [id: 101], Sunrise Precip [id: 50], Sunrise Wind [id: 51]) provided was also aggregated into monthly data. The NPS data were provided as either hourly or daily data. Daily values were computed if at least 12 hrs in that day were reported. When converting the daily values into monthly values, the monthly value was only computed if at least 22 d were reported for each month. Faulty snow depth data was evident at the Sunrise Precipitation site (negative values; mostly in summer). Those values were ignored in this analysis.

Freezing Level

A time series of the freezing level, defined as the height in the atmosphere where the temperature is equal to freezing (0°C), was downloaded from the Western Regional Climate Center’s North American Freezing Level Tracker (http://www.wrcc.dri.edu/cwd/products; WRCC 2013). The resolution is coarse as the values are based on the NCEP/NCAR Global Reanalysis (2.5 x 2.5 degrees of latitude and longitude; Kalnay et al. 1996), meaning that variability within the park is not possible to examine. Instead, the time series is a large-scale average for the region surrounding the park. The average freezing level from October through March is used to represent each year.

5.2.2 Data Continuity

Using raw, unadjusted data poses a variety of potential issues when looking at trends in the data. Sometimes changes in the climate observations at 1 station do not reflect changing climate, but instead can be the result of 1 or more of the following: station relocation, changes to the surrounding landscape/environment, a change in observer, or a change in instrumentation. For NOAA networks, these known changes have been documented in the station metadata (http://www.ncdc.noaa.gov/homr).

For the COOP sites used in this study, minor and major changes in station location occurred for many of the stations. For instance, the metadata indicate that the Paradise COOP station moved in December 1970, but lack any location information for 1906–1948, meaning that unrecorded station moves could have occurred. Both the move in 1970 and the unrecorded moves in the first half of the 20th century pose a challenge to trend analysis.

While we present the data from all of the available sites within MORA, we recommend that only the Longmire USHCN station be used for trend analysis. The records have been closely examined and adjusted by the National Climatic Data Center (NCDC) to account for station changes and other known measurement biases such as the changes in the time of observation and instrumentation. Undocumented changes have also been accounted for, using statistical techniques to identify other "breakpoints", or discontinuities in the data that are caused by non-climatic changes. Trends for all of the Pacific Northwest USHCN stations through 2010 can be viewed at a website provided by the Office of the Washington State Climatologist: http://climate.washington.edu/trendanalysis.

Furthermore, we recommend looking at averages of multiple stations to avoid making regional assumptions based on a single station. In addition to the problems noted above, point observations may only be representative of a much localized area; corroboration from nearby stations is necessary to ensure a robust assessment of conditions. This is not to imply that important climatic gradients do not exist – there are no doubt variations in climate sensitivities across the park, and such distinctions are of key importance to park managers. Unfortunately, the vast majority of observations do not currently offer the longevity or data quality needed to reliably differentiate between spurious and real trends.

5.2.3 Analysis Methods

Growing Degree Days

Growing Degree Days were calculated using daily data from the Longmire USHCN station, as follows:

$$GDD = \begin{cases} T_{daily} - T_{base}, & T_{daily} \geq T_{base} \\ 0, & T_{daily} < T_{base} \end{cases}$$

We use a standard base temperature of 10°C for plotting, but report trends for base temperatures ranging from 0°C to 20°C. Annual totals of GDD were calculated from daily data as described above.

Note that the daily USHCN data does not include the adjustments described in the Section 5.2.1–USHCN and 5.2.2 (above) that are applied to the monthly USHCN data.

Correlations

Correlations were calculated using the standard Pearson correlation. Uncertainty in the correlation estimates was estimated by using a Fisher transform (Fisher 1915) and assuming that individual years are statistically independent. We report 95% confidence limits (± 2σ).

Linear Trends

Linear trends are calculated using a modified form of ordinary least squares regression that is robust to outliers. Specifically, we use the Matlab function "robustfit," which uses the method of iteratively reweighted least squares, in which individual points are weighted based on their proximity to the linear prediction, favoring points that agree well with the estimated trend while assigning less weight to outliers. The method is applied iteratively by re-assigning weights and re-computing trends until the regression converges on a consistent value.

In general, the results of this fitting scheme are not substantially different from that obtained from ordinary least squares. However, given the above concerns regarding data quality, "robustfit" was deemed a more conservative approach with the present dataset. Trends are accompanied in the text with the associated 95% confidence limits (± 2σ).

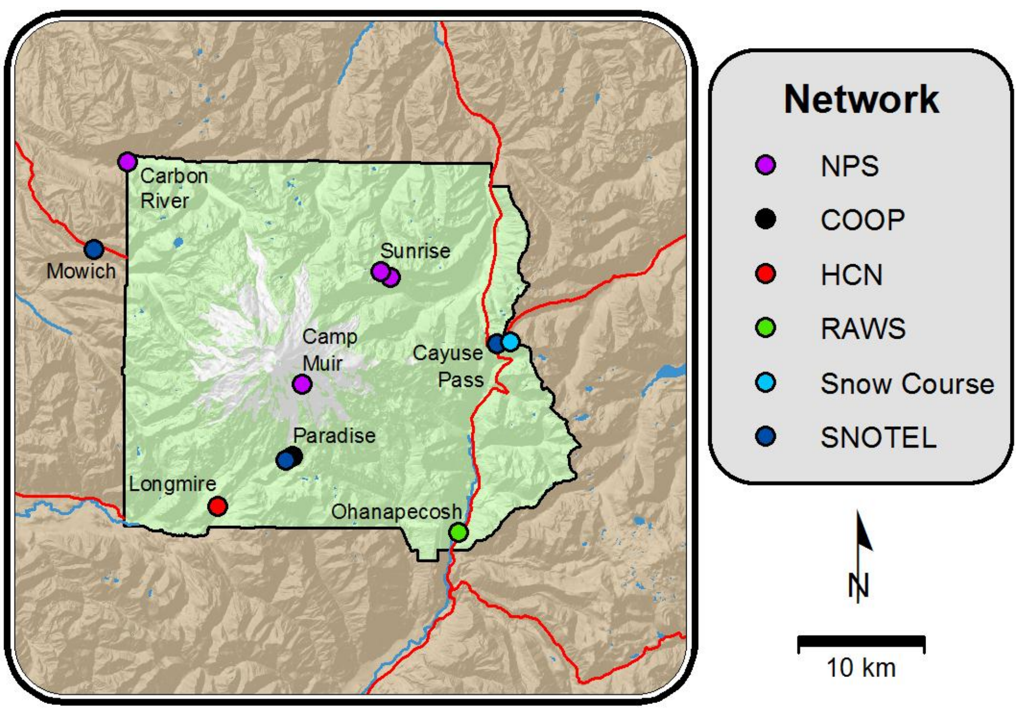

Figure 50. Weather stations by network type in MORA analyzed in this report.

Table 61. Weather stations in MORA analyzed in this report, sorted by elevation.

Station Name	Network	ID	Longitude	Latitude	Elev (m)	Temporal coverage
Camp Muir	NPS	288	-121.733	46.837	3078	09/2006 to 09/2011
Sunrise Wind	NPS	51	-121.651	46.917	2103	09/2004 to 09/2010
Sunrise Precip	NPS	50	-121.641	46.913	1957	11/2003 to 09/2012
Paradise Rainier	COOP	456898	-121.743	46.786	1654	12/1916 to 12/2011
Cayuse Pass	SC	21C06	-121.516	46.867	1616	01/1941 to 05/2008
Cayuse Pass	SNOTEL	1085	-121.530	46.866	1598	10/2006 to 12/2011
Paradise	SNOTEL	679	-121.750	46.783	1564	10/1980 to 12/2011
Mowich	SNOTEL	941	-121.950	46.933	963	10/1998 to 12/2011
Longmire	USHCN	454764	-121.820	46.750	842	01/1895 to 12/2011
Carbon River	NPS	101	-121.915	46.995	529	03/2008 to 09/2012
Ohanapecosh	RAWS	451119	-121.570	46.731	503	10/2003 to 10/2011
Mt. Rainier	CASTNET	MOR409	-122.124	46.758	415	08/1895 to 12/2011

5.3 Twentieth Century Climate: Observations and Trends in MORA

5.3.1 Climate Trends at Longmire USHCN station

The Longmire USHCN station is the longest-running weather station in Mt. Rainier National Park (1895–2011). In contrast with the other stations, it has also been subjected to a rigorous set of quality control corrections (Menne et al. 2011), implemented with the specific goal of facilitating climate change analyses (see above).

The time series of annual maximum temperature, minimum temperature, and precipitation for the Longmire USHCN station are shown in Figure 51. Although all variables show substantial year-to-year variability, a robust warming trend is evident for maximum temperatures. Surprisingly, there is a robust cooling trend for minimum temperatures. In contrast with temperature, there is no significant linear trend in precipitation.

Average annual temperature at Longmire is highly correlated with year-to-year variations across the Pacific Northwest as a whole ($r^2 = 0.75$; 2σ confidence limits: 0.64–0.83). However, the warming trend is substantially smaller; Mote (2003) found a PNW-wide warming trend of 0.9°C/century for 1920–2000, whereas the trend for the same time period is 0.3°C/century for Longmire (neither the Mote nor the Longmire trends are significant at the 95% confidence level). This suggests that strong correlations do not necessarily imply similar trends in response to warming. This is a key consideration when looking at observations across the park and a strong motivation for maintaining multiple long-term stations.

To further explore the relationship between season, period of record, and trend estimate, we calculated trends for annual, winter (December through February, “DJF”), and summer (June through July, “JJA”) climate for 3 different time periods: (1) the full period of record plotted in Figure 51 (1896–2012); (2) 1920–2000 (for comparison with Mote, 2003); and (3) 1950–2011. Trends and 95% confidence limits are shown in Table 62. Although the general results remain the same, the warming is greatest for the latter half of the 20th century and for the winter season. Trends in winter minimum temperature are even reversed (though not significant) for 1950–2011; in general, the cooling trend appears strongest in summer.

Although it is beyond the scope of this report to examine the causes behind the slight cooling trend in minimum temperatures, it is worth noting that this is quite unexpected. Greenhouse warming, by reducing the effectiveness of nighttime cooling, is expected to cause minimum temperatures to rise more rapidly than maximum temperatures. This is generally observed elsewhere in the Pacific Northwest, as shown in Figure 52 (OWSC 2013), where positive trends in maximum temperatures are weak but trends in minimum temperatures are strong. It is possible that the mechanisms at Longmire and MORA are different than elsewhere in the PNW; i.e., that there is a real physical mechanism behind the cooling trends in minimum temperatures. Alternatively, the trend could be spurious – a consequence of random annual and decadal variability that masks the warming signal. Regardless, this is an important trend to understand, and warrants further study.

5.3.2 Climate Observations across MORA

Although observations at Longmire represent the highest-quality, longest record of climate change in the park, the question remains as to whether or not these changes are representative of climate variations across the park. Figure 53 shows the annual time series of climate for all stations listed in Table 60, with the full record at Longmire included for comparison. Plots are shown for annual average, maximum, and minimum temperature as well as annual precipitation. Note that not all stations have data for all variables.

Annual variations in temperature and precipitation are remarkably similar among stations, with annual and decadal variations in fairly close agreement among all stations. Correlations with the Paradise COOP station (Table 63) show that Longmire explains about half of the variance in average temperature and precipitation, though the correlations are smaller for minimum and maximum temperature. Note that correlations were not calculated for other stations because Paradise is the only station with at least 30 yrs of valid data overlapping the Longmire record.

There are also some notable differences. For instance, the COOP and SNOTEL stations located at Paradise agree quite well in general, but show some marked differences on certain years. The differences are particularly notable given the close proximity of the 2 stations. Some examples of these discrepancies include the years 1999 and 2006–2007 for temperature, and 1996–1997 and 2008–2011 for precipitation. While some of this is of course related to the different siting locations, there is some evidence of other systematic factors. For precipitation, the SNOTEL tends to record higher values than the COOP site in the examples noted. During periods of inclement weather, the COOP site sometimes cannot be reached for the manual measurements to be taken, thus resulting in a systematic underestimate of precipitation. In addition, the snow collection tube at the SNOTEL site can occasionally be blocked after large snow events, which results in misattribution of precipitation to later dates (Rebecca Lofgren, pers. comm.). Another notable difference is that the Longmire record does not show the sharp drop in precipitation recorded at other stations (Cayuse Pass, Paradise, and Sunrise) in 2009. These are just examples, but serve to illustrate the fact that only about half of the variance at other stations within MORA can be explained with the observational record at Longmire.

Finally, we note that the previous discussion about station changes and missing data is important to keep in mind – other station records do not have the thorough suite of corrections applied to the USHCN data (changes in the time of observation, instrument used, measurement location, etc.). As a result, the correlations in Table 63 will be biased low, and some of the above differences are likely the result of measurement error rather than real physical distinctions between sites.

5.3.3 Snowpack Trends

Fewer observations of snow are available than for temperature and precipitation, but there are nonetheless good, high-quality, long-term records. Snow observations at MORA exist for the Sunrise precipitation, Paradise COOP, Paradise SNOTEL, Mowich SNOTEL, Cayuse Pass Snow Course (SC), Cayuse Pass SNOTEL, and Carbon River observing stations. Snow observations are not recorded for Longmire. Figure 54 shows the time series for April 1 snowpack, both snow depth and snow water equivalent. Snow water equivalent is the amount of water stored in the snowpack, and as with precipitation it is measured as a depth. April 1 snowpack is chosen because it approximates the annual peak in snow accumulation and is strongly tied to summer water availability. For comparison, linear trends for 1 January, 1 April, and 1 July are included in Table 63. For compatibility with Figure 53, the plots in Figure 54 are shown for the same time periods (1896–2012 and 1980–2012).

There is substantial agreement among records: Snow depth observations at Cayuse Pass SC and Paradise COOP stations correlate with an r^2 = 0.90 (95% confidence limits: 0.83–0.94), while SWE observations at Cayuse Pass SC and Paradise SNOTEL correlate with an r^2 = 0.71 (0.45–0.86). Note that the overlap for the latter is only 25 yrs, less than should generally be used for a robust correlation estimate.

There are no significant trends in snow depth (Figure 54, Table 64). In contrast, there is a statistically significant decreasing trend in 1 April SWE. As is observed elsewhere in the region, mid-winter snow accumulation (e.g., 1 January) is not as sensitive to warming, and is instead more influenced by variations in precipitation, for which the long-term trends are minimal (see, e.g., Table 62). The estimated 1 April SWE trends translate to a loss of approximately 6% per decade; this is at the high end of the Cascade Range-wide estimates discussed in the introduction to this chapter.

These observed snow trends are roughly consistent with the summary of changes in freezing level obtained from the U.S. Western Regional Climate Center (Figure 55; WRCC 2013). Freezing level is the height in the atmosphere at which air temperatures reach 0°C. Variations in the mean freezing level are an indication of fluctuations in the snowline, and are therefore related to the amount of winter snow accumulation. The results show substantial year-to-year variability but also a noticeable tendency towards higher freezing levels. The trend for the period of record (1949–2013) is a rise in the snowline of 220 ± 130 m/century (95% confidence limits). Note that freezing level is derived from a low-resolution dataset (see 5.3.2–Growing Degree Days) and therefore represents an average for the general region surrounding MORA.

5.3.4 Growing Degree Days

Because it is more directly associated with seasonal growth rates, we also calculate Growing Degree Days (GDD), computed using the daily data from the Longmire USHCN station (Figure 56; note that the daily USHCN is unadjusted, see 5.2.1–USHCN). Since definitions of GDD differ, we include results for 3 different base temperatures: 0°C, 10°C, and 20°C. Different choices of base temperature are more suitable for different organisms. Note that temperatures above 20°C are not frequently reached in MORA – thus the relatively small number of degree days for the higher base temperature. Also shown are the linear trends for the period of record (in degree days/century), which indicate that the warming trends are primarily confined to the warmest temperatures, while the trends for the 0°C base temperature are not statistically significant. This is particularly clear when considering the changes in percent terms, which correspond to an approximate change of –0.5%, 5%, and 50% for the 0°C, 10°C, and 20°C base temperatures, respectively. The mechanism for this may be consistent with the warming trends observed for maximum temperatures: weak trends for low temperatures, significant warming for higher temperatures. Further investigation would be needed to confirm a link between the 2.

