National Park Service
U.S. Department of the Interior

Natural Resource Stewardship and Science

North Cascades National Park Service Complex

Natural Resource Condition Assessment

Natural Resource Report NPS/NOCA/NRR—2015/901

ON THE COVER
Upper Blum Lake and Mt Shuksan
Photograph by: Brian Pickard

North Cascades National Park Service Complex

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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]
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

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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.

North Cascades National Park, Ross Lake National Recreation Area, and Lake Chelan Recreation Area were established by Congress in 1968 (82 Stat. 926), and signed into law by President Lyndon B. Johnson, 2 October 1968, to be administered as the North Cascades National Park Service Complex (NOCA). In 1988, Congress established the Stephen Mather Wilderness within NOCA, and in 2012 the Secretary of the Interior designated an additional 3550 ac of NOCA as wilderness.

NOCA is located in the North Cascade physiographic province in northwestern Washington. It is bounded on the west, south, and east by 1.9 million ha (4.7 million ac) of National Forest lands, of which 763,890 ha (1.9 million ac) are designated wilderness. Most of these wilderness areas are contiguous to the Stephen Mather Wilderness. The NOCA northern boundary is the international boundary with the Canadian province of British Columbia. Provincial forest lands and a recreation area are adjacent to the boundary in British Columbia; a provincial park is just to the east. NOCA spans the Cascade crest, placing within its boundary 2 major biogeographic zones: temperate marine and semi-arid continental. The climatic and biotic diversity are further increased by a transitional zone, roughly the lower elevations of the Ross Lake drainage. The third zone is created by an orographic divide west of the crest. Vegetal and climatic characteristics within this zone are intermediate between the mild, wet conditions typical of the west side and the semi-arid conditions typical of the east side of the Complex.

NOCA is characterized by deep, forested valleys between high, glaciated mountain peaks. The local topographic relief is 2682 m (8800 ft), with the lowest point being 122 m (400 ft) along the Skagit River and the highest elevations occurring on several mountain peaks over 2743 m (9000 ft). NOCA contains 316 glaciers, more than all of the other national parks within the conterminous states combined. From the glaciers, permanent snowfields, and 530 lakes flow approximately 6500 km (4039 mi) of rivers and streams (excluding intermittent streams, which may increase the total to over

10,000 km [6214 mi]). Several major rivers are present in NOCA: (1) the Chilliwack River flows into the Fraser River; (2) the Nooksack River flows to the Pacific Ocean at Bellingham Bay; (3) the Skagit River flows from its headwaters in British Columbia through NOCA and is the largest watershed flowing into Puget Sound; (4) the Baker River flows into the Skagit River; and (5) the Stehekin River flows into Lake Chelan whose water is released through the Lake Chelan Powerhouse into the Columbia River.

A Natural Resource Condition Assessment Workshop was convened in 2010. The multiple purpose of this 2-day workshop was to review and brainstorm the natural resources of NOCA, to identify and prioritize key indicators of the park’s natural resources and their stressors, and to develop a plan for creating and completing an assessment of the conditions of the natural resources. Following the scoping workshop, all available data, reports, and references pertinent to each of 11 general natural resource categories identified during the workshop were collected from NOCA 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.

A total of 14-focal NOCA natural resources were assessed as a part of this NRCA (see Table 3, 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. 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, 85% (17 of 20) 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 6 of these categories were estimated to have been seriously to significantly disturbed (see Table 58, Chapter 6). These resources included: (1) Air Quality–Nitrogen and Sulfur Deposition; (2) Air Quality–Persistent Bioaccumulative Toxics; (3) Forest Health–Disturbance Regime; (4) Forest Health–Whitebark Pine and White Pine Blister Rust; (5) Biodiversity–Exotic Plants; and (6) Glaciers. Five resources (Biodiversity–Wetlands, Mammalian Fauna, Mammalian Carnivores, Hoary Marmots–American Pika, and Bats) did not have sufficient data for estimating or predicting relative level of disturbance and condition.

Although only 6 resource categories were assessed as being seriously to significantly disturbed, many, if not all, of the NOCA 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 toward 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. NOCA 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, NOCA 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 fundamental threats that are now and will in the future affect the continued persistence and viability of the natural resources and ecosystems of NOCA 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-resident native and non-native plant and animal species. These threats are discussed in Chapter 6. Additional threats were also identified for specific resources and they 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 NOCA in the context of Pacific Northwest regional climate. This evaluation suggests that although there is some diversity of responses among long-term stations, minimum temperatures are increasing sharply in NOCA. 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 toward 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 toward 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 NOCA and understand what they imply for changes to the climate of the park.

An impressive amount of research, inventories and surveys, and monitoring of NOCA 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 59 (Chapter 6). A more detailed discussion of data needs for specific resource categories is available in Chapter 4 for each assessed natural resource.

Acknowledgments

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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

Acronyms (continued)

NRA – National Recreation Area

NRCA – Natural Resource Condition Assessment

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

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[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.

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 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 identified critical data gaps and described 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 was also important. These staff were asked to assist with the selection of study indicators; recommend data sets, methods, and reference conditions and values; and to 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

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 that is both credible and has practical uses for a variety of park decision making, planning, and partnership activities.

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

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[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

(part of this subsection adapted from the NOCA Foundation Statement 2006)

North Cascades National Park (505,000 ac; 204,366 ha), Ross Lake National Recreation Area (117,000 ac; 47,348 ha), and Lake Chelan Recreation Area (62,000 ac; 25,090) were established by Congress in 1968 (82 Stat. 926), and signed into law by President Lyndon B. Johnson, 2 October 1968, to be administered as the North Cascades National Park Service Complex (NOCA). The purpose of the enabling legislation was to: "…preserve for the benefit, use, and inspiration of present and future generations certain majestic mountain scenery, snowfields, glaciers, alpine meadows, and other unique natural features in the North Cascade Mountains of the State of Washington…" and to "…provide for the public outdoor recreation use and enjoyment … [and] for the conservation of the scenic, scientific, historic, and other values contributing to public enjoyment of such lands and waters…" In 1988, Congress established the Stephen Mather Wilderness within NOCA, and in 2012 the Secretary of the Interior designated an additional 3550 ac (1437 ha) of NOCA as wilderness (present size = 634,614 ac; 256,819 ha).

Combining 3 distinct units under a single unique administration recognizes their shared purpose of preserving the core of the greater North Cascades ecosystem and wilderness while also advancing their individual purposes:

1. The purpose of North Cascades National Park is to preserve a dynamic wilderness landscape of dramatic alpine scenery including a vast expanse of glaciated peaks, countless cascading creeks and deep forested valleys for the benefit and inspiration of all.
2. The purpose of Ross Lake National Recreation Area is to complement North Cascades National Park and conserve the scenic, natural, and cultural values of the Upper Skagit River Valley and surrounding wilderness, including the hydroelectric reservoirs and associated developments, for outdoor recreation and education.
3. The purpose of Lake Chelan National Recreation Area is to complement North Cascades National Park and conserve the scenic, natural and cultural values of the Lower Stehekin Valley, Lake Chelan and surrounding wilderness, while respecting the Stehekin community, for outdoor recreation and education.

2.1.2 Background and Geographic Setting

(Adapted from NOCA Resource Management Plan 1999)

The North Cascades National Park Service Complex is located in the North Cascade physiographic province in northwestern Washington (Figure 1). It is bounded on the west, south, and east by 1.9 million ha (4.7 million ac) of National Forest lands, of which 763,890 ha (1.9 million ac) are designated wilderness (Figure 2). Most of these wilderness areas are contiguous to the Stephen Mather Wilderness. The NOCA northern boundary is the international boundary with the Canadian province of British Columbia. Provincial forest lands and a recreation area are adjacent to the boundary in British Columbia; a provincial park is just to the east.

Figure 1. Geographical setting of North Cascades National Park Service Complex.

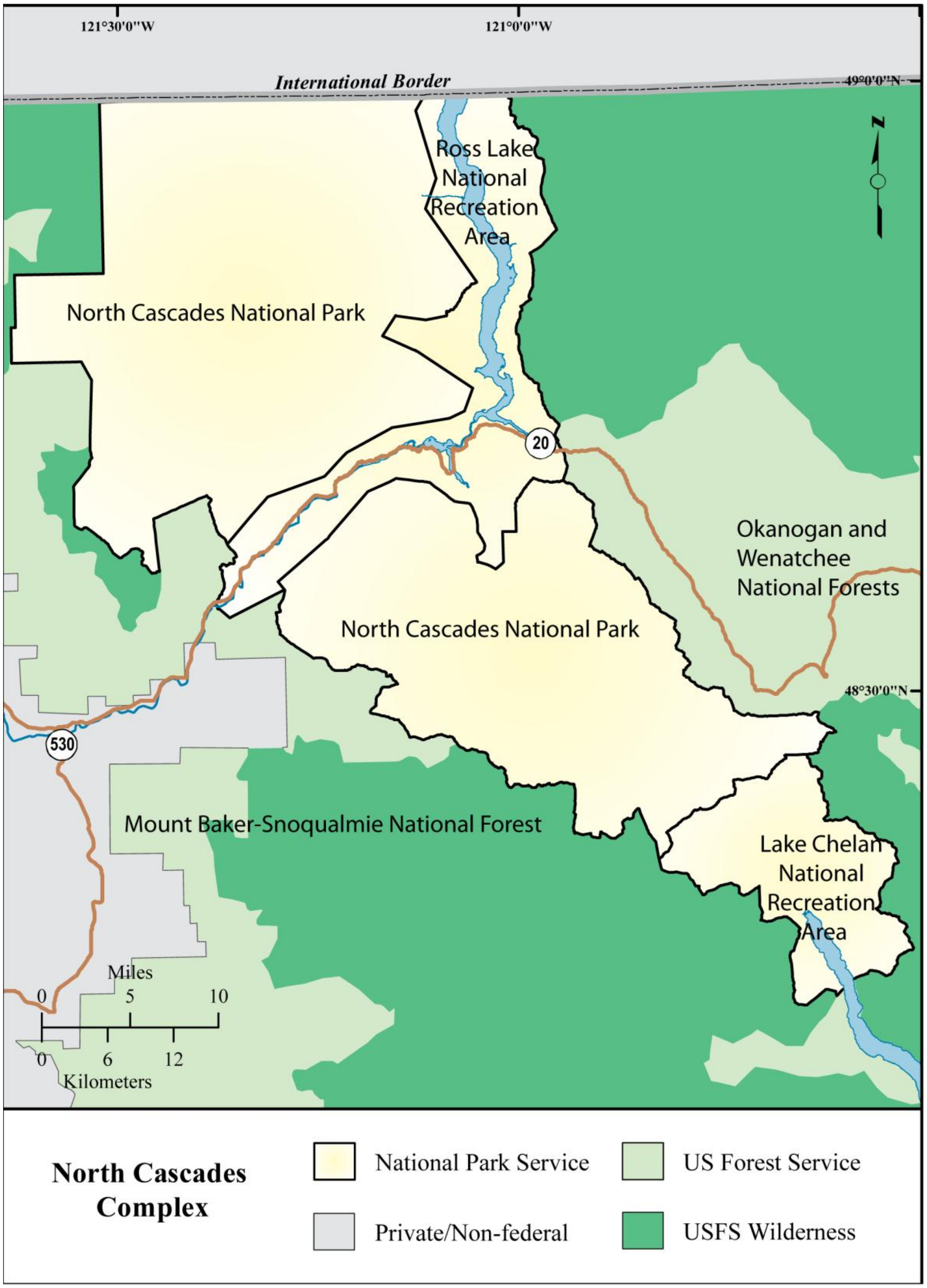

Figure 2. North Cascades National Park Service Complex and adjacent land ownership.

NOCA spans the Cascade crest, placing within its boundary 2 major biogeographic zones: temperate marine and semi-arid continental. The climatic and biotic diversity are further increased by a transitional zone, roughly the lower elevations of the Ross Lake drainage. This third zone is created by 3 orographic divides in the Skagit watershed: (1) Cascade-Pacific; (2) Skagit (west of the Cascade crest); and (3) North Cascade, which divides flow north to the Fraser River and south to the Skagit River. Vegetal and climatic characteristics within this zone are intermediate between the mild, wet conditions typical of the west side and the semi-arid conditions typical of the east side of the Complex.

NOCA is characterized by deep, forested valleys between high, glaciated mountain peaks. The local topographic relief is 2682 m (8800 ft), with the lowest point being 122 m (400 ft) along the Skagit River and the highest elevations occurring on several mountain peaks over 2743 m (9000 ft). The bedrock geology of the North Cascades differs greatly on either side of the Straight Creek Fault. West of the fault the Shuksan metamorphic suite is composed of green schist and phyllite. East of the fault are granite and gneiss, which compose the crystalline core of the North Cascades. The Complex has been shaped by a combination of uplifting of predominantly granitic formations and by repeated, intense alpine and continental glaciations Watersheds typically begin in high-elevation glaciers and snowfields, dropping in numerous cascading streams down precipitous valley walls to classic, U-shaped valley floors carved by glaciers during the Pleistocene. Mainstem streams are generally sinuous and whose pattern is predominantly of the island bar channel type, which is intermediate between meandering and braided.

Precipitation varies across elevation gradients and the crest of the North Cascades Range, with an average of about 400 cm/yr (157 in/yr) on the western peaks to an average of 50 cm/yr (20 in/yr) in the Lake Chelan corridor. The intermediate zone within the lower elevations of the Ross Lake basin averages 100–150 cm/yr (39–59 in/yr) precipitation; the slopes to the west and east of the valley typically receive 150–200 cm/yr (59–79 in/yr).

NOCA contains 316 glaciers, more than all of the other national parks within the conterminous states combined. From the glaciers, permanent snowfields, and 530 lakes flow approximately 6500 km (4039 mi) of rivers and streams (excluding intermittent streams, which may increase the total to over 10,000 km [6214 mi]). NOCA contains the headwaters for 3 major river systems: the Columbia, Fraser, and Skagit.

Air quality in NOCA is generally good, although the potential for deterioration of pristine air quality is very high because the Complex lies in the path of prevailing westerly winds blowing across the several, large urban-industrial areas of the Puget Sound lowlands. These areas stretch from Portland, Oregon in the south to Vancouver, B.C., in the north. NOCA is a Class I airshed under the Clean Air Act; both NRAs are Class II airsheds adjacent to the park. Class I airsheds are areas that require the highest level of protection under the Clean Air Act of 1963. Class II airsheds are areas representing National Forest System lands that are not classified as Class I and may receive greater amounts of human-made pollution relative to CI areas.

There are 3 reservoirs (Gorge, Diablo, and Ross) within Ross Lake NRA, all behind dams built to provide hydroelectric power. A small hydroelectric project on Newhalem Creek also provides power via a stream diversion. Lake Chelan, which developed within a deep, glacial trough, is the third deepest natural lake in the United States. The lake was dammed in the 1920s to regulate its elevation for hydroelectric power; the natural lake level is raised an additional 21 feet at full pool. The 3 reservoirs and Lake Chelan provide recreational opportunities and transportation routes as well as power. The dams also influence stream processes downstream and the migration of fish throughout the watershed. The reservoirs likely affect microclimate, cause erosion of terrestrial habitat, and limit the ranges of terrestrial species within the Complex.

The abundance of water and the wide variation in landforms, soil types, elevation, slope, and aspect create many types of habitat that support a diversity of flora and fauna. There are as many as 75 mammal, 200 bird, 27 fish, 17 reptile and amphibian, and roughly 1630 vascular plant species within NOCA. The Skagit River system is one of the few watersheds within the Puget Sound area that is managed for natural production of salmon. All the high lakes in NOCA were devoid of fish due to natural barriers to fish migration in their outlet streams. Today, over 75 NOCA high lakes support introduced populations of Rainbow Trout (*Oncorhynchus mykiss*), Cutthroat Trout (*Oncorhynchus clarkii*), Eastern Brook Trout (*Salvelinus fontinalis*), and Golden Trout (*Oncorhynchus aquabonita*).

In a broad sense, the vegetation of NOCA is typical of the vegetation found throughout mountainous areas of the Pacific Northwest. Douglas-fir (*Pseudotsuga menziesii*), Western Hemlock (*Tsuga heterophylla*), and Pacific Silver Fir (*Abies amabilis*) dominate the lower and montane slopes of the westside of the Complex. The eastside is drier and dominated by dry Douglas-fir and Ponderosa Pine (*Pinus ponderosa*) forests. Riparian zones throughout the Complex are dominated by deciduous trees including alder (*Alnus* spp.), cottonwood (*Populus* spp.), and willow (*Salix* spp.). The upper elevations of NOCA are primarily Subalpine Fir (*Abies lasiocarpa*) and Mountain Hemlock (*Tsuga mertensiana*) forests. The eastern mountain slopes have those components as well as Subalpine Larch (*Larix lyallii*), Whitebark Pine (*Pinus albicaulis*), and Engelmann Spruce (*Picea engelmannii*). Above forestline, moist to dry subalpine meadows dominate. Roughly 230 species of non-native plants are found within the Complex, including Diffuse (*Acosta diffusa*) and Spotted Knapweed (*Centaurea stoebe*), Rush Skeletonweed (*Chondrilla juncea*), St. John's Wort (*Hypericum perforatum*), Scotch Broom (*Cytisus scoparius*), Japanese Knotweed (*Fallopia japonicus*), Cheatgrass (*Bromus tectorum*), Common Mullein (*Verbascum thapsus*), and Herb Robert (*Geranium robertianum*).

Visitors enjoy the many resources of the NOCA, including the use of frontcountry roads, campgrounds, and trails, as well as backcountry hiking, skiing, and climbing. Ross Lake and Lake Chelan NRAs are particularly popular destinations for water-related activities during summer months. The majority of recreation visitation occurs during summer, because winter access is restricted due to snowpack, snow avalanches, and the approximately 5-month closure of the North Cascades Highway (State Highway 20).

NOCA also contains a rich cultural and historical heritage. Native Americans have used the area now contained within the Complex for at least 9000 yrs, including recent documentation of high-elevation use. Their activities throughout the North Cascades can be inferred through artifacts associated with settlements, trade routes, and historical accounts through contact with Euro-American settlers. There are hundreds of documented archeological sites in NOCA. In addition, NOCA representatives maintain ongoing communication with contemporary Native Americans in the region with respect to subsistence use of resources, and other activities of settlers and post-settlement activities that have affected current transportation and modern-day settlements in and near NOCA.

2.2 Natural Resources

2.2.1 Ecological Zones and Watersheds

NOCA is located within the Level III North Cascades ecoregion, which comprises 4 Level IV ecoregions: North Cascades Lowland Forest; North Cascades Highland Forest; North Cascades Subalpine/Alpine; and Wenatchee/Chelan Highlands (see http://www.epa.gov/wed/pages/ecoregions). The North Cascades Lowland Forest zone is dominated by Western Hemlock, Douglas-fir, and Western Redcedar (*Thuja plicata*) forests; the North Cascades Highland Forest zone is dominated by Pacific Silver Fir and Mountain Hemlock forests; the North Cascades Subalpine/Alpine zone is dominated by permanent snow and ice fields, glaciers, bare rock, Subalpine Fir, and subalpine meadows; the Wenatchee/Chelan Highlands is dominated by Douglas-fir, Lodgepole Pine (*Pinus contorta*), and Ponderosa Pine forests.

At the 5th field hydrologic-unit level, there are 11 watersheds (see Figure 5) in NOCA These watersheds include (from north to south): Chilliwack River; Nooksack River; Upper Skagit-Lightning Creek; Upper Skagit-Ross Lake; Upper Skagit-Baker River; Upper Skagit-Diobsud Creek; Upper Skagit-Ruby Creek; Upper Skagit-Gorge Lake; Upper Skagit-Cascade River; Upper Columbia-Stehekin River; and Upper Columbia-Lake Chelan.

2.2.2 Resource Descriptions

Air Quality

Visitor enjoyment, the health of park ecosystems, and the integrity of cultural resources depend upon clean air. North Cascades National Park is a Class I air quality area, and Ross Lake and Lake Chelan National Recreation Areas are Class II 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 area. The NPS manages Class II areas to the same degree of protection as Class I as required by the 1916 Organic Act, the 1964 Wilderness Act, and NPS Management Policies (2006). Air quality related values include resources sensitive to air quality including visibility, lakes, streams, vegetation, soils, and wildlife. NOCA is downwind of Seattle, Washington, and Vancouver, British Columbia, and there are substantial agricultural and livestock operations north and west of the Complex. Air pollutants of concern include sulfur (S) and nitrogen (N) compounds, ground-level ozone, and persistent bioaccumulative toxics (PBTs), such as mercury (Hg). To better understand and protect air quality, the NPS and collaborators have monitored air quality and air pollution-sensitive resources at NOCA since 1984.

Water Quality

Lakes, ponds, rivers, and steams are prominent features of the NOCA 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. NOCA has at least 301 confirmed lakes and ponds, although aerial photo interpretation of the park complex indicates that there could be as many as 561 lakes and ponds; and approximately 6500 km (4039 mi) of permanent streams and rivers in 11 NOCA watersheds. Water quality comprises physical, chemical, and biological constituents that express the overall health and condition of aquatic ecosystems; at NOCA, these systems are generally oligotrophic relative to nutrient status, low in acid neutralizing capacity, high in chemical quality, and typically cool in temperature.

Vegetation

The mountainous terrain and complex geology of NOCA create substantial variation in soil types, and steep gradients of elevation, aspect, temperature, and precipitation, leading to diverse plant life. Over 1381 vascular plant species occur in the Complex, more than in any other U.S. national park. In general, vegetation of the Pacific Northwest is typified by productive coniferous forests, with deciduous species restricted to frequently disturbed areas. In NOCA, plant communities are roughly organized in an east to west gradient reflecting the wetter, maritime-influenced climate on western slopes; cold temperatures and persistent snow at high elevations; and the drier, continental climate in the rainshadow on the eastern slopes. The Cascade Range is so wide in NOCA that the rainshadow begins west of the Cascade divide. Specifically, west-side vegetation is characterized by Western Hemlock–Western Redcedar–Douglas-fir forests at low elevations, Pacific Silver Fir forests at mid-elevations, and Mountain Hemlock–Subalpine Fir dominated forests at treeline. Heaths of dwarf shrubs, primarily heather, and sparsely vegetated alpine rocklands occur above treeline. Eastside vegetation includes Ponderosa Pine in the dry, southeast portion of the park, Douglas-fir–Lodgepole Pine (*Pinus contorta*)–Grand Fir (*Abies grandis*) forests at lower elevations, and Subalpine Fir, Whitebark Pine, Subalpine Larch, or Engelmann Spruce at treeline. The Ross Lake area is unique due to close juxtaposition of eastern and western vegetation patterns on north versus south aspects. Riparian areas and wetlands, including bogs, fens and marshes, occur throughout the park. Disturbance regime varies by location, but major agents include landslides, avalanches, fires, floods, and windstorms. 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.

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 NOCA complete all aspects of their life history within the park. Eleven species, 6 frogs-toads and 5 salamanders, have been identified as present in NOCA. One species, the Western Toad, is federally listed as a Species of Concern, as well as a Candidate species for listing by Washington State. The Columbia Spotted Frog is also listed as a Candidate species for listing in Washington, and the Coastal Tailed Frog is a species being monitored in Washington State. All but 3 of the species (Columbia Spotted Frog, Ensatina, and Red-legged Frog) have wide distributions within the park. Within their respective ranges, the status of 6 species are classified as stable, 4 species are classified as decreasing, and the status of 1 species is unknown.

Fish

Twenty-seven fish species have been observed or reported as being present in NOCA rivers, streams, and lakes. Most species (*n* = 21) are native to the park, and 5 species native to the Pacific Northwest have been introduced. Four species (California Golden Trout [*Oncorhynchus mykiss aquabonita*], Brown Trout [*Salmo trutta*], Eastern Brook Trout [*Salvelinus fontinalis*], and Lake Trout [*Salvelinus namaycush*]) have been introduced to the park from outside of their native ranges. All fish present in park lakes, except for some species in Lake Chelan and Ross Lake, have been introduced through stocking. The range of native Westslope Cutthroat Trout (*Oncorhynchus clarki lewisi*) in the Stehekin River drainage on the east side of the park has been greatly reduced through competition and genetic introgression with nonnative Rainbow Trout. 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*), Chum Salmon (*Oncorhynchus keta*), 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 (USFWS), and as state candidates of special concern by the Washington Department of Fish and Wildlife.

Land Birds

The avifauna of NOCA is exceptionally diverse, reflecting the broad range of habitat types encompassed by the park complex. Moist Douglas-fir and Western Hemlock forests on the west slope of the Cascade Range support species that are representative of old-growth, temperate rainforest in the region, including the threatened Northern Spotted Owl (*Strix occidentalis caurina*). A markedly different environment in the rain shadow on the east slope of the Cascades, contributes a unique suite of bird species characteristic of dry pine forests (e.g., White-headed Woodpecker [*Picoides albolarvatus*]) and Aspen groves (Red-naped Sapsucker [*Sphyrapicus nuchalis*]). Transitional areas between diverse habitat types further contribute to high bird species diversity. 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 NOCA. 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 NOCA also are important for some species of regional conservation concern, such as the Clark's Nutcracker (*Nucifraga Columbiana*). In this assessment we focused on 73 bird species of management concern because of the large number of species that occur in the park (222 bird species in NPSpecies database), and because management and monitoring of each species is logistically infeasible. NPSpecies is awebsite that "documents our knowledge about the occurrence and status of species on National Park Service lands", and can be accessed at https://irma.nps.gov/NPSpecies. We included species listed as Management Priority in NPSpecies (47 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

NOCA appears to have retained the full set of 78 historically present mammal species, with the exception of the Fisher (*Martes pennanti*) and the Cascades Red Fox (*Vulpes vulpes cascadensis*). NOCA lands 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. Currently, up to 77 native mammal species may reside during some or all of the year in NOCA, based on documentation in NPSpecies and published literature. That number does not include the Fisher, which appears to have been extirpated from the park complex and surrounding area. Five mammal species found in NOCA, or extirpated from NOCA, are federally or state listed as threatened or endangered; 5 species are federal Species of Concern; and 6 species are state listed as of interest for monitoring. Mammal groups of focused interest in this assessment include carnivores, Hoary Marmots (*Marmota caligata*), American Pika (*Ochotona princeps fenisex*), and bats.

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 NOCA in 1998, 316 glaciers covered more than 109 km^2 (42.1 mi^2) and had a combined volume of 9.3–10.1 km^3 (2.2–2.4 mi^3). The relatively small, temperate glaciers at NOCA 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 the Gray-crowned Rosy-Finch (*Leucosticte tephrocotis*) and other alpine species. NOCA 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. Stochastic events such as lahars, outburst floods, and massive sediment debris flows that originate from glaciers pose a potentially significant hazard to people visiting and working in the park and to downstream municipalities .

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. The Natural Sounds and Night Skies Division (NSNSD) of the National Park Service and NOCA have conducted acoustical monitoring at 20 sites within the park. The primary goal of this monitoring is to characterize the ambient sound levels of NOCA vegetation and management zones that occur at different elevations and are influenced by different climatic conditions.

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 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. NOCA, although located in an area of northern Washington that is relatively remote from cities and towns, is within 100 mi (96+ km) of the large metropolitan areas of Seattle and Vancouver, British Columbia. Therefore, the park is influenced by anthropogenic sky glow from the west, leading to a significant gradient of expected night sky quality from west to east. 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.

2.2.3 Resource Threats Overview

The natural resources of NOCA 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 snowpack, glaciers, temperature, 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 Complex, as well as diminish air quality within the park and alter precipitation chemistry. Changes in land use on US Forest Service and private ownership lands surrounding the Complex could also contribute to changes in the quality and characteristics of park ecosystems and habitats. Naturally occurring geologic disturbances (e.g., landslides, floods, snow avalanches) could profoundly re-organize the physical context and dynamics of the NOCA landscape; and the quality and condition of NOCA ecosystems can also be altered by visitor impacts concomitant with recreational activities such as picnicking, hiking, backpacking, camping, and climbing. More specifically, NOCA resource management staff are concerned with and participating in: (1) the recovery and monitoring of rare, threatened, endangered, or sensitive species such as the Gray Wolf, Grizzly Bear, Townsend's Big-eared Bat, and Bald Eagle; (2) conducting studies focused on documenting and monitoring air pollution impacts in the Complex; (3) monitoring and enhancing native fish species populations including Pacific salmon spawning populations; (4) managing lake ecosystems and native amphibian populations; and (5) continued tracking of the vital signs and health of all NOCA natural resources. A list of additional resource management concerns is available at http://www.nps.gov/noca/naturescience/natural-resource-issues.htm.

2.3 Resource Stewardship

2.3.1 Management Directives and Planning Guidance

The management and conservation of the natural resources of NOCA is primarily mandated by the National Park Service Organic Act of 1916. Planning and guidance for NOCA resource management is also provided as part of the NOCA General Management Plan completed in 1988. Additional NOCA-specific management plans include: (1) Lake Chelan NRA General Management Plan–1995;

(2) Ross Lake NRA General Management Plan–2012; (3) NOCA Resource Management Plan–1999; (4) Wilderness Management Plan–1989; (5) NOCA Fire Management Plan–2007; (6) NOCA Mountain Fishery Management Plan/EIS–2008; (7) NOCA Invasive, Non-native Plant Management Plan/EIS 2012; and (8) Stehekin River Corridor Implementation Plan/EIS–2012. As 1 of 8 units comprising the North Coast and Cascades Network (NCCN), NOCA also uses the North Coast and Cascades Network Vital Signs Monitoring Report (Weber et al. 2009) as guidance for natural resource planning and management, as well as the 9 NCCN natural resource monitoring protocols and 1 data management plan listed in Table 1.

Table 1. 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
Fish Assemblages	Brenkman and Connolly 2008
Forest Vegetation	Acker et al. 2010
Glaciers	Riedel et al. 2008
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

As a member park of the NCCN, NOCA is supported by network staff who assist NOCA staff with data management, data collection, and administration of monitoring programs on glaciers, high mountain lakes, and vegetation. The NOCA Science Advisor and NPS Cooperative Ecosystem Studies Units (CESU) coordinate in-park research efforts with multiple federal, state, academic, and non-profit agencies, universities, and organizations. NOCA is also a participant in the North Coast and Cascades Network Research Learning Network (NCCN RLN), established in 2001, and the Pacific Northwest Cooperative Ecosystem Studies Unit (PNW CESU). The NCCN RLN and PNW CESU play critical roles in developing and implementing collaborative research studies at member parks. A partial list of partners-collaborators includes 8 federal and state agencies and 13 universities. NOCA resource management staff also actively engages in collaborative research agreements with federal and state agencies, and universities.

2.4 NCCN Monitoring Protocols

The following protocols are available at http://science.nature.nps.gov/im/units/nccn/reportpubs.cfm, as are 36 NCCN Monitoring Reports.

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. Published report 2191587.

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 Connolly, P. J. 2008. Protocol for monitoring fish assemblages in Pacific Northwest National Parks. U.S. Geological Survey Techniques and Methods 2–A7. 130 p.

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.

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.

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., R. A. Burrows, and J. M. Wenger. 2008. Long term monitoring of small glaciers at North Cascades National Park: A prototype park model for the North Coast and Cascades Network, Natural Resource Report NPS/NCCN/NRR—2008/066. National Park Service, Fort Collins, Colorado. 252 p.

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.

Siegel, R. B., Wilkerson, R. L., Jenkins, K. J., Kuntz II, R. C., Boetsch, J. R., Schaberl, J. P., and Happe, P. J. 2007. Landbird monitoring protocol for national parks in the North Coast and Cascades Network. U.S. Geological Survey Techniques and Methods 2–A6. 200 p.

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.

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 NOCA, 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 NOCA 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 – ecosystems and communities; (2) animals – mammals and birds; (3) animals – amphibians and fish; (4) air and water quality; and (5) plants – vegetation. Questions created and prioritized to help facilitate the development of long-term monitoring at NOCA 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 2). 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 2. 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; US 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; US 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	

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

Table 2. Focal resources and their indicators-stressors, and reference conditions (continued).

Resource	**Indicators-Stressors**	**Reference Condition/Comparison Metric**
Land Birds	Breeding density and trends	Historical condition
	Harlequin Ducks	Minimally disturbed
	Raptors–nesting occupancy and productivity	Minimally disturbed
	Threatened and endangered species	Conservation and management status designations (NatureServe; US ESA; IUCN; WA-Species of Concern)[1]
	Climate change	
Mammalian Fauna	Carnivores	Conservation and management status designations (NatureServe; US ESA; IUCN; WA-Species of Concern)[1];
	Elk	
	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)
	Ambient sound levels	
	Intensity, duration, and distribution of sound	
Vegetation	Forest health	Historic range of variation; current conditions; distribution- abundance; biological integrity for backcountry; best attainable condition for frontcountry; overall disturbance
	Tree mortality	
	Forest insects and diseases	
	Exotic plant species	
	Whitebark Pine	
	Alpine-subalpine vegetation	
	Fire	
	Biodiversity	
	Climate change	

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

Table 2. 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)[2]	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[3]
	Ion chemistry	
	Physical parameters (Alka, Cond, pH, DO)[2]	
	Water temperature	
	Benthic macroinvertebrates	

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

[3]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 NOCA 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 summarized the analysis and evaluation of 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 3.

Each resource assessment is generally structured as follows: (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. 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 information and data needs-gaps 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 NOCA natural resources.

Table 3. Focal North Cascades National Park Service Complex 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
Stream Water Quality	Variability of 12 physical habitat attributes; use of benthic macroinvertebrate model for predicting level of impairment
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; Upper Skagit River basin char; Lake Chelan Kokanee spawning; Ross lake Redside Shiner diet
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)
Hoary Marmot- American Pika	Status and distributions
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

Chapter 4 Natural Resource Condition Assessments

4.1 Air Quality and Air Quality-Related Values

(Tonnie Cummings, National Park Service, Pacific West Region Air Resources Specialist)

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 (NPS 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 include requirements to "preserve, protect, and enhance the air quality" in Class I national parks and wilderness areas (42 U.S.C. 7470 et seq.). NOCA is a Class I air quality area; Ross Lake and Lake Chelan National Recreation Areas are Class II areas. 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. NOCA is downwind of Seattle, Washington, and Vancouver, British Columbia, and there are substantial agricultural and livestock operations north and west of the park (Figure 3). Based on Washington Department of Ecology's 2005 emissions inventory (WDOE website 2005), large point sources of air pollution within approximately 100 km of the park included refineries, aluminum smelters, cement plants and industrial facilities (WDOE website 2012). Significant sources of area emissions are on-road vehicles, non-road vehicles (e.g., forklifts, tractors and snowmobiles), and wildfire (WDOE website 2012). The air pollutants of concern include sulfur (S) and nitrogen (N) compounds, ground-level ozone, persistent bioaccumulative toxics (PBTs), and mercury (Hg).

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, fire, vehicle emmisions, 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.

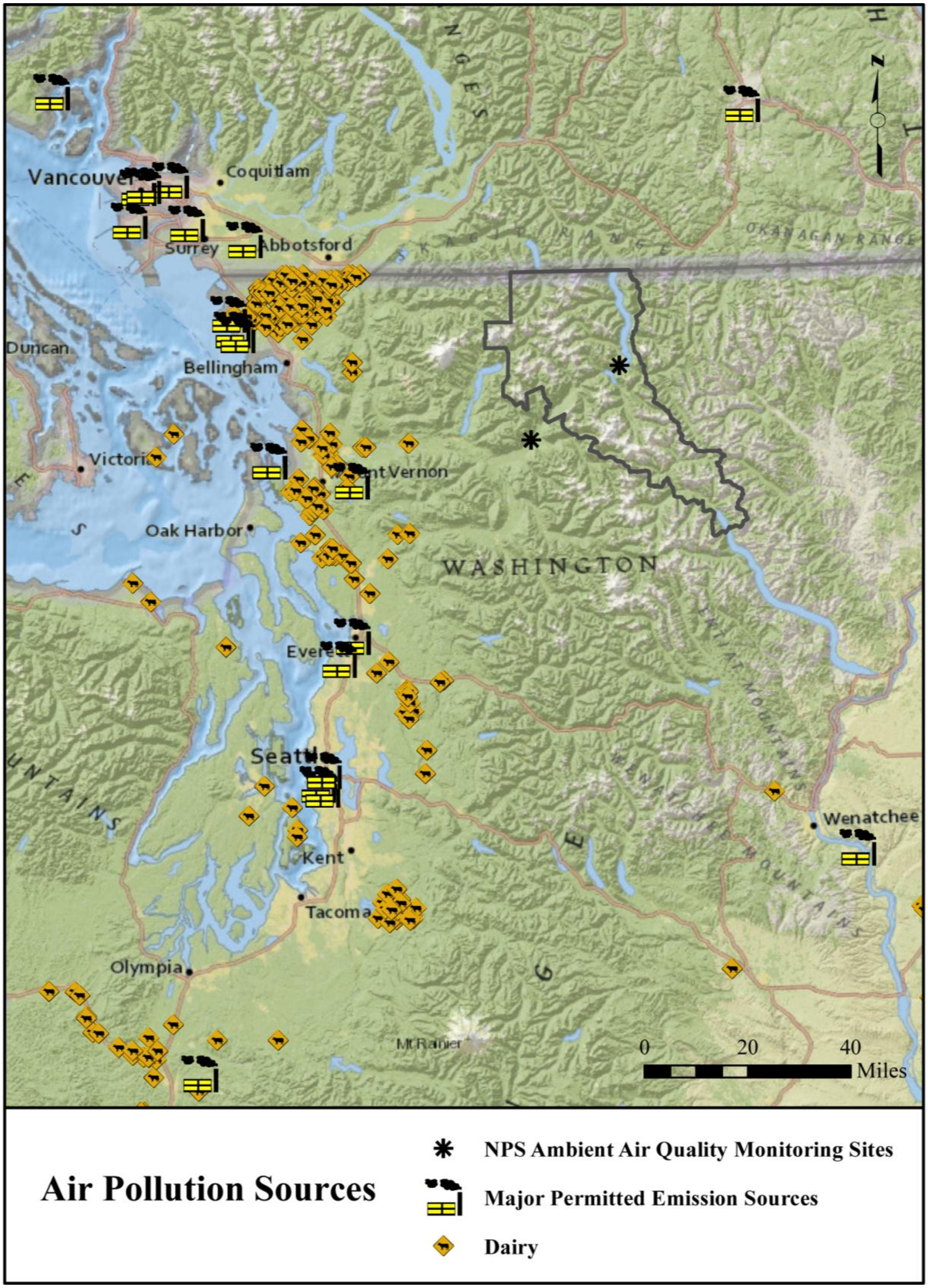

Figure 3. Pollution sources near North Cascades National Park Service Complex.

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 <10µm [PM10] and particles <2.5µm [PM2.5]). 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.Sulfur and N pollutants are eventually 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 a 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 NOCA since 1984 (Figure 4). 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 NOCA (Eilers et al. 1994); a 2003 addendum summarized visibility data collected at the 5 parks through 1999 (Air Resource Specialists 2003). Cummings (2013) provided an updated summary of air pollution monitoring and research conducted at NOCA through early 2013. Because a comprehensive discussion of air quality at NOCA is beyond the scope of this condition assessment, the overview reports should be consulted for additional information.

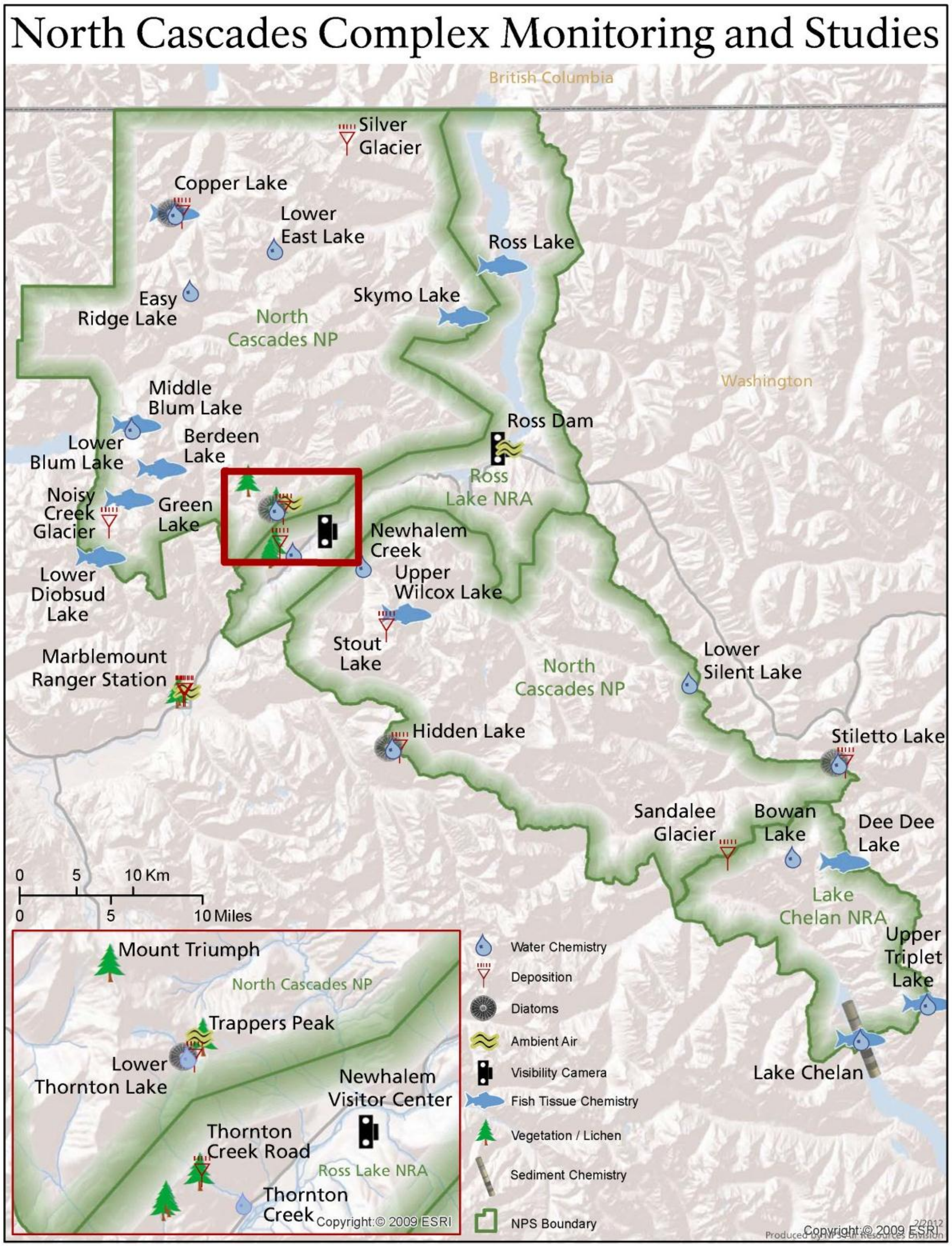

Figure 4. Locations of some of the air quality and AQRV monitoring and research at North Cascades National Park Complex (from Cummings 2013).

4.1.2 Approach

Visibility – Sources and Methods

The NPS began monitoring visibility at NOCA in. To provide qualitative documentation of visual conditions, pictures were taken with a 35-mm camera (1985–1991), and a digital camera (2003–present) (Figure 5). Based on an average of 2007–2011 data, on the 20% best visibility days the standard visual range was 313 km, and on the 20% worst visibility days the standard visual range was 110 km (Bret Schichtel, NPS Air Resources Division, pers. comm.). Standard visual range is the distance at which one can barely make out the presence of a large, dark object.

Figure 5. Examples of photographs documenting visibility conditions at North Cascades National Park Complex (from Cummings 2013).

Since 2000, an Interagency Monitoring of Protected Visual Environments (IMPROVE) particle monitor has been operating at Ross Lake Dam; the monitor provides quantitative measurements of mass, chemical elements, S, N, 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 2013). Data from the NOCA IMPROVE monitor are also used to represent visibility conditions at the nearby U.S. Forest Service Glacier Peaks Wilderness.

Nitrogen and Sulfur Deposition – Sources and Methods

There are 2 national deposition chemistry monitoring programs. The National Atmospheric Deposition Program (NADP) monitors wet deposition of sulfate, nitrate, and ammonium (NADP website 2014). The Clean Air Status and Trends Network (CASTNET) measures atmospheric concentrations of particles and gases including sulfate, nitrate, ammonium, sulfur dioxide, and nitric acid (CASTNET website 2012). Both NADP (1984–present) and CASTNET (1996–2007) monitoring have been conducted at the Marblemount Ranger Station at NOCA. In addition, from 2005–2007, limited sampling of bulk deposition (wet plus dry) and throughfall deposition (i.e., collected under the forest canopy) was conducted in the park (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 conditions and trends in parks throughout the country (NPS 2013).

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 for 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. Although Cummings et al. (2014) identified cumulative potential adverse ecological effects in the region (Figure 6), they determined that with the exception of lichens, N critical loads have not been well established for the Pacific Northwest.

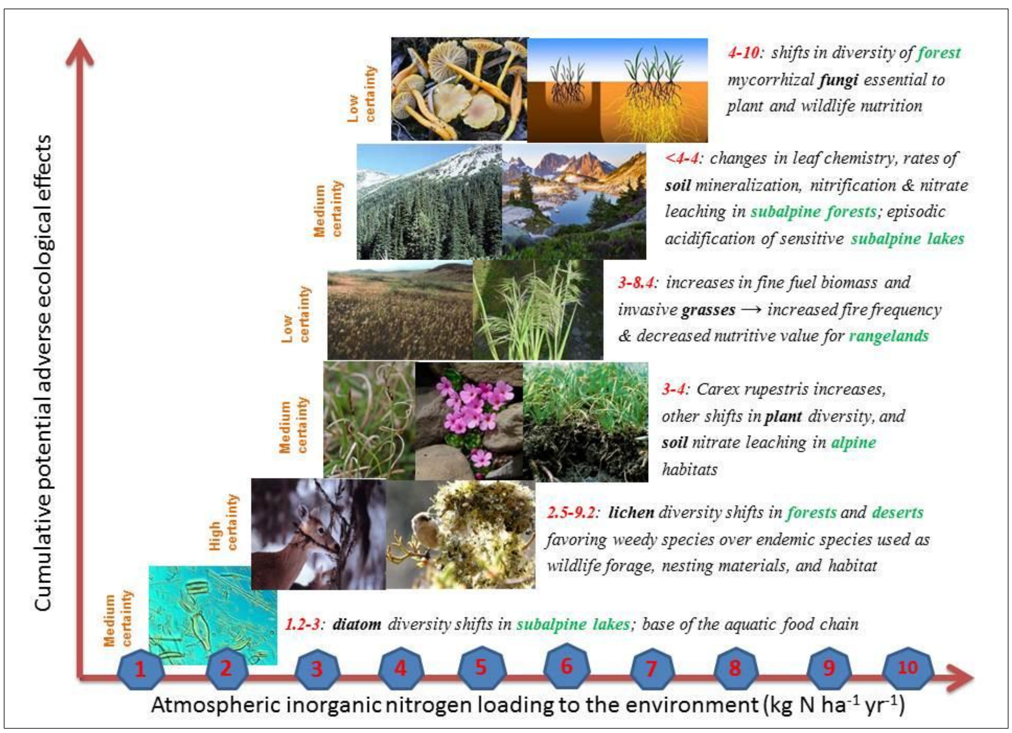

Figure 6. Cumulative potential adverse ecological effects associated with atmospheric N deposition in the Pacific Northwest (from Cummings et al. 2014). The reliability assessments are as follows: High Certainty when a number of published papers of various studies show comparable results, Medium Certainty 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 at the Marblemount Ranger Station from 1996–2007. Because concentrations were relatively low, monitoring was discontinued at that time. The NPS ARD uses park, EPA, state, tribal, and local monitors to interpolate air quality estimates for parks that do not have current on-site data.

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 4th highest daily maximum 8-hr ozone concentration and is currently set at 75 ppb. In January 2010, the 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], pp. 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 7–15 ppm-hrs.

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 and deposited around the globe. Hageman et al. (2010) correlated pesticide concentrations in snowpack from several national parks, including NOCA, with nearby cropland intensity and wind patterns and concluded that for all studied parks, less than 25 percent 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 0-10 percent of the Hg deposited in the Pacific Northwest is from local anthropogenic sources, approximately 20 percent 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 either of the sites adequately represent Hg deposition at NOCA. 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). Also in 2002, the NPS spearheaded a multi-agency study called 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 NOCA (Landers et al. 2008).). More recently, Eagles-Smith et al. (2014) analyzed Hg concentrations in fish collected between 2008 and 2012 from NOCA and 20 other western national parks.

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 bases condition assessments on wet deposition only because dry deposition data are not available for many areas. Wet deposition levels below 1.0 kilogram/hectare/year (kg/ha/yr) are not known to harm sensitive aquatic or terrestrial resources. Therefore, the NPS ARD classifies park condition of significant concern if wet deposition of S or N exceeds 3 kg/ha/yr, or if wet N deposition is 1–3 kg/ha/yr and the park contains N-sensitive ecosystems (NPS 2013). Based on over 1400 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 North Cascades, Mount Rainier, and Olympic National Parks to look for species changes associated with N deposition (Sheibley et al. 2014). Only 1 lake, Hoh Lake at Olympic NP, 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 was 1.2 kg/ha/yr of wet N.

Ozone

Given that there is relatively little information about the ozone sensitivity of many native plant species, and to be conservative, 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-hrs to protect vegetation; NPS 2013).

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, pers. comm.). Recommended Hg 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 Assessments

Visibility

The NPS ARD produces an annual report that provides condition and trend information for visibility, wet deposition, and ozone in parks, monuments and other areas managed by the NPS. The most recent report (NPS 2013), indicates no change in visibility on either the clearest or haziest days at NOCA from 2000–2009; however, there was an improvement on the clearest days over the entire period of record (i.e., 2000–2013; Figure X4).

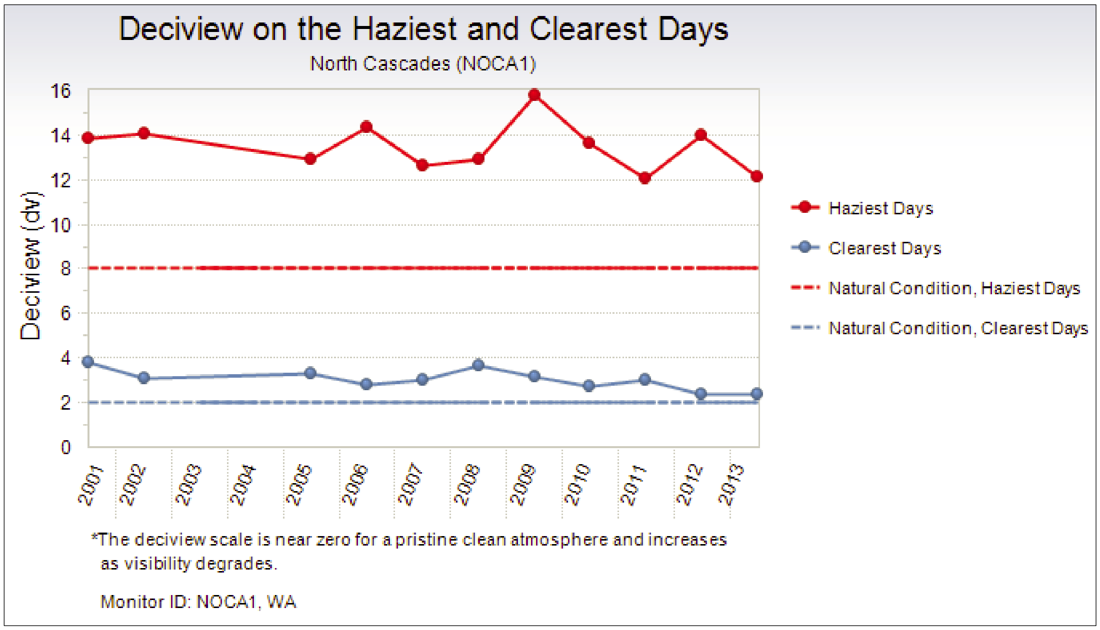

Figure 7. Deciview trends compared to natural conditions on the haziest and clearest days at North Cascades National Park Complex (from Federal Land Managers Environmental Database website 2014).

To quantify the amount of visibilityat a site, IMPROVE determines the dv difference between monitored visibility and calculated natural visibility conditions. The 2006–2011 average visibility difference at NOCA was 3.4 dv, indicating current visibility is 34% hazier than natural conditions (NPS website 2013). 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 (NPS 2013).

Nitrogen and Sulfur Deposition

Based on 2000–2009 NADP wet deposition data, there were improving trends in both S and N concentrations in precipitation at NOCA (Figure 8; NPS 2013).

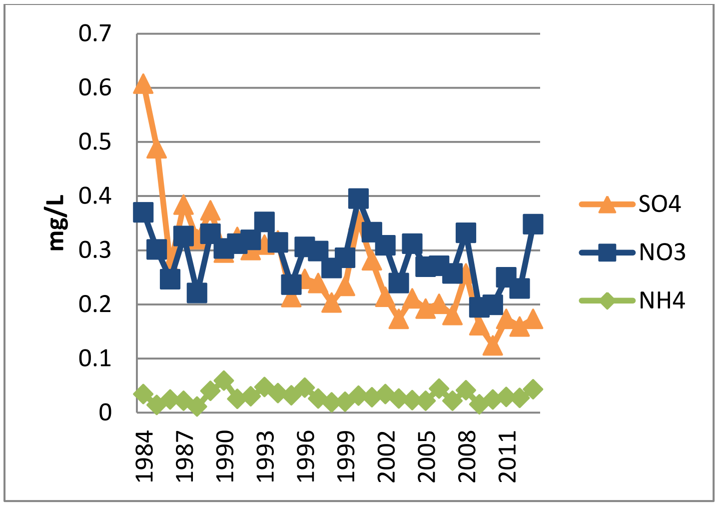

Figure 8. Trends in annual concentrations of sulfate, nitrate, and ammonium at the Marblemount Ranger Station NADP site at North Cascades National Park Complex (produced by NPS ARD 2014).

High elevation ecosystems in western Washington are though 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. NOCA was ranked in the highest risk category for both assessments.

Longterm NADP data show wet deposition of S and N at NOCA ranges between 1–2 kg/ha/yr (NADP website 2014). According to Geiser et al. (2010), the N critical load for lichens has likely not yet been exceeded at NOCA. However, the data indicate that in some years, wet N deposition may be at or approaching the critical load for aquatic ecosystems. 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, NOCA is in a condition of significant concern for atmospheric deposition.

Ozone

Based on 2003–2007 on-site data, the annual 4th-highest daily maximum 8-hr ozone concentration at NOCA was 54 ppb and the W126 was 2.0 ppm-hrs, both of which are below the proposed primary and secondary ozone NAAQS. The 2006-2010 interpolated data were comparable, with a 4th-highest daily maximum 8-hr ozone concentration of 55 ppb and a W126 of 2.3 ppm-hrs. The 1996–2007 on-site data showed slightly increasing ozone concentrations (Figure 9). Kohut (2004) assessed the risk of ozone-induced foliar injury at NOCA based on species sensitivity, ozone concentrations, and soil moisture (which influences ozone uptake). Kohut concluded there was low risk of ozone injury at NOCA. Therefore, given that current ozone concentrations are much lower than those known to threaten either human health or vegetation NOCA is in good condition for ozone.

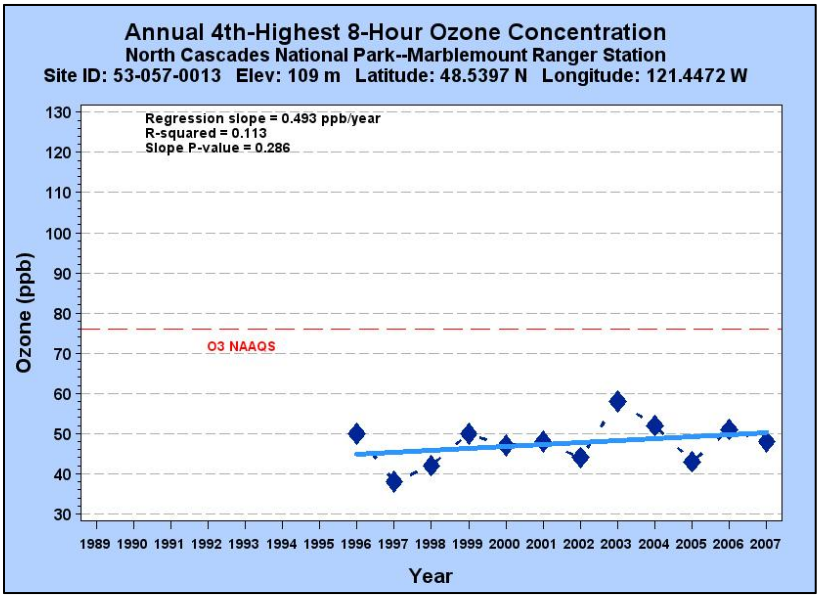

Figure 9. 1996-2007 ozone concentrations at North Cascades National Park Complex (from Cummings 2013).

PBTs

Moran et al. (2007) collected cutthroat trout (*Salmo clarkii*) from 5 lakes in NOCA, 5 lakes in Olympic National Park, and 4 lakes in Mount Rainier National Park in 2002–2003. Mercury was detected in trout from all lakes sampled, with the highest tissue concentration, 260 ppb, in a fish from Green Lake in NOCA. This value exceeds both Washington Department of Health's new human health consumption criteria and health thresholds for fish-eating wildlife. Fish from 2 lakes in NOCA with different Hg concentrations (Wilcox Lake with high concentrations and Skymo Lake with low concentrations) were examined for differences in gene expression. Fish from Wilcox Lake showed significant changes in metabolic, endocrine, and immune-related genes compared to fish from Skymo Lake. Eagles-Smith et al. (2014) analyzed fish samples from 3 lakes at NOCA and found relatively low concentrations of Hg. However, because a great deal of within-park variation was found at some intensively-studied parks (e.g., a 23-fold difference in Hg concentrations across the 17 sites at Mount Rainier NP), the authors caution that the 3 sample lakes at North Cascades may not adequately characterize Hg risk at the park. Moran et al. (2007) also detected low concentrations of 2 organochlorine compounds, total polychlorinated biphenyls, and dichlorodiphenyldichloroethylene in fish from all sampled lakes in NOCA.

As part of the WACAP study (Landers et al. 2008), passive air sampling devices, snow, conifer needles, and lichens from NOCA were sampled in 2005–2007. A number of PBTs typically associated with agriculture were detected in samples from the park. Given the occurrence of many PBTs and concentrations of Hg in some fish samples that exceeded human and wildlife health thresholds, NOCA 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 at NOCA by 2064; the plan proposes a glide path to reach natural conditions by 2280. Visibility monitoring at NOCA needs to continue so that NPS can track progress in achieving the goals of the Regional Haze Program.

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 loads estimates for NOCA, 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 NOCA are investigating the effects of N deposition on soils and alpine and subalpine vegetation (Darlene Zabowski and Anna Simpson, University of Washington). Results are expected in 2015. Also, as part of its long-term monitoring program, NPS is monitoring S and N concentrations in, and acid-sensitivity of, 6 NOCA lakes. A 2013–2015 nutrient enrichment experiment following up on the Sheibley et al. (2014) 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 (Jason Williams and Marc Beutel, Washington State University).

Ozone

If ozone concentrations at monitored locations in Washington state increase significantly in the future, ozone monitoring should be re-initiated at NOCA.

PBTs

More information is needed about the amount of, and trends in, deposition of Hg and other PBTs at NOCA. To better understand the extent of PBT occurrence and bioaccumulation, data should be collected from numerous locations throughout the park. Additional information is also 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. A current study is measuring Hg concentrations in dragonfly larvae from NOCA and several other parks nationwide. Results from recent Hg studies will inform future research needs.

Climate Change

It is not clear how climate change will affect air pollutant concentration and deposition in NOCA. 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 Pacific Northwest Region 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 NOCA (Susan Kaspari, Central Washington University). Further research is needed regarding the effects of black carbon on snowpack and glaciers in the park.

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4.2 Lake Water Quality

(Robert L. Hoffman, U.S. Geological Survey, 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). North Cascades National Park Service Complex (NOCA) recently implemented a program for the long-term monitoring of the park's aquatic ecosystems (Glesne et al. 2012, Rawhouser et al. 2012). NOCA has at least 301 confirmed lakes, although aerial photo interpretation of the park complex indicates that there could be as many as 561 lakes (Rawhouser et al. 2012:Table 1.4); and Weber et al. (2009) indicated that there are 530 lakes in NOCA. Many of the lakes are relatively small: 294 of the 301 lakes are <45 ha (median size: 0.36 ha; range: 0.003–39.3 ha); 7 lakes are >45 ha. In an unpublished report to NOCA, Lomnicky et al. (1989) catalogued the surface areas and elevations of 161 lakes and the relative depths of 74 lakes (Figure 10); these data are summarized in Table 4.

The primary objectives of this lake water quality assessment are to: (1) estimate the overall general trophic status of NOCA lakes; (2) determine average concentrations of cations, anions, acid neutralizing capacity, conductivity, pH, and dissolved oxygen; (3) describe the relative distributions of zooplankton and macroinvertebrates that inhabit NOCA lakes; and (4) summarize results reported in Rawhouser et al. (2012:Appendix D) for NOCA lakes of management concern ranked relative to their potential level of risk of impairment.

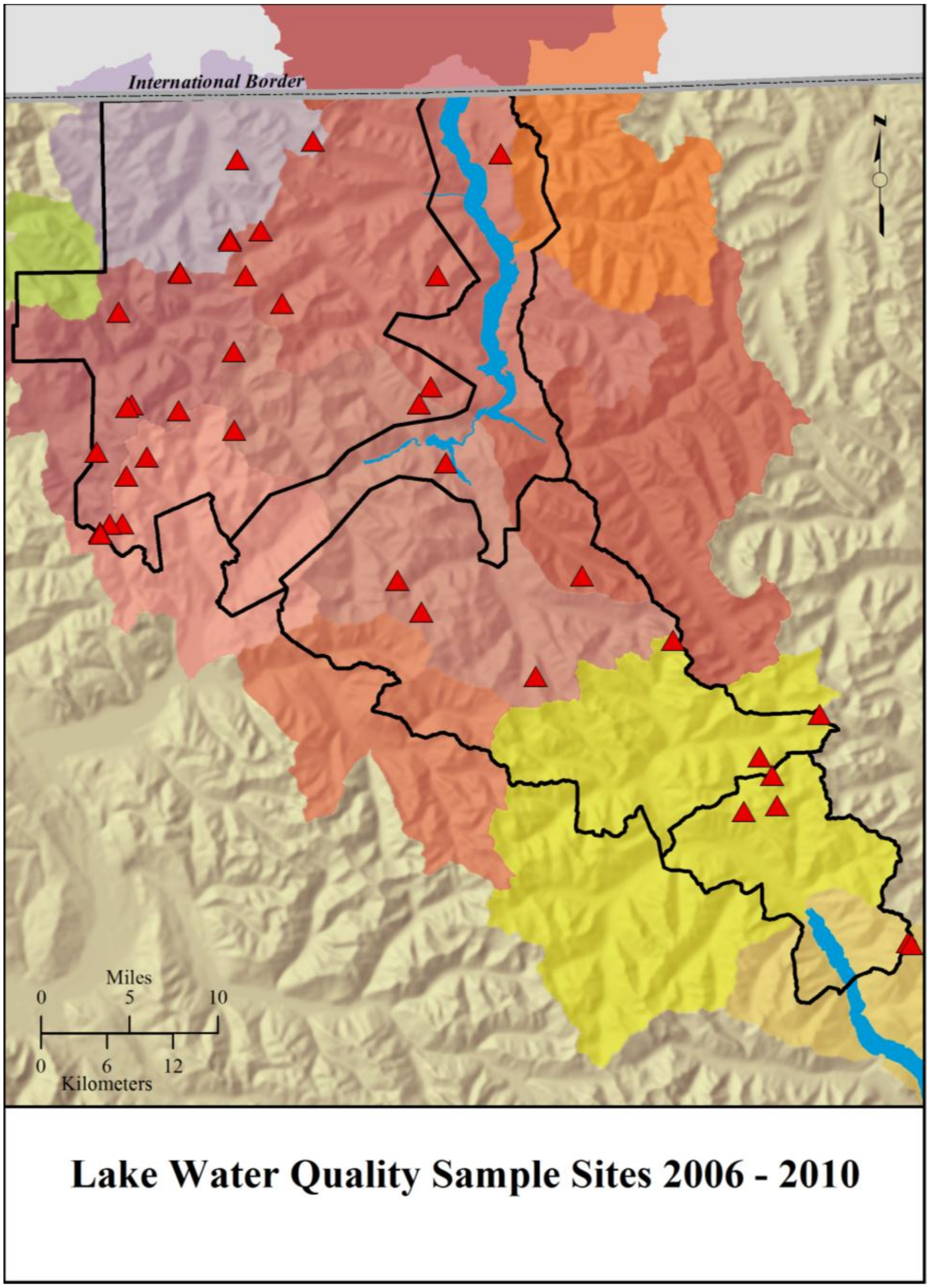

Figure 10. Distribution of NOCA lakes sampled 2006–2010 (see Figure 11 for key to 5th field HUC watershed boundary colors).

Table 4. Area, elevation, and relative depths of listed lakes, North Cascades National Park Service Complex, Washington (Lomnicky et al. 1989, unpublished report).

Parameters	*n*	Mean	Mode	Range
Area (ha)	161	4.8	0.1	00.1 – 65.1
Elevation (m)	161	1565	1388	412 – 2127
Relative depth (m)	74	6.0	2.0	1 – 30

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 2006 through 2009. The database comprised 66 CHLA measurements (representing 30 lakes; 23 sampled in 1 yr, 6 sampled in 2 yrs, and 1 sampled in 3 yrs); and 47 TN and TP measurements (32 lakes; 26 sampled in 1 year, 4 sampled in 2 yrs, and 2 sampled in 3 yrs). Descriptive statistics (mean, standard deviation, median, and range) were determined for each parameter. Nitrogen-phosphorus ratios were also calculated for 32 lakes.

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 primarily in August and September, 2006 through 2009. The database comprised 50 measurements representing 31 lakes for each parameter: 25 lakes were sampled in 1 yr; 4 lakes were sampled in 2 yrs; and 2 lakes were sampled in 3 yrs. Descriptive statistics (mean, standard deviation, median, and range) were determined for each parameter. Water samples were primarily collected from lake mid-depth.

Acid Neutralizing Capacity, Conductivity, pH, and Dissolved Oxygen

A database was created for measurements of acid neutralizing capacity (ANC, μeq/L), conductivity (COND, μS/cm), pH, and dissolved oxygen (DO, mg/L) for lakes sampled predominantly in August and September, 2006 through 2010. Descriptive statistics were determined for each parameter. The database comprised 52 measurements for ANC, COND, and pH representing 37 lakes: 26 lakes were sampled in 1 yr; 7 lakes were sampled in 2 yrs; and 4 lakes were sampled in 3 yrs. Water samples were primarily collected from lake mid-depth. The database also comprised 23 measurements for DO representing 17 lakes. Analysis was performed on water samples collected from the near surface and near bottom of each lake.

Zooplankton and Macroinvertebrates

Analysis of zooplankton taxa distribution was based on samples collected from 2006 through 2009, and the results were compared to summaries of the results of Deimling et al. (1997), Liss et al. (1998), and the 2009 Annual Report for North Coast and Cascades Network Core Mountain Lake Study Sites (Fradkin et al. 2012).

The distribution of macroinvertebrate taxa in NOCA lakes was based on samples collected from 1997 through 2009. These results were compared to results of a previous study by Hoffman et al. (1996).

Lakes of Management Concern

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 NOCA 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 NOCA 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). Nitrogen and phosphorus limitation in NOCA lakes were also assessed using the ratio of dissolved TN to dissolved TP concentration (Redfield 1958, Correll 1999). The ratio of dissolved inorganic nitrogen (DIN) to dissolved total phosphorus (DTP) concentration, considered to be a more accurate representation of nitrogen and phosphorus limitation in lakes (Morris and Lewis 1988, Bergström 2010), was not used in this analysis because concentrations of nitrate-nitrite were not available for calculating DIN (NO_3-NO_2 + ammonia). Lakes with a ratio of <7 were classified as nitrogen limited; lakes with a ratio of >15 were classified as phosphorus limited; and lakes with a ratio of 7 to 15 were classified as intermediate (i.e., either nitrogen or phosphorus limited or both; OECD 1982).

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 NOCA lakes was accomplished by comparing them to concentrations reported by Clow et al. (2002) and Bell-McKinnon (2010).

Acid Neutralizing Capacity, Conductivity, pH, and Dissolved Oxygen

Acid neutralizing capacity, 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 2006 through 2010 results with results reported by Landers et al. (1987; ANC), Larson et al. (1999; COND, pH), Clow et al. (2002; COND, pH), NPS (2009; ANC), and Mount Rainier National Park (MORA) 1988–2001 unpublished data (COND, pH, DO).

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 distribution and occurrence was compared to 2 previous studies of rotifer (Deimling et al. 1997) and diaptomid copepod (Liss et al. 1998) distributions in NOCA lakes, and a recent NPS report (Fradkin et al. 2012) on zooplankton assemblages in 6 NOCA lakes that are part of the North Coast and Cascades Network Mountain Lake Monitoring Protocol. The assessment of macroinvertebrates was accomplished using comparison 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 NOCA lakes 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. 2012:23–24); (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 5) were used to assign NOCA lakes sampled at least once between 2006 and 2009 to 1 of 4 trophic state classes. Based on concentrations of CHLA, 100% of the lakes sampled (n = 30) could be classified as oligotrophic (Table 6). This is a relatively important result because CHLA concentration is considered to be a better predictor of algal biomass, and by proxy productivity and trophic state, than TN or TP (Carlson and Simpson 1996). Based on TN concentrations, 97% of the sampled lakes (n = 32) could also be classified as oligotrophic; whereas, based on TP concentrations, 56% of the lakes sampled (n = 32) could be classified as oligotrophic, with the remainder of lakes classified as mesotrophic (22%) and eutrophic (22%) (Table 6). Compared to values for the 3 indices calculated for 30 non-NOCA Washington lakes (Bell-Mckinnon 2010), the mean concentration of CHLA is 28 times lower in NOCA lakes than the mean concentration of CHLA in the non-NOCA lakes; 8 times lower for TN; and equivalent for TP (Table 7). These differences in mean concentrations, especially for CHLA and TN, indicate that NOCA lakes, in general, are relatively low in productivity compared to the non-NOCA lakes.

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 the 32 NOCA lakes for which N:P ratios could be calculated, 21 (66%) were determined to be nitrogen limited ($\bar{x}$ ratio: 3; mode: 4; range: 1–6); 3 (9%) were phosphorus limited ($\bar{x}$ ratio: 23; mode: 18; range: 18–33); and 8 (25%) were intermediate ($\bar{x}$ ratio: 12; mode: 15; range: 7–15).

Table 5. 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 6. Number of NOCA lakes in each of 3 lake trophic classes based on measurements for chlorophyll *a* (CHLA), total nitrogen (TN), and total phosphorus (TP) concentrations (2006–2009).

Class	CHLA (*n* = 30)	TN (*n* = 32)	TP (*n* = 32)
Oligotrophic	30	31	18
Mesotrophic		1	7
Eutrophic			7

Table 7. Descriptive statistics: concentrations of chlorophyll a (µg/L), total nitrogen (mg/L), and total phosphorus (µg/L) for NOCA lakes sampled 2006–2009, and Washington (WA) lakes sampled in 2007[a].

Parameter	Metric	NOCA	WA Lakes
Chlorophyll a	*n* lakes	30 (66)[b]	30
	$\bar{x}$ (SD)	0.21 (0.23)	5.86 (6.1)
	median	0.12	1.91
	minimum	0.007	0.15
	maximum	1.11	26.08
Total Nitrogen	*n* lakes	32 (47)[b]	30
	$\bar{x}$ (SD)	0.05 (0.05)	0.41 (0.38)
	median	0.04	0.21
	minimum	0.01	0.03
	maximum	0.36	2.62
Total Phosphorus	*n* lakes	32 (47)[b]	30
	$\bar{x}$ (SD)	15.6 (20.1)	18.4 (25.02)
	median	7	7
	minimum	2	1
	maximum	96	190

[a] Bell-McKinnon, M. 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

Cations and Anions

Water for the analysis of the concentrations of cations and anions was collected at mid-maximum depth from 31 NOCA lakes sampled at least once, 2006 through 2009, and compared to concentrations calculated for 30 non-NOCA Washington lakes (Bell-McKinnon 2010) (Table 8). Mean values for all ions except NH4+ in NOCA lakes were from 2 to 53 times lower than mean concentrations for ion concentrations in the non-NOCA lakes; the mean values for $NH4^+$ in NOCA and non-NOCA lakes were similar. When compared to mean ion concentrations in 6 national parks in the western United States (Clow et al. 2002), NOCA mean concentrations were within the range of values for lakes sampled in the other parks: (1) K^+, Na^+, and NH_4^+ in NOCA lakes were similar to the other park mean concentrations; (2) $Cl^–$ and $NO_3^–$ mean concentrations in NOCA lakes were in the lower range of values; and (3) Ca^{2+}, Mg^{2+}, and $SO_4^{2–}$ mean concentrations in NOCA lakes were within the mid-range of mean values determined for the other parks (Table 8).

Table 8. Descriptive statistics: concentrations of cations and anions (μeq/L) in NOCA lakes (2006–2009; mid-depth), Washington (WA) lakes (2007)[a], and 6 national parks[b] in the western United States sampled in the fall of 1999.

Ion	Metric	NOCA	WA (2007)	GLAC	LAVO	ROMO	SEKI	YELL	YOSE
Ca^{2+}	*n* lakes	31 (50)[c]	30	4	7	22	20	6	9
	$\bar{x}$ (SD)	156.4 (195.8)	373.3 (392.7)	307.6	26.2	67.3	57.8	453.2	29.1
	median	110.4	184.6	239.3	10.4	62.3	55.4	319.8	26.9
	range	0 – 1323.8	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	31 (50)[c]	30	4	7	22	20	6	9
	$\bar{x}$ (SD)	4.3 (4.1)	43 (216.9)	3.0	4.4	3.6	3.3	203.8	3.7
	median	3.6	10	3.0	4.4	3.1	3.0	47.5	2.8
	range	0 – 22.3	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	31 (50)[c]	30	4	7	22	20	6	9
	$\bar{x}$ (SD)	33.0 (55.8)	321.7 (497)	157.5	20.4	16.9	5.5	135.6	4.8
	median	21.2	101.2	129.6	15.6	15.6	3.7	74.0	4.1
	range	0 – 367.1	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	31 (50)[c]	30	4	7	22	20	6	9
	$\bar{x}$ (SD)	21.4 (15.1)	603.3 (3720)	10.4	15.1	25.9	19.2	301.4	17.6
	median	17.4	114	10.5	8.4	10.5	19.4	110.3	16.4
	range	3.2 – 81.8	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	31 (50)[c]	30	4	7	22	20	6	9
	$\bar{x}$ (SD)	1.6 (2.6)	0.55 (1.11)	≤0.5	0.6	≤0.5	0.6	0.7	≤0.5
	median	0.21	0.55	≤0.5	≤0.5	≤0.5	≤0.5	≤0.5	≤0.5
	range	0 – 10.1	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	31 (50)[c]	30	4	7	22	20	6	9
	$\bar{x}$ (SD)	4.3 (2.2)	226.8 (1052.4)	1.8	2.5	2.2	1.9	403.6	1.7
	median	3.8	54.4	1.7	2.6+	1.9	1.4	16.8	1.7
	range	1.5 – 11.7	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 8. Descriptive statistics: concentrations of cations and anions (µeq/L) in NOCA lakes (2006–2009; mid-depth), Washington (WA) lakes (2007)[a], and 6 national parks[b] in the western United States sampled in the fall of 1999 (continued).