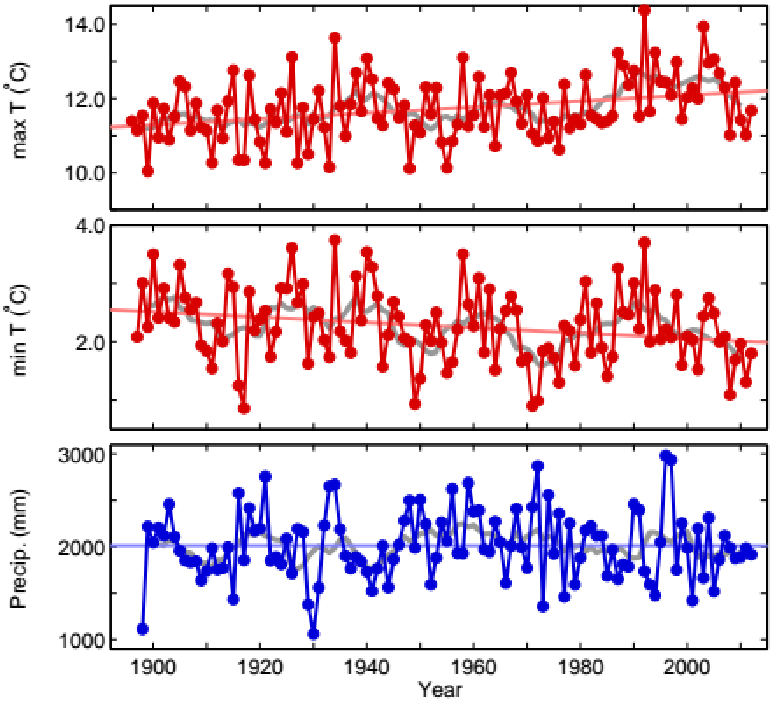

Figure 51. Annually averaged maximum (top) and minimum (middle) temperature, and annual total precipitation (bottom) time series and regression slopes for the Longmire USHCN station in MORA for the period of record 1896–2012. Also plotted are the linear trends (faded red and blue lines) and the 9-yr moving average (grey line), showing decadal variations in each variable.

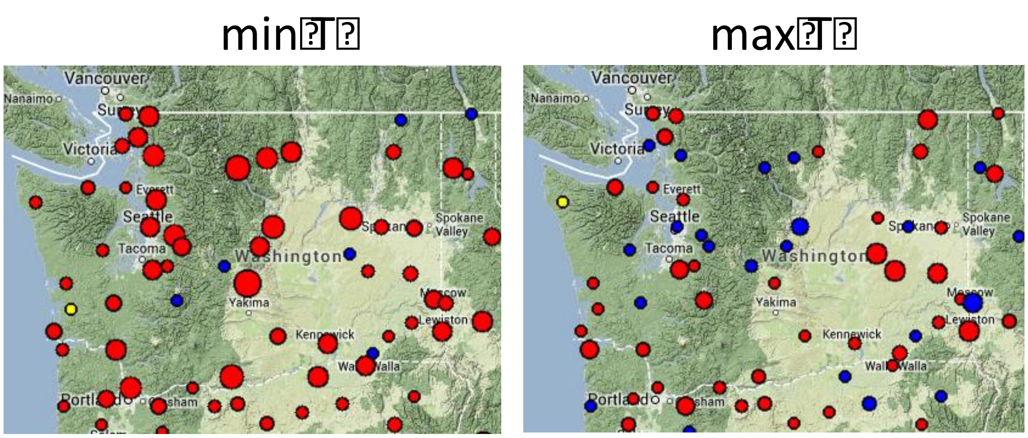

Figure 52. Trends in annual average minimum and maximum temperature for the period of record (1895–2010) at all of the USHCN stations in the state of Washington. The size of the circle indicates the magnitude of the trend at each station – as a reference, the minimum temperature trend for the Ellensburg station (just north of Yakima) is 0.51°C/decade. Red indicates a positive trend, blue indicates a negative trend, and yellow indicates no trend. Figure is from the Office of the Washington State Climatologist: www.climate.washington.edu/trendanalysis/.

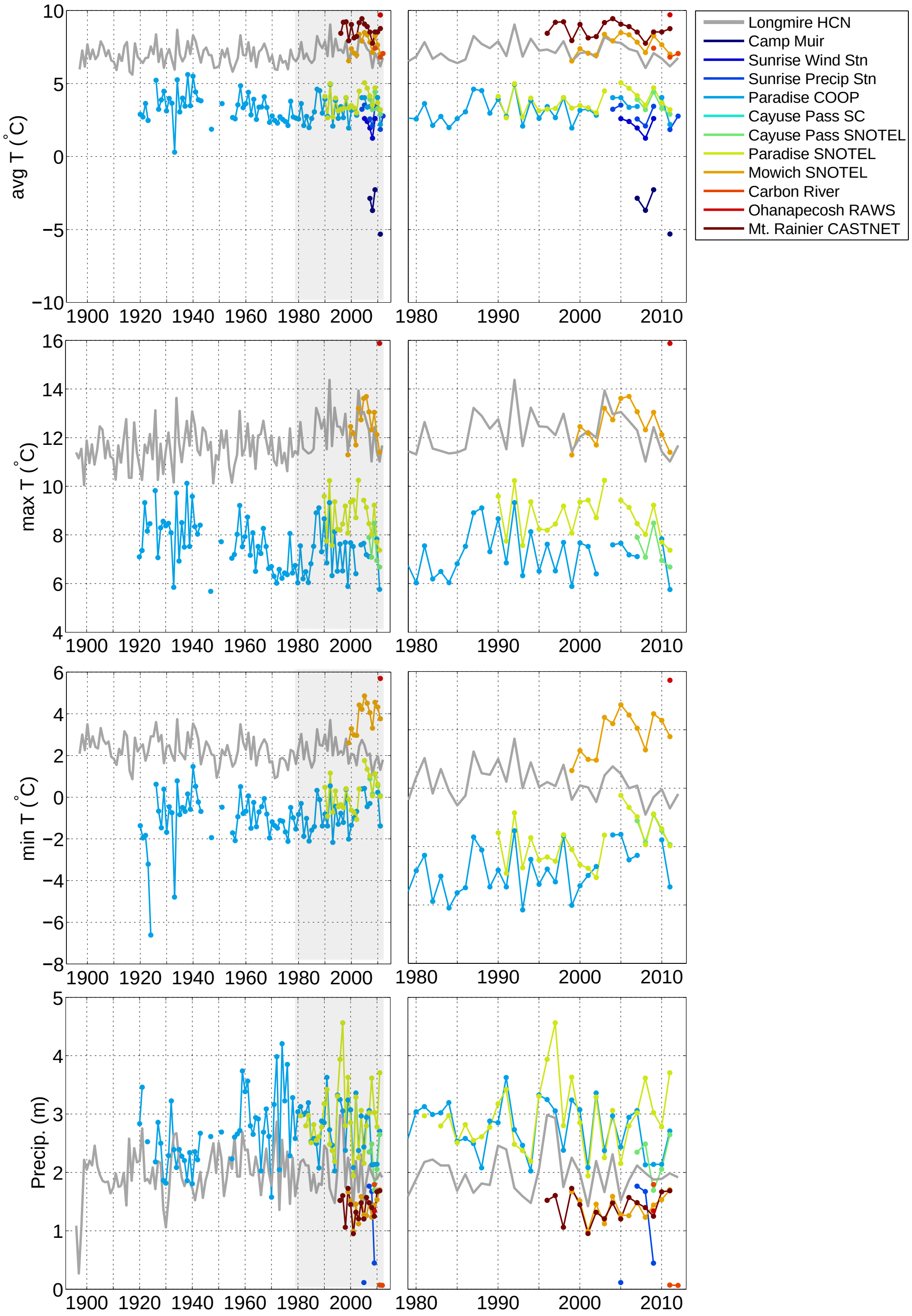

Figure 53. Time series of annual climate observations at all of the stations listed in Table 61. Plots are shown for the annual time series of average temperature (top), maximum temperature (*2*nd row), minimum temperature (third row), and precipitation (bottom). The full record at Longmire is shown for comparison (left column), along with a second set of plots zoomed in on the period from 1980 to present (right column). Stations are color-coded in order of decreasing elevation (highest/coldest in blue, lowest/warmest in red), except for Longmire, which is labeled in grey.

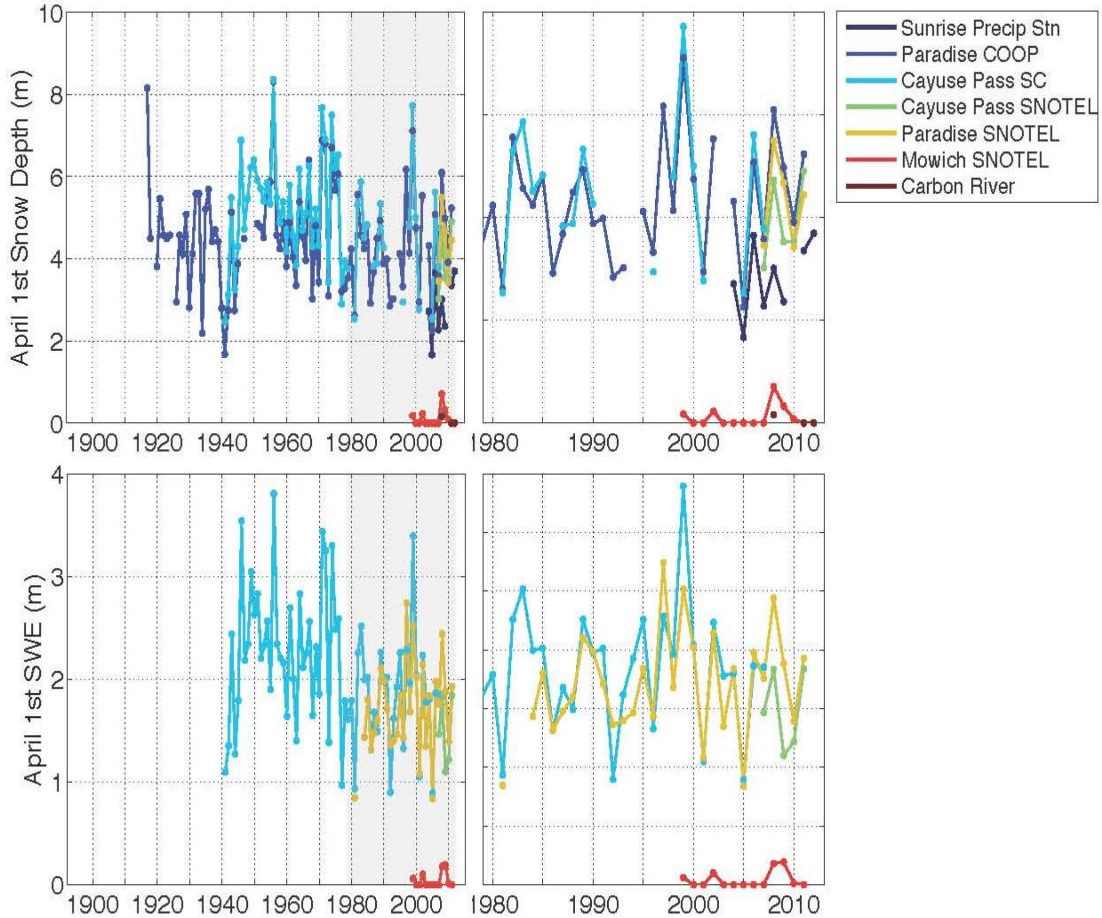

Figure 54. Time series of annual 1 April snow observations at observing stations in MORA. Plots are shown for snow depth (top) and snow water equivalent (SWE; bottom) for the 6 stations reporting snow observations within the park. For compatibility with Figure 53, plots are shown for the full record at Longmire (left column) and an expanded view for 1980–2012 (right column). The data are color-coded in order of decreasing elevation (highest/coldest in blue, lowest/warmest in red).

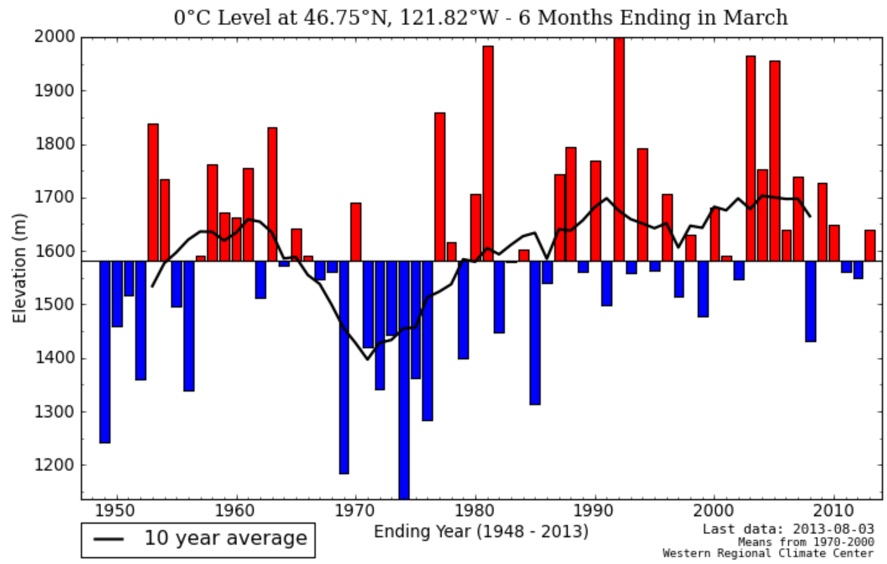

Figure 55. Time series of freezing level (elevation of 0°C isotherm) for MORA. Obtained from the U.S. Western Regional Climate Center North American Freezing Level Tracker.

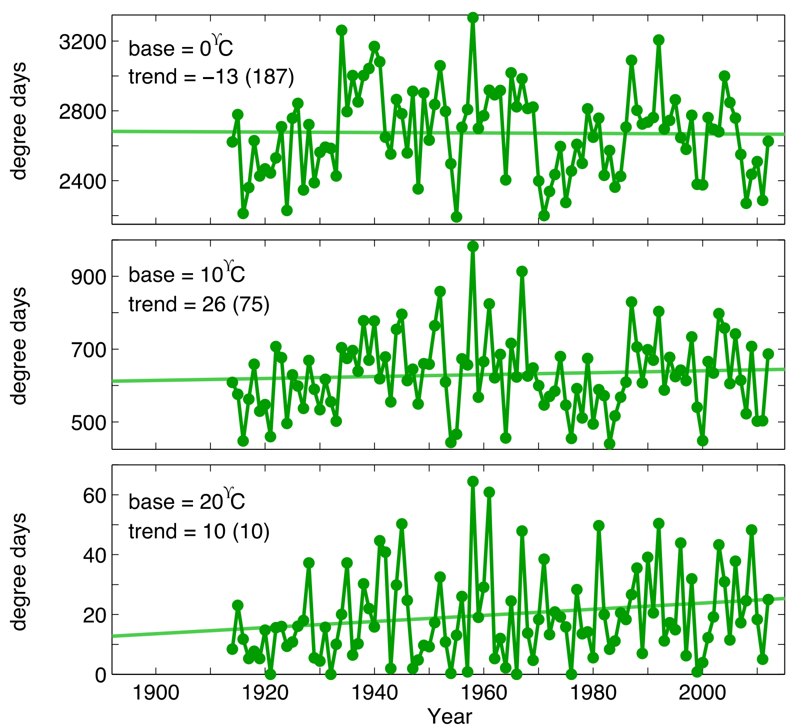

Figure 56. Trends in annual total Growing Degree Days (GDD), computed using daily temperature data from daily climate observations at Longmire. Since definitions of GDD differ, we have included the results using 3 different base temperatures: 0°C (top), 10°C (middle), and 20°C (bottom). Linear trends are also plotted for the period of record, as well as printed in the top left corner of each panel (2σ confidence interval in parentheses), in units of degree days/century.

Table 62. Annual and seasonal trends (± 2σ) in temperature and precipitation at Longmire. Winter is defined as December–February, summer as June–August. Trends that are statistically significant at the 95% level are highlighted in bold.

			Linear Trend		
Time	**Variable**	**Units**	**Annual**	**Winter**	**Summer**
1896-2011	Avg. Temp.	°C/century	0.2 ± 0.4	0.5 ± 0.7	0.0 ± 0.5
	Max. Temp.	°C/century	**0.8 ± 0.5**	**1.1 ± 0.7**	0.5 ± 0.7
	Min. Temp.	°C/century	**-0.5 ± 0.4**	-0.1 ± 0.7	**-0.6 ± 0.4**
	Precipitation	cm/century	0 ± 21	-2 ± 14	4 ± 4
1920-2000	Avg. Temp.	°C/century	0.3 ± 0.7	**1.4 ± 1.2**	-0.4 ± 0.8
	Max. Temp.	°C/century	**1.0 ± 0.8**	**1.9 ± 1.2**	0.5 ± 1.3
	Min. Temp.	°C/century	-0.4 ± 0.6	0.8 ± 1.2	**-1.1 ± 0.6**
	Precipitation	cm/century	7 ± 38	2 ± 25	6 ± 7
1950-2011	Avg. Temp.	°C/century	0.8 ± 1.0	1.6 ± 1.6	1.0 ± 1.5
	Max. Temp.	°C/century	**1.7 ± 1.2**	**2.7 ± 1.8**	**2.4 ± 2.3**
	Min. Temp.	°C/century	-0.1 ± 0.9	0.7 ± 1.6	-0.6 ± 1.0
	Precipitation	cm/century	46 ± 53	**40 ± 37**	-3 ± 11

Table 63. Correlations (r^2 and 95% confidence bounds) between the Longmire HCN and Paradise COOP stations. Correlations were calculated for the full record at Paradise (1920–2011). The sample size for each correlation ranged from 78 to 80 yrs.

Station	avg T	max T	min T	Precipitation
Paradise COOP	0.58 (0.65-0.84)	0.32 (0.16-0.49)	0.21 (0.07 0.38)	0.46 (0.29-0.61)

Table 64. Trends (± 2σ) in SWE and Snow Depth at 3 stations in MORA: Paradise COOP, Cayuse Pass Snow Course, and Paradise SNOTEL. All trends are in cm/century, and are in bold if significant at the 95% confidence level. Trends were not calculated if less than 30 yrs of data were available.

			Linear Trend		
Variable	**Station**	**Years**	**1 Jan**	**1 Apr**	**1 Jul**
Snow Depth	Paradise COOP	1917–2011	13 ± 72	-8 ± 100	-29 ± 100
		1950–2011	16 ± 130	-110 ± 190	-51 ± 190
	Cayuse Pass SC	1941–2007	—	-180 ± 210	—
		1950–2007	—	**-330 ± 240**	—
SWE	Cayuse Pass SC	1941–2007	8 ± 62	**-95 ± 81**	—
		1950–2007	36 ± 86	**-140 ± 92**	—

5.4 Climate Projections for Cascadia

Future climate in MORA is currently best described as the expected regional changes in temperature and precipitation and their likely effects on sub-regional hydrologic variation.

Regionally, temperature is expected to continue to increase in the PNW, warming on average by 1.1°C (2.0°F) by the 2020s (2010–2039), 1.8°C (3.2°F) by the 2040s (2030–2059), and 2.9°C (5.3°F) by the 2080s (2070–2099), compared to 1970–1999 (Mote and Salathé 2010; Figure 57). These 30-yr "windows" are a good way to characterize climate trends because the interannual variability dominates over shorter time periods. The 2 emission scenarios in Figures 57 and 58 are moderate warming scenarios that are based on future assumptions of greenhouse gas emissions, population growth, technological innovations, etc. (Nakicenovic and Swart 2000). The B1 is a low-end scenario and the A1b is a middle-of-the-road scenario for 21st century greenhouse gas emissions.

Expected changes in precipitation vary substantially across future climate models, with increases or decreases as much as 30% depending on the model (Figure 58). For the PNW, the seasonality of those changes is very important to the resources of the region. Figure 58 shows expected changes by season, with most models projecting increases in winter, spring, and fall (+2% to +5% depending on season), and decreases in the summer (on average, –5% to –11%), although some models project as much as +10% or as little as –30%.

Future temperature is projected to increase in all seasons, but climate models disagree on how quickly the temperature will increase. In contrast, future precipitation scenarios for the 2040s are widely divergent with some global climate models projecting decreasing precipitation and others increasing precipitation (Figure 58). However, more models project drier summers and wetter climate in winter, spring, and fall. These trends may be indistinguishable from the substantial interannual and interdecadal variability and perhaps difficult to see as the future unfolds, though the likelihood of a dry or wet year may change. Specifically, the historical range of variability at the Longmire USHCN station is about 1.4°C for annual average temperature and about ±40% for precipitation (for the full period of record: 1896 to 2012). This means that the mean projected changes across climate models put the average 2040 temperatures at the upper end of the historical range and the average 2080 temperatures largely outside of historical ranges. Precipitation variability, in contrast, remains larger than projected changes through the end of the 21st century. Note that this applies to changes in annual-average temperature and precipitation. Although the picture is similar for seasonal variations, there is a weak tendency towards decreases in precipitation in summer and increases for other seasons. On shorter time scales (daily, weekly), much debate remains regarding the potential for extremes in temperature and precipitation to change more rapidly than the average: the science, both past observations and modeling, is not yet clear on the trends that we can anticipate going forward.

The above discussion summarizes climate projections for the PNW as a whole. Since global climate models are limited in resolution, results from these models must be "downscaled" to view the implications at smaller scales. Downscaling is simply a means of relating the large-scale information from global models to smaller spatial scales; it can be applied either statistically, using observationally-based data, or dynamically, using a regional climate model. Here we provide information about past and future climate on the basis of zones with similar climate and vegetation, Omernik Level III ecoregions (Figure 59; Omernik, 1987), rather than summarizing averages for the park as a whole.

Table 65 lists historical averages and projected changes for warm and cool season temperature and precipitation, and April 1 snowpack for 3 Omernik ecoregions that correspond approximately to MORA. Data are derived from the statistically downscaled dataset described by Littell et al. (2011). Historically, the North Cascades (Omernik 77) is cooler and wetter than the Cascades (Omernik 4) and East Cascades (Omernik 9). The East Cascades region is particularly dry relative to the other regions. Under the future scenarios examined, temperature is projected to increase in all seasons in all ecoregions compared to the base period 1916–2006. Projected changes in precipitation vary substantially among models and within the region, but the average among 10 climate models that perform best in the PNW region is for slight increases during the cool season (October–March) and slight decreases during the warm season (April–September). Changes in April 1 Snow Water Equivalent are projected to be particularly large, ranging from a loss of 30–74% by mid-century. Note that these are the mean changes in snowpack for each ecoregion – changes within these areas will be concentrated at lower elevations near the snowline. These are higher than the estimates of Casola et al. (2010) and Stoelinga et al. (2010).

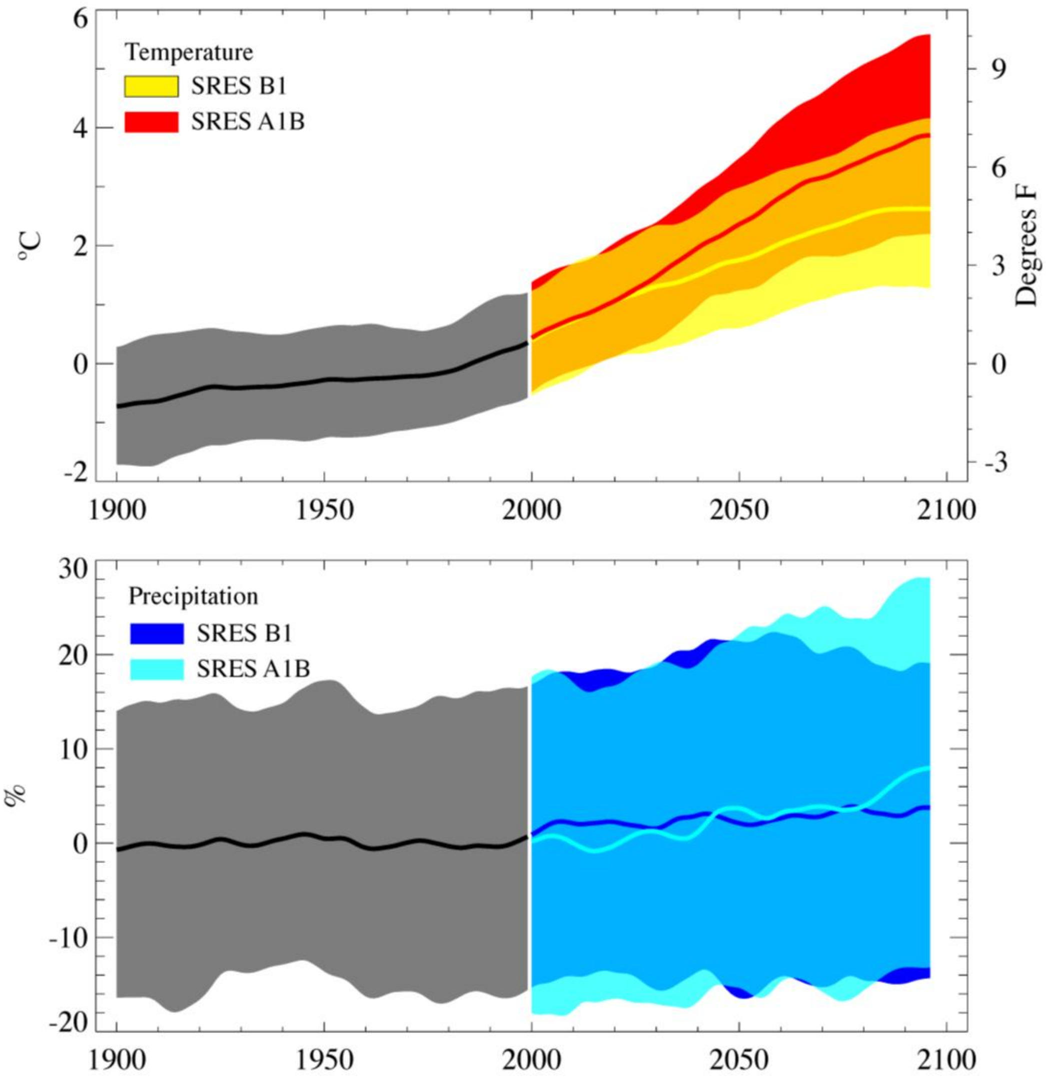

Figure 57. Modeled historical and expected PNW temperature and precipitation for the 20th and 21st century. The darker lines show the average of all models during the 20th century (black) and for the 21st century (yellow and red for temperature, light and dark blue for precipitation). The colored lines are the average of all models for 2 greenhouse gas emissions scenarios ("low" or B1, and "medium" or A1B) for the 21st century. The colored areas indicate the range (5th to 95th percentile) across 19 (B1) or 20 (A1B) climate models. All changes are relative to 1970–1999 averages. Image source: Mote and Salathé, 2010.

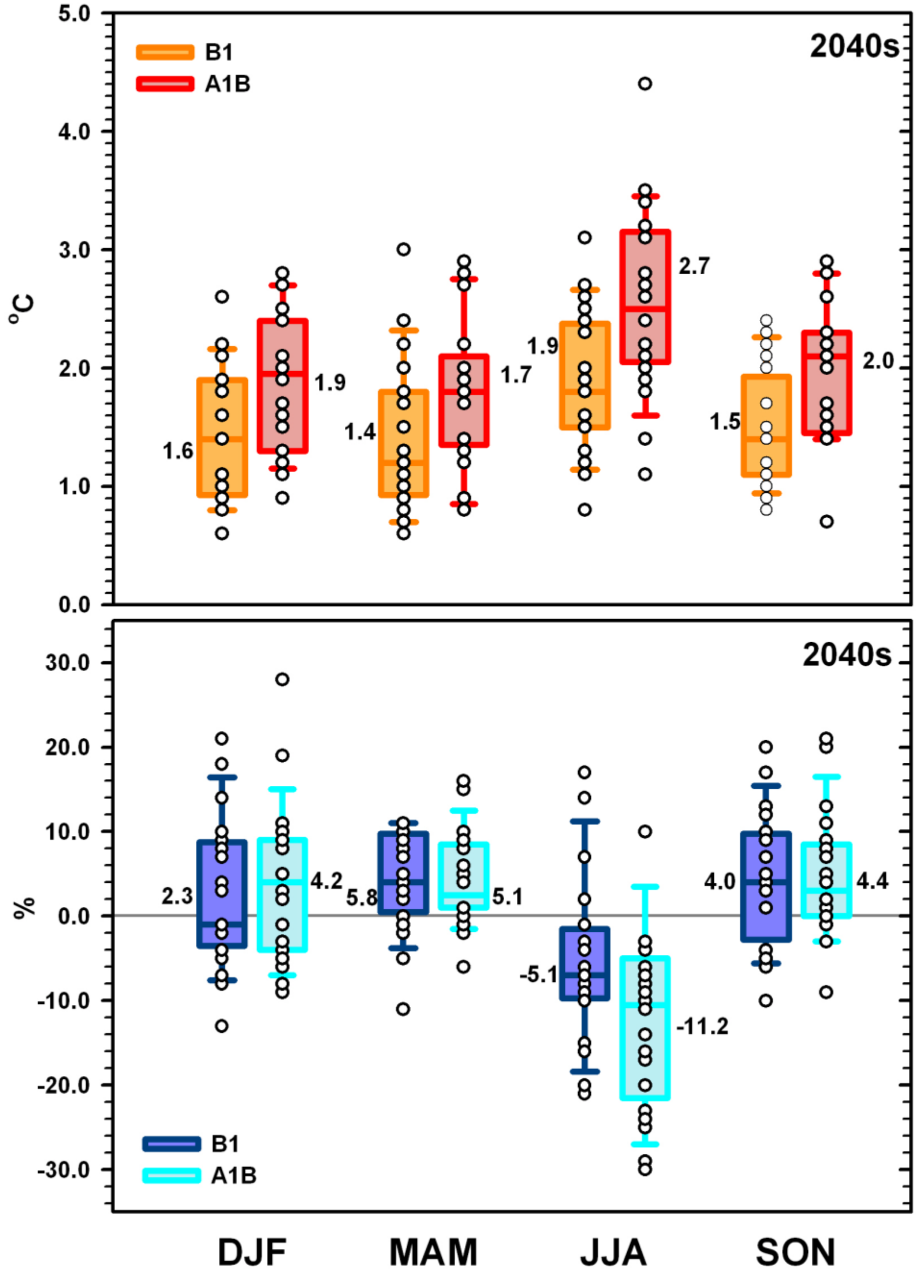

Figure 58. Range (lowest to highest) of projected changes in temperature (top) and precipitation (bottom) for each season (DJF = winter, etc.), relative to the 1970–1999 mean. In each pair of box and- whiskers, the left one is for greenhouse gas emissions scenario B1 (lower emissions) and the right is A1B (higher emissions); circles are individual model values. Box-and-whiskers plots indicate 10th and 90th percentiles (whiskers), 25th and 75th percentiles (box ends), and median (solid middle bar) for each season and scenario. Not all values are visible due to symbol overlap. Printed values are the average of all GCMs for the season and scenario. Image source: Mote and Salathé, 2010.

Figure 59. Omernik Level III ecoregions (Omernik 1987) used to summarize climate projections for the park.