Ion	Metric	NOCA	WA (2007)	GLAC	LAVO	ROMO	SEKI	YELL	YOSE
NO_3^-	*n* lakes	31 (50)[c]	30	4	7	22	20	6	9
	$\bar{x}$ (SD)	0.2 (0.5)	0.8 (4.03)	2.0	≤0.3	4.3	0.9	1.4	0.7
	median	0.0	0.16	1.7	≤0.3	1.9	≤0.3	0.5	≤0.3
	range	0 – 1.8	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	31 (50)[c]	30	4	7	22	20	6	9
	$\bar{x}$ (SD)	36.2 (37.5)	281.5 (1979.7)	21.8	4.0	25.7	9.1	646.9	5.8
	median	29.8	28.1	17.2	2.3	21.9	6.7	30.3	3.8
	range	0 – 236.1	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; GLAC = Glacier N; LAVO = Lassen Volcanic NP; ROMO = Rocky Mountain NP; SEKI = Sequoia and Kings Canyon NPs; YELL = Yellowstone NP; YOSE = Yosemite NP

[c]number of measurements

Acid Neutralizing Capacity, Conductivity, pH, and Dissolved Oxygen

Water for the analysis of acid neutralizing capacity (ANC) was collected at mid-maximum depth from 37 NOCA lakes sampled 2006 through 2010. Mean ANC concentration was 168.8 μeq/L (range: 7.1–1772.4 μeq/L). According to Landers et al. (1987), an ANC concentration ≤200 μeq/L has often been used as a threshold for separating acid-sensitive lakes from lakes less sensitive to acidic deposition. Twenty-nine of the 37 lakes sampled had ANC concentrations <200 μeq/L. An ANC concentration ≤100 μeq/L has also been identified as a threshold below which freshwater biota become increasingly negatively affected by acidic deposition and acidification (NPS 2009). Four major levels of impact concern include Severe, Elevated, Moderate, and Low (Table 9). Just over 50% (n = 19) of the 37 lakes sampled have ANC concentrations that classify them as being of Low concern for negative ecological effects to freshwater biota; 43% can be classified as being of Moderate (n = 8) and Elevated (n = 8) concern; and only 2 lakes can be classified as being of Severe concern for negative ecological effects.

Mid-maximum depth mean values for COND and pH of 37 NOCA lakes sampled 2006 through 2010 (Table 10) were compared to: (1) mean values of 58 NOCA lakes sampled 1989 through 1993 (Larson et al. 1999); (2) mean values of 21 to 25 MORA lakes sampled 1988 through 2001 (unpublished data); and (3) mean values determined by Clow et al. (2002) for 6 national parks in the western United States. The NOCA and MORA mean values for COND were equivalent, ranging from 22.5 to 26.6 μS/cm; pH mean values were also equivalent, ranging from 6.7 to 7.0. Compared to mean COND and pH calculated for the other 6 western US national parks, COND in NOCA lakes was most similar to the mean COND of the 4 lakes sampled in Glacier National Park; pH was circum-neutral, ranging from 6.6 to 7.4 (Table 10).

Near surface and near bottom mean concentrations of DO in 17 NOCA lakes sampled 2006 through 2010 were compared to mean concentrations in MORA lakes sampled 1988 through 2001 (Table 10). The mean values were similar between the 2 parks, although NOCA values were slightly higher, and ranged from 7.3 to 10.0 mg/L (near surface; $\bar{x}$ = 9.1 mg/L) and 7.0 to 10.0 mg/L (near bottom; $\bar{x}$ = 8.9 mg/L).

Table 9. Assignment of 37 NOCA lakes sampled 2006–2010, to 4 categories based on ANC concentrations (NPS 2009). The categories represent levels of concern and potential negative ecological effects to freshwater communities due to a lake's sensitivity to acidification.

Level of Concern	[ANC]	Ecological Effects	Lakes
Severe	0–20 µeq/L	Acid-tolerant species begin to outnumber acid-sensitive species, although almost all biota show some level of negative effects. Many species are greatly reduced in population size, and species composition and community richness are greatly reduced.	LS-05-01, MC-17-02
Elevated	20–50 µeq/L	Increase in negative effects on fitness and recruitment of acid-sensitive species. Loss of these species often results in distinct decreases in species richness and composition, although overall community abundance and productivity remain high. Short-term stress due to episodic acidification increases for many species.	LS-12-01, M-12-01, M-14-01, MC-03-01, MC-10-01, MC-27-01, MM-11-01, MS-04-01
Moderate	50–100 µeq/L	Fitness and recruitment in acid-sensitive species declines. Community diversity may decline due to effects on these species. However, there is generally minimal change in community abundance, productivity, and health.	LS-01-01, LS-07-01, M-04-01, M-07-01, MA-03-01, MC-20-01, MR-01-01, MR-12-01
Low	>100 µeq/L	Biota generally not harmed.	DD-01-01, EP-06-01, EP-11-01, FP-09-01, HM-03-01, LS-02-01, LS-06-01, M-11-01, MC-14-02, MC-28-01, ML-02-01, MR-05-01, MR-09-01, MSH-02-01, PM-01-01, PM-12-01, RD-02-01, SM-02-01, SM-02-02

Table 10. Descriptive statistics: values for conductivity (µS/cm), pH, and dissolved oxygen (mg/L) in NOCA lakes sampled 2006–2010, NOCA lakes sampled 1989–1993[a], MORA lakes sampled in August 1988–2001[b], and in 6 national parks[c] in the western United States sampled in the fall of 1999. Conductivity and pH measurements were from mid-maximum depth samples; dissolved oxygen measurements were from near surface (ns) and near bottom (nb) samples.

Index	**Metric**	**NOCA (2006–2010)**	**NOCA (1989–1993)**	**MORA ns (1988–2001)**	**MORA nb (1988–2001)**	**GLAC**	**LAVO**	**ROMO**	**SEKI**	**YELL**	**YOSE**
conductivity	*n* lakes	37 (52[d])	58	21 (30[c])	21 (28[c])	4	7	22	20	6	9
	$\bar{x}$ (SD)	26.8 (28.3)	24.2 (29.4)	22.9 (16.6)	22.5 (16.6)	44.4	7.0	12.2	9.0	201.3	6.2
	median	18.5		19.1	16.5	30.9	4.4	12.2	8.8	127.1	5.6
	minimum	4.4	1.9	5.4	4.8	6.1	3.1	6.3	3.1	21.0	2.9
	maximum	176.4	156.9	70.2	73.7	109.7	17.0	23.9	21.0	711.0	10.3
pH	*n* lakes	37 (52[d])	58	25 (43[c])	24 (44[c])	4	7	22	20	6	9
	$\bar{x}$ (SD)	6.8 (0.6)	7.0	7.0 (0.53)	6.7 (0.68)	7.4	6.7	6.9	6.8	7.2	6.6
	median	6.8		6.95	6.53	7.4	6.7	6.8	6.9	7.8	6.6
	minimum	5.6	5.9	5.77	5.37	6.7	6.3	6.3	6.0	4.3	6.2
	maximum	8.1	8.7	9.14	9.10	8.1	7.2	7.2	7.3	8.4	6.9
dissolved oxygen (ns)	*n* lakes	17 (23[d])		27 (45[c])							
	$\bar{x}$ (SD)	9.1 (0.8)		8.3 (0.97)							
	median	9.3		8.0							
	minimum	7.3		7.1							
	maximum	10.0		11.1							
dissolved oxygen (nb)	*n* lakes	17 (23[d])			24 (45[c])						
	$\bar{x}$ (SD)	8.9 (0.9)			7.2 (2.2)						
	median	9.2			7.6						
	minimum	7.0			1.8						
	maximum	10.0			10.6						

[a] Larson et al. (1999)

[b] MORA, unpublished data

[c] Clow et al. (2002); water samples were collected from the epilimnion; GLAC = Glacier N; LAVO = Lassen Volcanic NP; ROMO = Rocky Mountain NP; SEKI = Sequoia and Kings Canyon NPs; YELL = Yellowstone NP; YOSE = Yosemite NP

[d] number of measurements

Zooplankton

Samples were collected from 31 NOCA lakes from 2006 through 2009. A total of 42 taxa (24 rotifers and 18 crustaceans) were identified from 78 samples. Occurrence was relatively limited with 32 taxa (76%) each present in <10 samples (and 14 of these taxa each present in only 1 sample), and 10 taxa present in ≥10 samples (range: 10–62). The predominant taxa were the rotifers *Keratella chochlearis* (62 samples), *Keratella hiemalis* (51 samples), and *Synchaeta* spp. (20 samples); the calanoid copepod *Hesperodiaptomus kenai* (23 samples); the cladoceran *Chydorus sphaericus* (23 samples); and the cyclopoid copepod *Microcyclops varicans* (19 samples). Taxa distributions were also limited with the maximum number of taxa/lake, n = 12, accounting for just over 28% of all identified NOCA taxa. The mean number of taxa/lake was 5.3 (mode = 3.0 taxa/lake; range: 1–12 taxa/lake).

Macroinvertebrates

A total of 179 macroinvertebrate taxa were collected from 121 NOCA lakes sampled 1997 through 2009. These taxa represented 17-Level 2 taxonomic groups (i.e., phylum to order) and 50 identified families (Table 11). Occurrence and distributions were limited; for example: 92 taxa (51%) were each collected from ≤11 lakes, 28 taxa (16%) were present in 2–3 lakes each, and 24 taxa (13%) were each only collected from 1 lake. The average number of taxa/lake was 34 (mode: 80 taxa; range: 5–89).

Table 11. Macroinvertebrates collected from NOCA lakes, 1997–2009.

Level 1 Groups	Level 2 Groups	Number of Families
Arthropoda	Acari	
Turbellaria	Turbellaria	
Nematoda	Nematoda	
Nematophora	Nematophora	
Annelida	Oligochaeta	
	Hirudinea	1
Mollusca	Gastropoda	
	Pelecypoda	1
Crustacea	Amphipoda	3
Insecta	Coleoptera	2
	Diptera	12
	Ephemeroptera	7
	Hemiptera	3
	Megaloptera	1
	Odonata	5
	Plecoptera	6
	Trichoptera	9

Lakes of Management Concern

Fifty-one NOCA lakes were identified as being of management concern (Rawhouse et al. 2012:Appendix D). Lake Chelan was the only 303d listed lake under the CWA; only the most northern part of Lake Chelan is located within the southern boundary of NOCA. Based on informed risk criteria (Rawhouser et al. 2012:Table 1.24, p. 43), 34 of the 51 lakes (67%) 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 17 lakes 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. Eight lakes were ranked as threatened: (1) Gorge, Diablo, and Ross Lakes are each >50 ha (124 ac) and are impoundments of the upper Skagit River; (2) Lake Chelan is also >50 ha; and (3) County Line Pond, Newhalem Ponds E, Newhalem Ponds W, and Thunder Lake are each <50 ha.

Assessment

Examination of the trophic state of NOCA 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 NOCA lakes by Clow and Campbell (2008). A majority of NOCA lakes examined for nutrient limitation were also found to be nitrogen limited.

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). NOCA lakes, based on their ion concentrations in this assessment and past studies (Loranger et al. 1986, Clow and Campbell 2008), are no exception to this widely-accepted view. Although NOCA lakes at present show conflicting limited shifts in concentrations of ions (Clow and Campbell 2008, and the results of this report), the lakes in the park complex remain susceptible to potential future changes due to atmospheric deposition of pollutants, precipitation acidity and acidified snowmelt runoff (Clow and Campbell 2008), and changes in local and regional climate (Hauer et al. 1997, Murdoch et al. 2000, Parmesan 2006).

Measuring acid neutralizing capacity, 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 ANC <200 μeq/L, COND <35 μS/cm, and pH <6.0 are considered to be sensitive to acidification (NRCC 1981, Turney et al. 1986, Landers et al. 1987). Up to 78% of the 37 NOCA lakes examined in this analysis had ANC (n = 29) and COND (n = 26) values below the threshold for each parameter, indicating that many of the lakes surveyed are likely sensitive to acidification based on their ANC and COND levels. Conversely, 92% of the lakes had pH values above the pH threshold for acid sensitivity. Clow and Campbell (2008:Table 4) also found that concentrations of alkalinity in NOCA lakes was about one-half the concentrations in MORA lakes, indicating that NOCA lakes are even more sensitive to acidification than are MORA lakes.

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 NOCA 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 thresholds (6.0 and 8.0 mg/L, respectively) indicate some production impairment (Chapman 1986:31). The near surface and near bottom DO concentrations in NOCA lakes are most often above upper threshold limits and therefore adequate for supporting both invertebrate and vertebrate aquatic biota (DO concentration range 7.0 to 10.0 mg/L).

A total of 42 zooplankton taxa (24 rotifers and 18 crustaceans) were identified from NOCA lakes sampled from 2006 through 2009. Their occurrence and distributions were limited, although 6 of the taxa (*K. chochlearis, K. hiemalis, Synchaeta spp., H. kenai, C. sphaericus, and M. varicans*) were identified as relatively widely distributed. Fradkin et al. (2012) reported a total of 20 taxa (7 rotifers and 13 crustaceans) from 6 NOCA core study lakes, with the rotifers *K. chochlearis* and *K. hiemalis* also the most widely distributed (6 and 4 lakes, respectively). Fradkin et al. (2012) also reported that calanoid and cyclopoid copepodids and copepod nauplii were also widely distributed (4 to 5 lakes). For 66 NOCA lakes sampled 1989 through 1993, Deimling et al. (1997) identified 41 rotifer taxa. Similar to the results for the NOCA lakes sampled 2006 through 2009, rotifer occurrence and distributions were limited. Over half of the taxa (n = 21) were each present in <7 lakes, and 32% (n = 13) were each present in only 1 or 2 lakes. Dominant rotifer taxa included *Collotheca mutabilis, Conochilus unicornis, Kellicottia longispina*, and *K. chochlearis* and *K. hiemalis*. Also during the period 1989 thorough 1993, Liss et al. (1998) identified 5 diaptomid copepod species from 27 NOCA lakes. The most widely distributed species was *H. kenai* (similar to the 2006 through 2009 results) present in 22 lakes, followed by *Hesperodiatomus tyrrelli* present in 12 lakes. The other 3 species (*Hesperodiaptomus arcticus*, *Hesperodiaptomus leptopus*, and *Hesperodiaptomus lintoni*) were each present in only a few lakes. These results suggest that: (1) NOCA lakes are important habitats for uncommon and rare species present in the park and perhaps in the Cascade Range; and (2) that the species primarily contributing to zooplankton assemblage structure in NOCA lakes are relatively stable. The primary contributing rotifer and crustacean zooplankton taxa in NOCA lakes are also known to be common members of zooplankton assemblages in other western North American mountain lakes (Larson et al. 2009).

The limited distribution of macroinvertebrates in NOCA lakes sampled 1997 through 2009 is similar to their distributions in other relatively undisturbed and pristine mountain lakes. For example, Hoffman et al. (1996) analyzed the distributions of macroinvertebrates in 41 NOCA lakes, 1989 through 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 distributions 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 NOCA 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). Research also indicates that the introduction of non-native fish into naturally fishless mountain lakes can negatively affect the presence and distribution of lake macroinvertebrates, as well as zooplankton species (Parker et al. 2001, Knapp et al. 2005, Knapp and Sarnelle 2008, Hannelly 2009).

Clow and Campbell (2008) examined the atmospheric deposition of inorganic nitrogen and sulfur at NOCA. They found that wet deposition of inorganic nitrogen is highest in the vicinity of NOCA as compared to the deposition at MORA. This deposition is due, in part, to anthropogenic sources in the Puget Sound area (NPS 2002). Trend analysis also indicated, however, that inorganic nitrogen deposition at NOCA was relatively stable. Clow and Campbell (2008:Table 2) further determined that the average wet deposition of sulfate at the NOCA National Atmospheric Deposition Program/National Trends Network site at Marblemount (5.0 μeq/L) was equivalent to the deposition at the NADP/NTN site at Tahoma Woods near MORA (4.6 μeq/L), but was highest at the Paradise NADP/NTN site within the MORA park boundaries (7.5 μeq/L). Sulfate concentrations, however, are most likely declining as shown by a significant decrease in concentrations at Eunice Lake in MORA, which is the site nearest upwind from a power plant in Centralia, Washington, where emission controls were added in 2001. Potential effects of inorganic nitrogen and sulfate deposition include episodic or chronic acidification, and, with respect to nitrogen, possible lake eutrophication or increased productivity. 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.

Conclusion

NOCA lakes are generally low in productivity and nutrient concentrations, and they are primarily nitrogen limited (based on results for 32 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 NOCA landscape. Overall, NOCA lakes are predominantly oligotrophic with nutrient concentrations typically well below the upper threshold for this trophic state. At present, NOCA lakes can be rated as being minimally disturbed by non-stochastic natural perturbations or human activities. However, 51 lakes have been identified as being of management concern, and 17 of these lakes have been ranked as being at moderate to high risk of impairment due to non-stochastic natural perturbations or human activities; 8 lakes are considered threatened.

4.2.5 Emerging Issues

There are 3 basic issues that have the potential of affecting the present status and health of NOCA 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). Atmospheric deposition of nutrients (e.g., nitrogen, phosphorus, and carbon) and pollutants (e.g., sulfate and mercury), primarily from nearby urban locations (e.g., Vancouver, BC, and Puget Sound, WA), also have the potential of degrading NOCA lake water quality (Carpenter et al. 1998, Mast et al. 2003). Because of their overall low buffering capacity, NOCA 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 32 NOCA lakes with documented TP measurements, 14 (44%) have TP concentrations >10 μg/L. The atmospheric deposition of mercury in NOCA lakes is also a concern because of the long transport distances for this potentially toxic element. Although no mercury studies are presently being conducted at NOCA, recent research at Mount Rainier National Park 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 MORA 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 NOCA lakes is a potential threat to lake water quality. The primary avenue for introduction is most likely accidental, with deliberate introduction being least likely.

NOCA has implemented a lake monitoring program as part of the North Coast and Cascades Network natural resources monitoring program. Six core NOCA lakes are included as part of this monitoring effort. These lakes should continue to be monitored for 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.

4.2.6 Information and Data Needs–Gaps

The NOCA 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. 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. An on-going attempt should also be made to collect data from NOCA lakes to examine the possible presence of air-borne contaminants and pollutants of local, regional, and global origin. Lake riparian disturbance surveys have also been conducted at 33 lakes over multiple years (2006–2010); data collection includes survey plot impact descriptions and qualitative shore-nearshore disturbance scores. These data should be analyzed in the future using multivariate analysis. Finally, NOCA wetlands were inventoried in 1990, 1991, and 1994 (for example, see Holmes and Kuntz 1994). These inventories were designed to identify and classify wetlands in the park complex, and document their floral characteristics. It would be beneficial, if funding and time allow, for NOCA to consider more intensively sampling, and perhaps monitoring, a representative subset of these wetlands in the future.

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4.3 Stream Water Quality

(Robert L. Hoffman, U.S. Geological Survey, FRESC)

4.3.1 Introduction

Streams and rivers are an integral part of the landscape of North Cascades National Park Service Complex (NOCA). 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 6500 km (4039 mi) of permanent streams and rivers in 11 NOCA watersheds (Figure 11).

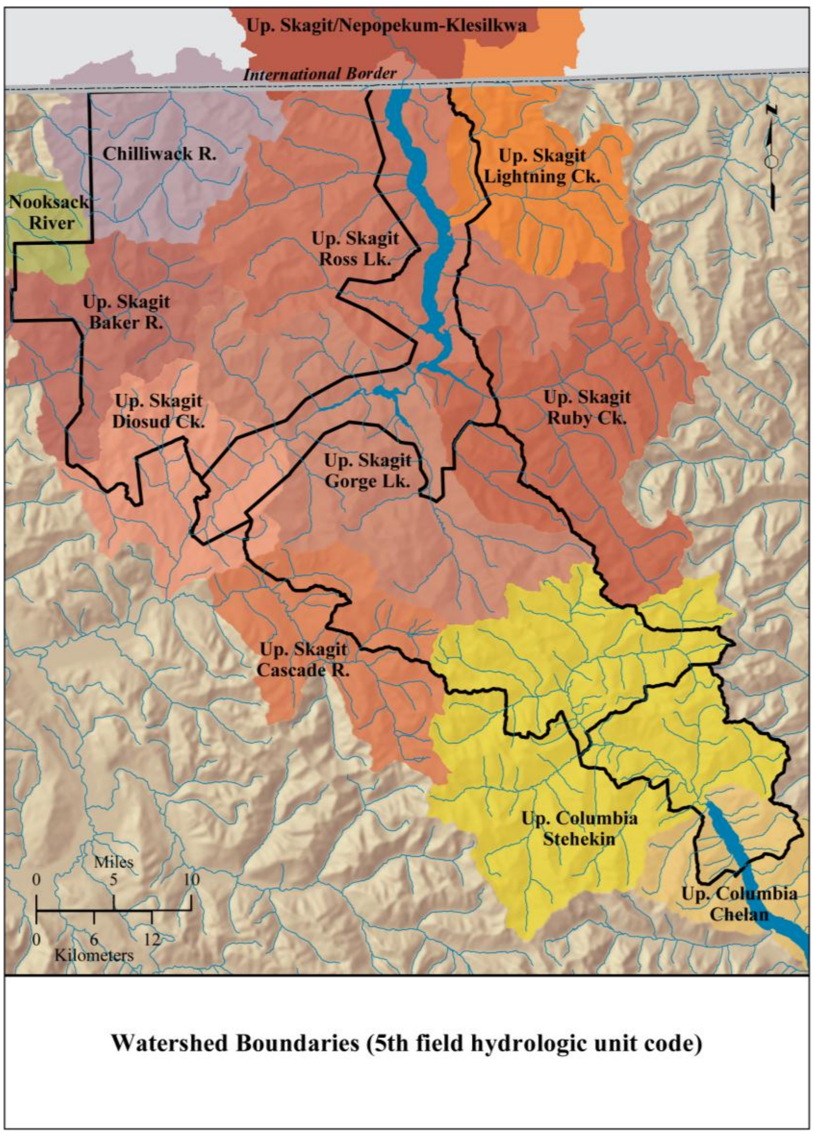

Figure 11. North Cascades National Park Service Complex 5th field HUC watershed boundaries.

4.3.2 Approach

Stream habitat attributes and the occurrence of bentic macroinvertebrates were used to assess the condition of NOCA streams and rivers. Zyskowski (2006) reported the results of surveys conducted 1995–2004 that variously measured 25 physical stream and river attributes, and these results are summarized as part of this assessment. The results of an unpublished NOCA report (Benthic Macroinvertebrate Predictive Model Development and Site Assessment) describing the outcome of the development and use of a predictive model based on the observed versus expected (O/E) occurrence of benthic macroinvertebrates in stream and river survey sites are also summarized as part of this assessment. 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 NOCA steams and rivers to impairment.

4.3.3 Reference Conditions and Comparison Metrics

The results of both reports mentioned in 4.3.2 above have each contributed to the assessment of the condition of NOCA streams and rivers. Results of the stream habitat surveys provide baseline information about the variability of stream habitat attributes among the surveyed study reaches, and are useful for the identification of general reference conditions against which the results of future surveys can be compared. The O/E scores calculated for NOCA study reaches as part of the benthic macroinvertebrate predictive model development and site assessment can be used to determine the condition of surveyed sites according to 5 condition classes or quality bands (Table 12).

Table 12. Biological condition quality bands for North Cascades Region streams. Labels and descriptions follow those of the Australian River Assessment System program, Simpson and Norris 2000. O/E = Observed/Expected. (Table from an unpublished NOCA report: Benthic Macroinvertebrate Predictive Model Development and Site Assessment).

Quality Band	Label	O/E Criteria	Description
X	Richer than reference	>1.213	More taxa than expected or mild organic enrichment
A	Reference	0.830–1.213	Expected number of taxa within the range found at 80% of reference sites
B	Below reference	0.553–0.829	Fewer taxa than expected; potential water and habitat impairment
C	Well below reference	0.276–0.552	Many fewer taxa than expected; substantial impairment of water and habitat quality
D	Impoverished	<0.276	Few of the expected taxa remain; severe impairment

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 NOCA 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 NOCA (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. 2012:23–24); (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 NOCA that receive water from any of the above sources, even if those sources are outside park boundaries.

4.3.4 Results and Assessment

Stream habitat attributes were measured during 5 different surveys conducted 1995–2004 (Zyskowski 2006:59–72). The purpose of the surveys was to characterize NOCA stream habitat, to document the range of attribute variability among the surveyed reaches, and to create a general reference of conditions for future surveys. Twenty-five physical attributes were variously measured at 127 sites during the survey period (Zyskowski 2006:54–57). Table 13 summarizes the results and variability for 12 of the 25 physical attributes measured in up to 85 sample reaches with gradients <8% and reach lengths ≥20 bankfull widths.

A predictive model based on benthic macroinvertebrate (BMI) occurrence was developed for assessing the condition of NOCA stream sites (unpublished NOCA report). BMI were collected from 95 reference sites and the results of the cluster analysis of the data were used to identify 8 reference site groups with relatively different environmental attributes (Table 14). A total of 115 taxa were collected from the 95 sites. The most predominant and widely distributed taxa were Ephemeroptera, Plecoptera, and Trichoptera (Table 15). Three Ephemeroptera (*Baetis* spp., *Drunella doddsii*, and *Rhithrogena* spp.) were each distributed in ≥75% of sites within each of the 8 reference groups, and *Epeorus deceptivus* (Ephemeroptera) and Chironomidae were present in ≥75% of sites in all but 1 reference group. The 4 Ephemeroptera taxa above were also the most abundant BMI collected. The mean and range of the observed/expected (O/E) scores for all of the reference sites are presented in Table 16; the scores are used to assign each site to a quality band, which defines the condition of the site (Table 12). Most (n = 86) of the reference sites were determined to be either in good reference condition (quality band A; unimpaired) or richer in taxa than expected for a site in unimpaired condition (quality band X) (Table 16). O/E scores were also calculated for 62 test sites (Table 16); 50 sites were on NPS and USFS managed lands, and 12 sites were on private or Washington Department of Natural Resources (WDNR) managed lands. Forty-six of the test sites were determined to be relatively unimpaired (quality band A), and 15 sites were assigned to quality band B, indicating some potential water and habitat impairment. Just over 50% of these sites were on private and WDNR managed lands. Only 1 site was determined to potentially have substantial water and habitat quality impairment (quality band C), and this was a private/WDNR site. For all NPS and USFS reference and test sites combined, 89% (129 of 145) of the sites were determined to be unimpaired or better than unimpaired, indicating that NOCA stream sites are predominantly in relatively pristine condition.

Table 13. Variability of physical attributes measured in stream reaches with gradients <8% and bankfull widths ≥20 bankfull widths. This table is Table 8 in Zyskowski (2006:73).

Attribute	Sample size	Mean	SD	Range
Elevation (m)	85	671.1	287.8	137–1597
Gradient (%)	85	2.3	1.8	0.1–7.97
Bankfull width (m)	85	16.2	8.6	2.2–41.8
% Fines (<2 mm dia)	48	6.1	6.9	0–35.5
D_{50} substrate size (mm)	48	85.1	51.8	14–220
USFS pools/km[1]	58	11.1	7.6	0–35
TFW pools/km[2]	27	20.8	24.8	2.5–126.7
Residual pool depth (cm)	77	78.5	34.6	26–200
Maximum pool depth (cm)	77	115.5	47.4	33–300
USFS LWD/km	71	29.2	26.9	0–102
TFW LWD/km	85	143.4	80.4	0–403
Log jams/km	85	8.6	8.5	0–30

[1]USFS Pacific Northwest Region 6, stream inventory protocol

[2]Northwest Indian Fisheries Commission – Timber Fish, and Wildlife Ambient Monitoring Program protocol; LWD = large woody debris

Table 14. Summary of NOCA Reference Site Group environmental attributes. L = Low; M = Moderate; H = High. (Summarized from an unpublished NOCA report: Benthic Macroinvertebrate Predictive Model Development and Site Assessment).

	Reference Site Group							
Attribute	1	2	3	4	5	6	7	8
Number Sites	16	15	16	12	6	9	17	4
Elevation[1]	L	I	H	I	I	I	L	I
Gradient	M	M	M	H	L	H	L	L
Size[2]	M	M	S–M	S	L	S–M	M–L	L
Glacial Influence[3]	L	M	M	L	H	H	M	M

[1]low median = 270–405 m; moderate median = 604–716 m; high median = 1094 m

[2]small = 2nd order; moderate = 3rd–4th order; large = ≥4th order

[3]median % glacial area in catchment: low = 1–3; moderate = 9–14; high = 25–30

Table 15. Predominant benthic macroinvertebrate taxa in NOCA reference site groups. Frequency of occurrence for each taxon is ≥75% of sites within each reference site group. Numbers in parentheses are number of sites/group. This is Table 1 in the unpublished NOCA report titled "Results and Discussion: Benthic Macroinvertebrate Predictive Model Development and Site Assessment."

		Reference Site Group							
Taxa Group	**Taxon Name**	**1 (16)**	**2 (15)**	**3 (16)**	**4 (12)**	**5 (6)**	**6 (9)**	**7 (17)**	**8 (4)**
TURBELLARIA				x	x				
OLIGOCHAETA		x	x		x			x	
ACARINA		x							
EPHEMEROPTERA									
Ameletidae	*Ameletus* spp.			x					
Baetidae	*Baetidae* spp.	x	x	x	x	x	x	x	x
Ephemerellidae	*Caudatella* spp.				x	x			
	Drunella doddsii	x	x	x	x	x	x	x	x
	D. coloradensis/flavilinea							x	x
	Seratella spp.	x							
Heptageniidae	*Cinygmula* spp.	x	x	x	x			x	x
	Epeorus deceptivus	x	x	x	x		x	x	x
	E. grandis			x	x	x	x	x	x
	Rhithrogena spp.	x	x	x	x	x	x	x	x
Leptophlebiidae	*Paraleptophlebia* spp.				x				
PLECOPTERA									
Capniidae				x			x		
Chloroperlidae			x			x		x	x
	Neaviperla/Suwallia spp.								x
	Sweltsa group	x	x	x	x				x
Leuctridae				x					
Nemouridae	*Visoka cataractae*				x				x
	Zapada cinctipes	x				x		x	x
	Z. columbiana			x	x				
Peltoperlidae	*Yoraperla* spp.				x				
Perlidae	*Doroneuria* spp.				x				
	Hesperoperla pacifica								x
Perlodidae	*Isoperla* spp.				x		x		
	Megarcys spp.		x	x	x		x	x	x
Taenioterygidae		x			x		x	x	x
TRICHOPTERA									
Hydropsychidae	*Arctopsyche grandis*	x			x				
	Parapsyche spp.			x	x				
Limnephilidae	*Ecclisomyia* spp.		x						

Table 15. Predominant benthic macroinvertebrate taxa in NOCA reference site groups. Frequency of occurrence for each taxon is ≥75% of sites within each reference site group. Numbers in parentheses are number of sites/group. This is Table 1 in the unpublished NOCA report titled “Results and Discussion: Benthic Macroinvertebrate Predictive Model Development and Site Assessment.” (continued)

		Reference Site Group							
Taxa Group	**Taxon Name**	**1 (16)**	**Taxa Group**	**Taxon Name**	**1 (16)**	**Taxa Group**	**Taxon Name**	**1 (16)**	**Taxa Group**
DIPTERA									
Chironomidae		x	x	x	x		x	x	x
Simuliidae									x
Tipulidae	*Dicranota* spp.				x			x	
Rhyacophilidae	*Rhyacophila* Betteni group								
	R. Brunnea/Vemna group	x	x	x	x	x		x	
	R. Hyalinata group		x	x	x	x	x		
	R. Sibirica group			x		x			
Uenoidae	*Neothremma* spp.								
	Oligophlebodes spp.					x			

Table 16. Comparison of O/E values for reference and test sites. O/E = Observed/Expected. S.D. = Standard Deviation (Table from an unpublished NOCA report: Benthic Macroinvertebrate Predictive Model Development and Site Assessment). [1]Washington Department of Natural Resources.

					Quality Bands			
Sites	**n**	**Mean**	**S.D.**	**Range**	**X**	**A**	**B**	**C**
All reference	95	1.02	0.14	0.71–1.30	8	78	9	
All test	62	0.91	0.16	0.53–1.26		46	15	1
NPS and USFS test	50	0.95	0.14	0.64–1.26		43	7	
Private and State WDNR[1] test	12	0.72	0.12	0.53–0.94		3	8	1

One hundred thirty-seven NOCA 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 (this report). For an explanation of this process see Rawhouser et al. (2012:Appendix B). Of these catchments, 68 (49.6%) 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). Twenty-seven catchments were ranked based on water quality associated mertrics also listed in 4.3.3. Of these catchments, 19 (70%) were ranked as being of moderate to high risk of impairment, and all of these catchments were ranked as threatened (Rawhouser et al. 2012:Appendix D). Only 1 of the wadeable stream and river catchments of management concern (Newhalem Creek) was 303d listed under the CWA due to instream flow and its effects on habitat.

4.3.5 Emerging Issues

There are a number of issues that have the potential of affecting lotic ecosystems, including climate change, atmospheric deposition, and the introduction of exotic and nonnative species (Malmqvist and

Rundle 2002). Climate change can 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 from changes in precipitation patterns and the impact of climate change on glaciers and snowfall 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). 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, NOCA has compiled physical habitat attribute data for approximately 127 streams and rivers in the park. Data collection covers the periods 1995–2004. The park has also developed a useful BMI predictive model for future assessments of the water and habitat quality of NOCA streams and rivers. NOCA will also participate in the NCCN water quality monitoring program. The program sampling design includes up to 32 eligible wadeable streams in NOCA (26 of which have been designated as of highest priority) from which will be collected samples for 10+ water quality parameters (Rawhouser et al. 2012). Benthic macroinvertebrates will be sampled as part of the monitoring effort, and this will help increase the NOCA benthic macroinvertebrate database and enhance the park's ability to elucidate the distribution and occurrence of these invertebrates in NOCA streams and rivers. Ultimately, the monitoring effort will 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.

4.3.7 Literature Cited

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4.4 Landscape-scale Vegetation Dynamics

(Andrea Woodward and Patricia Haggerty, U.S. Geological Survey, FRESC)

4.4.1 Introduction

The mountainous terrain and complex geology of NOCA create considerable variation in soil types and steep gradients of elevation, aspect, temperature, and precipitation. The range of conditions contributes to diverse plant life, including over 1381 vascular plant species (Bivin and Rochefort 2010). In general, vegetation of the Pacific Northwest is typified by productive coniferous forests, with deciduous species restricted to frequently disturbed areas (Agee and Kertis 1987). Specifically in NOCA, plant communities are roughly distributed in an east-west gradient reflecting the wetter, maritime-influenced climate on western slopes; cold temperatures and persistent snow at high elevations; and a drier, continental climate in the rainshadow on the eastern slopes. The Cascade Range is so wide in NOCA that the rainshadow begins west of the Cascade divide (Agee and Kertis 1987). Specifically, west-side vegetation is characterized by Western Hemlock (*Tsuga heterophylla*)–Western Redcedar (*Thuja plicata*)–Douglas-fir (*Pseudotsuga menziesii*) forests at low elevations, Pacific Silver Fir (*Abies amabilis*) forests at mid-elevations, and Mountain Hemlock (*Tsuga mertensiana*) at treeline. Dwarf shrublands, consisting primarily of heather, and sparsely vegetated alpine rocklands occur above treeline (Douglas and Bliss 1977). Eastside vegetation includes Ponderosa Pine (*Pinus ponderosa*)– Douglas-fir in the dry, southeast portion of the park, Douglas-fir–Lodgepole Pine (*Pinus contorta*)–Grand Fir (*Abies grandis*) forests at lower elevations, and Subalpine Fir (*Abies lasiocarpa*), Whitebark Pine (*Pinus albicaulis*) or Subalpine Larch (*Larix lyallii*) at treeline. The Ross Lake area is unique due to the juxtaposition of eastern and western vegetation patterns on north versus south aspects (Agee and Kertis 1987). Riparian areas and wetlands, including swamps, fens, and marshes occur throughout the park. Disturbance regime varies by location, but major agents include landslides, avalanches, fires, floods, and windstorms (Crawford et al. 2009).

In consultation 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 a map of nationally defined vegetation classes. 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 through 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

Because a new 'ground-truthed' vegetation map for NOCA has not yet been completed, we used the Ecological Systems (ES) map from NatureServe (Comer et al. 2003) to assess status of landscape-scale vegetation distribution. ES units are meant to describe mid-scale units (tens to thousands of hectares), which is a scale thought to usefully inform conservation and resource management. They are defined as "recurring groups of biological communities that are found in similar physical environments and are influenced by similar dynamic ecological processes, such as fire or flooding" (Comer et al. 2003), and consist of aggregations of plant associations (Rocchio and Crawford 2009). ESs are meant to be capable of being mapped using remote imagery and recognizable in the field; there are 599 ESs nationwide. Units are mapped in the Pacific Northwest at 30 m resolution with a minimum mapping unit of 1 ha.

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 et al. 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 also 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 20th 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 ES classes to describe current status of landscape-scale vegetation pattern; (2) proportion each ES class contributes to total park area to identify classes that are significant to the park; (3) proportion each ES class contributes to the national inventory of each ES to indicate the national significance of each ES class; and (4) the global conservation status of each ES class as determined by NatureServe 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 NOCA vegetation is evident in the environmental range encompassed by the 38 ES classes present in the park (Table 17) which nest hierarchically in 14 National Vegetation Classification (NVC) Macrogroups plus 3 other classes (Table 17, Figure 12). 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. However, some of the classes may not be accurately identified based on their rarity in the park and the unlikely existence of the vegetation. Examples include the sagebrush-containing ESs 5257 Inter-Mountain Basins Big Sagebrush Shrubland, 5454 Inter-Mountain Basins Big Sagebrush Steppe, 5455 Inter-Mountain Basins Montane Sagebrush Steppe and Douglas-fir Madrone Forest, and ES 4222 North Pacific Dry Douglas-fir–(Madrone) Forest and Woodland, which occurs primarily in the Puget Trough and Willamette Valley (Rocchio and Crawford 2009).

Of ESs present in the park, 4 are nationally significant in that more than 20% of the national inventory is in the park (Table 1; ESs 4225 North Pacific Maritime Mesic Subalpine Parkland, 5260 North Pacific Avalanche Chute Shrubland, 7157 North Pacific Alpine and Subalpine Dry Grassland, and 3155 North Pacific Montane Massive Bedrock, Cliff and Talus) and more than 10% is in 2 other classes (ESs 5205 North Pacific Dry and Mesic Alpine Dwarf-Shrubland, Fell-field and Meadow, and 3118 North Pacific Alpine and Subalpine Bedrock and Scree). All of these classes are limited to the naturally rare habitat of north Pacific subalpine or alpine areas. None of the park ES classes are globally threatened, but 6 classes are ranked between vulnerable (G3) and apparently secure (G4). Of these, 3 are wetland-riparian classes that have trees or shrubs (ESs 9106 North Pacific Lowland Riparian Forest and Shrubland, 9173 North Pacific Shrub Swamp, and 9190 North Pacific Hardwood-Conifer Swamp), 2 are forests (ESs 4226 North Pacific Maritime Mesic-Wet Douglas-fir-Western Hemlock Forest [west-side], and 4205 East Cascades Mesic Montane Mixed-Conifer Forest and Woodland [east-side]), and 1 is a subalpine meadow class (ES 7157).

It is difficult to determine classes that are significant to the park based on vegetation maps alone because some classes may be truly rare and others may simply be misclassifications. Nevertheless, wetlands are undoubtedly of management concern because they are identified as significant resources in NOCA enabling legislation, they are vulnerable to climate change, and some classes have the poorest global conservation status of any vegetation class in the park (G3G4). Several forest types may also be worthy of concern, but conifer forests on steep terrain are notoriously difficult to map (Dorren et al. 2003) so other forms of information regarding rarity of forest types is needed. The subalpine meadow class ES 7157 is both globally and nationally significant, and is subject to invasion by Subalpine Fir when snowpack is low (Bivin and Rochefort, pers. comm.); consequently, it may also be significant to park management.

Trend

We have no park-wide information to describe trends in vegetation pattern. When the NOCA vegetation map is completed it will serve as a baseline for assessing future changes.

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 18). Aubry and others (2011) also predict that wetland communities are vulnerable to climate change. Results are less consistent for lower elevation species. Shafer and others (2001) predict that the ranges of Douglas-fir (Pseudotsuga menziesii), Pacific Yew (Taxus brevifolia), Red Alder (Alnus rubra), and maybe Western Hemlock (Tsuga heterophylla) 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 more true of understory communities rather than the long-lived overstory forest component.

Table 17a. Areal extent of forest Ecological Systems (ES) vegetation classes in NOCA. Classes are grouped by National Vegetation Classification (NVC) Macrogroup classes.

NCV Macrogroup Class	ES Code	ES Vegetation Class	NOCA area (km^2)	% Park	% ES nationally	Global Status[1]
Vancouverian Lowland and Montane Rainforest (westside lowland-montane forest, NVC M024)	4224	North Pacific Maritime Dry-Mesic Douglas-fir-Western Hemlock Forest	80.16	2.91	0.48	G4
	4226	North Pacific Maritime Mesic-Wet Douglas-fir-Western Hemlock Forest	45.59	1.65	0.21	G3G4
	4229	North Pacific Mesic Western Hemlock-Silver Fir Forest	6.48	0.24	0.39	G5
	4272	North Pacific Dry-Mesic Silver Fir-Western Hemlock-Douglas-fir Forest	467.38	16.96	4.67	G5
	4304	North Pacific Broadleaf Landslide Forest and Shrubland	2.93	0.11	0.213	G5
Vancouverian Subalpine Forest (westside high-elevation forest, NVC M025)	4225	North Pacific Maritime Mesic Subalpine Parkland	431.46	15.66	20.63	G5
	4228	North Pacific Mountain Hemlock Forest	397.45	14.42	7.08	G5
Central Rocky Mountain Lower Montane & Foothill Forest (eastside montane forest, NVC M017)	4103	Northern Rocky Mountain Western Larch Savanna	1.44	0.05	0.16	G5
	4205	East Cascades Mesic Montane Mixed-Conifer Forest and Woodland	193.25	7.01	4.44	G3G4
	4232	Northern Rocky Mountain Dry-Mesic Montane Mixed Conifer Forest	61.92	2.25	0.07	G5
	4240	Northern Rocky Mountain Ponderosa Pine Woodland and Savanna	6.86	0.25	0.02	G5
Californian-Vancouverian Foothill & Valley Forest & Woodland (NVC M019)	4222	North Pacific Dry Douglas-fir-(Madrone) Forest and Woodland	0.06	0.00	0.00	G4
Rocky Mountain Subalpine & High Montane Conifer Forest (eastside high-elevation forest, NVC M020)	4104	Rocky Mountain Aspen Forest and Woodland	0.87	0.03	0.00	G5
	4233	Northern Rocky Mountain Subalpine Woodland and Parkland	151.11	5.48	0.71	G5
	4237	Rocky Mountain Lodgepole Pine Forest	5.40			G5

Table 17a. Areal extent of forest Ecological Systems (ES) vegetation classes in NOCA. Classes are grouped by National Vegetation Classification (NVC) Macrogroup classes (continued).

NCV Macrogroup Class	ES Code	ES Vegetation Class	NOCA area (km^2)	% Park	% ES nationally	Global Status[1]
Rocky Mountain Subalpine & High Montane Conifer Forest (eastside high-elevation forest, NVC M020) (continued)	4242	Rocky Mountain Subalpine Dry-Mesic Spruce-Fir Forest and Woodland	51.89	1.88	0.12	G5
	4243	Rocky Mountain Subalpine Mesic-Wet Spruce-Fir Forest and Woodland	103.67	3.76	0.39	G5

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

Table 17b. Areal extent of grassland and shurbland Ecological Systems (ES) vegetation classes in NOCA. Classes are grouped by National Vegetation Classification (NVC) Macrogroup classes.

NCV Macrogroup Class	ES Code	ES Vegetation Class	NOCA area (km^2)	% Park	% ES nationally	Global Status[1]
Northern Vancouverian Lowland & Montane Grassland & Shrubland (westside subalpine meadows, NVC M172)	5260	North Pacific Avalanche Chute Shrubland	117.60	4.27	22.19	G5
	5261	North Pacific Montane Shrubland	18.52	0.67	6.19	G5
	7157	North Pacific Alpine and Subalpine Dry Grassland	168.49	6.12	33.27	G3G4
Southern Vancouverian Lowland Grassland & Shrubland (NVC M050)	7162	North Pacific Herbaceous Bald and Bluff	0.19	0.01	0.12	G4
Vancouverian Alpine Scrub, Forb Meadow & Grassland (alpine heather, NVC M101)	5205	North Pacific Dry and Mesic Alpine Dwarf-Shrubland, Fell-field and Meadow	22.33	0.81	10.20	G5
Northern Rocky Mountain Montane & Foothill Grassland & Shrubland (eastside lowland grass- and shrublands, NVC M048)	7112	Northern Rocky Mountain Lower Montane, Foothill and Valley Grassland	26.05	0.94	0.16	G5
Great Basin & Intermountain Tall Sagebrush Shrubland & Steppe (NVC M169)	5257	Inter-Mountain Basins Big Sagebrush Shrubland	0.08	0.00	0.00	G5
	5454	Inter-Mountain Basins Big Sagebrush Steppe	0.04	0.00	0.00	G5
	5455	Inter-Mountain Basins Montane Sagebrush Steppe	0.01	0.00	0.00	G5

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

Table 17c. Areal extent of wetland Ecological Systems (ES) vegetation classes in NOCA. Classes are grouped by National Vegetation Classification (NVC) Macrogroup classes.

NCV Macrogroup Class	ES Code	ES Vegetation Class	NOCA area (km^2)	% Park	% ES nationally	Global Status[1]
Vancouverian Flooded & Swamp Forest (westside, NVC M035)	9106	North Pacific Lowland Riparian Forest and Shrubland	2.94	0.11	0.06	G3G4
	9108	North Pacific Montane Riparian Woodland and Shrubland	7.23	0.26	0.60	G5
	9173	North Pacific Shrub Swamp	0.41	0.01	0.08	G3G4
	9190	North Pacific Hardwood-Conifer Swamp	3.73	0.14	1.46	G3G4
North Pacific Bog and Fen (NVC M063)	9166	North Pacific Bog and Fen	1.61	0.06	3.57	GU
Western North American Montane Wet Shrubland & Wet Meadow (NVC M075)	9265	Temperate Pacific Subalpine-Montane Wet Meadow	0.26	0.01	0.06	G5
Rocky Mountain & Great Basin Flooded & Swamp Forest (NVC M034)	9155	Northern Rocky Mountain Lower Montane Riparian Woodland and Shrubland	4.90	0.18	0.09	G5
	9171	Rocky Mountain Subalpine-Montane Riparian Woodland	0.09	0.00	0.01	G5
Western North American Temperate Lowland Wet Shrubland, Wet Meadow & Marsh(NVC (M073)	9260	Temperate Pacific Freshwater Emergent Marsh	1.88	0.07	0.26	G3G4

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

Table 17d. Areal extent of rock Ecological Systems (ES) vegetation classes in NOCA. Classes are grouped by National Vegetation Classification (NVC) Macrogroup classes.

NCV Macrogroup Class	ES Code	ES Vegetation Class	NOCA area (km^2)	% Park	% ES nationally	Global Status[1]
Vancouverian Cliff, Scree & Rock Vegetation (westside rock, NVC M114)	3155	North Pacific Montane Massive Bedrock, Cliff and Talus	155.11	5.63	20.96	G5
Vancouverian Alpine Cliff, Scree & Rock Vegetation(westside alpine rock, NVC M120)	3118	North Pacific Alpine and Subalpine Bedrock and Scree	55.51	20.1	16.66	G5
Rocky Mountain Alpine Cliff, Scree & Rock Vegetation (eastside alpine rock, NVC M119)	3135	Rocky Mountain Alpine Bedrock and Scree	4.78	0.17	0.06	G5

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

Table 17d. Areal extent of other Ecological Systems (ES) vegetation classes in NOCA. Classes are grouped by National Vegetation Classification (NVC) Macrogroup classes.

NCV Macrogroup Class	ES Code	ES Vegetation Class	NOCA area (km^2)	% Park	% ES nationally	Global Status[1]
Other	1	Non-Specific Disturbed	11.67	0.42		
	11	Open Water	54.78	1.99		
	21	Developed-Open Space	0.29	0.01		
	22	Developed-Low Intensity	1.63	0.06		
	24	Developed-High Intensity	0.05	0.00		
	81	Agricultural-Pasture/Hay	0.04	0.00		
	2192	Recently Logged Timberland-Shrubland Cover	6.43	0.23		
	2193	Recently Logged Timberland-Woodland Cover	0.02	0.00		
	3130	North American Glacier and Ice Field	79.92	2.90		
	8602	Recently Logged Timberland	0.83	0.03		

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

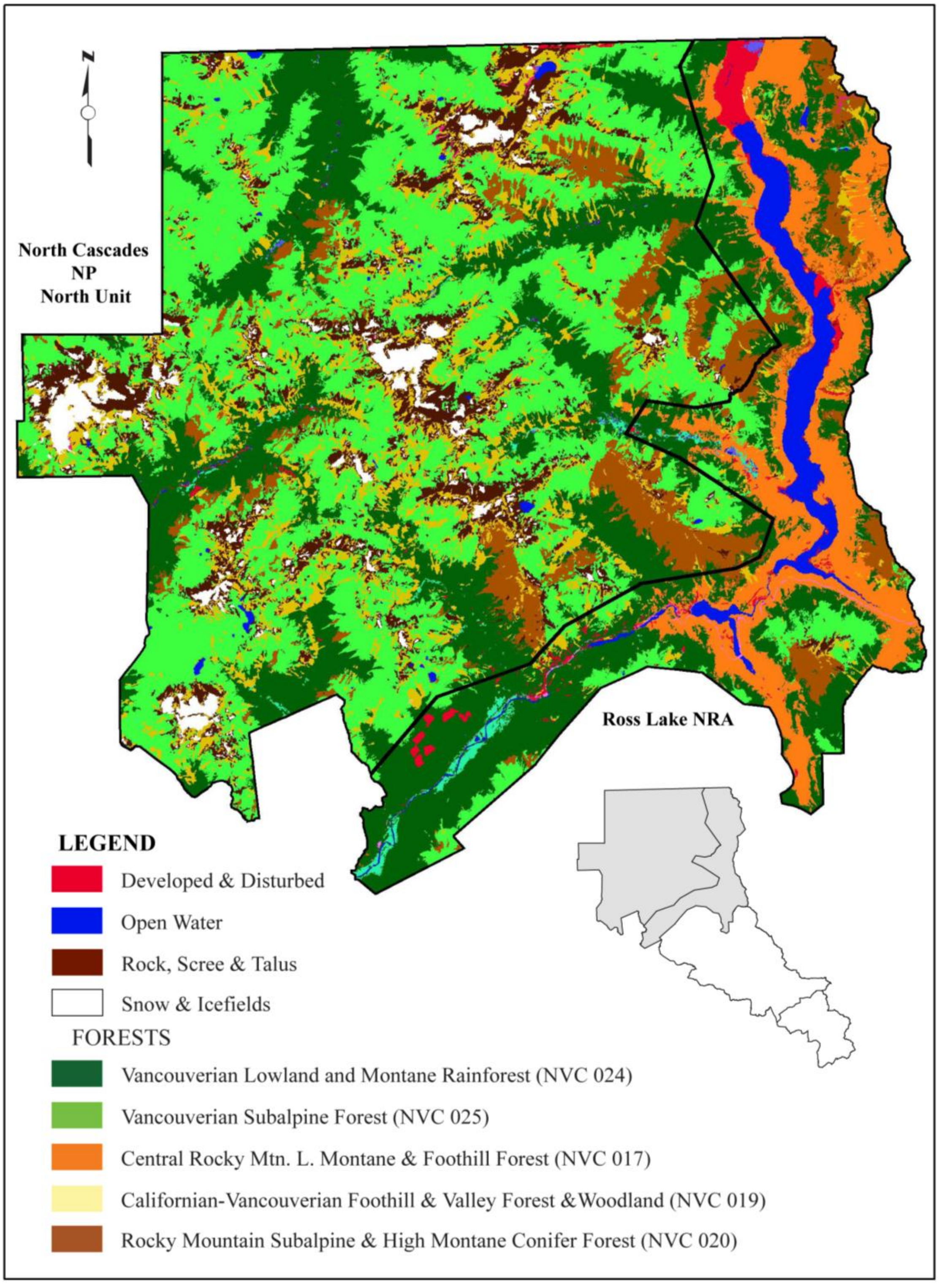

Figure 12. National Vegetation Classification Macrogroups found in NOCA.

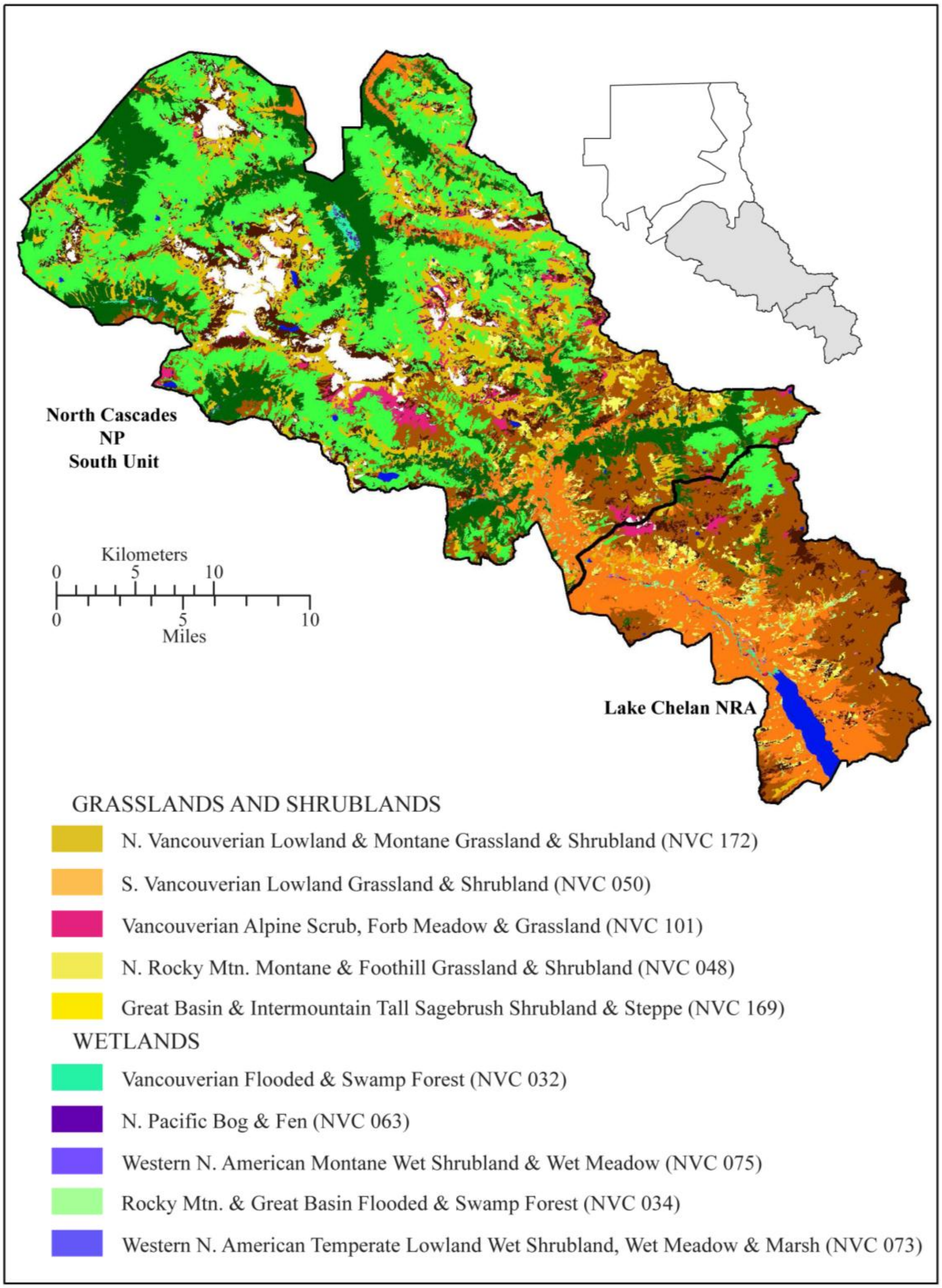

Figure 12. National Vegetation Classification Macrogroups found in NOCA (continued).

Table 18. 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 Aubrey 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.

	Western Washington		**Western United States**		**North America**	
Metric & 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 the desired state through backcasting (Sutherland 2006).

4.4.6 Information and Data Needs–Gaps

- Using remotely-sensed data is the most efficient means to analyze broad-scale changes in vegetation structure 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.
- Predictions on spatial and temporal scales relevant to national parks require field-based monitoring or research and are generally 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 using 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).

4.4.7 Literature Cited

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4.5 Forest Health: Disturbance Regime

(Andrea Woodward and Patricia Haggerty, U.S. Geological Survey, 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 root rot pockets), or the widespread decline of individual species (e.g., insect infestation). Events in the Pacific Northwest include fires, windstorms, ice storms, avalanches, 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 eruptions 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 NOCA 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 other potential disturbance agents.

4.5.2 Approach

The longest-term comprehensive description of the disturbance regime in NOCA is provided by Aerial Detection Survey (ADS) data collected by the USDA Forest Service. These data have been collected annually since 1947 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 agent 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. A similar method has been used by the British Columbia Ministry of

Forest, Lands and Natural Resource Operations since 1999 (Westfall and Ebata 2012). Surveys of Canada were also conducted from 1914 to 1995, but we have not obtained the data.

Creating disturbance maps using the sketchmapping method is highly subjective and therefore variable among observers (Klein et al. 1983), and is not effective at detecting root disease, dwarf mistletoe, or minor defoliation. 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 systems for mapping in 2001 (digital aerial sketchmap system [DASM], Schrader-Patton 2002), including touch screen and integrated GPS. The change can be noticed as more finely drawn polygons. Nevertheless, remotely determining the cause of a disturbance will remain subjective for the foreseeable future. For example, damage polygons attributed to 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 NOCA and the buffer area around it (hereafter, buffer) 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 ecologic processes. It is defined as a 16.1 km (10 mi) wide ring around the park, expanded to include the Chilliwack and Upper Skagit watershed in British Columbia and truncated to the east of Lake Chelan to accommodate the geometry of available satellite imagery (Antonova et al. 2010). The ADS data set does not extend into Canada, so that portion of the buffer area is not included in this analysis.

As part of the NPS Inventory and Monitoring Program, NOCA 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 NOCA (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. 2013). 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) or are influenced by weather (Dale et al. 2001) primarily by affecting the success of agents or the susceptibility of hosts (Bentz et al. 2010). Consequently, we investigated whether a shift in weather regime could explain trends in disturbance from a reference period to present. Considering the time span of available ADS data (1947–2011), data from Washington State Climate Division 5 (monthly average of daily data from all weather stations in Divison 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 1947 (6.3°C; Figure

13). While there has not been corresponding change in precipitation, we define the reference period to be from the beginning of the ADS record (1947) until 1985.

To describe status and trends of forest disturbance agents, we evaluated ADS data for the following metrics: (1) total area of NOCA and surrounding buffer affected by disturbance agents through time, 1947–2011; (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 extrapolating changes observed in ADS data from 1986 to 2011 compared with 1947 to 1985. The complete digital data set including disturbance polygons and calculations of severity and disturbance agents for NOCA and the buffer area will be provided to the park in a geodatabase.

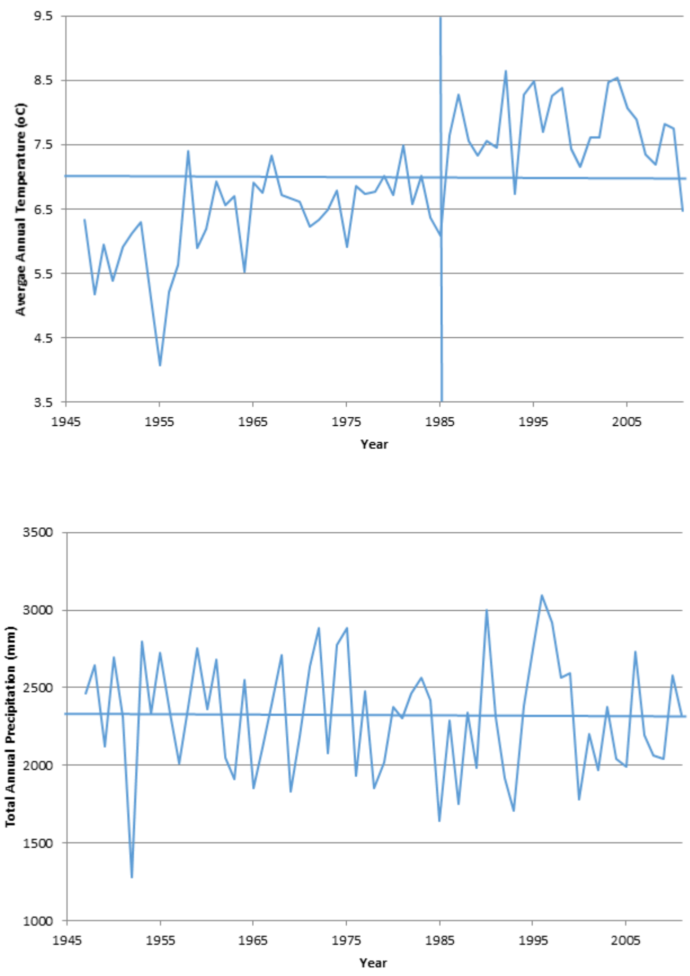

Figure 13. Time series of average annual temperature and total annual precipitation from 1947–2011 for Washington State Division 5, Cascade Mountains West. Horizontal line indicates average for record; vertical line indicates 1985.

4.5.4 Results and Assessment

Current Condition (1986-2011)

Since 1985, forests in NOCA and the surrounding buffer have experienced damage due to several native insects (Figure 14), primarily Mountain Pine Beetle (Dendroctonus ponderosae) and Western Spruce Budworm (Choristoneura occidentalis), but also Silver Fir Beetle and Douglas-fir Beetle. The introduced insect, Balsam Woolly Adelgid (Adelges piceae), has also been active. These insects are responsible for 85.4% (NOCA) and 73.5% (buffer) of tree damage documented by ADS. Considering all agents, 93.1% (NOCA) and 88.5% (buffer) of observed tree damage has been due to insects; 1.3% (NOCA) and 2.2% (buffer) due to diseases; 3.9% (NOCA) and 4.0% (buffer) due to physical disturbances (i.e., fire, bear damage, slides, water, wind, ice); and 1.7% (NOCA) and 5.4% (buffer) due to unknown causes.

While disturbance is widespread within the park and surrounding buffer during 1986 to 2011, most has occurred at lower elevations and along the drier eastern and southern sides of the park. Within the park, it has occurred in the vicinity of Ross Lake, Bridge Creek, and Lake Chelan (Figure 15). Disturbance has also occurred to the west of the park, especially between Skagit River and Baker Lake. Canadian data show that most disturbances north of NOCA are due to Mountain Pine Beetle, with lesser amounts of Western Spruce Budworm, Douglas-fir Beetle and Western Balsam Bark Beetle (Figure 16). Western Spruce Budworm has been mostly limited to Engelmann Spruce (Picea engelmannii) in the southeast part of the park and buffer since 1985 (Figure 17), while Mountain Pine Beetle has affected all species of pines primarily in the Ross Lake area as well as having some effect on the southeastern area (Figure 18). Silver Fir Beetle has been found in small patches throughout the park and buffer except for the central area west of Thunder Creek (Figure 19). Douglas-fir Beetle primarily has been found in the northeast region near Ross Lake and also in the southeast. Balsam Woolly Adelgid has been seen in Subalpine Fir in the northwest corner of the park and above Diablo Lake. Western Balsam Bark Beetle (Dryocoetes confusus), Spruce Beetle (Dendroctonus rufipennis), Larch Needle Case (Meria laricis), Lodgepole Pine Needle Cast (Lophodermella concolor), and Western Hemlock Looper (Lambdina fiscellaria) have also disturbed at least 1000 ha (2471 ac) of the park and buffer since 1985.

Trend

We compared the recent period (1986–2011), which shows dramatically higher temperatures, with the reference period (1947–1985) to describe trend (Table 19). In general, disturbance in the park was most prevalent in the eastern region during both periods; while still lower than in the east, disturbance impacts have been greater in the western part of the park in recent years compared with the reference period (Figure 15). In addition, both periods are strongly dominated by disturbance due to insects compared with diseases and abiotic agents in the park and surrounding buffer (Table 19). Regarding specific insects, the reference period was dominated by Western Spruce Budworm while dominance has shifted toward Mountain Pine Beetle more recently. In the park there has been a concurrent increase in Silver Fir Beetle, and Douglas-fir Beetle. The introduced insect Balsam Woolly Adelgid (Table 19) appeared in the buffer area in 1975, but didn’t gain a foothold in the park until 1987. Disturbance from all agents peaked during the 1970s in the reference period and during the 2000s in recent times (Figure 14) with no apparent relationship to climate. Disturbance activity was also relatively high in the 1950s and early 1960s in the buffer area. A trend toward smaller polygons through time is likely due to methodological refinement.

Table 19. 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	
	NOCA	Buffer	NOCA	Buffer	NOCA	Buffer
Western Spruce Budworm	68.3	42.2	36.2	32.9	-32.1	-9.3
Silver Fir Beetle/Fir Engraver	4.8	26.6	8.6	8.6	+3.8	-18.0
Mountain Pine Beetle	23.1	12.0	32.1	27.1	+9.0	+15.1
Douglas-fir Beetle	1.0	3.2	4.1	2.2	+3.1	-1.0
Balsam Woolly Adelgid	0.0	0.5	4.4	2.7	+4.4	+2.2
Total insects	97.8	87.4	93.1	88.5	-4.7	+1.1
Total disease	0.0	0.0	1.3	2.2	+1.3	+2.2
Total physical damage	0.3	0.5	0.9	4.0	+0.6	+3.5
Other	1.9	12.1	1.7	5.4	-0.2	-6.7
Total ha/yr	6,675	16,578	5,285	15,071	-1390	-1507

Western Spruce Budworm

Western Spruce Budworm defoliates Douglas-firs, true firs and Engelmann Spruce over multiple years. Trees that are defoliated for 5–10 yrs are likely to have dead tops or be killed while surviving trees are more vulnerable to bark beetles. Western Spruce Budworm is the most abundant disturbance agent in the record and is most severe in the southeast part of the park and buffer (Figure 17). During the reference period, it also occurred near Ross Lake. Damage during the current period generally overlaps areas that were affected during the reference period. The observed peak in damage during the 1970s and again in the 2000s corresponds well with data showing that outbreaks occur at 30 to 43 yrs intervals in central British Columbia (Campbell et al. 2006).

Mountain Pine Beetle

Mountain Pine Beetle is a bark beetle that attacks and kills all species of pines. During both time periods it occurred mostly on the east side of the park, and both eastern and western parts of the buffer (Figure 18). Since 1985, it has primarily attacked Lodgepole Pine and has killed over 3900 ha (9637 ac) of Whitebark Pine. During the reference period it attacked mostly Western White Pine and had no impact on Whitebark Pine. Although Mountain Pine Beetle outbreaks seem to be increasing in recent decades and expanding into previously unaffected areas of western Canada and Alaska (Logan et al. 2003, Carroll et al. 2004), from the perspective of a 64-yr record in NOCA, the park seems to be experiencing cyclic disturbance associated with this insect pest.

Silver Fir Beetle, Fir Engraver—Fir Engraver beetles primarily feed on Grand Fir, a species that is sparse or absent in NOCA. Subsequently, Forest Service staff suspect that Silver Fir, which is widespread in the park, was mistaken for Grand Fir, and that the true agent is the Silver Fir Beetle

(Carlson 2013). Consequently, all damage attributed to the Fir Engraver has been included with Silver Fir Beetle records in this analysis. Silver Fir Beetle kills large diameter trees and often attacks areas previously affected by Western Spruce Budworm. However, the spatial distribution of Silver Fir Beetle in NOCA does not entirely correspond with areas affected by Western Spruce Budworm (Figures 17 and 19). In recent years, Silver Fir Beetle has affected areas of the park that were not affected during the reference period. Specifically, there has been an increased incidence in the northern, southeastern, and central-eastern parts of the park (Figure 19). Silver Fir Beetle affected over 10% of the buffer area in 1953 at the peak of an eruption beginning in the early 1950s until the early 1960s. This suggests that the recent activity is trivial compared with past events (Figure 14).

Douglas-fir Beetle

Douglas-fir Beetle also kills large diameter trees that have been weakened by drought, fire, root disease, defoliating insects, or windthrow. The recent damage attributed to the Douglas-fir Beetle in the Ross Lake area (Figure 19) occurred in areas where trees were previously damaged during severe wind storms (Carlson 2013).

Balsam Woolly Adelgid

This is an exotic pest of Subalpine Fir that can cause branch stunting and topkill; death can result after several years of heavy infestation. Balsam Woolly Adelgid was not evident in the park during the reference period except for a small amount in 1978 (Figure 14). Since then, it has affected approximately 6000 ha (14,826 ac) of NOCA.

Two trends in the ADS data are particularly notable because they involve high elevation species with limited distributions. 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, it appears that the combination of Mountain Pine Beetle and White Pine blister rust have nearly extirpated Western White Pine. In recent times, warmer climate may be enabling Mountain Pine Beetles to infest Whitebark Pine, a high-elevation species also susceptible to White Pine blister rust.

Second, Balsam Woolly Adelgid is an exotic insect that affects true firs and is primarily affecting Subalpine Fir in NOCA (Carlson 2013). This tree species 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 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 35–45 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 in frequency and area affected (Dale et al. 2000). Based on a 65-yr time series of ADS records, it appears that the natural range of variation has not increased to date. While there may be a trend toward greater synchronization of agents, including a non-native insect, the total area affected and duration of outbreaks are not greater than past events (Figure 8). Given the difficulty of assigning causes to damage from the air, this result is probably most robust when considering all 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.

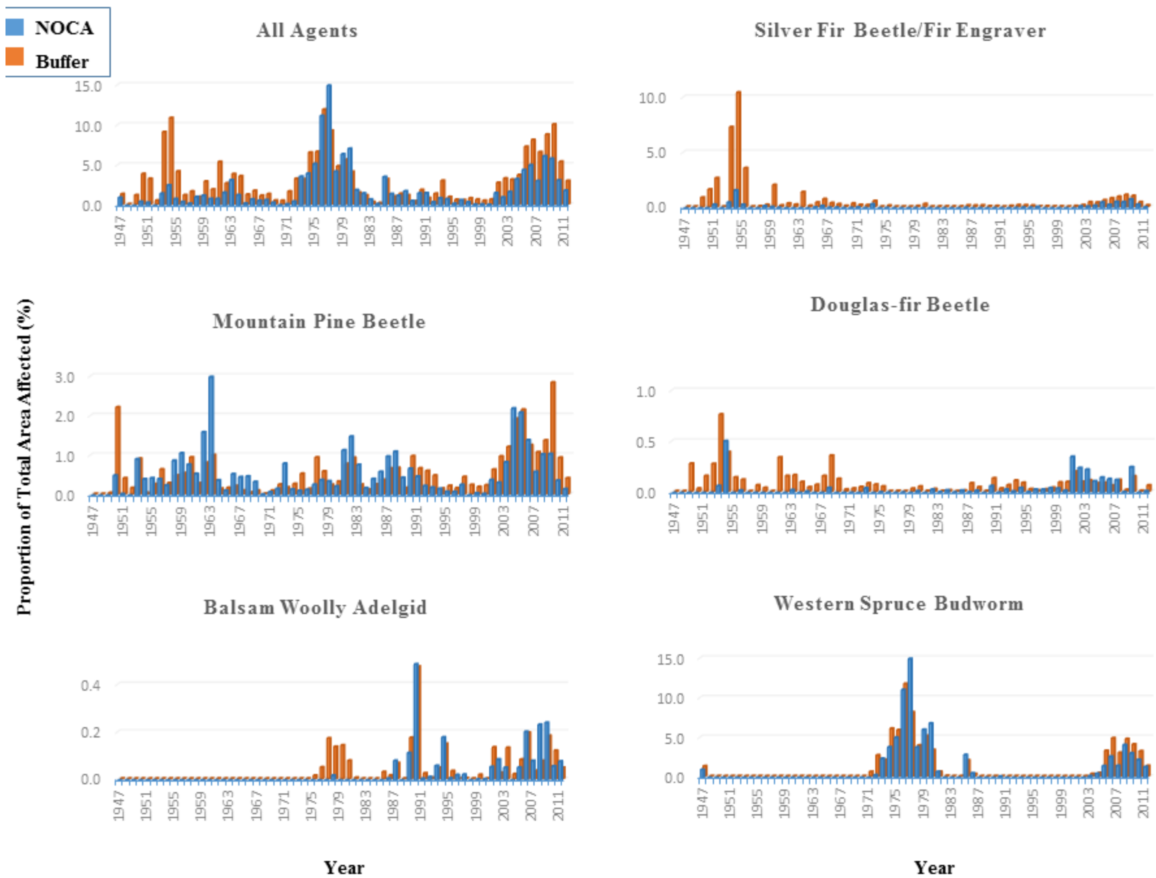

Figure 14. Aerial Detection Survey results describing area affected by various agents through time.

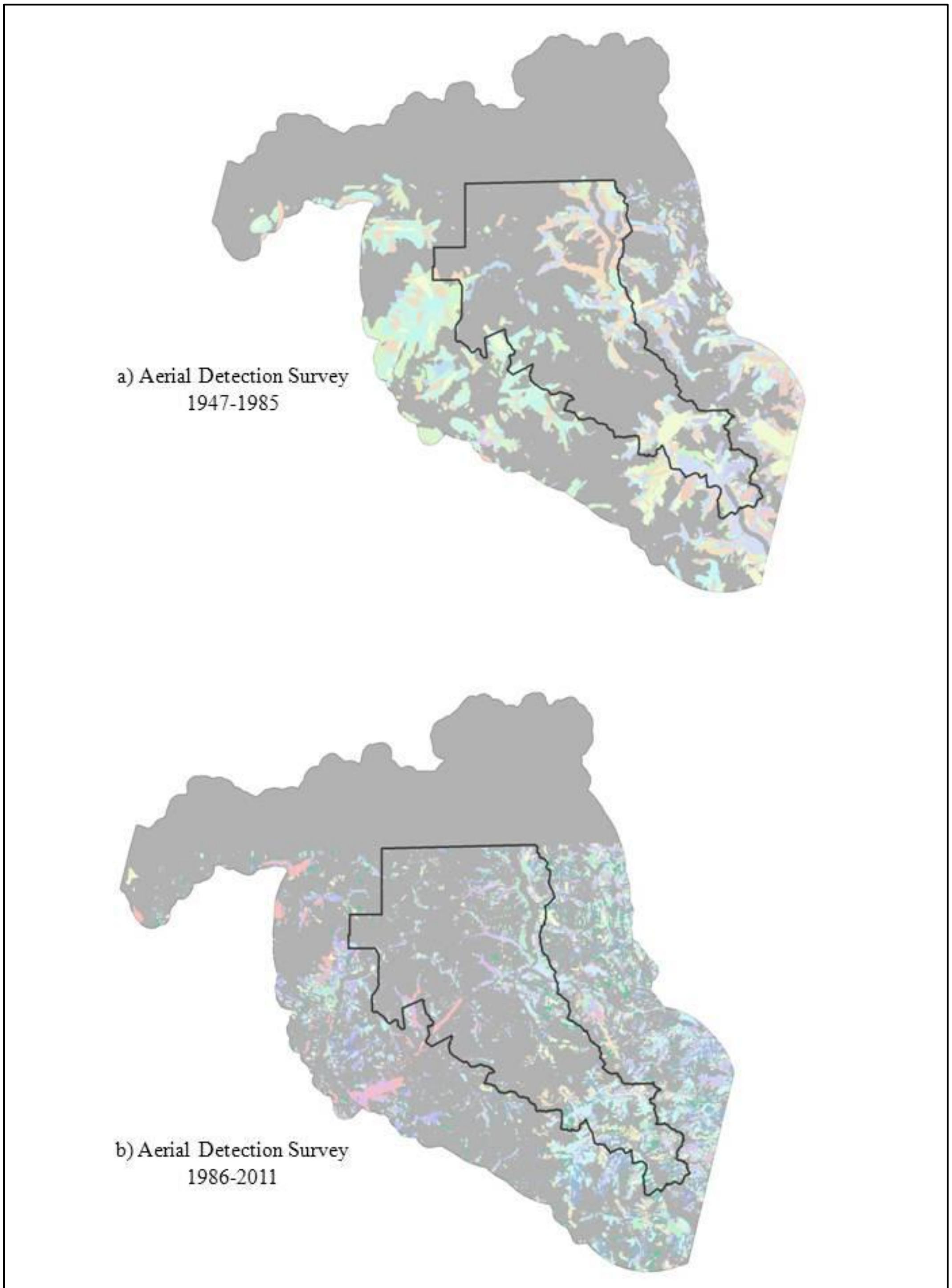

Figure 15. Spatial distribution of all areas affected by disturbance agents detected in the Aerial Detection Survey during 2 time periods. Colors indicate different years.