Table 65. Temperature and precipitation in 3 Omernik level III ecoregions of the Pacific Northwest. The values in the table represent averages over the Omernik Ecoregions derived from interpolated station data for the period 1916–2006. Future projections are for 10 global climate models for the 2040s (2030–2059) that perform well in the PNW and averaged for emissions scenarios A1B and B1. The changes listed are the mean value followed by the range among models in parentheses. Changes are highlighted in bold if all models agree on the sign of the change.

	Cascades (Omernik 4)	**East Cascades (Omernik 9)**	**North Cascades (Omernik 77)**
DJF Temp (°C)	0.5 **+1.7 (0.8 to 2.4)**	-0.9 **+1.8 (0.9 to 2.5)**	-3.0 **+1.9 (1.1 to 2.5)**
JJA Temp (°C)	16.6 **+2.6 (1.7 to 3.8)**	16.3 **+2.6 (1.8 to 3.9)**	13.3 **+2.6 (1.7 to 3.9)**
Oct-Mar Precip	850 mm 0% (-8 to +7%)	360 mm +1% (-7 to +10)	1410 mm +8% (-1 to +22%)
Apr-Sep Precip	220 mm -5% (-13 to +4%)	130 mm -5% (-12 to 0%)	440 mm -8% (-18 to +1%)
April 1st SWE	85 mm **-57% (-79 to -29%)**	15 mm **-74% (-93 to -36%)**	490 mm **-30% (-49 to -23%)**

5.5 Discussion and Conclusions

In this report, we evaluate the historical and possible future climate of MORA in the context of PNW regional climate. We relied on several sources of climatic data to evaluate climate trends in temperature, precipitation, and snowpack. Although there is some diversity of responses among long-term stations, maximum temperature is increasing in MORA. The trends are less evident for minimum temperature, and there is a statistically significant decreasing trend at the station with the longest record (Longmire USHCN). This trend is in contrast to an increasing trend in minimum temperatures throughout the region as a whole. All trends for temperature show a tendency towards more warming in the recent record (1950 to present). Precipitation trends are essentially flat. Although snow depth measurements do not show a clear trend, observations of snow water equivalent appear to show robust declining trends.

Unfortunately, the number and distribution of long-term climate stations with records that are of sufficiently quality to evaluate trends is too low to provide the spatial coverage and replication necessary to understand within-park variations. The stations analyzed in this report suggest somewhat different sensitivities in different parts of the landscape, but without longer records and more replication, it is not yet possible to know whether these differences reflect actual differences in climate or in the observation of that climate as affected by other factors. We have attempted to evaluate the existing stations, but 1 important conclusion of this report is that existing stations need to be maintained, and possibly new stations added, to have sufficient basis for understanding within-park changes.

Missing data also create difficulty because trends calculated on variables with missing data can result in biased estimates of annual or seasonal values. Most of the stations we evaluated had missing data. Finally, station inhomogeneities caused by moving stations, changing the time of observation, or even different instruments have likely occurred in the record, introducing further bias. Of all the weather and climate observing stations in MORA, only Longmire is of sufficient quality and duration to qualify for the U.S. Historical Climate Network (USHCN; Karl et al. 1990), a subset of the Cooperative Observer (COOP) network meteorological stations, selected for their longevity, completeness, and high quality of data. These records are the best available for the study of long term variations and trends, and their bias has been reduced by adjusting for known station moves and observational biases. We note that this is another fruitful area for future research, digitization of previously un-recorded metadata and additional work to remove artifacts from the observations; such work could substantially improve efforts to distinguish different zones and regimes of climate sensitivity.

The expanded network of observations available through other networks (e.g., SNOTEL, RAWS, etc., discussed in 5.2.1) provides an opportunity to continue developing the climate data resources needed to understand responses in the parks. Most records are not yet of long enough duration to provide much insight into climate trends or multi-year variations. It is imperative to keep these monitoring stations operational and to maintain the completeness and quality of the datasets so that, as observational records lengthen, a basis exists for future analyses to better understand the climate of MORA.

Projections of future change, though limited by the low resolution of global climate models, are consistent with the trends indicated by the observations. These show a continued warming trend that exceeds the range of historical variability by mid-century, and no clear trend in precipitation.

Seasonally, projections indicate greater warming in summer than in winter, and a slight tendency towards drier summers and wetter winters. These changes have important implications for water stress and ecosystem health. These changes, though useful, lack the granularity needed to identify areas that may be impacted by climate change more strongly. Warming, for instance, is anticipated to be greater in areas near the snowline; global models are not able to resolve these sorts of small-scale sensitivities. Numerous datasets currently exist that "downscale" climate projections from large to small spatial scales. Additional work is needed to assess the merits of these approaches within MORA and understand what they imply for changes to the climate of the park.

Summaries of climatic conditions over a complex and diverse landscape (e.g., the PNW, or more locally, MORA) are generalizations. First, there are relatively few climate observations from high elevations (which comprise a significant percentage of National Park area), though there are ongoing efforts to better understand higher elevation climate (e.g., Minder et al. 2010). Second, the climate on the west slope of the Cascades is typically quite different from that east of the Cascade Range crest; average conditions for a single national park or mountain range will hide those differences. Third, with respect to future climate change, most global climate models do not resolve the topography at sufficient detail to understand how the climate of different places within an individual park might change. This report summarizes the findings that are currently available from surface observing stations and global model projections of future climate. Our hope is that this can serve as a basis for ongoing work, and help to inform the direction of future research.

5.6 Literature Cited

Baumgardner, R. 1995. CASTNET national dry deposition network 1990-1992 status report. Technical Report No. PB--95-234506/XAB. Environmental Science and Engineering, Inc., Gainesville, Florida.

Casola, J. H., L. Cuo, B. Livneh, D. P. Lettenmaier, M. T. Stoelinga, P. W. Mote, and J. M. Wallace. 2009. Assessing the impacts of global warming on snowpack in the Washington Cascades. Journal of Climate 22:2758–2772.

Daly, C., W., P. Gibson, G. H. Taylor, G. L. Johnson, and P. Pasteris. 2002. A knowledge-based approach to the statistical mapping of climate. Climate Research 22:99–113.

Diamond, H. J., T. R. Karl, M. A. Palecki, C. B. Baker, J. E. Bell, R. D. Leeper, D. R. Easterling et al. 2013. U. S. Climate Reference Network after one decade of operations: Status and assessment. Bulletin of the American Meteorological Society 94, no. 4, 485–498.

Fisher, R. A. 1915. Frequency distribution of the values of the correlation coefficient in samples from an indefinitely large population. Biometrika 10:507–521.

Hamlet, A. F., P. W. Mote, M. P. Clark, and D. P. Lettenmaier. 2005. Effects of temperature and precipitation variability on snowpack trends in the Western United States. Journal of Climate 18:4545–4561.

Kalnay, E., M. Kanamitsu, R. Kistler, W. Collins, D. Deaven, L. Gandin, M. Iredell, S. Saha, G. White, J. Woollen, and others. 1996. The NCEP/NCAR 40-year reanalysis project. Bulletin of the American Meteorological Society 77:437–471.

Karl, T. R., C. N. Williams, Jr., F. T. Quinlan, and T. A. Boden. 1990. United States Historical Climatology Network (HCN) serial temperature and precipitation data. Environmental Science Division, Publication No. 3404, Carbon Dioxide Information and Analysis Center, Oak Ridge National Laboratory, Oak Ridge, Tennessee.

Karl, T. R., V. E. Derr, D. R. Easterling, C. K. Folland, D. J. Hofmann, S. Levitus, N. Nicholls, D. E. Parker, and G. W. Withee. 1995. Critical issues for long-term climate monitoring. Climatic Change 31:185–221.

Littell, J. S., M. M. Elsner, G .S. Mauger, E. R. Lutz, A. F. Hamlet, and E. P. Salathé. 2011. Regional climate and hydrologic change in the Northern U.S. Rockies and Pacific Northwest: Internally consistent projections of future climate for resource management. Preliminary project report, USFS JVA 09-JV-11015600-039. Prepared by the Climate Impacts Group, University of Washington, Seattle, Washington.

Mantua, N. J., S. R. Hare, Y. Zhang, J. M. Wallace, and R. C. Francis. 1997. A Pacific interdecadal climate oscillation with impacts on salmon production. Bulletin of the American Meteorological Society 78:1069–1079.

Menne, M. J., C. N. Williams Jr., and R. S. Vose. 2009. The U.S. historical climatology network monthly temperature data, version 2. Bulletin of the American Meteorological Society 90:993–1007.

Menne, M. J., C. N. Williams Jr., and R. S. Vose, 2011. United States Historical Climatology Network (USHCN), Version 2, Serial Monthly Dataset. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, Oak Ridge, Tennessee.

Minder, J. R., P. W. Mote, and J. D. Lundquist. 2010. Surface temperature lapse rates over complex terrain: Lessons from the Cascade Mountains. Journal of Geophysical Research 115:D14122. DOI: 10.1029/2009JD013493.

Mote, P.W. 2003. Trends in temperature and precipitation in the Pacific Northwest during the twentieth century. Northwest Science 77:271–282.

Mote, P. W. 2006. Climate-driven variability and trends in mountain snowpack in western North America. Journal of Climate 19:6209–6220.

Mote, P. W., and E. P. Salathé. 2010. Future climate in the Pacific Northwest. Climatic Change 102:29–50. DOI: 10.1007/s10584-010-9848-z.

Nakicenovic N., and R. Swart, editors. 2000. Special report on emissions scenarios. A special report of working group III of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, United Kingdom.

Omernik, J. M. 1987. Ecoregions of the conterminous United States. Map (scale 1:7,500,000). Annals of the Association of American Geographers 77:118–125.

Smoliak, B. V., J. M. Wallace, M. T. Stoelinga, and T. P. Mitchell. 2010. Application of partial least squares regression to the diagnosis of year-to-year variations in Pacific Northwest snowpack and Atlantic hurricanes. Geophysical Research Letters 37:L03801.

Stoelinga, M. T., M. D. Albright, and C. F. Mass. 2010. A new look at snowpack trends in the Cascade Mountains. Journal of Climate 23:2473–2491.

Stott, P.A. 2003. Attribution of regional-scale temperature changes to anthropogenic and natural causes. Geophysical Research Letters 30. DOI:10.1029/2003GL017324.

[WRCC] Western Regional Climate Center, cited 2013: North American Freezing Level Tracker. Available online at: http://www.wrcc.dri.edu/cwd/products/.

Chapter 6 Discussion

6.1 MORA Natural Resource Condition

The data used to complete the assessments of the conditions of the MORA natural resources included in this report have been collected over varying temporal and spatial intervals. Some data, such as for certain lake water quality parameters, have been collected over relatively long-time intervals (e.g., 1988–2009) from sites throughout the park (e.g., 137 of 407 lakes). Other collected data, such as for elucidating the presence and distribution of stream fish, although collected from sites throughout the park, were collected in single years or during inventories conducted over relatively short-time intervals (e.g., 2001–2003). Due to this temporal and spatial variability, the extrapolation of assessment results to the entire park can only be viewed as an estimate of overall condition rather than as a determination of absolute condition. An estimate of the condition of each resource category, therefore, is based on the subjective criteria defined in Table 66.

Table 66. Scale and definitions for condition levels of assessed resource categories.

Scale	Definition
0	Insufficient data for estimating condition based on level of disturbance
1	**Minimal** – No net loss to minimal documented signs of limited and isolated change-degradation
2	**Moderate** – Documented signs of moderate, generalized change-degradation
3	**Serious** – Documented signs of widespread and potentially uncontrolled change-degradation
4	**Significant** – Documented signs of potentially catastrophic and irreparable change-degradation

Overall, 23 of 28 of the natural resource categories for which present condition based on disturbance level could be assessed were identified as having some documented signs of moderate to significant change and degradation; and 10 of these categories were estimated to have been seriously to significantly disturbed (Table 67). The ratings for management level of concern for future condition in Table 67 considers existing and future stressors that could potentially affect each of the resource categories. Levels of concern in ascending order are: Low, Moderate, Serious, and Significant. Of the 31 categories, 15 are considered to be of serious to significant concern for possible future decline or degradation of condition. A more detailed summary of the overall disturbance and condition of each natural resource assessed as part of this report is presented in sub-section 6.2.

Table 67. Estimated conditions of MORA natural resource categories based on assessed level of disturbance (see Table 66), and management level of concern for future condition. SOC = Species of Concern; ES = Endangered Species.

Category	Present Assessed Condition	Future Condition
Air Quality – Ozone	2	Moderate
Air Quality – Visibility	2	Moderate
Air Quality – N-S deposition	3	Significant
Air Quality – PBT deposition	3	Significant
Lake Water Quality (general)	1	Moderate
Lake Water Quality (contaminants)	3	Serious
Stream Water Quality (general)	1	Moderate
Stream Water Quality (temperature, flow)	3	Serious
Landscape-scale Vegetation Dynamics	2	Moderate
Forest Health – Disturbance Regime	3	Serious
Forest Health – Whitebark Pine	4	Significant
Forest Health – Air Quality	2	Moderate
Fire Ecology	2	Moderate
Biodiversity – Exotic Plants	2	Moderate
Biodiversity – Wetlands	0	Significant
Biodiversity – Alpine-Subalpine Vegetation	2	Significant
Biodiversity – Sensitive Vegetation Species	2	Moderate
Amphibians (general)	2	Significant
Amphibians (SOC)	3	Significant
Stream Fish (non-ES, non-SOC)	2	Serious
Stream Fish (ES, SOC)	3	Serious
Land Birds (general)	2	Moderate
Land Birds (species with evidence of decline)	3	Serious
Mammalian Fauna (Biodiversity)	1	Low
Mammalian Carnivores	0	Moderate
Cascade Red Fox	2	Moderate
Elk	1	Low
Bats	0	Serious
Glaciers	3	Serious
Soundscape	1	Moderate
Dark Night Skies	2	Moderate

Although only 10 resource categories were assessed as being seriously to significantly disturbed, many, if not all, of the MORA resources are also susceptible to increased levels of disturbance and change due to anthropogenically-generated perturbation, especially climate change. Projections of future climate change, though limited by the low resolution of global climate models, are consistent with the trends that show a continued warming trend that exceeds the range of historical variability by mid-century, and no clear trend in precipitation. Seasonally, projections indicate greater warming in summer than in winter, and a slight tendency towards drier summers and wetter winters. These changes in temperature and precipitation regime have important implications for water stress and ecosystem health. For example, climate change continues to be a global, regional, and local threat to aquatic ecosystems, with the potential of leading to chronically degraded water quality due to episodes of climate-induced stress related to changes in precipitation and temperature regimes (Hauer et al. 1997, Murdoch et al. 2000). MORA lake and stream water quality, including native biota such as aquatic insects, fish, and amphibians, will certainly be affected and potentially degraded by this climate-induced stress. Both direct and indirect effects of climate change on birds can be expected, although predictability of specific effects is currently low because of the complexity of interacting factors (Halofsky et al. 2011, Tingley et al. 2012). Changes in temperature and precipitation regimes are expected to cause changes in distribution and structure of plant communities that provide important food and cover for birds in the park. Thus, a major effect of climate change is expected to be changes in bird species presence and distributions. The most consistent conclusions drawn from projections of changes in spatial distributions and vulnerability of plant communities and species due to changing climate agree that subalpine, alpine, and tundra communities and species will decline or disappear (Shafer et al. 2001, Nielson et al. 2005, Rehfeldt et al. 2006, Aubry et al. 2011, Coops and Waring, 2011). Aubry et al. (2011) also predict that wetland communities will be vulnerable to climate change. Finally, MORA may, in the future, experience an increase in the area burned by wildfires as a consequence of climate change. The fire season will be longer, given that summer temperatures are expected to increase and snowpack levels decrease with climate change (Mote et al. 2005).

6.2 Natural Resource Condition Summaries

6.2.3 Air Quality and Air Quality-related Values

The assessment indicates that the condition of ozone is presently of low concern; the condition of visibility is of moderate concern; and the conditions of nitrogen-sulfur (N-S) and persistent bioaccumulative toxics (PBT) deposition are of serious to significant concern. Assessed data (2000–2009) indicate that the trend in ozone concentration has been improving at MORA, and there is presently low risk of ozone-induced foliar injury. During the period 2000–2009, the NPS Air Resources Division reported a significant improvement in visibility at MORA. The average haze-index (2008–2012), however, indicated that MORAs current visibility was still 54% hazier than natural conditions. Wet deposition data for the period 2000–2009, indicated improving trends in N and S deposition, although Sullivan et al. (2011a, 2011b) determined that MORA was at high risk for surface water acidification and N enrichment (also see lake water quality). Multiple PBTs have been detected at MORA including: mercury; dieldrin; current- and historic-use pesticides; combustion by-products; industrial chemicals and metals; and flame retardant chemicals. PBTs have been detected in snow, sediment, and vegetation samples, and the concentrations of mercury and other contaminants in MORA fish have been determined to exceed human and wildlife health thresholds. The concern level for future condition is significant (Table 66).

6.2.4 Lake Water Quality

MORA lakes, overall, can be rated as being minimally disturbed by non-stochastic natural perturbations or human activities. However, 25 lakes have been identified as being of management concern, and 9 of these lakes have been ranked as being at moderate to high risk of impairment due to non-stochastic natural perturbations or human activities; 4 lakes are considered threatened. MORA lakes are predominantly oligotrophic, and identified changes in water quality parameters occur below the upper threshold for this trophic state. Lakes tend to be low in productivity and nutrient concentrations, and either nitrogen limited (58 of 127 lakes analyzed) or co-limited (nitrogen-phosphorus; 61 of 127 lakes). The lakes have low ion concentrations and tend to be poorly buffered, which makes them susceptible to acidification and atmospheric deposition of nutrients and pollutants. Zooplankton and macroinvertebrates are limited in occurrence and distribution, and many individual taxa tend to each be present in a relatively small number of lakes, which act as refuges for numerous localized taxa occurring across the MORA landscape. Finally, although the temporal length of surface water temperature measurements is short (i.e., maximum 7 yrs) and collected from a small number of lakes (i.e., 9), it appears that the timing of ice-out in some MORA lakes is occurring later in the snowmelt and ice-out period (mid-May through mid-August). As noted above, multiple PBTs have been detected in MORA lakes and Sullivan et al. (2011a, 2011b) determined that MORA surface waters are at high risk for acidification and N enrichment.

6.2.5 Stream Water Quality

The MORA streams and rivers examined in this assessment were found to be generally in good condition relative to the environmental characteristics of the watersheds and landscape within which they are embedded. Comparison of ion concentrations at 6 MORA stream and river sites with ion concentrations at 5 western USGS Hydrologic Benchmark Network water quality stations indicated that the MORA ion concentrations fit well within the overall variability of ion concentrations among all of the sites. Based on water quality standards for surface water dissolved oxygen, pH, and water temperature developed by Washington State, 29 MORA sites assessed for each parameter were classified as being in extraordinary condition. Disturbance thresholds for concentrations of conductivity, total nitrogen, and total phosphorus developed as part of the EMAP assessment of western streams and rivers were also used to assess the condition of the 29 MORA sites. The primary disturbance categories are most-disturbed and least-disturbed. Based on the thresholds for mountain systems for each category and parameter, each of the MORA streams with conductivity and total nitrogen concentration measurements could be categorized as least-disturbed; whereas for sites with total phosphorus concentration measurements, 19 could be categorized as moderately- to most-disturbed. Streams, however, can naturally acquire substantial quantities of phosphate from minerals in bedrock and subsoil. So, although these sites could be categorized as moderately- to most-disturbed based on their total phosphorus mean concentrations, these higher levels are derived naturally and naturally occurring phosphorus concentrations are rarely acutely or chronically toxic. Eighty streams were sampled for macroinvertebrates (2004–2006), and used to develop a preliminary impairment prediction model based on macroinvertebrate O/E scores. Forty-five of these streams were used as assessment sites. Model analysis determined that all of the streams were potentially impaired. However, the O/E scores for 40 of the streams (89%) were either below the range or within the range of O/E scores for the reference streams (20), indicating that only a small percent of the streams evaluated by this model appear to be impaired beyond the baseline calculated for the reference streams. An important caveat is that ≥51% of wadeable stream and river catchments of management concern have been ranked as being of moderate to high risk of impairmanet based on human activity and water quality associated metrics, and 14 of these catchments have been ranked as threatened. The assignment of a level of serious concern for stream temperature and flow in Table 66 (above) reflect the potential effects of climate change on these parameters.

6.2.6 Landscape-scale Vegetation Dynamics

There are 31 vegetated map classes in MORA, indicating that park vegetation is quite diverse. None of the classes are globally threatened, but 4 riparian-swamp associated classes are ranked between vulnerable (G3) and apparently secure (G4) based on the status of the corresponding Ecological Systems classification for each. Several forest types are rare in the park and may therefore be of management concern. The forest types include Western Hemlock-Douglas-fir forest (both wet [M043] and dry [M044]), Dry Subalpine Forest and Woodland (M012), Conifer Shrubland (M015), and Subalpine Fir–Whitebark Pine Woodland (M017). There is presently no description of trends in park-wide vegetation pattern, although a preliminary park-wide vegetation map has recently been completed and can serve as a eline for assessing potential future changes.

6.2.7 Forest Health: Disturbance Regime

MORA forests and the forest buffer surrounding the park have experienced relatively widespread damage since 1985 caused by native and introduced insects (95% of damage in MORA), physical disturbances (4.3%), diseases (0.3%), and unknown causes (0.3%). Most of the damage has occurred at lower elevations and along the drier eastern side of the park, although damage has increased in the western part of the park in recent years. Glacial watersheds may undergo increased levels of disturbance, such as increased debris flows, that may affect forest health as a result of changes in glaciers.

6.2.8 Forest Health: Whitebark Pine and White Pine Blister Rust

Subalpine Fir-Whitebark Pine woodland covers 1133 ha (2800 ac) or 1.2% of MORA. It occurs at high elevation on all aspects of the park, but is most dense in the northeastern region. Based on field data collected from permanent plots in 2009, greater than a quarter of mature Whitebark Pine are infected with blister rust and mortality is 52%, and 43% of saplings are infected. According to the U.S. Fish and Wildlife Service finding regarding listing of Whitebark Pine under the Endangered Species Act, the species is experiencing an overall long-term pattern of decline. On a landscape scale, Whitebark Pine appear to be in danger of extinction, potentially within as few as 2 to 3 generations (generation time = approximately 60 yrs).

6.2.9 Forest Health: Air Quality Effects

Lichen samples were used to assess the potential effects of nitrogen (N) and sulfur (S) compounds on MORA vegetation. MORA lichen communities were determined to contain all expected sensitive species, indicating that N and S concentrations were not elevated above background levels typical of remote areas. Ozone concentrations in MORA have exceeded what are considered to be elevated levels (> 80 ppb) at various times, especially in the late 1980s and early 1990s. Brace and Peterson (1998) determined that ozone concentrations increase with elevation and are higher on the west side of the park. Even though ozone levels higher than 60 ppb have been known to harm vegetation, systematic evaluation of Subalpine Fir and Black Cottonwood in MORA have produced no evidence of damage; however, damage to Ponderosa Pine has been observed in Pack Forest, just outside of the park, and is hypothesized to have been caused by an ozone-sulfur dioxide synergism. Concentrations of all SOCs measured in samples of lichens and conifer needles from MORA were at or above the median values for the 20 western national parks sampled by WACAP. Typical of results across all parks, pesticide and PCB concentrations in the lichens sampled in MORA increased with elevation. Because needle productivity is high, the ecological effects of cumulate SOCs contributed by needle litterfall are a potential concern. Mercury levels in MORA were at or well above the concentrations observed at the other western parks in the WACAP study; however, the WACAP parks did not have higher levels of mercury than expected of remote areas in the western United States.

6.2.10 Fire Ecology

Using data from Hemstrom and Franklin (1982) and NPS fire records after 1978, we calculated the following natural fire rotation (NFR) for MORA: 109-yr reconstruction + fire record (1900–2009) = 4553 acres (183 ha) burned, 3207-yr NFR for the forested area. We also calculated the NFR for all vegetation types in MORA as: 80-yr period (1930–2009) of NPS records = 5003 ac burned, 2923-yr NFR. The NFR calculated from the reconstruction with additions from the fire records indicates a substantial departure from the pre-settlement NFR of 465 yrs, and the reference condition calculation for the modern fire suppression era (2583-yr NFR). All of the modern fire suppression era calculations suggest that fire suppression has had some impact on the natural fire rotation of MORA and that the natural fire rotation at MORA has been attenuated by fire suppression. There is no indication, however, that fire suppression has or will cause an unnatural accumulation of dead and downed fuel at MORA. The natural fire rotation is sufficiently long to accumulate and maintain large quantities of coarse woody debris; therefore, there is little to no additional effect due to fire suppression. Future climate change in the eastern watersheds of the park, however, may result in the increased availability of large fuels resulting in a shortening of the natural fire rotation in this area of the park.

6.2.11 Biodiversity: Exotic Plants

152 non-native plant species have been observed in MORA; 51 of these species have location information. Of the 152 species, 26 are classified as noxious by Washington State, and are considered to be threatening to park resources. Based on a reference condition of zero non-native species, the presence of 152 non-native species indicates a substantial increase in the invasion of non-native species into MORA.

6.2.12 Biodiversity: Wetlands

The MORA wetland map based on NWI data identifies 1636.6 ha (4045 ac) of wetlands including 279 ha (689 ac) of lakes and ponds. Wetland types include riverine wetlands, freshwater emergent wetlands, and freshwater forested/shrub wetlands. This compares with 4245.3 ha (10,490 ac) of wetland vegetation mapped by the MORA vegetation map. The 2 maps differ in that the NWI description of wetlands is more limited to fluvial areas and impoundments while the wetland vegetation classes describe a wider riparian influence and palustrine areas. At present there is no information to describe wetland trends in MORA. Nationally, factors causing losses in wetlands include agriculture, forested plantations, rural development, urban development, and other land uses, while restoration and conservation have resulted in wetland improvement. Predicted climate change, however, will potentially affect the aerial extent and depth of wetlands and wetland dependent species. The net effect of these changes is difficult to predict, but modeled montane wetlands show earlier and more rapid drawdown, lower water levels, and a longer dry season in summer in response to projected climate change. The effects are expected to be greatest for intermediate wetlands (those that dry in late summer or early fall in years with low precipitation) because they are shallow and are highly sensitive to summer water availability.

6.2.13 Biodiversity: Subalpine Vegetation

The MORA landscape comprises 23.4% of vegetation classes that span the ecotone from the upper edge of continuous forest, through tree clumps and krummholz, to alpine meadows. Subalpine habitat (meadows and forests) occur at 1200 m (3937 ft) to 1500 m (4921 ft.) all around the park. We detected no dramatic changes in tree distribution upon examining time series of aerial photography and satellite imagery for 2 subalpine meadows on the west side of MORA over the period 1959 to present. New tree patches and in-filling of meadows, however, were apparent in Van Trump Park from 1951 to present. The images from Van Trump Park correspond to the study of Rochefort and Peterson (1996) showing continuous recruitment in west-side meadows since 1930, attributed to warm dry summers, which lengthen the growing season in this area with high annual snowpack. These results correspond to other studies showing increasing tree establishment in subalpine meadows elsewhere in the Pacific Northwest, and the observation that increases in tree density are a potential impact of climate change.

6.2.14 Biodiversity: Sensitive Vegetation Species

There are currently 8 species having a state conservation rank of ‘vulnerable’ or higher among species documented to occur in MORA; 6 have state sensitive status while 2 have watch status. In addition, of the 8 species, 2 are considered globally vulnerable to imperiled (*Castilleja crypthantha*, *Pedicularis rainierensis*). Both of these species occur in subalpine areas and were thought to be endemic to MORA, but have also been documented outside of the park boundary. Several surveys of non-vascular plants and macrofungi have been conducted in localized areas of MORA. Although these efforts are limited, surveys discovered several lichen species that are listed by Washington, are globally vulnerable, or were identified as rare. Five additional species besides are listed as species of management concern for MORA. *Agoseris elata* is listed as sensitive by WNHP and there is an historic record of it in MORA (WNHP website). Although it was targeted with field surveys in 2011, it has not been relocated. *Carex atrosquama* (syn *Carex atrata* var. *atrosquama* (Mackenzie) Cronq.) is no longer listed by WNHP, and Biek (2000) indicates that the voucher for this species from the park actually misapplied the name to *Carex spectabilis*. It was not located during the survey conducted in 2011. *Dryopteris cristata* is on the species list for the park, but is unlikely to occur there (Biek 2000). *Poa nervosa* is currently considered to be a rare plant of the lower Columbia gorge. The 2 vouchers from MORA were collected in the 1890s and are of *Poa wheeleri*, which is not listed by WNHP. *Pinus albicaulis* has been proposed for listing under the federal Endangered Species Act and is also subject to White Pine blister rust. Finally, *Thuja plicata* and *Xerophyllum tenax* are of concern because they are both of cultural importance to tribes for basketry. Among the sensitive species documented as occurring in MORA, none have been elevated in status since 1997, while 2 have been downgraded from sensitive to watch and 1 has been removed from the list. Improved status is most commonly due to the location of previously unknown populations. There is insufficient information to describe trends in non-vascular plants and macrofungi.

6.2.14 Amphibians

All amphibian species with a reasonable potential to occur in MORA have been detected in the park with perhaps 1 exception, the Cascade Torrent Salamander (*Rhyacotriton cascadae*). This species is found to the southwest of the park, and although stream surveys have been thorough, not enough of them have been conducted to allow us to determine with complete certainty that the species does not occur in the park. Four species have relatively limited distributions within MORA, and none are endemic to the park. The main species for which there is some concern regarding their conservation status are Cascades Frogs and Western Toads. The concern for these species is due to declines in other parts of their range rather than any information that they are declining in MORA. There is also reason for concern about the conservation status of Van Dyke's Salamanders and, especially, Larch Mountain Salamanders due to their limited distributions inside and outside of the park. Because of potential declines or limited range, these 4 species are likely a higher priority for future monitoring. In addition, predicted climate change effects are cause for concern for wetland dependent species such as amphibians, as well as for the potential of an increase in diseases and pathogens that affect them. Predicted temperature increases may also affect terrestrial breeding species. High levels of mercury in wetland and lacustrine habitat also threaten aquatic breeding amphibians.

6.2.15 Fish Species in Streams and Lakes

Fourteen fish species have been confirmed as present in MORA streams and lakes. In streams, 9 species are native, 1 species is an introduced native, and 2 species are introduced non-natives. In lakes, 6 species are introduced natives and 1 species is an introduced non-native. Several species have been identified as species of special conservation or management concern at the federal and state levels. In particular, Bull Trout, Chinook Salmon, Coho Salmon, Sockeye Salmon, and Steelhead have all been identified as threatened or endangered, at least partially within their ranges, by the U.S. Fish and Wildlife Service, and as state candidates of special concern by the Washington Department of Fish and Wildlife. Although not necessarily threatened and endangered within MORA, these species, because of their partial range conservation status, would most likely warrant a higher priority for future monitoring. MORA streams and rivers also are included as "essential fish habitat" (EFH), as defined by the Magnuson-Stevens Act, for Chinook, Coho, and Pink Salmon. Climate change predictions will have significant effects on stream temperature and flow, especially in glacial systems. Cold water dependent and anadromous species such as Bull Trout and salmon species are most at risk. All fish species present in MORA lakes were originally stocked, and the populations that remain in 37 of the lakes after stocking was discontinued after 1972 represent populations that were able to establish some level of natural reproduction. Their continued presence in lakes could potentially affect native populations of amphibians as well as zooplankton and aquatic macroinvertebrate assemblages.