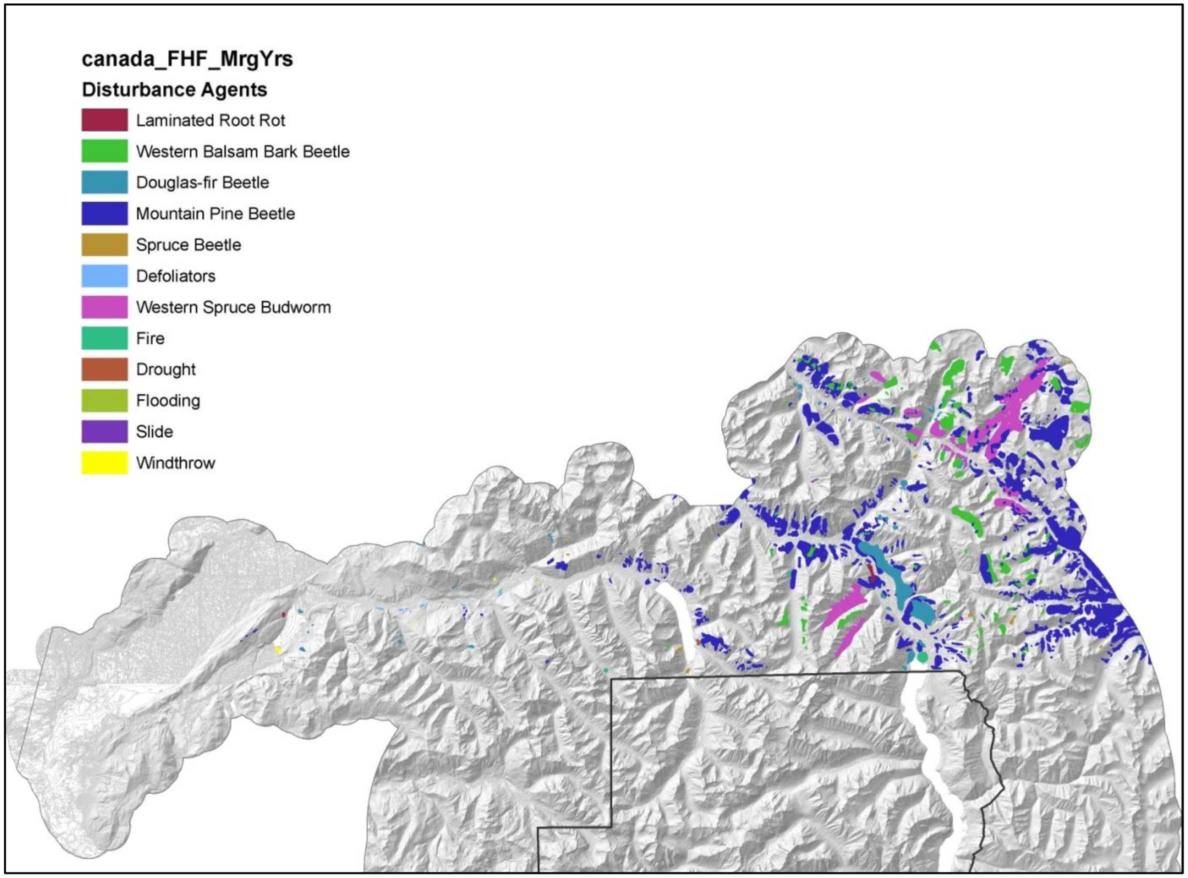

Figure 16. Occurrence of disturbance agents in the Canadian portion of the NOCA buffer area, 1999–2011.

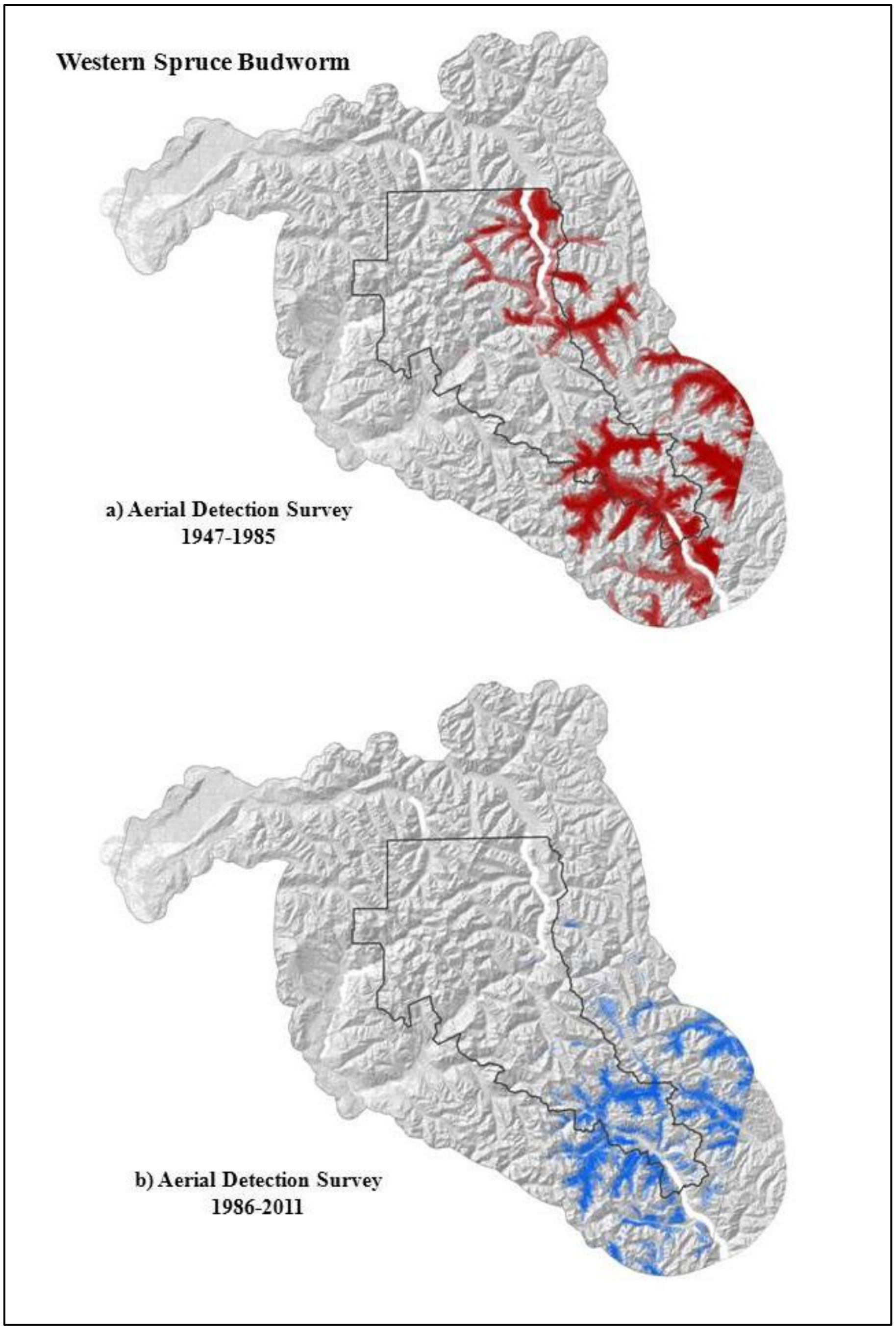

Figure 17. Western Spruce Budworm pre- and post-1985. Darker colors in a) and b) indicate greater number of years with presence.

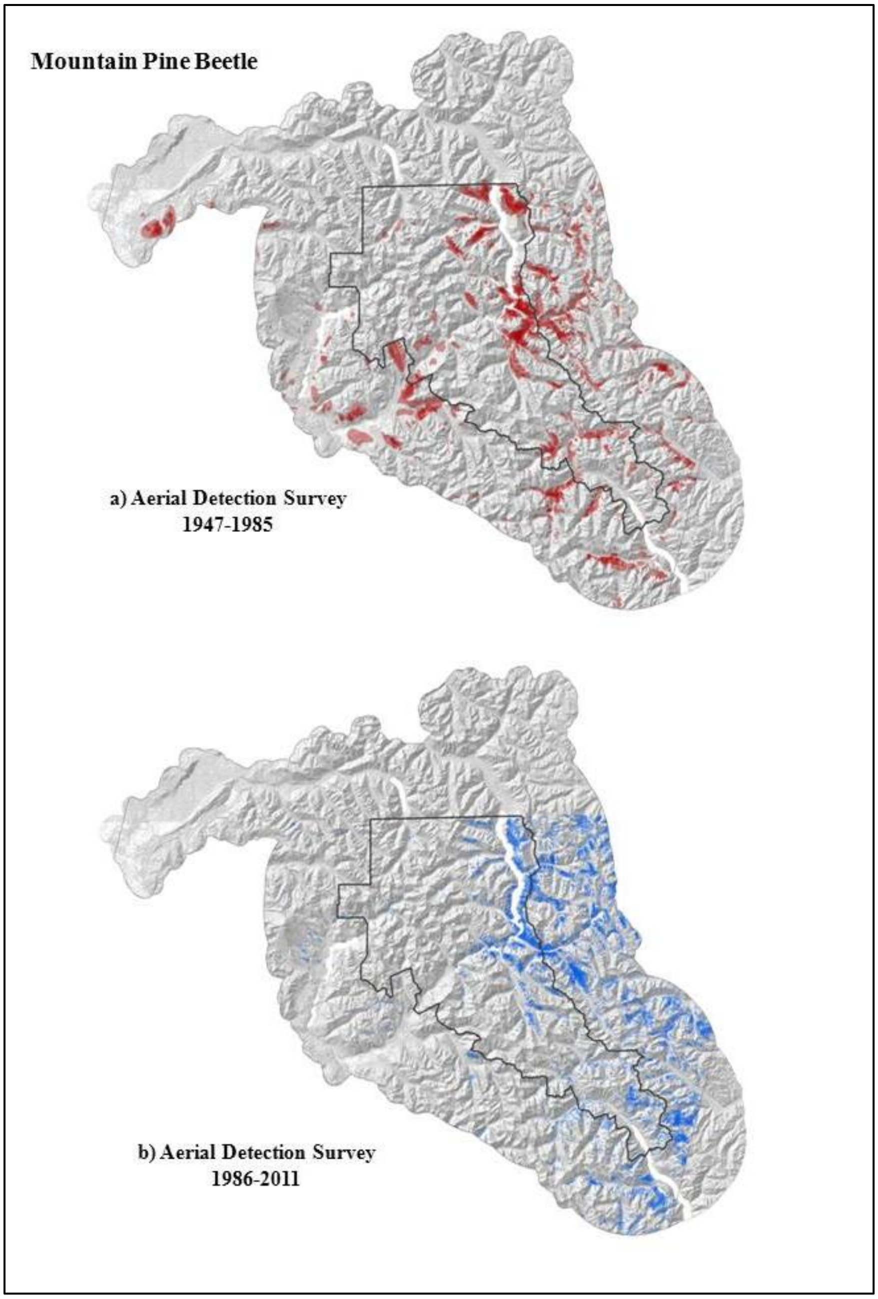

Figure 18. Mountain Pine Beetle pre- and post-1985. Darker colors indicate greater number of years with presence.

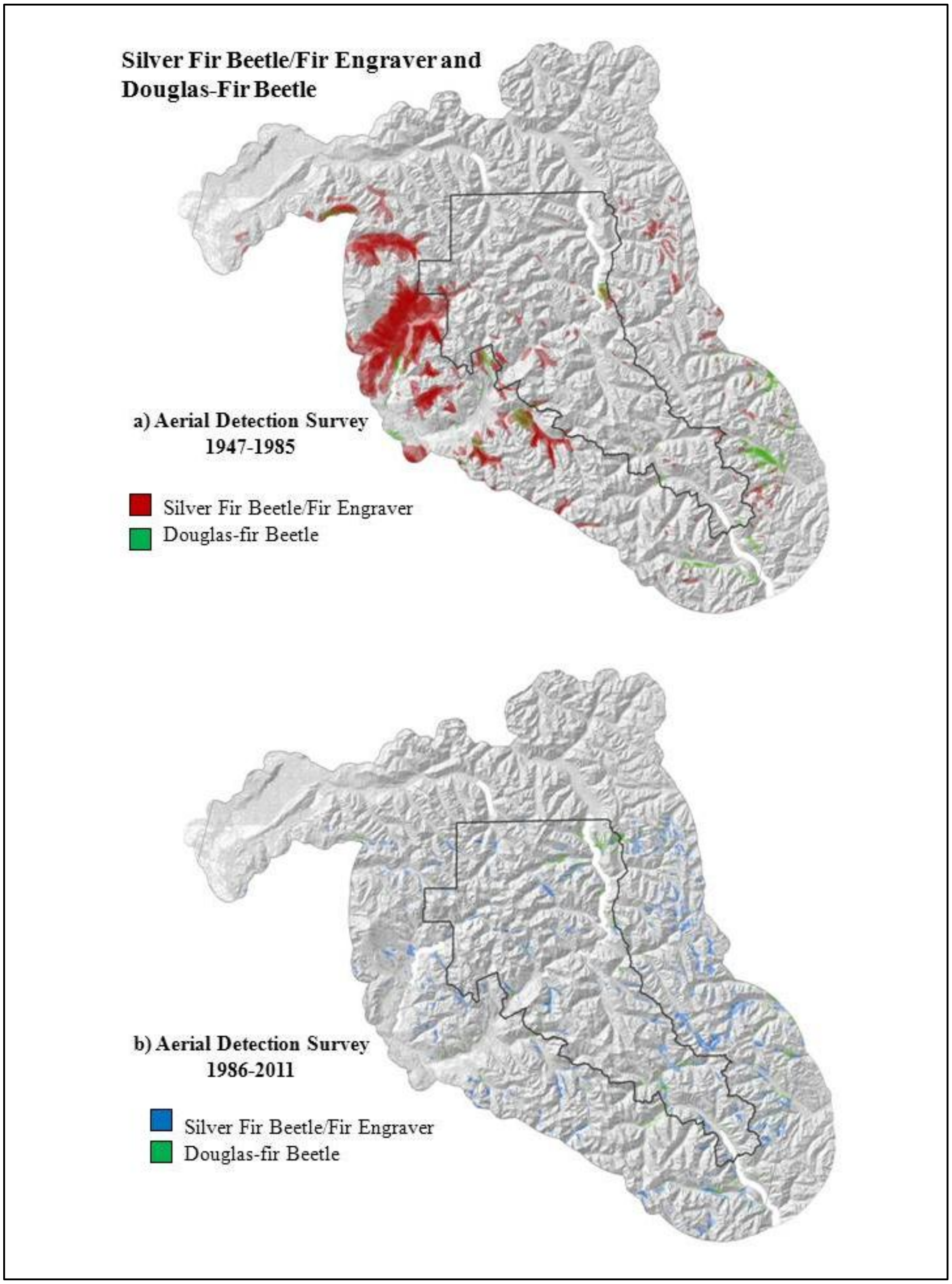

Figure 19. Silver Fir Beetle-Fir Engraver and Douglas-fir Beetle pre- and post-1985.

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 NOCA, at least as detected in ADS surveys (but see Section 4.6 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 ecology). 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 NOCA. Specifically, throughout the record, the most severe effects of insects and pathogens have occurred in the warmest and driest parts of the park near Ross Lake and south of Bridge Creek. 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.

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 the North Cascades. 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 LandTrendr based protocol is an improved tool, the time delay to delivery of results still render it less useful as a detection tool in cases when 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 and early 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 NOCA. In particular, responses to climate change may vary by region within the park and by elevation zone (Littell et al. 2010). 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

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4.6 Forest Health: Whitebark Pine and White Pine Blister Rust

(Andrea Woodward, U.S. Geological Survey, FRESC)

4.6.1 Introduction

Whitebark Pine (*Pinus albicaulis*) grows on cold, dry sites above 5000 ft. (1524 m) on the east side of NOCA and in small, disjunct populations on the west side of the park. Especially in the xeric conditions of the eastern Cascade Range, it is often the first tree species to establish in subalpine meadows or alpine ridges; it influences snowmelt patterns, soil development, and provides important microsites 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 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 10 plots that were conducted in NOCA during 1999 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 include change in extent of mapped vegetation classes that include Whitebark Pine and change in infection rate and mortality from 1999 to 2009.

4.6.4 Results and Assessment

Current Condition

The vegetation map of NOCA showing ecological systems (see Figure 12) indicates that Northern Rocky Mountain Subalpine Woodland Park, which is the class most associated with Whitebark Pine, covers 151 km^2 (58 mi^2) or 5.5% of the park (Table 17: 4.4 above) at high elevation in the eastern part of the park. This area is much larger than the 3922 ha (9691 ac) of Whitebark Pine communities estimated from existing vegetation maps (Agee and Kertis 1986) and by field personnel in 1999 (Rochefort 2008). Based on field data collected from permanent plots in 2009, 39% of mature trees are infected and mortality is 29%, while 21% of saplings are infected (Table 20). Mountain Pine Beetle occurs at <3% of sites (NCCN Inventory and Monitoring, undated).

Table 20. Infection and mortality rates of Whitebark Pine due to White Pine blister rust.

		Percent of trees		
		1999	**2004**	**2009**
Infected	Mature trees	37.6	29	39
	Saplings	32.0	17	21
Mortality	Mature trees	24.0	17	29
	Saplings	7.2	na	na

Trend

White Pine blister rust was introduced to North America in 1910 (Keane and Arno 1993) and first appeared in Mount Rainier in 1928, but there are no early records for NOCA (Rochefort 2008). Studies show that infection rate of adult trees (>2.54 cm (>1 in) diameter at breast height, dbh) has increased slightly and the infection rate of saplings (individuals taller than 50 cm (20 in) but <2.54 cm dbh) has decreased since 1999, (Rochefort 2008, NCCN undated; Table 20). Perhaps due to the small area occupied by Whitebark Pine in NOCA, Mountain Pine Beetles were rarely observed in 1999 (Rochefort 2008) and in <3% 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. According to Sattelberg (2011), "Recent predictions indicate a continuing downward trend within the majority of its range. While individual trees may persist, given current trends, the Service 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."

4.6.5 Emerging Issues

- Resistant genotypes may exist that could be used for restoration in the future. A project with collaboration between the USDA Forest Service Dorena Genetic Resource Center and Mount Rainier National Park has shown that some Whitebark Pine trees have promising levels of resistance (Richard Sniezko, pers. comm.).

4.6.6 Information and Data Needs–Gaps

- Continued survey and monitoring of blister rust infection rates and locations as well as the prevalence of Mountain Pine Beetles will describe the extent and trend of the infestation and potential exacerbation by Mountain Pine Beetles.
- The identification of blister rust-resistant genotypes of Whitebark Pine that may be used for restoration in the future; however, the distribution of Whitebark Pine in NOCA is within federally designated wilderness and the feasibility of introducing rust-resistent genotypes into wilderness is not clear.

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4.7 Forest Health: Air Quality Effects

(Andrea Woodward, U.S. Geological Survey, FRESC)

4.7.1 Introduction

Air quality is a concern of park resource managers because NOCA is downwind from the urban and agricultural areas of the Puget lowlands and Fraser River Valley, including the cities of Seattle, Washington, and Vancouver, British Columbia. Moreover, the Pacific Northwest receives pollutants in air masses from Asia (Jaffe et al. 1999, 2005, Weiss-Penzias et al. 2007, Fiore et al. 2002). Pollutants potentially arriving at NOCA 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, particularly 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 mychorrhizal 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, especially in conditions typical of the Pacific Northwest, which include N limitations, 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. 2003a). 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 snow pack (Blais et al. 1998), and cold fractionation of lighter SOCs in the atmosphere, which may result in deposition of these and other compounds at higher (colder) alpine areas than previously (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 NOCA 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 changes in air quality for park vegetation, we consulted 2 recent studies of the effects of contaminant concentrations on vegetation that incorporated data from

NOCA. The first study included an evaluation of whether lichen communities described in plots in NOCA 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, S, and lead. The second study was an assessment of airborne contaminants, including nitrogen, sulfur, 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). 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 rare events (e.g., natural fires, 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 (see Chapter 4.1).

4.7.4 Results and Assessment

Current Condition

Nitrogen and Sulfur Compounds—In a lichen evaluation of nitrogen and sulfur compounds, 3 sites within NOCA were rated ‘best’ on a 6-step scale. This means that all sensitive species were expected to be present and the sites were in the 75% quantile for a measure describing pollutant concentration. The sites represented high elevation, montane, and lowland climates. However, the NADP site at Marblemount, 10 km (6.2 mi) west of the park, was rated only ‘fair’, which is 3rd best on a 6-step scale. This means that some sensitive species were present and the site was in the 97.5% quantile for all sensitive species. Meanwhile, N concentration in lichens were not elevated above background ranges typical of remote areas (Landers et al. 2008).

Ozone—Ozone concentrations in NOCA are low and ozone injury to plants has not been evaluated (http://www.nature.nps.gov/air/permits/aris/noca). Nevertheless, 12 ozone-sensitive vascular plant species occur in the park (Porter 2003): Red Alder (*Alnus rubra*); Saskatoon (*Amelanchier alnifolia*); Spreading Dogbane (*Apocynum andorsaemifolium*); Douglas’s Sagebrush (*Artemisia douglasiana*); Western Mugwort (*Artemisia ludoviciana*); 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 NOCA were at or above the median values for the 20 western national parks sampled by WACAP (Landers et al. 2008). Dominant SOCs were polycyclic aromatic hydrocarbons (PAHs) (bdl-7773 ng/g lipid); pesticides: endosulfans (24-355), dacthal (3-34), hexachlorbenzene (HCB (8-60)), and organochlorides a-HCH (6-49) and g-HCH (2-11). Low concentrations of pesticides trifluralin (<0.2), chlorpyrifos (3-8), chlordanes (1-6), dichlorodiphenyltrichloroethanes (DDTs (<7)) and industrial–urban-use compound polychlorinated biphenlys (PCBs (<6)) were also detected. These values were similar to those in other PNW parks (CRLA, MORA, OLYM). Typical of results across all parks, pesticide and PCB concentrations in the lichen Common Witch's Hair (*Alectoria sarmentosa*) sampled in NOCA increased with elevation. Because needle productivity is high, the ecological effects of cumulate SOCs contributed by needle litterfall are a potential concern.

Mercury—NOCA was among the parks for which mercury in lichens was not measured in the WACAP study. However, mercury levels in parks where samples were analyzed were not above background values measured in remote sites across the western U.S. (Landers et al. 2008).

Trend

None of these pollutant chemicals were present prior to industrial influences. The potential consequences for plant species and the park ecosystem, especially for SOCs and mercury, is unkown. The trend of increasing pollutant concentrations has not apparently impacted vegetation in NOCA to date.

Predicted Changes

Despite improving trends in some air pollutants over recent decades, 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. Ozone damage to sensitive species may eventually become evident, and lichen communities are expected to shift to nitrophilous or pollution tolerant species (Fenn et al. 2003b, 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, it is unknown what affect changing climate might have on the response of plants to pollutants.

4.7.5 Emerging Issues

- Increasing urban–industrial development and intensifying 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 (Bertschi et al. 2004, Jaffe et al. 2005) 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

- 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 at these elevations.
- 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 nitrogen have been identified for lichens (Geiser et al. 2010), but still need to be identified for vascular plants.

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4.8 Fire Ecology

(Karen Kopper, National Park Service, NOCA)

4.8.1 Introduction

Forest conditions are greatly influenced by fire regime properties. Fire frequency and severity control forest structure by influencing the distribution and density of vegetation by size, age and species composition (Agee 1993, Turner et al. 1994, Sugihara et al. 2006). There are several distinct fire regimes within the North Cascades National Park Service Complex based on climate, vegetation, and topography. Each fire regime has an inherent range of fire occurrences (fire interval) and level of fire severity (low, moderate or high tree mortality per fire or group of fires). Fire regimes with the shortest fire intervals are most susceptible to alteration by fire, which lengthens the time between fires and prolongs the accumulation of dead and downed fuels (Brown 1983, Graham et al. 2004), or climate change, which usually shortens fire intervals and increases the number of acres burned (Littell et al. 2009). Despite the presence of frequent (short) fire regimes on the dry east-side of the park, longer fire intervals and high severity fire effects are more prevalent throughout the park.

4.8.2 Approach

The natural fire rotation (NFR) is used to quantify the natural fire frequency of an ecosystem. It is the length of time required for an area equal to the size of a study area to burn, assuming that some areas will burn multiple times and some areas not at all (Agee 1993). We calculated the NFR for all combustible land at NOCA between 1960 and 2011 using the NPS fire records that are archived at the Wildland Fire Management Information (WFMI) website (USDI 2013). We mapped and corrected the point locations on the WFMI database with the paper records of fire locations stored in the park's fire management office (Figure 20). We use the whole park NFR and comparisons between historic mean fire intervals and calculations of the NFR for different fire regimes within the park, to identify departure from the natural fire regime.

A historic fire interval map was made by lumping Landscape Fire and Resource Management Planning Tools Project (LANDFIRE) fire regime classes (LANDFIRE 2013a) by fire interval, condensing 5 fire interval and severity classes into 3 fire interval classes. We also used LANDFIRE (LANDFIRE 2013b) fuel model data to identify the number of acres of combustible fuel in NOCA for our calculation of the whole park NFR. We included all grass, shrub and timber fuel models in our estimate.

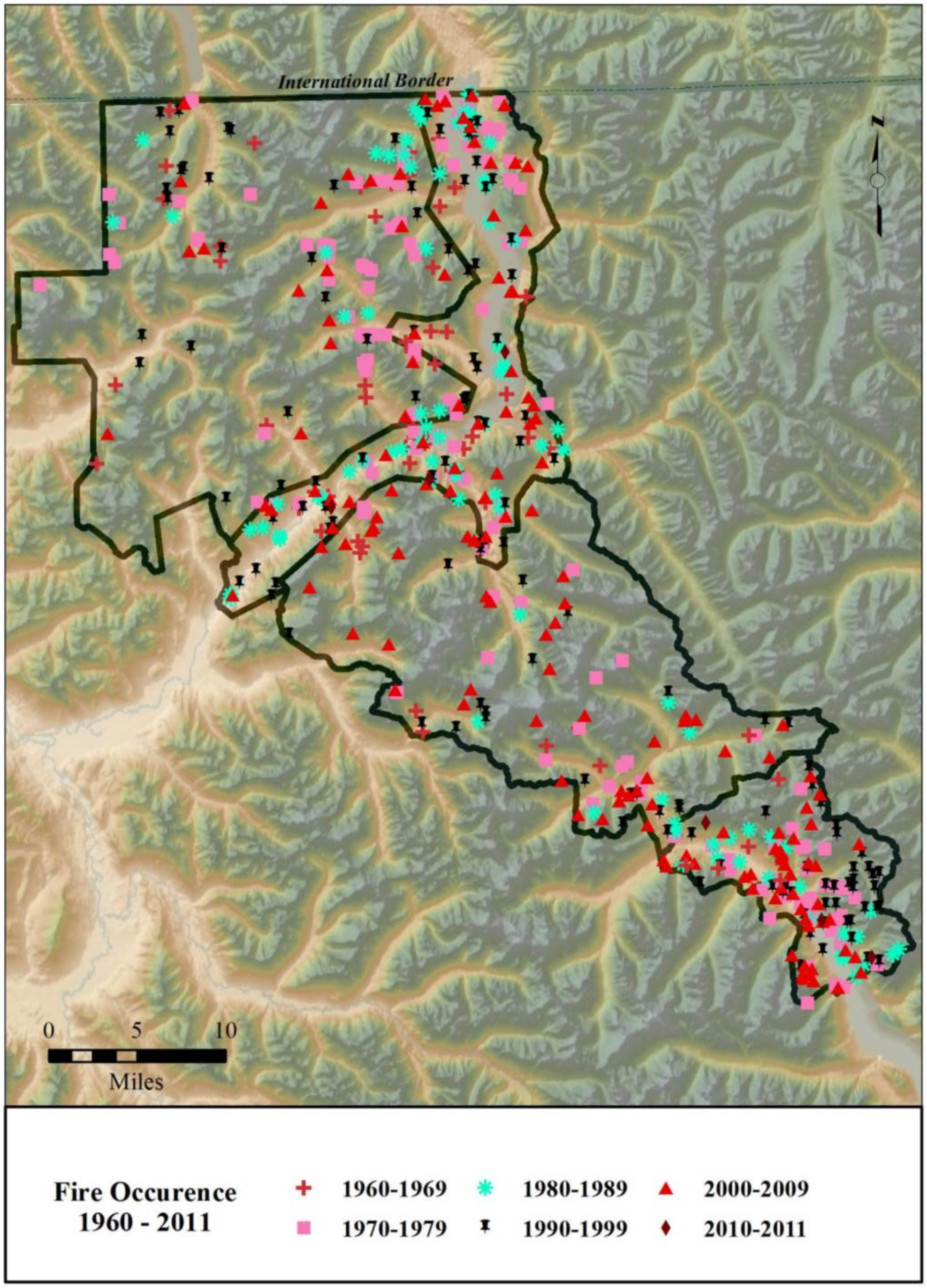

Figure 20. Location of fire occurences in North Cascades National Park Service Complex by decade between 1960 and 2011.

4.8.3 Reference Condition and Comparison Metrics

The historic fire-interval map (Figure 21) constructed from LANDFIRE data, displays the reference condition for the fire regimes of NOCA. The following historic fire interval classes were constructed by associating the LANDFIRE fire regime data with fire intervals from local fire history studies:

1. Frequent Interval: Frequent fires (<100-yr fire rotations, 10 to 70-yr mean fire interval) are associated with dry Douglas-fir–Ponderosa Pine mixed conifer forests. These forests are primarily east of the Cascade crest in the forest surrounding Stehekin. There are no fire histories in this area (although one is underway); however, we estimate that the lowest frequencies found on the driest sites (ponderosa pine dominated) are comparable to other local studies. A fire history in the northeastern Cascades reports an 18.8-yr mean fire interval on dry Douglas-fir sites dominated by Ponderosa Pine (Wright and Agee 2004), and another study reports an 11-yr natural fire rotation in pre-settlement Ponderosa Pine dominated stands (Everett et al. 2000). Fire frequencies throughout the majority of the Stehekin Douglas-fir–Ponderosa Pine forest are probably much longer, but still <100 yrs/rotation. Frequent fire intervals (44 to 52 yrs) were also documented west of the Cascade crest on the driest Douglas-fir–Ponderosa Pine dominated sites on the east side of Ross Lake (Agee et al. 1990).

   A fire history of Whitebark Pine (*Pinus albicaulis*) (Siderius and Murray 2005) communities found Whitebark Pine-Subalpine Fir (*Abies lasiocarpa*) forests on the south-east side of the park with frequent fire return intervals (mean fire return 67) and mixed severity fire effects.

2. Moderate Interval: Moderately long fire intervals (100- to 250-yr fire rotation, 70- to 200-yr mean fire interval) are associated with dry mixed conifer forests (other than the driest Douglas-fir–Ponderosa Pine types) on the east-side of Ross Lake (Agee et al. 1990, Prichard 2003). The Ross Lake area has a unique mix of continental and maritime plant associations, and a mix of low and high severity fire regime properties; despite being west of the Cascade crest, it is east (and in the rain-shadow) of Mount Baker and Mount Shuksan.

3. Long Interval: Long fire intervals (>250-yr fire rotations) characterize the majority of the forests west of the Cascade crest. Low elevation Western Hemlock–Western Redcedar–Douglas- fir forests have fire rotations comparable to those of Mount Rainier (450-yr fire rotation) (Hemstrom and Franklin 1982). Subalpine and alpine forests at NOCA also have long fire free intervals between stand-replacing events. In a 10,500-yr charcoal analysis from a lake sediment cores, fire frequency was found to fluctuate between 30 to 400 yrs in subalpine forests (Prichard 2003).

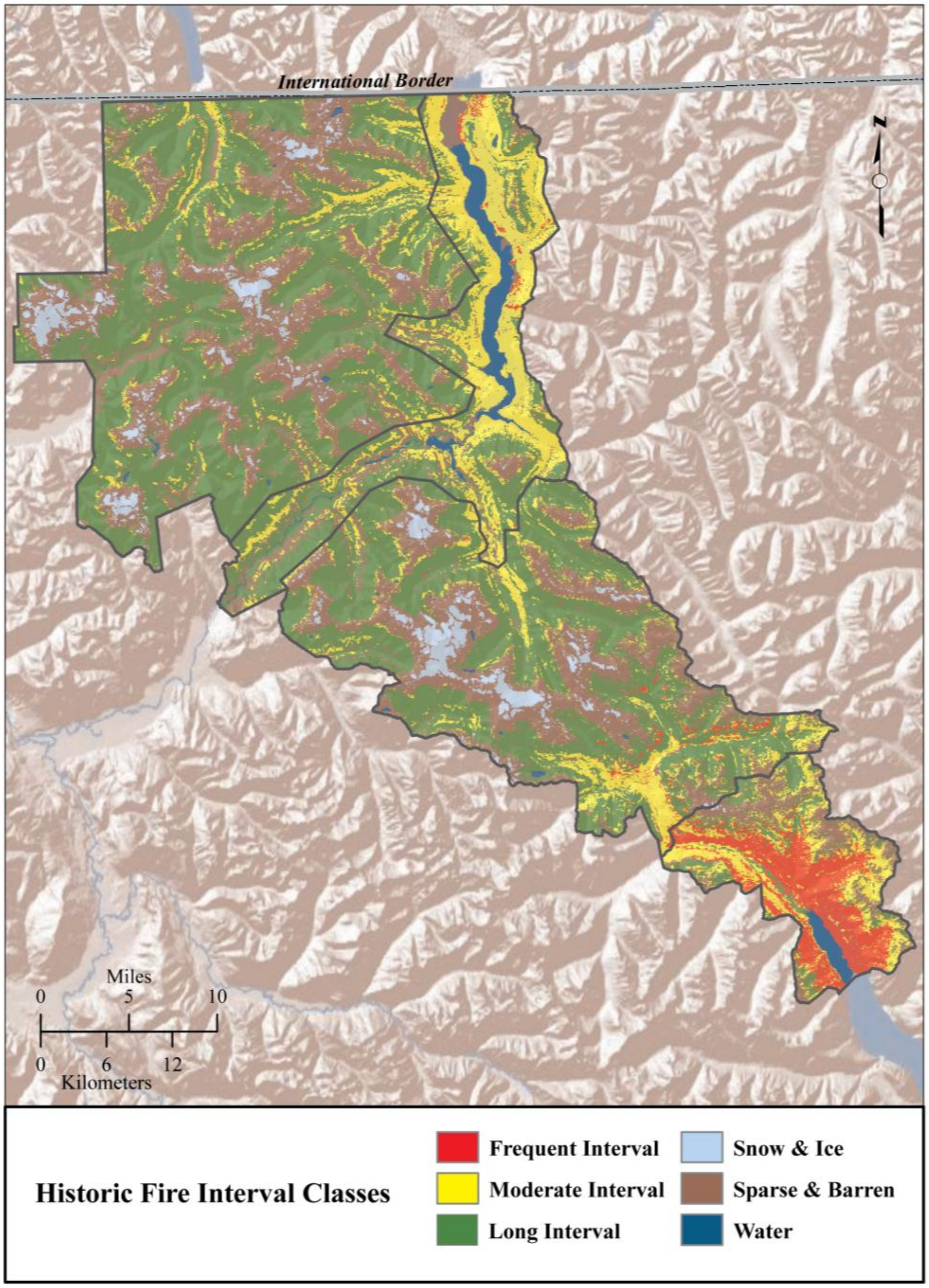

Figure 21. Historic ranges of fire return intervals for vegetation types at NOCA based on local fire histories and LANDFIRE fire regime data. The north end of Ross Lake was assumed to be sparsely vegetated before the construction of Ross Lake Dam. Frequent Interval is <100-yr fire rotations, 10- to 70-yr mean fire interval; Moderate Interval is 100- to 250-yr fire rotation, 70- to 200-yr mean fire interval; and Long Interval is >250-yr fire rotations.

4.8.4 Results and Assessment

Current Condition

The NPS fire records document a total of 611 fires in the park between 1960 and 2011 (Table 21). The majority of fires (68%) were lightning caused, compared to 30% caused by humans and 2%

which lack data regarding cause. The majority of fires (77%) were suppressed, compared to 7% that went out naturally and 15% that were managed for resource benefit (previously referred to as "prescribed natural fire" or "wildland fire use [WFU]").

Table 21a. Number of fires/fire type in North Cascades National Park Service Complex for each decade from 1960 to 2011 (* = only 2 yrs in last decade). Total number of fires does not equal the total number of fires by cause, type, or acres burned because some fires lacked any information other than location. WFU = wildland fire use (i.e., managed for resource benefit).

Decade	Natural	Human	Suppressed	Natural out	WFU	Total no. fires
1960	35	21	56	0	0	64
1970	111	45	126	0	30	156
1980	49	53	70	6	26	102
1990	108	29	104	27	6	137
2000	112	34	109	8	29	146
*2010	3	3	6	0	0	6
Total Fires	418	185	471	41	91	611
Fires/Year	8	4	9	1	2	12
Relative %	68.4	30.3	77.1	6.7	14.9	100

Table 21b. Number of acres burned/fire regime group in North Cascades National Park Service Complex for each decade from 1960 to 2011 (* = only 2 yrs in last decade). Total number of fires does not equal the total number of fires by cause, type, or acres burned because some fires lacked any information other than location.

	Frequent		Moderate		Long		Other Group		Total Burned	
Decade	Number	Acres	Number	Acres	Number	Acres	Number	Acres	Number	Acres
1960	5	30	25	198	30	40	4	117	64	361
1970	35	19	44	1843	72	1415	5	482	156	3767
1980	20	43	38	41	43	109	1	27	102	221
1990	26	3321	40	3465	67	2707	4	1812	137	9787
2000	28	5062	49	2606	62	4693	7	824	146	13,186
2010	2	3187	2	383	2	42	0	21	6	3634
Number fires	116		198		276		21		611	
Acres burned	11,663		8536		9006		3283		32,488	
Acres in FRG	27,448		110,679		328,134		55,280		521,541	
Relative acres	35.9 %		26.3 %		27.7 %		10.1 %		100 %	
NFR	122		675		1857		881		839	

There are 521,541 ac (211,060 ha) of combustible land within the park, of which 32,488 ac (13,147 ha) have burned between 1960 and 2011. Therefore, the 52-yr NFR for the whole park and each fire interval group are trending as follows: (1) Whole park: 6.2% of 521,541 ac (211,060 ha) burned, yielding a 839-yr NFR; (2) Frequent interval: 42.5% of 27,448 ac (11,108 ha) burned, yielding a 122-yr NFR; (3) Moderate interval: 7.7% of 110,679 ac (44,790 ha) burned, yielding a 675-yr NFR; and (4) Long interval: 2.8% of 328,134 ac (132,791 ha) burned, yielding a 1857-yr NFR.

The NFR calculations are described as "trending" to emphasize that they are only intended to reflect the trend of the fire regimes at this time. NFRs constructed from short time periods (such as these) are less meaningful, especially for estimating departure for long interval fire regimes where 1 or 2 large fires occurring outside of the time period used for calculation could alter the NFR substantially (Hemstrom and Franklin 1982, Agee 1993). The NFR calculation for the frequent interval is the most reliable estimate because the length of the fire record (52 yrs) approximates the length of its estimated historical NFR.

Trend

The historic NFR for the whole park is presumed to be much smaller than the NFR calculated for the park between 1960 and 2011 (839 yrs) since the natural fire rotation in even the longest fire interval group is estimated at 450 yrs. The NFRs calculated for each fire interval group are also substantially longer than estimates of the historic NFR for each. As expected, the NFR for the frequent interval group is the shortest (122 yrs), the moderate interval group is mid-length (675 yrs), and the long interval group is the longest (1857 yrs). These results suggest that fires are occurring most often in the areas that are most likely to have fires, but that fire suppression has altered the amount of area burned. This is supported by the fact that 77% of all fires were suppressed even though they were primarily caused by lightning.

Fire suppression was most prevalent in the frequent interval group, given that more than half of the fires in this group occurred before 1980 (when fire suppression was most prevalent) and comprised <1% of the acres burned. The moderate and long interval groups show less evidence of fire suppression; although they also had more fire occurrences and fewer acres burned before 1980, the contrast was not as great as it was in the frequent interval group. Climate may have influenced the low number of acres burned across all fire interval groups in the 1960s and 1980s.

Although the results suggest that fire suppression may have attenuated the NFR of each fire interval group, it has a greater impact on fuel loads in the frequent fire interval group because the fuels that have accumulated during suppression would have been consumed in an uninterrupted fire regime. Unnatural fuel accumulation is less of an issue in the areas associated with a moderate fire interval, although fire suppression will become more problematic if suppression continues. There is no indication that fire suppression has or will cause an un-natural accumulation of dead and downed fuel in the long interval group. The natural fire rotation of the long interval group is comparable to that of Mount Rainier National Park; it 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).

Predicted Changes

In the future, NOCA 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 is expected to be greatest in the long and moderate fire interval groups at NOCA, where climate (not fuel) is the limiting factor (Hemstrom and Franklin 1982, Agee 1993, Littell et al. 2009).

4.8.5 Emerging Issues

The long-term effects and interactions between climate, fire, and insect infestations are complex and still unclear (Field et al. 2007). Drought stress could increase tree mortality due to fires and insect infestations more rapidly than anticipated. Fuel could become a limiting factor in the moderate and long interval fire regime groups after 1 or more severe wildfires. Future species interactions due to shifts in climate conditions may alter post-fire regeneration. For example, 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, such as forest thinning and hazardous fuel reduction as steps in reducing fire risk and restoring forests, should focus on resiliency and ecosystem function rather than historical conditions which may no longer be suitable with climate change (Churchill et al. 2013).

Understanding the natural range of fire severity (e.g. tree mortality) is integral to the characterization and management of natural fire regimes, especially those with moderate fire intervals and mixed severity effects (Halofsky et al. 2011). The Monitoring Trends in Burn Severity (MTBS) project (Eidenshink et al. 2007) has mapped fire severity for several fires on the east-side of the park, many of which have been analyzed (Cansler 2011), but there have been far fewer large fires on the west side of the park since this project began.

4.8.6 Information and Data Needs–Gaps

We have identified 3 categories of relatively important future data requirements for NOCA: (1) development of models for climate, fire, and insect interactions relevant to NOCA; (2) development of climate adaptation strategies for post-fire communities at NOCA; and (3) continue to collect fire severity data through MTBS, especially for west-side moderate interval, mixed-severity fire regimes.

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4.9 Biodiversity: Exotic Plants

(Andrea Woodward, U.S. Geological Survey, 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 the 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). 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 and animal assemblages as well as individual native species (Hiebert and Stubbendieck 1993, Vitousek et al. 1996, Mack et al. 2000, 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 in NOCA comes from several sources. An environmental assessment (EA) was developed in 2011 regarding proposed changes to management of exotic species and includes lists of species and some location descriptions. NPS staff also provided some geospatial data as well as surveys of back-country trails not having spatial data for purposes of the present project. Finally, lists of noxious weeds found on adjacent national forest lands were obtained to identify species that are in the vicinity but not currently included in geospatial data in the park. The study area for this assessment was NOCA plus adjacent parts of 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 to be impossible, it is nevertheless a baseline for evaluating trend. The assessment metric is distribution of exotic species in the park.

4.9.4 Results and Assessment

Current Condition

More than 225 non-native species have been observed in NOCA, of which 40 are considered current management priorities (Jones Wining et al. 2011). Priorities were determined using a decision tool that reflects National Park Service Management Policies (NPS 2006) and calls for action if the invasive species: (1) alters ecosystem processes; (2) out-competes native species; (3) does not out compete native species, but prevents recruitment and regeneration, reduces or eliminates resources, or provides resources to nonnative animals; (4) may overtake or exclude native species following disturbance; (5) is listed as required to control on a state, county, or federal noxious weed list; and (6) infestation occurs in high quality and value habitat or resource areas, including designated wilderness. While there are many non-native species in the park, most of them occur in the 5% of the park that is not designated wilderness, and are primarily limited to areas of frequent disturbance such as roads, administrative areas, primary riparian corridors, and reservoir edges.

The process determined that there are18 high priority, 17 second priority, and 5 third priority taxa (*Centaurea* spp., *Hieracium* spp., *Polygonum* spp. and *Quercus* spp. are counted as single taxa). Geospatial data exist for 53 species of the 225 invasive species found in the park (Table 22). Twenty-seven species are classified as noxious weeds in Washington State, meaning that they are considered to threaten agricultural crops, local ecosystems, or fish and wildlife habitat (Table 22). Notably, Cheatgrass (*Bromus tectorum*) is not on the list of noxious weeds despite reducing wheat yield in eastern Washington and potentially affecting fire regime (http://www.fws.gov/nevada/nv_species/invasive_species/documents/cheat_grass.pdf). It has been observed to establish following fires in eastern areas of NOCA. Projects to manage Cheatgrass (1994 ac; 807 ha) and species of knotweed (456 ac; 185 ha) are the largest invasive plant control projects in the park.

Park geospatial and survey records provided for the NRCA indicate that the most widespread exotic species are Knapweed (*Centaurea* spp.), Orchard Grass (*Dactylis glomerata*), Ox-eye Daisy (*Leucanthemum vulgare*), English Plantain (*Plantago lanceolata*), Common Plantain (*Plantago major*), Annual Bluegrass (*Poa annua*), Compressed Bluegrass (*Poa compressa*), Perennial Bluegrass (*Poa pratense*), Creeping Buttercup (*Ranunculus repens*), Sheep Sorrel (*Rumex acetosela*), Red Clover (*Trifolium pratense*), White Clover (*Trifolium repens*), and Speedwell (*Veronica* spp.) (Table 22); although most are not priority species for the park. Most geospatially documented sites are on the SR-20 corridor; near Lake Chelan and the Stehekin Valley; and a few are near Ross Lake (Figure 22), although this may reflect greater efforts at inventory in these areas. Approximately 90% of backcountry trails have also been surveyed (Jones Wining 2011) but geospatial data are not available. Records show that front-country areas have the greatest diversity of exotic plants, followed by trails; surprisingly, the SR-20 corridor is least diverse (Table 22), although this may reflect differences in survey methodologies among areas.

Inventories of invasive species on national forest lands surrounding NOCA identify species that are not included in the geospatial records of NOCA. There are 9 such species in the Mount Baker Ranger District to the west of the park; to the east, there are 20 species in the Methow Valley Ranger District and 50 throughout the Okanogan-Wenatchee National Forest (Table 23). Information for the Chelan Ranger District, which is adjacent to the park, was not available.

Trend

Compared to the reference condition of zero invasive species, the flora of NOCA has experienced an increase in plant invasion resulting in 225 non-native species (http://www.nps.gov/noca), of which only 53 have geospatial data and 27 are designated as noxious weeds by Washington State. Cheatgrass is also establishing following fires.

Assessing short-term trends is difficult because many areas have not been surveyed more than once. An exception is the SR-20-Skagit River corridor which was surveyed for knotweed in 2001 and again in 2007 (Figure 23). Results show a substantial decrease in knotweed detections, which describes the net result of eradication efforts, spread from established populations, and repeat introductions. Also, the Skagit River and tributaries are surveyed annually and the Stehekin River has been surveyed several times. Data from the Stehekin River show a 100% increase in the knotweed population between 2005 and 2009 (NPS 2011). 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 influence 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; increased ability for non-native survival in subalpine and alpine areas due to climate change; 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 CO_2 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 22. Invasive plant species by region of NOCA as described in Environmental Assessment (Jones Winings 2011) or geospatial and survey data provided for NRCA.

				Park Region						
Species name	**Common name**	**Park priority[1]**	**Washington Class[2]**	**SR-20 Corridor, Skagit River**	**SR-20 Corridor trails[3]**	**Ross Lake and trails[4]**	**Northern trails[5]**	**Central trails and roads[6]**	**Southern trails[7]**	**Lake Chelan/Stehekin[8]**
Agropyron repens	Quack Grass					X				
Agrostis alba	Red Top								X	
Aira caryophylla	Hair Grass					X		X		
Artemisia absinthium	Absinth Wormwood	1	C	X						
Bromus hordeaous	Soft Brome					X				
Bromus tectorum	Cheatgrass	3		X	X	X				X
Buddleja davidii	Butterfly Bush	1	B							
Centaurea diffusa	Diffuse Knapweed	2	B	X						
Centaurea jacea	Brown Knapweed		B							?
Centaurea maculosa	Spotted Knapweed	2								
Centaurea spp.	knapweed			X		X	X	X		X
Cerastium glomeratum	Sticky Chickweed				X			X		
Chondrilla juncea	Rush Skeleton Weed	2	B							X
Cirsium arvense	Canada Thistle	2	C	X		X				X
Cirsium vulgare	Bull Thistle	2	C	X		X				X
Clematis vitalba	Traveler's Joy	1	C	X						
Conium maculatum	Poison Hemlock	1	B							
Cytisus scoparius	Scot's Broom	2	B	X						X
Dactylis glomerata	Orchard Grass				X	X		X	X	?
Digitalis purpurea	Foxglove					X		X		
Euphorbia myrsinites	Myrtle Spurge	1	B							
Euphorbia oblongata	Eggleaf Spurge	1	A							
Geranium robertianum	Herb Robert	2	B	X			X	X		
Hedera helix	English Ivy	1	C	X						
Hieracium pilosella	Mouse-ear Hawkweed	2	B	X			X			
Holcus lanatus	Velvet Grass				X	X				
Hypericum perforatum	Common St. John's Wort	3	C	X	X	X		X		
Ilex aquafolium	English Holly	1		X						
Juglans cinerea	Butternut	1								
Lactuca serriola	Prickly Lettuce							X		?
Lathyrus latifolius	Evergreen (Sweet) Pea	1		X						X
Leucanthemum vulgare	Oxeye Daisy	3	C	X		X	X	X		X
Linaria dalmatica	Dalmatian toadflax	1	B	X						X
Linaria vulgaris	Yellow Toadflax	1	C	X						X
Medicago polymorpha	Burr Clover					X				
Melilotus alba	White Sweet Clover	2		X		X	X	X		
Mycelis muralis	Wall Lettuce				X	X	X	X		
Phalaris arundincea	Reed Canary Grass	2	C	X		X	X			X
Phleum pretense	Timothy								X	
Plantago lanceolata	English Plantain				X		X	X	X	X
Plantago major	Common Plantain				X	X	X	X	X	X

Table 22. Invasive plant species by region of NOCA as described in Environmental Assessment (Jones Winings 2011) or geospatial and survey data provided for NRCA (continued).

				Park Region						
Species name	Common name	Park priority[1]	Washington Class[2]	SR-20 Corridor, Skagit River	SR-20 Corridor trails[3]	Ross Lake and trails[4]	Northern trails[5]	Central trails and roads[6]	Southern trails[7]	Lake Chelan/Stehekin[8]
Poa annua	Annual Bluegrass				X	X	X	X	X	X
Poa bulbosa	Bulbous Bluegrass									X
Poa compressa	Compressed Bluegrass				X	X	X	X	X	
Poa pratense	Perennial Bluegrass				X	X	X	X	X	
Polygonum cuspidatum	Japanese Knotweed	2	B	X						X
Polygonum sachalinense	Giant Knotweed	2	B	X						X
Potentilla recta	Sulfur Cinquefoil	1	B	X						X
Prunella arvense	Self-heal							X		
Quercus spp.	oak	1		X						
Ranunculus repens	Creeping Buttercup				X	X	X	X		X
Robinia hispuda	Bristly Locust	1								
Robinia pseudo-acacia	Black Locust	1								X
Rubus discolor (armeniacus)	Himalayan Blackberry	2	C	X						X
Rubus lasciniatus	Cut-leaved Blackberry	2	C	X	X		X			X
Rumex acetosella	Sheep Sorrel					X	X	X	X	?
Rumex crispus	Curly Dock						X			?
Senecio jacobaea	Tansy Ragwort	1	B							
Spergula rubra	Sand Spurrey								X	
Stellaria crispa	Crisp Starwort						X			
Stellaria media	Common Chickweed							X		
Tanacetum vulgare	Common Tansy	3	C	X	X	X		X		
Trifolium arvense	Clover					X				
Trifolium dubium	Little Clover					X				
Trifolium pratense	Red Clover				X	X	X	X		X
Trifolium repens	White Clover				X	X	X	X	X	X
Verbascum thapsus	Common Mullein	1				X				?
Veronica spp.	Speedwell				X	X	X	X	X	
Vicia spp.	vetch							X		
Vinca major	Periwinkle	3		X						
Vulpia spp.	six-week brome					X	X			X

[1]1, high priority; 2, second priority; 3, third priority

[2]Washington State noxious weed classes, 2013: 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

[3]Includes Sourdough, Thornton Lakes, Panther, Thunder Knob

[4]Includes Lighting Creek, Desolation Mountain, Ruby Arm, East Bank, Ross Dam, Ross haul road, Hozomeen, Ridley Lake

[5]Include Big Beaver, Little Beaver, Chilliwack, Copper Ridge, Brush Creek

[6]Includes North Fork Cascade River, Cascade Pass, Thunder Creek, Park Creek, Monogram Lake

[7]Includes Bridge Creek, McAlester Lake, Dagger Lake

[8]Question marks indicate uncertainty due to 2-letter species abbreviations used in data collection

Table 23. Noxious weeds found in USDA Forest Service Ranger Districts (RD) adjacent to NOCA. Large X's indicate the species is not currently documented in NOCA.

Species	Common name	Mount Baker-Snoqualmie NF, Mount Baker RD[1]	Okanogan-Wenatchee NF[2]	Okanogan-Wenatchee NF, Methow Valley RD[3]
Amsinckia menziesii	Common Fiddleneck		X	
Arctium lappa	Greater Burdock		X	
Artemisia absinthium	Absinthium		X	
Artemisia biennis	Biennial Wormwood		X	
Berteroa incana	Hoary Alyssum		X	X
Bromus tectorum	Cheatgrass		x	
Buddleja davidii	Butterfly Bush	X		
Capsella bursa-pastoris	Shepherd's Purse		X	
Cardaria draba	Whitetop		X	X
Carduus acanthoides	Spiny Plumeless Thistle		X	
Carduus nutans	Musk Thistle		X	X
Centaurea biebersteinii	Spotted Knapweed	x	x	x
Centaurea debeauxii	Meadow Knapweed		x	
Centaurea diffusa	Diffuse Knapweed		x	x
Centaurea repens	Russian Knapweed		x	X
Centaurea solstitialis	Yellow Star-thistle		x	
Cichorium intybus	Chicory		X	
Cirsium arvense	Canada Thistle	x	x	x
Cirsium vulgare	Bull Thistle	X	X	
Crupina vularis	Common Crupina		X	
Cynoglossum officinale	Hound's Tongue		X	X
Cytisus scoparius	Scot's Broom	x	x	x
Daucus carota	Queen Anne's Lace	X	X	
Digitalis purpureum	Purple Foxglove		x	
Geranium robertianum	Herb Robert	x		
Gypsophila paniculata	Baby's Breath		X	X
Hedera helix	English Ivy	X		
Hieracium aurantiacum	Orange Hawkweed	X	X	X
Hieracium caespitosum	Meadow Hawkweed	X	X	X[4]
Hyoscyamus niger	Black Henbane		X	
Hypericum perforatum	St. John's Wort	x	x	x[4]
Hypochaeris radicata	Spotted Cats'-ear	X	X	
Kochia scoparia	Kochia		X	X
Lanaria vulgaris	Butter and Eggs		X	
Leucanthemum vulgare	Oxeye Daisy	x	x	x[4]
Linaria dalmatica	Dalmatian Toadflax		x	x
Lysimachia spp.	Yellow Loosestrife		X	
Matricaria perforata	Scentless False Mayweed		X	
Myriophyllum spicatum	Eurasian Watermilfoil		X	
Onopordum acanthium	Scotch Thistle		X	X

Table 23. Noxious weeds found in USDA Forest Service Ranger Districts (RD) adjacent to NOCA. Large X's indicate the species is not currently documented in NOCA (continued).

Species	Common name	Mount Baker-Snoqualmie NF, Mount Baker RD[1]	Okanogan-Wenatchee NF[2]	Okanogan-Wenatchee NF, Methow Valley RD[3]
Phalaris arundinacea	Reed Canarygrass	x	x	
Poa bulbosa	Bulbosa Bluegrass		x	
Polygonum cuspidatum	Japanese Knotweed	x	x	
Polygonum polystachyum	Cultivated Knotweed		X	
Polygonum x bohemicum	Bohemian Knotweed	x		
Potentilla recta	sulfur Cinquefoil		x	x
Rubus armeniacus	Himalayan Blackberry	X	X	
Rubus lasciniatus	Cut-leaf Blackberry	x		
Salsola	Russian Thistle		X	
Senecio jacobaea	Tansy Ragwort	x	X	x
Senecio sylvaticus	Woodland Ragwort		X	
Senecio vulgaris	Common Groundsel		X	
Silene latifolia	Bladder Campion	X		
Sonchus arvensis	Field Sowthistle		X	
Tanacetum vulgare	Common Tansy		x	x[4]
Verbascum thapsus	Common Mullein		x	

[1]Source: Fuentes et al. (2007)

[2]Source: Brigitte Ranne, USDA Forest Service Chelan Ranger District, personal communication (list for only Chelan RD was not available)

[3]Dean McFetridge, USDA Forest Service Methow Valley Ranger District, Range and Invasive Plant Specialist, personnel communication

[4]Species most commonly seen on Highway 20 near park and from East Creek Trailhead to park

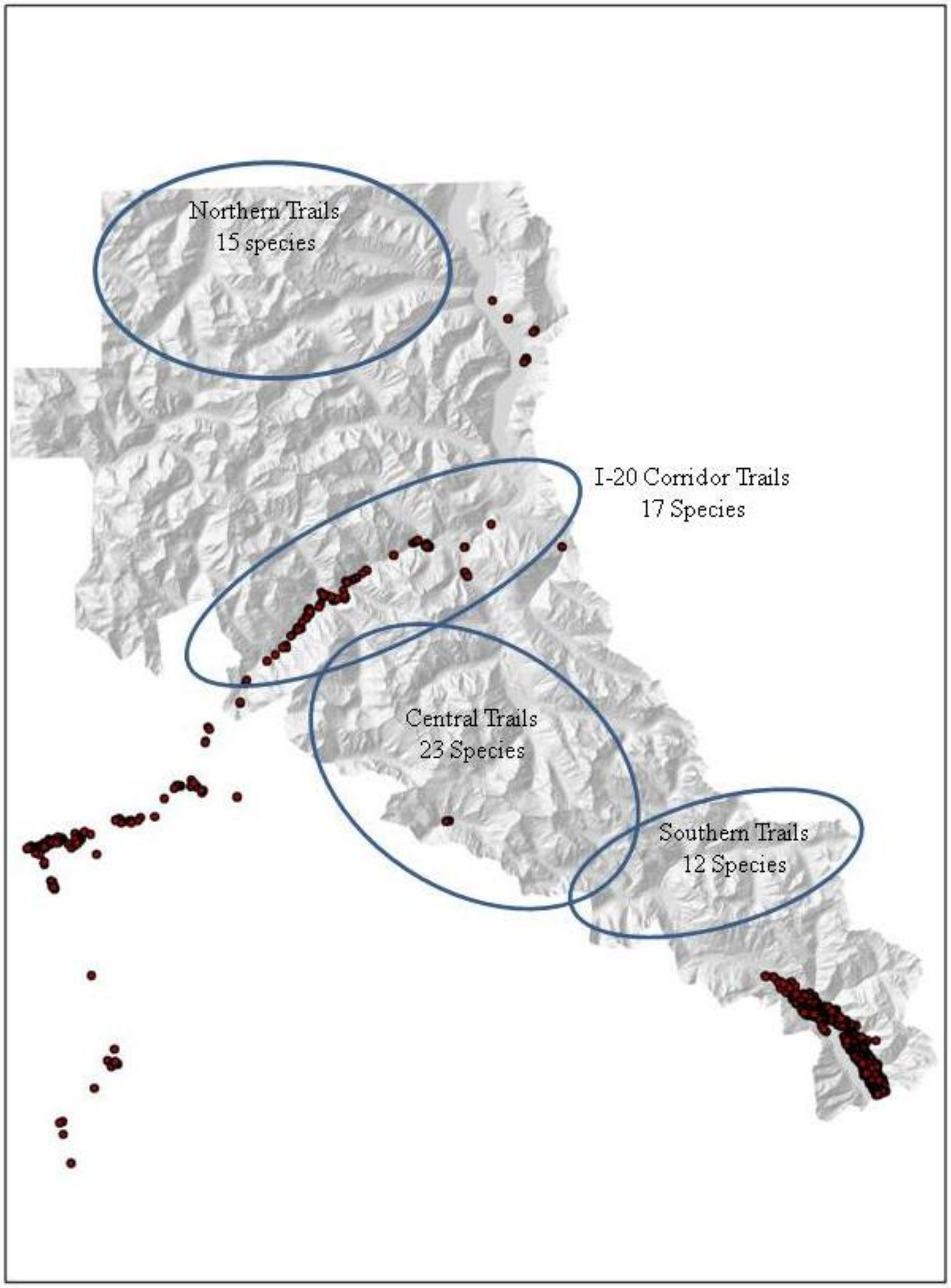

Figure 22. Distribution of invasive species throughout NOCA.

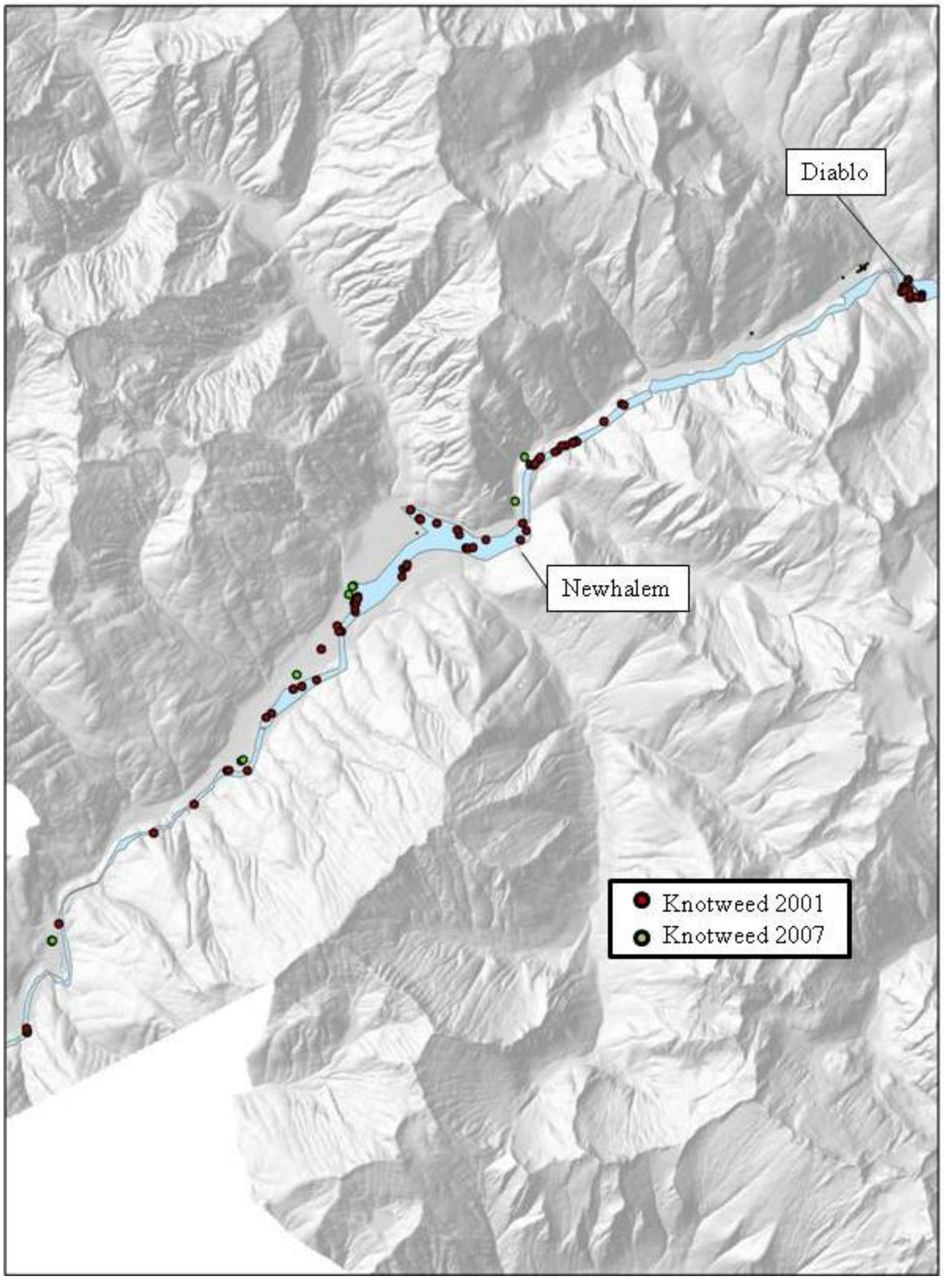

Figure 23. Repeat surveys for Knotweed along the SR-20 corridor.

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).
- Currently most exotic species 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 NOCA and therefore may pose imminent threats (Table 23).
- Climate change is predicted to influence invasion dynamics and ecosystem consequences due to invasive species (Hellman et al. 2008, Pejchar and Mooney 2009, Walther et al. 2009).

4.9.6 Information and Data Needs–Gaps

- Frequent and comprehensive monitoring of the most vulnerable areas, such as the front-country areas and georeferencing exotic weed locations, 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.
- Periodic analysis of exotic plant data that incorporates Exotic Plant Management Team efforts such as was conducted for the EA will apprise park staff of management success.

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4.10 Biodiversity: Wetlands

(Andrea Woodward and Patricia Haggerty, U.S. Geological Survey, 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 seasons (Halls 1997). High elevation wetlands in the North Cascades are exceptional in that they my have greater floristic diversity than montane wetlands in the Rocky Mountains and lowland wetlands in western Washington (Risvold and Fonda 2001), although this conclusion is not supported by others (Peet 1978, Baker 1990, Roccio, written communication). The importance of wetlands and their processes played a significant role in the establishment of NOCA (Holmes and Kuntz 1994). Consequently, park staff has endeavored to gather information about wetland resources since the park was established, with digitized records created in the early 1990s Holmes and Kuntz 1994).

Typical vegetation in low elevation riparian wetlands includes 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 riparian 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). Montane wetland meadows are dominated by Small Red Peat Moss (*Sphagnum capillifolium*), White March Marigold (*Caltha biflora*), and Many Spiked Cotton Grass (*Eriophorum polystachion*) (Risvold and Fonda 2001).

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 Salathe 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 NOCA 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/.NWI) and the Cowardin wetland classification system (Cowardin et al. 1979). These maps were validated in the early 1990s by NOCA staff for areas in 15 USGS quadrangle maps, mostly in the western region of the park. These surveys only cover approximately half of the park, but park staff estimate that 95% of the wetlands in NOCA were ground-truthed (Holmes and Kuntz 1994). However, there is doubt that the high-elevation wetlands were ground-truthed (Mignonne Bivin and Regina Rochefort, NOCA and NCCN, pers. comm.). While NWI also assesses trend in wetland area, this has only been done on a national basis and for selected areas not including the Pacific Northwest.

4.10.3 Reference Conditions and Comparison Metrics

There is no evidence to date that total extent and quality of wetlands are changing in NOCA, although no studies have been conducted to assess water quality. Consequently, the current inventory of wetlands describing spatial extent and wetland class 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 NOCA wetland map (Holmes and Kuntz 1994), created by ground-truthing NWI maps in selected areas of the central and western part of the park (Figure 24a), identifies 835.5 ha (2065 ac) of wetlands (reservoirs and most lakes were not mapped). Wetland types include riverine wetlands, freshwater lakes and ponds (lacustrine), and freshwater emergent and freshwater forested-shrub wetlands (palustrine). This compares with 3204.9 ha (7920 ac) mapped by NWI, excluding reservoirs (Figure 24b). When only comparing emergent and forest-shrub wetlands plus ponds, the comparison is closer (NOCA: 726.8 ha, 1796 ac; NWI: 115.4 ha, 284 ac). Areas shown on the NWI map but not the NOCA ground-truth map occur on Flat Creek just inside the park boundary; the north fork of Bridge Creek; Stehekin River; Park Creek; a pond on Fisher Creek; as well as small amounts on Big and Little Beaver Creeks and west of Mount Spickard. These are primarily areas that were not ground-truthed by the park. The NOCA map shows areas not included on the NWI map such as on the Baker River and north fork of the Cascade River just inside the park boundary; and on the Skagit River near Goodell Creek. Examining a representative area in detail (Figure 24b) shows the NPS survey found more forested palustrine and riverine-unconsolidated shore wetlands than shown on the NWI map, while NWI showed more palustrine-scrub–shrub wetlands than the NPS survey. Many areas classed as palustrine-scrub–shrub were classed as riverine unconsolidated shore and palustrine-forested by NPS. 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).

Trend

At present there is no information to describe wetland trends in NOCA. 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 NOCA. However, there may have been historic alteration of wetlands near roads and trails and administrative areas of the park.

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.ncdn.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 Bodie 1998) while also being difficult to survey and monitor.

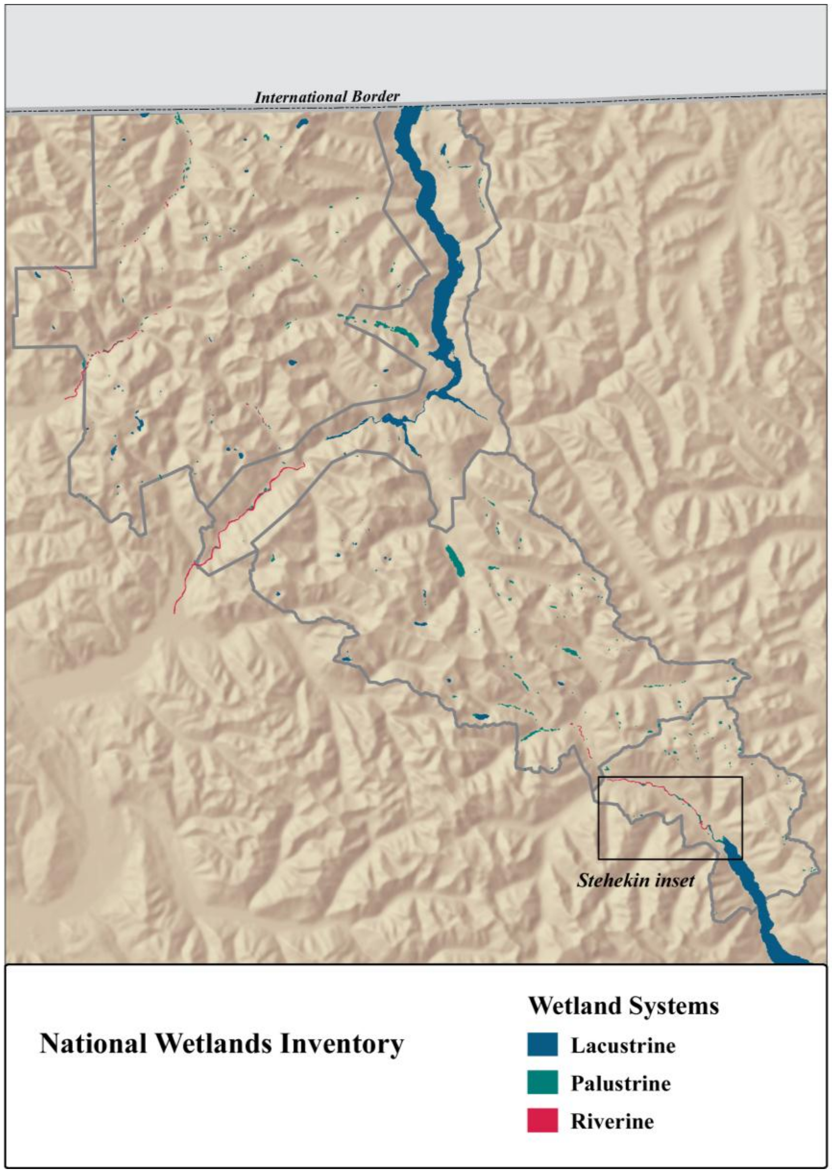

Figure 24a. National Wetland Inventory map for NOCA.

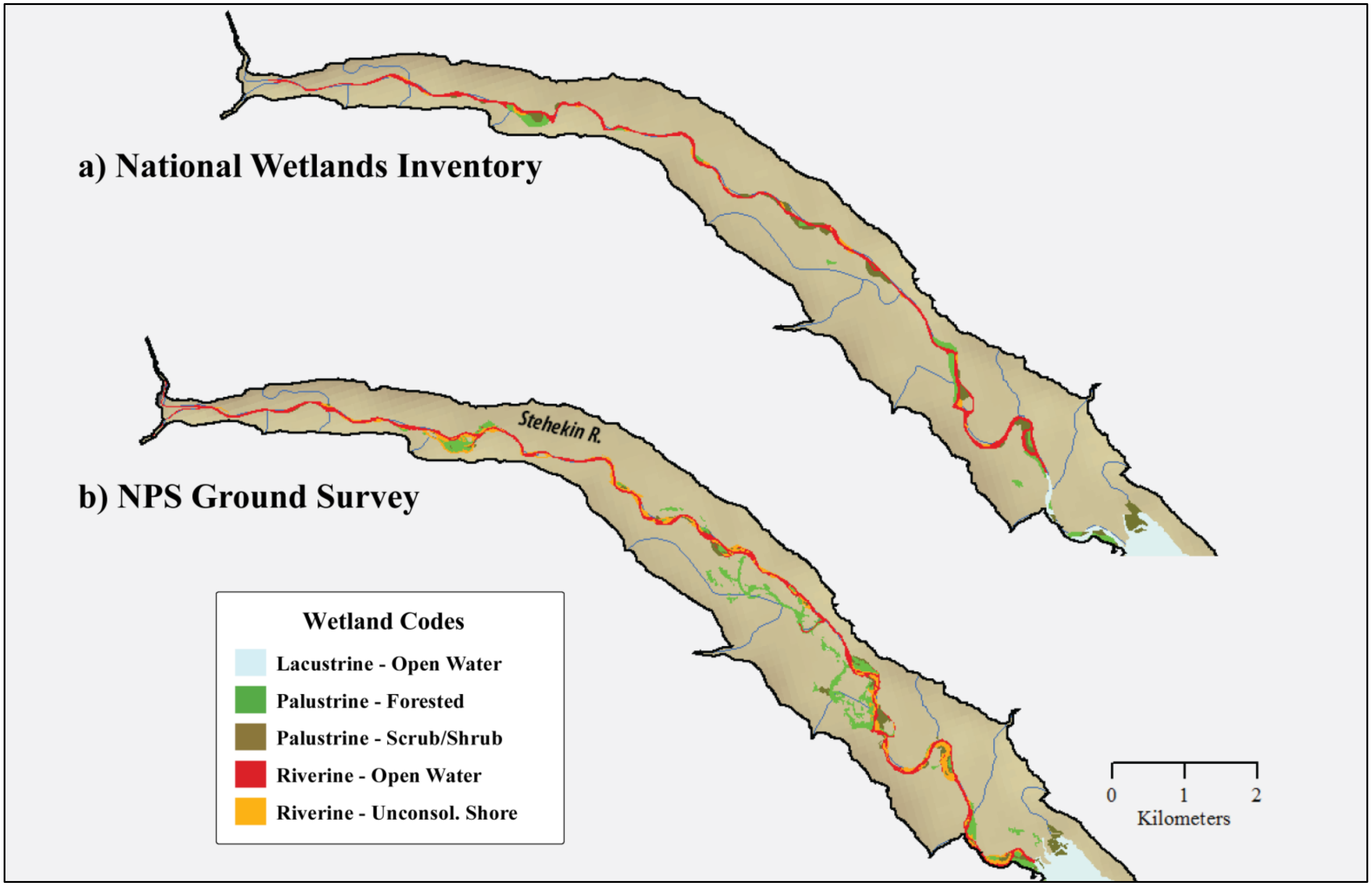

Figure 24b. Representative area comparing National Wetlands Inventory map comared with results of NOCA ground-truth survey.