6.2.16 Land Birds

There are >175 bird species in MORA according to the NPSpecies database. Because of the large number of species that occur in the park, we focused this assessment on 48 bird species of management concern because management and monitoring of all species is logistically infeasible. We categorized the 48 bird species into 4 groups, based on frequency of occurrence in the park and the data available for assessing the status of each: (1) regularly occurring, well sampled species (n = 15); (2) species that occur in the park but are difficult to detect and not well sampled (n = 12); (3) detectable species that occur infrequently in the park (n = 6); and (4) species unlikely to occur regularly in the park (n = 15). Of the 15 species in group 1, 8 are estimated to be in decline in MORA, 6 are apparently stable, and 1 is likely increasing. The 12 species in group 2 are difficult to sample for a variety of reasons. Many occur at low densities, either because they are extremely wide-ranging or because they are associated with unique, localized, or remote habitat; and some species are not amenable to sampling with the point count methodology used for other passerines because they are non-territorial and occur in flocks. MORA, however, may represent important habitat for most or all of these species, but an assessment of status and trends within the park would require special survey efforts. Although MORA is within the geographic range of all 6 species in group 3, they occur in low abundances in the park and MORA may provide only small amounts of suitable habitat for them. For the 15 species in group 4, MORA is peripheral to their current geographic ranges or lacks suitable habitat for the species in this group. These species were not detected during NCCN surveys, and few if any records of occurrence in the park exist for them. The well-established NCCN avian inventory and monitoring program is a tremendous asset that provides critical information about the status of many land bird species to park managers. Declining populations of forest-associated birds, including both rare and common species, is an overarching issue for bird conservation efforts in the Pacific Northwest. Habitat loss and degradation, often in the form of forest fragmentation, are major threats implicated in many population declines. MORA represents an important refuge and stewardship opportunity for forest-associated bird species because it supports large tracts of unmanaged, late-seral, coniferous forest habitat which has become increasingly rare in the region as a result of intensive forest management. Direct and indirect effects on birds can be expected with climate change. Changes in temperature and precipitation regimes are expected to cause changes in bird distributions. Species at the margins of their geographic ranges may be most susceptible to changes in status within the park. In addition, contaminants such as mercury are a concern for insectivorous species in wetland and lacustrine habitats (see air quality discussions).

6.2.17 Mammalian Fauna

Up to 58 native mammal species may currently reside during some or all of the year in MORA, based on documentation in NPSpecies and the published literature we reviewed. MORA appears to have retained most of the mammal species historically present in the park, except for the notable absence of 5 carnivores: Canada Lynx, Fisher, Gray Wolf, Grizzly Bear, and Wolverine. Three groups of mammals, carnivores, Elk, and bats have been separately assessed. MORA lands alone do not provide adequate habitat to maintain viable populations of many of the larger mammal species, but are valuable for those species in a regional context. MORA anchors 1 high point in a network of protected lands, so the park is important for population connectivity for many mammals in the region. Although MORA is a relatively small park compared to the surrounding federal land holdings, the subalpine parklands, lower elevation forests, and extensive riparian habitats in MORA serve as important habitat in the conservation of many mammalian species in southern Cascade Range ecosystems. With the exception of several of the larger carnivores, the mammalian fauna in MORA is intact, and there are negligible known populations of exotic mammalian species. We conclude that the current status of mammalian biodiversity is close to the Minimally Disturbed reference condition, but that the loss of the extirpated carnivores has very likely affected populations of the remaining mammalian species.

6.2.18 Glaciers

There are 143 glaciers and permanent snowfields on Mount Rainier with a total area of 83.3 km2 (32.2 mi2); 27 of these are named glaciers. Total ice volume on the volcano is an estimated 4.4 km^3 (1.1 mi^3). The temperate glaciers at MORA are valuable as sensitive, dramatic indicators of climate change and are themselves ecosystems that are linked to larger alpine food webs. They are the sole habitat for some species such as the Ice Worm, which is preyed upon by Rosy Finches and other alpine species. Glaciers are also valuable to park aquatic ecosystems, downstream municipalities, and regional ecosystems and industries because they provide vast quantities of cold, fresh melt-water during the hot, dry summer months. Glacier area and cumulative net mass balance (volume) are decreasing rapidly at MORA due to increasing temperature and decreasing snowfall. The amount of recession between 1913 and 2007 is approximately 24.3 km^2 (9.4 mi^2) or 21%. The areal change pattern for the last century, however, includes a brief, modest period of glacier growth in the middle part of the 20th century that slowed but did not reverse the long-term trend. The pattern of retreat is dominated by down-wasting of the ice surface, with retreat of the glacier terminus (back-wasting) less perceptible. Decrease in the proportion of the park covered by glaciers over the last century is lower than for other glaciated mountain ranges in the region. For example, in the 20th century glacier area declined about 57% at Olympic National Park and 44% at Garibaldi Provincial Park. The reasons for the lower apparent rate of glacial extent change at MORA are that the glaciers extend to more favorable climates above 3000 m (9843 ft) and have extensive debris cover, which has slowed surface melting of parts of the glaciers by 75% between 2003 and 2010. Based on the mass balance trend, glaciers at MORA appear to be thinning more rapidly than they are decreasing in area. Predicted climate change effects will significantly affect park glaciers and the timing of glacial streamflows and stream temperature.

6.2.19 Soundscape

Visitors to national parks often indicate that an important reason for visiting the parks is to enjoy the relative quiet that parks can offer. Sound plays a critical role in intraspecies communication, courtship and mating, predation and predator avoidance, and effective use of habitat. Studies have shown that wildlife can be adversely affected by sounds and sound characteristics that intrude on their habitats. Natural ambient sound levels measured at the 8 MORA sites ranged from 20.5–47.3 dBA during the day, and 14.1–48.4 dBA at night within the 20–1250 Hz frequency band, representing a very quiet acoustical environment. Although natural sounds predominate throughout the park, human-caused noise has the potential to mask these sounds. Examples of human-caused sounds heard in the park include aircraft (i.e., high-altitude and military jets, fixed-wing aircraft, and helicopters), vehicles, generators, and visitors. At backcountry sites aircraft were the most pervasive non-natural sound sources, audible between 3% and 23% of the day (07:00 to 19:00), mostly caused by high altitude or military jets, except at Sunrise Ridge and Crystal Mountain where fixed-wing aircraft and helicopters were heard more frequently. At the frontcountry sites, Trail of Shadows and Nisqually Corridor, vehicles were the most pervasive non-natural summer sound source, audible 43 and 61.6% of the day, respectively. At Trail of Shadows in the winter, generators were the most commonly heard human-caused sound, audible 70% of the day. Despite the presence of various human-caused noise intrusions, natural sounds can be heard at all sites between 56 and 96% of the day, and these natural sounds make for a rich and spectacular acoustical environment at MORA. Increased noise from motorcycles, commercial and military air flights, as well as increased general recreational use are of future concern.

6.2.20 Dark Night Skies
The resource of a dark night sky is important to the National Park Service for a variety of reasons: (1) preservation of natural lightscapes will keep the nocturnal photopic environment within the range of natural variability; (2) a natural starry sky absent of anthropogenic light is a key scenic resources, especially in large wilderness parks remote from major cities; (3) the natural night sky is an important cultural resource, especially in areas where evidence of aboriginal cultures is present; (4) dark night skies is an important recreational value to campers and backpackers, allowing the experience of having a campfire or "sleeping under the stars"; and (5) night sky quality is an important wilderness value, contributing to the ability to experience a feeling of solitude in a landscape free from signs of human occupation and technology. The night sky as seen from MORA is impaired by anthropogenic sky glow from the large metropolitan areas of Seattle, Tacoma, and Olympia. At the 2 park measurement sites, sky luminance and illuminance from anthropogenic sources is seen to be about twice as high at Burroughs Mountain than at Plummer Peak. However, both sites are given Bortle Class 4, indicating that even at the darker site the impairment from city light domes is quite significant. Overall, the night sky quality of MORA is impaired significantly, primarily from sky glow originating in the major cities 50–150 km (31–93 mi) distant, and all measures of sky quality exceed the reference condition for natural night skies. At best, visitors to MORA looking for a view of the natural night sky will be disappointed if they consider the entire celestial hemisphere. An increase in sky glow in the Puget Sound region will likely be due to predicted population growth.

6.3 Main Resource Threats and Emerging Issues
There are 4 major fundamental threats that are now and will in the future affect the continued persistence and viability of the natural resources and ecosystems of MORA. They are: (1) climate change; (2) the continued atmospheric deposition of nutrients and pollutants; (3) the presence and emergence of pests and pathogens; and (4) introduction and range expansions of non-resident native and non-native plant and animal species.

6.3.1 Climate Change
Climate change will affect all ecosystems of MORA natural resources. One fundamental outcome of climate change will be later patterns and variability of precipitation events and temperature, which will result in degraded water quality. Diminished water quality will affect biotic species and

assemblages (i.e., zooplankton, aquatic insects, amphibians, and fish) in lakes and streams, and changes in flow regime as well as decreased quantity and availability of water could lead to the decline or loss of wetland, lake, and stream habitats. Changes in climate will also intensify the effects of floods and droughts, and the capacity for sustaining natural lotic ecosystem services (Covich 2009). The impact of climate change on glaciers and snow precipitation will affect the overall availability of water, potentially increasing demands for water and conflicts related to its use, as well as complicating the ability of resource agencies such as the NPS in managing aquatic ecosystems (Everest et al. 2004). Climate change will also likely affect water quality due to perturbations such as glacial recession, increases in debris flow events and sedimentation, and changes in the timing of snowmelt and runoff. Shifts in the spatial and elevational distribution of forest communities and species will occur as a response to changes in precipitation and temperature; and subalpine, alpine, and tundra habitats will most likely shift upward in elevation as well as decline with a concomitant loss of some vegetation communities. Although predictions for individual species are variable and difficult to interpret at the spatial scale of the park, the conclusion of Rehfeldt et al. (2006) that by 2090 most of the park will have a different biotic community than today may be general enough to be accurate, although this may be truer for understory communities rather than the long-lived overstory forest component. In general, warming climate is predicted to increase the effects of forest insects (Dale et al. 2001, Bentz et al. 2010) and diseases (Sturrock et al. 2011), primarily through climate-induced increase in host stress, decreased limitations on pest survival, or both. The role of forest and plant pathogens is also expected to increase due to climate change because most disease agents will adapt faster than their hosts (Sturrock et al. 2011). Changes in climate may also result in the increased availability of fuels and thus change the potential natural fire rotation in some areas of the park further altering plant communities and species distributions. As the distribution, structure, and composition of forest and plant communities change in response to climate change, so too will the presence and distribution of bird species that rely on these ecosystems for persistence and survival. Species at the margins of their geographic ranges may be most susceptible to changes in status within the park. However, other species with already restricted ranges or currently declining population trends may also be vulnerable to climate change effects. Mammals, too, will be affected by climate change, especially species that occupy higher elevation, subalpine, and alpine habitats. Climate change associated disturbances resulting in habitat loss and fragmentation, reduced snowpack and duration of snow, and increased range expansion of lower elevation species will likely impact species that are adapted to, occupy, and rely on higher elevation habitats, such as occur in MORA, for their survival (e.g., Canada Lynx, Cascade Red Fox, Hoary Marmot, Mountain Goat, Pika, Snowshoe Hare, and Wolverine).

6.3.2 Atmospheric Deposition

The continued deposition of nutrients and pollutants from local, regional, and global sources will contribute to the degradation of MORA ecosystems. Despite improvements due to the Clean Air Act, nitrogen emissions are expected to increase by 2020 due to population growth (Schary 2003), regional ozone and NOx concentrations are predicted to increase through trans-Pacific transport concomitant with population and standard of living increases in Asia (Bertschi et al. 2004), atmospheric pollutants are predicted to increase due to a number of anthropogenic pressures, and increasing energy needs are likely to negate air quality gains regarding acidifying and oxidizing pollutants (Dahlgren 2000). One definite effect of these increases and their deposition will be a decrease in the water quality of aquatic ecosystems. All MORA lakes are generally oligotrophic as a consequence of their low productivity and nutrient concentrations, and have low ion concentrations that make them poorly buffered and susceptible to acidification and potential change in trophic status due the atmospheric deposition of nutrients and pollutants. The cascading effects of increasing concentrations of nutrients and pollutants leading to diminished water quality and changing trophic status will subsequently affect aquatic biotic species and assemblages. The effect that atmospheric deposition of nutrients and pollutants will have on vegetation is still relatively unclear. However, ozone damage to sensitive species will eventually become evident; lichen communities are expected to shift to nitrophilous or pollution tolerant species (Fenn et al. 2003, Geiser and Neitlich 2007) with consequent loss of species diversity; and biomagnification of semi-volatile organic compounds and mercury, although they may not directly affect the plants where they collect, may spread by leaching or burning to affect other parts of ecosystems (Friedli et al. 2003, Landers et al. 2008). In general, continued deposition of nutrients and pollutants will potentially affect vegetative components such as soil microbe and mycorrhizal fungi composition and function, alter plant resistance to insects and pathogens, change or disrupt plant growth, and increase the potential for acid rain and acidification of terrestrial habitats. The ultimate outcome will be changes in and degradation of the present terrestrial habitats and their floral structure and diversity, and the species that will have a competitive advantage with increased nutrient levels (N and P especially) will include many of the non-native invasive plant species, and may increase the potential distribution of these species. Land birds and mammal species and assemblages occupying these habitats will also be affected.

6.3.3 Pests and Pathogens

Pests and pathogens have always affected biotic species and have contributed at least minimally to the destabilization of ecosystem composition and structure. This has been considered a necessary part of the process, and a component of species life history and persistence. However, changes in climates and the rates and concentration levels of atmospherically deposited nutrients and pollutants are thought to be contributing to an increase in the frequency of occurrence and intensity of the effects of pests and pathogens on species and ecosystems, even in protected landscapes such as national parks and wilderness areas. Presently, one-third of amphibian species worldwide are thought to be in decline (Adams et al. 2013). Amphibian species and populations are affected by changing climate, the deposition of contaminants, the introduction of introduced species, habitat degradation and loss, and emerging diseases. Two of these diseases are chytridiomycosis, caused by the fungal pathogen *Batrachochytrium dendrobatidis* (Bd), and a viral infection caused by ranavirus in the family Iridoviridae. Although their effect and the susceptibility of individuals and populations is highly variable and not well understood, both diseases are affecting amphibian populations worldwide, even in protected area. Mammal and bird populations, in the future, could also be affected by the emergence of new parasites and pathogens. White Nose Syndrome (WNS), for example, is a new fungal pathogen apparently native to Eurasia that kills hibernating bats. WNS has severely reduced bat populations of many species in the northeast USA since around 2008, and it appears to be steadily spreading west (Blehert et al. 2011). Wild ungulate populations that move over wide areas may be more susceptible to pathogen spread than more sedentary mammal species. Certain diseases and pests pose known risks to Elk (e.g., Chronic Wasting Disease, and others), and Deer (e.g., Hair

Loss Syndrome, Epizootic Hemorrhagic Disease, and others), and we can expect the emergence of additional pathogens and pests in the future. Birds in the Pacific Northwest also are being affected by disease, including Avian Influenza (Fuller et al. 2010) and West Nile Virus (Scott et al. 2008).

6.3.4 Introduced Non-Native Invasive and Range Expanding Native Species

The introduction of non-native invasive species and the range expansion of native species, together with habitat loss and changes in climate are considered to be the major drivers of global environmental change (Pejchar and Mooney 2009). Introduced species have the potential for: altering how ecosystems cycle nutrients and energy; changing food web structure and dynamics; and causing decline or loss of native biotic species and assemblages, leading to reduced biotic diversity. Introduced fish are known to diminish the presence of or extirpate amphibian (Pilliod and Peterson 2001, Hoffman et al. 2004) and other aquatic species and populations (Knapp et al. 2001; Parker et al. 2001) in montane lakes, and range expansions of non-resident native species (e.g., Barred Owl-Spotted Owl interactions in the Pacific Northwest) can affect the presence and continued survival of resident native species. Migratory bird and bat species also can be affected by threats to their persistence and survival (e.g., wind-turbines, habitat degradation and loss; habitat fragmentation; deforestation; presence and persistence of herbicides and pesticides, and others) outside of the park. Some native species seem to be expanding their range and abundance (e.g., Western Juniper, White Fir, Reed Canary Grass), but these changes are also in response to human-induced ecosystem changes such as direct and indirect fire suppression, logging practices, nutrient pollution, and disturbance of wetlands. Introduced species, especially plants, may also expand into areas where previously climate has limited their distribution. At present in MORA, the primary effects from species introductions and range-expansions are associated with introduced fish in lakes, the range expansion of Barred Owls, and the presence of many species of invasive non-native plants.

6.4 Information and Data Needs–Gaps

An impressive amount of research, inventories and surveys, and monitoring of MORA natural resources have been conducted by park staff, as well as by university, state, and federal scientists, and non-profit agency cooperators. This effort spans decades, and the results have been reported in various types of reports and factsheets, presented at symposia and conferences, and published in peer-reviewed scientific journals. Much of this information has been reviewed and synthesized as a part of this assessment. One of the objectives of the assessment was to identify future data needs that could help park management plan for and focus future sampling effort, and fill data gaps that would complement already gathered information and further enhance existing knowledge of the park's natural resources. A general summary of the information gaps and data needs identified by this assessment is presented in Table 68. We also include information needs and data gaps associated with resources not addressed in this assessment at the end of Table 68. A more detailed discussion of information gaps and data needs for specific resource categories is available in Chapter 4 for each assessed natural resource.

Table 68. Recommendations for critical information gaps and data needs.

Resource Category	Information Gaps and Data Needs
Air Quality and Air Quality-related Values	• Continue visibility monitoring. • Additional information is needed about both the amount of deposition and the sensitivity of AQRVs to improve critical load estimates for nitrogen and sulfur, • with follow up on previous deposition studies (Geiser et al. 2010, Sheibley et al. 2012, Agren et al. 2013, Fenn et al. 2013) to collect additional information about total nitrogen and sulfur deposition loading and the sensitivity of park resources to deposition. In particular, studies are needed to evaluate the response of high elevation lakes to elevated nitrogen deposition. • Ozone monitoring should continue in the park to provide data for monitoring trend. Ozone levels are expected to increase with temperature warming. • More information is needed about the amount of and trends in deposition of Hg and other PBTs. • More information is needed about the extent of air toxics occurrence and bioaccumulation in the park. Along with this, more information about wildlife health thresholds and sensitive life stages for a number of pesticides and other air toxics is needed to evaluate impacts. • Studies to evaluate the risk of Hg methylation in different habitats and measuring Hg concentrations in fish, amphibians, aquatic invertebrates, and songbirds should continue.Hg levels in songbirds should be monitored to develop a better understanding of the geographic regions, climates, and habitats that are at risk to Hg exposure. • Quantify landscape factors that drive Hg levels in aquatic and terrestrial indicator species; evaluate the potential effects of climate change on Hg availability and subsequent exposure in park wildlife; and investigate whether current wildlife exposure to Hg in the park is causing toxicological responses to sensitive hormones associated with endocrine disruption; use this information to identify areas where risk is greatest and by assessing the important factors controlling mercury bioaccumulation, targeting efforts to mitigate Hg contamination through species conservation efforts for species at risk. • Further research is needed regarding the effects of black carbon on snowpack and glaciers in the park. • Sensitive vista points should be identified in the park that includes views extending beyond NPS boundaries. For each of these vista points it would be beneficial to: (1) assess the existing and desired future conditions of the visual setting; and (2) prepare a visibility analysis including photo documentation and a description of the view, surrounding land use (existing and planned), the general level of visitor use, and importance to the visitor experience. • Campfire smoke monitoring should be conducted in Cougar Rock and White River Campgrounds. • It is critical to better understand the interaction between air pollution and climate change in the Pacific Northwest.
Lake Water Quality	• Data should be organized and consolidated into a single database with categories or components for physical, chemical, and biological characteristics that can be linked for analysis. • All site and sample labels should be made consistent for all years and for the metrics of all measurements and concentrations should be clearly identified and defined. • It would be advantageous to continue to measure air and water temperatures and water level at core lakes, expanding to additional lakes whenever possible. • Collect data from selected lakes to examine the possible presence of air-borne contaminants and pollutants. • Analysis of lake riparian disturbance surveys should be completed. • It would be beneficial to more intensively sample and monitor a representative subset of wetlands. • Conduct studies to evaluate the risk of Hg methylation in different lake and pond habitats; measuring Hg concentrations in fish, amphibians, and aquatic invertebrates should continue. • Assess landscape factors important in controlling Hg concentrations in MORA lakes and wetlands (factors that drive Hg production and bioaccumulation within and between aquatic and terrestrial foodwebs). • Complete analysis and report on use of macroinvertebrates for the assessment of impairment of water quality and biological integrity in MORA lakes. • Continue to implement the NCCN WQ protocol for the collection of core WQ parameters as mandated by the NPS WRD. • Consider some level of monitoring for fecal indicator bacteria in water relative to the potential effects on visitors and their recreational use of park water resources.

Table 68. Recommendations for critical information gaps and data needs (continued).

Resource Category	Information Gaps and Data Needs
Stream Water Quality	• Stream water quality data should be combined into a single database and the metrics of all measurements and concentrations should be clearly identified and defined. • Data about the hyporheic zone of streams and rivers is limited, and an effort should be made to increase the available information for this important lotic habitat. • Placement of continuous temperature data loggers in selected streams and rivers would contribute useful information about the potential effects of climate change on the temperature environment of these lotic systems. • Monitor streamflow in selected streams and rivers to gain information about the potential effects of climate change on timing and amount of flow. • Expand the number of stream and river sites monitored annually for water chemistry, temperature, and benthic macroinvertebrates, and target headwater streams for which no baseline data exist (current NCCN water quality program focuses only on 6 potentially disturbed sites). • Complete analysis and report on developing reference site data for monitoring bological iIntegrity and water quality of streams. • Continue to implement the NCCN WQ protocol for the collection of core WQ parameters as mandated by the NPS WRD. • Consider some level of monitoring for fecal indicator bacteria in water relative to the potential effects on visitors and their recreational use of park water resources.
Landscape-scale Vegetation Dynamics	• The use of remotely-sensed data to predict landscape-scale changes in vegetation dynamics could be quite useful for making predictions regarding changes in distribution of species and communities as well as locations of potential refugia where species might be assisted to migrate.
Forest Health: Disturbance Regime	• Develop mechanistic models that describe the effects of climate changes on disturbance agents and tree physiology for predicting future changes due to the affects of these agents. • Monitor regeneration in forests following disturbance to determine if changes in tree species ranges and distributions are changing in response to climate change.
Forest Health: Whitebark Pine and White Pine Blister Rust	• Continue to monitor blister rust infection rates and the occurrence of Mountain Pine Beetles, as well as identify blister rust-resistant genotypes of Whitebark Pine that may be used for restoration in the future. • Continue to monitor Whitebark Pine regeneration to evaluate status of individual populations and to identify sites where active restoration programs are needed.
Forest Health: Air Quality Effects	• Implement routine monitoring of contaminants in air and vegetation needs to be implemented to better elucidate the relationships among contaminant levels in air with levels in plants due to bioaccumulation and biomagnifications and consequences for plants and ecosystems.
Fire Ecology	• Develop models for climate, fire, and insect interactions relevant to MORA. • Develop climate adaptation strategies, especially for dry-forests on the east-side of MORA.
Biodiversity: Exotic Plants	• Combine records of invasive species locations should be combined into a single spatial database to help determine an effective strategy for the control of invasive species. • Frequent and comprehensive inventory and monitoring of would help the park understand the extent of invasive species distribution, effectiveness of control and prevention efforts, and would provide the basis for studies of potential long-term consequences and climate change effects.

Table 68. Recommendations for critical information gaps and data needs (continued).

Resource Category	Information Gaps and Data Needs
Biodiversity: Wetlands	• Repeated inventories of wetland resources are warranted given the importance of wetlands to supporting park biodiversity and the potential for climate change to dramatically alter wetlands. A park-wide assessment of ecological integrity and spatial extent of wetland type would be valuable. • Identify the distribution of rare wetland plant associations tracked by the Washington Natural Heritage Program. • Studies to evaluate the risk of Hg methylation in different wetland habitats are needed. • Assess landscape factors important in controlling Hg concentrations in MORA wetlands (factors that drive Hg production and bioaccumulation within and between aquatic and terrestrial foodwebs). • Determine the potential consequences of climate change on Hg availability and risk in MORA wetlands. • Continue to develop hydrologic models to assess wetland changes predicted with climate change. • Conduct vegetation surveys of wetlands to develop species lists, describe wetland plant associations, and identify species most vulnerable to climate change.
Biodiversity: Alpine and Subalpine Vegetation	• Ground-based monitoring is required to provide early warning of changes to alpine and subalpine composition, structure, and extent. Continue to support the Alpine and Subalpine Vegetation Monitoring Protocol. • Monitor the duration and extent of annual snowpack to provide valuable information to supplement temperature and precipitation data for understanding alpine and subalpine responses to climate change. • Conduct studies to describe composition and distribution of cryptobiotic crusts and to better understand their role in alpine and subalpine function and processes. Currently, studies are limited to a few species lists and no studies on function, although they may be critical to plant establishment in alpine environments and are extremely vulnerable to recreational use, warming temperatures, and nitrogen deposition.
Biodiversity: Sensitive Vegetation Species	• Conduct surveys of relevant habitats for species that have been reported in the park but not relocated in the NCCN or park inventory efforts. • Participate in establishing a formal classification method for NPS species of management concern that could be cross-referenced to the classifications of surrounding federal agencies. • Conduct forecasts of where relevant habitats of sensitive species may migrate due to changing climate would be useful. • Conduct more extensive and systematic surveys for non-vascular plants and fungi to adequately describe their status to serve as a baseline for eventually detecting trends. • Monitor populations of species whose range limits are within the park to determine if they are responding to climate change.
Amphibians	• Conduct additional surveys for Van Dyke's and Larch Mountain Salamanders would be desirable due to their cryptic nature and limited distribution within the park and region. • Conduct additional inventory work targeting the genus *Dicamptodon* to differentiate Coastal Giant Salamanders (*D. tenebrosus*) from Cope's Salamanders (*D. copei*). • Investigate the unexplained die-offs of amphibians such as observed at Crystal Lake to determine the cause of these apparent episodic declines. • Continue Western Toad breeding habitat monitoring and analyze trends to asses their population status in the park. • Monitor the status and trends of Chytrid disease and other emerging diseases and pathogens affecting amphibian species present in the park. • Monitor headwater stream amphibians using a subset of sites selected from the 1996–1998 surveys in order to assess trends. • Monitor *Ambystoma* species population status and trends where fish species continue to survive in park lakes. • Monitor a subset of wetlands for amphibian status and trends given the high potential for alteration of these habitats by climate change. • Conduct studies to evaluate the risk of Hg methylation in different aquatic habitats and measurement of Hg concentrations in amphibians and their prey (aquatic invertebrates) should continue. • Determine the specific biological effects of wildlife exposure to Hg and the potential effects on wildlife populations. • Determine if exposure to Hg in MORA is causing toxicological responses to sensitive hormones associated with endocrine disruption in amphibians. • Assess the physiological effects of Hg exposure on salamanders across habitats. • Continue and expand monitoring of amphibians inhabiting park lakes using NCCN mountain lakes monitoring protocols. • Continue to maintain the existing parkwide amphibian database and expand the database to accommodate asssociated habitat data being collected; Park data should be periodically published as Natural Resources Data Series reports to facilitate access by other scientists.

Table 68. Recommendations for critical information gaps and data needs (continued).

Resource Category	Information Gaps and Data Needs
Fish	• Continue to expand the scope of the present fish database by surveying additional park streams, rivers, and lakes; by conducting focused-surveys of potentially sensitive species, such as Bull Trout and anadromous salmon; and by initiating surveys for detecting species for which occurrence and distribution are relatively unknown, such as Mountain Whitefish. • Conduct surveys designed to identify species potentially present in the park but not confirmed, such as lamprey (*Lampetra* spp.) and dace (*Rhinicthys* spp.). • Continue genetic analysis of Bull Trout tissue for confirming the absence (or presence) of Dolly Varden in park streams and rivers, as well as identifying any potential hybridization between Bull Trout and Eastern Brook Trout. • Conduct targeted surveys of endangered, threatened and species of concern (Bull Trout, Chinook Salmon, Coastal Cutthroat, Steelhead) to assess population status throughout the park. • Continue genetic analysis of Rainbow Trout and Westslope Cutthroat Trout to further document the extent of hybridization between these 2 species, and analyze Rainbow Trout tissue to help elucidate the extent of occurrence of native and hatchery stocks in park streams and rivers • Sculpin-focused surveys should be conducted so that additional sculpin species, if any, in the park can be identified and their distributions documented. • Evaluate the risk of Hg methylation in different aquatic habitats and measure Hg concentrations in fish. • Determine the specific biological effects of fish exposure to Hg and the potential effects on fish populations. Determine if exposure to Hg in MORA is causing toxicological responses to sensitive hormones associated with endocrine disruption in fish. • Conduct surveys to gather data for assessing the status of fish populations in the park. • All survey efforts should include: (1) a habitat-survey component for the purpose of documenting and monitoring the present condition and potential future changes to the health and integrity of park stream, river, and lake habitats; and (2) an estimate of the potential impact of introduced nonnative species on native aquatic biota. • Prepare a Comprehensive Fisheries Management Plan for the park.
Land Birds	• Conduct focused surveys of land birds that are difficult to detect or occur too infrequently to monitor effectively at the spatial scale of the park. The well-established NCCN avian inventory and monitoring program is a tremendous asset that provides critical information about the status of many land bird species to park managers; however, data are lacking for these species • Survey and monitor special status species, such as Marbled Murrelet and Harlequin Duck, to enhance management understanding of the occurrence and distribution of these species in the park. • Monitor Hg levels in songbirds to develop a better understanding of the geographic regions, climates, and habitats that are at risk to Hg exposure. • Assess the physiological effects of Hg exposure on aquatic dependent songbirds across habitats. • Continue to support the Landbird Long-term Monitoring Protocol,
Mammalian Fauna	• Conduct research and monitoring that would improve our present level of knowledge of the current status and trends of mammal populations in the park. • Determine climate change factors that have the potential to increase production of Hg and potentially increase wildlife exposure risk.
Mammalian Carnivores	• Test for temporal trends in the occupancy rate of surveyed mammalian carnivore species in MORA using the methods used by Reid et al. (2010). • Conduct radio-telemetry based studies that identify corridors and important habitat features for carnivores at the regional scale would to aid in focusing interagency conservation strategies. • Conduct additional monitoring designed to verify the current population status and trends of the Cascade Red Fox in MORA and to determine the effectiveness of management practices designed to reduce habituation and food conditioning of foxes to humans.
Elk	• Continue Elk surveys in the developed standard protocol (on an every other year basis); the data will provide good statistical power for the NPS to evaluate future trends in the seasonal abundance of Elk using subalpine meadows in the park during summer. • Conduct additional monitoring designed to measure ecosystem effects of Elk on species composition of subalpine vegetation, percent of bare soil, or the extent and characteristics of Elk trails to link Elk numerical trends to changes in ecosystem structure or processes.

Table 68. Recommendations for critical information gaps and data needs (continued).