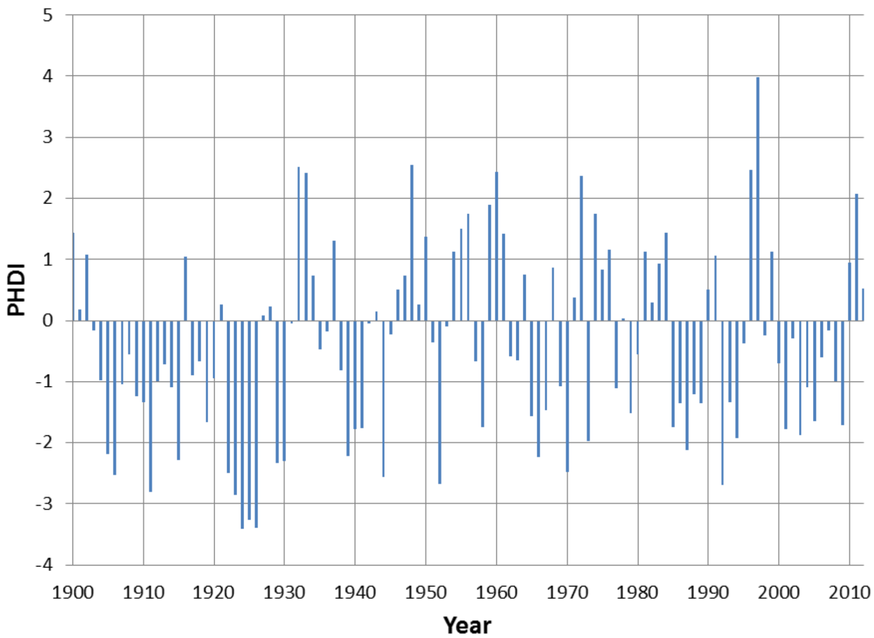

Figure 25. Palmer Hydrologic Drought Index for Climate Division 5 of Washington State (Cascade Mountains West). Negative numbers indicate drought conditions.

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 NOCA. Instead, wetland types present in NOCA 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 also likely affect water quality, particularly temperature, as well as quantity.
- Increasing levels of air pollutants from local and global sources may affect wetland water quality in the future. Wetlands in NOCA are especially sensitive because they are oligotrophic and have low acid-neutralizing capacity (Clow and Campbell 2008).

4.10.6 Information and Data Needs–Gaps

- The park would benefit from an updated, complete map of wetlands for the entire park complex. Although Holmes and Kuntz (1994) mapped wetlands in the northern and central portion of the park, surveys were based on NWI maps and reports of existing wetlands and therefore may not have documented all wetlands in forested areas or high-elevation wetlands. Recently, NOCA staff has been collaborating with UW researchers to develop remote-sensing methods to improve spatial documentation of monitored wetlands (Hamlet 2012). This research is a high priority for the park to develop a baseline of wetlands.
- While changes in extent and perhaps wetland class 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).

- Wetland loss may not be the most significant change caused by a changing climate; it may be a shift in wetland types on the landscape, with resulting shifts in ecological functions.
- The National Wetland Inventory identifies wetlands in the southern part of the park that have not been validated by park staff. Because this area is relatively dry, these wetlands may be most vulnerable to expected increases in summer drought. Also, high-elevation wetlands have not been ground-truthed.
- 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. However, monitoring of wetland extent alone will give limited insight into changes in wetland biodiversity. Ideally, creating a wetland profile (extent of wetland types) 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).

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4.11 Biodiversity: Subalpine Vegetation

(Andrea Woodward and Patricia Haggerty, U.S. Geological Survey, 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 et al. 1994). 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), 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 Ecological Systems map (Comer et al. 2003) to assess current status of subalpine vegetation in NOCA. To describe trend, we summarized the 1 research study describing trends in subalpine meadows conducted in NOCA. 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. Moreover, the period of record for NOCA is very short relative to decadal-scale climate fluctuations. Consequently, the present condition may simply serve as the reference for future change. The vegetation map currently in development could serve as a baseline.

4.11.4 Results and Assessment

Current Condition

The most detailed vegetation map for NOCA, at present, is the Ecological Systems (ES) map created by NatureServe (Comer et al. 2003; see section 4.4.1). This map has not been ground-truthed for the NOCA area by NatureServe or NOCA staff, therefore conclusions are provisional. According to this map, 31.7% of NOCA is comprised of vegetation classes that span the ecotone from continuous forest, through tree clumps, krummholz to alpine meadows. These classes include the North Pacific

Maritime Mesic Subalpine Parkland (ES 4225, 15.7% of NOCA) on the west side of the Cascades in areas with deep, late-lying snow. The Northern Rocky Mountain Subalpine Woodland and Parkland (ES 4233, 5.5% of NOCA) occupies areas on the east side of the Cascades and consists of tree clumps dominated by Whitebark Pine (Pinus albicaulis), Subalpine Larch (Larix lyallii), some Subalpine Fir (Abies lasiocarpa), open woodlands, and herb or dwarf-shrub dominated openings. North Pacific Alpine and Subalpine Day Grasslands (ES 7157, 6.1% of NOCA) are dominated by Fescue spp. and are embedded in or above subalpine forests and woodlands. Finally, North Pacific Dry and Mesic Alpine Dwarf-shrubland, Fell-field and Meadows (ES 5205, 0.8% of NOCA) are dominated by graminoids, foliose lichens, dwarf-shrubs and forbs, and are found above treeline (Rocchio and Crawford 2009).

Trend

We detected no dramatic changes in tree distribution upon examining time series of aerial photography and satellite imagery for 2 subalpine meadows in NOCA over the period 1958 to present. However, an intensive examination of photographs and imagery for a meadow on Goode Mountain in the southwestern part of the park did detect changes in tree cover and treeline position (Brookman 2010). Specifically, area with open canopy decreased by 7% while closed canopy increased by 4% from 1958 to 2009, possibly indicating increased density of trees in areas originally having open canopies. In addition, vegetation patches above treeline were seen to increase in area and density and treeline migrated upslope by 25 m (82 ft). These changes were associated with an increase in growing season temperature, variable amounts of precipitation, and a decline in snowpack over the study period. 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).

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 protection (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 (Dendroctonus ponderosae) 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, fire history (Agee 1993), 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 such as phenology (Dunne et al. 2003), disturbance due to native and non-native insects and pathogens in subalpine meadows (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 satellite-based remotely sensed data because the harsh subalpine environment significantly limits tree growth. Therefore, ground-based monitoring is important to provide early warning and documentation of changes in herbaceous species composition as well as tree distribution. 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).

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4.12 Biodiversity: Sensitive Species

(Andrea Woodward, U.S. Geological Survey, 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

Status of sensitive species was assessed using lists of vascular and non-vascular plant species and fungi, compiled by Bivin and Rochefort (2010), and by adjacent national forests (http://www1.dnr.wa.gov/nhp/refdesk/fguide/htm/fsfgabc.htm), and surveys by Hutten and by Trappe (data on file at NOCA), although the non-vascular list for the park is quite limited. The range of each species in North America was extracted from the Plant Profiles website (USDA NRCS 2012) of the U.S. Department of Agriculture. 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 the change in species status in Washington State since 1997. The study area for this assessment was NOCA plus adjacent parts of 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 WNPS status.

4.12.4 Results and Assessment

Current Condition

There are currently 23 species having conservation status of ‘vulnerable’ or higher among species documented or suspected to occur in NOCA; 7 other species are to be watched because they may become vulnerable (Table 24). Of these, 3 species are considered globally vulnerable (*Botrychium paradoxum*, *Erigeron salishii*, *Iliamna longisepala*) and 2 are ranked globally vulnerable to imperiled (*Botrychium pedunculosum*, *Silene seelyi*). *Silene seelyi* is endemic to the Wenatchee Mountains and is threatened mainly by rock climbers. *Iliamna longisepala* is also endemic to Washington State and is threatened by fire suppression because this practice allows stands of trees to replace suitable habitat. *Erigeron salishii* populations only occur at high elevations in Washington State and British Columbia, and may be vulnerable to climate change. Note that while *Iliamna longisepala* and *Silene seelyi* are on the plant list for the park, they have not been found in the park (Mignonne Bivin,

NOCA, pers. comm.). Also, *Pinus albicaulis* is a candidate to be listed under the federal Endangered Species Act and is discussed in more detail in section 4.6 of Chapter 4.
Numerous additional sensitive species occur in adjacent national forests (Table 25). While any of these species could occur in NOCA, those that have been observed near the park boundary seem most likely to also have populations in the park. Candidates include *Botrychium ascendens, Carex stylosa, Chaenactis thompsonii, Cryptogamma stelleri, Draba cana, Eritrichium nanum var. elongatum,* and *Saxifraga cernua.*

Several surveys of non-vascular plants have been conducted in localized areas of NOCA, specifically areas thought to be vulnerable to rock-climbing, bouldering, and road maintenance activities (Hutten, undated spreadsheet on file at NOCA). Macrofungi have been more widely documented in the park (Trappe, undated spreadsheets on file at NOCA), but not in a systematic survey. Although these efforts are limited, surveys discovered several species of importance to WNHP (Table 26). More work on non-vascular plants and fungi is clearly warranted.

Trend

Among the sensitive species documented or suspected to occur in NOCA, 5 changed status from 'sensitive' to 'threatened' since 1997 (Botrychium paradoxum, Carex capillaris, Carex macrochaeta, Loiseleuri procumbens, Parnassia kotzebuei), while 7 have been downgraded from threatened to sensitive (Silene seelyi) or removed from the list to 'watch' status (Botrychium pinnatum, Carex buxbaumii, Carex saxatilis var. major, Epipactis gigantea, Impatiens aurella, Pinguicula vulgaris) (Table 24). However, Carex macrochaeta was recently (2013) found in a new location (Mignonne Bivin, NPS, pers. comm.). Improved status is most commonly due to the location of previously unknown populations, while degrading status most likely reflects loss of habitat and as such does not provide insight into the status or vulnerability of populations within the park complex (i.e. status changes are generally based on the entire state of Washington). There is insufficient information to begin to describe trends in non-vascular plants or 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 because of their relative rarity, they are at the edge of their range, may be in the park but have not been documented include:

1. *Botrychium paradoxum*–globally vulnerable (G3) and T, S2 in Washington–is suspected to be in NOCA; surveys may be valuable;
2. *Carex capillaris*: T, S1 in Washington and at the southern edge of its range;
3. *Carex rostrata*: S, S1 in Washington and at the southern edge of its range;
4. *Erigeron salishii*: S, S2 in Washington and occurs only in Washington and British Columbia;
5. *Iliamnus longisepala*: globally vulnerable (G3) and S, S3 in Washington, but is endemic to Washington and is suspected to be in NOCA; surveys may be valuable;

6. *Loiseleuria procumbens*: T, S1 Washington; not documented in NOCA since 1963; Washington is at the southern edge of its range;
7. *Parnassus kotzebuei*: T, S1 in Washington, and is at the edge of its range;
8. *Silene seelyi*: T, S1 in Washington, and is endemic.

Table 24. Sensitive species of North Cascades National Park Service Complex. (Source for ranges is USDA NRCS. 2012).

Species name	Common name	Last documented[1]	Global Rank[2]	State status (rank) 2012[3]	Change since 1997[4]	Range in North America[5]
Botrychium paradoxum	Twin-spiked Moonwort	Susp.	G2	T (S2)	↑S-T	British Columbia, Alberta, Saskatchewan, WA, OR, ID, MT, UT
Botrychium pedunculosum	Stalked Moonwort	2010	G2G3	S (S2)		AK, WA, OR, ID, MT, eastern and western Canada
Botrychium pinnatum	Northwestern Moonwort	2010	G4	W(S3)	↓S-W	Northern US, Canada, Greenland, AK, NV, UT, CO, NM
Carex buxbaumii	Buxbaums's Sedge	2010	G5	W(S3)	↓S-W	Canada, AK, Greenland, northern half contiguous US, AR, TN, NC, SC, GA
Carex capillaris	Hair-like Sedge	2010	G5	T(S1)	↑S- T	Canada, AK, Greenland, northern contiguous US, NV, UT, CO, NM
Carex macrochaeta	Large Awned Sedge	2010	G5	T(S1)	↑S-T	AK, WA, OR, western Canada
Carex magellanica ssp. irrigua	Poor Sedge	1986	G5T5	S(S2S3)		Canada, Greenland, AK, northern contiguous US except ND and SD, WY, US CO
Carex pluriflora	Several Flowered Sedge	1988	G5	S(S1/S2)		AK, British Columbia, WA, OR
Carex rostrata	Beaked Sedge	2010	G5	S(S1)		AK, Canada, Greenland, WA, ID, MT, Great lakes region
Carex saxatilis var. major	Russet Sedge	2010	G5	W(S5)	↓S-W	AK, western Canada, eastern Canada, WA, OR, ID, MT, WY, CO, UT, NV
Draba aurea	Golden Draba	Susp.	G5	S(S1S2)		AK, Canada, Greenland, SD, western U.S except OR and CA
Eriophorum viridicarinatum	Thinleaf Cotton Sedge	2010	G5	S(S2)		Northern US, Canada, AK, CO
Epipactis gigantea	Giant Hellebore	2010	G5	W(S3)	↓S-W	BC, western contiguous US, SD, OK, TX
Erigeron salishii	Salish Fleabane	2010	G3	S(S2)		BC, WA
Gentiana glauca	Glaucous Gentian	Susp.	G4G5	S(S2)		AK, western Canada, WA, MT
Githopsis specularioides	Common Blue-cup	1970	G5	S(S3)		BC, WA, OR, CA, MT
Iliamna longisepala	Longsepal Globemallow	Susp.	G3	S(S3)		WA
Impatiens aurella	Orange Balsam	1976		W(S4)	↓R1-W	BC, WA, OR, ID, MT
Loiseleuria procumbens	Alpine Azalea	1963	G5	T(S1)	↑S-T	AK, Canada except Quebec, NY, most of northeastern US, WA

Table 24. Sensitive species of North Cascades National Park Service Complex. (Source for ranges is USDA NRCS. 2012) (continued).

Species name	Common name	Last documented[1]	Global Rank[2]	State status (rank) 2012[3]	Change since 1997[4]	Range in North America[5]
Luzula arcuata	Curved woodrush	2010	G5T3T5	S(S1)		Western and eastern Canada, Greenland, AK, WA, OR, MT
Lycopodiella inundata	Bog Clubmoss	2010	G5	S(S2)		Southern Canada, AK, WA, OR, CA, MT and upper mid-western and eastern U.S. to NC except ND, SD
Lycopodium dendroideum	Treelike Clubmoss	2010	G5	S(S2)		Canada, northern US except ND, eastern US except KY, AL, NC, TN
Montia diffusa	Branching Montia	Susp.	G4	S(S2S3)		British Columbia, WA, OR, CA
Oxytropis campestris var. gracilis	Slender Crazyweed	Susp.	G5T5	S(S2)		AK, British Columbia, Alberta, Saskatchewan, Manitoba, WA, OR, ID, MT, WY, CO, ND, SD
Parnassia kotzebuei	Kotzebue's Grass of Parnassus	2010	G5	T(S1)	↑S-T	Canada except Nunavut, WA, ID, MT, WY, CO, NV
Pinguicula vulgaris	Butterwort	2010	G5	W(SNR)	↓R1-W	AK, Canada, NE and N central US (PP)
Platanthera obtusata	Small Northern Bog Orchid	1991	G5	S(S2)		Canada, north contiguous US except ND, SD, UT, CO
Poa arctica ssp. arctica	Gray's Bluegrass	1982	G5T4T5	W?(SNR)		Canada, AK, western contiguous US except OR, CA, AZ
Polemonium viscosum	Skunk Polemonium		G5	S(S1S2)		British Columbia, Alberta, western U.S. except CA
Saxifraga rivularis	Pygmy Saxifrage	2010	G5	?(S3)		Western contiguous US, Canada except Saskatchewan, Ontario; AK, Greenland
Silene seelyi	Seely's Silene	2000	G2G3	S(S2S3)	↓T-S	WA

[1]Source: Bivin and Rochefort 2010; 'Susp.' indicates species suspected to occur in NOCA and included in the plant inventory (Bivin and Rochefort 2010) and are indicated as sensitive by USDA Forest Service Interagency Special Status/Sensitive Species Program.

[2]Codes and source (NatureServe 2012)

[3]Codes (http://www1.dnr.wa.gov/nhp/refdesk, accessed December 2012)

[4] http://www1.dnr.wa.gov/nhp/refdesk, accessed December 2012

[5] USDA NRCS 2012

Table 25. Sensitive species found in adjacent national forests.

Species name	Common name	Global Rank[1]	WNHP State status[2]	WNHP WDFW State Rank[3]	MBS[4]	OW[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	Northeast WA
Astragalus arrectus	Palouse Milk-vetch	G2G4	ST	S2		D	Chelan Co.
Astragalus microcystis	Least Bladdery Milk-vetch	G5	SS	S2		S	Northeast WA
Botrychium ascendens	Upward-lobed Moonwort	G2G3	SS	S2	D	D	Maybe in park
Botrychium crenulatum	Crenulate Moonwort	G3	SS	S3		D	Okanogan Co.
Botrychium lineare	Slender Moonwort	G2?	ST	S1		S	Ferry Co.
Carex chordorrhiza	Cordroot Sedge	G5	SS	S1		D	Northwestern Okanogan Co.
Carex comosa	Bristly Sedge	G5	SS	S2	S	D	W. of park and Chelan Co.
Carex gynocrates	Yellow Bog Sedge	G5	SS	S1		D	Eastern Okanogan Co.
Carex media/norvegica	Intermediate Sedge	G5?	SS	S2		D	North-central Okanogan Co.
Carex pauciflora	Few-flowered Sedge	G5	SS	S2	D	S	Maybe in park; Whatcom, Snohomish Co.s
Carex proposita	Smokey Mountain Sedge	G4	ST	S2		D	Wenatchee mountains
Carex scirpoidea var. scirpoidea	Canadian Single-spike Sedge	G5T5	SS	S2	D	D	Western and north-central Okanogan Co.
Carex stylosa	Long-styled Sedge	G5	SS	S1S2	D	S	Whatcom, Skagit, Snohomish Co.
Carex sychnocephala	Many-headed Sedge	G4	SS	S2		D	Central and western Okanogan Co.
Carex tenuiflora	Sparseflower Sedge	G5	ST	S1		D	Central Okanogan Co.
Carex vallicola	Salley Sedge	G5	SS	S2		D	North-central Okanogan Co.
Castilleja cryptantha	Obscure Indian Paintbrush	G2G3	SS	S2S3	S	D	Mount Rainier
Chaenactis thompsonii	Thompson's Chaenactis	G2G3	SS	S2S3	D	D	Chelan, Whatcom Co.; serpentine soil
Chrysosplenium tetrandrum	Northern Golden-carpet	G5	SS	S2		D	Eastern Okanogan Co.
Coptis aspleniifolia	Spleenwort-leaved Goldthread	G5	SS	S2	D	S	Snohomish Co.
Cryptogamma stelleri	Steller's rockbrake	G5	SS	S1S2		D	Western Okanogan, Chelan Co.
Cypripedium parviflorum	Yellow Lady's-slipper	G5	ST	S2		D	Western Okanogan Co.

Table 25. Sensitive species found in adjacent national forests (continued).

Species name	Common name	Global Rank[1]	WNHP State status[2]	WNHP WDFW State Rank[3]	MBS[4]	OW[4]	Nearest record since 1980[5]
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	Northeast WA
Eritrichium nanum var. elongatum	Pale Alpine Foret-me-not	G5T4	SS	S1		D	Western Okanogan, eastern Chelan Co.s
Fritillaria camschatcensis	Black Lily	G5	SS	S2	D		Central Whatcom and Snohomish Co.s
Gaultheria hispidula	Creeping Snowberry	G5	SS	S2	S		Central Snohomish Co.
Gentiana douglasiana	Swamp Gentian	G4	SS	S2	D	D	Kittitas Co.
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	Mid-Chelan Co.
Heterotheca oregona var. oregona	Oregon Goldenaster	G4T4?	ST	S1		D	Mount Rainier area
Juncus howellii	Howell’s Rush	G4	ST	S1		D	Skamania Co.
Microseris borealis	Northern Microseris	G4?	SS	S2	S		Skamania Co.
Mimulus pulsiferae	Pulsifer’s Monkey-flower	G4?	SS	S2		D	Eastern Okanogan Co.
Mimulus suksdorfii	Suksdorf’s Monkey-flower	G4	SS	S2		D	Northeastern Chelan Co.
Nicotiana attenuata	Coyote Tobacco	G4	SS	S2		D	Southern Chelan Co.
Pedicularis rainierensis	Mt. Rainier Lousewort	G2G3	SS	S2S3	D	D	Mount Rainier
Pellaea brachyptera	Sierra Cliffbrake	G4G5	SS	S2		D	Northeastern Chelan Co.
Pellaea breweri	Brewer’s Cliffbrake	G5	SS	S2	S	D	Northwestern Chelan Co.
Penstemon eriantherus var. whitedii	Whited’s Penstemon	G4T2	SS	S2		D	Southeastern and eastern Chelan Co.
Petrophytum cinerascens	Chelan Rockmat	G1	SE	S1		D	Eastern and southern Chelan Co.
Phacelia minutissima	Dwarf Phacelia	G3	SE	S1		D	Northern Kittitas Co.
Physaria didymocarpa var. didymocarpa	Common Twinpod	G5T4	ST	S1		D	Northern Kittitas Co.
Pilularia americana	American Pillwort	G5	ST	S1S2		D	Central eastern WA
Platanthera chorisiana	Choris’ Bog-orchid	G3G4	ST	S2	D	S	Western Snohomish Co.

Table 25. Sensitive species found in adjacent national forests (continued).

Species name	Common name	Global Rank[1]	WNHP State status[2]	WNHP WDFW State Rank[3]	MBS[4]	OW[4]	Nearest record since 1980[5]
Platanthera sparsiflora	Canyon Bog-orchid	G4G5	ST	S1	D	D	Whatcom Co., maybe in park
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		Central Snohomish Co.
Ribes oxyacanthoides ssp. irriguum	Idaho Gooseberry	G5T3T4	ST	S2		D	Eastern WA
Rotala ramosior	Lowland Toothcup	G5	ST	S1		D	No nearby records since 1980
Rubus arcticus ssp. acaulis	Nagoonberry	G5T5	ST	S1		D	Central and eastern Okanogan Co.
Salix glauca ssp. glauca var. villosa	Glaucous Willow	G5T5?	SS	S1S2		D	Northern central Okanogan Co.
Salix maccalliana	Maccall's Willow	G5?	SS	S1		D	Northeastern WA
Sanicula marilandica	Black Snakeroot	G5	SS	S2		D	Northern 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.
Sisyrinchium sarmentosum	Pale Blue-eyed Grass	G1G2	ST	S1S2		S	South-central WA
Spiranthes porrifolia	Western Ladies-tresses	G4	SS	S2		D	Northeastern Chelan, north-central Okanagon Co.s
Trifolium thompsonii	Thompson's Clover	G2	ST	S2		D	Southeastern Chelan Co.
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/issssp/agency-policy/ (accessed December 2012)

[5]Source: http://www1.dnr.wa.gov/nhp/refdesk/fguide/htm/fsfgabc.htm; most species descriptions were updated in 2003

Table 26. Sensitive non-vascular plants and macrofungi found in NOCA.

Group	Species (NOCA surveys)	No. Collections	Species (WNHP)	Global Rank[1]	State Rank[2]
Mosses	*Campylium stellatum* var. *protensum*	1	*Campylium stellatum*	G5	SNR
	Fissidens grandifrons	4	*Fissidens grandifrons*	G4	S2
	Fissidens osmundoides	1	*Fissidens osmundoides*	G5	S1
	Grimmia incurva	1	*Grimmia incurva*	G4G5	S1
	Plagiopus oederiana	2	*Plagiopus oederiana*	G5?	S2
Lichens	*Alectoria nigricans*	1	*Alectoria nigricans*	G5	S2
	Cetrelia cetrarioides	2	*Cetrelia cetrarioides*	G4G5	SNR
	Collema nigrescens	5	*Collema nigrescens*	G5?	SNR
	Leptogium cyanescens	3	*Leptogium cyanescens*	G5	SNR
	Umbilicaria angulata	11	*Umbilicaria angulata*	G4?	SNR
	Umbilicaria phaea	2	*Umbilicaria phaea* var. *cocinea*	G5?TNR	S1
Macrofungus	*Alboleptonia sericella*	?	*Alboleptonia sericella*	G1?	S1

[1]G1, globally critically imperiled; G2, globally imperiled; G3, globally vulnerable; G4, globally apparently secure; G5, globally secure; NR, not yet ranked; T# indicates same categories for varieties and subspecies

[2]S1, state critically imperiled; S2, state imperiled; S3, state vulnerable; NR, not yet ranked

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 for species that are known to occur in adjacent national forests but have not been located in the park would help confirm their absence.
- Population monitoring of vulnerable species or populations of rare species and forecasts of where relevant habitats may migrate due to changing climate would provide valuable information 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.

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4.13 Amphibians

(Michael J. Adams, U.S. Geological Survey, 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. Eleven species (6 frogs-toads and 5 salamanders) have been identified as present in NOCA (Table 27). One species, the Western Toad, is federally listed as a Species of Concern, as well as a Candidate species for listing by Washington State. The Columbia Spotted Frog is also listed as a Candidate species for listing in Washington, and the Coastal Tailed Frog is a species being monitored in Washington State. All but 3 of the species (Columbia Spotted Frog, Ensatina, and Northern Red-legged Frog) have wide distributions within the park (Table 28). Within their respective ranges, the status of 6 species are classified as stable, 4 species are classified as decreasing, and the status of 1 species (Coastal Tailed Frog) is unknown (Table 28).

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 the inventory work that was completed 1984–2005; however, we also consulted 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 NOCA have attributed to them management status designations (Table 27), as well as global trend and within park and regional distribution information (Table 28). This information can be used to indirectly attribute some level of conservation or management importance to the presence of these species in NOCA 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 27. Amphibians and management status for North Cascades National Park Service Complex.

		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
Ensatina eschscholtzii	Ensatina	NL	NL	Least Concern	G5
Pseudacris regilla	Northern Pacific Treefrog	NL	NL	Least Concern	G5
Rana aurora	Northern Red-Legged Frog	NL	NL	Least Concern	G4
Rana cascadae	Cascaes Frog	NL	NL	Near Threatened	G3G4
Rana luteiventris	Columbia Spotted Frog	Candidate	NL	Least Concern	G4
Taricha granulosa	Rough-skinned Newt	NL	NL	Least Concern	G5

G: Global; 3: Vulnerable; 4: Apparently Secure; 5: Secure; IUCN: International Union for Conservation of Nature; NL: Not listed

Table 28. Global trends and distributional extent of amphibians in North Cascades National Park Service Complex. pnw = Pacific Northwest.

		Trends		Extent	
Scientific Name	**Common Name**	**IUCN**	**NatureServe**	**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	west
Dicamptodon tenebrosus	Coastal Giant Salamander	stable		wide	pnw
Ensatina eschscholtzii	Ensatina	decreasing		narrow	west
Pseudacris regilla	Northern Pacific Treefrog	stable		wide	pnw
Rana aurora	Northern Red-Legged Frog	stable		narrow	pnw
Rana cascadae	Cascades Frog	decreasing		wide	pnw
Rana luteiventris	Columbia Spotted Frog	decreasing		narrow	pnw
Taricha granulosa	Rough-skinned Newt	stable		wide	pnw

IUCN: International Union for Conservation of Nature

4.13.4 Results and Assessment

All amphibians with reasonable potential to occur in NOCA have been detected in the park (Figure 26) with perhaps 1 exception, the Western Red-backed Salamander (*Plethodon vehiculum*), which occurs near NOCA and has some potential to occur in lower elevation wooded areas on the western slopes of the Cascade Range. Also, *Ensatina eschscholtzii* have been reported in the Stehekin portion of NOCA, and were collected in pitfall traps near the Park Slough spawning channel in Newhalem (near the Skagit River) during the mid-1990s. These are terrestrial species and we have not found records for appropriate terrestrial inventories in NOCA other than in the Stehekin Valley.

Because of the relatively low mobility of amphibians compared to other vertebrates, all species found in NOCA complete all aspects of their life history within the park. No species present in NOCA is endemic to the park. Within park trend information for species is currently not available for populations inside the parks. Some monitoring of pond breeding species is ongoing by park staff and NCCN, and has the potential to provide trend information at very long time intervals (decades).

Amphibian inventories have been thorough and completed by park staff and the USGS. Pond and stream inventories with good spatial coverage have been completed. Nearly all lentic habitats have been surveyed for amphibians and a large number of streams have been sampled. The only terrestrial surveys conducted were in the Ross Lake National Recreation Area. Those surveys appear reasonably complete.

A large portion of the amphibian locality data (20 databases spanning 1984–2005) have been aggregated in a single report (Galvan et al. 2005). The report has dot maps for all species and all parks in the North Coast and Cascades Network.

The main species for which there is some concern regarding their conservation status are Cascades Frog, Columbia Spotted Frog, and Western Toad. The concern for all of these species is due to declines in other parts of their range rather than any information that they are declining in NOCA. 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; however no information is available for Washington. The genetically disparate southern populations of the Columbia Spotted Frog are Candidates for federal listing under the Endangered Species Act. Little information is available for the northern populations. Western Toads have declined severely in Colorado, and there is weak evidence of decline in eastern Oregon and in the Oregon Cascades. No information, however, is available for Washington.

Reasonable inventories for all amphibians have been completed. Additional surveys for terrestrial salamanders might be warranted but any new locations would simply represent minor additions to the distribution of 2 broadly distributed species that are not thought be declining: *Ensatina eschscholtzii* and *Plethodon vehiculum*. NOCA is marginal for these species. Note that the IUCN lists Ensatina as decreasing due to possible declines in 1 subspecies found in California.

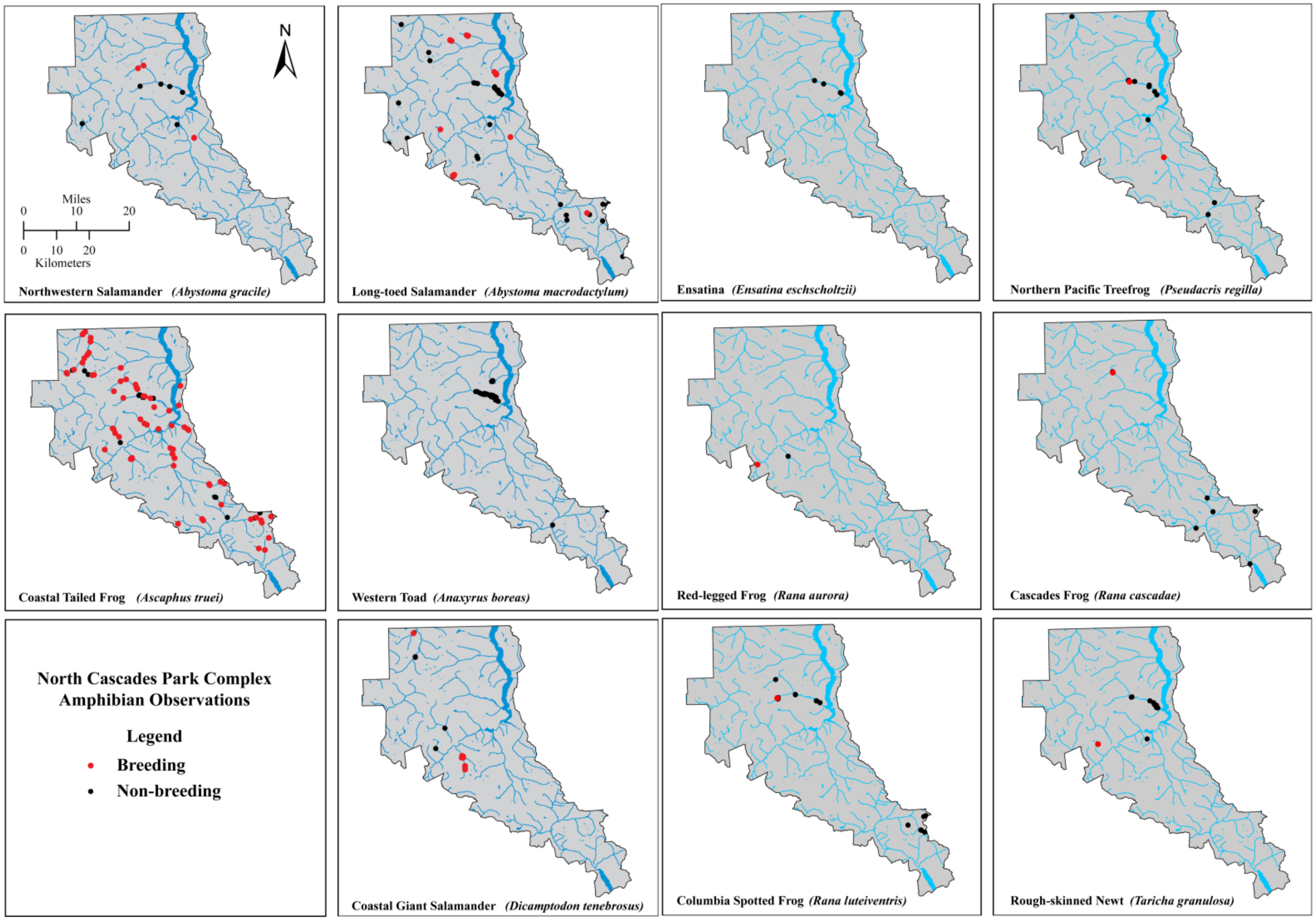

Figure 26. Distribution of amphibian species in North Cascades National Park Service Complex. Distribution maps revised from maps originally published in Galvan et al. (2005).

4.13.5 Emerging Issues

Threats to consider for the amphibian species in NOCA include aerial deposition of contaminants, introduced nonnative species, and disease transmission. Direct disturbance of habitat appears rare and inconsequential. 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 NOCA mountain lakes and are known to reduce or displace some species of amphibians (Pillipod and Peterson 2001, Knapp 2005). Species such as the Northwestern Salamander and Long-toed Salamander that occupy and rely on permanent lakes to complete their life history seem particularly vulnerable (Tyler et al. 1998, Hoffman et al. 2004, Pilliod et al. 2010). Columbia Spotted Frogs, Western Toads, and Rough-skinned Newts are exceptions that seem to coexist relatively well with fish (Welsh et al. 2006, Pilliod et al. 2010). In NOCA mountain lakes introduced trout have been documented as negatively affecting the abundances and distributions of native biota including amphibians (Hoffman et al. 1996, Liss et al. 1998, Tyler et al. 1998). These negative effects are most often related to trout population density and lake productivity (Tyler et al. 1998), and so are not consistent across the landscape. However, in response to the overall potential negative effects of stocked trout on the native biota of NOCA mountain lakes, park management finalized the Mountain Lakes Fishery Management Plan (NPS 2008) designed to address and limit the effect of these introduced fish. Although the preferred alternative management strategy would allow the presence of fish in 42 lakes, implementation of this alternative would require Congressional action which has not yet occurred. At present, NOCA management is operating under Alternative D of the plan, which requires that all 91 lakes historically stocked with trout be returned to their fishless condition.

Worldwide amphibian declines are thought to be driven by multiple factors but most of the more enigmatic declines (i.e., mysterious declines in protected areas) seem to be explained by a disease called chytridiomycosis and perhaps by interactions between this disease and climate or contaminants. Chytridiomycosis is caused by the fungal pathogen named *Batrachocytrium 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; however, 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

Reasonable inventories for all amphibians present in NOCA have been completed. Additional surveys for terrestrial salamanders might be warranted, but any new locations would simply represent minor additions to the distribution of 2 broadly distributed species that are not thought to be declining, Ensatina and the Western Red-backed Salamander. NOCA is marginal for these 2 species. Note that the IUCN lists Ensatina as decreasing due to possible declines in 1 subspecies found in California.

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4.14 Fish Species in Streams and Lakes

(Robert L. Hoffman, U.S. Geological Survey, FRESC)

4.14.1 Introduction

Twenty-seven fish species have been observed or reported as being present in North Cascades National Park Service Complex (NOCA) streams and lakes (Table 29; NOCA 2002; Zyskowski 2007). Most species (*n* = 21) are native to the park, and 5 species native to the Pacific Northwest have been introduced. Four species (California Golden Trout [*Oncorhynchus mykiss aquabonita*], Brown Trout [*Salmo trutta*], Eastern Brook Trout [*Salvelinus fontinalis*], and Lake Trout [*Salvelinus namaycush*]) have been introduced to the park from outside of their native ranges. All fish present in park lakes, except for some species in Lake Chelan and Ross Lake, have been introduced through stocking.

Several species have been identified as species of special conservation or management concern at the federal and state levels (Table 29, Table 30). Bull Trout (*Salvelinus confluentus*), Chinook Salmon (*Oncorhynchus tshawytscha*), Chum Salmon (*Oncorhynchus keta*), 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 (USFWS), and as state candidates of special concern by the Washington Department of Fish and Wildlife (Table 30). 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 30). Dolly Varden (*Salvelinus malma*) has been federally and state listed as threatened because of its similarity in appearance to Bull Trout. Pygmy Whitefish (*Prosopium coulterii*) is listed as a species of special concern by USFWS, and as sensitive by the State of Washington. The Salish Sucker (*Catostomus catostomus* sp. 4) and Slimy Sculpin (*Cottus cognatus*) are species being monitored by the Washington Department of Fisheries and Wildlife (WDFW). Although listed as vulnerable in Washington by NatureServe and as endangered in British Columbia by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC), the Nooksack Dace (*Rhinichthys cataractae* sp. 4) has no listed conservation status according to the WDFW or USFWS.

Table 29. Distributions, occurrences, and trends for fish species confirmed to be present in North Cascades National Park Service Complex. (I = Introduced nonnative; In = Introduced native; M = Migratory; N= Native; NA = Not applicable).

			Park		Conservation Status [4]	
Scientific Name	**Common Name**	**Range-wide Distribution** [3]	**Occurrence**	**Habitation**	**Range-wide**	**Washington**
Catostomus catostomus	Longnose Sucker	USA (24); Canada (12)	unknown	N	N5	S4
Catostomus catostomus sp. 4	Salish Sucker	WA, BC	Skagit, Sauk	N	N1	S1
Catostomus macrocheilus	Largescale Sucker	ID, MT, NV, OR, WA, AB, BC	unknown	N	N5	S5
Cottus aleuticus	Coastrange Sculpin	AK, CA, OR, WA, BC	unknown	N	N5	S5
Cottus asper [1]	Prickly Sculpin	AK, CA, OR, WA, AB, BC	unknown	In	N4 – N5	S5
Cottus cognatus	Slimy Sculpin	USA (20); Canada (12)	Lake Chelan and tributaries	N	N5	S3
Gasterosteus aculeatus	Threespine Stickleback	USA (17); Canada (13)	Lake Chelan	N	N5	S5
Lota lota	Burbot	USA (24); Canada (11)	Lake Chelan	N	N5	S3
Mylocheilus caurinus	Peamouth	ID, MT, OR, WA, BC, NT	Lake Chelan	N	N5	S5
Oncorhynchus clarkii lewisi [5]	Westslope Cutthroat Trout (WCT)	CO, ID, MT, OR, WA, WY, AB, BC	Streams, Lakes	In, In	N3	SNR
Oncorhynchus mykiss [2, 5]	Rainbow Trout (RBT) – Steelhead	USA (48) and Canada (12)	Streams, Lakes	N [M], In	N5	S5
Oncorhynchus mykiss aquabonita	California Golden Trout	USA (11); Canada (AB)	unknown (Lakes)	I	N1	SNA
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	SNR
Oncorhynchus keta	Chum Salmon	AK, CA, NV, OR, WA, BC, NT, ON, YT	Streams	N [M]	N4 – N5	S3
Oncorhynchus kisutch [5]	Coho Salmon	USA (22) and Canada (6)	Streams	N [M]	N4	S3
Oncorhynchus nerka	Sockeye Salmon - Kokanee	USA (18) and Canada (6)	Streams, Lake	N [M], In	N4	S2 – S3
Oncorhynchus tshawytscha	Chinook Salmon	USA (16) and Canada (4)	Streams	N [M]	N4	S3 – S4
Prosopium coulterii	Pygmy Whitefish	AK, ID, MI, MT, WA, WI, AB, BC, NT, ON, YT	Lake Chelan	N	N4	S1 – S2

Table 29. Distributions, occurrences, and trends for fish species confirmed to be present in North Cascades National Park Service Complex. (I = Introduced nonnative; In = Introduced native; M = Migratory; N= Native; NA = Not applicable) (continued).

			Park		Conservation Status [4]	
Scientific Name	**Common Name**	**Range-wide Distribution** [3]	**Occurrence**	**Habitation**	**Range-wide**	**Washington**
Prosopium williamsoni [5]	Mountain Whitefish	CA, CO, ID, MT, NV, OR, UT, WA, WY, AB, BC, NT, YT	Streams	N	N5	S5
Ptychocheilus oregonensis	Northern Pikeminnow	ID, MT, NV, OR, WA, AB, BC	Streams	N	N5	S5
Richardsonius balteatus [1]	Redside Shiner	USA (9); Canada (AB, BC)	Ross, Diablo	In, In	N5	S5
Rhinichthys cataractae	Longnose Dace	USA (38); Canada (8)	unknown	N	N5	S5
Rhinichthys cataractae sp. 4	Nooksack Dace	WA, BC	unknown	N	N3	S3
Salmo trutta	Brown Trout	USA (44); Canada (10)	Middle Blum	I	NA	SNA
Salvelinus confluentus [5]	Bull Trout	AK, CA, ID, MT, NV, OR, WA, AB, BC, NT, YT	Streams	N [M?]	N4	S3
Salvelinus fontinalis [5]	Eastern Brook Trout	USA (42) and Canada (13)	Streams, Lakes	I, I	N5	SNA
Salvelinus malma	Dolly Varden	AK, NM, NV, WA, WY, AB, BC, NT, YT	Ross Lake	In?	N5	S3
Salvelinus namaycush	Lake Trout	USA (30); Canada (12)	Lake Chelan	I	N5	SNA

[1] Suspected

[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] N: national rank; S: subnational rank; 1: critically imperiled; 2: imperiled; 3: vulnerable; 4: apparently secure; 5: secure; NA: not applicable; NR: unranked (from NatureServe accessed July–August 2012)

[5] Identified as present in NOCA streams during the 2001–2003 surveys reported by Zyskowski (2007)

Table 30. North Cascades National Park Service Complex fish species information: Management status and threats.

	Management Status[1]			
Species	**US ESA**	**COSEWIC**	**WA**	**Major Threats (NatureServe)**
Longnose Sucker	None	None	None	No known threats
Salish Sucker	None	E	M	Habitat degradation, fragmentation, and loss; acute hypoxia; presence of exotic species
Largescale Sucker	None	None	None	No known threats
Coastrange Sculpin	None	None	None	No known threats
Prickly Sculpin	None	None	None	No known threats
Slimy Sculpin	None	None	M	No known threats
Threespine Stickleback	PS	None	None	Spawning habitat degradation and loss; decreased water quality; introduced non-native predatory fish
Burbot	None	None	None	No known threats
Peamouth	None	None	None	No known threats
Westslope Cutthroat Trout	None	SC	None	Hybridization; habitat degradation and loss; fishing pressure; competition with introduced fish species
Rainbow Trout – Steelhead	PS(FT)	C	C	Habitat degradation; competition with introduced fish species; siltation; water flow
California Golden Trout	None	None	None	No known threats (introduced species in NOCA)
Pink Salmon	None	C	None	Habitat degradation and loss; water flow; overharvest
Chum Salmon	PS(FT)	C	C	Degraded water quality; overharvest; habitat degradation; hatchery fish
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
Chinook Salmon	PS(FT, FE)	C	C	Resource extraction activities; dams; habitat modification and degradation
Pygmy Whitefish	(FCo)	C	S	Habitat degradation and loss; decreased water quality; use of piscicides; introduced exotic fish
Mountain Whitefish	None	None	None	No known threats
Northern Pikeminnow	None	None	None	No known threats
Redside Shiner	None	None	None	No known threats
Longnose Dace	None	PS(X)	None	No known threats to species in Washington; subspecies extirpated in Alberta (*R. c. smithi*)
Nooksack Dace	None	E	None	Habitat alteration and loss; urban and agricultural pollution
Bull Trout	PS(FT)	None	C	Hybridization; competition with introduced fish species; siltation; habitat fragmentation and degradation
Brook Trout	None	PS	None	In eastern USA: habitat degradation and loss; competition with introduced fish species
Dolly Varden	PS(FT)	PS(SC)	FT	Listed due to similarity in appearance to Bull Trout
Lake Trout	None	None	None	No known threats (introduced species in NOCA)

[1] C: Candidate; E: Endangered; FCo: Federal Species of Concern; FE: Federal Endangered; FT: Federal threatened; M: Monitored; PS: Partial Status in range; S: Sensitive; SC: Special Concern; WA: Washington; X: Extinct

4.14.2 Approach

Several sources of information and data were used to complete the assessment of fish in NOCA streams and lakes. Summaries of range-wide distributions, conservation and management status, and potential major threats to the 27 fish species in NOCA 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 presence and occurrence of fish species in NOCA streams was summarized from inventory information reported by Zyskowski (2007) and from the NOCA (2002) fish checklist. The presence and occurrence of fish species in NOCA lakes and the history of stocking activities in those lakes was summarized from the NOCA Mountain Lakes Fishery Management Plan (NPS 2008, Volume One). Information about the hybridization of Westslope Cutthroat Trout (*Oncorhynchus clarkia lewisi*) and Rainbow Trout (*Oncorhynchus mykiss*) in the Stehekin River watershed was summarized from results reported by Ostberg and Rodriguez (2006) and Ostberg and Chase (2012). Results from Smith and Naish (2010) were used to summarize Bull Trout genetics in the Skagit River watershed; and information about juvenile bull trout migration in the Skagit River was derived from a draft report by Zimmerman and Kinsel (2010). Stock status assessments of 5 Pacific salmon species and Steelhead were used to compare stock status between 1992 and 2002. Finally, surveys by Keesee et al. (2009) were summarized to elucidate the spawning of Lake Chelan Kokanee.

4.14.3 Reference Conditions and Comparison Metrics

Each of the fish species documented as present in NOCA have attributed to them both conservation and management status designations (Table 29, Table 30). These designations or listings can be used to indirectly attribute some level of conservation or management importance to the presence of these species in NOCA 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 Inventory

Fourteen tributaries (56.1 km) of the Skagit and Stehekin Rivers were sampled for fish 2001 through 2003 (Zyskowski 2007). During the survey period, 6 species were observed. The most numerous species observed was Rainbow Trout (RBT), which was collected from 10 of 14 tributaries, followed by Bull Trout/Dolly Varden (BT/DV; the 2 species were not differentiated) in 6 of 14 tributaries, and Westslope Cutthroat Trout (WCT) in 3 of 14 tributaries. Coho Salmon (CS) were observed in the lower sections of the Skagit River downstream of the Skagit River dams; 2 Mountain Whitefish (MW; *Prosopium williamsoni*) were collected from Sulfide Creek (a tributary of the Baker River that flows into the Skagit River), as well as in the Chilliwack River; and Eastern Brook Trout (BrT) were collected from Hozomeen Creek, which is located in the northeast part of NOCA. Four species (BT/DV, CS, MW, RBT) were collected within the Skagit River basin downstream of the Ross Lake dam; and 4 species (BrT, BT/DV, WCT, RBT) were collected within the Upper Skagit River basin from tributaries to Ross Lake. RBT, WCT, and RBT X WCT hybrids were collected within the Stehekin River basin. Although 27 fish species have been observed or reported as being present in NOCA, only 6 species were confirmed by this inventory. Proposed reasons for this low detection of species included: (1) apparent localized distributions of species; (2) limited temporal sampling effort of the inventory; and (3) the use of sampling methods that potentially excluded the detection of many species (Zyskowski 2007).

Mountain Lakes

There are approximately 245 mountain lakes in NOCA that were historically fishless (NPS 2008, Volume One). Ninety-one of these lakes have stocking records: 69 are located in the National Park; 15 are located in the Lake Chelan National Recreation Area; and 7 are located in the Ross Lake National Recreation Area. All but 1 of the lakes are also located in the Stephen T. Mather Wilderness. Stocking of the lakes by settlers began in the late 1800s. In 1933, WDFW assumed responsibility for conducting a systematic stocking program. After NOCA was established in 1968, a conflict emerged between NPS and WDFW about the continued stocking of fish in park lakes, but attempts to discontinue stocking were abandoned based on objections from the state. In 1986, former NPS Director William Mott issued a NPS policy variance to allow continued stocking in previously stocked lakes. Then in 1987, the Assistant Secretary of the Interior for Fish and Wildlife and Parks finalized an agreement between NPS and WDFW to allow continued stocking in certain park lakes. The agreement included a stipulation for research into the ecological impacts of stocking on lake water quality and native biota. The research began in 1988 and concluded in 2002. In 2003, preparation of the Mountain Lakes Fishery Management Plan/Environmental Impact Statement was begun with the final draft published in June 2008. The final draft included 4 management alternatives which are summarized in NPS (2008; p. xiv–xvi). Although the preferred alternative is Alternative B, which would allow the presence of fish in 42 lakes, implementation of this alternative would require congressional action which has not yet occurred. At present, NOCA management is operating under Alternative D, which requires that all 91 lakes historically stocked be returned to their fishless condition. For additional information about the NOCA fish stocking issue and the potential impact of introduced native and nonnative fish on NOCA lake ecosystems see NPS (2008).

The fish species that were historically stocked into NOCA mountain lakes include California Golden Trout, Coastal Cutthroat Trout, Eastern Brook Trout, Rainbow Trout, and Westslope Cutthroat Trout. Sixty-one lakes still have fish populations: 26 lakes have non-reproducing populations and 35 lakes have reproducing populations.

Westslope Cutthroat Trout–Rainbow Trout Hybridization

Ostberg and Rodriguez (2006) examined hybridization between native Westslope Cutthroat Trout (WCT) and introduced Rainbow Trout (RBT) in the Stehekin River watershed from 1999 through 2003. During this period they collected 1763 DNA samples from 18 locations. They determined 3 major multilocus population structure groups: (1) only WCT; (2) only RBT; and (3) WCT-RBT hybrids. They found that non-hybrid WCT were present only upstream of passage barriers in the Stehekin River and Park Creek. Passage barriers within these sample locations appeared to protect WCT from introgression. All sample locations below passage barriers contained some level of introgression, with hybrids in some locations having >30% RBT alleles, and hybrids in other locations with <10% RBT alleles. Ostberg and Rodriguez (2006) speculated that physical passage barriers were the single refuge protecting native WCT from introgression. They further speculated that populations below passage barriers would experience decline and increasing introgression, while populations above barriers would experience no impact. In 2010, Ostberg and Chase (2012) resampled 6 locations originally sampled 1999 through 2003 and added 2 new locations from the lower Stehekin River drainage. They found that the frequency of WCT, RBT, and hybrids was not significantly different between the 2 sampling periods.

Skagit River Bull Trout Genetics

Skagit River Bull Trout are part of the Puget Sound Management Unit–Puget Sound/Coastal Distinct Population Segment that was listed in 1999 as threatened by the USFWS. During 2001 through 2009, 595 juvenile and adult Bull Trout tissue samples were collected from 14 Skagit River tributary sites (Smith and Naish 2010). Four sites were located above the Ross Lake Dam, 1 site was located between the Diablo and Gorge dams, and 9 sites were below the 3 dams. An additional 435 samples were collected from the mainstem Skagit River below the dams 2006 through 2008 (Smith and Naish 2010). A total of 584 samples from the 14 tributary sites that scored ≥7 loci were used in the analysis of Bull Trout genetics. Bull Trout accounted for 545 of these samples, 29 samples had Dolly Varden alleles (Lightning Creek = 24, Stetattle Creek = 5), and 10 samples were identified as having Eastern Brook Trout alleles. Of the 434 mainstem samples with ≥7 loci, none had Dolly Varden or Eastern Brook Trout alleles. The fundamental results of this study were: (1) above dam populations were less genetically diverse than downstream populations; (2) genotypic distributions among most populations were significantly different indicating a relatively high level of reproductive isolation; (3) higher levels of gene flow occurred among above dam populations than among below dam populations; and (4) above and below dam populations were highly differentiated and reproductively isolated.

There are 3 historically known tributaries in NOCA where anadromous Bull Trout spawning has been observed: Goodell Creek and west fork Bacon Creek (Skagit River), and Marble Creek (Cascade River) (Zimmerman and Kinsel 2010). Spawning in each of these tributaries is thought to contribute out-migrating anadromous juvenile Bull Trout to the Skagit River system; however, further investigation will be required to better identify and quantify the contribution of source populations that originate within NOCA.

Pacific Salmon and Steelhead Stock Assessments

Five Pacific Salmon species (Chinook, Chum, Coho, Pink, and Sockeye) and Steelhead have been observed in NOCA rivers and streams. Table 31 summarizes reports comparing 1992 and 2002 stock status assessments for these species. Chum–Skagit Fall and Pink–Skagit stocks were assessed as healthy in 1992 and 2002, and the Coho–Baker stock was assessed as healthy in 2002. Two stocks, Chinook–Upper Cascade and Steelhead–Skagit Summer, were considered to be depressed in 2002; whereas the Sockeye–Baker stock assessed as critical in 1992 improved to healthy in 2002. The status of Skagit-Cascade–Summer, Skagit-Cascade–Winter, and Cascade–Summer Steelhead stocks were unknown in 1992 and 2002. Genetic analysis also indicates the potential uniqueness of 6 of the stocks, which were found to be relatively distinct from all other Skagit River basin, Washington, or Canadian stocks examined for comparison (Table 31).

Table 31. Summary of stock status reports (1992 and 2002) for Pacific Salmon and Steelhead in NOCA.

		Status		Spawning		
Stock	**Origin**	**1992**	**2002**	**Distribution**	**Timing**	**Genetic Analysis**
Chinook–Upper Cascade	N–WP	U	D	Cascade R; NF Cascade R; Marble CK; Found CK; Kindy CK	Aug – Sept	Distinct from all other Washington stocks examined (Marshall et al. 1995)
Chum–Skagit Fall	N–WP	H	H	Skagit R; Cascade R; Nooksack CK; Illabot CK; Bacon CK	Nov – Dec	Distinct from all other Washington and Canadian stocks examined (Phelps et al. 1995)
Coho–Baker	M–CoP	U	H	Baker R and some tributaries above upper dam	Jan – Feb	None
Pink–Skagit	N–WP	H	H	Skagit R and tributaries	Aug – Oct [odd numbered years]	High gene flow among Skagit, Stillaguamish, and Snohomish R basins
Sockeye–Baker	N–CuP	CR	H	Baker Lake spawning beaches; Baker R above lake	Sept – Dec	Distinct from all other Washington stocks examined (Gustafson and Winans 1999)
Steelhead–Skagit-Cascade Summer	U–WP	U	U	U–possibly upper Cascade R	Jan – May	Potentially distinct from other Skagit R basin stocks examined (Phelps et al. 1997)
Steelhead–Skagit-Cascade Winter	N–WP	U	U	U	U (March – June)	Potentially distinct from other Skagit R basin stocks examined (Phelps et al. 1997)
Steelhead–Skagit Summer	N–WP	H	D	Skagit R and all major tributaries including Cascade and Sauk R	March – June	Associated with following stocks: Sauk (S&W); Suiattle (W); NF Stillaguamish; Skokomish; Dosewallips; and Dungeness R (Phelps et al. 1997)
Steelhead–Cascade Summer	U–WP	U	U	U–thought to occur in upper reaches of Cascade R and forks	Jan – May	Distinct from other Skagit R basin stocks examined, although caution advised for this interpretation ((Phelps et al. 1997)

Lake Chelan Kokanee Spawning

Kokanee were introduced into Lake Chelan in 1917, and were the dominant sport fishery in the lake until the mid-1970s (Keesee et al. 2009). Kokanee have been reported to spawn in 2 Stehekin River mainstem side channels located within NOCA. Keesee et al. (2009) reported that the number of observed spawners in these side channels has declined since 2003 and 2005, respectively, and that the 2009 estimated escapement from both declined by ≥50% compared to the 2008 estimated limited escapement. The decline of Lake Chelan Kokanee has been attributed, in part, to the introduction of Opossum Shrimp (*Mysis relicta*) into Lake Chelan in 1967. This decline also affected the Chinook Salmon population introduced into Lake Chelan in the mid-1970s and 1990s because Chinook Salmon growth and survival is correlated with Kokanee abundance in the lake (Brown 1984). Very limited Chinook Salmon spawning occurs in Blackberry and Company Creeks ($n_{spawners}$ 2009 = 5 and 33, respectively), and escapement in 2009 was estimated at 9 from Blackberry Creek and 49 from Company Creek (Keesee et al. 2009).

*Upp*er Skagit Basin Char Genetics

Small et al. (2012) conducted genetic analysis of native char (Bull Trout and Dolly Varden) and an introduced nonnative char (Brook Trout) collected during surveys of the 3 Skagit River reservoirs in NOCA (Diablo Lake, 2010; Gorge Lake, 2011; and Ross Lake, 2012). They found that the composition of char differed among the reservoirs. Of the char collected: 38% were Bull Trout collected primarily from Ross Lake; 33% were Dolly Varden collected primarily from Gorge Lake; and only 4% were Brook Trout. Hybrids represented about 26% of all individuals collected: 13% were Dolly Varden-Bull Trout hybrids present primarily in Ross Lake and 13% were Dolly Varden-Brook Trout hybrids present primarily in Gorge Lake.

Park Slough Spawning Surveys

As part of the 1991 Skagit Settlement Agreement (FERC license number 553 for the Skagit River Hydroelectric project) a program entitled “Off-Channel Chum Habitat Development and Improvement Program” was designed to protect, restore or construct functioning off-channel habitat for the benefit of Chum Salmon. Ten sites were ultimately developed, including Park Slough which is located within NOCA. Park Complex personnel conduct spawning surveys at Park Slough during the months of November and December, counting live and dead Chum and Coho Salmon and enumerating newly constructed redds. This information is relayed to WDFW and is used in the annual estimation of Chum escapement within the Skagit watershed.

Diet of the Introduced Redside Shiner in Ross Lake, Washington

The Redside Shiner (*Richardsonius balteatus*) was introduced to Ross Lake around 2000 (Welch 2000). According to Welch (2012), shiners can be found at densities of hundreds/m^3 in the shallow areas of the reservoir during summer. Welch (2012) examined the ages and diet of shiners collected from Ross Lake, 2009–2010, and found that their ages ranged from 0+ to 6 yrs and that they primarily consumed zooplankton and insects as well as oligochaetes, cestodes, and algae. Welch (2012) concluded that the shiners most likely competed for food with the juveniles of the native fish species in Ross Lake, and that this competition potentially has negative results for the native predator fish species for which the introduction of the shiners was intended. Redside Shiners were also captured in the Diablo Lake reservoir during separate assessments completed by NOCA staff in 2010 (Hugh Anthony, NOCA, pers. comm.).

Assessment

Although only 6 fish species were observed during the 2001 through 2003 surveys, 21 additional species have been reported as present in NOCA rivers and streams. In addition, 5 salmonid species have been at one time or another stocked into NOCA mountain lakes. Of these 27 species, 10 have assigned to them some level of special conservation or management concern at the state or federal levels, which makes their presence in NOCA an important contribution to the continued survival of each species.

Bull Trout are 1 of 2 char species (the other being Dolly Varden) native to the western U.S., and are considered threatened and endangered at least partially within their range. 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. In NOCA, resident Bull Trout have been documented as present in 14 tributaries above and below the Skagit River dams, and individuals expressing an anadromous life history are historically known to spawn in 2 Skagit River tributaries below the dams. Genetic analysis of individuals present in these tributaries showed that the majority sampled were Bull Trout, with only 4% having Dolly Varden or Eastern Brook Trout alleles (Smith and Naish 2010). This result suggests that NOCA Bull Trout have a low level of genetic introgression and that the population is relatively stable.

Nine stocks of 5 Pacific Salmon species and Steelhead are present in NOCA (Baker, Cascade, and Skagit Rivers). Each of these species except Pink Salmon are considered threatened and endangered at least partially within their range. As of 2002, 4 stocks were considered to be healthy, 2 were depressed, and the condition of 3 stocks was unknown. The overall importance of these NOCA stocks is that 6 of them have been found to be genetically distinct from all other stocks to which they have been compared.

Four additional species are considered by WDFW to be either a sensitive species of concern (Pygmy Whitefish) or a state monitored species (Salish Sucker, Slimy Sculpin), or by COSEWIC as endangered (Nooksack Dace in British Columbia). The presence of populations of these species in NOCA represents an important contribution to the continued viability of each species within its range.

Native Westslope Cutthroat Trout in the NOCA Stehekin River basin, although not a species of concern in Washington, are being affected by hybridization with introduced Rainbow Trout. One detrimental outcome of this hybridization is that introgression will increase below upstream passage barriers causing non-hybrid Westslope Cutthroat Trout to decline. However, Westslope Cutthroat Trout above passage barriers would be protected from introgression, effectively maintaining non-affected populations in the upper reaches of the basin.

The stocking of introduced trout into mountain lakes has been shown to negatively affect native biota such as large-bodied zooplankton, aquatic breeding amphibians, and some aquatic macroinvertebrate taxa and communities (Parker et al. 2001, Pilliod and Peterson 2001, Schilling et al. 2009). In NOCA mountain lakes, introduced trout have been documented as negatively affecting the abundance of diaptomid copepods (Liss et al. 1998) and larval Long-toed Salamanders (*Ambystoma macrodactylum*; Tyler et al. 1998), and limiting the presence and distribution of at least 2 macroinvertebrate taxa (a stonefly and caddisfly; Hoffman et al. 1996). These negative effects are most often related to trout population density and lake productivity, and so are not consistent across the landscape. However, in response to the overall potential negative effects of stocked fish on the native biota of NOCA mountain lakes, park management has finalized the Mountain Lakes Fishery Management Plan (NPS 2008) designed to limit the effect of introduced trout while still allowing fish populations to remain in some lakes as part of a high mountain lakes recreational fishery.

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 NOCA rivers, streams, 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 native or nonnative fish species, especially the potential for hybridization of Bull Trout with Dolly Varden or Eastern Brook Trout and Westslope Cutthroat Trout with Rainbow Trout, and the decline or loss of 1 or more native amphibian species, especially from mountain lakes.

Future survey and research activities should include a design element useful for tracking and documenting any impacts to NOCA fish species and populations due to these potential environmental-ecosystem changes and perturbations.

4.14.6 Information and Data Needs–Gaps

NOCA could, if funding and time allow, expand the scope of their fish species surveying and monitoring in park and recreation area streams by:

1. Conducting additional focused-surveys of potentially sensitive species such as Bull Trout and anadromous salmon;
2. Initiating surveys for species reported to be present in NOCA but not observed in the 2001 through 2003 surveys (see Table 29; Zyskowski 2007) and for whom occurrence and distribution are relatively unknown;
3. Completing surveys designed to elucidate the potential presence of Nooksack Dace, as well as the critically-imperiled and state-monitored Salish Sucker (as differentiated from the Longnose Sucker) in NOCA streams;

4. Continued monitoring of the salmon stocks that spawn in NOCA tributaries (Table 31) because of their important genetic distinctiveness;
5. Surveying and sampling NOCA Bull Trout populations to better understand their life history characteristics, habitat requirements, and population dynamics; and
6. Continued monitoring of Westslope Cutthroat Trout populations above and below Stehekin River passage barriers, focusing on maintaining genetically pure native Westslope Cutthroat Trout above the barriers.
7. Compiling an electronic database for 1980s–1990s era stream fish surveys.

All surveying and monitoring 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.

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4.15 Land Birds

(Joan Hagar, U.S. Geological Survey, FRESC)

4.15.1 Introduction

The avifauna of NOCA is exceptionally diverse, reflecting the broad range of habitat types encompassed by the park complex. Moist Douglas-fir and Western Hemlock forests on the west slope of the Cascade Range support species that are representative of old-growth, temperate rainforest in the region, including the threatened Northern Spotted Owl. A markedly different environment in the rain shadow on the east slope of the Cascade Range contributes a unique suite of bird species characteristic of dry pine forests (e.g., White-headed Woodpecker) and Aspen groves (Red-naped Sapsucker). Transitional areas between diverse habitat types further contribute to high bird species diversity.

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 NOCA. 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 NOCA also are important for some species of regional conservation concern such as the Clark's Nutcracker.

Information on bird species occurrence, abundance, and status within the park is available from multiple sources. We have summarized available information for 73 bird species of management concern (listed as Management Priority in NPSpecies, or identified as focal species for conservation strategies developed by Partners In Flight (PIF) and the North American Bird Conservation Initiative (NABCI) in Table 32 (the scientific names of these species are presented in this table). 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 more than 30 land bird species in the park complex. Data from intensive studies are available for assessing status and distribution of some special status species, such as the Harlequin Duck, Bald Eagle, and Northern Spotted Owl. However, the status of many species of conservation concern within the park is difficult to determine because of rarity or a lack of data.

Table 32. Distributions, occurrences, habitation, and conservation status of 73 bird species of manangement concern in North Cascades National Park Service Complex. These species are listed as Management Priority in NPSpecies, or identified as focal species for conservation strategies developed by Partners In Flight and the North American Bird Conservation Initiative.

		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 (disjunct): AB, BC, YT, and NB, NL, NT, QC	Coastal ME and coast of NE Canada; In w. NA, along coasts of BC and s. AK, coastal OR, WA, n. CA	Uncommon	N [M]	N4B, N4N	S2B, S3N
Dendragapus fuliginosus	Sooty Grouse	USA: AK, CA, NV, OR, WA; CAN: BC	Resident throughout range	Uncommon	N [YR]	N5	SNR
Gavia immer	Common Loon	USA (12 northern tier); CAN (13)	East and west coasts of NA, from AK and Newfoundland to Mexico	Uncommon	N [M]	N4B, N5N	S2B, S4N
Aechmophorus occidentalis	Western Grebe	USA (18); CAN: AB, BC, MB, SK	West coast from Vancouver Is. To south of Baja Mexico; NM, TX, and central Mexico	Uncommon	N [M]	N5B, N5N	S3B, S3N
Pelecanus erythrorhynchos	American White Pelican	USA (10 - locally distributed); CAN: AB, BC, MB, SK, ON	Southern US , Mexico, and northern Central America	Occasional	E	N4	S1B
Cathartes aura	Turkey Vulture	USA (32); CAN: AB, BC, MB, ON, SK, QC	On west coast (California), winters north to northern CA.	Unconfirmed	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

Table 32. Distributions, occurrences, habitation, and conservation status of bird species in North Cascades National Park Service Complex (continued).

		Range-wide Distribution		Park		Conservation Status	
Scientific Name	**Common Name**	**Breeding**	**Wintering**	**Occurrence**	**Habitation**	**U.S.**	**Washington**
Haliaeetus leucocephalus	Bald Eagle	USA (50); CAN (13)	Majority of wintering population located in lower 48 states, coastal Canada and Alaska	Common	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.	Rare	N [YR]	N4B, N4N	S2S3B, S3N
Buteo swainsoni	Swainson's Hawk	USA (19); CAN: AB, BC, MB, SK	South America	Uncommon	N [M]	N5B	S3, S4B
Buteo lagopus	Rough-legged Hawk	USA: AK; CAN (7)	Throughout continental United States, except southeastern states	Rare	N [M]	N5B, N5N	S4N
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/U.S. border	Rare	N [E]	N4B, N4N	S2B, S3N
Grus canadensis	Sandhill Crane	USA (13); CAN (8)	TX, extreme sw OK, southern CA, AZ, and NM, and northern Mexico	Occasional	N [M]	N5B, N5N	S1B, S3N
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.	Unconfirmed	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	Rare	N [M]	N4B,N4N	S3, S4B, S4N

Table 32. Distributions, occurrences, habitation, and conservation status of bird species in North Cascades National Park Service Complex (continued).

		Range-wide Distribution		Park		Conservation Status	
Scientific Name	**Common Name**	**Breeding**	**Wintering**	**Occurrence**	**Habitation**	**U.S.**	**Washington**
Otus flammeolus	Flammulated Owl	USA: AZ, CA, CO, ID, MT, NM, NV,OR, , UT, WA, WY; CAN: BC					
Strix occidentalis caurina	Northern Spotted Owl	USA: CA, OR, WA; CAN: BC	Resident throughout range	Rare	N [YR]	N1	S1
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 flammeus	Short-eared Owl	USA (26); CAN (13)	Lower 48 U.S. and northern Mexico	Occasional	N[E]	N5B, N5N	S2, S3B, S3N
Aegolius funereus	Boreal Owl	USA: AK, CO, ID, MN, MT, NM, OR, WA, WY; CAN (11)	Mostly the same as breeding range	Occasional	N [YR]	N4	S3
Cypseloides niger	Black Swift	USA: AZ, CA, CO, ID, MT, NM, OR, UT, WA; CAN: AB, BC	South America	Uncommon	N [M]	N4B	S3B
Chaetura vauxi	Vaux's Swift	USA: CA, ID, MT, OR, WA; CAN: BC	Central Mexico to South America	Uncommon	N [M]	N4B	S3, S4B
Selasphorus calliope	Calliope Hummingbird	USA: CA, ID, MT, NV, OR, UT, WA, WY; CAN: AB, BC	Southwestern Mexico	Rare	N [M]	N5B	S4, S5B

Table 32. Distributions, occurrences, habitation, and conservation status of bird species in North Cascades National Park Service Complex (continued).

		Range-wide Distribution		Park		Conservation Status	
Scientific Name	**Common Name**	**Breeding**	**Wintering**	**Occurrence**	**Habitation**	**U.S.**	**Washington**
Selasphorus rufus	Rufous Hummingbird	USA: AK, CA, ID, MT, NV, OR, WA; CAN: AB, BC, YT	Extreme southern US, Mexico	Common	N [M]	N5B	S4B
Melanerpes lewis	Lewis's Woodpecker	USA (13 western states); CAN: BC	Winters in southern portion of breeding range, as far north as sw OR	Unknown	N[E]	N4B, N4N	S2S3
Sphyrapicus thyroideus	Williamson's Sapsucker	USA (11); CAN: BC	Resident from sw OR through southern CA, and northern AZ and NM; winters western CA to southern AZ and NM into Mexico	Occasional	N[E]	N5B, N5N	S3, S4B
Sphyrapicus nuchalis	Red-naped Sapsucker	USA (12); CAN: AB, BC, SK	From extreme southern NV and UT to central Mexico	Rare	N [M]	N5B, NNRN	S4, S5B
Sphyrapicus ruber	Red-breasted Sapsucker	USA: AK, CA, OR, WA; CAN: BC	Southwestern BC south through most of CA to northern Baja California	Uncommon	N [YR]	N5	S4, S5
Picoides albolarvatus	White-headed Woodpecker	USA: CA, ID, NV, OR, WA; CAN: BC	Resident throughout range	Unconfirmed	N[E]	N4	S2, S3
Picoides dorsalis	American Three-toed Woodpecker	USA (18); CAN (13)	Resident throughout range	Rare	N[YR]	N5	S3
Picoides arcticus	Black-backed woodpecker	USA (15); CAN (13)	Resident throughout range	Occasional	N[YR]	N5	S3
Dryocopus pileatus	Pileated Woodpecker	USA (38); CAN: AB, BC, MB, NB, NS, ON, SK, QC	Resident throughout range	Rare	N[YR]	N5	S4
Contopus cooperi	Olive-sided Flycatcher	USA (23); CAN (13)	Central and, primarily, South America	Uncommon	N [M]	N4B	S3B

Table 32. Distributions, occurrences, habitation, and conservation status of bird species in North Cascades National Park Service Complex (continued).

		Range-wide Distribution		Park		Conservation Status	
Scientific Name	**Common Name**	**Breeding**	**Wintering**	**Occurrence**	**Habitation**	**U.S.**	**Washington**
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	Common	N [M]	N5B	S5B
Empidonax oberholseri	Dusky Flycatcher	USA (12); CAN: AB, BC, SK, YT	Extreme southern AZ and NM, and Mexico	Occasional	N [M]	N5B	S4, S5B
Empidonax difficilis	Pacific-slope Flycatcher	USA: CA, OR, WA; CAN: BC	Mexico	Common	N [M]	N5B	S4, S5B
Lanius excubitor	Northern Shrike	USA: AK; CAN (8)	Southern Canada, northern U.S.	Unconfirmed	N [M]	N4B, N5N	S4N
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	Occasional	N[YR]	N5	S5
Perisoreus canadensis	Gray Jay	USA (18); CAN (13)	Resident throughout range	Common	N[YR]	N5	S5
Cyanocitta stelleri	Steller's Jay	USA (13); CAN: AB, BC	Resident throughout range	Common	N[YR]	N5	S5
Nucifraga columbiana	Clark's Nutcracker	USA (11); CAN: AB, BC	Resident throughout range	Uncommon	N[YR]	N5	S4?
Poecile rufescens	Chestnut-backed Chickadee	USA: AK, CA, ID, MT, OR, WA; CAN: BC	Resident throughout range	Abundant	N [YR]	N5	S5
Poecile hudsonicus	Boreal Chickadee	USA (11); CAN (13)	Resident throughout range	Occasional	N [YR]	N5	S3

Table 32. Distributions, occurrences, habitation, and conservation status of bird species in North Cascades National Park Service Complex (continued).

		Range-wide Distribution		Park		Conservation Status	
Scientific Name	**Common Name**	**Breeding**	**Wintering**	**Occurrence**	**Habitation**	**U.S.**	**Washington**
Sitta pygmaea	Pygmy Nuthatch	USA (13); CAN: BC	Resident throughout range	Unconfirmed	N[E]	N5	S3, S4
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.	Uncommon	N [YR]	N5	S4, S5B, S5N
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	Common	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	S4, S5B, S4, S5N
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	Unconfirmed	N[E]	N5	S3B
Sialia currucoides	Mountain Bluebird	USA (13); CAN: AB, BC, MN, SK, YT	Year-round resident AZ, CA, CO, NM, NV, OR, UT, western TX; also winters from sw NE and central CA south into Mexico	Rare	N [M]	N5	S4B
Catharus ustulatus – *Catharus guttatus*	Swainson's Thrush - Hermit Thrush	USA (23); CAN (13)	Mexico and northern South America	Common	N [M]	N5B	S5B

Table 32. Distributions, occurrences, habitation, and conservation status of bird species in North Cascades National Park Service Complex (continued).