Resource Category	Information Gaps and Data Needs
Bats	• Conduct studies on the ecology of bats in MORA to contribute new information to the interagency Bat Grid program. It will not be possible to detect any changes in bat resources unless there is an improved understanding of bat abundance in the Cascade Range. The interagency Bat Grid program, currently supported by the U.S. Forest Service, Bureau of Land Management, and Department of Defense, is the only existing program that is structured to gauge bat populations in the Pacific Northwest. Any studies on the ecology of bats in MORA and the Southern Cascades would provide useful new information to this program.
Glaciers	• Continue monitoring glacier mass balance. • Continue monitoring decadal glacier extents. • Assess trends in ice surface elevations and continue monitoring established sites on the Nisqually Glacier. • Continue monitoring changes in glacier terminus changes. • Monitor stream bed elevations in glacial systems of the park to assess stream aggradation and potential effects on developed areas. • Monitor trends in summertime stream temperatures and glacier runoff to gain a better understanding of the effects of glacier change on dependent aquatic ecosystems. • Monitor changes in benthic macroinvertebrate communities in glacial streams. • Research and monitor glacial influence on stream temperature and channel stability to provide a framework for understanding ecosystem response to loss of glaciers. • Gain a better understanding of groundwater contribution in watersheds with minimal or no glacial cover. • Gain a better understanding of the hyporheic zone of glacial and non-glacial systems and the relationship to habitat, especially for native and threatened and endangered species. • Investigate the effects of rockfall on glaciers and identify past rockfalls (location, timing, magnitude). • Investigate the effects climate has on rockfall including on glacier velocities. • Investigate how stagnant ice contributes to outburst floods. • Monitor glacier change and debris flows on the Carbon Glacier. • Study the interaction between sediment and forests and effects on floodplains.
Soundscape	• Continue monitoring of natural and anthropogenic sound production in the park. • Conduct research dedicated to the affects of chronic noise exposure on wildlife, especially near developed areas in the park.
Dark Night Skies	• Investigate light trespass from within-park developments and the impacts of the Crystal Mountain Ski Area in winter to adjacent wilderness areas.
Data Needs–Gaps for Resources Not Assessed in NRCA due to lack of baseline information	
Invertebrates	• Conduct parkwide surveys of terrestrial and aquatic invertebrates for which data are lacking and target species most vulnerable to stressors. • Conduct baseline surveys and monitor select species to track the status and trends for important pollinators, such as bees and butterflies, which are most likely to be affected by climate change and other anthropogenic stressors. • Conduct baseline surveys of listed mollusk and insect Species of Concern.
Riverine Landforms	• Define and quantify the extent of alteration in riverine landform condition and explore the potential implication of these types of changes for aquatic biota. • Assess how this indice could be used as an integrated metric for monitoring climate change stressors. • Potential systems of focus are Fryingpan Glacier – Fryingpan Creek, NE quadrant; Emmons Glacier – Upper White River, NE quadrant; Nisqually Glacier – Nisqually River, SW quadrant; Kautz Glacier – Kautz Creek, SW quadrant.

Table 68. Recommendations for critical information gaps and data needs (continued).

Resource Category	Information Gaps and Data Needs
Human Use	• Continue to assess the effects that human use has on park terrestrial and aquatic ecosystems. • Complete reports on recreational use effects on park lakes and streams. • Complete study on spatial metrics to evaluate the influence of recreational impacts on ecosystems. • Target water quality monitoring to areas being potentially impacted (vehicle bridge crossings where stormwater runoff directly leads to streams and rivers; management activities that impact water quality; etc.). • Assess the effects of developed water supplies on streamflow and dependent organisms. • Complete studies on the use of benthic macroinvertebrates to assess recreational use impacts. • Complete study of Cascade Red Fox habituation and development of indicators and recommended standards for addressing human habituation and food conditioning by humans.
Newly Aquired Lands	• Conduct baseline surveys of aquatic and terrestrial ecosystems within the newly acquired Carbon River lands.
Soils	• Investigate the effects of airborne toxins on soils. • At the completion of the NRCS parkwide soil survey, determine if any soils are at risk from human use impacts.

6.5 Concluding Remarks

Mount Rainier National Park was established by Congress on 2 March 1989 as the nation's fifth national park. The Mount Rainier National Park Act was signed by President McKinley for "...the benefit and enjoyment of the people…for the preservation from injury or spoliation of all timber, mineral deposits...natural curiosities, or wonders within said park and their retention in their natural condition." Since its beginning, park management has been vigilant in maintaining its commitment to the preservation and persistence of MORA's natural resources; and since the park's establishment, much has changed, and the challenges of sustaining the natural quality and largely unspoiled wildness of the park have grown. Today, the MORA landscape is being affected by perturbations associated, for example, with climate change, the vagaries of industrialization and a concomitant growth in population, by increasing visitation and use by human visitors, and by the introduction of nonnative plant and animal species. These threats and emerging issues will most likely compromise the health and integrity of MORA ecosystems at some level. It is imperative that the park continue the long NPS tradition of commitment to resource stewardship, by maintaining and expanding their present comprehensive inventory and monitoring efforts and programs, and by enhancing those efforts with new innovative programs and strategies.

6.6 Literature Cited

Adams, M. J., D. A. W. Miller, E. Muths, P. S. Corn, E. H. Campbell Grant, L. L. Bailey, G. M. Fellers, R. N. Fisher, W. J. Sadinski, H. Waddle, and S. C. Walls. 2013. Trends in amphibian occupancy in the United States. PLOS One: www.plosone.org.

Agren, J., C. Johnson, and A. M. Johansen. 2013. Precipitation chemistry at Mount Rainier (Paradise Ranger Station) collection site: Final Report for data collected between June 2, 2010 and June 1, 2011. Chemistry Department, Central Washington University, Ellensburg, Washington.

Aubry, C., W. Devine, R. Shoal, A. Bower, J. Miller, and N. Maggiuli. 2011. Climate change and forest biodiversity: A vulnerability assessment and action plan for national forests in western Washington. U.S. Department of Agriculture, U.S. Forest Service, Pacific Northwest Region. Olympia, Washington.

Bentz, B. J., J. Regniere, C. J. Fettig, M. Hansen, J. L. Hayes, J. A. Hicke, R. G. Kelsey, J. F. Negron, and S. J. Seybold. 2010. Climate change and bark beetles of the western United States and Canada: direct and indirect effects. BioScience 60:602–613.

Bertschi, I. T., D. A. Jaffe, L. Jaegle, H. U. Price, and J. B. Dennison. 2004. PHOEBE/ITCT 2002 airborne observations of transpacific transport of ozone, CO, volatile organic compounds, and aerosols to the northeast Pacific: Impacts of Asian anthropogenic and Siberian boreal fire emissions. Journal of Geophysical Research 109: D23S12.

Biek, D. 2000. Flora of Mount Rainier National Park. Oregon State University Press, Corvallis, Oregon. 506 p.

Blehert, D. S., J. M. Lorch, A. E. Ballmann, P. M. Cryan, and C. U. Meteyer. 2011. Bat white-nose syndrome in North America. Microbe 6:267–273.

Brace, S., and D. L. Peterson. 1998. Spatial patterns of tropospheric ozone in the Mount Rainier region of the Cascade Mountains, U.S.A. Atmospheric Environment 32:3621–3637.

Coops, N. C., and R. H. Waring. 2011. Estimating the vulnerability of fifteen tree species under changing climate in Northwest North America. Ecological Modeling 222:2119–2129.

Covich, A. P. 2009. Emerging climate change impacts in freshwater resources: A perspective on transformed watersheds. Resources for the Future (RFF) Report. 42 p.

Dahlgren, T. 2000. 1999 air quality trends in Washington. Publications No. 00-02-011. State of Washington, Department of Ecology, Seattle, Washington.

Dale, V. H., L. A. Joyce, S. Mcnulty, R. P. Neilson, M. P. Ayres, M. D. Flannigan, P. J. Hanson, L. C. Irland, A. E. Lugo, C. J. Peterson, D. Simberloff, F. J. Swanson, B. J. Stocks, and B. M. Wotton. 2001. Climate change and forest disturbances. BioScience 51:723–734.

Everest, F. H., D. J. Stouder, C. Kakoyannis, L. Houston, G. Stankey, J. Kline, and R. Alig. 2004. A review of scientific information on issues related to the use and management of water resources in the Pacific Northwest. General Technical Report PNW-GTR-595. USDA Forest Service, Pacific Northwest Research Station, Corvallis, OR. 128 p.

Fenn, M. E., J. S. Baron, E. B. Allen, H. M. Rueth, K. R. Nydick, L. Geiser, W. D. Bowman, J. O. Sickman, T. Meixner, D. W. Johnson, and P. Neitlich. 2003. Ecological effects of nitrogen deposition in the western United States. BioScience 53:404–420.

Fenn, M. E., C. S. Ross, S. L. Schilling, W. D. Baccus, M. A. Larrabee, and R. A. Lofgren. 2013. Atmospheric deposition of nitrogen and sulfur and preferential canopy consumption of nitrate in forests of the Pacific Northwest, USA. Forest Ecology and Management 302:240–253.

Friedli, H. R., L. F. Radke, J. Y. Lu, C. M. Banic, W. R. Leaitch, and J. I. MacPherson. 2003. Mercury emissions from burning of biomass from temperate North American forests: Laboratory and airborne measurements. Atmospheric Environment 37:253–267.

Fuller, T. L., S. S. Saatchi, E. E. Curd, E. Toffelmier, H. A. Thomassen, W. Buermann, D. F. DeSante, M. P. Nott, J. F. Saracco, C. J. Ralph, J. D. Alexander, J. P. Pollinger, and T. B. Smith. 2010. Mapping the risk of avian influenza in wild birds in the US. BMC Infectious Diseases 10:187. Available online at http://www.biomedcentral.com/1471-2334/10/187.

Geiser, L., and P. Neitlich. 2007. Air pollution and climate gradients in western Oregon and Washington indicated by epiphytic macrolichens. Environmental Pollution 145:203–218.

Geiser, L. H., S. E. Jovan, D. A. Glavich, and M. K. Porter. 2010. Lichen-based critical loads for atmospheric nitrogen deposition in western Oregon and Washington forests, USA. Environmental Pollution 158:2412–2421.

Halofsky, J. E., D. L. Peterson, M. J. Furniss, L. A, Joyce, C. I. Millar, and R. P. Neilson. 2011. Workshop approach for developing climate change adaptation strategies and actions for natural resource management agencies in the United States. Journal of Forestry 109:219–225.

Hauer, F. R., J. S. Baron, D. H. Campbell, K. D. Fausch, S. W. Hostetler, G. H. Leavesley, P. R. Leavitt, D. M. McKnight, and J. A. Stanford. 1997. Assessment of climate change and freshwater ecosystems of the Rocky Mountains, USA and Canada. Hydrological Processes 11:903–924.

Hemstrom, M. A., and J. F. Franklin. 1982. Fire and other disturbances of the forests in Mount Rainier National Park. Quaternary Research 18:32–51.

Hoffman, R. L., G. L. Larson, and B. Samora. 2004. Responses of *Ambystoma gracile* to the removal of introduced nonnative fish from a mountain lake. Journal of Herpetology 38:578–585.

Knapp, R. A., K. R. Matthews, and O. Sarnelle. 2001. Resistance and resilience of alpine lake fauna to fish introductions. Ecological Monographs 71:401–421.

Landers, D. H., S. L. Simonich, D. A. Jaffe, L. H. Geiser, D. H. Campbell, A. R. Schwindt, C. B. Schreck, M. L. Kent, W. D. Hafner, H. E. Taylor, K. J. Hageman, S. Usenko, L. K. Ackerman, J. E. Schrlau, N. L. Rose, T. F. Blett, and M. M. Erway. 2008. The fate, transport, and ecological impacts of airborne contaminants in western national parks (USA). EPA/600/R-07/138. U.S. Environmental Protection Agency, Office of Research and Development, NHEERL, Western Ecology Division, Corvallis, Oregon.

Mote, P. W., A. F. Hamlet, M. P. Clark, D. P. Lettenmaier. 2005. Declining mountain snowpack in western North America. Bulletin of the American Meteorological Society 86:39–49.

Murdoch, P. S., J. S. Baron, and T. L. Miller. 2000. Potential effects of climate change on surface-water quality in North America. Journal of the American Water Resources Association 36:347–366.

Nielson, R. P., L. F. Pitelka, A. M. Solomon, R. Nathan, G. F. Midgley, J. M. V. Fragoso, H. Lischke, and K. Thompson. 2005. Forecasting regional to global plant migration in response to climate change. BioScience 55:749–759.

Parker, B. R., D. W. Schindler, D. B. Donald, and R. S. Anderson. 2001. The effects of stocking and removal of a nonnative salmonid on the plankton of an alpine lake. Ecosystems 4:334–345.

Pejchar, L., and H. A. Mooney. 2009. Invasive species, ecosystem services and human well-being. Trends in Ecology and Evolution 24:497–504.

Pilliod, D. S., and C. R. Peterson. 2001. Local and landscape effects of introduced trout on amphibians in historically fishless watersheds. Ecosystems 4:322–333.

Rehfeldt, G. E., N. L. Crookston, M. V. Warwell, and J. S. Evans. 2006. Empirical analyses of plant-climate relationships for the western United States. International Journal of Plant Sciences 167:1123–1150.

Rochefort, R. M., and D. L. Peterson. 1996. Temporal and spatial distribution of trees in subalpine meadows of Mount Rainier National Park, Washington, U.S.A. Arctic and Alpine Research 28:52–59.

Schary, C. 2003, Future trends impacting air quality in the Pacific Northwest. 20 March 2003; http://yosemite.epa.gov/r10/homepage.nsf/3061430ee8351cae88256cdb005af493/ec3990566baac3d888256cd30075ed08/$FILE/Future%20Trends.ppt.

Scott, T., L. Pey-Yi, K. Paggett, R. Carney, S. Husted, and W. Koenig. 2008. The impact of West Nile Virus on birds in California's hardwood rangelands. In: Merenlender, A., D. McCreary, and K. L. Purcell, technical editors. Proceedings of the sixth California oak symposium: Today's challenges, tomorrow's opportunities. General Technical Report PSW-GTR-217. USDA, Forest Service, Pacific Southwest Research Station, Albany, California. p. 151–163.

Shafer, S. L., P. J. Bartlein, and R. S. Thompson. 2001. Potential changes in the distributions of western North America tree and shrub taxa under future climate scenarios. Ecosystems 4:200–215.

Sheibley, R.W., J. R. Foreman, P. W. Moran, and P. W. Swarzenski. 2012. Atmospheric deposition, water-quality, and sediment data for selected lakes in Mount Rainer, North Cascades, and Olympic National Parks, Washington, 2008–10: U.S. Geological Survey Data Series 721, 34 p.

Sturrock, R. N., S. J. Frankel, A. V. Brown, P. E. Hennon, J. T. Kliejunas, K. J. Lewis, J. J. Worrall, and A. J. Woods. 2011. Climate change and forest diseases. Plant Pathology 60: 133–149.

Sullivan, T. J., T. C. McDonnell, G. T. McPerson, S. D. Mackey, and D. Moore. 2011a. Evaluation of the sensitivity of inventory and monitoring national parks to nutrient enrichment effects from atmospheric nitrogen deposition. North Coast and Cascades Network (NCCN). Natural Resource Report NPS/NRPC/ARD/NRR—2011/319.

Sullivan, T. J., T. C. McDonnell, G. T. McPerson, S. D. Mackey, and D. Moore. 2011b. Evaluation of the sensitivity of inventory and monitoring national parks to acidification effects from atmospheric sulfur and nitrogen deposition. North Coast and Cascades Network (NCCN). Natural Resource Report NPS/NRPC/ARD/NRR—2011/365.

Tingley, M. W., M. S. Koo, C. Moritz, A. C. Rush, and S. R. Beissinger. 2012. The push and pull of climate change causes heterogeneous shifts in avian elevational ranges. Global Change Biology 18:3279–3290.

NPS 105/127528, December 2014

National Park Service
U.S. Department of the Interior

Natural Resource Stewardship and Science
1201 Oakridge Drive, Suite 150
Fort Collins, CO 80525

www.nature.nps.gov

EXPERIENCE YOUR AMERICA ™