		Range-wide Distribution		Park		Conservation Status	
Scientific Name	**Common Name**	**Breeding**	**Wintering**	**Occurrence**	**Habitation**	**U.S.**	**Washington**
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	Common	N[R]	N5	S5B, S5N
Bombycilla garrulus	Bohemian Waxwing	USA: AK; CAN (7)	Southern Canada, northern U.S.	Rare	N [M]	N5B, N5N	S5N
Calcarius lapponicus	Lapland Longspur	USA: AK; CAN (7)	Northeastern U.S.; extreme southern-central Canada and central U.S. to Gulf of Mexico; western CA, OR, WA	Unconfirmed	N [M]	N5B, N5N	S3N
Oreothlypis peregrina	Tennessee Warbler	USA: ME, MI, MN, NH, NY, VT; CAN (12)	Mexico and Central America	Unconfirmed	N [M]	N5B	.
Geothlypis tomiei	MacGillivray's Warbler	USA (13); CAN: AB, BC, SK, YT	Southern Baja, central Mexico, Central America	Common	N [M]	N5B	S4, S5B
Oreothlypis ruficapilla	Nashville Warbler	USA (19); CAN (8); disjunct breeding population in BC, CA, OR, WA	Mexico and Central America	Uncommon	N [M]	N5B	S4, S5B
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	Occasional	N [M]	N4, N5B	S4B
Spizella arborea	American Tree Sparrow	USA: AK; CAN (10)	Extreme southern Canada, and U.S.	Unconfirmed	N[E]	N5B, N5N	S4N
Spizella passerina	Chipping Sparrow						

Table 32. Distributions, occurrences, habitation, and conservation status of bird species in North Cascades National Park Service Complex (continued).

		Range-wide Distribution		Park		Conservation Status	
Scientific Name	**Common Name**	**Breeding**	**Wintering**	**Occurrence**	**Habitation**	**U.S.**	**Washington**
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
Passerella iliaca	Fox Sparrow	USA (11); CAN (12)	Coastal North America, from BC to Baja CA, and NB/NS to northern FL; southern and southeastern U.S.	Common	N [M]	N5B, N5N	S4B, S5N
Zonotrichia atricapilla	Golden-crowned Sparrow	USA: AK; CAN:AB, BC, NT, YT	Western NA from BC to northern Baja CA	Rare	N [M]	N5B, N5N	S5N
Pheucticus melanocephalus	Black-headed Grosbeak	USA (15); CAN: AB, BC, SK	Mexico	Uncommon	N [M]	N5B	S5B
Passerina cyanea	Indigo Bunting	USA (43); CAN: MB, NB, ON, QU	Mexico, Central America, Bahamas	Occasional	N[E]	N5B	SNA
Xanthocephalus xanthocephalus	Yellow-headed Blackbird	USA (25); CAN: AB, BC, MB, ON, SK	Southwestern U.S., and Mexico	Occasional	N [M]	N5B, N5N	S3N, S4B
Pinicola enucleator	Pine Grosbeak	USA (18); CAN (13)	Resident throughout range	Rare	N[YR]	N5	S3B, S3N
Haemorphous cassinii	Cassin's Finch	USA (12); CAN: BC	Resident through most of range; also winters southern CA, AZ, NM, into Mexico	Uncommon	N[YR]	N5	S4B
Loxia leucoptera	White-winged Crossbill	USA (17); CAN (13)	Resident throughout range	Rare	N[YR]	N5	S3B

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 NatureServe accessed July–August 2012

4.15.2 Approach

We focused this assessment on 73 bird species of management concern because of the large number of species that occur in the park (222 bird species in NPSpecies database), and because management and monitoring of each species is logistically infeasible. We included species listed as Management Priority in NPSpecies (47 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. NOCA is located in BCR 9, the Great Basin, which includes the Northern Basin and Range, Columbia Plateau, and the eastern slope of the Cascade Range (http://www.nabci-us.org/bcr9.html). Strategies developed by PIF nest within and coordinate with the BCR framework at smaller spatial scales. Within BCR 9, the PIF conservation strategy for coniferous forests in western Oregon and Washington (Altman 2000) covers land bird species associated with habitats west of the crest of the Cascade Range; land bird species associated with major habitats on the east side of the park complex, including Ponderosa Pine, Aspen, and montane meadows are covered in the conservation strategy for the east slope of the Cascade Range in Oregon and Washington (Altman 2000) (Table 33).

Table 33. Conservation plans and population trends for 73 bird species of management concern in North Cascades National Park Service Complex.

		Partners In Flight		Washington Department of Fish & Wildlife			
Common name	**NOCA Management Priority**	**BCR9/ East slope Cascades OR and WA**	**Physiographic Area 93**	**Priority Species**	**State Monitor List**	**BCR 9 Short-term trend (% / year, 95% CI)**	**NCCN within park trend**
Harlequin Duck				X		.	low detection rate
Sooty Grouse	X	X	X	X		1.0 (-6.0, 9.4)	possible decrease
Common Loon	X					-0.4 (-3.6, 3.6)	low detection rate
Western Grebe	X					4.2 (-1.3, 18.8)	not detected
American White Pelican	X					13.1 (3.9, 32.8)	not detected
Turkey vulture					X	4.1 (1.6, 7.4)	not detected
Osprey					X	5.7 (2.8, 8.6)	low detection rate
Bald Eagle	X			X		.	not detected
Northern Goshawk	X			X		.	detected outside of point counts
Swainson's Hawk	X				X	3.3 (0.8, 6.3)	low detection rate
Rough-legged Hawk	X					.	not detected
Golden eagle				X		0.7 (-1.9, 3.4)	not detected
Peregrine Falcon	X			X		.	not detected
Sandhill Crane		X		X		2.9 (0.3, 6.8)	not detected
Marbled Murrelet							not detected
Band-tailed Pigeon	X		X	X		.	not detected
Flammulated Owl		X		X		.	not detected
Northern Spotted Owl	X		X	X		.	detected outside of point counts
Great Gray Owl					X	.	not detected
Short-eared Owl	X					-0.2 (-6.9, 7.6)	not detected
Boreal owl					X	.	not detected
Black Swift			X		X	-8.9 (-17.2, 0.2)	low detection rate
Vaux's Swift			X	X		0.3 (-4.7, 4.8)	low detection rate
Calliope Hummingbird	X					1.3 (-2.1, 4.3)	low detection rate

Table 33. Bird species and conservation plans (continued).

		Partners In Flight		Washington Department of Fish & Wildlife			
Common name	**NOCA Management Priority**	**BCR9/ East slope Cascades OR and WA**	**Physiographic Area 93**	**Priority Species**	**State Monitor List**	**BCR 9 Short-term trend (% / year, 95% CI)**	**NCCN within park trend**
Rufous Hummingbird	X		X			-1.7 (-4.3, 0.6)	no trend
Lewis's Woodpecker	X	X	X	X		0.9 (-3.3, 5.3)	not detected
Williamson's Sapsucker	X	X				1.6 (-3.6, 6.2)	not detected
Red-naped Sapsucker	X	X				-0.7 (-3.8, 2.4)	low detection rate
Red-breasted Sapsucker	X					4.0 (0.6, 7.4)	no trend
White-headed Woodpecker	X	X		X		3.4 (-0.5, 7.0)	not detected
American Three-toed Woodpecker					X	.	low detection rate
Black-backed woodpecker		X		X	X	0.0 (-8.0, 12.4)	not detected
Pileated Woodpecker				X		1.7 (-1.9, 5.4)	no trend
Olive-sided Flycatcher	X	X				0.0 (-2.0, 2.7)	no trend
Willow Flycatcher	X		X			-1.9 (-3.8, -0.1)	low detection rate
Hammond's Flycatcher			X			0.8 (-1.3, 2.8)	no trend
Dusky Flycatcher	X					0.8 (-7.2, 3.4)	possible decrease
Pacific-slope Flycatcher	X		X			-0.1 (-2.9, 13.0)	no trend
Northern Shrike	X					.	not detected
Cassin's Vireo			X			1.1 (-1.5, 3.1)	no trend
Hutton's Vireo			X			1.1 (-8.6, 17.7)	not detected
Gray Jay	X					1.4 (-3.5, 6.9)	no trend
Steller's Jay	X					1.0 (-0.6, 2.7)	no trend
Clark's Nutcracker	X	X				2.0 (-2.3, 6.9)	no trend
Chestnut-backed Chickadee	X		X			-2.1 (-6.7, 2.1)	no trend
Boreal Chickadee	X				X	.	not detected
Pygmy Nuthatch		X			X	-4.9 (-12.4, 1.5)	not detected
Brown Creeper		X				0.9 (-2.7, 3.8)	no trend
Pacific Wren	X					-6.4 (-9.6, -3.4)	possible decrease

Table 33. Bird species and conservation plans (continued).

Common name	NOCA Management Priority	Partners In Flight: BCR9/ East slope Cascades OR and WA	Partners In Flight: Physiographic Area 93	Washington Department of Fish & Wildlife: Priority Species	Washington Department of Fish & Wildlife: State Monitor List	BCR 9 Short-term trend (% / year, 95% CI)	NCCN within park trend
Golden-crowned Kinglet			X			-6.6 (-10.5, -3.0)	possible decrease
Western Bluebird					X	5.9 (2.3, 10.8)	not detected
Mountain Bluebird	X					2.4 (0.5, 5.4)	low detection rate
Swainson's Thrush			X			-0.3 (-1.7, 1.1)	possible increase
Hermit Thrush		X				-0.6 (-2.5, 1.6)	no trend
Varied Thrush	X					-4.0 (-8.3, 0.2)	no trend
Bohemian Waxwing	X					.	not detected
Lapland Longspur	X					.	not detected
Tennessee Warbler	X					.	not detected
MacGillivray's Warbler			X			0.8 (-2.1, 6.7)	possible increase
Nashville Warbler	X	X				2.0 (-0.2, 4.0)	possible increase
Black-throated Gray Warbler	X		X			2.9 (-0.9, 7.9)	no trend
Hermit Warbler	X		X			4.3 (-3.0, 13.8)	not detected
American Tree Sparrow	X					.	not detected
Chipping Sparrow		X				-0.8 (-2.2, 0.4)	no trend
Lincoln's Sparrow	X					3.7 (-0.7, 11.6)	low detection rate
Fox Sparrow	X					3.5 (-1.2, 8.5)	no trend
Golden-crowned Sparrow	X					.	not detected
Black-headed Grosbeak			X			4.0 (1.7, 6.1)	no trend
Indigo Bunting	X					.	not detected
Yellow-headed Blackbird	X					1.3 (-1.9, 5.7)	not detected
Pine Grosbeak	X					-5.4 (-23.9, 2.9)	no trend
Cassin's Finch	X					2.8 (-0.5, 6.8)	possible increase
White-winged Crossbill	X					.	low detection rate

BCR 9 = Great Basin, which includes the Northern Basin and Range, Columbia Plateau, and the eastern slope of the Cascade Range (http://www.nabci-us.org/bcr9.html).

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 (NCCN) Landbird Monitoring. As a part of the NCCN, NOCA 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 2007–2013. 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 to >1350 m (<2132 to >4429 ft). Information on avian population dynamics resulting from the monitoring program can be used in an adaptive management framework to help set priorities and guide management decisions. 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 2001–2002 by the Institute for Bird Populations (Siegel et al. 2009a). This intensive effort sampled land birds at 1551 point counts conducted along 229 transects distributed in 20 of the 26 habitat types defined for the park. Information on species associations with habitats within NOCA 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. Parts of 2 BBS Routes lie within the boundaries of NOCA. The North Cascades route (Route 89903; Longitude: 121° 09' 27" West, Latitude: 48° 42' 43" North) was surveyed for a total of 23 yrs between 1988 and 2011. The Cascade River route (Route 89902; Longitude: 121° 15' 09" West, Latitude: 48° 30' 44" North) was surveyed for a total of 19 yrs between 1988 and 2006. 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.

NOCA conducted annual Christmas Bird Counts (CBC) every year between 1988 and 2009 (except 2008). The North Cascades CBC took place on 1 d/yr within 12 d of Christmas Day, within a 25-km-diameter circle centered on the Newhalem Creek gaging station. Participants are voluntary field observers. As with BBS data, CBC data can be used to monitor populations of resident and wintering birds at large geographic scales, but data from single count areas cannot be used to infer trends. We used CBC data to assess indications of changes in abundance of resident focal species within the park complex. To do this, we divided the CBC data into 2 time periods, 1988–1999 and 2000– 2009, and calculated the difference in the average counts between periods for each resident focal species with sufficient data. Because winter bird count data are typically highly variable across years, we also used the average of the 3 highest counts as an index of change in local abundance.

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 were conducted in NOCA from 2008 to 2010 (Hamer Environmental 2010). Survey data do not provide information on population status or trends, which have been estimated from surveys of murrelets in near-shore marine waters (Miller et al. 2012).
2. NOCA conducted a 4-yr baseline inventory of Spotted Owls from 1993–1996 (Kuntz and Christophersen 1996). These sites were resurveyed 2007–2010 (Siegel et al. 2009b, 2012). The results provide information on status of historical Spotted Owl activity sites, and record incidental observations of other owl species, including Barred Owls (*Strix varia*).

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 the park checklist (Kuntz et al., no date), eBird (http://ebird.org/content/ebird/about), and the Washington GAP Analysis Program (Smith et al. 1997). As an online checklist, eBird collects and integrates bird observations contributed by recreational and professional bird watchers. The resulting bird distribution data is available via interactive queries; eBird registers 7 birding "Hotspots" at NOCA and 13 at the Ross Lake NRA, with aggregated data available for bird observations made from these specific locations by multiple observers (Figure 27). 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, detractions, and shifts.

The Washington GAP Analysis Program (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 NOCA.

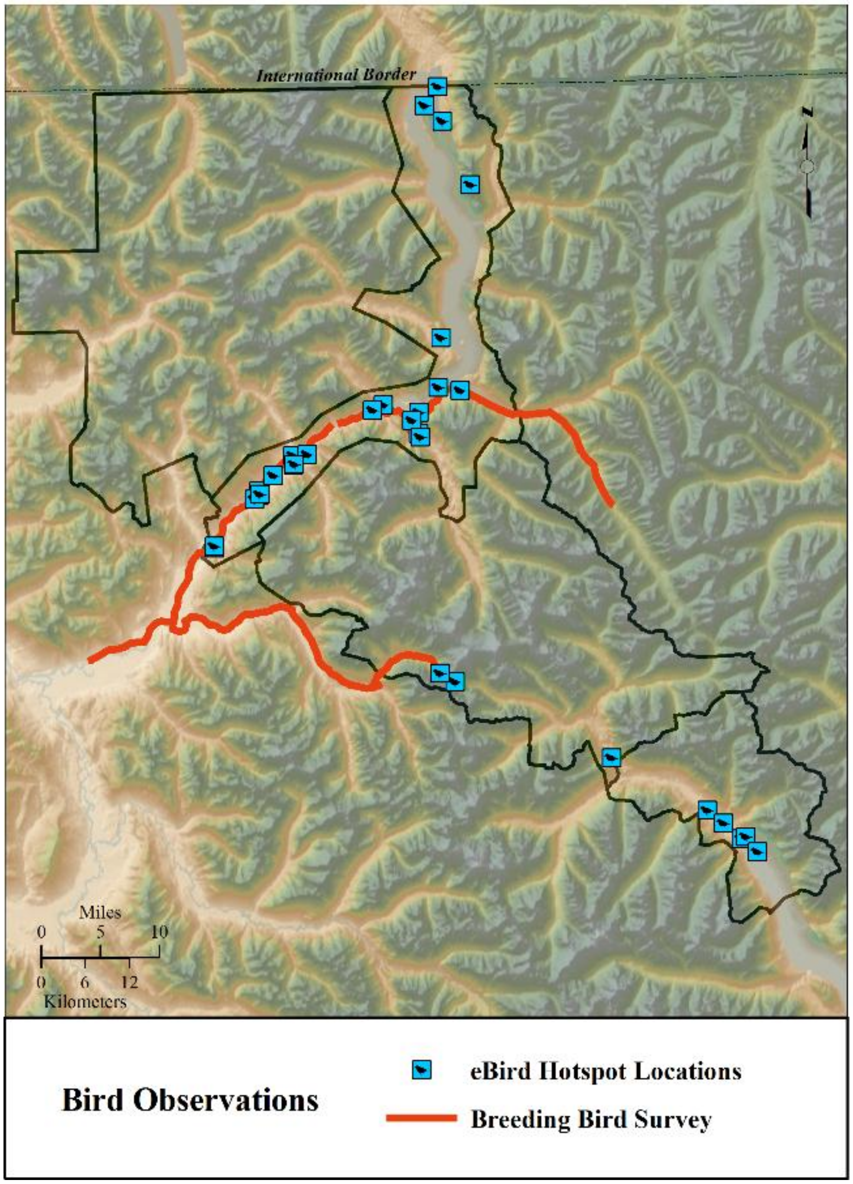

Figure 27. Registered "Hotspot" locations on the eBird website (http://ebird.org/content/ebird/about), and breeding bird survey routes in NOCA.

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 bird species that are common throughout their range are currently experiencing steep population declines (e.g., Sooty Grouse, Rufous Hummingbird, Boreal Chickadee, Cassin's Finch; PIF Species Assessment Database, http://pif.rmbo.org/).

4.15.4 Results and Assessment

We categorized the 73 bird species of potential conservation concern into 4 species groups, based on frequency of occurrence in the park and the data available for assessing the status of each: (1) species regularly occurring and well sampled; (2) species regularly occurring but are difficult to detect and not well sampled; (3) detectable species that occur infrequently in the park; and (4) species with currently undocumented occurrence in the park. The Regularly Occuring species group was assessed using 3 categories: Evidence of Decline, Apparently Stable, and Evidence of Increase.

Regularly Occurring – Well Sampled Species (n = 25)

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 bird monitoring are pending statistical analyses that are being conducted under the NPS Inventory & Monitoring Program. However, we used the preliminary results from the land bird surveys conducted from 2003 to 2011 in conjunction with other data sources (primarily from the BBS route) to make provisional interpretations of the current status and trends for some of the most abundant, well sampled species. This preliminary assessment suggests that 9 of these species may be declining within the park, 11 are apparently stable, and 5 are likely increasing.

Species with Evidence of Decline

Sooty Grouse—This species, considered a common bird in steep population decline (Panjabi et al. 2012), occurs in many habitat types at NOCA. Based on habitat-specific density estimates, Siegel et al. (2009a) estimated a park wide abundance of between 12,000 and 19,000 birds. It has been regularly detected during NCCN surveys, so this monitoring effort is expected to provide information on within-park trends. The preliminary numbers indicate a possible decrease in the detection rate at NOCA and throughout the NCCN (Holmgren et al. 2012). Major threats to this species include habitat degradation, primarily from forestry practices and grazing (Zwickel and Bendell 2005).

Spotted Owl—The Northern Spotted Owl is experiencing population declines within NOCA and throughout their geographic range (Davis et al. 2011). Populations in Washington exhibited a long, gradual decline after the mid-1990s, and have declined 40−60% over the last 15 yrs (Davis et al. 2011). Surveys conducted during 2007 and 2008 in the portion of NOCA east of the crest of the Cascades documented Spotted Owl pairs at 4 of 5 historically occupied sites (Siegel et al. 2009b). However, west of the Cascades crest in the Upper Skagit watershed, only 2 individual owls were detected in a survey of 5 historically occupied sites during breeding season surveys conducted in

2009 and 2010 (Siegel et al. 2012). Average habitat suitability for Spotted Owls has remained relatively high in the western Washington Cascades, and habitat loss has been estimated at only 0.4% (Davis et al. 2011). Similarly, habitat within the park has not changed substantially since the early 1990s, but abundance of Barred Owls has increased on both sides of the Cascades crest by more than 25% (Siegel et al. 2012). Thus, displacement by Barred Owls is implicated as a major cause of Spotted Owl population decline in NOCA, and throughout the region (Forsman et al. 2011).

Vaux's Swift— BBS data for the North Cascades route indicate a decrease in annual frequency of observations of this species: it was detected every year on this route from 1988 to 1995, but was detected in only 2 of the subsequent 16 yrs. Regular observations of Vaux's Swifts are reported on eBird for Ross Lake and Lake Chelan NRAs. The low but consistent detection rate of this species on NCCN surveys provides data for monitoring abundance and occurrence within the park complex.

Rufous Hummingbird—Raw data from NCCN surveys suggest a relatively stable rate of detection for this species in NOCA. However, data from both BBS routes suggest a decline in the number and annual frequency of detections from 1988 to 2012. Regionally, this species has declined at a rate of 1.7 % /yr over the last decade (Sauer et al. 2012).

Pacific-slope Flycatcher—This species is well-sampled by the NCCN surveys, and was one of the most frequently counted bird species on the BBS Routes in previous decades. The highest densities of Pacific-slope Flycatchers in NOCA were in Mountain Hemlock (0.37 birds/ha), Western Redcedar, and Meadow habitat types (Siegel et al. 2009a) at elevations from 145–1705 m (476–5594 ft) (Siegel et al. 2012). Route-level BBS data suggest a decrease in the rate of detection over the last decade, with the species being detected in only 3 of the last 15 yrs on the North Cascades BBS route. The consistent detection rate of this species on NCCN surveys provides data for verifying this trend and monitoring abundance within the park complex.

Pacific Wren, Varied Thrush, Golden-crowned Kinglet—These resident species are among the most abundant birds at NOCA, and are well-sampled by all landbird survey efforts. Golden-crowned Kinglets were the second most frequently detected species on the CBC, with an overall average of 147 individuals counted per year. There is evidence that regional population declines of the 3 species are potentially being mirrored within NOCA. Route-level BBS and CBC data show a decline in number of detections of Pacific Wrens and Golden-crowned Kinglets over the last 2 decades. Average winter counts of Kinglets have decreased by more than 30% in the last decade (Table 34). CBC data also indicate a 40% decrease in winter counts of Varied Thrushes in the last decade (Table 34). 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.

Black-throated Gray Warbler—This species has been regularly recorded on NCCN and BBS surveys. It was detected from 120 to1256 m (394–4121 ft) elevation (n = 116; Siegel et al. 2012), with highest densities (0.33 birds /ha) in Douglas-fir West habitat type (Siegel et al. 2009a). Detections on the NCCN surveys were notably lower in 2011 than the 6 previous years of the survey.

Species which are Apparently Stable within NOCA

Red-breasted Sapsucker—Although uncommon in NOCA, this species is regularly observed during NCCN surveys. It occurred most frequently in "Western Hemlock" and "Douglas-fir West" habitat types (Siegel et al. 2009a), from 120 to 1365 m (394–4478 ft) elevation (Siegel et al. 2012). Based on habitat-specific density estimates, Siegel et al. (2009a) estimated a park-wide abundance of between 6300 and 13,300 birds. No trends in detection rates are apparent from preliminary NCCN survey data, but formal analyses of these data will provide quantitative information.

Pileated Woodpecker—This species uses mid- to late successional conifer forest mainly between 346–1178 m (1135–3865 ft) elevation at NOCA (Siegel et al. 2012). Based on habitat-specific density estimates, Siegel et al. (2009a) estimated a park-wide abundance of between 2390 and 7700 Pileated Woodpeckers at NOCA. The species occurred in several forest types, and were detected every year on the NCCN surveys (Holmgren et al. 2012), suggesting that NCCN data will be useful for monitoring within-park abundance trends.

Olive-sided Flycatcher—This species uses edges and openings in a broad range of conifer forest types on both sides of the Cascades. In NOCA, it occurs in nearly all habitat types (Siegel et al. 2009a), mainly between 500–2020 m (1640–6627 ft) elevation at NOCA (Siegel et al. 2012). Olive-sided Flycatchers are experiencing steep population declines throughout most of their geographic range, but are relatively abundant at NOCA. In fact, NOCA supports the highest abundance of this species among the 3 NCCN parks. Based on habitat-specific density estimates, Siegel et al. (2009a) estimated a park-wide abundance of between 7800 and 12,000 birds. Because it has been well sampled by the landbird monitoring program, NCCN data will be useful for monitoring within-park abundance trends.

Hammond's Flycatcher—Within NOCA, this species occurs in most habitat types from 115–1500 m (377–4921 ft) elevation (Siegel et al. 2012). Highest densities were in Conifer-Deciduous Mix (1.31 birds per hectare (bph)), Western Redcedar (0.89 bph), and Douglas-fir East (0.72 bph; Siegel et al. 2009a). Based on habitat-specific density estimates, Siegel et al. (2009a) estimated a park-wide abundance of between 76,300 and 100,000 birds. Because it has been well sampled by the landbird monitoring program, NCCN data will be useful for monitoring within-park abundance trends. Hammond's Flycatchers seem to have stable population trends both throughout the region and within the park complex (Table 33).

Cassin's Vireo—This species uses many habitat types in NOCA, primarily between 280–1210 m (919–3970 ft) elevation, and highest densities were recorded in Douglas-fir (West and East of Cascade crest), Lodgepole Pine, and Conifer-Deciduous Mix types (Siegel et al. 2009a). Based on habitat-specific density estimates, Siegel et al. (2009a) estimated a park-wide abundance of between 12,800 and 22,250 birds. Because it has been well sampled by the landbird monitoring program, NCCN data will be useful for monitoring within-park abundance trends.

Chestnut-backed Chickadee—This year-round resident is one of the most abundant bird species at NOCA (Siegel et al. 2009a), 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, BBS and CBC surveys. CBC data indicate a slight decrease in the average counts of Chestnut-backed Chickadees at NOCA in the last decade (Table 34).

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 detections is evident for the Brown Creeper from either data set. CBC data indicate a decrease in counts of Brown Creepers in the last decade (Table 34).

Swainson's Thrush, Hermit Thrush—Both species are well sampled during NCCN surveys and on the BBS routes; NOCA hosts by far the highest abundance of both species of all the NCCN parks. Based on landbird inventory data, Swainson's Thrushes occurred in most habitat types in the park, typically at elevations from 125–1610 m (410–5282 ft). Hermit Thrushes reached highest densities in Subalpine Fir, Mountain Hemlock, and Meadow habitats, and occurred mainly at elevations from 550–1970 m (1804–6463 ft). Although the Swainson's Thrush is experiencing population declines in many parts of its breeding range, monitoring data for NOCA indicate apparently stable abundance within the park complex.

Chipping Sparrow—This species is well-sampled by NCCN surveys, and also was detected on both BBS routes. Highest densities were in Subalpine Fir, Douglas-fir East, and Shrub habitats. They were observed from 336–2041 m (1102–6696 ft) elevation. Data from NCCN surveys are likely to be useful for monitoring abundance trends of this species within the park.

Fox Sparrow—Fox Sparrows were observed in high elevation habitats (1143–2077 m; 3750–6814 ft), with highest densities in Subalpine Fir, Shrub, and Meadow habitats. They were detected in 5 out of 7 yrs of NCCN surveys.

Species with Evidence of Increase

Steller's Jay—This species occurs at low densities in a wide range of habitat types, primarily between 110–1920 m (361–6299 ft) elevation at NOCA. BBS data for the North Cascades route and CBC data indicate a possible increase in detections over the last 2 decades. Data from NCCN surveys may provide better estimates of trends of this species within the park, although low densities and high variability may be problematic for analyses.

MacGillivray's Warbler, Nashville Warbler—These are focal species for the PIF Oregon and Washington conservation strategy because they represent dense, deciduous vegetation in early seral forests. MacGillivray's Warbler is experiencing significant long-term and recent population declines throughout much of the PNW portion of its range. Deciduous vegetation is an important element of biodiversity in PNW conifer forests with which both species are strongly associated. Both species are well sampled by NCCN surveys. MacGillivray's Warblers mainly occurred in Shrub and Conifer-Deciduous Mix habitats, between 280–1600 m (919–5249 ft) elevation. Nashville Warblers reached highest densities in Douglas-fir east habitats. Survey data suggest that both species have at least stable, and possibly increasing, abundance in the NOCA complex.

Black-headed Grosbeak—This species occurred in low densities in low elevation habitats (mainly <1100 m; <3609 ft) (Siegel et al. 2012). Increases in numbers of detections on the NOCA BBS routes over recent decades are consistent with the population increase for this species suggested by regional BBS data (Sauer et al. 2012). Data from NCCN surveys are likely to provide robust information for monitoring abundance trends of this species.

Cassin's Finch—This species is a common breeder in dry, open coniferous forests throughout eastern Washington, but becomes less common near the Cascade crest and to the west. Cassin's Finches were detected at low densities (< 0.28 birds/ha) in only a few habitat types during the landbird inventory surveys in 2001–2002 (Siegel et al. 2009a). However, this species has been detected annually during NCCN monitoring surveys, with the highest numbers of detections in 2010 and 2011. The Cassin's Finch is listed by PIF (Berlanga et al. 2010) as a common bird in steep decline because populations have decreased by at least 50% in the last 4 decades. Continued NCCN monitoring efforts will provide valuable data with which to compare within-park abundance trends of this species to regional population trends from BBS data.

Table 34. NOCA Christmas Bird Count data summary for 1988–1999 and 2000–2009.

	1988 to 1999		2000 to 2009				
Species	**Ave.**	**Mean max.**	**Ave.**	**Mean max.**	**Ave. diff.**	**Max. diff.**	**Percent change**
Golden-crowned Kinglet	172.58	308.00	113.67	190.00	-58.92	-118.00	-0.34
Chestnut-backed Chickadee	48.67	95.33	41.11	65.00	-7.56	-30.33	-0.16
Pacific Wren	22.75	39.00	24.33	37.00	1.58	-2.00	0.07
Steller's Jay	22.08	35.33	24.78	43.00	2.69	7.67	0.12
Bald Eagle	15.75	29.00	22.44	35.67	6.69	6.67	0.43
Varied Thrush	16.67	40.67	10.00	24.33	-6.67	-16.34	-0.40
Brown Creeper	4.50	10.33	3.00	4.33	-1.50	-6.00	-0.33

Species That Occur But Are Not Well Sampled (n = 15)

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). 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., White-winged Crossbills, Band-tailed Pigeons), or have large territories (woodpeckers). NOCA 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 is 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. This may be 1 reason why fewer than 10 observations have been registered on eBird for NOCA during the breeding season. Monitoring of Harlequin Ducks requires special survey methods because they are not well sampled by the land bird NCCN surveys. Special surveys conducted in NOCA for riverine bird species between 1997 and 2002 documented presence of breeding pairs of Harlequin Ducks and their young on Baker River, Newhalem Creek, Chilliwack River, Big Beaver Creek, Little Beaver Creek, Thunder Creek, and the Stehekin River.

Common Loon—This species is listed as generally uncommon in NOCA from April–October, and rare during the winter, because it is restricted to the large freshwater reservoirs within the complex. Although loons were detected on a few occasions in the land bird inventory (Siegel et al. 2009a) and on the North Cascades BBS route, neither of these survey efforts are likely to provide sufficient data to monitor abundance trends of this species.

Western Grebe—This species is rare at NOCA during the breeding season, and only a few (<6) sightings have been registered on eBird. Like loons, grebes are restricted to lakes and reservoirs, and have not been detected during NCCN surveys or on the BBS routes.

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). Ospreys are common during the breeding season along the larger waterways in the park complex (Kuntz et al., no date), but abundance trend data are not available.

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). Bald Eagles are rare at NOCA during the breeding season; core breeding habitat for Bald Eagles occurs along lakes, estuaries, and large rivers at lower elevations in western Washington, excluding much of the Cascade Range (Smith et al. 1997, Stinson et al. 2001). However, the upper reaches of large rivers such as the Nooksack (Stalmaster and Newman 1979) and Skagit support wintering Bald Eagles that congregate to feed in salmon spawning areas. Mid-winter Bald Eagle surveys conducted by NOCA between November and March since 1982, along with CBC data, may provide an index to trends in population size and demographics of wintering eagles.

Northern Goshawk—Goshawks are uncommon throughout their range, and are listed as rare on the checklist for the park complex. No observations of Goshawks have been reported on eBird for NOCA, and only 1 individual has been detected during the NCCN surveys. However, the mature, mid- to high-elevation coniferous forests within NOCA constitute core habitat for this species (Smith et al. 1997). Gallinaceous birds, including Sooty Grouse, are particularly important prey for Goshawks at northern latitudes (Squires and Kennedy 2006). Therefore, demographics of goshawks in and around NOCA may be linked to abundance of Sooty Grouse and other prey species.

Golden Eagle—In spite of long-term population declines throughout much of the western U.S. (Kochert and Steenhof 2002), Golden Eagle populations have been stable in BCR 9 over the last decade. Sightings of Golden Eagles are rare to uncommon in NOCA, and few sightings (<10) have been registered on eBird. They are likely to be more common in the open, dry forests on the east slope of the Cascades than in the denser westside forests. NOCA is within the zone of potential core habitat for breeding, although no evidence of Golden Eagles breeding in the park has been documented. 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) (Kochert et al. 2002).

Peregrine Falcon—This species was only incidentally detected during landbird inventory surveys (Siegel et al. 2009a), and <20 observations in the park have been recorded on eBird. No evidence of nesting has been documented in NOCA. 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 home range size (>300 km^2; >116 mi^2) (White et al. 2002).

Boreal Owl—NOCA is near the western margin of the species range, and near the southern edge of the range for this longitude. The park checklist indicates that Boreal Owls are very rare in NOCA, consistent with the lack of observations reported in eBird. The southeast portion of NOCA supports potentially suitable breeding habitat, consisting of high elevation forests (Subalpine Fir, Engelmann Spruce, Lodgepole Pine). Boreal Owls are rarely found below 4000 ft (1220 m) (Smith et al. 1997). 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. This species has been recorded on both NOCA BBS routes. A high count of 263 individuals was recorded on the North Cascades route in 1995, but no Black Swifts have been recorded on this route since 2002 (through 2012). Records on eBird are mainly from the Ross Lake NRA, although a few observations have been recorded at higher elevations, such as Cascade Pass. The Washington Cascades are the southern extent of contiguous breeding range for this species in the U.S. and Canada. Black Swifts were detected on a few point counts during the land bird inventory (Siegel et al. 2009a), but special survey methods are needed for monitoring their population trends.

Calliope Hummingbird—Core habitat for this species occurs in dry, open forest types east of the Cascade crest. It was most frequently detected in the Douglas-fir East forest type in the NOCA land bird inventory (Siegel et al. 2009a), but the detection rate has been too low in the NCCN surveys to assess abundance trends. Calliope Hummingbirds have not been recorded on the BBS survey routes, and only a few sightings are documented within the park complex on eBird.

Gray Jay—This species is regularly detected at NOCA by NCCN surveys and on BBS routes. They occur mainly between 600-1850 m (1968–6070 ft) elevation, in a wide range of habitats, with highest densities in Pacific Silver Fir, Engelmann Spruce, and Douglas-fir West habitat types (Siegel et al. 2009a). Densities are low and variable, but monitoring data may provide information on abundance trends and changes in distribution within the park over time.

Clark's Nutcracker—Throughout much of its range, this species is closely associated with White-bark Pine, a high- elevation conifer species. It also uses low elevation Ponderosa Pine habitats in the Okanogan Highlands. Nutcrackers were detected primarily in Douglas-fir East, Meadow, and Subalpine Fir habitats in NOCA, from 1185–2100 m (3888–6890 ft) elevation. Siegel et al. (2009a) estimated a park-wide abundance of 1880–4250 individuals. Nutcrackers have been detected annually in NOCA on the NCCN surveys, although counts are highly variable.

Pygmy Nuthatch—NOCA is peripheral to the geographic range of this species, which corresponds to zones of low elevation Ponderosa Pine forests. The species is common to uncommon in suitable habitat throughout eastern Washington, but no observations have been recorded in NOCA.

White-winged Crossbill—High elevation conifer forests in the North Cascades mark the southern extent of this species breeding range. This species is difficult to monitor because it is nomadic as it follows cone crops, and can breed whenever food is sufficiently abundant regardless of time of year.

Detectable Species That Occur Infrequently (n = 9)

Point count methodology used by the NCCN land bird survey is effective for sampling these species, but they occur in low abundances at NOCA. NOCA is within the geographic range of all 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, or with changes in vegetation community in response to changing climate.

Band-tailed Pigeon—NOCA is near the northern extent of the breeding range of this species. Regular breeding season observations of Band-tailed Pigeons at the Ross Lake NRA have been documented in eBird since 2008, but it has not been detected during NCCN point counts or on BBS routes in NOCA. NOCA's high elevation forests are outside the core habitat for this species, as are forests east of the Cascade crest.

Red-naped Sapsucker—The Cascade Range crest bounds the eastern extent of this species geographical range. It is rare in NOCA, but 19 observations were recorded from 480–1570 m (1575–5151 ft) elevation during landbird inventory surveys in 2001–2002 (Siegel et al. 2009a). More than half of these observations were in the Douglas-fir East habitat type (Siegel et al. 2009a). Based on habitat-specific density estimates, Siegel et al. (2009a) estimated a park-wide abundance of between 1000 and 5400 birds; eBird documents just 1 record for the complex, in the Ross Lake NRA.

American Three-toed Woodpecker—American Three-toed Woodpeckers are generally found in dense, closed-canopy conifer forests and burn-over lands. Although this species is rarely detected (only a few observations from the landbird inventory and NCCN surveys), NOCA lies within its core habitat of high elevation conifer forest in the Cascades. Data from the Breeding Bird Atlas Explorer (2013) confirmed breeding of this species in the Mt. Baker-Snoqualmie National Forest, adjacent to NOCA in the northeast corner of Skagit County.

Willow Flycatcher—Because NOCA lies outside of the region of core habitat predicted for this species in Washington (Smith et al. 1997), Willow Flycatchers are rare at NOCA. Within the park, they are restricted to shrubby, deciduous habitats at relatively low elevations (<1000 m; <3281 ft) (Siegel et al. 2012). The majority of eBird observations for NOCA were recorded along the North Cascades Highway in the Ross Lake NRA.

Dusky Flycatcher—Dusky Flycatchers are associated with dry, open conifer forests east of the Cascades. Because NOCA lies primarily outside of the region of core habitat predicted for this species in Washington (Smith et al. 1997), Dusky Flycatchers are rare in the park complex. Only a few observations were recorded in Shrub and Subalpine Fir habitats within the park during the landbird inventory (Siegel et al. 2009a); the majority eBird of observations for NOCA were recorded along the North Cascades Highway in the Ross Lake NRA.

Mountain Bluebird—This species is rare in NOCA, and was observed only in Meadow and Shrub habitats at relatively high elevations (>1500 m; >4921 ft). Only a few sightings of this species in the park complex have been registered in eBird, all in the southern end of the Ross Lake NRA. Mountain Bluebirds are detected too infrequently in landbird surveys to provide sufficient data for estimating abundance trends, but the data may be useful for monitoring occurrence of the species within the park complex.

Bohemian Waxwing—This species breeds in northwest Canada and Alaska, and is only likely to occur in NOCA during the winter. Two December records are registered in eBird, and it has been recorded on the CBC in 2007 and 2009. NCCN surveys will not provide data on Bohemian Waxwing occurrence because they are conducted during the breeding season.

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 only detected incidentally during NCCN surveys, and has not been detected to date during BBS surveys. Regular observations registered on eBird, the majority of which are for the Ross Lake NRA, are primarily from the non-breeding season, and are likely migrating birds.

Pine Grosbeak—This species is rare to uncommon at NOCA, but has been regularly recorded on NCCN surveys. Subalpine Fir, Mountain Hemlock, and Alpine Parkland at NOCA constitute core habitat for this species in Washington (Smith et al. 1997). The few observations that were made of this species during landbird inventory surveys were at elevations from 1082–1897 m (3550–6224 ft) (Siegel et al. 2012). Detections of Pine Grosbeaks from NCCN surveys may be too irregular to evaluate abundance trends, but should be useful for monitoring occurrence of this species within the park complex.

Species with Currently Undocumented Occurrence (n = 24)

NOCA is peripheral to the current geographic range of or is currently lacking in suitable habitat for most species in this group. These species were not detected during NCCN surveys, and few, if any records of occurrence in the park exist. However, given the potential for range shifts to occur particularly as plant communities respond to climate change, these species should not be completely discounted as irrelevant to park management.

American White Pelican—This species is listed as “very rare” on the park checklist (Kuntz et al., no date), and no observations within the park complex have been recorded in eBird. The species occurs locally throughout the Columbia Basin (Smith et al. 1997), primarily on deltas and sandbars in large, slow-flowing rivers, or on lakes and impoundments (Wahl et al. 2005).

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 at Ross Lake and along the Skagit River are reported on eBird, but this species has not been detected during NCCN surveys or on the BBS routes. Vultures primarily use low elevation, open forests for breeding (Smith et al. 1997, Wahl et al. 2005).

Swainson’s Hawk—Core habitat for this species occurs in the steppe and prairie regions of southeastern Washington. Swainson’s Hawks nest in riparian corridors, but generally use open habitats below treeline. Although they are occasionally observed west of the Cascade crest, these hawks are listed as very rare on the NOCA checklist.

Rough-legged Hawk—Although this species is a fairly common winter resident throughout the Washington State, it uses non-forested habitats such as agricultural fields, shrub-steppe, and coastal shorelines. It therefore may occasionally be observed passing over NOCA on migration, but habitat within the park complex is largely unsuitable for foraging or roosting.

Sandhill Crane—Although this species historically nested in prairie and wetland habitats to 6000 ft (1829 m), it currently breeds only locally in south-central Washington. Core habitat for cranes in Washington consists of marshes, open wetlands, and fields (Smith et al. 1997), but they use wet meadow habitats at elevations above 1500 m (4921 ft) in some parts of their range (Tacha et al.

1992). The park checklist indicates this species has very rarely been observed. Cranes have not been detected during NCCN surveys, on BBS routes, nor have they been documented in NOCA by eBird.

Marbled Murrelet—Surveys for Marbled Murrelets conducted in NOCA in 2008 provided evidence of murrelet presence in the park complex from radar detections of targets moving at speeds, directions, and times of day consistent with expected Marbled Murrelet flight patterns. However, detection rates were very low, and presence was not confirmed during audio-visual surveys conducted in 2009 and 2010. Therefore, Marbled Murrelet use of NOCA for nesting remains unconfirmed and likely occurs only at very low densities. Outside of NOCA, 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 have also been the greatest (Raphael et al. 2011).

Flammulated Owl—Core habitat for this cavity-nesting species in Washington is limited to low elevation Douglas-fir and Ponderosa Pine forests east of the Cascades crest. No records exist for NOCA. Several observations of this species have been documented in eBird for Okanogan County.

Great Gray Owl—There are no confirmed records of this species at NOCA, 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 (9186 ft) elevation offer suitable nesting habitat for this species (Bull and Duncan 1993).

Short-eared Owl—This species is rare and local in western Washington, and uncommon east of the Cascades. There are no confirmed records for NOCA, nor any detections reported in eBird. Suitable habitat for Short-eared Owls is non-forested, including open shrub-steppe, grasslands, agricultural lands, and meadows.

Lewis' Woodpecker—This species is common in open forest habitats in eastern Washington. Although breeding has been documented east of NOCA in Chelan and Okanogan Counties (WDFW 2013), Lewis' Woodpeckers are only rarely observed within the NOCA park complex. This species has not been detected during landbird inventories or NCCN surveys, or on BBS routes, and only a few observations have been registered on eBird in the Ross Lake NRA.

Williamson's Sapsucker—This species uses low to moderate elevation, mid- to late seral pine and Douglas-fir forests of the east Cascades. It breeds in the Okanogan Valley and Highlands, but has rarely been observed in NOCA: only 1 observation has been made during NCCN surveys. A few sightings have been recorded in eBird for the Lake Chelan NRA. NOCA is near the northern extent of this species' range in southern British Columbia.

White-headed Woodpecker—NOCA is peripheral to the northwestern extent of the range of this species. White-headed woodpeckers are most common in the Ponderosa Pine forest region east of the Cascades. Although they breed in eastern Okanogan County, they have not been observed in NOCA.

Black-backed Woodpecker—Most of NOCA 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 east of the Cascades. Only 1 observation of this species in NOCA is registered by eBird, and it has not been recorded by NCCN and BBS surveys.

Northern Shrike—This species breeds in Alaska and Canada and is infrequently observed in non-forest habitats at low elevations in Washington during winter. No confirmed observations have been recorded for NOCA.

Hutton's Vireo—Hutton's vireos are most often found in hardwood or mixed second-growth forest with a strong hardwood component west of the Cascades (Smith et al. 1997). Because the range of this species does not extend beyond the west slope of the Cascades, NOCA lies outside of the region of predicted core habitat in Washington (Smith et al. 1997).

Boreal Chickadee—NOCA is peripheral to the geographic range of this species, which is a year-round resident in high elevation forests. The species has been detected during the breeding season in Subalpine Fir and Alpine–Parkland habitats in Whatcom and Okanogan Counties, but no observations have been confirmed for NOCA.

Western Bluebird—This species is locally common in open conifer forest and steppe habitats of eastern Washington, and in open woodlands in the south Puget Sound region in western Washington. NOCA is outside of both these regions of core habitat. Western Bluebirds have not been recorded during NCCN surveys or on the BBS routes in NOCA. No observations have been recorded in eBird.

Lapland Longspur—This species breeds in far northern Canada and Alaska, and can be found during the winter in western Washington. During the winter, it uses sparsely vegetated habitats along the coast and agricultural fields in major valleys.

Tennessee Warbler, American Tree Sparrow, Golden-crowned Sparrow—These species breed north of the Canadian border. Tennessee Warblers winter in Central America and are only very rarely observed in western Washington during migration and in winter. Tree Sparrows can be found during winter in eastern Washington in non-forested habitats. Golden-crowned Sparrows winter on both sides of the Cascades, but are more common in Westside lowlands. No observations of Tennessee Warblers and American Tree Sparrow have been confirmed in NOCA. The Golden-crowned Sparrow has historically been found breeding on rare occasions in high, remote areas of the North Cascades (Smith et al. 1997). Several observations of this species in NOCA have been documented in eBird from April through early June, and in September.

Hermit Warbler—NOCA is well beyond the northern limits of this species' geographical range, and no records of occurrence have been confirmed for the park complex.

Indigo Bunting, Yellow-headed Blackbird—NOCA is outside the breeding range for both of these species. The Indigo Bunting breeds mainly east of the Rocky Mountains and is considered an accidental or casual visitor to the Pacific Northwest. One observation of an Indigo Bunting made in

NOCA in 1992 is recorded in eBird. Yellow-headed Blackbirds breed in wetlands in eastern Washington. Although they can occur in wetland patches in forested regions, no sightings have been recorded for NOCA.

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 35). NOCA 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, 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., Rufous Hummingbird, Chestnut-backed Chickadee, Varied Thrush). The Clark's Nutcracker is an iconic high elevation species that has a limited and discontinuous range. Climate change threatens this species with further population fragmentation.

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 North American native Barred Owl because of its negative effect on survival of Spotted Owls (Forsman et al. 2011). 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 NOCA by non-native bird species, such as the European Starling (*Sturnus vulgaris*) and House Sparrow (*Passer domesticus*). Similarly, changes in the distribution or abundance of native nest-parasites (Brown-headed Cowbird, *Molothrus ater*) and nest-predators (e.g., corvids and small mammals), could affect productivity of many bird species. West Nile virus (WNV) is a disease that affects many species of birds, including songbirds, hawks, owls, eagles, waterfowl, woodpeckers, and hummingbirds, but corvids are the most commonly affected group. WNV was first reported in Washington state in 2002 (Washington Department of Fish and Wildlife: http://wdfw.wa.gov/conservation/health/west_nile/).

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. For example, raptors, waterbirds, and potentially all night-migrating songbirds are at risk of colliding with wind turbines that are sited in areas they frequent, particularly wildlife refuges, migratory corridors, and breeding areas (Longcore et al. 2013). 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.

Table 35. Management status and major threats to73 bird species of management concern in North Cascades National Park Service Complex, listed in taxonomic order. These species are listed as Management Priority in NPSpecies, or identified as focal species for conservation strategies developed by Partners In Flight and the North American Bird Conservation Initiative. Sources for identifying major threats were NatureServe and the Conservation and Management sections for individual species accounts in The Birds of North America Online (Poole 2014).

	Management Status			
Species	**US ESA**	**COSEWIC**	**WA**	**Major Threats**
Harlequin Duck	NL	PS	.	Habitat degradation; pesticides; recreational disturbance; over-harvesting; pollution (oil spills)
Sooty Grouse	NL	None	.	Habitat degradation, primarily from forestry practices and grazing
Common Loon	NL	NAR	SS	Human disturbance (recreational boating), habitat loss and degradation (shoreline development), contaminants (esp. marine oil spills)
Western Grebe	NL	C	SC	Oil spills, gill nets, human disturbance, habitat loss and degradation
American White Pelican	NL	NR	SE	Human disturbance at breeding colonies
Turkey vulture	NL	None	SM	Eggshell thinning resulting from ingestion of contaminated food; lead, poisoning
Osprey	NL	None	SM	Pesticides; shooting and trapping; powerline electrocution
Bald Eagle	NL	None	SS	Habitat loss, disturbance by humans, biocide contamination, lead, poisoning, decreasing food supply, and illegal shooting
Northern Goshawk	SC	PS (T)	SC	Habitat loss and degradation, primarily from timber harvest
Swainson's Hawk	NL	None	SM	Habitat loss and degradation; contaminants
Rough-legged Hawk	NL	NAR	.	On wintering grounds: highway mortality (collisions); contaminants; shooting and trapping
Golden eagle	NL	None	SC	Powerline electrocution; poisoning; wind/solar energy development
Peregrine Falcon	NL	SC	SS	Habitat loss and degradation; poaching; shooting; pesticides
Sandhill Crane	PS (E)	PS (E)	SE	Loss and degradation of wetland habitat; collisions with powerlines
Marbled Murrelet	PS (FT)	T	ST	Habitat loss and degradation; gillnet fisheries; pollution (oil spills)
Band-tailed Pigeon	NL	SC	.	Habitat degradation and destruction; overhunting
Flammulated Owl				
Northern Spotted Owl	FT	E	SE	Habitat degradation and destruction; barred owl range expansion
Great Gray Owl	NL	None	SM	Habitat loss through logging; overgrazing of meadow habitat
Short-eared Owl	NL	SC	.	Habitat loss and degradation on wintering grounds; contaminants
Boreal owl	NL	None	SM	Habitat degradation and destruction, primarily from timber harvest
Black Swift	NL	C	SM	Disturbance from recreationists at nest and roost sites
Vaux's Swift	NL	None	SC	Habitat degradation and destruction, primarily from timber harvest
Calliope Hummingbird	NL	None	.	None identified

Table 35. Management status and major threats to bird species present in NOCA (continued).

Species	Management Status US ESA	COSEWIC	WA	Major Threats
Rufous Hummingbird	NL	None	.	None identified
Lewis's Woodpecker	NL	T	SC	Habitat degradation and destruction, primarily from timber management; fire suppression
Williamson's Sapsucker	NL	E	.	Habitat degradation and destruction: timber harvest of old-growth western larch
Red-naped Sapsucker	NL	None	.	Degradation and loss of aspen and riparian woodland habitats
Red-breasted Sapsucker	NL	None	.	Unstudied
White-headed Woodpecker	NL	E	SC	Habitat degradation and destruction, primarily from timber harvest and fire suppression
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
Dusky Flycatcher	NL	None	.	Habitat degradation and destruction, especially of riparian habitat; tower collisions
Pacific-slope Flycatcher	NL	None	.	Unstudied
Northern Shrike	NL	None	.	Unstudied
Cassin's Vireo	NL	None	.	Habitat degradation; cowbird nest-parasitism
Hutton's Vireo	NL	None	.	None identified
Gray Jay	NL	None	.	None identified
Steller's Jay	NL	None	.	None identified
Clark's Nutcracker	NL	None	.	Habitat degradation, primarily due to fire suppression
Chestnut-backed Chickadee	NL	None	.	None identified
Boreal Chickadee	NL	None	SM	Unstudied
Pygmy Nuthatch	NL	None	SM	Habitat degradation and destruction, primarily loss of mature Ponderosa pine;
Brown Creeper	NL	None	.	Habitat degradation and destruction, primarily from timber harvest;
Pacific Wren	NL	None	.	Habitat degradation and destruction, primarily from timber harvest;
Golden-crowned Kinglet	NL	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)

Table 35. Management status and major threats to bird species present in NOCA (continued).

Species	Management Status			Major Threats
	US ESA	COSEWIC	WA	
Mountain Bluebird	NL	None	.	None identified
Swainson's Thrush - Hermit Thrush	NL	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
Bohemian Waxwing	NL	None	.	None identified
Lapland Longspur	NL	None	.	Collision with human-made structures
Tennessee Warbler	NL	None	.	Habitat degradation and destruction: conversion of boreal forest to agriculture
MacGillivray's Warbler	NL	None	.	Habitat degradation (breeding and wintering), primarily forest management
Nashville Warbler	NL	None	.	None identified
Black-throated Gray Warbler	NL	None	.	Unstudied
Hermit Warbler	NL	None	.	Habitat degradation (breeding and wintering), primarily timber harvest
American Tree Sparrow	NL	None	.	None identified
Chipping Sparrow				
Lincoln's Sparrow	NL	None	.	Unstudied
Fox Sparrow	NL	None	.	Unstudied
Golden-crowned Sparrow			.	None identified
Black-headed Grosbeak	NL	None	.	None identified
Indigo Bunting	NL	None	.	Cage-bird trade; collisions; habitat degradation from intensive agriculture
Yellow-headed Blackbird	NL	None	.	Degradation and destruction of wetland habitat
Pine Grosbeak	NL	None	.	Habitat degradation, primarily from forestry practices
Cassin's Finch	NL	None	.	Unstudied
White-winged Crossbill	NL	None	.	Habitat degradation, primarily from forestry practices

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

4.15.6 Information and Data Needs–Gaps

The well-established NCCN 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 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. For example, the Harlequin Duck 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 NOCA 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. Special surveys conducted in NOCA for riverine bird species between 1997 and 2002 documented presence of Harlequin Ducks on several of the Park's rivers (NPS NOCA, unpub. data), but data for assessing abundance or demographic trends are not available.

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4.16 Mammalian Fauna

(Paul Griffin and Kurt Jenkins, U.S. Geological Survey, FRESC)

4.16.1 Introduction

NOCA appears to have retained the full set of 78 historically present mammal species, with the exception of the Fisher and the Cascade Red Fox (*Vulpes vulpes cascadensis*). Abundance and distribution patterns are not well documented for most species, so it is difficult to infer trends in biodiversity. NOCA lands 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. For example, the Grizzly Bear, Gray Wolf, and Canada Lynx are at lower densities than existed primevally (Almack et al. 1993, Stinson 2001, Wiles et al. 2011), and today they are only occasionally documented in the park (IGBC 2011; R, Christophersen, NOCA, pers. comm.; also see Chapter 4.17.4). The Cascade Red Fox, a native subspecies, seems to be extirpated while the fox subspecies that is occasionally seen in the park is most likely not native (Aubry 1984). None of 3 known exotic species present (Eastern Cottontail, House Mouse, and Norway Rat; Table 36) are abundant or widely distributed. Hence the mammalian fauna in NOCA is mostly intact. Climate change is likely to redistribute habitats on which mammals rely, which may lead to shifting distributions and abundance for many species. New pathogens, such as white nose syndrome for bats, also could reduce mammalian populations in the future.

Presence and Management Status

Currently, up to 77 native mammal species may reside during some or all of the year in NOCA, based on documentation in NPSpecies and published literature (Table 36; scientific names of species are presented in this table). That number does not include the Fisher, which appears to have been extirpated from NOCA and the surrounding area. Fisher sightings have become extremely rare in the last few decades, leading the Washington Department of Fish and Wildlife to conclude in 1998 that the species no longer occurred in Washington (Lewis and Stinson 1998). Three native species listed in Table 36 are unlikely to actually occur in NOCA (i.e., Pallid bat, Keen's Myotis, and Townsend's Mole). There are no records for those 3 species, and geographic range modeling (Johnson and Cassidy 1997) suggests that the species ranges are not close to the park. For the 74 other native species potentially present in NOCA, there are legitimate questions about the occurrence of 4 species (i.e., Western Red Bat, Western Small-footed Myotis, Fringed Myotis, and Western Jumping Mouse); their presence is suggested in the NPSpecies database and by habitat modeling (Johnson and Cassidy 1997), but has not been confirmed by verified observations, vouchers, data sets, or published studies. After excluding extirpated and unconfirmed species, there are 70 native mammal species with confirmed evidence that they occur in NOCA. The NPSpecies database indicates that, in addition to the native species, 4 species of non-native mammals may inhabit the park complex (i.e., Virginia Opossum, Eastern Cottontail, House Mouse, and Norway Rat). None of these exotic species have been documented in NOCA, suggesting that none is currently widespread. In addition, the lowland subspecies of Red Fox that is occasionally seen within the park is also non-native.

Five mammal species found in NOCA, or extirpated from NOCA, are federally or state listed as threatened or endangered (Table 37); these species are all carnivores. In the geographic area including NOCA, 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. One rodent (Western Gray Squirrel) and 5 bats (Townsend's Big-eared Bat, Western Long-eared Bat, Western Small-footed Myotis, Fringed Myotis, and Long-legged Myotis) are federal species of special concern. The Gray Wolf, Grizzly Bear, and Fisher are state listed as endangered in Washington; the Canada Lynx and Western Gray Squirrel are state listed as threatened; the Cascade Red Fox, Wolverine, and Townsend's Big-eared Bat are state candidate species; and 6 species are state listed as of interest for monitoring (i.e., Western Long-eared Bat, Western Small-footed Myotis, Fringed Myotis, Long-legged Myotis, Northern Bog-Lemming, and Bendire's Water Shrew). British Columbian populations of 2 species are listed as endangered (i.e., Bendire's Water Shrew and Townsend's Mole), and 3 are of special concern (i.e., Grizzly Bear, Wolverine, and Mountain Beaver) under the Committee on the Status of Endangered Wildlife in Canada (COSEWIC). International conservation efforts will continue to be important in the North Cascades region. Canadian populations of Gray Wolf, Fisher, Wolverine, and Canada Lynx may be sources for natural immigration and human-aided reintroductions into the NOCA region of the USA. Conversely, Bendire's Water Shrew, Townsend's Mole, and the Mountain Beaver are thought to have robust populations in the US that could augment populations in BC in the future.

Table 36. Distributions, occurrences, habitation, and status of mammal species present, historically present, or potentially present in North Cascades National Park Service Complex. Sources include NPSpecies, NatureServe, and in-park observation and voucher information and data.

Species (common and 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	Uncommon	Native	Resident year round to seasonal resident	Not assessed	Number seen in Stehekin area has declined on average from the 1980s
Bighorn Sheep *Ovis canadensis*	AZ, CA, CO, ID, MT, ND, NM, NN, NV, OR, SD, TX, UT, WA, WY; AB, BC	Present	Unknown	Native	Occasional use by individuals	Relatively stable	Unknown
Moose *Alces alces* (syn. *A. americanus*)	AK, CO, CT, ID, MA, ME, MI, MN, MT, ND, NH, NY, UT, VT, WA, WY; AB, BC, LB, MB, NB, NF, NS, NT, NU, ON, QC, SK, YT	Present	Rare	Native	Resident, seasonal resident, or occasional use by individuals	Unknown	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	Rare	Unknown	Seasonal resident	Unknown	Unknown
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	Common	Native	Resident year round to seasonal resident	Unknown	Unknown

Table 36. Distributions, occurrences, habitation, and status of mammal species present, historically present, or potentially present in North Cascades National Park Service Complex (continued).

Species (common and 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
White-tailed Deer *Odocoileus virginianus*	AL, AR, AZ, 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, NY, OH, OK, OR, PA, RI, SC, SD, TN, TX, UT, VA, VT, WA, WI, WV, WY; AB, BC, LB, MB, NB, NS, ON, PE, QC, SK, YT	Unconfirmed	NA	Native	Seasonal resident to occasional use by individuals	Range has expanded northward farther into Canada as a result of habitat changes caused by humans.	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	Rare	Native	Resident year round	Unknown	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	Present	Occasional	Native	Occasional use by individuals	Increasing, but rate is not known	Increasing in the North Cascades region and in Okanogan NF; no wolf use until recent activity of Lookout Pack in Methow Valley area.

Table 36. Distributions, occurrences, habitation, and status of mammal species present, historically present, or potentially present in North Cascades National Park Service Complex (continued).

Species (common and 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
Red Fox *Vulpes vulpes*	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	Unknown	Native	Occasional use by individuals	Unknown	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	Probably present	NA	Native	Occasional use by individuals	Short-term trend unknown	NA
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	Rare	Native	Resident year round	Relatively stable	Unknown

Table 36. Distributions, occurrences, habitation, and status of mammal species present, historically present, or potentially present in North Cascades National Park Service Complex (continued).

Species (common and 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 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	Uncommon	Native	Resident year round	Short-term trend unknown	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	Unconfirmed	NA	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	Not listed in NPSpecies for NOCA	Not listed in NPSpecies for NOCA	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	Probably present	NA	Native	Occasional use by individuals	Relatively stable to decline of 30%	Unknown

Table 36. Distributions, occurrences, habitation, and status of mammal species present, historically present, or potentially present in North Cascades National Park Service Complex (continued).

Species (common and 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
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	Uncommon	Native	Resident year round	Relatively stable	Unknown
Pine 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	Common	Native	Resident year round	Relatively stable	Unknown
Fisher *Martes 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	Present	Unknown	Native	Historically present, now possibly extirpated	Relatively stable to decline of 30% (West Coast population segment)	Unknown
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	Unknown	Native	Resident year round	Unknown. Ermine populations fluctuate with vole abundance	Unknown

Table 36. Distributions, occurrences, habitation, and status of mammal species present, historically present, or potentially present in North Cascades National Park Service Complex (continued).

Species (common and 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
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	Unknown	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	Unknown	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	Unknown	Native	Resident year round	Not assessed	Unknown

Table 36. Distributions, occurrences, habitation, and status of mammal species present, historically present, or potentially present in North Cascades National Park Service Complex (continued).

Species (common and 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	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	Present	Occasional	Native	Occasional use by individuals	Decline of 10–30%	Unknown
Pallid Bat *Antrozous pallidus*	AZ, CA, CO, ID, KS, MT, NM, NN, NV, OK, OR, TX, UT, WA, WY; BC	Unconfirmed	NA	Native	Unlikely to occur, but listed in NPSpecies	Unknown	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	Occasional	Native	Resident year round or seasonal resident	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	Common	Native	Resident year round or seasonal resident	Unknown	Unknown

Table 36. Distributions, occurrences, habitation, and status of mammal species present, historically present, or potentially present in North Cascades National Park Service Complex (continued).

Species (common and 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
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	Common	Native	Seasonal resident	Not assessed	Unknown
Western Red Bat *Lasiurus blossevillii*	AZ, CA, NM, NV, OR, TX, UT; BC	Unconfirmed	NA	Native	Potentially present, not documented	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	Rare	Native	Seasonal resident	Not assessed	Unknown
California Myotis *Myotis californicus*	AK, AZ, CA, CO, ID, MT, NM, NN, NV, OR, TX, UT, WA; BC	Present	Uncommon	Native	Resident year round or seasonal resident	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	Uncommon	Native	Resident year round or seasonal resident	Relatively stable	Unknown

Table 36. Distributions, occurrences, habitation, and status of mammal species present, historically present, or potentially present in North Cascades National Park Service Complex (continued).

Species (common and 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
Keen's Myotis *Myotis keenii*	AK, WA; BC	Unconfirmed	NA	Native	Unlikely to occur, but listed in NPSpecies	Relatively stable to decline of 30%	Unknown
Western Small-footed Myotis *Myotis ciliolabrum* (formerly *M. leibii*)	AZ, CA, CO, ID, KS, MT, ND, NE, NM, NN, NV, OK, OR, SD, TX, UT, WA, WY; AB, BC, SK	Unconfirmed	NA	Native	Potentially present, not documented	Unknown	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	Common	Native	Resident year round or seasonal resident	Not assessed	Unknown
Fringed Myotis *Myotis thysanodes*	AZ, CA, CO, ID, MT, NE, NM, NN, NV, OR, SD, TX, UT, WA, WY; BC	Unconfirmed	NA	Native	Potentially present, not documented	Relatively stable to decline of 30%	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	Rare	Native	Resident year round or seasonal resident	Relatively stable	Unknown
Yuma Myotis *Myotis yumanensis*	AZ, CA, CO, ID, MT, NM, NN, NV, OK, OR, TX, UT, WA, WY; BC	Present	Common	Native	Resident year round or seasonal resident	Unknown	Unknown

Table 36. Distributions, occurrences, habitation, and status of mammal species present, historically present, or potentially present in North Cascades National Park Service Complex (continued).

Species (common and 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
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	Encroaching	NA	Native	Potentially present, not documented	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	Uncommon	Native	Resident year round	Not assessed	Unknown
Eastern Cottontail *Sylvilagus floridanus*	AL, AR, AZ, CO, CT, DC, DE, FL, GA, IA, IL, IN, KS, KY, LA, MA, MD, MI, MN, MO, MS, MT, NC, ND, NE, NH, NJ, NM, NY, OH, OK, OR, PA, RI, SC, SD, TN, TX, VA, VT, WA, WI, WV, WY; BC, MB, ON, QC, SK	Encroaching	NA	Non-native	Potentially present, not documented	Not assessed	Unknown
American Pika *Ochotona princeps*	CA, CO, ID, MT, NM, NN, NV, OR, UT, WA, WY; AB, BC	Present	Common	Native	Resident year round	Not assessed	Unknown
Mountain Beaver *Aplodontia rufa*	CA, NV, OR, WA; BC	Present	Rare	Native	Resident year round	Not assessed	Unknown

Table 36. Distributions, occurrences, habitation, and status of mammal species present, historically present, or potentially present in North Cascades National Park Service Complex (continued).

Species (common and 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
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	Uncommon	Native	Resident year round	Increase of 10 to >25%	Unknown
Western Jumping Mouse *Zapus princeps*	AK, CA, CO, ID, MT, ND, NM, NV, OR, SD, UT, WA, WY; AB, BC, MB, SK, YT	Probably present	NA	Native	Potentially present, not documented	Not assessed	Unknown
Pacific Jumping Mouse *Zapus trinotatus*	CA, OR, WA; BC	Present	Unknown	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	Uncommon	Native	Resident year round	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	Unknown	Native	Resident year round	Not assessed	Unknown

Table 36. Distributions, occurrences, habitation, and status of mammal species present, historically present, or potentially present in North Cascades National Park Service Complex (continued).

Species (common and 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
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	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	Rare	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	Uncommon	Native	Resident year round	Not assessed	Unknown
Water Vole *Microtus richardsoni*	ID, MT, OR, UT, WA, WY; AB, BC	Present	Unknown	Native	Resident year round	Not assessed	Unknown
Townsend's Vole *Microtus townsendii*	CA, OR, WA; BC	Unconfirmed	NA	Native	Resident year round	Not assessed	Unknown

Table 36. Distributions, occurrences, habitation, and status of mammal species present, historically present, or potentially present in North Cascades National Park Service Complex (continued).

Species (common and 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
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	Unconfirmed	NA	Non-native	Potentially present, not documented	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	Uncommon	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	Present	Unknown	Native	Resident year round	Not assessed	Unknown
Keen's Mouse *Peromyscus keeni*	AK, WA; BC, YT	Present	Common	Native	Resident year round	Unknown	Unknown

Table 36. Distributions, occurrences, habitation, and status of mammal species present, historically present, or potentially present in North Cascades National Park Service Complex (continued).

Species (common and 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
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	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	Unknown	Native	Resident year round	Unknown	Unknown
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	Unconfirmed	NA	Non-native	Potentially present, not documented	Not assessed	Unknown
Northern Bog-lemming *Synaptomys borealis*	AK, ID, ME, MN, MT, NH, WA; AB, BC, LB, MB, NB, NT, NU, ON, QC, SK, YT	Present	Unknown	Native	Resident year round	Unknown	Unknown

Table 36. Distributions, occurrences, habitation, and status of mammal species present, historically present, or potentially present in North Cascades National Park Service Complex (continued).

Species (common and 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
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	Rare	Native	Resident year round	Not assessed	Unknown
Hoary Marmot *Marmota caligata*	AK, ID, MT, WA; AB, BC, NT, YT	Present	Common	Native	Resident year round	Not assessed	Unknown
Yellow-bellied Marmot *Marmota flaviventris*	CA, CO, ID, MT, NM, NN, NV, OR, SD, UT, WA, WY; AB, BC	Unconfirmed	NA	Native	Resident year round	Not assessed	Unknown
Western Gray Squirrel *Sciurus griseus*	CA, NV, OR, WA;	Present	Uncommon	Native	Resident year round	Not assessed	Unknown
Columbian Ground Squirrel, *Spermophilus columbianus*	ID, MT, OR, WA; AB, BC	Present	NA	Native	Resident year round	Not assessed	Unknown
Cascade Golden-mantled Ground Squirrel *Spermophilus saturatus*	WA; BC	Present	Uncommon	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	Uncommon	Native	Resident year round	Not assessed	Unknown
Least Chipmunk *Tamias minimus* (syn. *Neotamias minimus*)	AZ, CA, CO, ID, MI, MN, MT, ND, NE, NM, NN, NV, OR, SD, UT, WA, WI, WY; AB, BC, MB, NT, ON, QC, SK, YT	Present	Unknown	Native	Resident year round	Not assessed	Unknown
Townsend's Chipmunk *Tamias townsendii* (syn. *Neotamias townsendii*)	OR, WA; BC	Present	Common	Native	Resident year round	Not assessed	Unknown

Table 36. Distributions, occurrences, habitation, and status of mammal species present, historically present, or potentially present in North Cascades National Park Service Complex (continued).

Species (common and 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
Douglas's Squirrel *Tamiasciurus douglasii*	CA, NV, OR, WA; BC	Present	Common	Native	Resident year round	Not assessed	Unknown
Red Squirrel *Tamiasciurus hudsonicus*	AK, AZ, CO, CT, DC, DE, GA, IA, ID, IL, IN, MA, MD, ME, MI, MN, MT, NC, ND, NH, NJ, NM, NN, 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	Uncommon	Native	Resident year round	Not assessed	Unknown
Bendire's Water Shrew *Sorex bendirii*	CA, OR, WA; BC	Present	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	Present	Unknown	Native	Resident year round	Not assessed	Unknown
Montane Shrew *Sorex monticolus*	AK, AZ, CA, CO, ID, MT, NM, NN, NV, OR, UT, WA, WY; AB, BC, MB, NT, SK, YT	Present	Common	Native	Resident year round	Not assessed	Unknown

Table 36. Distributions, occurrences, habitation, and status of mammal species present, historically present, or potentially present in North Cascades National Park Service Complex (continued).

Species (common and 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 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	Unknown	Native	Resident year round	Relatively stable to decline of 30%	Unknown
Trowbridge's Shrew *Sorex trowbridgii*	CA, NV, OR, WA; BC	Present	Common	Native	Resident year round	Unknown	Unknown
Vagrant Shrew *Sorex vagrans*	CA, ID, MT, NN, NV, OR, UT, WA, WY; AB, BC	Present	Common	Native	Resident year round	Not assessed	Unknown
American Shrew Mole *Neurotrichus gibbsii*	CA, OR, WA; BC	Present	Common	Native	Resident year round	Not assessed	Unknown
Pacific Mole *Scapanus orarius*	CA, ID, OR, WA; BC	Present	Uncommon	Native	Resident year round	Not assessed	Unknown
Townsend's Mole (aka Snow Mole) *Scapanus townsendii*	CA, OR, WA; BC	Unconfirmed	NA	Native	Unlikely to occur, but listed in NPSpecies	Not assessed	Unknown

Table 37. Management status of mammals present or potentially present in NOCA.

					NatureServe					
Common name	**US ESA**	**COSEWIC**	**WA**	**BC Status and SARA**	**Global (G)**	**US (N)**	**WA (S)**	**IUCN**	**NOCA**	**Comments**
Mountain Goat	No listing	No listing			5	5	2,3	LC		
Bighorn Sheep	PS	No listing			4	4	3,4	LC		The Peninsular ranges and Sierra Nevada subspecies are LE; both are in California
Moose	No listing	No listing			5	5	2,3	LC		
Elk	No listing in US				5	5	5	LC		No listing in US. Some Eurasian subspecies are LE
Black-tailed Deer	No listing in US	No listing			5	5	5	LC		No listing in US. The *O. h. cedrosensis* subspecies in Mexico is LE
White-tailed Deer	PS	No listing			5	5	5	LC		The Key Deer (in Florida) and Columbian (on Columbia River islands of OR and WA) subspecies are LE; NatureServe status for the US does not include those, or the Blackbeard Island deer in Georgia
Coyote					5	5	5	LC	Mgmt. priority	
Gray Wolf	PS: LE	NAR	SE		4	4	1	LC		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 are NAR, except the arctic subspecies in NT and NU are DD
Red Fox	No listing	No listing	SC		5	5	5	LC		*The native subspecies (Cascade Red Fox, *V. v. cascadensis*) is state listed, but not the lowland subspecies (*V. v. fulva*), which was introduced via fur farming
Canada Lynx	LT in lower 48	NAR	ST		5	4	1	LC	Mgmt. priority	

Table 37. Management status of mammals present or potentially present in NOCA (continued).

					NatureServe					
Common name	**US ESA**	**COSEWIC**	**WA**	**BC Status and SARA**	**Global (G)**	**US (N)**	**WA (S)**	**IUCN**	**NOCA**	**Comments**
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	Mgmt. priority	The Florida panther (*P. c. coryi*) and eastern puma (*P. c. cougar*) are LE; Outside the US, *P. c. costaricensis* is LE; In Canada, no listing for western population; eastern population = DD
Striped Skunk	No listing	No listing			5	5	5	LC		
Western Spotted Skunk	No listing	No listing			5	5	4	LC		
Wolverine	C in lower 48	SC, E	SC	Red* Blue*	4	4	1	LC	Mgmt. priority	In Canada, western population listed as SC, and the eastern population listed as E. The Vancouver Island subspecies is listed Red and the mainland subspecies is listed Blue in BC
River Otter	No listing	No listing			5	5	4	LC		
Pine 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	Mgmt. priority	Western population segment is a candidate for ESA listing
Ermine	No listing	PS			5	5	5	LC		In British Columbia, 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, MB are 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	Mgmt. priority; Pest	The Louisiana Black Bear population (*U. a. luteolus*) is LT in Louisiana, Mississippi, and Texas

Table 37. Management status of mammals present or potentially present in NOCA (continued).

					NatureServe					
Common name	**US ESA**	**COSEWIC**	**WA**	**BC Status and SARA**	**Global (G)**	**US (N)**	**WA (S)**	**IUCN**	**NOCA**	**Comments**
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 Idaho and Montana; In Canada, prairie population extirpated from AB, MB, and SK; special concern for Northwestern population in AB, BC, NU, NT, YT; LE in Mexico, Italy, and parts of China
Pallid Bat	No listing	T	SM	Red: 1	5	5	2,3	LC		
Townsend's Big-eared Bat	PS, SC	No listing	SC	Blue	4	4	2,3	LC	Mgmt. priority	Federal SC in Washington state; 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		
Western Red Bat	No listing	No listing	SM		4	3,4	SU	LC		*It is questionable whether the range of this species extends into NOCA
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		
Keen's Myotis	No listing	DD	SC	Red: 3	2	1,3	1	LC	Mgmt. priority	*It is questionable whether the range of this species extends into NOCA
Western Small-footed Myotis	SC	No listing	SM		5	5	4	LC		
Little Brown Bat	No listing	No listing			5	5	4,5	LC		
Fringed Myotis	SC	DD	SM		4,5	4,5	3,4	LC		
Long-legged Myotis	SC	No listing	SM		5	5	3,4	LC		
Yuma Myotis	No listing	No listing			5	5	5	LC		
Virginia Opossum	No listing	No listing			5	5	SNA	LC	Pest	

Table 37. Management status of mammals present or potentially present in NOCA (continued).

					NatureServe					
Common name	**US ESA**	**COSEWIC**	**WA**	**BC Status and SARA**	**Global (G)**	**US (N)**	**WA (S)**	**IUCN**	**NOCA**	**Comments**
Snowshoe Hare	No listing	No listing		Red*	5	5	5	LC		The *L. a. washingtonii* subspecies, in the Fraser Valley, is listed Red in BC
Eastern Cottontail	No listing	No listing			5	5	SNA	LC	Pest	
American Pika	No listing	No listing			5	5	5	LC		
Mountain Beaver	PS	SC		Blue: 1*	5	5	5	LC		The Point Arena subspecies (*A. r. nigra*) in Mendocino County, California, is LE; The *A. r. rufa* subspecies is Schedule 1 in BC
Beaver	No listing	No listing			5	5	5	LC		
Western Jumping Mouse	No listing	No listing			5	5	4,5	LC		
Pacific Jumping Mouse	No listing	No listing			5	5	5	LC		
Porcupine	No listing	No listing			5	5	5	LC		
Northern Pocket Gopher	No listing	No listing		Red*	5	5	5	LC		The *T. t. segregatus* subspecies, from near Wyndell, BC, is listed Red in BC
Southern Red-backed Vole	No listing	No listing		Red*	5	5	5	LC		The *M. g. occidentalis* subspecies, 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		The *M. t. cowani* subspecies from Triangle Island, off the northern tip of Vancouver Island is listed Red in BC
House Mouse	No listing	No listing			5	NNA	SNA	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	Pest	

Table 37. Management status of mammals present or potentially present in NOCA (continued).

					NatureServe					
Common name	**US ESA**	**COSEWIC**	**WA**	**BC Status and SARA**	**Global (G)**	**US (N)**	**WA (S)**	**IUCN**	**NOCA**	**Comments**
Deer Mouse	No listing	No listing			5	5	5	LC	Pest	
Heather Vole	No listing	No listing			5	5	5	LC		
Norway rat	No listing	No listing			5	NNA	SNA	LC	Pest	
Northern Bog-lemming	No listing	No listing	SM	Blue*	4	4	3,4	LC		The *S. b. artemisae* subspecies, from near Princeton, BC is listed as Blue in BC
Northern Flying Squirrel	PS	No listing			5	5	4,5	LC		The Appalachian subspecies (*G. S. coloratus*) is LE
Hoary Marmot	No listing	No listing			5	5	4,5	LC		
Yellow-bellied Marmot	No listing	No listing			5	5	4	LC		
Western Gray Squirrel	SC	No listing	ST		5	5	2	LC	Mgmt. priority	
Columbian Ground Squirrel	No listing	No listing			5	5	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		
Least Chipmunk	No listing	No listing		Red*	5	5	4	LC		The Selkirk subspecies (*N. m. selkirki*) is listed Red in BC
Townsend's Chipmunk	No listing	No listing			5	5	5	LC		
Douglas's Squirrel	No listing	No listing			5	5	5	LC		
Red 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		The Vancouver Island subspecies (*S.p. brooksi*) is listed Red in BC

Table 37. Management status of mammals present or potentially present in NOCA (continued).

					NatureServe					
Common name	**US ESA**	**COSEWIC**	**WA**	**BC Status and SARA**	**Global (G)**	**US (N)**	**WA (S)**	**IUCN**	**NOCA**	**Comments**
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		

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

Relative Significance of NOCA to Species—Because of its size, protected status, inaccessibility to humans, and geographic position, NOCA lands serve as important habitat in the conservation of many mammalian species in the greater North Cascades ecosystem. NOCA lands straddle both sides of the Cascade Range crest, and are contiguous with other large public lands to the west (Mt. Baker-Snoqualmie National Forest), east (Okanogan NF), south (Wenatchee NF), and north (Chilliwack, Skagit Valley, and EC Manning BC Provincial Parks, along with other provincially-owned forest lands). This placement at the center of a network of protected lands underscores the importance of NOCA lands for connectivity of many mammal species populations in the whole region. Underscoring this is the number of mammal species that occasionally use NOCA, or that use NOCA lands as part of an annual pattern of migration. Of the 70 species with documented occurrence, evidence suggests that the park complex is only occasionally used by some individuals of the larger species (e.g., Grizzly Bear, Gray Wolf, Wolverine, Canada Lynx, Red Fox, Striped Skunk, Moose, Bighorn Sheep, and White-tailed Deer). NOCA lands may be important in annual migrations of some Elk, Black-tailed deer, Mountain Goats, and some bat species. NOCA lands are not adequate, by themselves, to sustain populations of these migratory and vagrant species, but do contribute to the viability of these species in the region. At the longer time scale of years to decades, even those species that are resident year-round in NOCA almost certainly benefit from demographic and genetic connectivity with populations on other nearby lands. NOCA is at the margin of the geographic range for many species that are predominantly found on the east side of the Cascade Range (i.e., Bighorn Sheep, Western Gray Squirrel, Cascade Golden-mantled Ground Squirrel, and Fringed Myotis. Populations of these species may expand further into NOCA, or find refuge in NOCA lands as climate and vegetative patterns change in the future.

Low elevation, late-seral stage forests in NOCA and other public lands tend to have a long growing season, and a diversity of habitat structures (Hansen et al. 1991), and plant species (Halpern and Spies 1995). Old-growth forests are associated with higher abundance of roosting bats (Thomas 1988), Northern Flying Squirrels (Carey 1995), and Red-backed Voles (Aubry et al. 1991), but no mammal in Table 36 is strictly limited to old-growth forests. The old-growth forests in NOCA are mostly in large contigous blocks that contrast with the patchwork of successional stages on nearby National Forests.

4.16.2 Reference Conditions and Comparison Metrics

The reference condition for mammalian biodiversity is the Minimally Disturbed Condition, which refers to the condition of a resource in a landscape with minimum human disturbance. For mammalian biodiversity, this condition would be characterized by the full set of mammalian species that were historically present.

4.16.3 Results and Assessment

Very few species have been well studied in the park complex. There is virtually no information about short-term population trends or spatial distribution within the park complex for most species. Many species have been recorded in the park incidental to other studies, or by visitors, without a thorough park-wide sampling effort. There are a few species for which inventories have been completed or existing research permits a more complete assessment. We discuss these species in sub-sections 4.17, 4.18, and 4.19 of this NRCA.

NOCA habitats are valuable in supporting mammalian biodiversity, but should be considered in the context of the larger North Cascades region. The wilderness character of the park complex lands generally translates to a low level of human disturbance and relatively high habitat quality for the habitat types present. The remote nature of most of the park complex protects species from anthropogenic forms of mortality such as poaching and vehicle. The high elevations characterizing most of the park, however, have relatively low annual productivity, and so may be of relatively low quality for many species when compared to lower elevation lands to the north, south, east, and west. This means that NOCA by itself probably will not support viable populations of many of the larger species. Rather, many of these will probably continue to move in and out of the park complex lands seasonally (i.e., Elk, Moose, and Black-tailed Deer) or as part of larger home ranges (i.e., Gray Wolf, Canada Lynx, Wolverine, and Grizzly Bear).

The mammalian fauna in NOCA is remarkably intact, with only a few exceptions. One native species and 1 native subspecies seem to be extirpated, and the population size of some carnivores may be lower than would have been historically typical. Any populations of exotic mammalian species, though, are negligible. We conclude that the current status of mammalian biodiversity is very close to the Minimally Disturbed reference condition, but that there are several potential threats to future trends in biodiversity.

4.16.4 Emerging Issues

The primary range-wide threats to each of the mammal species is summarized in Table 38. Generally, the types of anthropogenic disturbance that may threaten populations of these mammals in other parts of their geographic ranges are not as pressing within the boundaries of NOCA. One exception is climate change which is likely to pose a threat to species that rely on high elevation habitats, such as Pika and Hoary Marmot (Krajick 2004), or long snow pack duration, such as Snowshoe Hare and Canada Lynx (Rosner 2012), and Wolverine (McKelvey et al. 2011). Climate change is also expected to influence the composition, structure, and function of forest ecosysems broadly throughout the Pacific Northwest through its influence on natural fire regimes, insect infestations, and many other disturbance patterns (see Chapters 4.5–4.8), which will influence distribution and abundance of wildlife populations through complex, yet poorly understood, interactions (Krebs et al. 2001, Halofsky et al. 2011). Changes in habitat distribution due to climate change could lead some presently connected populations to become fragmented in the future (i.e., Canada Lynx; Koehler et al. 2008). As the climate warms, species that are currently restricted to the Puget Sound lowlands and eastern foothills of the Cascade Range may increase in abundance and expand their range to higher elevations, potentially into NOCA lands. Such changes could include exotic (i.e., Virginia Opossum) and native species. Changes in exotic plant populations as outlined in Chapter 4.9 also have the potential to affect wildlife hatitats and foods and warrant greater attention in the future. The difficulty of predicting how complex communities of interacting species will change in the future (Halofsky et al. 2011), suggests the value of broad-based regional monitoring of selected wildlife groups.

One last potential threat that could influence any mammal population in the future is the emergence of new parasites or 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 approximately 2008, and it appears to be steadily spreading west (Blehart et al. 2011). Additionally, wild ungulate populations that move over wide areas, some of which may be grazed by domestic congeners, may be more susceptible to pathogen spread than some other mammal species. Certain diseases and pests pose known risks to Bighorn Sheep (e.g., scabies and *Pasturella*), Elk (e.g., chronic wasting disease), and deer (e.g., hair loss syndrome and epizootic hemorrhagic disease), and we can expect the emergence of new pathogens and pests in the future.

Table 38. Some potential threats, as listed by NatureServe, to mammals present or potentially present in NOCA. 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 NOCA.

Common name	Threats (NatureServe)
Bighorn Sheep	Habitat loss and degradation; *Pasturella*, scabies, and other diseases from domestic sheep
Black-tailed Deer	Habituated deer are at elevated risk of collisions with vehicles; Hunting is not a threat, per se, because it is regulated
White-tailed Deer	Under some Climate change scenarios, epizootic hemorrhagic disease could spread to this region, from the Midwest US
Canada Lynx	Climate change may reduce snowpack, changing the distribution of preferred Engelmann Spruce habitats (leading to fragmentation; Koehler et al. 2008.) 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 (McKelvey et al. 2011).
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 (Rogers 1986)
Pallid Bat	Species probably does not occur in NOCA; Pallid bats are long distance migrants (Sherwin and Rambaldini 2005), so they may be at risk of trauma at wind turbine facilities; Recreational caving, and mine and cave surveys may disturb bats (Thomas 1995 J. Mammalogy 76:940-946); If White Nose Syndrome (WNS) spreads to the Pacific northwest, it may pose a risk to all bats in the region, including those that migrate
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 (Thomas 1995); In this species, gates can reduce this threat (Sherwin and Piaggio 2005). There is threat potential if mine and cave surveys are conducted during breeding periods and winter hibernation (Thomas 1995); This species is a colonial hibernator in cool, moist caves, therefore, if 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 (Perkins 2005a); Species may roost in large-diameter snags (Perkins 2005); Recreational caving, and mine and cave surveys may disturb bats (Thomas 1995); 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 (Perkins 2005b); 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 (Perkins 2005b), so species may still face high risk of WNS
Western Red Bat	Intensive pesticide use in orchards may directly affect roosting bats; pesticide use may reduce prey insect populations (Bolster 2005a); Red bats typically roost in trees; Prescribed fires may harm red bats that hibernate in leaf litter (Bolster 2005a); If WNS spreads to the Pacific Northwest, all bats may be at risk. The Western Red Bat, though, is a long-distance migrant, so it may be somewhat protected from WNS

Table 38. Some potential threats, as listed by NatureServe, to mammals present or potentially present in NOCA. 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 NOCA (continued).

Common name	Threats (NatureServe)
Hoary Bat	Pesticide use on forest lands may affect the bats directly, and their insect prey (Bolster 2005b); Species roosts in trees (Bolster 2005b); 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 (Bolster 2005b), and so may be somewhat protected from WNS
California Myotis	Species could be affected by loss of large-diameter snags (Bogan et al. 2005a); Recreational caving, and mine and cave surveys may disturb bats (Thomas 1995); 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 (Bogan et al. 2005b); Recreational caving, and mine and cave surveys may disturb bats (Thomas 1995); 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
Keen's Myotis	The species probably does not occur in NOCA; Habitat loss through logging: species is associated with old-growth forests (Wenger 2005); Recreational caving, and mine and cave surveys may disturb bats (Thomas 1995); If WNS spreads to the Pacific Northwest, hibernating bats species such as this will be particularly at risk
Western Small-footed Myotis	Recreational caving, and mine and cave surveys may disturb bats (Thomas 1995); If WNS spreads to the Pacific Northwest, hibernating bats species such as this will be particularly at risk
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 (Thomas 1995); 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 (Frick et al 2010); Hibernation sites in the west are poorly known (Rainey 2005)
Fringed Myotis	Threat due to destruction of buildings and bridges used as roosts; This forest-associated bat is affected by logging, it forages in and near trees; Recreational caving, and mine and cave surveys may disturb bats (Thomas 1995); Threats from disturbance or destruction of water sources and riparian habitat; If WNS spreads to the Pacific Northwest, hibernating bats species such as this will be particularly at risk
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 (Thomas 1995); 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 (Bogan et al. 2005c); 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 (Thomas 1995); 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 (Mills, unpublished)
Beaver	Logging of deciduous trees

Table 38. Some potential threats, as listed by NatureServe, to mammals present or potentially present in NOCA. 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 NOCA (continued).

Common name	Threats (NatureServe)
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 stormwater 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

4.16.5 Information and Data Needs–Gaps

With so little known about the current status and trends of mammal populations in NOCA, it would be valuable to conduct research and monitoring that would improve our present level of knowledge. In particular, studies of wildlife occupancy patterns conducted at a regional scale that includes NOCA would provide important information on the role of the park in sustaining connectivity of mammalian populations and biodiversity throughout the region.Unless there is baseline information on the distribution or abundance of mammalian wildlife populations in the Park and region, it will be difficult to diagnose future changes or to assess the influence of management decisions on those species. We elaborate data needs for several taxa, including opportunities for regional monitoring, in the following sections.

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4.17 Mammalian Carnivores

(Paul Griffin and Kurt Jenkins, U.S. Geological Survey, FRESC)

4.17.1 Introduction

When Europeans first came to Puget Sound, as many as 18 mammalian carnivore species used NOCA lands for at least part of the year. With the exception of the Fisher, all known historically present mammalian carnivore species still are at least occasionally present in NOCA. The native subspecies of Cascade Red Fox that formerly used montane and subalpine habitats has been extirpated, though the non-native lowland subspecies of Red Fox has occasionally been observed. In the context of the greater North Cascades ecosystem, there appear to be self-sustaining populations of Mountain Lions, Black Bears, Bobcats, Coyotes, River Otters, and the smaller predators. Although they have large home ranges, a small number of Wolverines regularly traverse NOCA. There is little documented use of NOCA by the Gray Wolf and Canada Lynx. Even when including lands in British Columbia, the regional population of Grizzly Bears is very low, and their documentation in NOCA is very rare. Fisher reintroduction to the Washington Cascades may occur in the near future.

4.17.2 Approach

The park conducted the first park-wide effort to document carnivore species presence with a statistically valid sample in January to May of 2003 and 2004 (Christophersen et al. 2005), and summer 2005 (Christophersen 2006). Baited, motion-triggered cameras were placed within systematically located 4-mi^2 (10.4-km^2) sampling blocks, but camera sites were limited to locations that were <4 mi (<7 km) from a road and on slopes <25 degrees. We cannot make park-wide inferences about species occurrence patterns because much of the park was out of the sampling frame. In a separate ongoing study aimed to detect bears and Pine Martens, scent-baited barbed wire corrals and baited hair-snagging cubbies are being used to collect genetic samples and photographs along the Highway 20, Highway 2, and Interstate 90 corridors (Long et al. 2012). Although density estimates are lacking for all mammalian carnivore species in NOCA, we interpreted evidence of widespread detections from non-invasive sampling surveys as general evidence of a relatively abundant population. 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 or any guarantee of population resilience in the face of future stressors, such as climate change.

We referred to available georeferenced wildlife observation card records on file at NOCA, which provide some measure of carnivore distribution, although the locations sampled by observers are likely to be biased in favor of roads, trails, and park facilities, and observer reliability is unknown in many cases. This database is the result of unquantified detection, reporting, and recording rates, so a lack of observations in that database should not be interpreted as absence. We also had to weigh the validity of observations in this database with some caution; we generally followed guidelines from Aubry and Houston (1992) in ranking the reliability of different reported sightings, for example with more weight ascribed to a photo than to a report of a track or scent. We also reviewed available published literature, museum records, and any unpublished reports provided to us. Where possible, we summarize the status and trend of each mammalian carnivore species in Table 36 (4.16; species scientific names are presented in the table).

4.17.3 Reference Conditions and Comparison Metrics

The reference condition for mammalian carnivore populations is the Minimally Disturbed Condition, which refers to the condition of a resource in a landscape with minimum human disturbance. 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 Northern Cascades.

4.17.4 Results and Assessment

Mammalian carnivore species diversity in NOCA is high today compared to most of the United States, but it is lower compared to the reference condition. Moreover, some extant carnivore populations in NOCA appear to be less viable than at the time of first contact with European-Americans. 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 (Christophersen et al. 2005, Christophersen 2006), we cannot make any firm conclusions about trend. Nonetheless, there is some suggestive evidence from which to make some inference about trend for some species. We find 4 species that may be in a recent decline, 5 species that may be recently increasing, and 9 species for which we cannot make any inference about population trend.

Species With Some Evidence Suggesting Recent Or Historical Population Decline

Fisher—Fishers appear to be extirpated from NOCA, or if they are present they are exceedingly rare. Before Fishers were reintroduced to Olympic National Park in 2008, the Washington Department of Fish and Wildlife concluded in 1998 that Fisher no longer occurred in Washington (Lewis and Stinson 1998). WDFW sampling leading to that conclusion included lands around, but not within, NOCA. There were 4 Fisher observations in the NOCA database from 1999–2001, but these were not documented with photos. No Fishers were detected by Christophersen et al. (2005) and Christophersen (2006), nor were any photographed or genotyped in the North Cascade ecosystem in 2009–2010 (Long et al. 2012).

Red Fox—The native subspecies, Cascade Red Fox, may be extirpated; it was not detected in large-scale Wolverine and Canada Lynx detection efforts in the region (Sacks et al. 2010). Cascade Red Foxes are still found in the southern Cascades (in the ecosystems around Mount Rainier National Park and Mount Adams). The non-native lowland subspecies of red fox was introduced to the Pacific Northwest and is now widespread in low elevations (Aubry 1984). Recent red fox sightings in the NOCA wildlife database are limited to lowland locations in the Skagit and Stehekin valleys; these are most likely of the non-native subspecies.

Canada Lynx—The eastern portions of NOCA are part of the Okanogan lynx management zone (LMZ), the largest in Washington. Lynx populations in the region probably depend on immigrants from further north in British Columbia (Stinson 2001). Lynx have been noted on wildlife observation cards in the Stehekin valley and along highway 20. Recently, Lynx were detected with remote cameras in the Hozomeen area, near the US/Canada border during the winter of 2011/12 (R. Christophersen, NOCA, pers. comm.). Lynx populations in the Okanogan LMZ have declined since the 1970s, and were estimated at 50 individuals in 2001 (Stinson 2001).

Grizzly Bear—Grizzly Bears are rarely seen in NOCA; the October 2010 sighting at the Upper Cascade River watershed was a Grizzly Bear, the first confirmed sighting in the US portion of the ecosystem since 1996 (IGBC 2011). An individual grizzly bear was confirmed approximately 15 miles outside of NOCA in BC's EC Manning Provincial Park in 2010 (photograph) and 2012 (DNA, photograph) (AN Hamilton, Ministry of the Environment, pers. comm.).The park complex comprises approximately 11% of the North Cascades Ecosystem grizzly bear recovery zone (USFWS 2011). Long et al. (2012) reported no genetically detected hair samples in 2009–2011.

Species For Which Some Evidence Suggests Population Is Stable Or Increasing From Low Numbers

Gray Wolf—Once common, wolves were rarely seen in Washington from 1946 to 1988, but lone wolves or small groups were documented in the North Cascades in the 1990s (Wiles et al. 2011). As many as 9 wolves were in the 'Lookout' pack in Okanogan County, which bred in 2008–2009. Illegal killing seems to have reduced the Lookout pack. Scat, tracks and photos documented 2 wolves at Hozomeen on Ross Lake in late 2010 and winter 2011. Furthermore, tracks of at least 3 wolves were photographed, side by side, during early spring 2012 in the Hozomeen area (R. Christophersen, NOCA, pers. comm.). These wolves are likely part of a pack that dens in British Columbia, but potentially from a pack east of the park. The State recovery plan for wolves calls for at least 4 wolf packs in the Northern Cascades region (Wiles et al. 2011), and the trajectory for this species appears to be increasing on the whole statewide. The region near NOCA is well positioned for wolf population increase, because of proximity to British Columbia sources and wolves colonizing from northern Idaho and Eastern Washington.

Black Bear—Black Bears are widespread and common. Christophersen (2006) detected Black Bears at nearly every sampling block visited, and Black Bear hair was collected at most of the hair corral sites visited in the park and nearby National Forests (Long et al. 2012). Numbers of Black Bears harvested in the management unit including NOCA generally increased from 2001–2010 (WDFW 2011).

Pine Marten, Ermine, Spotted Skunk—These species were detected regularly in NOCA (Christophersen et al. 2005) and throughout the North Cascades (Long et al. 2012). Marten were recorded at 30 of 50 4-mi^2 (10.4-km^2) sampling blocks of the carnivore inventory (Christophersen et al. 2005, Christophersen 2006), and have also been observed throughout the park. Spotted Skunk were found in the Skagit watershed. Ermine were detected in the Skagit and Stehekin watersheds, and have been recorded by observers broadly throughout the park (Christophersen et al. 2005).

Species For Which Evidence Of Any Change In Status Is Ambiguous

Wolverine—A small population of Wolverines inhabits the North Cascades, including NOCA lands. Individual Wolverines ranged widely in the North Cascades of Washington and southern British

Columbia; 1 home range was approximately as large as NOCA. Seven or more GPS-collared Wolverines used NOCA lands to varying extent from 2007–2012 (Aubry et al. 2012). One wolverine captured (but not collared) east of the park in 2012 was later confirmed by photograph and DNA west of the park, the westernmost documentation of a Wolverine in 18 yrs (R. Christophersen, NOCA, pers. comm.). An additional Wolverine was confirmed in 2012 by photograph and DNA southwest of the park (Long et al. 2013). These westside detections may suggest an even broader range than that previously confirmed by the USDA Forest Service project, whose trap sites are east of the park. Despite their confirmed low level of presence, Wolverines were not photographed in NOCA by Christophersen et al. (2005), Christophersen (2006), or Long et al. (2012). However, during 2012 a successful reproductive den site was located in the park, with a second just northeast of the park, the first 2 documented Wolverine reproductive dens ever located in Washington (Aubry et al. 2012).

Mountain Lion, Bobcat—Both species of large cats have been noted on wildlife observation cards, especially in lower elevation areas near roads and trails. Both species have a wider distribution, as evidenced by detections at higher elevations (Christophersen et al. 2005). Cougar harvests in the game management unit including NOCA declined from 2000–2010 (WDFW 2011), but that trend may or may not correlate with population size or use of lands within NOCA.

River Otter—Otter sightings in the NOCA wildlife database are fairly common along the Skagit, including Ross Lake and Diablo Lake, and in the Stehekin watershed, but there is no general evidence of population trend.

Mink, Raccoon—Both species are noted in the NOCA wildlife database, with observations along low elevation floodplains in the Skagit and Stehekin watersheds. Their distributions may be more widespread, as suggested by the Raccoon observation in the Chilliwack watershed (Christophersen 2006).

Coyote—Coyotes have been recorded near Stehekin (Christophersen 2006) and Diablo Lake (NPS blog 2009), as well as in Boston Basin near Cascade Pass in 2011 and in the Lower Stehekin Valley in 2012 (Christophersen, NOCA, pers. comm.).

Long-tailed Weasel—The species is likely to occur, but is not well documented in NOCA, and was not noted by Christophersen et al. (2005) and Christophersen (2006).

Striped Skunk—Striped Skunks are associated with low elevation habitats, and are a common human commensal in suburban and exurban areas. They appear to be at least occasionally present in the Stehekin Valley, which GIS modeling found to be in the peripherally acceptable zone of the Striped Skunk range, but outside of the acceptable range for Spotted Skunk (Johnson and Cassidy 1997).

Species not Considered Native to NOCA Lands But That Have Been Noted

Badger—We do not include American Badger (*Taxidea taxus*) as a species that would have been present historically in NOCA. Badgers are associated with interior steppe and grassland habitats of eastern Washington. We ascribe low weight to the 1 report of a Badger as having been seen by a visitor at Newhalem, near the Skagit River.

4.17.5 Information and Data Needs–Gaps

It would be possible to test for temporal trends in the occupancy rate of surveyed species in NOCA if the methods used by Christophersen et al. (2005) and Christophersen (2006) were repeated. 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.

Radio-telemetry based studies that identify corridors and important habitat features for carnivores at the regional scale would be useful in focusing interagency conservation strategies. For example, the ongoing interagency Wolverine study (Aubry et al. 2012) is providing information about what lands in the surrounding region are important for supporting Wolverines within NOCA. Similar studies would be useful in demonstrating landscape connections for Gray Wolves, Canada Lynx and, Grizzly Bears if there were sufficient numbers of animals to support a study.

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4.18 Hoary Marmot and American Pika

(Paul Griffin and Kurt Jenkins, U.S. Geological Survey, FRESC)

4.18.1 Introduction

Hoary Marmots (*Marmota caligata*) are large (up to ~10kg [22 lbs.]), highly social, burrowing ground squirrels that live almost exclusively in subalpine meadows, particularly in meadow habitats with sufficient soil development for their burrow systems. They are found in the Cascade Range, Rocky Mountains, and other mountains of Washington, Idaho, Montana, Alaska, and western Canada. Hoary Marmots are active in late spring and summer, hibernating 7–8 months/yr. Demography of 2 closely related species, the Olympic Marmot and Vancouver Island Marmot, has been intensively studied due to concern over population declines in those species (Bryant and Page 2005; Griffin et al. 2008).

American Pika (*Ochotonoa princeps*) are small (~175g [0.4 lbs.] relatives of rabbits, making their dens in rocky talus near suitable vegetation. American Pika are found throughout the mountainous western U.S., British Columbia and Alberta; the subspecies in NOCA (*O. p. fenisex*) occurs in British Columbia, Washington, and Oregon (Hafner and Smith 2010). Unlike marmots, pika do not hibernate. Rather, they store conspicuous 'haypiles' of drying vegetation during summers to provide winter food. Although there is concern over the effects of warming temperatures on both the habitat and physiology of pika, the USFWS recently concluded that listing pika as endangered or threatened was not warranted (USFWS 2010).

Subalpine meadow and talus field habitats of marmots and pika are distributed patchily throughout high elevation mountain ecosystems. Talus fields tend to be larger and more common at high elevations. Populations of both marmots and pika are generally interpreted in the context of metapopulations in which the larger population comprises several local populations limited by habitat distributions. Individuals move and interact frequently within local populations, but far less often between local populations (Moilanen et al 1998, Griffin et al. 2008). In both species, the number of individuals in the local population is influenced by the area of available habitat (meadow or talus patch). Local populations may increase or decrease in abundance independent of other local populations. The larger-scale metapopulation can persist in a dynamic equilibrium so long as unoccupied habitats are recolonized and grow at comparable rates as other local populations decline to zero. The metapopulation as a whole may decline severely, though, if habitats shrink or become more isolated, or if there are range-wide stressors that cause many local populations to decline all at once.

4.18.2 Approach

Christophersen (2013) conducted baseline surveys of Hoary Marmot distribution in NOCA. Surveys were limited to points along trails, above 1219 m (4000 ft) elevation, in meadow habitats. Out of 131 randomly selected origination points, spaced 1 km (0.6 mi) from each other, 31 were surveyed. Surveyors conducted 30 minute point counts at the origination point, and at 2 to 9 other points located sequentially on a trail, and spaced 400 m (1312 ft) between points. Each survey site comprised the origination point and associated points. The total number of marmots at each site was the sum of those seen at all the points. Surveyors counted the minimum number of marmots at any colony, though the true number was unknown because individuals can be difficult to differentiate, and some may have stayed underground. Christophersen (2013) modeled the counts as a function of elevation, meadow area, and spatial position east or west of the Picket Crest and Cascade Crest. Twelve sites were resurveyed once or twice in 2008.

Bruggeman (2010) examined distribution of the American Pika in NOCA. He created a systematic grid of all 1-km^2 (0.4-mi^2) sampling cells in NOCA that were within 3 km (1.9 mi) of a road or trail. He randomly selected a sample of cells from 15 strata classified by elevation and position relative to the Picket Crest and Cascade Crest. This sample frame allowed for inference to ~65% of the park, which did not include areas far from trails, such as the central Picket Range. Within each sampled cell pika were counted in all the 1-ha (2.5-ac) patches that included talus habitat, and summed. Bruggeman (2010) modeled the counts as a function of elevation, total talus perimeter /km^2, subsurface temperature in talus patches, and spatial position east or west of the Picket Crest and Cascade Crest. Eight of 30 sites were resurveyed once or more.

4.18.3 Reference Conditions and Comparison Metrics

The reference condition for Hoary Marmots and American Pika is the Minimally Disturbed Condition, which refers to the condition of a resource in a landscape with minimum human disturbance. For these species, this condition would be characterized by a persistent, viable metapopulation at the larger scale of NOCA, and the surrounding mountainous landscape. At smaller scales, local population dynamics in suitable subalpine habitats would include marmot colony persistence, local extinction, and colonization, all influenced by interactions between marmots, climate, forage availability, and predation.

4.18.4 Results and Assessment

A total of 242 Hoary Marmots were detected at 19 of 31 surveyed sites, with 1 to 25 marmots counted at occupied sites. Thus, Hoary Marmots appeared to be widespread in subalpine meadow habitats (Figure 28). Christophersen (2013) did not estimate total marmot abundance in NOCA because such an estimate would be prone to bias from the effect of distance on detection probability, and any sampling bias in the selection of origination points on trails. Christophersen (2013) concluded that detection rate at occupied sites was high. Two sites where marmots were seen in the first 2008 survey, though, had no marmots observed in September 2008. It appears that detection rate at occupied sites may be low in September; perhaps because some marmots were in hibernacula. Using the maximum distance from the point center that marmots were detected (484 m [1588 ft]) as a radius around each visited point, Christophersen (2013) concluded that 48.3 km^2 (18.6 mi^2) were surveyed, representing approximately 9% of the ~490 km^2 (189 mi^2) of subalpine meadow area in NOCA. The number of animals seen, though, probably represented results from a smaller effectively sampled area, considering that ~75% of the detections were within 200 m (656 ft) of the point center.

American Pika were widespread and numerous across the sample frame in NOCA. Bruggeman (2010) found pika at 27 of 30 1-km^2 cells, with from 1 to 101 pika in occupied cells. Pika were found in talus from 351 to 2130 m (1152 to 6989 ft) elevation. Density per 1-ha patch, and per km^2 cell peaked at mid-elevations (from 1219–1523 m [4000–4997 ft]). Pika abundance per 1-ha patch declined as sub-surface temperature increased. All 8 areas visited more than once had pika detected on every visit, indicating that per-visit detection rate was high. Adjusting for the sampling rate in each stratum, and assuming 100% detection rate, Bruggeman (2010) estimated a total population of 22,279 pika (95% confidence interval from 6706 to 37,852) in the portion of NOCA within 3 km of a trail.

Both Hoary Marmots and American Pika appear to be widespread and numerous in NOCA. Although both surveys provide a baseline for assessing future trends in species occupancy patterns, it is not possible to assess current population trends for either species. Changes in climate, predicted to diminish snowpack and expand forests at treeline, may adversely affect both species in the future.

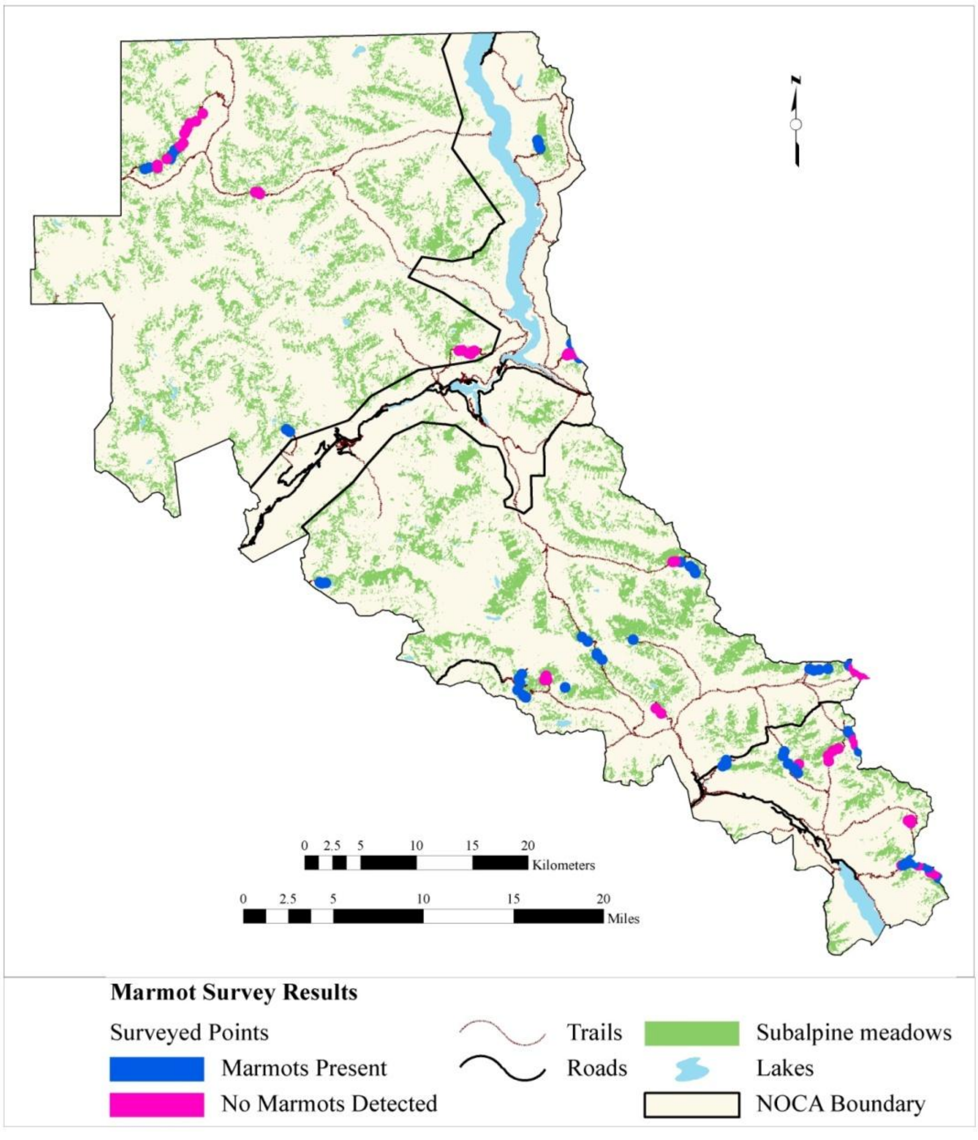

Figure 28. Distribution within NOCA of ~489 km2 of potential marmot habitat (green), defined as subalpine meadow habitats. Surveyed points are indicated where marmots were detected (blue) or were not detected (pink). Each surveyed point is buffered with a 484 m radius to reflect Christophersen's (2013) assumption about detection distances. Surveys were limited to areas accessible by trails.

4.18.5 Emerging Issues

Subalpine wildlife species are likely to be sensitive to climate change (Krajick 2004). Pika, in particular, have become emblematic of the risks of climate change to wildlife (NPS 2012). Some pika populations at warm low elevation sites (i.e., in the Great Basin) may be threatened directly by increased temperatures (USFWS 2010). Both marmots and pika are poor thermoregulators; on hot days, they need access to cool burrows or dens. Effects of changing snow pack may pertain to NOCA, but are less straightforward. Snowline is expected to rise in elevation, with more rain and less snow in the mid-elevations of the Cascade Range (Minder 2010). A lack of winter snowpack could directly cause local pika extirpations because a blanket of snow insulates pika dens from colder winter temperatures (Beever et al. 2010). Decreased snowpack in late spring does not appear to affect adult over-winter mortality in Olympic Marmots (Griffin and Taper, in review), but it may foster easier access for predators to juvenile marmots in the summer (Griffin and Taper, in review).

The future viability of marmot and pika populations will be influenced by changes in the amount and distribution of habitat; a warming climate will tend to raise treeline, reducing the size of subalpine meadows. Populations will also be affected by changes in birth and death rates resulting directly from changes in climatic conditions, by changes in the abundance, distribution, and hunting success of predators, and by management actions which could influence dispersal, survival or habitat availability.

4.18.6 Information and Data Needs–Gaps

Although both surveys provide a useful baseline for future comparisons, the data necessary to determine current population status or trends of marmots or pika are lacking. Repeat surveys based on methods used by Christophersen (2013) and by Bruggeman (2010) would be useful for monitoring future changes in species occupancy patterns, although the sample sizes of surveyed sites should be reconsidered, depending on the desired monitoring goals of the NPS. Future marmot surveys could make inferences about marmot abundance and trend in the sample frame if they account for detection probabilities through the use of distance sampling analysis (Buckland et al. 2004). Expansion of the sampling frame to include all potential habitats of marmots and pika, although more costly, would permit parkwide inference.

Bruggeman (2010) found that repeat surveys would have adequate statistical power to detect a 50% decline in the pika population, but that the sample size of surveyed 1-km^2 cells should be increased for the lowest 2- and the highest of the 5-elevation strata. Determining what sampling rate and frequency of monitoring would be adequate to detect long-term trend in the larger marmot population is outside the scope of this assessment, and would require a power analysis including a range of assumptions about rates of colony creation, local extinction, and persistence.

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4.19 Bats

(Paul Griffin and Kurt Jenkins, U.S. Geological Survey, FRESC)

4.19.1 Introduction

NOCA, with extensive old growth forests close to lakes, streams, and rivers, provides valuable habitat for bats. 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 Fringed Myotis, 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 over open areas and water features, where flying insect are abundant and where bats obtain water (Hayes 2003).

All of the 12 bat species (scientific names are presented in Table 36, 4.16) that may use NOCA are insectivores that either hibernate or migrate away from NOCA in winter, when insect prey are not available. Townsend's Big-eared Bat, Big Brown Bat, and the 7 Myotis species are thought to be year-round residents, short-distance migrants, or elevational migrants. Bats that migrate long distances to and from wintering grounds include the Hoary Bat and Western Red Bat. If the Western Red Bat occurs in NOCA, it is extremely rare. Silver-haired Bats are generally long-distance migrants (Kunz 1982), but at least some in the Pacific Northwest hibernate (Nagorsen et al. 1993).

Bats typically have a 'slow' life history (K-selected), with high adult survival and low reproductive rates (Barclay et al. 2004). Consequently, reduced adult survival can cause rapid declines in the overall populations. 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. Land managers take measures to prevent humans from disturbing hibernating bats (i.e., installing gates at mine and cave entrances), because bats that awake from torpor use critical fat reserves. Compared to some regions of the United States, there are relatively few natural caves in the North Cascades where large numbers of bats could roost, but there are inactive mines in Washington (Norman 2000) and British Columbia (Day and Harpley 1992). Boulder Cave in the Wenatchee National Forest is a popular tourist destination that is also a known winter roost (hibernaculum) for Townsend's Big-eared Bats, a state and federally listed species of special concern. Out of concern over White Nose Syndrome (WNS) (see Emerging Issues, below), the U.S. Forest Service has closed all caves and abandoned mines on its lands in the Rocky Mountain and Northern regions.

4.19.2 Approach

We reviewed a baseline survey conducted in NOCA (Christophersen and Kuntz 2003) and available literature and reports pertinent to the surrounding area. We reviewed available bat evidence surveys conducted by Washington DNR in abandoned and inactive mines within ~10 km (6.2 mi) of NOCA. Species detection data collected by the interagency Bat Grid Inventory and Monitoring Group (Pat Ormsbee, USFS, Oregon, pers. comm.) on nearby US Forest Service lands were not yet available for us to review; that group does not currently survey NPS lands. Christophersen and Kuntz (2003) used acoustic sampling and capture techniques to survey for bats at 32 sites in NOCA. Sites were in 3 habitats (riparian, forest, subalpine) and 2 positions relative to the Cascade Crest (east, west).

Elevations sampled ranged from 159–1685 m (522–5529 ft). The methods were appropriate for documenting presence and relative frequency of the bats detected, but not population abundance.

4.19.3 Reference Conditions and Comparison Metrics

The reference condition for all bat species is the Minimally Disturbed Condition, which refers to the condition of a resource in a landscape with minimum human disturbance. For these species, this condition would be characterized by persistent, viable populations of those species that breed and hibernate within the North Cascades region (including all the locally occurring Myotis species, Townsend's Big-eared Bats, Big Brown Bats, and some Silver-haired Bats), and of species that migrate to and from landscapes outside of the North Cascades ecosystem (Hoary Bats, Western Red Bat, and some Silver-haired Bats).

4.19.4 Results and Assessment

It is not possible to make park-wide conclusions because the sample frame in Christophersen and Kuntz (2003) included some intentionally located and some randomly located points. At the sites sampled, however, the Little Brown Bat and Yuma Myotis were consistently the most commonly detected species. Based on frequencies of recorded calls and of captures, Little Brown Bats appeared to be the most prevalent species in forest habitats, while Yuma Myotis appeared the most prevalent in riparian habitats. California Myotis was also fairly common, but was not detected in subalpine habitats. Other fairly commonly detected species were Western Long-eared Bat, Big Brown Bat, and Silver-haired Bat. Long-legged Myotis and Hoary Bat were detected in NOCA, but were relatively rare. Four species not detected included Townsend's Big-eared Bat, Western Small-footed Myotis, Fringed Myotis, and Western Red Bat.

Christophersen and Kuntz (2003) found greatest bat diversity and relative abundance in riparian habitats. Luszcz (2001) found the highest level of bat activity in cottonwood-associated riparian areas, and Duke Engineering (2000) noted greatest bat activity levels where streams entered Lake Chelan. As has been found east of Mount Rainier (Baker and Lacki 2004), male bats appeared more common at higher elevations in NOCA surveys. Directed surveys documented a nursing colony of approximately 1200–1500 Little Brown Bats and Yuma Myotis in a warehouse building at Hozomeen Ranger Station (Christophersen and Kuntz 2003). Of 22 mines within 25 km (15.5 mi) outside of NOCA, surveys at the Azurite (Wolff et al. 2002), Boundary Red Mountain (Wolff et al. 2005a), Lone Jack (Wolff et al. 2005b), Great Excelsior (Wolff et al. 2004), Red Mountain (Wolff et al. 2003), and Holden (Hart Crowser 2005) mines detected no evidence of bats; no bat information was available for 16 other mines within approximately 25 km of NOCA (John Fleckenstein, Washington Department of Natural Resources, unpubl. data).

Nine bat species are known from NOCA, and 3 more (Fringed Myotis, Western Small-footed Myotis, and Western Red Bat) may use NOCA at least occasionally (Table 36: 4.16). During baseline surveys from 1998–2001, 8 bat species were detected, with Little Brown Bat and Yuma Myotis the 2 most frequently detected and captured (Christophersen and Kuntz 2003). Hibernating bat populations in North America face an urgent threat from WNS, a deadly new fungal pathogen that has spread from New York to Missouri in only 6 yrs, killing millions of bats (USFWS 2012). U.S. Forest Service, BLM, and the Department of Defense are cooperating in a Pacific Northwest regional bat monitoring network (Rodhouse et al. 2012); precision of trend estimates for the North Cascades would be improved by sampling in NOCA.

4.19.5 Emerging Issues

White nose syndrome (WNS) is a disease new to North American bats that has killed millions of hibernating bats in the eastern United States since its effects were first noted in 2006. WNS may cause regional population collapse and extinction of what were formerly the most common bat species (Frick et al. 2010). This disease, already confirmed as far west as Missouri, will almost certainly kill high numbers of hibernating bats when it reaches the western US. 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; humans may carry the WNS fungus from cave to cave on clothing or gear used in caves where WNS is already present.

Bats that migrate long distances, such as Hoary Bats and Western Red Bats, may not be as susceptible to WNS because they do not hibernate, but they may be at the greatest risk of collision and trauma from wind turbines (Arnett et al. 2008). Although at this time the nearest large turbine facility is in Kittitas County, there are others in Klickitat County. At least some Silver-haired Bats in the vicinity of NOCA hibernate putting them at risk of WNS, while those that migrate may be at risk from wind turbines.

Heat and water stress may affect bat reproduction (Adams and Hayes 2008). Climate change is expected to cause warmer, drier summers in the Pacific Northwest (Mote et al. 2005). If climate change reduces populations regionally, bat populations in the North Cascades ecosystem would likely be affected.

4.19.6 Information and Data Needs–Gaps

It will be impossible to detect any changes in bat resources unless there is an improved understanding of bat abundance in the North Cascades. The interagency Bat Grid Inventory and Monitoring Group (Rodhouse et al. 2012), currently supported by the U.S. Forest Service, BLM, and Department of Defense and other agencies and groups, is the only existing program that is structured to gauge bat populations in the Pacific Northwest. Bat Grid sampling took place near Mt. Baker in 2011, but inference to NOCA would be improved by cooperative sampling within the park.

Virtually any studies on the ecology of bats in the North 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 for 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 the Hoary Bat and Silver-haired Bat are not well known in this area, and it would be useful to know what wind turbine facilities pose risks to migratory bat species that use NOCA. It would also be useful to use telemetry or bio-trackers on NOCA bats to enhance understanding of migration patterns and landscape-level threats to migration.

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4.20 Glaciers

(Jon Riedel, National Park Service, NOCA)

4.20.1 Introduction

Glaciers are significant features at NOCA, covering more than 109 km^2 (42 mi^2) and having a combined volume of 9.3–10.1 km^3 (2.2–2.4 mi^3) (Granshaw 2001). Relatively small, temperate glaciers are valuable as sensitive, dramatic indicators of climate change (Figure 29), and host 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 the Gray-Crowned Rosy Finch (*Leucosticte tephrocotis*) and other alpine species. Glaciers are also valuable to NOCA, downstream municipalities, and regional ecosystems and industries because they provide vast quantities of cold, fresh melt-water during the hot, dry summer months (Meier 1969, Fountain and Tangborn 1985). Ice falls, sudden releases of glacial melt-water, and massive, unstable piles of loose glacial sediment represent hazards to park staff and visitors (Walder and Driedger 1995). During extreme rain events and glacial outburst floods, streams can incorporate enough of this sediment to become debris flows (Scott et al. 1995).

The importance of glaciers as hazards, habitat, indicators of climate change, and timely providers of cold, fresh water led the NPS to initiate a monitoring program at NOCA in 1993. The focus of this effort is on seasonal measurement of glacier accumulation and melt (mass balance) at 18 points on 4 glaciers, and decadal measurement of the extent of glaciers park-wide (Figure 30). These measurements and complimentary research form the basis of this natural resource condition assessment.

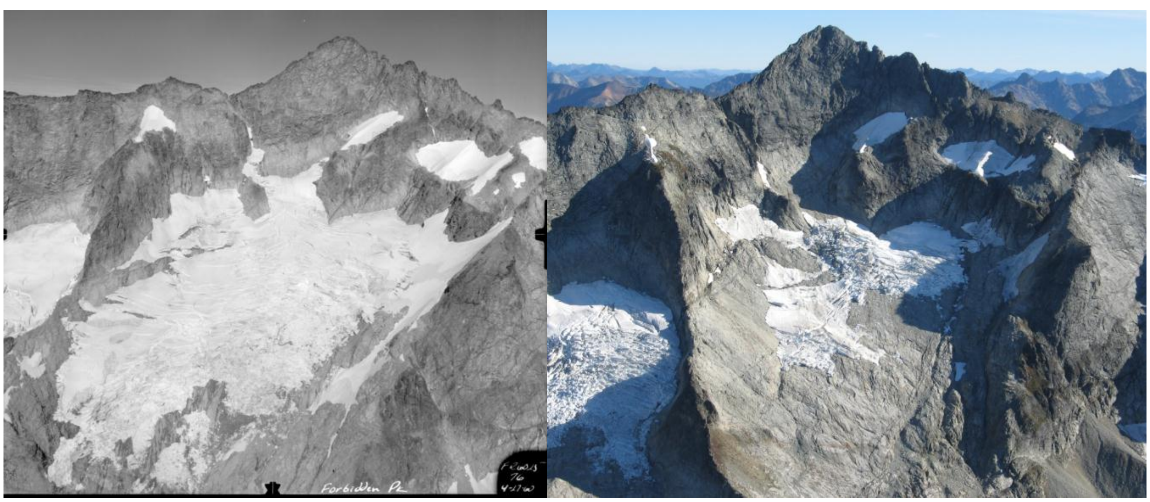

Figure 29. Comparative photos of glaciers on Forbidden Peak, NOCA, at left in 1960 (Austin Post) and at right in 2005 (John Scurlock).

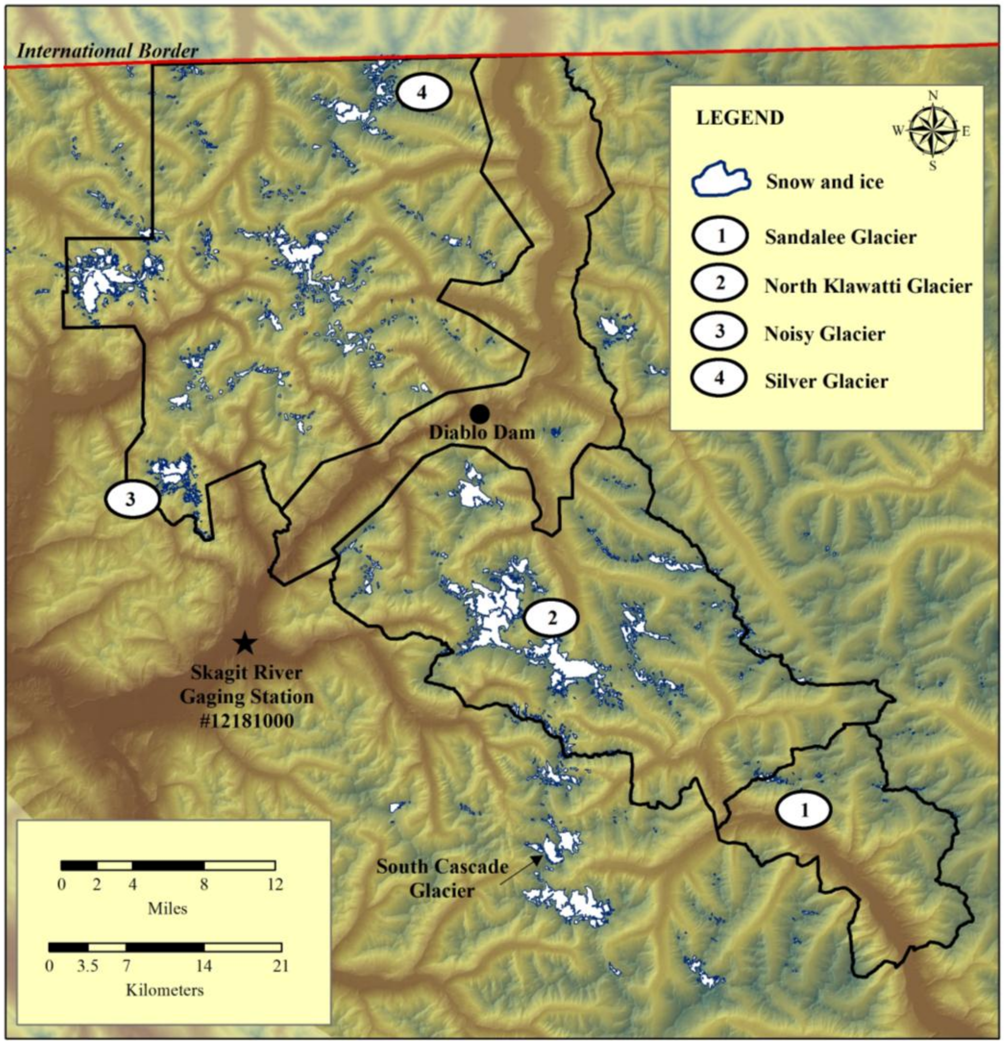

Figure 30. Glaciers monitored in and near North Cascades National Park Service Complex.

4.20.2 Reference Conditions and Comparison Metrics

Two main indicators of glacier status and trends are used in this assessment, including the park's total glacier area and the mass balance of 4 index glaciers. Glacial extent was chosen because it can be determined accurately from aerial photographs, and there are several published surveys. 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 indicator sensitivity to the primary climate stressors.

Post et al. (1971) provide a baseline ice extent for NOCA that was re-measured by several others at various times (Table 39). Additional reference is provided by estimates of glacier extent in 1900 A.D. from a NPS surficial geology mapping program. This effort made use of unpublished maps drawn by Austin Post of the U.S. Geological Survey that covered some areas of the park. Granshaw

(2001) estimated the error in his comparison of glacier area change from 1958 to 1998 was ±1 km^2 (<1%).

Mass balance trends were identified by examining the cumulative net mass balance of the monitored glaciers since 1959. Cumulative net mass balance is based on standardized seasonal measurements of winter accumulation and summer melt at 4 or 5 fixed locations on each index glacier (Riedel et al. 2008). Point measurements are averaged across the glacier surface to determine annual net mass balance, which is used to determine cumulative net mass balance by simply adding/subtracting the net balance from year-to-year. The 4 index glaciers at NOCA represent varying characteristics of glaciers found in the North Cascades, including altitude, aspect, and climate (Figure 30; Riedel et al. 2008). They are located from the wet western slope of the range to the drier, colder eastern side (Stehekin), drain into 3 hydroelectric projects, and represent a 1000-m (3281-ft) range in altitude from the terminus of Noisy Glacier to the top of Silver Glacier.

The error associated with the net mass balance of the 4 NOCA glaciers ranged from ±0.3–0.4 m w.e./year (Riedel and Larrabee, 2011). In a 50-yr period, if all of the errors were of the same sign, this could amount to a large cumulative balance error. Since cumulative balance was largely neutral in 1959–1976 and 1995–2000 (half of the record), the cumulative balance error for each glacier is probably much smaller. Further, surface mass balance measurements tend to under-represent mass loss (cumulative balance) on temperate alpine glaciers (Krimmel 1996), making the cumulative balance record presented below a somewhat conservative estimate.

Table 39. 20th century extent of glaciers at NOCA. Sources include Post et al. (1971) for 1958, Granshaw (2001) for 1998, NPS (unpublished) for 1900, Riedel et al. (2008) for 1993, and Riedel and Larrabee (2011) for 2004–2006. Variability is due in part to scale of mapping and methods; 1993 and 2004–2006 area estimates considered most accurate since they were obtained from large scale stereo photos taken late in the melt season.

Monitored Glacier	1900 A.D. (km^2)	1958	1993	1998	2004–2006
North Klawatti	3.67	1.76	1.52	1.69	1.41
Noisy	1.13	0.78	0.52	0.72	0.44
Silver	2.46	0.84	0.49	0.67	0.44
Sandalee	0.48	0.24	0.20*	0.22	0.18
All NOCA Glaciers	233	116.6	n/a	109	n/a

*Sandalee Glacier mapped in 1995

4.20.3 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 due to a rising freezing level starves a glacier of mass, and warm autumn rains can result in enhanced melting, particularly near the terminus. Together, increased temperature and lower snowfall lead to a decreasing cumulative net mass balance and, played out over decades, a dramatic decline in the extent of glaciers.

Since 1920, average annual air temperature increased 0.8°C in this region, and the last 2 decades are the warmest on record (Mote 2003). Long weather records are available from only 2 low elevation sites within NOCA. The longest records are from Diablo Dam (elevation: 272m; 892 ft) on the west side of the Cascade Range and Stehekin on the east side (elevation: 375 m; 1230 ft). Stehekin is the only site with a record suitable for the U.S. Historical Climate Network and is examined in Chapter 5. While average and maximum annual air temperatures at Stehekin have not changed significantly, minimum annual air temperature has risen and may be leading to a longer daily melt cycle (Chapter 5-Figure 55, this report).

Higher elevation weather records are shorter and less complete than DiabloDam and Stehekin, but indicate that annual (winter) and daily minimum tempeartures in the alpine zone are changing more rapidly than annual average tempearatures at lower elevation sites. Rasmussen and Conway (2001) reported a 3°C increase in average January–March temperature at Blue Glacier in the Olympic Mountains, Washington, from 1948–1998. The change in winter temperature at high elevations is also reflected in the rise of the average winter elevation of the freezing level (see Chapter 5, this report).

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.

Natural climate variability within this region is reflected in the mass balance of glaciers (Bitz and Battisti 1999). Primary sources of climate variability include the temperature of the equatorial (El Nino-Southern Oscillation-ENSO) and the northeastern Osean (Pacific Decadal Oscillation, PDO). The variability in mass balance due to these phenomena is on the order of ±0.5m/yr at South Cascade Glacier (McCabe and Fountain 2013). These events can be identified in cumulative mass balance records where they are expressesed as changes on 2–4 (ENSO) and decadal (20–40 and 60–80 yrs – PDO) timescales (Mantua et al. 1997, Ware and Thomson 2000).

North Cascades Reference Condition

Glacier extent and volume (mass balance) are decreasing rapidly at NOCA. The area covered by all glaciers in the park reached a post ice-age maximum of 233 km^2 (90 mi^2) about 1900 A.D., at the end of the Little Ice Age (Table 39; NPS, unpubl. data). Since that time, glacial area has declined about 53%, which is comparable to adjacent mountain ranges (Figure 31). In the 20th century, glacier area declined about 57% at Olympic National Park (NPS, unpubl. data) and 44% at Garibaldi Provincial Park (Koch et al. 2007). There was no increase in the size of index glaciers between 1993 and 1998; apparent increases shown in Table 39 are due to different resolution and inconsistent methods.

In the last half of the 20th century, between 1958 and 1998, glacier area in the park declined about 8% (Table 39; Granshaw and Fountain 2006). This included periods in 1961–1965 and 1970–1976 when most of the glaciers gained mass, which slowed retreat, but did not lead to glacier expansion. More recently, loss of glacier area has accelerated at the 4 monitored glaciers (Table 39). Comparison between large scale air photos taken in 1993 (1995 Sandalee Glacier) and 2004–2006 indicate the area of Silver Glacier shrunk 16%; while the other 3 glaciers lost between 5.4–8% (Riedel and Larrabee 2011).

In a climate that continues to warm, the future decline in glacier area may not be linear. As glaciers recede to higher elevations and northerly aspects, melt may slow and the relative importance of accumulation by snow drifting and avalanching could increase. However, point measurements on all 4 glaciers (as discussed below) show that these glaciers still have accumaulation zones that are gaining a small amount of mass. Therefore, although the park glaciers are retreating rapidly to adjust to a warmer climate, it seems reasonable to assume that there will continue to be glaciers at NOCA for many decades, at least on northern aspects at higher elevations, and in favorable locations for snow accumulation from avalanches and wind-drifting.

The mass balance record has the same pattern and trend as area changes, but provides a more detailed, continuous, and ecologically relevant record. Glacier mass balance has been monitored since the late 1950s by the USGS at South Cascade Glacier, and since 1993 at 4 other glaciers by the NPS (Figure 30). Data from all 5 glaciers show a strongly negative trend, with most of the loss occurring since the mid-1980s (Figure 32).

Cumulative net mass balance between the 4 glaciers since 1959 varies from –16 to –37 m (–52 to –121 ft) water equivalent (w.e.), which illustrates how each glacier has a unique relationship to climate (Figure 32). Sandalee Glacier is the least negative because it rests on a shaded north aspect at a high elevation, and receives snow from wind drifting and snow avalanching. The more negative values for North Klawatti and Noisy glaciers are due primarily to the low elevation of their termini, and to the east aspect of North Klawatti.

Changes in glacier area combined with mass balance measurements provide estimates of volume change for NOCA glaciers. When cumulative net mass balance of each glacier is multiplied by glacier area, the total volume loss from all 4 since 1959 is 0.10 km^3 (0.02 mi^3) w.e. The range in volume loss varies considerably, however, by glacier size and area-altitude distribution (hypsometry). North Klawatti Glacier lost 0.057 km^3 (0.01 mi^3) of water since 1959, while farther east, smaller, and higher elevation Sandalee Glacier lost 0.003 km^3 (0.0007 mi^3).

If the average cumulative net mass balance of the 5 monitored glaciers of –27 m w.e. is multiplied by the glacier area in 1959, total volume lost by 2011 is 3.1 km^3 (0.53 mi^3). This estimate assumes the monitored glaciers are representative of the entire population of glaciers in NOCA, which is reasonable given that they represent most of the range in glacier elevation (1000 m; 3281 ft), have different aspects, and are located from west to east across the mountains. The 3.1 km^3 loss estimate is much higher than the volume loss of 0.8 ± 0.1 km^3 (0.19 ± 0.02 mi^3) estimated by Granshaw (2001) for the same period. The latter estimate may have a larger error than surface mass balance measurements because it relies on lower resolution, non-georeferenced air photos of glaciers, and because ice volume was determined from the general relationship between glacier area and volume. More accurate measure of total ice volume will remain problematic due to complex sub-glacial topography, access, and accuracy of ice radar on more than 300 small hanging and cirque glaciers.

Loss of volume for NOCA glaciers is taking place primarily at lower elevations where air temperature is warmer (Figure 33). For example, at North Klawatti Glacier the cumulative balance since 1993 at stakes 4 and 5 are –40 and –50 m (–131 and –164 ft) w.e., respectively. Balance at the upper 3 stakes is slightly positive for the past 19 yrs, but has not been sufficient to offset the massive loss of ice at lower elevations (i.e. cumulative net mass balance for this glacier is –16 m [–52 ft] over the same period).

Due to the rise of glacier mean altitudes across a gradient from wet maritime to dry continental climates (Post et al. 1971), the loss of glacier mass is occurring at a higher elevation on the east slope of the North Cascades. Most glacier losses are occurring at elevations of <1800 m (<5906 ft) in the Noisy Glacier area, below 2100 m (6890 ft) in the Thunder Creek-Ross Lake area, and below 2300 m (7546 ft) on the east side of the park. Above 2500 m (8203 ft) the trend in cumulative balance on Silver Glacier is slightly positive (Figure 34), even though winter accumulation on Silver Glacier is decreasing at all elevations. Reasons for the net growth at the top of this glacier include its north aspect, wind accumulation of snow, and lower melt rates at a high elevation. Unfortunately, very little of the glacier is above the zone of positive accumulation, and Silver Glacier will therefore continue to shrink as it adjusts to the modern climate.

The negative cumulative net mass balance trend at NOCA glaciers has been punctuated by periods of positive balance in 1961–1965, 1970–1976, and 1997–2002 (Figure 32). These periods of net mass gain are a feature of the region's climate variability associated with the cool phase of the PDO (cooler temperatures result in lower snowline and less melt) or the La Nina phase of ENSO (higher winter accumulation; Bitz and Battisti 1999). During the past 50 yrs, the short duration of these positive mass balance events has not led to a reversal of the longer-term trend of volume loss. Recent analysis of benchmark glacier mass balance records led Josberger et al. (2007) to suggest that the correlation between winter balance and the PDO is getting weaker.

Warmer air temperatures are driving the strongly negative trends in glacier area and mass balance at NOCA in several ways. Warmer temperatures increase the summer melt rate (Figure 35) and length of the summer melt season, at the expense of accumulation season length. In fall and winter, warmer temperatures bring higher freezing levels and rainfall on the lower parts of glaciers. Rainfall may not accumulate on the glacier if there is no significant pre-existing snowpack, and can cause significant melt events.

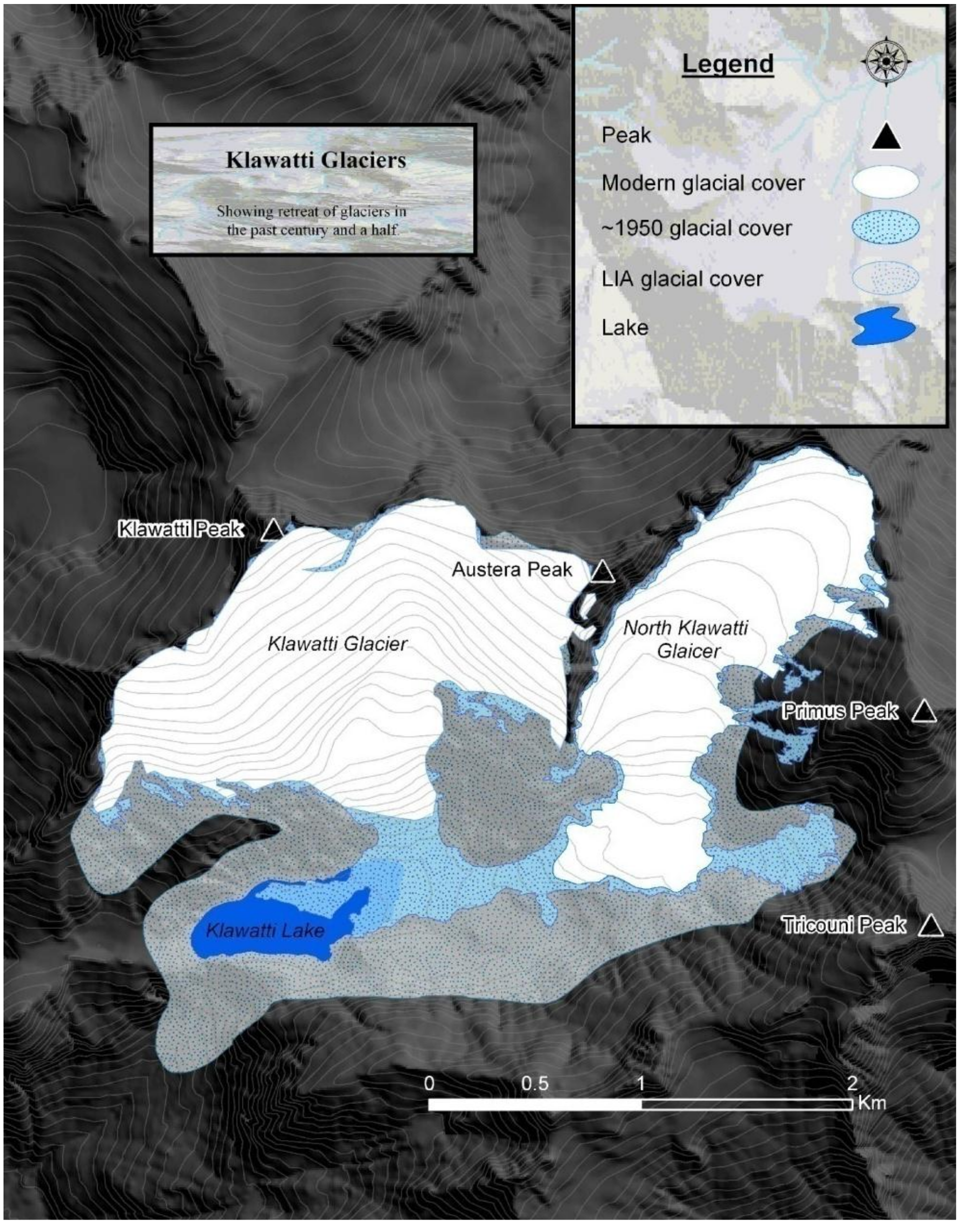

Figure 31. Change in extent of North Klawatti Glacier, 1900–1998.

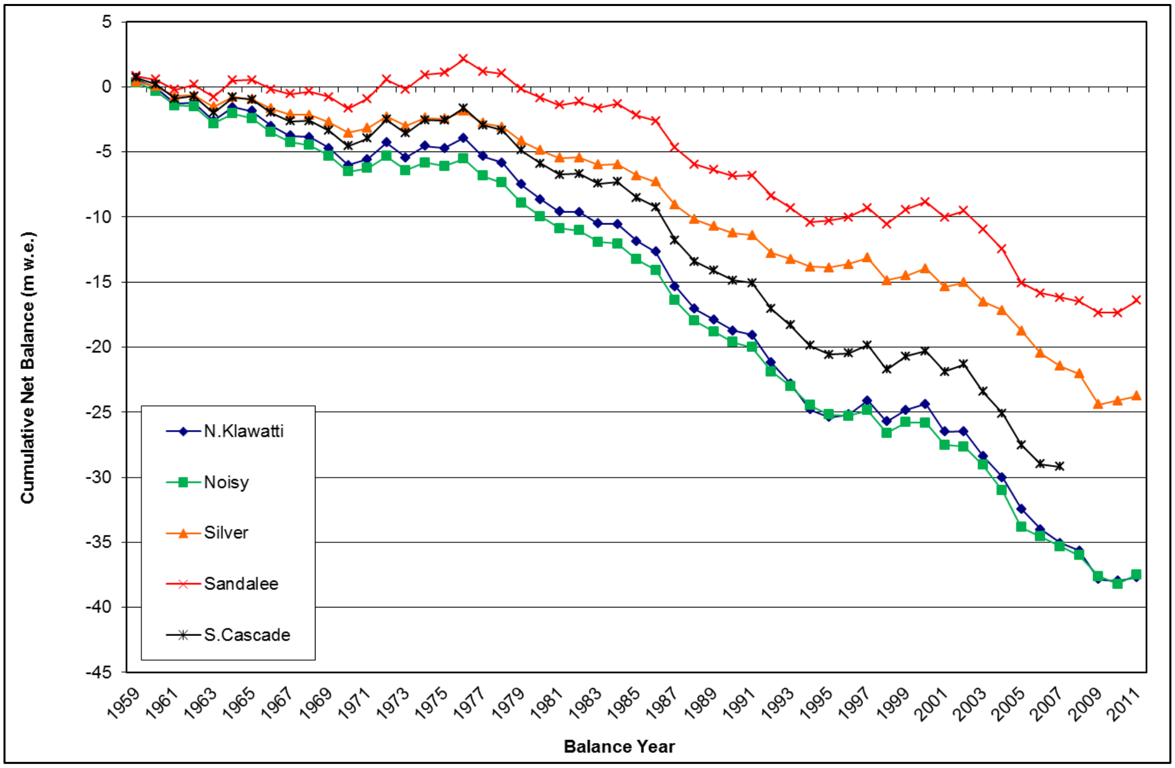

Figure 32. Cumulative net mass balance of 5 glaciers in the North Cascades mountains. Data for pre-1993 cumulative balance for NOCA glaciers by Granshaw (2001).

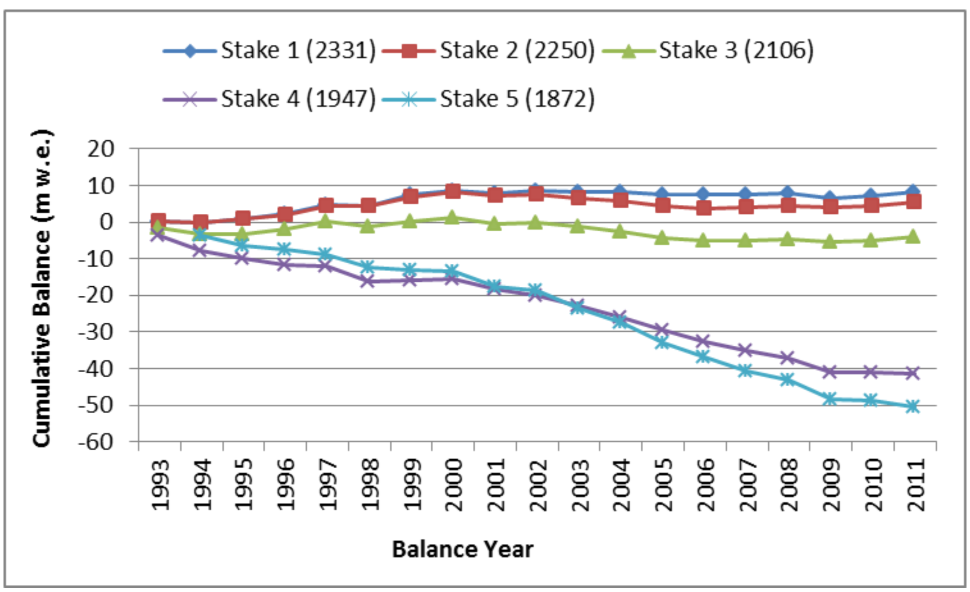

Figure 33. Cumulative balance by stake (elevation in meters) for North Klawatti Glacier.

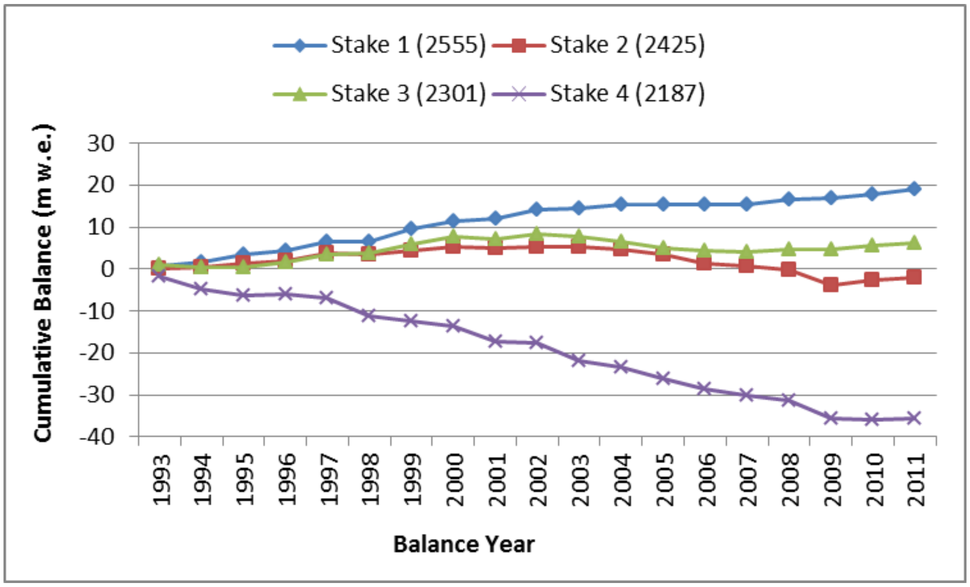

Figure 34. Cumulative balance by stake (elevation in meters) for Silver Glacier.

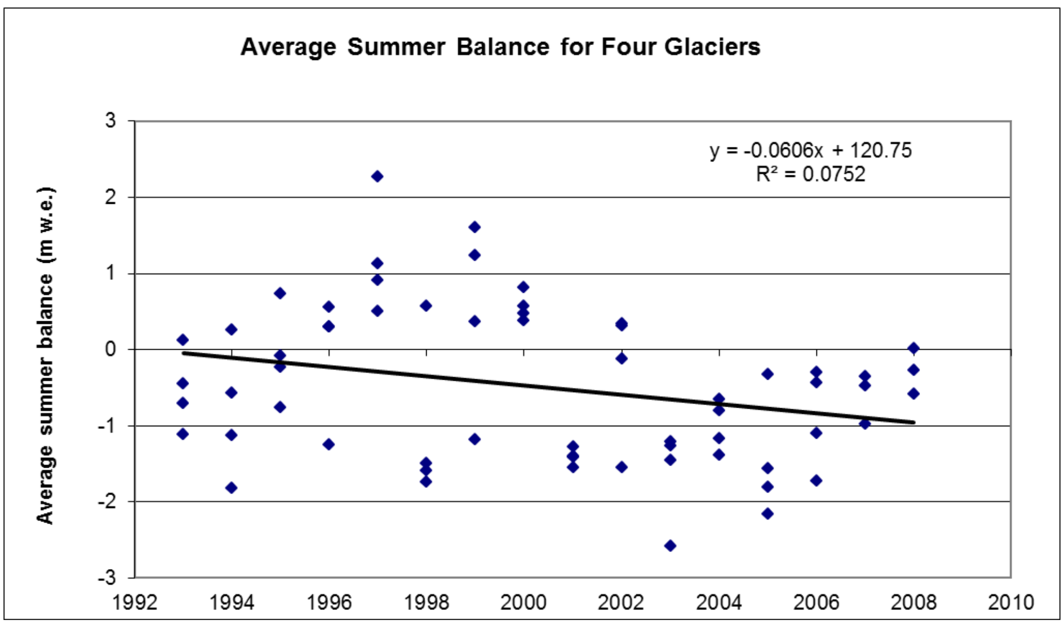

Figure 35. Increase of summer melt rate for 4 glaciers at NOCA; each diamond represents a glacier's net melt of a glacier averaged from 4–5 stakes for a given summer. Dark line is trend.

4.20.4 Emerging Issues and Data Needs–Implications for the Park

There are several management implications for the observed recent and projected future decline of glaciers at NOCA in a 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 change that are invaluable public education assets. Figure 29 is but 1 example of how glaciers are helping the public value parks as places to recognize and understand impacts of climate change. Glacier mass balance measurements are sensitive enough to provide a clear context for understanding the role of climate variability in a warming climate. For example, cold wet periods in the last 50 yrs led to short-term increases in glacier volume, but did not reverse the 50-yr trend in rapid volume loss or lead to expansion of glaciers.

With the strong climatic gradients that cause a rise in the elevation of glaciers across the Cascade Range, major changes to snow and ice hydrology in a warming climate are occurring at different elevations. Cumulative balance is changing rapidly below 1800 m (5906 ft) in the more maritime climate of the Baker Valley, while on the east side of the park, in the upper Stehekin Valley, it is occurring below 2300 m (7546 ft).

Recreational climbing routes will continue to change due to thinning and receding glaciers. At NOCA, the 2 most-often used routes to the summit of Mount Shuksan, the park's premier climbing destination, cross glaciers. 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 (Snover et al. 2013). 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. Species such as the stonefly *Lednia borealis* occupy cold glacial meltwater streams, and their habitat will continue to decline with glacier recession.

Glaciers currently supply a significant amount of water to nearly all of the major streams in the park at a critical time of year (Post et al. 1971, Fountain and Tangborn 1985, Riedel and Larrabee 2011). Mass balance measurements at a wide range of elevations and GIS data on the distribution of glaciers by elevation are used to estimate glacial snow, firn, and ice contribution to summer (May–September) stream flow for 4 watersheds (Figure 36; Riedel and Larrabee 2011). 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 >1000 m (>3281 ft) in elevation, and only 3 measurement periods per glacier each year.

Glacial contribution to stream-flow varies by more than 100% from year-to-year due to the amount of snow melt in the basin, rainfall, and the summer melt rate (Figure 36). This variability, combined with an increasing rate of melt, makes it difficult to discern a trend in glacial runoff since 1993 at NOCA. However, a higher melt rate will not offset the continued loss of surface area, and glacial melt-water contribution to stream flow has likely been in decline since the early 20th century. Chennault (2002) used a distributed hydrologic-soil-vegetation model to estimate that late summer glacial ice runoff to Thunder Creek at NOCA declined 30% between 1900 and 1998, and would decline an additional 25% with the loss of all glaciers. The proportion of summer runoff that may be lost to future warming in several large watersheds is summarized in Figure 36.

The loss of glaciers in the past 50 yrs is in addition to the loss of snowpack on summer stream flow and stream temperature (Mote 2006). The loss of snow and ice as sources for summer stream flow when combined with higher air temperatures, has resulted in a trend toward increasing summer stream temperatures. Average August stream temperature on the Skagit River at Marblemount, 6 km (3.7 mi) west of NOCA, has risen nearly 0.8°C in 25 yrs, although the data are limited and the trend is not strong (Figure 30, Figure 37). Our current understanding of the glacial influence on stream temperature is limited by a lack of long-term records from sites distributed across the landscape. It is clear, however, that as snowpack declines, glaciers become more important to sustain late summer base flow and cool stream temperatures (Meier 1969).

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 (Brittain and Milner 2001, Milner et al. 2001, Brown et al. 2007). Benthic macroinvertebrate adaptation 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 NOCA. Research and monitoring of the glacial influence on stream temperature and channel stability is needed to provide a framework for understanding of ecosystem response to the loss of glaciers.

Those communities that are adapted to abundant glacial melt-water (i.e. low stream temperatures) will become extirpated in watersheds that will lose glaciers in the coming decades. At NOCA, these include the eastern portions of the Ross Lake and Stehekin basins, where glacial cover is less than 3%. In these valleys, groundwater may play a key role for some species in stream 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*).

In many cases the complete loss of glaciers will mean the creation of new alpine lakes and the expansion of some aquatic habitats. Lakes will provide opportunities to understand how lentic ecosystems develop following glacial retreat. At sites where glaciers remain above newly formed shallow lakes, high sedimentation rates in the next century will convert many of them into wetlands.

Widespread exposure of unconsolidated sand, rock, and gravel exposed by glacial recession has created a massive new source for sediment for rivers, reservoirs, and lakes (Czuba et al. 2012). At NOCA, several lakes are being rapidly filled with sediment. Thunder Arm of Diablo Lake, which is located near the park’s main campground, will likely be converted to a marsh in the next few decades and become unsuitable for boating and fishing. Failure of glacial moraines at high elevations will lead to debris flows on some streams, particularly those on steep slopes. This type of event occurred unexpectedly in the summer of 2008 in the headwaters of Little Beaver Creek when a thunderstorm rapidly raised the discharge of a small alpine stream, which undercut a 50 m (164 ft) tall moraine. Failure of the moraine led to a debris flow that reached across the valley floor and isolated a park work crew from their camp.

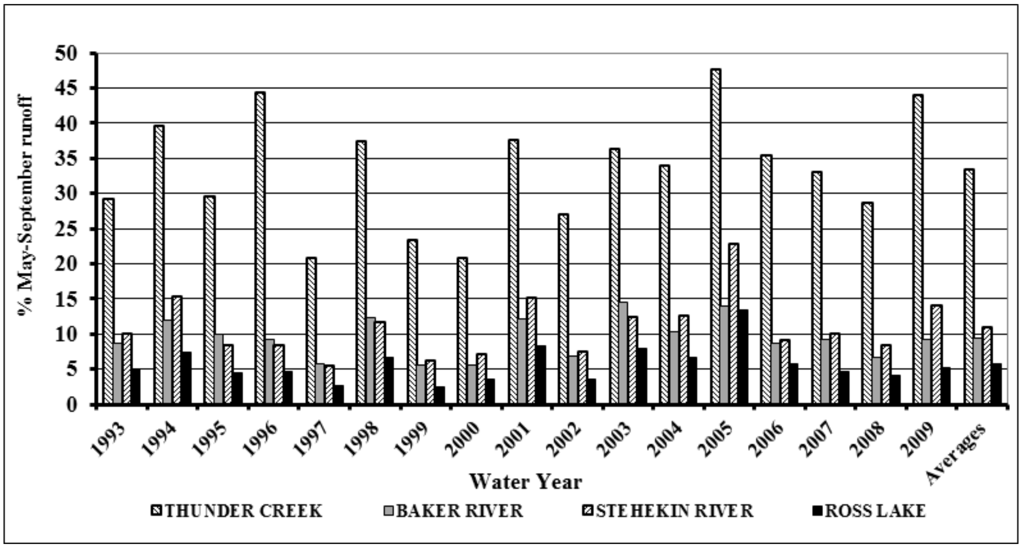

Figure 36. Total summer glacier melt-water contributions to 4 watersheds at NOCA. Glacier cover in Thunder Creek is currently 13% of total basin area, ~6% for the Baker River, 2% for Stehekin River, and 1% for Ross Lake.

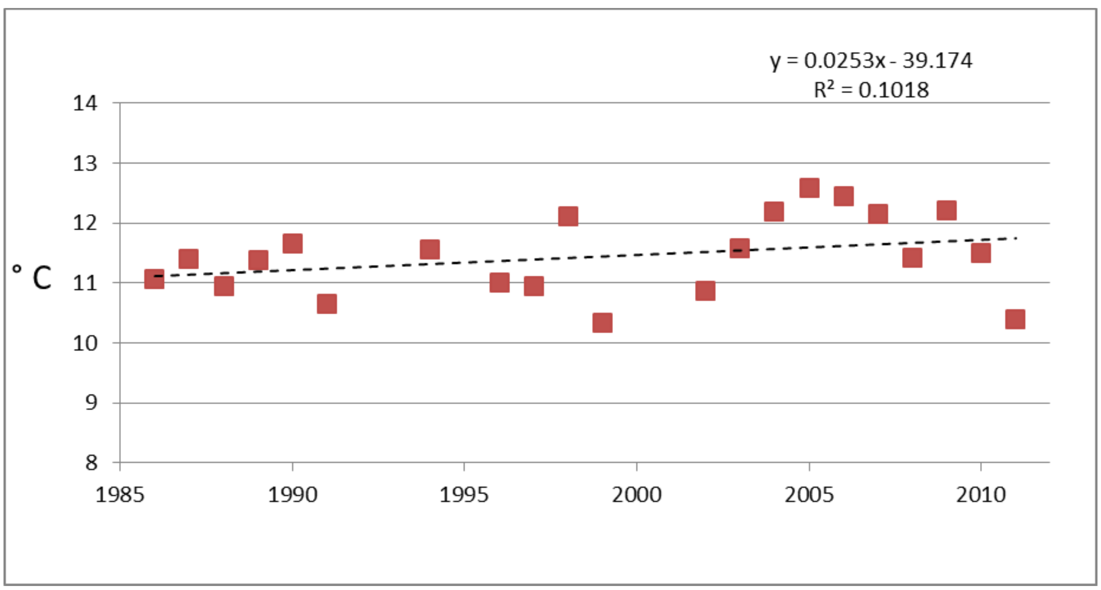

Figure 37. Mean August water temperature for the Skagit River at Marblemount (USGS 2012). Dashed line is trend. Range is 2.3°C and average is 11.4°C.

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4.21 Soundscape

(Lelaina Marin, U.S. Fish and Wildlife Service)

4.21.1 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 NOCA 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.).

The NOCA soundscape is composed of a variety of both natural ambient sounds and human-caused sounds. Natural sounds are integral components of the "unique natural features" that the park is charged to protect. Over 93% of the park complex is designated as the Stephen Mather Wilderness, and opportunities for solitude and experiencing natural sights and sounds are high. Many visitors who come to the park complex to have a true wilderness experience expect the soundscape to be comprised of natural sounds and mostly absent of human-made sounds. In addition to the human values placed on it, the natural soundscape is important for the well-being and survival of other resources, especially wildlife within the park complex.

4.21.2 Approach

During 2006–2011, staff from the Natural Sounds and Night Skies Division (NSNSD) and NOCA conducted acoustical monitoring at 20 sites within the park. Acoustical monitoring systems were deployed at 8 frontcountry locations from 2006–2011 and 12 backcountry locations from 2008–2011 (Figure 38, Table 40, Table 41). All systems were deployed during the summer months (June–September) except for NOCA012, which was deployed in February near the Ross Dam Trailhead. The primary goal of the site selection process was to identify 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 (Figure 38). Table 40 and Table 41 separate the 20 sites into frontcountry and backcountry and provide information on habitat types, dates, and exact locations of the sites monitored. In characterizing natural and non-natural acoustic conditions (noise) in a park, knowledge of the intensity, duration, and distribution of 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 For further details on data collection and analysis please see the full acoustical monitoring reports (NPS 2008a, 2008b, 2011).

Table 40. Measurement site locations in the NOCA frontcountry.

Site ID	Site Name	Year Monitored	Habitat Type	Coordinates (latitude/longitude in decimal degrees)	Elevation (m)
NOCA001	Hozomeen	2006	Open mixed conifer	48.98057°/ -121.07953°	509
NOCA002	Rainbow Point	2007	Douglas fir	48.81127° / -121.04354°	490
NOCA003	Ruby Arm	2007	Lodgepole pine	48.73472° / -121.03521°	514
NOCA008	Newhalem	2009	Douglas fir, lodgepole pine	48.677114°/ --121.240368°	213
NOCA011	Colonial Campground	2009	Douglas fir	48.684388°/ -121.094286°	370
NOCA012	Ross Dam Trailhead	2009	Whitebark pine, Douglas fir	48.731624°/ -121.058243°	707
NOCA013	Thunder Knob	2010	Lodgepole pine, Douglas fir	48.700613°/ -121.105343°	166
NOCA020	Stehekin Airstrip	2011	Douglas fir	48.347768°/ -120.720572°	398

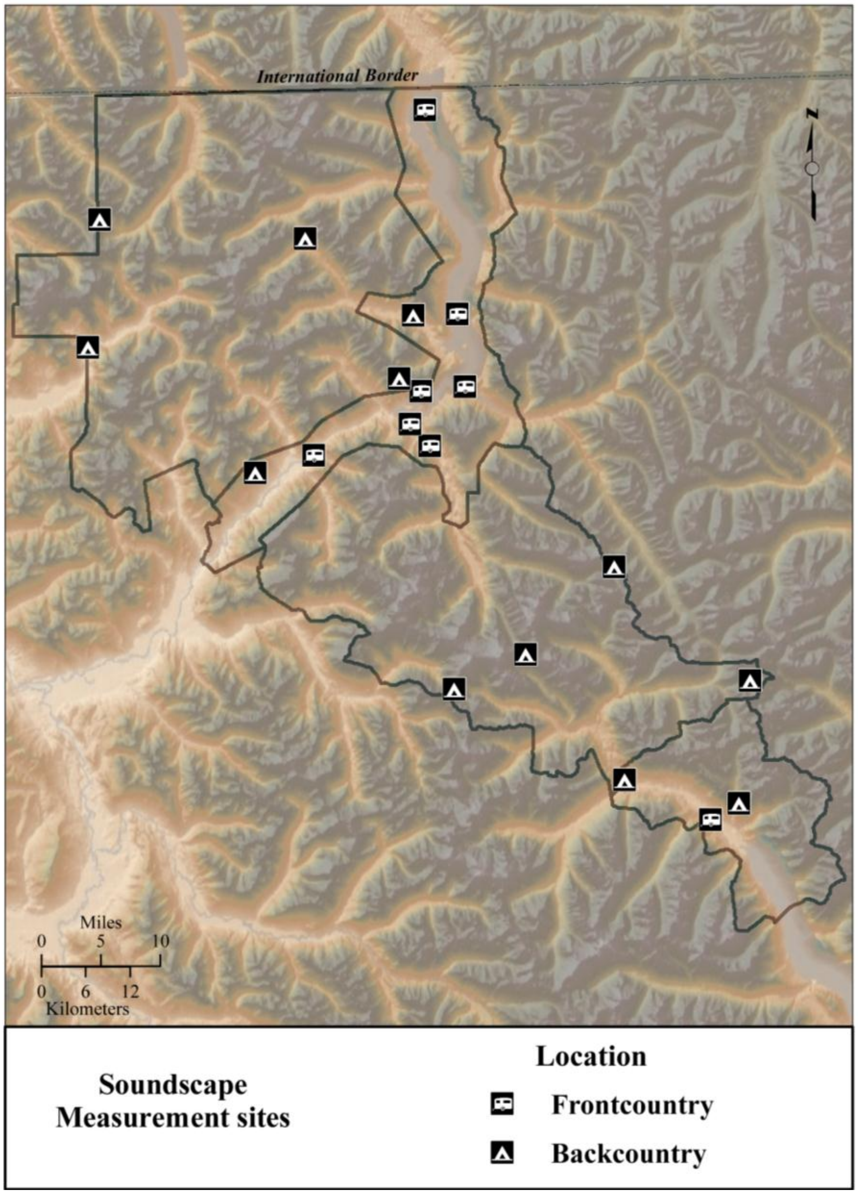

Figure 38. Frontcountry and backcountry Soundscape sampling locations, NOCA.

Table 41. Measurement site locations in the NOCA backcountry.

Site ID	Site Name	Year Monitored	Habitat Type	Coordinates (latitude/longitude in decimal degrees)	Elevation (m)
NOCA004	Coon Lake Trail	2008	Douglas fir (wilderness)	48.3829°/ -120.83544°	396
NOCA006	Cascade Pass	2008	Subalpine (Wilderness)	48.46709° / -121.05992°	1677
NOCA007	Boundary Camp	2008	Silver fir (Wilderness)	48.89004° / -121.52149°	1434
NOCA009	Rainbow Loop	2009	Open mixed conifer	48.347117°/ -120.698593°	628
NOCA010	Easy Pass	2009	Subalpine mountain pass	48.571843°/ -120.841577°	2055
NOCA014	Big Beaver Valley	2010	Western red cedar, Douglas fir, hemlock	48.798918°/ -121.102065°	524
NOCA015	Sourdough Mountain	2010	Silver fir, western hemlock	48.743278° / -121.12284°	1597
NOCA016	Park Creek Pass	2010	Subalpine mountain pass	48.496378°/ -120.963382	1848
NOCA017	Dagger Lake	2010	Mountain hemlock, silver fir	48.46726°/ -120.664122°	1656
NOCA018	Sulphide Creek	2011	Forest	48.777061°/ -121.540783°	277
NOCA019	Beaver Pass	2011	Forest	48.869272°/ -121.244899°	1067
NOCA021	Thornton Lakes Trail	2011	Forest	48.662878°/ -121.319592°	954

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), which 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, the A-weighted values are used to describe potential effects on the park's acoustical environment and soundscape. Table 42 provides examples of A-weighted sound levels.

Table 42. Examples of sound levels.

Reference Sound	dBA 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.

4.21.3 Reference Conditions and Comparison Metrics

Natural ambient sound level at each measurement site location will be used as 1 reference condition. The existing ambient sound level can then be compared to the natural ambient level to determine deviation from the reference condition. In the future, measured existing ambient levels can be compared with the natural ambient to determine if deviation from the reference condition has changed. Natural and existing ambient sound levels for frontcountry and backcountry sites are provided in the "Acoustical Conditions in the Park" section.

Percent time audible of human-caused noise at each measurement site location will also be used to determine the current amount of noise heard within the park throughout a 24-hr day. The park can compare future percent time audible values to current levels to determine if human-caused noise is more or less prevalent. Percent time audible values for frontcountry and backcountry sites are provided in the "Acoustical Conditions in the Park" section.

4.21.4 Results and Assessment

Natural ambient sound levels measured at the frontcountry sites ranged from 22.5–43 dBA during the day and 21–42 dBA at night (Table 43). At the backcountry sites, natural ambient sound levels ranged from 25–35.8 dBA during the day and 21.7–36.7dBA at night (Table 44). Existing ambient sound levels at the frontcountry sites ranged from 24.2–46 dBA during the day and 21–42 dBA at night (Table 43). At the backcountry sites, existing ambient sound levels ranged from 27–36.3 dBA during the day and 27–36.8 dBA at night (Table 44) (NPS 2008a, 2008b, 2011). For all 20 sites, the lowest natural ambient sound level was heard at Hozomeen during the day and at Colonial Campground at night. Lower natural ambient sound levels occurred at these frontcountry sites due to the lack of flowing water that many of the backcountry sites had. Additionally, natural ambient sound levels measured during the day and night were very close for several sites due to the constant flowing water sounds. The highest existing ambient sound levels were heard at Newhalem and Stehekin

Airstrip due to noise from power lines and power generation equipment, and aircraft and vehicle traffic, respectively.

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: (1) sounds produced by birds, frogs, or insects to define territories or attract mates; (2) sounds produced by bats to navigate or locate prey; and (3) sounds produced by physical processes such as wind in trees, flowing water, or thunder.

While listening to audio recordings, NPS staff discovered recordings of chipmunks, squirrels, birds, reptiles, and amphibians at many of the sites. Staff also collected recordings of a rock slide, and thunder at Cascade Pass, Newhalem, and Easy Pass. These recordings along with insects, rain, wind, and flowing water, are just a few of the many natural sounds which join to create the NOCA acoustical environment.

Although natural sounds predominate throughout NOCA, 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), automobiles and motorcycles, generators, heavy equipment, watercraft, and visitors. At frontcountry sites, vehicles were the most often heard non-natural sound at 5 (Ruby Arm, Newhalem, Colonial Campground, Thunder Knob, Stehekin Airstrip) of the 8 sites, with a percent time audible ranging from 1.2 to 51.5% of a 24-hr day (Table 45, Figure 39). At backcountry sites, except for Sourdough Mountain and Thornton Lakes Trail, aircraft were the most pervasive non-natural sound source, audible between 4.9 and 15.6% of a 24-hr day, mostly caused by high altitude jets, although air tours are alos presently allowed at NOCA (Judy Rocchio, pers. comm). At Sourdough Mountain, vehicle sounds were the most often heard human-caused sound (42% time audible over a 24-hr day) (Table 46, Figure 40). For all 20 sites, non-natural sounds were heard the greatest at Newhalem (100% time audible) and Ross Dam Trailhead (96.8% time audible) (Table 45) (NPS 2008a, 2008b, 2011).

Despite the presence of various human-caused noise intrusions, natural sounds can be heard at all sites. The most common natural sounds were birds, water, wind, flowing water, and insects. Calculating Noise Free Interval (NFI) provides one way to measure the length of time that natural sounds can be heard in the park. NFI describes the length of time between extrinsic or human-caused events when only natural sounds are audible. The longest NFI for all of the sites occurred at Big Beaver Valley and Dagger Lake, with a NFI of approximately 1 hr; however, the attended listening sessions used to collect NFI data were 1 hr in length, therefore NFI values for these sites could be longer. All of the backcountry sites had NFI’s longer than 10 min (Table 46). The shortest NFI occurred at Newhalem, with a NFI of 51 sec. The frontcountry site with the longest NFI occurred at Rainbow Point (NFI of approximately 25 min) (Table 45). All of the NOCA sites have a diversity of natural sounds that make for a rich and spectacular acoustical environment.

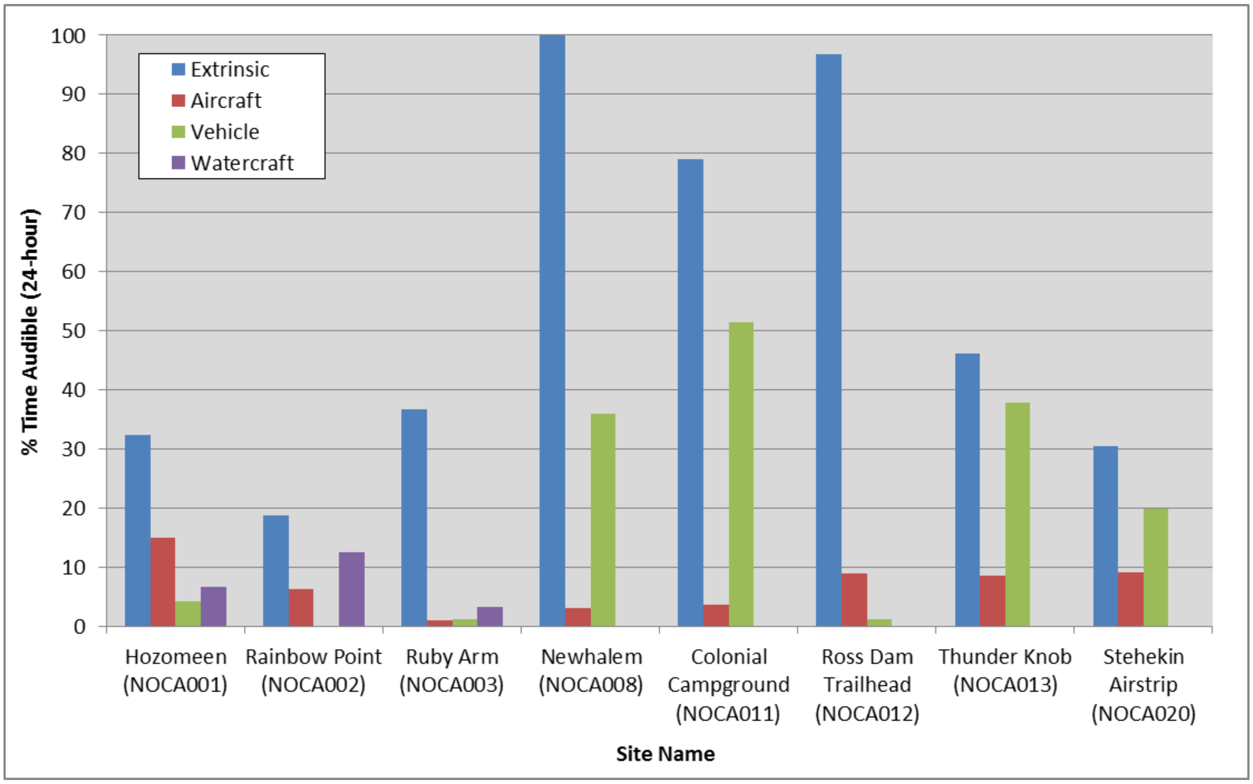

Figure 39. Percent time audible for human-caused sound in frontcountry areas, NOCA.

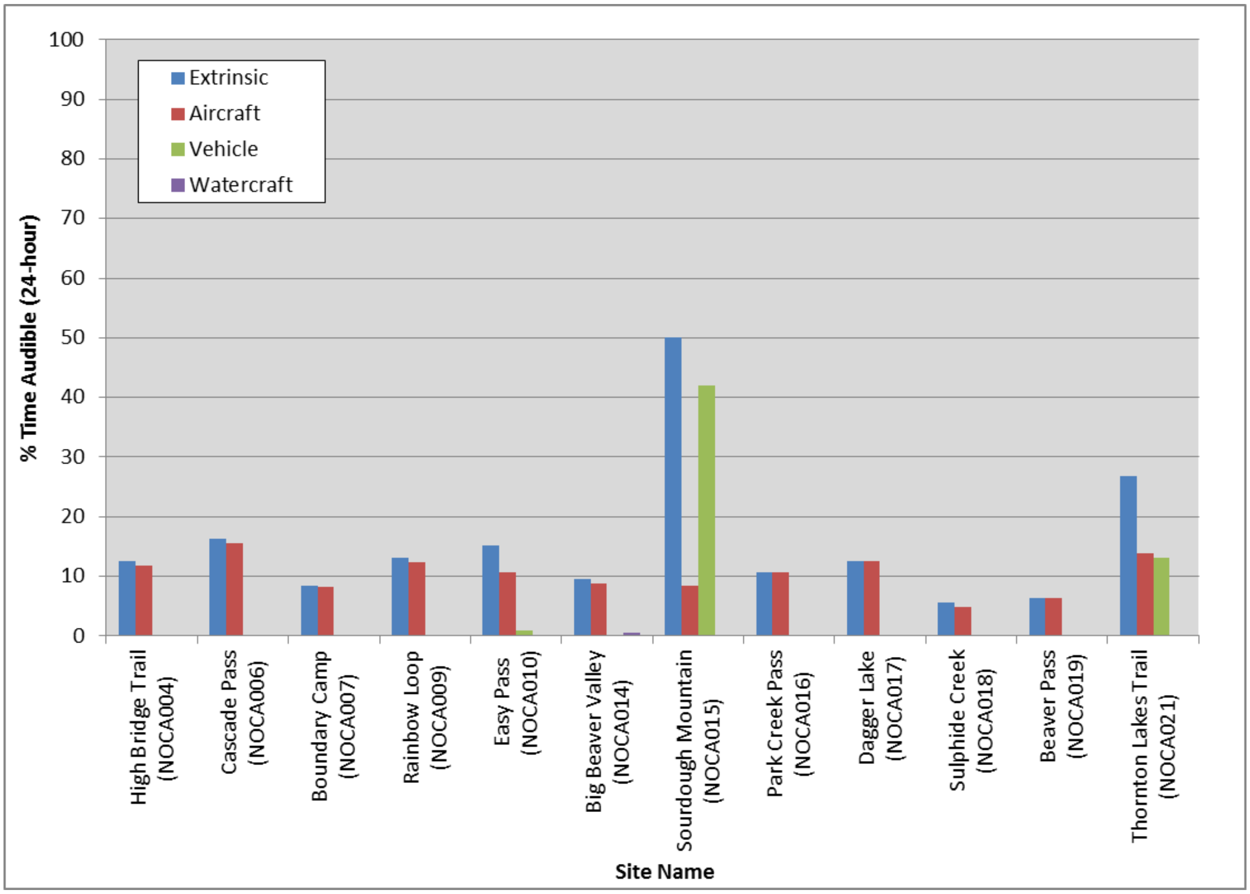

Figure 40. Percent time audible for human-caused sound in backcountry areas, NOCA.

Table 43. Natural and existing ambient sound levels for NOCA frontcountry sites.

		Daytime (7 am to 7 pm)		Nighttime (7 pm to 7 am)	
Site ID	**Site Name**	**Natural**[1]	**Existing**	**Natural**	**Existing**
NOCA001	Hozomeen	22.5	24.2	22.0	22.2
NOCA002	Rainbow Point	30.5	31.8	28.6	28.6
NOCA003	Ruby Arm	32.0	35.0	28.2	28.8
NOCA008	Newhalem	43.0	46.0	42.0	43.0
NOCA011	Colonial Campground	25.2	32.0	21.0	23.0
NOCA012	Ross Dam Trailhead	25.0	27.0	25.0	27.0
NOCA013	Thunder Knob	27.0	29.0	28.0	28.0
NOCA020	Stehekin Airstrip	41.0	42.0	42.0	42.0

[1] Natural ambient levels represent the reference condition and are compared to existing ambient to determine the deviation from the reference condition.

Table 44. Natural and existing ambient sound levels for NOCA backcountry sites.

Site ID	Site Name	Daytime (7 am to 7 pm)		Nighttime (7 pm to 7 am)	
		Natural[1]	Existing	Natural	Existing
NOCA004	High Bridge Trail	35.8	36.3	36.7	36.8
NOCA006	Cascade Pass	34.6	35.1	35.2	35.3
NOCA007	Boundary Camp	29.7	29.8	30.2	30.2
NOCA009	Rainbow Loop	33.0	33.0	34.0	34.0
NOCA010	Easy Pass	29.0	30.0	26.0	27.0
NOCA014	Big Beaver Valley	27.0	27.0	27.0	27.0
NOCA015	Sourdough Mountain	25.0	27.0	27.0	27.0
NOCA016	Park Creek Pass	32.0	32.0	34.0	34.0
NOCA017	Dagger Lake	25.0	25.0	21.0	22.0
NOCA018	Sulphide Creek	38.0	38.0	39.0	39.0
NOCA019	Beaver Pass	34.0	34.0	34.0	34.0
NOCA021	Thornton Lakes Trail	28.0	29.0	28.0	28.0

[1] Natural ambient levels represent the reference condition and are compared to existing ambient to determine the deviation from the reference condition. At many of the sites, there appeared to be no human events loud enough to be heard above ambient, therefore the natural and existing values are the same or relatively similar.

Table 45. Percent time audible for human-caused sound in frontcountry areas.

Site ID	Site Name	% Time Audible[1]				Noise Free Interval (maximum event, mm:ss)
		Extrinsic Sounds	Aircraft Sounds	Vehicle Sounds	Watercraft sounds	
NOCA001	Hozomeen	32.3	14.9	4.2	6.6	10:53
NOCA002	Rainbow Point	18.7	6.2	0	12.6	25:21
NOCA003	Ruby Arm	36.7	.9	1.2	3.3	05:30
NOCA008	Newhalem	100	3	36	0	00:51
NOCA011	Colonial Campground	79.1	3.7	51.5	0	01:22
NOCA012	Ross Dam Trailhead	96.8	9	1.1	0	14:44
NOCA013	Thunder Knob	46.1	8.5	37.9	0	18:38
NOCA020	Stehekin Airstrip	30.4	9.1	19.9	0	N/A*

*N/A – Noise Free Interval was not calculated for site NOCA020

[1] Over 24-hr period, based on 8 days of off-site listening analysis

Table 46. Percent time audible for human-caused sound in backcountry areas.

Site ID	Site Name	% Time Audible[1]				Noise Free Interval (maximum event, mm:ss)
		Extrinsic Sounds	Aircraft Sounds	Vehicle Sounds	Watercraft sounds	
NOCA004	High Bridge Trail	12.6	11.7	0	0	17:58
NOCA006	Cascade Pass	16.3	15.6	0	0	30:09
NOCA007	Boundary Camp	8.4	8.3	0	0	20:41
NOCA009	Rainbow Loop	13.2	12.4	0	0	52:37
NOCA010	Easy Pass	15.1	10.7	1	0	16:05
NOCA014	Big Beaver Valley	9.6	8.8	0	0.6	60:01
NOCA015	Sourdough Mountain	50.1	8.4	42	0	10:33
NOCA016	Park Creek Pass	10.6	10.6	0	0	46:18
NOCA017	Dagger Lake	12.5	12.5	0	0	60:01
NOCA018	Sulphide Creek	5.6	4.9	0	0	38:42
NOCA019	Beaver Pass	6.4	6.4	0	0	32:13
NOCA021	Thornton Lakes Trail	26.8	13.8	13.1	0	N/A*

*N/A – Noise Free Interval was not calculated for site NOCA021

[1] Over 24-hr period, based on 8 days of off-site listening analysis

4.21.5 Emerging Issues

One common noise heard in NOCA is that of transportation (i.e., airplanes and land vehicles). Growth in transportation is increasing faster than the human population (Barber et al. 2009). 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). Aircraft traffic grew 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). As these noise sources increase throughout the United States, the ability to protect pristine and quiet natural areas becomes more difficult (Mace et al. 2004). Therefore, noise generated by land vehicles and aircraft (e.g., due to air tours) appears to be an increasingly important management issue.

The Stephen Mather Wilderness is one piece of an interagency designated wilderness that is a 2.2 million-ac (890,308 ha) contiguous block. This large block of protected lands, however, is not free from human-caused noise. Common noise intrusions are produced by aircraft (air tours, administrative helicopter use, passenger jets, and military overflights), vehicle noise (the park complex is bisected by a national scenic highway that draws large volumes of traffic during the summer months), and motorboats (which are used on 3 reservoirs, the largest of which, Ross Lake, covers over 12,300 ac (4978 ha) and stretches over 135 mi (217 km) of shoreline). Although vehicle and motorboat usage occur outside of designated wilderness, their noise impacts reach inside its protective borders.

The western boundary of the NOCA complex is within 2 to 3 hr driving time from the metropolitan centers of Seattle, Washington and Vancouver, British Columbia. The population of these areas is expected to expand significantly within the next several decades. With this population expansion, visitation to nearby natural areas is expected to increase, putting greater pressure on the resources the NPS is charged to protect, including the acoustical environment. Given that approximately 83% of the current visitors who come to the park complex stay within the North Cascades Scenic Highway Corridor, it is expected that traffic and the noise associated with it will have a similar increase. Although the road corridor will likely experience the greatest increase in noise, it is also expected that the number of air tours, landings at the Stehekin Airstrip, and backcountry and reservoir visitation (including motorboat usage) will increase.

4.21.6 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?

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4.22 Dark Night Skies

(Dan Duriscoe, National Park Service, Death Valley National Park)

4.22.1 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, allowing the experience of "sleeping under the stars." 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.

NOCA is located in an area of northern Washington that is relatively remote from cities and towns, but is within 161 km (100 mi) of the large metropolitan areas of Seattle, Washington, and Vancouver, British Columbia. Therefore, this area is influenced by anthropogenic sky glow from the west (Figure 41). This leads to a significant gradient of expected night sky quality from west to east. There are few internal threats or sources of light pollution within the park boundaries. In fact, there are no developments with permanent outdoor lighting within the park itself, the vast majority of which is designated Wilderness (Figure 42). The NOCA Recreation Areas contain significant development, but are still relatively rural. This condition results in a situation where even small increments of anthropogenic light will be easy to detect as a change from the natural condition. Also, it is particularly important that within-park sources of light be contained, eliminating light trespass and minimizing anthropogenic sky glow.

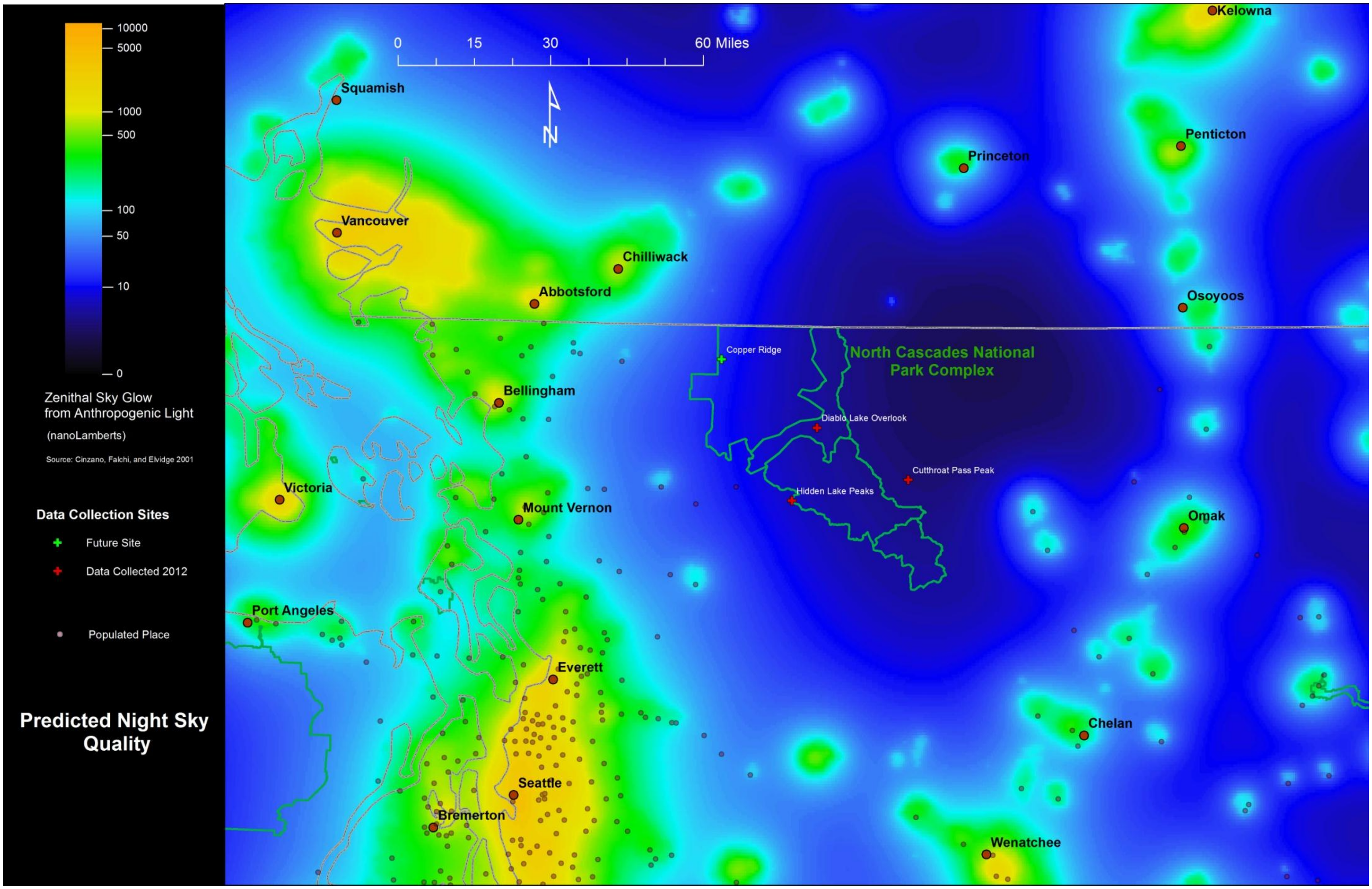

Figure 41. Model of sky quality from late 1990’s satellite imagery at night and sky glow model by Cinzano et al. (2001). Note the logarithmic scale for the color ramp. The Milky Way would generally not be visible in areas appearing yellow or orange.

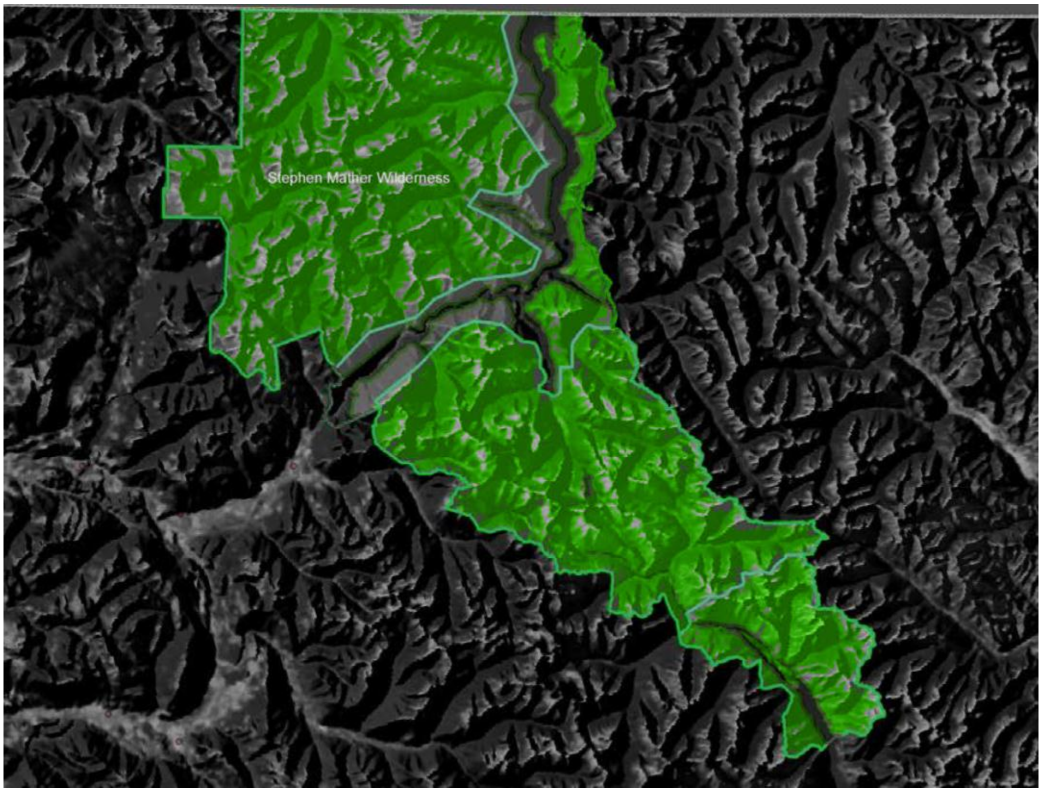

Figure 42. Approximate boundaries of the Stephen Mather Wilderness within the North Cascades National Park Service Complex, shown in green.

4.22.2 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 per square meter), or relative to natural conditions ("Skies", where 1 Sky = 22.0 V magnitudes per square arc second), often shown as a sky brightness contour map of the entire sky (such as Figure 43, Figure 44). 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 meters elevation. An SQI of 0 would indicate only the brightest 10 or 20 stars visible, while at value of 50 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 the Wilderness boundary), in milli-Lux;
5. Visual observations by a human observer, such as Bortle Class (Bortle 2001) and Zenithal limiting magnitude;
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/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.

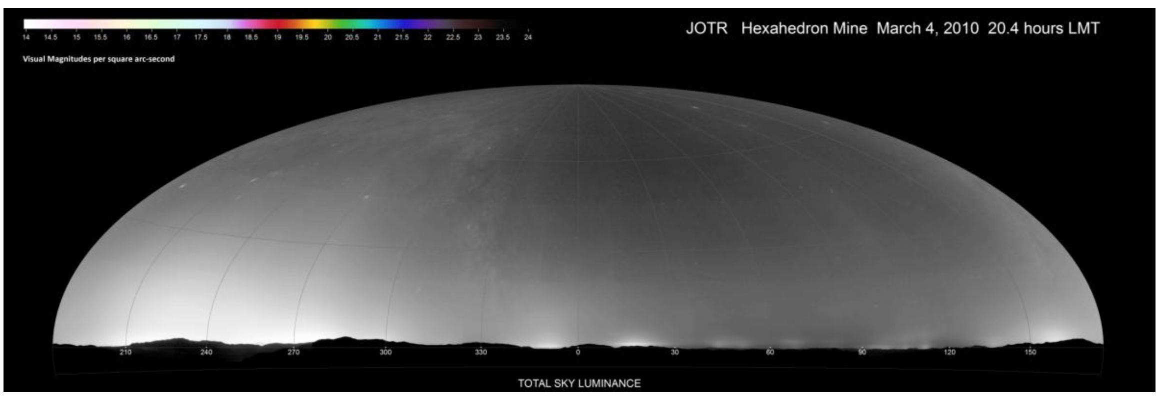

Figure 43. Example all-sky mosaic of a moderately light polluted area in Hammer-Aitoff projection with a grayscale representation of sky luminance. Data from a location in Joshua Tree National Park.

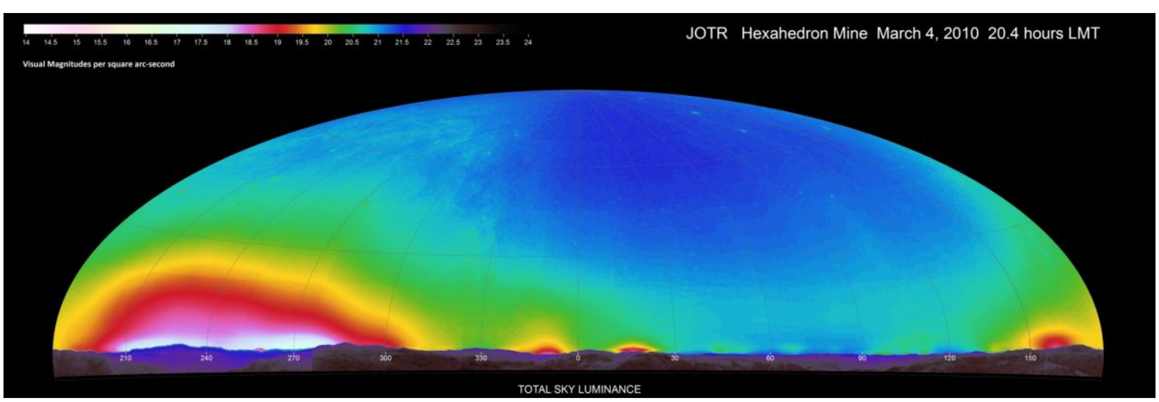

Figure 44. False color representation of Figure 43, after a logarithmic stretch of pixel values. Note that the core of the bright light dome at left is 17 V magnitudes/square arc second, 100 times brighter than the natural baseline of 22.0.

4.22.3 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%. 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 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/square arc second (0.171 milli-Candela/m^2 or 54 nanoLamberts). Average natural illuminance is defined for moonless nights as: Hemispherical = 0.8 milli-Lux; Horizontal = 0.8 milli-Lux; Vertical = 0.4 milli-Lux.

Achieving this reference condition for preserving natural night skies is well summarized in 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 NOCA 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.

4.22.4 Results and Assessment

Current Condition and Trend

The night sky as seen from NOCA is impaired by anthropogenic sky glow from distant cities and by local light trespass. As described on the official park website: "With over 600,000 acres designated as the Stephen Mather Wilderness, most of the park complex is free from the disturbance of man-made lights. Here the heavens seem to shine with more vigor and vibrance as the wilderness serenades us with its symphony of nighttime activity" (http://www.nps.gov/noca/naturescience/lightscape.htm, accessed on 16 September 2012). However, while the remote high mountains exemplify pristine wilderness character during the daylight hours, there are significant impacts to the natural lightscape of NOCA at night.

The National Park Service has conducted an inventory of night sky quality at NOCA, with data collection beginning in 2012. Three locations for measuring sky luminance and light trespass have been visited, and a fourth is planned. The locations from which data were obtained include Hidden Lake Peaks ridge, Cutthroat Pass Peak (not within the park boundary but nearby and representing sky quality in most of the eastern part of the park), and Diablo Lake Overlook on Highway 20 in Ross

Lake National Recreation Area. The fourth location, Copper Ridge, is in the northwestern part of the park, and predicted to have the brightest Zenith sky glow from light pollution (see Figure 41).

Important statistics from these data are presented in Tables 47–50. Illustrations of total sky brightness and anthropogenic sky glow are presented as false color maps of the sky hemisphere in Hammer-Aitoff projections in Figures 45–48. Table 47 and Table 49 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. Table 48 and Table 50 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). As expected, data for the westernmost site at Hidden Lake Peaks (Table 47 and Table 48) displays more anthropogenic sky glow than the eastern site at Cutthroat Pass Peak (Table 49 and Table 50). Both of these data nights have complicating factors, smoke and haze at Hidden Lake Peaks and very bright natural airglow at Cutthroat Pass Peak, but the data are considered of good quality after analysis with the natural sky model.

Sky luminance and illuminance from anthropogenic sources is seen to be about twice as high at Hidden Lake Peaks as at Cutthroat Pass Peak. However, both are given Bortle Class 3, indicating that even at the more remote eastern site, the impairment from city light domes is significant compared to a sky free of light pollution. Hemispherical illuminance is probably the most robust of the statistics listed; for this indicator Hidden Lakes Peaks yielded a ratio of 0.43–0.48 (43–48%) of anthropogenic to natural luminance, while Cutthroat Pass Peak had ratios of 0.21–0.37 (21–37%), the minimum value being close to the reference condition of 20%. Sky luminance in the brightest portion of the sky was observed to be 200% above the reference condition at both sites, reaching a maximum of 17.2 (1720%) at Hidden Lake Peaks. The ratio of anthropogenic to natural luminance at the Zenith met the reference condition (20%) at Cutthroat Pass Peak for all 3 data sets, but only the 2 later sets at Hidden Lake Peaks. This statistic verifies the model presented in Figure 37, generally agreeing with the predicted values.

The narratives from each of these nights reveal some interesting differences in conditions that may affect the sky brightness results. First, the natural airglow varies considerably between nights and even throughout a single night. This in itself does not affect sky quality, but will lower the contrast between stars and the sky, and may result in a brighter observed zenithal limiting magnitude under brighter airglow conditions. Bright airglow also may be more difficult to model and subtract from the total sky brightness, resulting in an increased error in the estimate of anthropogenic sky glow, especially near the Zenith.

The extinction coefficient for each of these nights indicates relatively clear air, however high altitude smoke and haze were observed, presumably from fires in Asia. This smoke was especially noticeable at Hidden Lake Peaks on 11 August. It actually intensified in the region on 12 and 13 August, but was minimal by 14 August (Cutthroat Pass Peak).

The brighter natural airglow is obvious in Figure 47 (Cutthroat Pass Peak) compared to Figure 45 (Hidden Lake Peaks) as an overall brightening of the sky background, especially near the Zenith. When the natural sources are removed (Figure 46 and Figure 48) both nights reveal a low level anthropogenic sky glow near the Zenith, but significant brightening to the west from the light domes of distant cities.

A light trespass measurement from the streetlamps along Diablo Dam was made from Diablo Lake Overlook. Figures 49 and 50 illustrate the results from an application of the inverse square law. The observation of 0.416 milli-Lux of vertical illuminance is extrapolated to the landscape around the dam. Simplifying assumptions of this analysis include: (1) the cluster of unshielded lamps along the dam may be treated as a single isotropic source; and (2) all of the lamps are visible from all locations, including the point where the observation was made. Neither of these assumptions is strictly correct, but the analysis demonstrates within a reasonable error the potential sphere of influence of obtrusive light, including beyond the Wilderness boundary.

In summary, below are the quantities from the Hidden Lake Peaks and Cutthroat Pass Peak data nights for each of the metrics described in the Approach sub-section:

1. Sky luminance: Ratio of anthropogenic to natural: maximum = 17, minimum = 0; Sky Quality Index = 66–79;
2. Maximum vertical illuminance from anthropogenic sky glow: 0.44 mLux (Azimuth 265 at Hidden Lake Peaks), ratio of anthropogenic to natural 1.09 or 109%;
3. Illuminance from anthropogenic sky glow as a ratio of anthropogenic to natural: Hemispherical: Hidden Lake Peaks 0.53–0.59 (53–59%), Cutthroat Pass Peak 0.17 (17%) minimum; Horizontal: Hidden Lake Peaks 0.34–0.40 (34–40%), Cutthroat Pass Peak 0.26 (26%) minimum;
4. Vertical illuminance from light trespass: At Diablo Lake Overlook: 0.41 mLux from streetlamps at Diablo Dam (Figures 45 and 46);
5. Visual observations: Hidden Lake Peaks Bortle Class 3, ZLM 7.1; Cutthroat Pass Peak Bortle Class 3, ZLM 6.6;
6. Sky quality meter: 21.42 at Hidden Lake Peaks.

Overall Condition

NOCA night sky quality is very good, although localized areas are subject to light trespass and glare and the western part of the sky exceeds the reference condition for sky luminance in all parts of the park investigated.

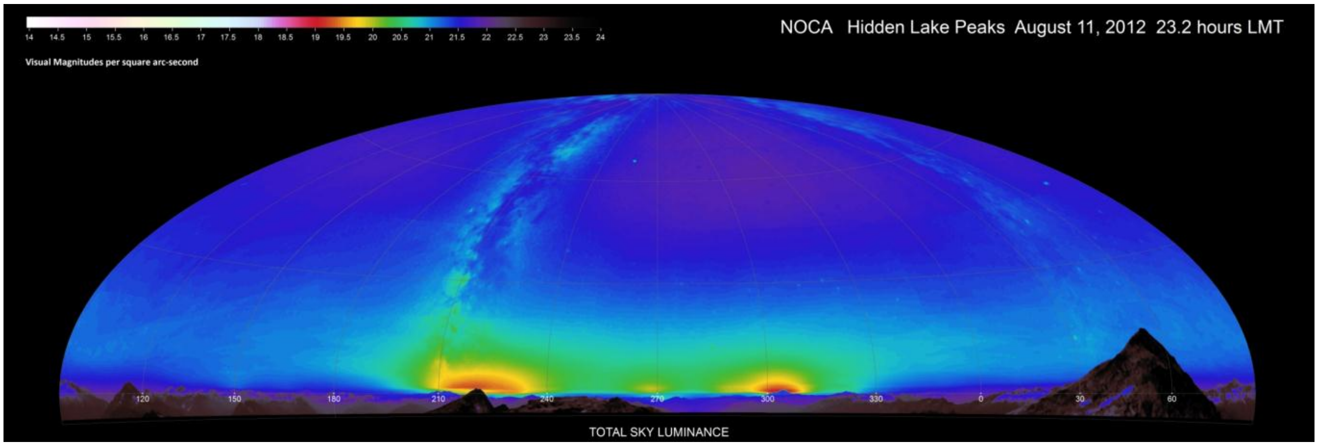

Figure 45. Contour map of night sky brightness in Hammer-Aitoff projection, Hidden Lake Peaks, 11 August 2012. The Milky Way is seen curving over the upper portion of the map. Light blue areas 10–20° above the horizon are the natural airglow, and wispy details in this region are either bands in the airglow or light reflecting off upper level haze and smoke.

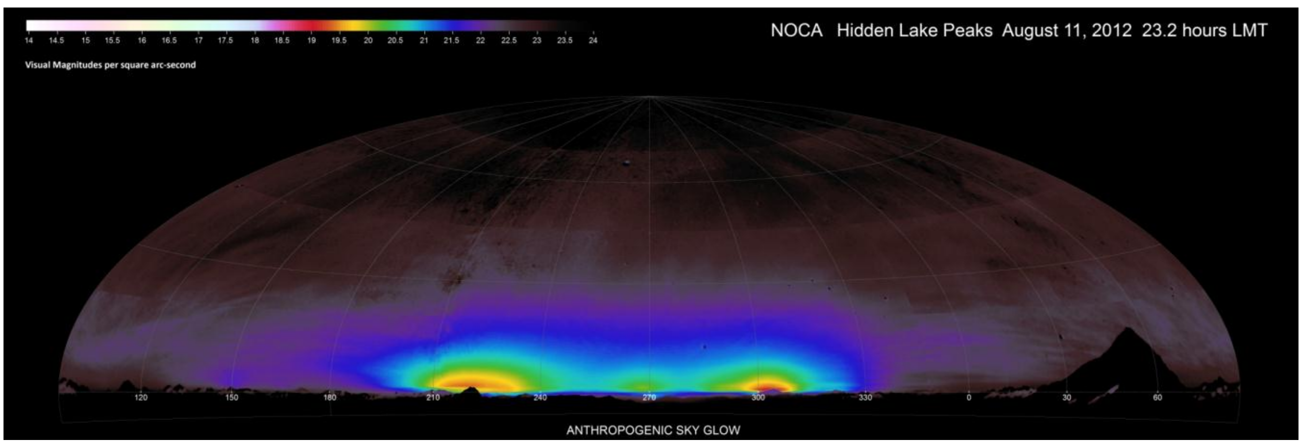

Figure 46. Same data as in Figure 45, but with the natural sources of sky brightness removed with the natural sky model. Wispy banding is still visible to the north and east, features that the model cannot remove. However, the light domes of the metropolitan areas of Seattle, WA, and Vancouver, B.C. are clearly seen, while the Zenith is virtually free of anthropogenic sky glow.

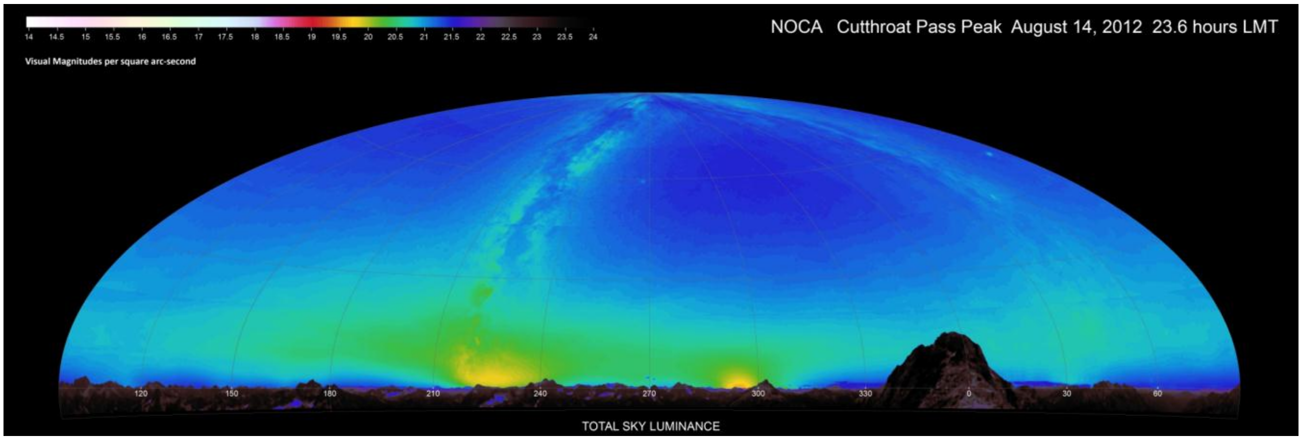

Figure 47. Contour map of night sky brightness in Hammer-Aitoff projection, Cutthroat Pass Peak, 14 August 2012. The Milky Way merges with the light dome of the Seattle area at 225 azimuth. The natural airglow is moderately strong on this night.

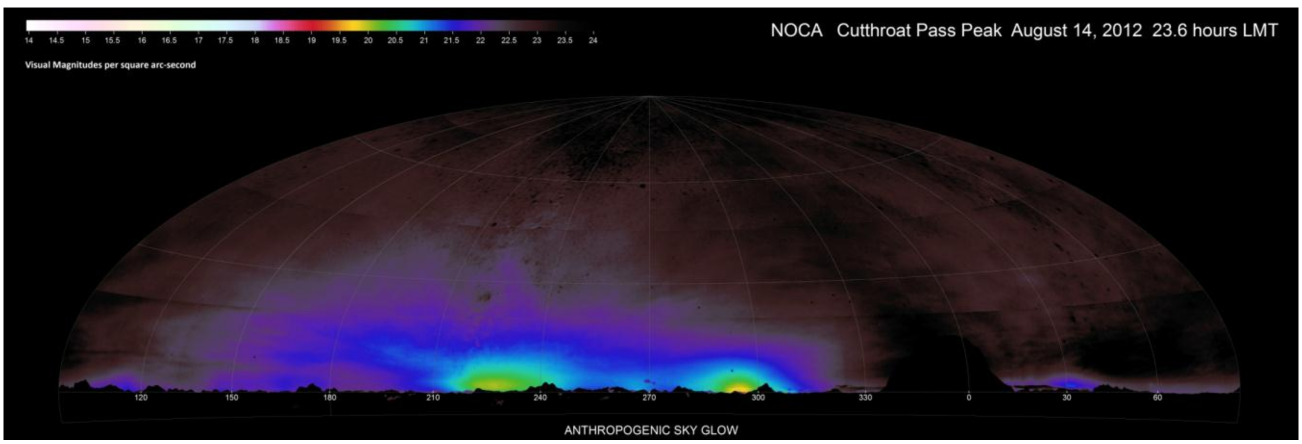

Figure 48. Same data as in Figure 47, but with the natural sources of sky brightness mostly removed with the natural sky model. Airglow artifacts remain left of Seattle at azimuth 160–210, features that the model cannot remove. The cores of the city light domes are much fainter than at Hidden Lake Peaks.

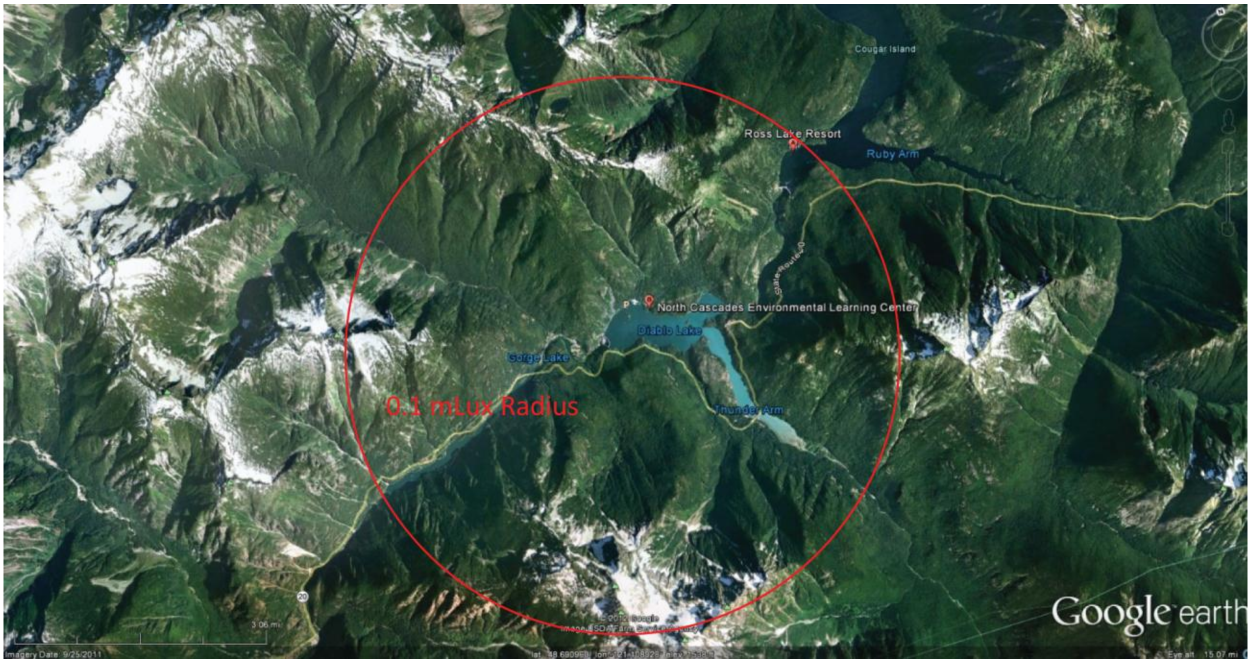

Figure 49. Satellite image of the Diablo Lake area showing a 5350 m radius from the approximate center of Diablo Dam not accounting for slope distance. At this distance, the predicted vertical illuminance from the streetlamps along Diablo Dam is 0.1 mLux, about as bright as the planet Venus. Locations inside the radius will experience brighter values according to the inverse square law. Note that the north slope of Pinnacle Peak nearly to its summit is illuminated to this level and brighter.

Figure 50. Close up view of Diablo Lake showing the relative locations and distance from the dam to the Overlook on Highway 20 (2626 m) and the Environmental Learning Center (1125 m). The value for vertical illuminance of 0.416 mLux was measured at the Overlook, and the value of 2.26 mLux at the Environmental Learning Center is predicted based on these numbers and the inverse square law. Also shown in black is a radius from the dam where a vertical illuminance of 5 mLux is predicted.

Table 47a. Data night attributes, NPS Night Skies Program, Hidden Lake Peaks, 11–12 August 2012.

Site Parameter	Attribute	Site Parameter	Attribute
SITE NAME:	Hidden Lake Peaks Ridge	EQUIPMENT:	SBIG1, 50mm f/2, 8582
LONGITUDE:	-121.20045	OBSERVERS:	D Duriscoe, R Meadows
LATITUDE:	48.49907	AIR TEMP (°F):	59.2
ELEVATION (m):	2097	REL HUMID (%):	38.5
DATE (UT):	August 12, 2012	WIND SP (mph):	3.5
TIME START (UT):	5:38:58	CCD TEMP (°C):	-20
DATA QUALITY:	Good	EXP (seconds):	14
		ZLM	7.1

Table 47b. Summary of all Sky Photometry for each Data, NPS Night Skies Program, Hidden Lake Peaks, 11–12 August 2012.

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	21.7	0.175	0.034	67.1	21.45	21.65	18.88	1.22	1.01	0.83	
2	22.4	0.185	0.036	66.9	21.48	21.52	18.86	1.16	0.97	0.79	Airglow increasing to east
3	23.1	0.183	0.043	69.4	21.51	21.47	18.93	1.11	0.94	0.76	Airglow increasing to south, extends to 30° alt, many meteors
4	23.6	0.183	0.042	69.4	21.50	21.47	19.04	1.11	0.95	0.76	SQM 21.42, light domes dimmer

NARRATIVE: Drive to Hidden Lake Trailhead, walk to the pass between the Hidden Lakes Peaks on the Lookout trail. The higher summit is to the north (7080’), the south summit contains the old fire lookout building. The north summit is the best monitoring site, but difficult to access from the south because of large blocky boulders. Ascended a snowfield to a flat area on the ridge at 6850’, at the base of the slope leading to the northern summit. Very good monitoring site with plenty of room to set up and safe location for people.

Night of Perseid meteor shower, many bright meteors seen. Bortle Class 3. Seeing very good, transparency fair. Smoke from distant fires throughout, brown color seen to east. Visibility in daytime no more than 40 miles. Light dome seen from Vancouver as a broad glow stretching from 340 azimuth across the northwestern horizon, centered on Mt. Baker, to about 300, up to 15 degrees altitude, significantly brighter than the brightest part of the Milky Way. Another light “bump” at 270-280, much smaller than Vancouver, then an even brighter light dome beginning at 220, 35-40 degrees wide, 15-20 degrees tall, bright enough to affect night vision. No other light domes. Bright airglow, extending to 30-35 degrees altitude. Around the Zenith, the Milky Way exhibits all details from Scutum to Cassiopeia, excellent sky within 40 degrees of Zenith. Zodiacal Light not seen, partly because of its position low in the east and south. Darkest area of the sky around the head of Draco, considerably darker than the other side of the Milky Way where more airglow is present. SQM 21.42 end of 4^{th} set. ZLM 7.1 in Draco (both Dan and Bob).

Table 48. Anthropogenic sky glow observed at Hidden Lake Peaks, 11 August 2012: Illuminance (mLux); Luminance (nL); and Ratio of Light Pollution to Natural Conditions (LPR).

	Hemispherical Illuminance (±0.05 mLux)		Vertical Illuminance (±0.05 mLux)						Horizontal Illuminance (±0.05 mLux)		Sky Luminance			
			Maximum		Average		Minimum				Brightest		Zenith	
Local Mean Time (hours)	mLux	LPR	mLux	LPR	mLux	LPR	mLux	LPR	mLux	LPR	nL (±10)	LPR (skies)	nLl(±5)	LPR (skies)
21.7	0.48	0.59	0.44	1.09	0.27	0.67	0.14	0.35	0.32	0.40	903	16.7	18.0	0.33
22.4	0.47	0.58	0.43	1.07	0.26	0.66	0.15	0.36	0.30	0.38	931	17.2	13.9	0.26
23.1	0.43	0.54	0.40	1.01	0.25	0.61	0.13	0.32	0.27	0.34	866	16.0	10.9	0.20
23.6	0.43	0.53	0.40	1.00	0.24	0.61	0.13	0.32	0.27	0.34	781	14.5	8.4	0.16

Table 49a. Data night attributes, NPS Night Skies Program, Hidden Lake Peaks, 11–12 August 2012.

Site Parameter	Attribute	Site Parameter	Attribute
PARK:	NOCA	EQUIPMENT:	ML4, 50mm f/2, 9047B
SITE NAME:	Cutthroat Pass Peak	OBSERVERS:	R Meadows, D Duriscoe
LONGITUDE:	-120.70839	AIR TEMP (°F):	49.5
LATITUDE:	48.56228	REL HUMID (%):	64
ELEVATION (m):	2298	WIND SP (mph):	6
DATE (UT):	August 15, 2012	CCD TEMP (°C):	-20
TIME START (UT):	5:44:42	EXP (seconds):	16
DATA QUALITY:	Good	BORTLE CLASS:	3
		ZLM:	7.1

Table 49b. Summary of night Sky Photometry for each Data, NPS Night Skies Program, Hidden Lake Peaks, 11–12 August 2012.

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	21.86	0.184	0.040	80.9	21.38	21.48	19.97	1.18	1.05	0.72	
2	22.65	0.179	0.034	77.7	21.56	21.29	19.54	1.27	1.14	0.79	Airglow increasing
3	23.56	0.176	0.037	72.9	21.46	21.15	19.08	1.37	1.23	0.85	Airglow increasing further

NARRATIVE: Cutthroat Pass area on the Pacific Crest Trail, set up on mountain summit about 1/2 mile north/northwest of the pass, highest mountain in the area 7500'+. Actual summit too risky for access, but only about 20 degrees to the north is blocked by it from the set up point just to the south on a gravelly slope. Location is not in the park, but close to the boundary on National Forest. Light domes of Seattle area and Vancouver, B.C. area are bright enough to move into Bortle Class 3, Seattle about 20 degrees wide, 10 degrees tall, while Vancouver somewhat brighter and larger, but not much. Haze toward Vancouver in early evening, clearing later, rendering the light dome brighter instead of dimmer as expected. Airglow is moderately bright at start, brightening significantly as the night progresses. Breezy, seeing fair, transparency good. With bright airglow, extending at least to 40 degrees altitude, and less than high quality seeing, ZLM suffers to 6.6, despite the remote location. Zodiacal light barely seen in early morning, airglow even brighter by then. Despite these challenges, this part of the world offers a spectacular view of the night sky and mountain peaks on clear nights.

Table 50. Anthropogenic sky glow observed at Cutthroat Pass Peak, 14 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)
21.9	0.21	0.26	0.19	0.48	0.12	0.29	0.05	0.12	0.14	0.17	281	5.2	6.5	0.12
22.7	0.26	0.32	0.24	0.61	0.14	0.36	0.06	0.15	0.18	0.23	475	8.8	6.4	0.12
23.6	0.33	0.41	0.29	0.73	0.18	0.46	0.09	0.23	0.25	0.31	752	13.9	10.8	0.20

4.22.5 Emerging Issues

Light trespass and glare from within the Ross Lake and Lake Chelan National Recreation Areas may be impairing the wilderness character of nearby areas. These within-park sources should be addressed, either directly if they are within the control of the NPS or through education and communication with the outdoor light owners and operators. Sky glow from the large metropolitan areas of Seattle, WA, and Vancouver, B.C., are impairing the sky quality over the entire park complex, even in remote wilderness areas. Continued growth of the I-5 corridor and the Vancouver and Victoria, B.C., areas may cause a greater impact in the future. The possibility of growth in communities immediately adjacent to the park boundary may pose an even greater threat.

4.22.6 Information and Data Needs–Gaps

Potential impacts from light trespass in the Stehekin Valley should be investigated. A monitoring site near Copper Ridge would provide a "worst case" data point for the park area in terms of anticipated sky glow from external communities.

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Chapter 5 Climate and Climate Change in NOCA

(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 National Park Service 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., 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 years 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 Range divides 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 side of the range (typically the west, southwest, or south) than on the leeward side. Figure 51 shows that the west-facing slopes within NOCA receive the highest precipitation on average due to the predominance of westerly and southwesterly winds in the area that NOCA is located among the Cascade Range. Figure 51 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 52. The record shows substantial interannual and interdecadal variability. Despite this variability, a warming trend is evident in statewide-average temperatures. In contrast, precipitation changes are dominated by year-to-year variability, and 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 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 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. 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. 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 NOCA (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 add up and have large effects on the resources of national parks. Average annual temperature increased 0.8°C in the PNW between 1920 and 2000 (Mote 2003), and the 1st decade of the 21st century (2001–2010) was tied with the previous decade (1991–2000) for the warmest in the PNW 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, the implications of warming for PNW snowpack has been the topic of heated debate, and has 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; Mote (2006) drew similar conclusions using observational data. Nearly all studies of Cascade Range 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) used a simple regression approach to estimate that 71% of the variance in Cascade Range snowpack can be explained by natural variations in large-scale climate. Using a more objective approach, Smoliak et al. (2010) obtained a nearly identical estimate. Mote (2006) did not estimate the combined effect of all modes of variability, but found 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. (2010) estimated that global warming led to a loss of 16% of snowpack between 1930 and 2007, and projected a loss of 9% between 1985 and 2025. Casola et al. (2010) showed 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 estimated a loss of 8–16% 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 NOCA, 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.

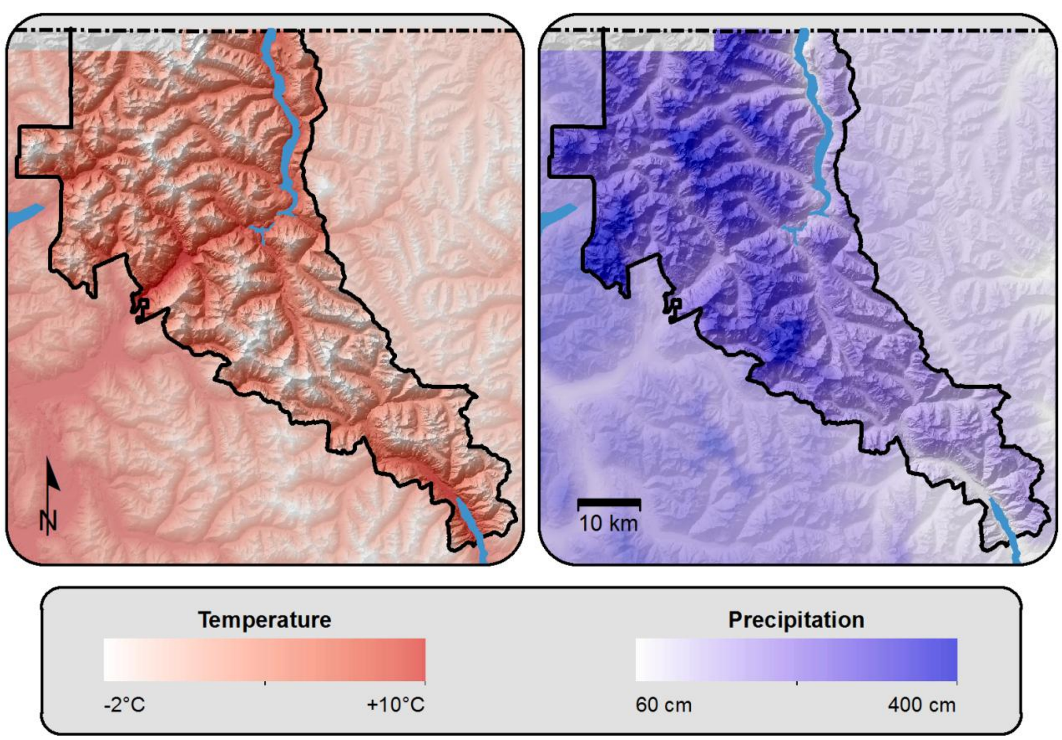

Figure 51. Map of climatological average (1971–2000) temperature and precipitation for North Cascades National Park, obtained at 30 arc-second resolution from PRISM (Parameter Regressions on Independent Slopes Model; Daly et al. 2002). Note that the elevational gradients play a dominant role in climatic variations across the park, and the east-west contrast is evident in precipitation.

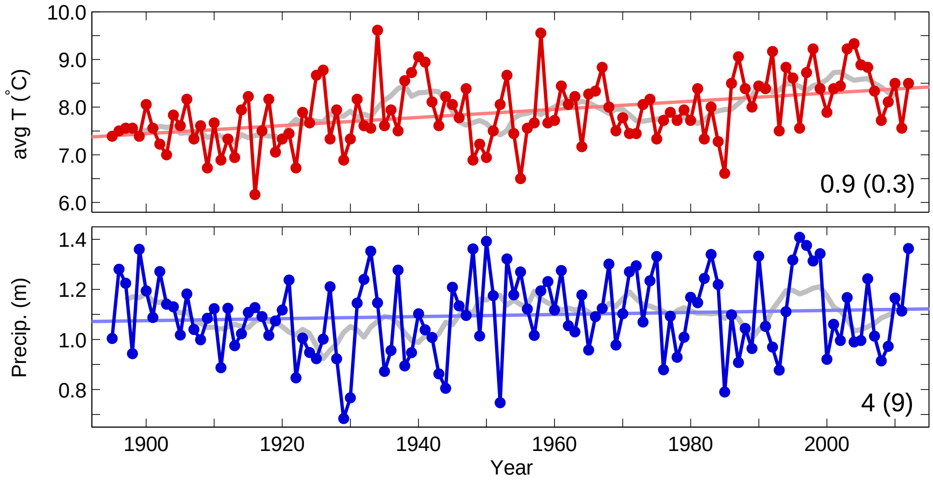

Figure 52. Annual average temperature (top) and annual total precipitation (bottom) for the state of Washington (1895–2012; data obtained from http://www.cefa.dri.edu/Westmap). The linear trend for the entire record is shown (straight red line for temperature, blue for precipitation), along with the 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 NOCA by the NPS and several different agencies or networks (Figure 53, Table 51). This section describes each data source and its treatment (5.2.1), data continuity (5.2.2) and analysis methods (5.2.3).

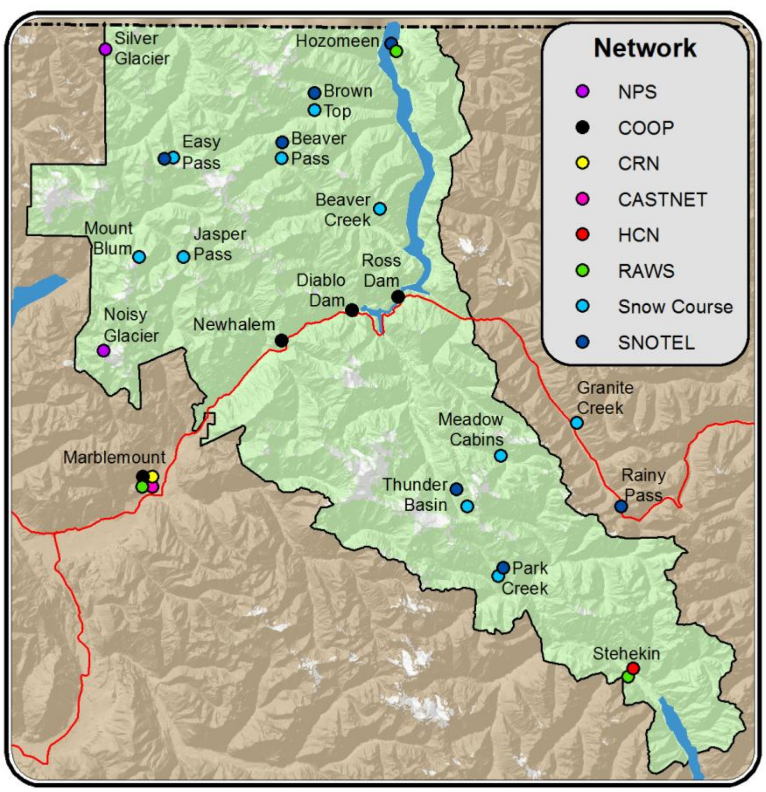

Figure 53. Weather stations by network type in NOCA analyzed in this report.

Table 51. Weather stations in NOCA analyzed in this report, sorted by elevation.

Station Name	Network	ID	Latitude	Longitude	Elev.[1]	Temporal coverage
Silver Glacier	NPS	44	-121.251	48.976	2325	10/2009 to 08/2011
Noisy Glacier	NPS	43	-121.521	48.672	2000	10/2010 to 09/2011
Brown Top	SC	21A28	-121.200	48.916	1829	02/1970 to 05/2011
Brown Top	SNOTEL	1080	-121.200	48.933	1777	10/2009 to 12/2011
Mount Blum	SC	21A18	-121.467	48.767	1768	02/1965 to 06/2011
Jasper Pass	SC	21A06	-121.400	48.767	1646	02/1959 to 06/2011
Easy Pass	SNOTEL	998	-121.430	48.866	1607	10/2008 to 12/2011
Easy Pass	SC	21A07	-121.416	48.867	1585	02/1959 to 06/2011
Rainy Pass	SNOTEL	711	-120.733	48.516	1491	10/1981 to 12/2011
Park Creek	SNOTEL	681	-120.916	48.450	1402	10/1978 to 12/2011
Park Creek	SC	20A12	-120.916	48.450	1402	04/1928 to 04/2011
Thunder Basin	SNOTEL	817	-120.983	48.533	1317	10/1987 to 12/2011
Swamp Creek	SNOTEL	975	-120.470	48.566	1198	10/1999 to 12/2011
Beaver Pass	SC	21A01	-121.250	48.867	1122	03/1944 to 05/2011
Beaver Pass	SNOTEL	990	-121.250	48.883	1107	10/2001 to 12/2011
Granite Creek	SC	20A06	-120.800	48.600	1067	02/1971 to 05/2011
Thunder Basin	SC	20A07	-120.967	48.516	732	02/1949 to 05/2011
Beaver Creek	SC	21A04	-121.100	48.816	671	03/1944 to 05/2011
Meadow Cabins	SC	20A08	-120.916	48.567	579	03/1945 to 05/2011
Hozomeen	RAWS	451412	-121.078	48.981	518	11/2004 to 12/2011
Hozomeen Camp	SNOTEL	991	-121.083	48.983	515	01/2000 to 12/2011
Stehekin	USHCN	458059	-120.720	48.350	387	01/1895 to 12/2011
Ross Dam	COOP	457185	-121.072	48.727	377	09/1960 to 12/2011
Stehekin	RAWS	452121	-120.720	48.347	375	07/2001 to 12/2011
Diablo Dam	COOP	452157	-121.143	48.714	272	12/1914 to 12/2011
Newhalem	COOP	457690	-121.250	48.683	162	04/1909 to 12/2011
Darrington[2]	USCRN	4223	-121.446	48.541	124	04/2003 to 12/2011
Marblemount	CASTNET	NCS415	-121.447	48.540	109	03/1996 to 12/2007
Marblemount	RAWS	451504	-121.446	48.539	109	07/2003 to 12/2011
Marblemount Rng	COOP	454999	-121.450	48.538	106	04/1950 to 05/2011

[1] Elevation is listed in meters (m)

[2] The Darrington 21 NNE USCRN station is often alternately referred to as “Marblemount

5.2.1 Data Sources

Data from 30 stations in proximity to NOCA were analyzed (Figure 53, Table 51). Data were aggregated as follows: (1) hourly data were aggregated to daily only if data were available for all hours of the day; (2) monthly values were only computed for months with at least 22 days of valid data (i.e., <9 days of missing data), except as noted below; (3) annual values were computed if at least 10 months of valid data were available for that year; all 3 months were required to be complete to compute seasonal values; (4) all annual averages were 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, and tests have shown 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 5 COOP stations in the vicinity of NOCA (Table 51): Diablo Dam, Newhalem, Ross Dam, Marblemount, and Stehekin. The latter is designated as an USHCN station (see below).

Data were obtained through NOAA's National Climatic Data Center (NCDC; http://www.ncdc.noaa.gov). Data for different stations were not always available in a monthly format and had to be aggregated from daily and hourly, as follows:

- Monthly; the Diablo Dam (id: 452157), Newhalem (id: 457690), and Ross Dam (id: 457185) COOP temperature and precipitation records were available in monthly format from NCDC;
- Daily; the daily snow depth values for the Diablo Dam, Newhalem, and Ross Dam COOP station were obtained through the daily NCDC utility since those values were not available in a monthly format;
- Hourly; precipitation data from Marblemount Ranger Station (id: 454999) were only available in an hourly format from the NCDC site. The hourly values were processed into monthly data for the station. For this station, it was uncommon for precipitation data to be reported for each day in the month, making it difficult to judge the completeness of the data. It appeared as if zero precipitation was often unreported. As a consequence, the constraint for monthly aggregation was relaxed to at least 14 days of valid data needed to compute a monthly total. As a result of this approximation, additional caution should be used when interpreting these data.

USHCN

A high quality subset of the COOP station data is archived as part of the U.S. 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 – Stehekin (id: 458059) – 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 Stehekin (1906); 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 have not been adjusted as described above, nor has the daily data for all variables for the USHCN stations – these data do not differ from the COOP data for the same station, and are therefore less reliable for assessing trends.

USCRN

The U.S. Climate Reference Network (USCRN; Diamond et al. 2013; Karl et al. 1995; NRC 1999; http://www.ncdc.noaa.gov/crn) is a set of high-quality automated observing stations designed specifically for monitoring 21st century climate change. There is triple redundancy among measurements, and stations are located at fairly pristine locations with a required minimum of open space free from measurement obstructions – specifications designed to ensure reliable long-term climate monitoring. Because this network is new (most installed in the early 2000s), records are not of sufficient length to evaluate trends.

Monthly temperature and precipitation data were obtained for the Marblemount (id: 4223) USCRN station located near the Skagit River about 5 miles beyond the western boundary of NOCA. USCRN sites do not record snow information.

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: (1) through the NRCS main site for daily temperature and precipitation (http://www.wcc.nrcs.usda.gov/snotel); and (2) 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 Beaver Pass (id: 990), Brown Top (id: 1080), Easy Pass (id: 998), Hozomeen Camp (id: 991), Park Creek (id: 681), Rainy Pass (id: 711), Swamp Creek (id: 975), and Thunder Basin (id: 817) SNOTEL sites were accessed using both of these portals. The daily temperature and precipitation data were aggregated into monthly values using the same 22-day threshold for including the month that was used for the other networks. 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 Beaver Creek (id: 21A04), Beaver Pass (id: 21A01), Brown Top (id: 21A28), Easy Pass (id: 21A07), Granite Creek (id: 20A06), Jasper Pass (id: 21A06), Meadow Cabins (id: 20A08), Mount Blum (id: 21A18), Park Creek (id: 20A12), and Thunder Basin (id: 20A07) snow course sites 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 Hozomeen (id: 451412) and Marblemount (id: 451504) RAWS sites. WRCC aggregated the monthly data from the hourly data, and performed basic quality control (QC) on the data. If temperature is <–62°C or >77°C then WRCC flags the value as missing. Similarly, values are flagged as missing if precipitation is <0 in/hr or >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 days. 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 Marblemount (id: NCS415) CASTNET site were downloaded through the EPA site (http://java.epa.gov/castnet).

NPS

The NPS provided recent daily temperature observations (water years 2010 and 2011) for the Noisy (id: 43) and Silver Glacier (id: 44) sites. These were aggregated to annual averages as described above.

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. Table 52 summarizes the month and year of a location move. Note that, unfortunately, the metadata may not always be complete. For instance, the latitude and longitude were missing for many of the stations in the early part of the record, meaning that unrecorded station moves could have occurred – these dates are also listed in the table.

While we present the data from all of the available sites within NOCA, we recommend that only the Stehekin 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 very 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.

Table 52. Dates of station moves or unrecorded station location for COOP observations.

Station	Location changed	Location unknown
Ross Dam	October 2000, April 2002	
Newhalem	December 1958, October 2000	1909–1948
Diablo Dam	March 2004	1914–1948

5.2.3 Analysis Methods

Growing Degree Days

Growing Degree Days were calculated using daily data from the Stehekin 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° to 20°C. Note that the daily USHCN data does not include the adjustments described in 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 ($\pm 2\sigma$).

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 re-weighted 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 ($\pm 2\sigma$).

5.3 Station Data: Observations

5.3.1 Climate Trends at Stehekin USHCN Station

The Stehekin USHCN station is the longest-running weather station in NOCA (1895–2011). In contrast with the other stations, it has also been subjected to a rigorous set of quality control corrections (Menne et al. 2009), 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 Stehekin USHCN station are shown in Figure 54. Although all variables show substantial year-to-year variability, a robust warming trend is evident for minimum temperatures. In contrast, maximum temperature variations appear to be dominated by natural variability, showing a week but not statistically significant cooling trend. Precipitation shows a slight positive trend.

Average annual temperature at Stehekin is highly correlated with year-to-year variations across the PNW as a whole ($r^2 = 0.74$; 2σ confidence limits: 0.63–0.82). However, the warming trend is substantially smaller for the longest-running observations in NOCA. 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 0.1°C/century for Stehekin; neither the Mote nor the Stehekin 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 54 (1896–2012); (2) 1920–2000 (for comparison with Mote 2003); and (3) 1950–2012. Trends and 95% confidence limits are shown in Table 53. Although the general results remain the same, it is evident that trends are quite sensitive to the choice of time period for trend analysis, which is an indication of the importance of natural variability. Nevertheless, there is a consistent pattern of significant warming trends in annual minimum temperatures and accelerated warming for the summer season.

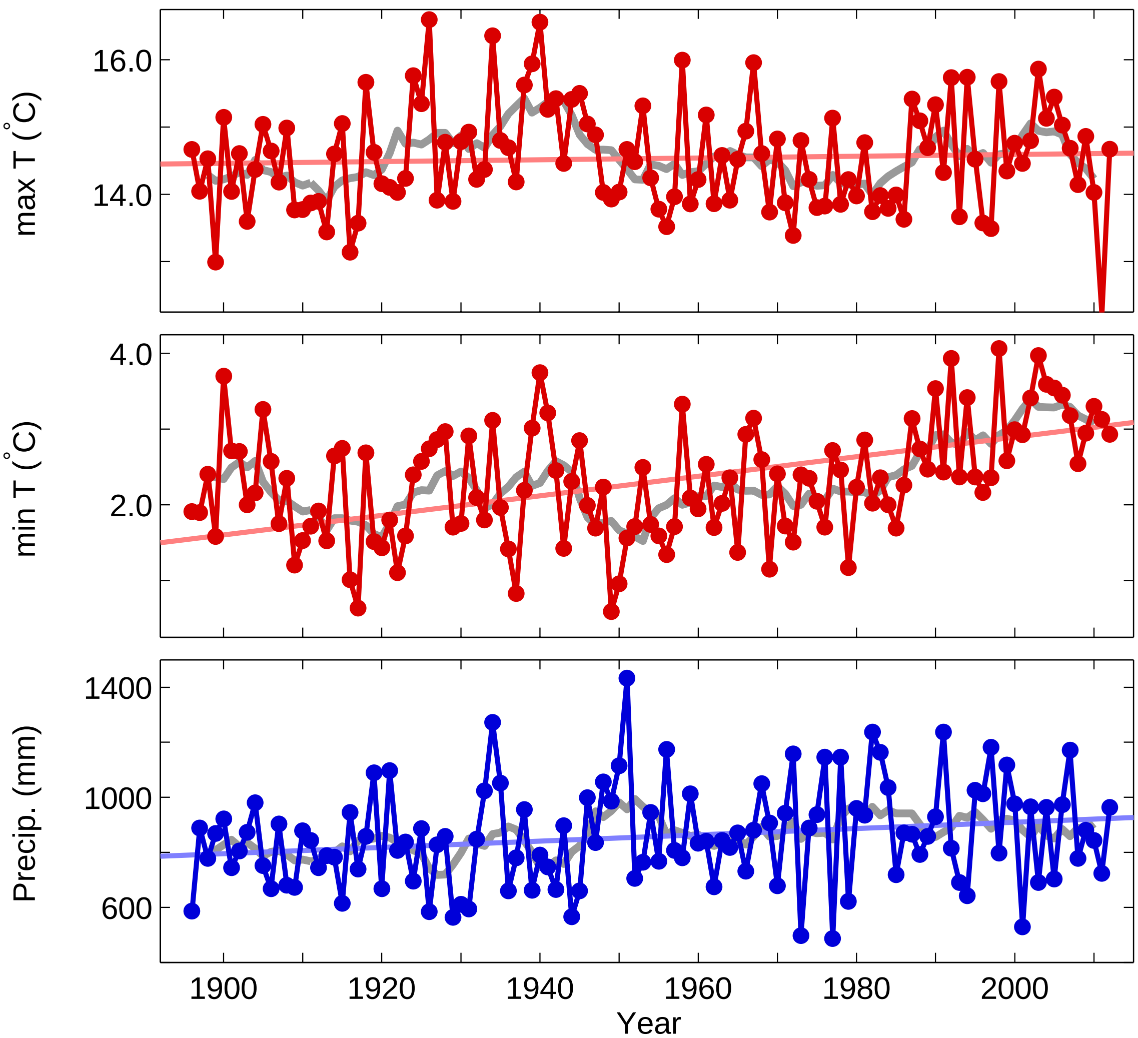

Figure 54. Annually averaged maximum (top) and minimum (middle) temperature, and annual total precipitation (bottom) time series and regression slopes for the Stehekin USHCN station in NOCA for the period of record 1896–2012. Also plotted are the linear trends (faded red and blue lines) and the 9-yr moving average (grey line), showing decadal variations in each variable.

This pattern of warming, robust increases in minimum temperatures accompanied by weak or insignificant trends in maximum temperatures is consistent with observations from elsewhere in the region (Figure 55; OWSC). It is also consistent with the anticipated effect of global warming; by reducing the effectiveness of nighttime cooling, greenhouse gases are expected to cause minimum temperatures to rise more rapidly than maximum temperatures.

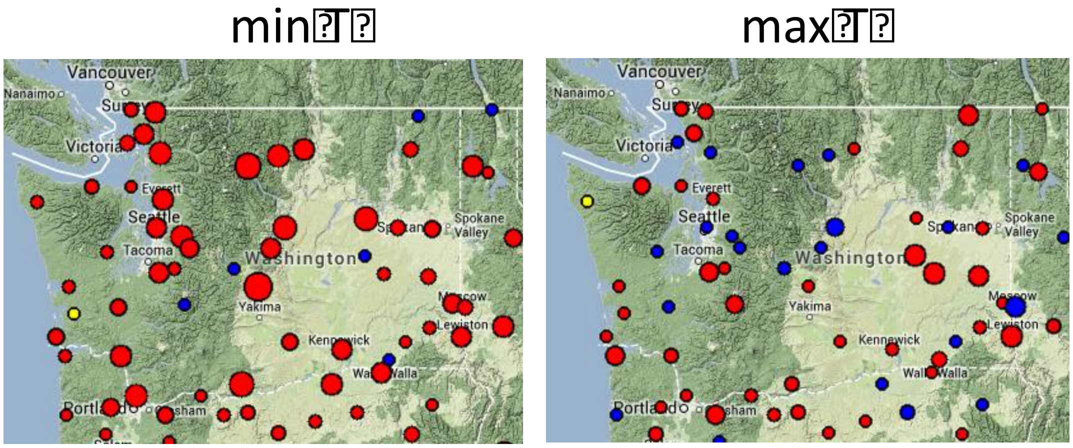

Figure 55. Trends in annual average minimum and maximum temperature for the period of record (1895–2010) at all of the USHCN stations in the state of Washington. The size of the circle indicates the magnitude of the trend at each station; as a reference, the minimum temperature trend for the Ellensburg 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. This figure is from the Office of the Washington State Climatologist: www.climate.washington.edu/trendanalysis.

Table 53. Annual and seasonal trends (± 2σ) in temperature and precipitation at Stehekin. 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	0.4 ± 0.4	0.4 ± 0.8	**1.3 ± 0.5**
	Max. Temp.	°C/century	0.1 ± 0.4	-0.5 ± 0.8	**1.5 ± 0.6**
	Min. Temp.	°C/century	**0.9 ± 0.4**	**1.4 ± 0.9**	**1.1 ± 0.5**
	Precipitation	cm/century	**12 ± 10**	4 ± 7	1 ± 1
1920–2000	Avg. Temp.	°C/century	0.1 ± 0.7	0.2 ± 1.5	0.7 ± 1.0
	Max. Temp.	°C/century	-0.6 ± 0.8	-1.2 ± 1.4	0.6 ± 1.2
	Min. Temp.	°C/century	**0.8 ± 0.7**	**1.7 ± 1.6**	**1.0 ± 0.8**
	Precipitation	cm/century	**22 ± 19**	8 ± 12	3 ± 3
1950–2011	Avg. Temp.	°C/century	**1.6 ± 0.9**	-0.2 ± 1.8	**4.0 ± 1.5**
	Max. Temp.	°C/century	0.7 ± 1.1	-1.5 ± 1.7	**3.5 ± 2.0**
	Min. Temp.	°C/century	**2.7 ± 0.8**	1.3 ± 2.0	**4.5 ± 1.0**
	Precipitation	cm/century	0 ± 29	-5 ± 19	-3 ± 4

5.3.2 Climate Observations Across NOCA

Although observations at Stehekin represent the highest quality and 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 56 shows the annual time series of climate for all stations listed in

Table 51, with the full record at Stehekin 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 Diablo Dam, Ross Dam, and Newhalem COOP stations (Table 54), which are the stations with at least 50 yrs of overlap with Stehekin, show that Stehekin explains about 50–75% of the variance in each variable at both locations. Results are similar for maximum and minimum temperature (not shown). Note that some correlations were computed using <30 yrs of overlapping observations; these are not likely to be robust estimates and should be treated with caution.

Despite the strong relationship between stations, there are also some notable differences. For instance, the Rainy Pass SNOTEL station recorded a markedly cool year in 2001 and again in 2004 that was not generally reflected in other stations, and has since shown a stronger cooling tendency than other locations. Similarly, the Hozomeen camp SNOTEL station appears to have recorded a stronger recent cooling trend. In precipitation, the Marblemount RAWS site recorded an anomalously dry year in 1998; other sites show an occasional excursion from the variability experienced at other sites. In general, however, the degree of agreement among all stations is striking, given the large area and quite disparate elevations.

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 54 will be biased low, and some of the above differences are likely the result of measurement error rather than real physical distinctions between sites.

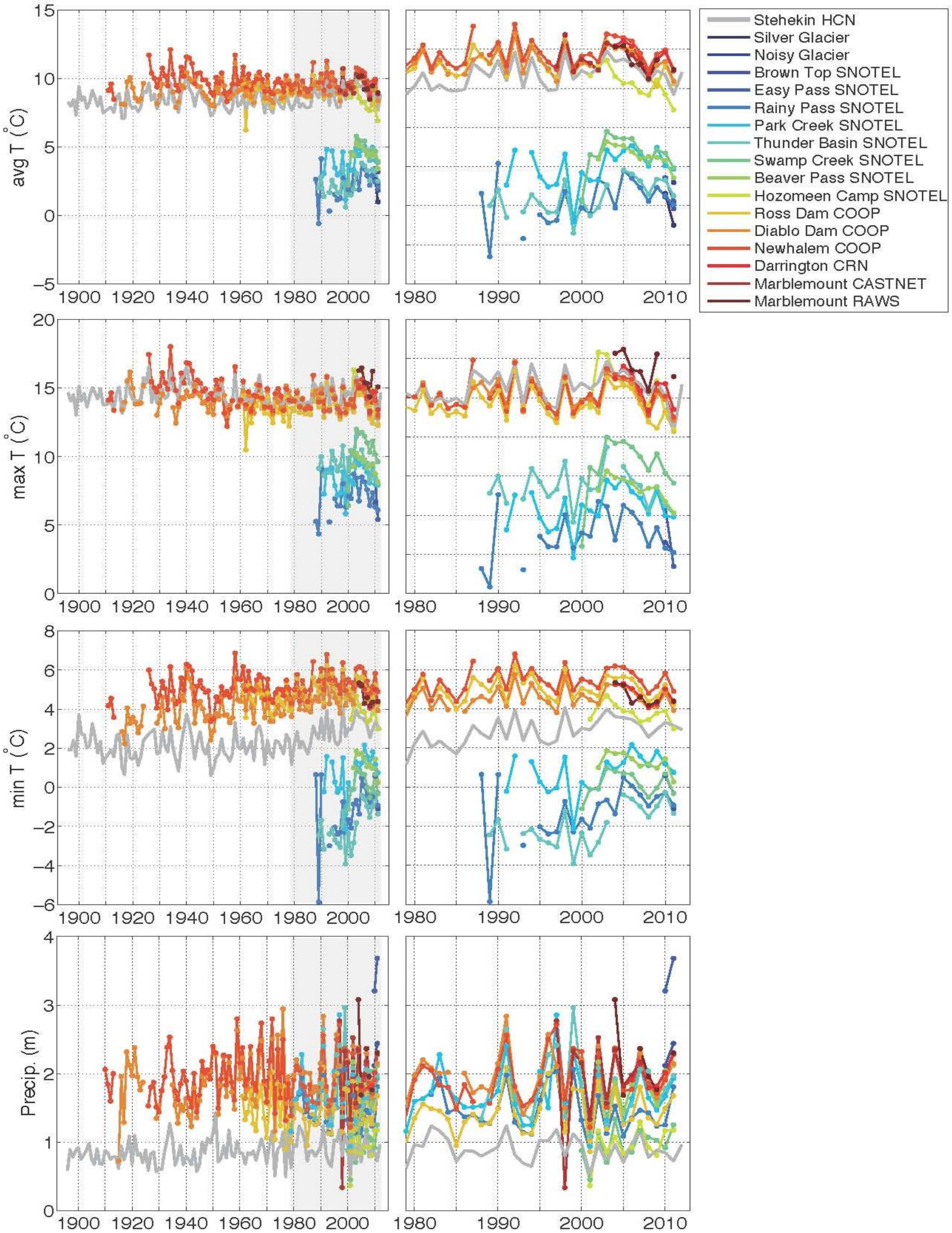

Figure 56. Time series of annual climate observations at all of the stations listed in Table 51. Plots are shown for the annual time series of average temperature (top), maximum temperature (2nd row), minimum temperature (3rd row), and precipitation (bottom). The full record at Stehekin is shown for 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 Stehekin, which is labeled in grey.

Table 54. Correlations (r^2, 95% confidence bounds, and the sample size for each correlation) with the Stehekin USHCN station for all stations with at least 20 yrs of overlap with the Stehekin record. Correlations were calculated for the full record in each case, and are accompanied by the 95%.

Station	Avg T	Precipitation
Rainy Pass SNOTEL	0.42 (0.09-0.71; N=21)	0.59 (0.31-0.78; N=30)
Park Creek SNOTEL	0.40 (0.07-0.71; N=20)	0.66 (0.43-0.82; N=33)
Thunder Basin SNOTEL	0.35 (0.05-0.67; N=21)	0.66 (0.37-0.84; N=24)
Ross Dam COOP	0.60 (0.41-0.75; N=51)	0.55 (0.34-0.71; N=51)
Diablo Dam COOP	0.68 (0.55-0.78; N=88)	0.54 (0.39-0.67; N=90)
Newhalem COOP	0.71 (0.59-0.80; N=88)	0.54 (0.38-0.67; N=89)

5.3.3 Snow Observations

Fewer observations of snow are available than for temperature and precipitation, but there are nonetheless good, high-quality, long-term records. Figure 57 shows the time series for April 1 snowpack (both snow depth and snow water equivalent) for the stations reporting snow observations. Snow water equivalent (SWE) 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 compatibility with Figure 56, the plots in Figure 57 are shown for the same time periods (1896–2012, 1980–2012). Linear trends for April 1 are included in Table 59.

Figure 57 shows that the different records share very similar year-to-year variability. Correlations (r^2) among all stations with at least 30 yrs of overlap range between about 0.45–0.75 for snow depth and 0.25–0.80 for SWE, though only 7 out of the 36 SWE correlations are below 0.5. As with temperature and precipitation, this suggests strong covariation across the park.

There are significant trends declining in snow depth and SWE at Beaver Pass, Thunder Basin, and Meadow Cabins (Figure 57, Table 55) with all showing declines over the last half century. Other stations generally show the same sign of changes but the trends are not statistically significant.

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 59; 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 time series in Figure 58 stems from a low-resolution data set, and therefore apply broadly to NOCA as a whole. The results show substantial year-to-year variability, but also a noticeable tendency toward higher freezing levels. The trend for the period of record (1949–2013) is a rise in the snowline of 230 ± 120 m/century (95% confidence limits). Note that freezing level is derived from a low-resolution dataset (see 5.2.3–Growing Degree Days) and therefore represents an average for the general region of NOCA.

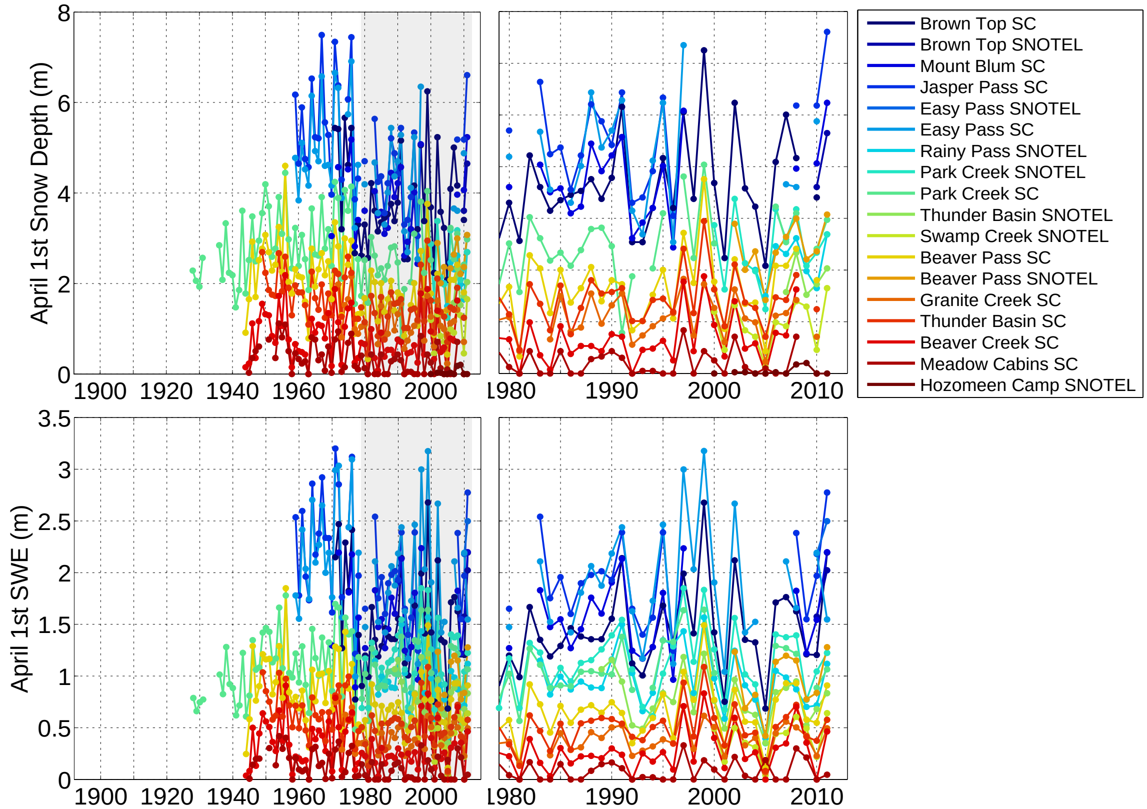

Figure 57. Time series of annual April 1 snow observations at observing stations in NOCA. Plots are shown for snow depth (top row) and snow water equivalent (SWE; bottom row) for the 6 stations reporting snow observations within the park. Only stations with average April 1 snow depth >10 mm are shown. For compatibility with Figure 52, plots are shown for the full record at Stehekin (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).

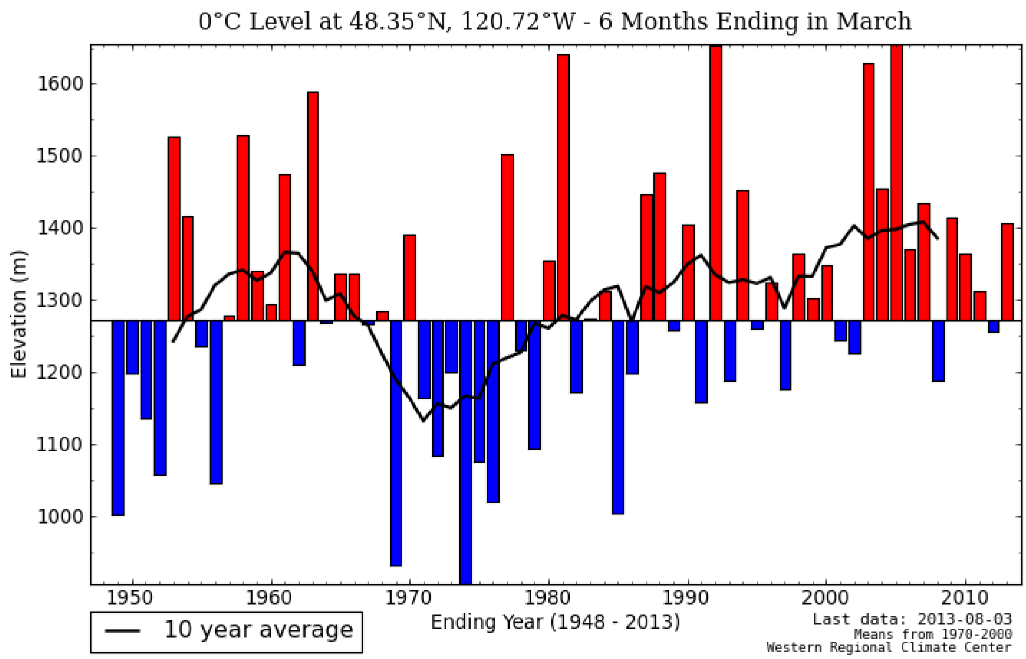

Figure 58. Time series of freezing level (elevation of 0°C isotherm) for NOCA. Obtained from the U.S. Western Regional Climate Center North American Freezing Level Tracker.

Table 55. Trends (± 2σ) in April 1 SWE and Snow Depth for all stations with at least 30 yrs of valid data. Trends are calculated for the period of record for each station as well as, if possible, for 1950-present. All trends are in cm/century, and are highlighted in bold if significant at the 95% confidence level.

		Linear Trend	
Station	**Years**	**Snow Depth**	**SWE**
Brown Top SC	1971–2010	-100 ± 330	-30 ± 140
Jasper Pass SC	1959–2011	-220 ± 270	-97 ± 120
Easy Pass SC	1959–2010	-220 ± 260	-70 ± 110
Park Creek SNOTEL	1979–2011	--	44 ± 130
Park Creek SC	1928–2011	11 ± 88	30 ± 33
Beaver Pass SC	1944–2010	**-140 ± 90**	**-49 ± 38**
Granite Creek SC	1971–2010	-100 ± 140	-19 ± 49
Thunder Basin SC	1949–2010	**-120 ± 72**	**-45 ± 29**
Beaver Creek SC	1944–2010	-54 ± 72	-14 ± 29
Meadow Cabins SC	1945–2010	**-72 ± 44**	**-22 ± 17**
Ross Dam COOP	1961–2011	0 ± 0.4	--
Diablo Dam COOP	1915–2011	0 ± 0.6	--
Newhalem COOP	1929–2011	0 ± 0	--
Park Creek SC		-110 ± 130	-19 ± 50
Beaver Pass SC	1950–2011	**-170 ± 106**	**-55 ± 43**
Thunder Basin SC		**-110 ± 72**	**-40 ± 29**

Table 55. Trends (± 2σ) in April 1 SWE and Snow Depth for all stations with at least 30 yrs of valid data. Trends are calculated for the period of record for each station as well as, if possible, for 1950-present. All trends are in cm/century, and are highlighted in bold if significant at the 95% confidence level (continued).

		Linear Trend	
Station	**Years**	**Snow Depth**	**SWE**
Beaver Creek SC		-72 ± 80	-20 ± 32
Meadow Cabins SC		**-86 ± 50**	**-27 ± 19**
Diablo Dam COOP		0 ± 0.1	--
Newhalem COOP		0 ± 0.1	--

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 Stehekin USHCN station (Figure 55; note that the daily USHCN is unadjusted, see 5.2.1-USHCN above). Since definitions of GDD differ, we include results for 3 different base temperatures: 0°, 10°, and 20°C. Different choices of base temperature are more suitable for different organisms. Note that temperatures >20°C are less frequently reached at Stehekin, 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). In percent terms, these indicate an increase of approximately 10, 25, and >100% for the 0°, 10°, and 20°C base temperatures, respectively. In other words, the warming trends appear to be greatest for the warmest temperatures.

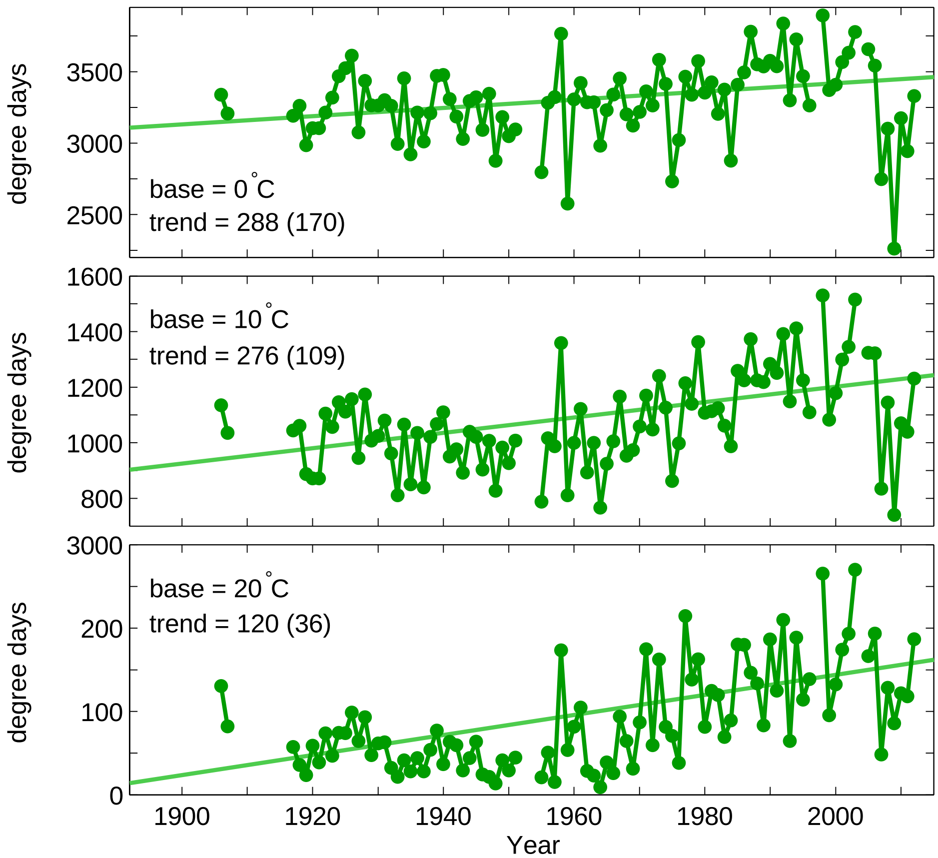

Figure 59. Trends in annual total Growing Degree Days (GDD), computed using daily temperature data from daily climate observations at Stehekin. Since definitions of GDD differ, we have included the results using 3 different base temperatures: 0°C (top), 10°C (middle), and 20°C (bottom). Linear trends 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.

5.4 Climate Projections for Cascadia

Future climate in NOCA 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 60). These 30-yr "windows" are a good way to characterize climate trends because interannual variability dominates over shorter time periods. The 2 emission scenarios in Figure 60 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 61). For the Pacific Northwest, the seasonality of those changes is very important to the resources of the region. Figure 61 shows expected changes by season, with most models projecting increases in winter, spring, and fall (+2 to +5% depending on season), and most models projecting 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 61); however, more models project drier summers and wetter climate in winter, spring, and fall. These trends may be indistinguishable from the substantial year-to-year and decade-to-decade 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 Stehekin 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 toward 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. Because 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, and 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 62; Omernik 1987), rather than summarizing averages for the park as a whole.

Table 56 lists historical averages and projected changes for warm and cool season temperature, and precipitation for April 1 snowpack for 3 Omernik ecoregions that correspond approximately to NOCA. 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).

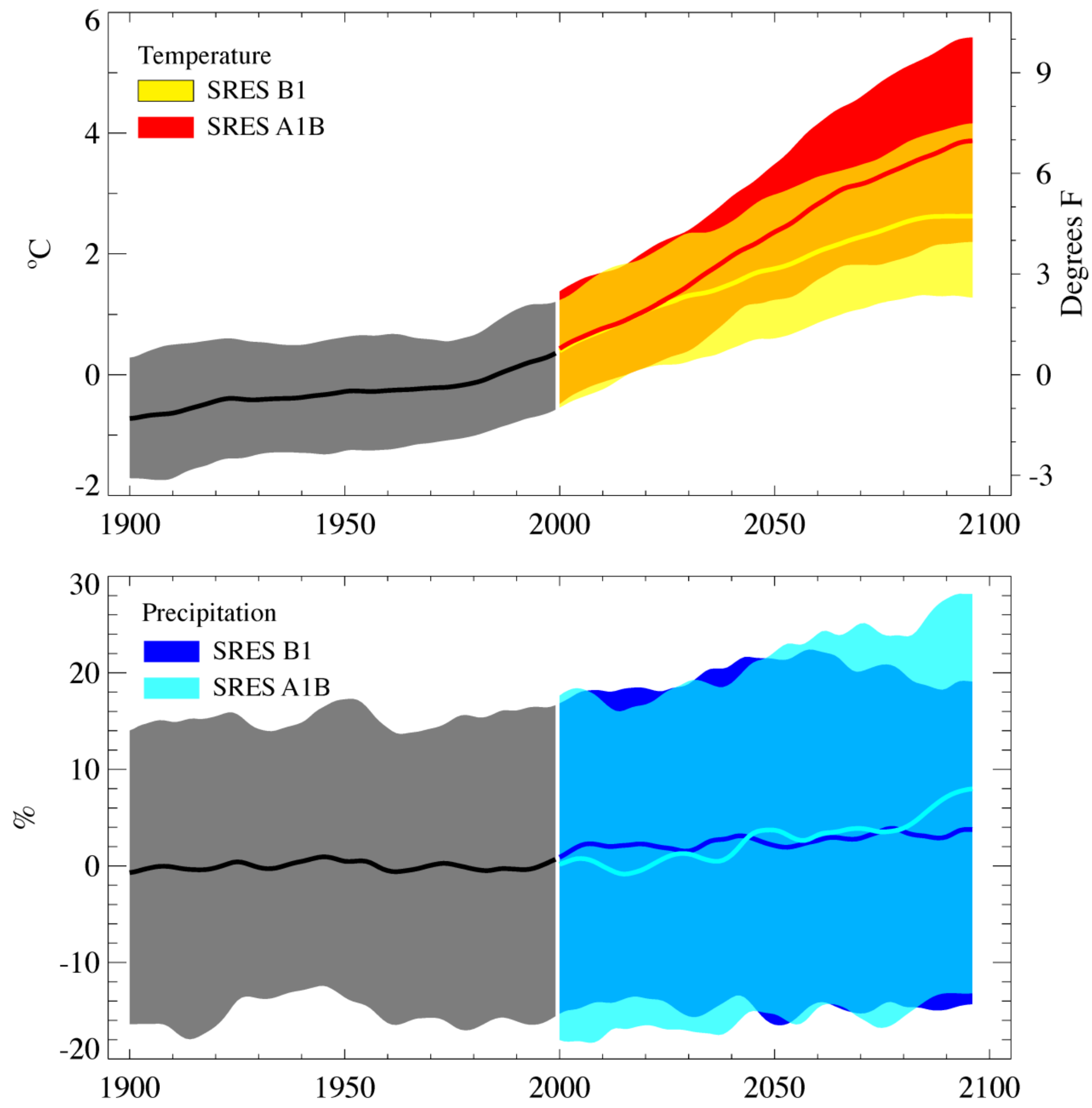

Figure 60. Modeled historical and expected PNW temperature for the 20th and 21st centuries. The darker lines show the average of all models during the 20th century (black) and for the 21st century (yellow and red). The colored lines are the average of all models for 2 greenhouse gas emissions scenarios ("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.

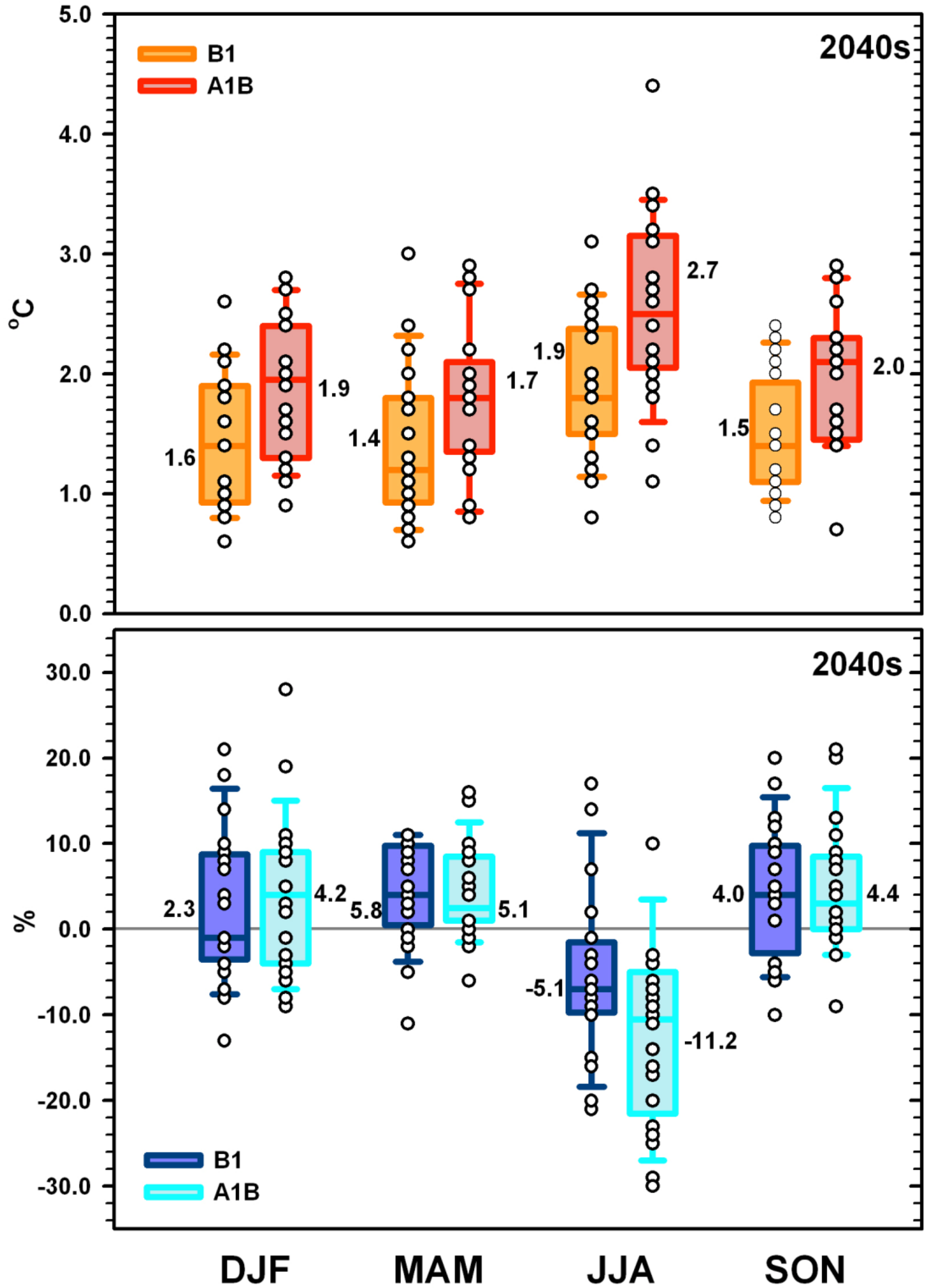

Figure 61. Range (lowest to highest) of projected changes in temperature for each season (DJF = winter, etc.), relative to the 1970–1999 mean. In each pair of box and whiskers, the left one is for greenhouse gas emissions scenario B1 (lower emissions) and the right is A1B (higher emissions); circles 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 62. Omernik Level III ecoregions (Omernik 1987) used to summarize climate projections for the park.

Table 56. 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	-0.9	-3.0
	+1.7 (0.8 to 2.4)	**+1.8 (0.9 to 2.5)**	**+1.9 (1.1 to 2.5)**
JJA Temp (°C)	16.6	16.3	13.3
	+2.6 (1.7 to 3.8)	**+2.6 (1.8 to 3.9)**	**+2.6 (1.7 to 3.9)**
Oct–Mar Precip	850 mm	360 mm	1410 mm
	0% (-8 to +7%)	+1% (-7 to +10)	+8% (-1 to +22%)
Apr–Sept Precip	220 mm	130 mm	440 mm
	-5% (-13 to +4%)	-5% (-12 to 0%)	-8% (-18 to +1%)
April 1 SWE	85 mm	15 mm	490 mm
	-57% (-79 to -29%)	**-74% (-93 to -36%)**	**-30% (-49 to -23%)**

5.5 Discussion and Conclusions

In this report we evaluated the historical and possible future climate of NOCA 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, minimum temperatures are increasing sharply in NOCA. The trends are less evident for maximum temperature, a pattern which is consistent with observations elsewhere in the PNW. All trends for temperature show a tendency toward 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.

Unfortunately, the number and distribution of long-term climate stations with records that are of sufficient 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 the use of different instruments have likely occurred in the record, introducing further bias. Of all the weather and climate observing stations in NOCA, only Stehekin is of sufficient quality and duration to qualify for the U.S. Historical Climate Network (USHCN; Karl et al. 1990) – a subset of the 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 such as 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 above) 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 and 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 NOCA.

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 toward drier summers and wetter winters. These changes have important implications for water stress and ecosystem health. These changes, though useful, also 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, although 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 NOCA 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, NOCA) 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 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.

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Chapter 6 Discussion

6.1 NOCA Natural Resource Condition

Data used to complete the assessments of the conditions of the NOCA natural resources included in this report have been collected over varying temporal and spatial intervals. Some data, such as for 25 stream habitat attributes and benthic macroinvertebrates, have been collected over relatively long-time intervals (e.g., 1995–2004) from sites throughout the park (e.g., 127 stream sites). Other data, such as for multiple water quality parameters, although collected from 37 lakes and ponds throughout the park, were collected during inventories conducted over relatively short-time intervals (e.g., 2006–2010). 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 relative 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 57.

Table 57. Scale and definitions for condition levels of assessed resource categories.

Scale	Definition
0	Insufficient data for estimating condition based on level of disturbance
1	No net loss to minimal documented signs of limited and isolated change-degradation
2	Documented signs of moderate, generalized change-degradation
3	Documented signs of widespread and potentially uncontrolled change-degradation
4	Documented signs of potentially catastrophic and irreparable change-degradation

Of the 20 resource categories that had sufficient data for predicting level of disturbance, 90% (n = 18) show some documented signs of moderate to significant change and degradation; and 6 of these categories are estimated to have been seriously to significantly disturbed (Table 58). A more detailed summary of the overall disturbance and condition of each natural resource assessed as part of this report is presented in the following sub-section of Chapter 6.

Table 58. Estimated conditions of NOCA natural resource categories based on assessed level of disturbance.

Category	Disturbance-level	Condition
Air Quality – Ozone	Minimal	1
Air Quality – Visibility	Moderate	2
Air Quality – N-S deposition	Serious	3
Air Quality – PBT deposition	Serious	3
Lake Water Quality	Moderate	2
Stream Water Quality	Moderate	2
Landscape-scale Vegetation Dynamics	Moderate	2
Forest Health – Disturbance Regime	Serious	3
Forest Health – Whitebark Pine	Significant	4
Forest Health – Air Quality	Moderate	2
Fire Ecology	Moderate	2
Biodiversity – Exotic Plants	Serious	3
Biodiversity – Wetlands	Insufficient data for predicting level of disturbance*	0
Biodiversity – Alpine-Subalpine Vegetation	Moderate	2
Biodiversity – Sensitive Vegetation Species	Moderate	2
Amphibians	Moderate	2
Fish	Moderate	2
Land Birds	Moderate	2
Mammalian Fauna (Biodiversity)	Insufficient data for predicting level of disturbance	0
Mammalian Carnivores	Insufficient data for predicting level of disturbance	0
Hoary Marmots-American Pika	Insufficient data for predicting level of disturbance	0
Bats	Insufficient data for predicting level of disturbance	0
Glaciers	Serious	3
Soundscape	Minimal	1
Dark Night Skies	Moderate	2

* The Washington Natural Heritage Program has developed a GIS model to assign each NWI wetland polygon a condition score based on adjacent land use. The layer is now available and is an initial data source for completing an analysis of wetland condition.

Although only 6 resource categories were assessed as being seriously to significantly disturbed, many, if not all, of the NOCA 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 toward 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). NOCA 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, NOCA 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

6.2.1 Air Quality and Air Quality-related Values

The assessment indicates that the level of resource disturbance by ozone at NOCA has been minimal; changes in visibility have moderately affected air quality; and nitrogen-sulfur (N-S) and persistent bioaccumulative toxics (PBT) deposition have seriously affected NOCA resources. There was no trend in ozone at NOCA from 1999–2008. Kohut (2004) assessed the risk of ozone-induced foliar injury at NOCA based on species sensitivity, ozone concentrations, and soil moisture (which influences ozone uptake), and concluded there was low risk of injury due to ozone. During the period 1999–2008, the NPS Air Resources Division reported no change in visibility at NOCA; the average haze-index (2005–2009) indicated that NOCAs current visibility was still 43% hazier than natural conditions. Based on 1999–2008 NADP wet deposition data, there is a decreasing trend in S concentration, but no trend in N concentration at NOCA. Analysis of long-term data for 1989–2007 indicates a significant decrease in the concentrations of both S and N in precipitation at the park. NOCA was among the parks with the lowest monitored S and N concentrations in precipitation. Sullivan et al. (2011a, 2011b), however, determined that NOCA was at high risk for surface water acidification and N enrichment. Multiple PBTs associated with agriculture have been detected in snow, conifer needles, and lichens at NOCA, and mercury and low concentrations of 2 organochlorines have been detected in fish. The concentrations of mercury in NOCA fish have been determined to exceed human and wildlife health thresholds.

6.2.2 Lake Water Quality

NOCA lakes, overall, can be rated as being minimally disturbed by non-stochastic natural perturbations or human activities. However, 51 lakes have been identified as being of management concern, and 17 of these lakes have been ranked as being at moderate to high risk of impairment due to non-stochastic natural perturbations or human activities; 8 lakes are considered threatened. NOCA 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 either nitrogen limited (21 of 32 lakes analyzed) or co-limited (nitrogen-phosphorus; 8 of 32 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. For example, the potential effects of inorganic nitrogen and sulfate deposition include episodic or chronic acidification, and, with respect to nitrogen, possible lake eutrophication or increased productivity. The primary influence on lake acidity at NOCA 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. 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 that occur across the NOCA landscape. Climate change continues to be a global, regional, and local threat to aquatic ecosystems, which could potentially result in chronically degraded lake water quality due to episodes of climate-induced stress related to changes in precipitation and temperature regimes. Even small changes in precipitation and temperature could have detrimental effects on the physical, chemical, and biological characteristics of NOCA lakes.

6.2.3 Stream Water Quality

Five separate stream surveys have been conducted at 127 NOCA stream sites, 1995–2004. Data collected included measurements of 25 physical attributes useful in characterizing the conditions of streams. The data from these surveys will be useful for creating general reference conditions to which future survey results can be compared. A predictive model based on benthic macroinvertebrate (BMI) occurrence was also developed for assessing the condition of NOCA stream sites. BMI were collected from 95 reference sites and the results of the cluster analysis of the data were used to identify 8 reference site groups with relatively different environmental attributes. The observed/expected (O/E) scores for most (n = 86) of the reference sites were determined to be either in good reference condition (unimpaired) or richer in taxa than expected for a site in unimpaired condition. O/E scores were also calculated for 62 test sites; 50 sites were on NPS and USFS managed lands, and 12 sites were on private or Washington Department of Natural Resources (WDNR) managed lands. For all NPS and USFS reference and test sites combined, 89% were determined to be unimpaired or better than unimpaired, indicating that NOCA stream sites are predominantly in relatively pristine condition. An important caveat is that up tp 70% 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 19 catchments have been ranked as threatened. In addition, climate change, especially changes in precipitation and temperature regimes, could, in the future, negatively affect the health of NOCA streams, causing their physical, chemical, and biological characteristics to degrade.

6.2.4 Landscape-scale Vegetation Dynamics

There are 38 Ecological Systems (ES) vegetation classes in NOCA, indicating that park vegetation is quite diverse. Classes include maritime to Rocky Mountain forest types, low elevation Douglas-fir forests to subalpine forests and meadows, alpine meadows, and a variety of wetland and rocky habitat types. Of the ESs present in the park, 4 are nationally significant in that more than 20% of the national inventory is in the park. All of these classes are limited to the naturally rare habitat of north Pacific subalpine or alpine areas. None of the park ES classes are globally threatened, but 6 classes are ranked between vulnerable (G3) and apparently secure (G4). Of these, 3 are wetland-riparian classes that have trees or shrubs, 2 are forests, and 1 is a subalpine meadow class. There is presently no description of trends in park-wide vegetation pattern, although a preliminary park-wide vegetation map has recently been completed by the NCCN I&M program that can serve as a baseline for assessing future changes in pattern. Nevertheless, wetlands are undoubtedly of management concern because they are identified as significant resources in NOCA enabling legislation, they are vulnerable to climate change, and some classes have the poorest global conservation status of any vegetation class in the park. Several forest types may also be worthy of concern. Finally, the subalpine meadow class ES 7157 may also be significant to park management because it is globally and nationally significant, and is subject to invasion by Subalpine Fir when snowpack is low.

6.2.5 Forest Health: Disturbance Regime

NOCA forests and the forest buffer surrounding the park have experienced relatively widespread damage since 1985 caused by native and introduced insects (93.1% of damage in NOCA), physical disturbances (3.9%), diseases (1.3%), and unknown causes (1.7%). While disturbance has been widespread during the period 1986–2011, most of the damage has occurred at lower elevations and along the drier eastern and southern sides of the complex, especially in the vicinity of Ross Lake, Bridge Creek and Lake Chelan.

6.2.6 Forest Health: Whitebark Pine and White Pine Blister Rust

The Northern Rocky Mountain Subalpine Woodland Park, which is the class most associated with Whitebark Pine in NOCA, covers 151 km^2 (58 mi^2) or 5.5% of the park. It occurs at high elevation in the eastern part of the park. Based on field data collected from plots in 2009, 39% of mature trees are infected and mortality is 29%, while 21% 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).

6.2.7 Forest Health: Air Quality Effects

Lichen samples were used to assess the potential effects of nitrogen (N) and sulfur (S) compounds on NOCA vegetation. At 3 sites rated as best on a 6-step scale, 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; however, 1 site at Marblemount was rated only as fair. Ozone concentrations in NOCA are low and 12 ozone-sensitive vascular plant species occur in the complex. Concentrations of all semi-volatile organic compounds (SOCs) measured in samples of lichens and conifer needles from NOCA were at or above the median values for the 20 western national parks sampled by WACAP (Landers et al. 2008). Dominant SOCs were polycyclic aromatic hydrocarbons, pesticides; endosulfans, dacthal, hexachlorbenzene, and organochlorides a-HCH and g-HCH. Because needle productivity is high at NOCA, the ecological effects of cumulate SOCs contributed by needle litterfall are a potential concern. NOCA was among the parks for which mercury in lichens was not measured in the WACAP study. However, mercury levels in parks where samples were analyzed were not above background values measured in remote sites across the western United States. The potential consequences for plant species and the park ecosystem, especially for SOCs and mercury, is unkown. The trend of increasing pollutant concentrations has not apparently impacted vegetation in NOCA to date.

6.2.8 Fire Ecology

The NPS fire records document a total of 611 fires in the park between 1960 and 2011. The majority of fires (68%) were lightning caused, compared to 30% caused by humans, and 2% which lack data regarding cause. The majority of fires (77%) were suppressed, compared to 7% that went out naturally and 15% that were managed for resource benefit (referred to as “prescribed natural fire” or “wildland fire use”). The historic natural fire rotation for NOCA is presumed to be much smaller than the NFR calculated for the park between 1960 and 2011 (1185 yrs) since the natural fire rotation in even the longest fire interval group is estimated at 450 yrs. All of the modern fire suppression era calculations suggest that fire suppression has had some impact on the natural fire rotation of NOCA and that the natural fire rotation 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 NOCA. 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.

6.2.9 Biodiversity: Exotic Plants

More than 225 non-native species have been observed in NOCA, of which 40 are considered current management priorities; 18 are high priority taxa, 17 are second priority, and 5 are third priority. Of the 225 species, 27 are classified as noxious by Washington State. Based on a reference condition of zero non-native species, the presence of 225 non-native species indicates a substantial increase in the invasion of non-native species into NOCA.

6.2.10 Biodiversity: Wetlands

According to the NOCA wetland map, there are 836 ha (2066 ac) of wetland vegetation present in the complex (excluding reservoirs and lakes). Wetland types include riverine wetlands, freshwater lakes and ponds (lacustrine), and freshwater emergent and freshwater forested-shrub wetlands (palustrine). At present there is no information to describe wetland trends in NOCA. 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. None of these factors are especially relevant to NOCA. However, there may have been historic alteration of wetlands near roads and trails and administrative areas of the park.

6.2.11 Biodiversity: Subalpine Vegetation

The NOCA landscape comprises 31.7% of vegetation classes that span the ecotone from continuous forest, through tree clumps and krummholz, to alpine meadows. We detected no dramatic changes in tree distribution upon examining time series of aerial photography and satellite imagery for 2 subalpine meadows in NOCA over the period 1958 to 2009. However, an intensive examination of photographs and imagery for a meadow on Goode Mountain in the southwestern part of the park did detect changes in tree cover and treeline position. These changes were associated with an increase in growing season temperature, variable amounts of precipitation and a decline in snowpack over the study period. These results correspond to other studies showing increasing tree establishment in subalpine meadows elsewhere in the Pacific Northwest.

6.2.12 Biodiversity: Sensitive Vegetation Species

There are currently 23 species having conservation status of 'vulnerable' or higher among species documented or suspected to occur in NOCA; 7 other species are to be watched because they may become vulnerable. Of these, 3 species are considered globally vulnerable (*Botrychium paradoxum, Erigeron salishii, Iliamna longisepala*) and 2 are globally vulnerable to imperiled (*Botrychium pedunculosum, Silene seelyi*). *Silene seelyi* is endemic to the Wenatchee Mountains and is threatened mainly by rock climbers. *Iliamna longisepala* is also endemic to Washington State and is threatened by fire suppression because this practice allows stands of trees to replace suitable open habitat. Note that while *Silene seelyi* and *Iliamna longisepala* are on the plant list for the park, they have not been found in the park (Mignonne Bivin, NOCA, pers. comm.). Also, Whitebark Pine is a candidate to be listed under the federal Endangered Species Act. Among the sensitive species documented or suspected to occur in NOCA, 5 changed status from 'sensitive' to 'threatened' since 1997, while 7 have been downgraded from threatened to sensitive or removed from the list to 'watch' status. Improved status is most commonly due to the location of previously unknown populations while degrading status most likely reflects loss of habitat and as such does not provide insight into the status or vulnerability of populations within the park complex (i.e. status changes are generally based on the entire state of Washington). Several surveys of non-vascular plants have been conducted in localized areas of NOCA, specifically areas thought to be vulnerable to rock-climbing, bouldering and road maintenance activities. Macrofungi have been more widely documented in the park, but not in a systematic survey. Although these efforts are limited, surveys discovered several species of importance to Washington Natural Heritage Program. There is insufficient information to begin to describe trends in non-vascular plants or macrofungi.

6.2.13 Amphibians

All amphibians with reasonable potential to occur in NOCA have been detected in the park with perhaps 1 exception, the Western Red-backed Salamander, which occurs near NOCA and has some potential to occur in lower elevation wooded areas on the western slopes of the Cascade Range. Also, *Ensatina eschscholtzii*, a terrestrial species, has only been reported in the Stehekin portion of NOCA, most likely because we have not found records for appropriate *Ensatina* inventories in NOCA other than in the Stehekin Valley. Pond and stream inventories with good spatial coverage have been completed. Nearly all lentic habitats have been surveyed for amphibians and a large number of streams have been sampled. The main species for which there is some concern regarding their conservation status are Cascades Frog, Columbia Spotted Frog, and Western Toad. The concern for these species is due to declines in other parts of their range rather than any information that they are declining in NOCA. The continued presence of introduced nonnative fish in NOCA lakes remains a source of potential negative impact on amphibian species and populations. Climate change also could contribute to the decline of amphibian species and populations in NOCA.

6.2.14 Fish Species in Streams and Lakes

Although only 6 fish species were observed during the 2001 through 2003 surveys, 21 additional species have been reported as present in NOCA rivers and streams. In addition, 5 salmonid species have been at one time or another stocked into NOCA mountain lakes. Of these 27 species, 10 have assigned to them some level of special conservation or management concern at the state or federal levels, which makes their presence in NOCA an important contribution to the continued survival of each species. Bull Trout are 1 of 2 char species (the other being Dolly Varden) native to the western U.S., and are considered threatened and endangered at least partially within their range. In NOCA, resident Bull Trout have been documented as present in 14 tributaries above and below the Skagit River dams, and individuals expressing an anadromous life history are historically known to spawn in 2 Skagit River tributaries below the dams. NOCA Bull Trout have a low level of genetic introgression indicating that the population is relatively stable. Nine stocks of 5 Pacific Salmon species and Steelhead are present in NOCA (Baker, Cascade, and Skagit Rivers). The overall importance of these NOCA stocks is that 6 of them have been found to be genetically distinct from all other stocks to which they have been compared. Four additional species are considered by WDFW to be either a sensitive species of concern (Pygmy Whitefish) or a state monitored species (Salish Sucker, Slimy Sculpin), or by COSEWIC as endangered (Nooksack Dace in British Columbia). The presence of populations of these species in NOCA represents an important contribution to the continued viability of each species within its range. Native Westslope Cutthroat Trout in the NOCA Stehekin River basin, although not a species of concern in Washington, are being affected by hybridization with introduced Rainbow Trout. One detrimental outcome of this hybridization is that introgression will increase below upstream passage barriers causing non-hybrid Westslope Cutthroat Trout to decline. Finally, in response to the overall potential negative effects of stocked fish on the native biota of NOCA mountain lakes, park management has finalized the Mountain Lakes Fishery Management Plan (NPS 2008) designed to limit the effect of introduced trout. Although the preferred alternative management strategy would allow the presence of fish in 42 lakes, implementation of this alternative would require Congressional action which has not yet occurred. At present, NOCA management is operating under Alternative D, the strategy requiring that all 91 lakes historically stocked be returned to their fishless condition.

6.2.15 Land Birds

There are 222 bird species in NOCA according to the NPSpecies database. Because of the large number of species that occur in the park, we focused this assessment on 73 bird species of management concern because management and monitoring of all species is logistically infeasible. We categorized the 73 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 = 25); (2) species that occur in the park but are difficult to detect and not well sampled (n = 15); (3) detectable species that occur infrequently in the park (n = 9); and (4) species unlikely to occur regularly in the park (n = 24). Of the 15 species in group 1, 9 are estimated to be in decline in NOCA, 11 are apparently stable, and 5 are likely increasing. The 15 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. NOCA, 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 NOCA is within the geographic range of the 9 species in group 3, they occur in low abundances in the park and NOCA may provide only small amounts of suitable habitat for them. For the 24 species in group 4, NOCA 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. NOCA 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.

6.2.16 Mammalian Fauna

Very few species have been well studied in the park complex. There is virtually no information about short-term population trends or spatial distribution within the park complex for most species. Many species have been recorded in the park incidental to other studies, or by visitors, without a thorough park-wide sampling effort. Three groups of mammals – carnivores (4.17), Hoary Marmot and American Pika (4.18), and bats (4.19) – have been separately assessed. Because mammalian carnivores have been monitored by at most 1 study with park-wide sampling effort (Christophersen et al. 2005, Christophersen 2006), we cannot make any firm conclusions about trend. Nonetheless, there is some suggestive evidence from which to make some inference about trend for some species. We find 4 species that may be in a recent decline, 5 species that may be recently increasing, and 9 species for which we cannot make any inference about population trend. Both Hoary Marmots and American Pika appear to be widespread and numerous in NOCA; however, present surveys provide only a baseline for assessing future trends in species occupancy patterns and it is not possible to assess current population trends for either species. Nine bat species are known from NOCA, and 3 more may use NOCA at least occasionally. The designs of past surveys were not appropriate for making park-wide trend estimates. NOCA habitats are valuable in supporting mammalian biodiversity, but should be considered in the context of the larger North Cascades region. The wilderness character of the park complex lands generally translates to a low level of human disturbance and relatively high habitat quality for the habitat types present. Remoteness may make the park complex attractive for species that are sensitive to human disturbance, such as Wolverine. The high elevations characterizing most of the park, however, have relatively low annual productivity, and so may be of relatively low quality for many species when compared to lower elevation lands to the north, south, east, and west. This means that NOCA by itself probably will not support viable populations of many of the larger species. Rather, many of these will probably continue to move in and out of the park complex lands seasonally (i.e., Elk and Black-tailed Deer) or as part of larger home ranges (i.e., Canada Lynx, Wolverine, and Grizzly Bear). The mammalian fauna in NOCA is remarkably intact, with only a few exceptions. One native species and 1 native subspecies seem to be extirpated, and the population size of some carnivores may be lower than would have been historically typical. Any populations of exotic mammalian species, though, are negligible. We conclude, given the caveats cited above, that the current status of mammalian biodiversity is very close to the Minimally Disturbed reference condition, but that there are several potential threats to future trends in biodiversity.

6.2.17 Glaciers

At NOCA, 316 glaciers cover about 109 km^2 (42 mi^2), with a combined volume of 9.3–10.1 km^3 (2.2–2.4 mi^3). The temperate glaciers at NOCA 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 Gray-crowned 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 extent and volume (mass balance), however, are decreasing rapidly at NOCA. The area covered by all glaciers in the park reached a post ice-age maximum of 233 km^2 (90 mi^2) about 1900 A.D., at the end of the Little Ice Age. Since that time, glacial area has declined about 53%, which is comparable to adjacent mountain ranges, and there was no increase in the size of index glaciers between 1993 and 1998. The negative trend in glacier extent during the past 100 yrs is not linear, but has been punctuated by decadal climate variability. Further, as glaciers recede to higher elevations in the Cascade Range, melt is slowed by cooler temperatures in the shadows of adjacent peaks, which also contribute accumulation by snow drifting and avalanching onto the glacier surface. In the last half of the 20th century, between 1958 and 1998, glacier area in the park declined about 8.1%. This included periods in 1961–1965 and 1970–1976 when most of the glaciers gained mass, which slowed retreat, but did not lead to glacier expansion. More recently, loss of glacier area has accelerated at the 4 monitored NOCA glaciers. However, point measurements on all 4 glaciers show that these glaciers still have accumaulation zones that are gaining a small amount of mass. Therefore, although the park glaciers are retreating rapidly to adjust to a warmer climate, it seems reasonable to assume that there will continue to be glaciers at NOCA for many decades, at least on northern aspects at higher elevations, and in favorable locations for snow accumulation from avalanches and wind-drifting. 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 due to a rising freezing level starves a glacier of mass, and warm autumn rains can result in enhanced melting, particularly near the terminus. Together, increased temperature and lower snowfall lead to a decreasing cumulative net mass balance and, played out over decades, a dramatic decline in the extent of glaciers.

6.2.18 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 NOCA frontcountry sites ranged from 22.5–43 dBA during the day and 21–42 dBA at night. At the backcountry sites, natural ambient sound levels ranged from 25–35.8 dBA during the day and 21.7–36.7dBA at night. These levels, within the 20–1250 Hz frequency band, represent a very quiet natural acoustical environment. Existing ambient sound levels at the frontcountry sites ranged from 24.2–46 dBA during the day and 21–42 dBA at night. At the backcountry sites, existing ambient sound levels ranged from 27–36.3 dBA during the day and 27–36.8 dBA at night. 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 frontcountry sites, vehicles were the most often heard non-natural sound at 5 (Ruby Arm, Newhalem, Colonial Campground, Thunder Knob, Stehekin Airstrip) of the 8 sites, with a percent time audible ranging from 1.2 to 51.5% of a 24-hr day. At backcountry sites, except for Sourdough Mountain and Thornton Lakes Trail, aircraft were the most pervasive non-natural sound source, audible between 4.9 and 15.6% of a 24-hr day, mostly caused by high altitude jets. At Sourdough Mountain, vehicle sounds were the most often heard human-caused sound (42% time audible over a 24-hr day). For all 20 sites, non-natural sounds were heard the greatest at Newhalem (100% time audible) and Ross Dam Trailhead (96.8% time audible). Despite the presence of various human-caused noise intrusions, natural sounds can be heard at all sites, which make for a rich and spectacular acoustical environment at NOCA.

6.2.19 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 NOCA is impaired by anthropogenic sky glow from the large metropolitan areas of Seattle, Washington, and Vancouver, British Columbia. Sky luminance and illuminance from anthropogenic sources is seen to be about twice as high at Hidden Lake Peaks as at Cutthroat Pass Peak. However, both are given Bortle Class 3, indicating that even at the more remote eastern site (Cutthroat Pass Peak) the impairment from city light domes is significant compared to a sky free of light pollution. Yet overall, the night sky quality of NOCA is very good, although localized areas are subject to light trespass and glare and the western part of the sky exceeds the reference condition for sky luminance in all parts of the complex investigated.

6.3 Main Resource Threats and Emerging Issues

There are 4 fundamental threats that are now and will in the future affect the continued persistence and viability of the natural resources and ecosystems of NOCA. They are: (1) climate change; (2) the continued atmospheric deposition of nutrients and pollutants; (3) the presence and emergence of native and nonnative animal and plant pest species 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 NOCA natural resources. Projections for future changes in climate within the Cascadia region of which NOCA is a part include a continued warming trend that exceeds the range of historical variability with no clear trend in precipitation. Seasonal projections, however, indicate increased warming during summer months and a slight tendency toward drier summers and wetter winters. For NOCA stations reporting snowpack observations, there are documented trends toward declining snow depth and snow water equivalent, although not all modeled trends are significant. There is also a tendency toward higher (in elevation) freezing levels. One fundamental outcome of thes changes in climate will be altered 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 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). 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.

6.3.2 Atmospheric Deposition

The continued deposition of nutrients and pollutants from local, regional, and global sources will contribute to the degradation of NOCA 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 NOCA 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 affect 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, which will also impact land bird and mammal species and assemblages occupying these habitats.

6.3.3 Pests and Pathogens

Native and nonnative animal and plant pest species and pathogens have always affected non-pest biotic species and have contributed at least minimally to the destabilization of ecosystem composition and structure. This has been considered a necessary part of ecosystem 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

Batrachocytrium dendrobatidis (Bd), and a viral infection caused by ranavirus in the family Iridoviridae. Although their affect and the susceptibility of individuals and populations is highly variable and not well understood, both diseases are affecting amphibian populations worldwide, even in protected areas. 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 and Range Expanding Native and Non-Native Species

The introduction of invasive native and non-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 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. At present in NOCA, the primary effects from species introductions and range-expansion are associated with introduced fish in lakes, 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 NOCA 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 and data needs identified by this assessment is presented in Table 59. A more detailed discussion of information and data needs for specific resource categories is available in Chapter 4 for each assessed natural resource.

Table 59. Recommendations for critical information and data needs.

Resource Category	Primary Information and Data Needs
Air Quality and Air Quality-related Values	• Visibility monitoring needs to continue • Additional information is needed about both the amount of deposition and the sensitivity of AQRVs to improve critical load estimates for nitrogen and sulfur. • Ozone monitoring should be re-initiated at the park, if ozone concentrations increase significantly in the future. • More information is needed about the amount of and trends in deposition of Hg and other PBTs.
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. • Collection of 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. • 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.
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. • Park should continue development of their BMI predictive model for assessing stream condition. • 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	• Development of mechanistic models that describe the effects of climate changes on disturbance agents and tree physiology are needed for predicting future changes due to the effects of these agents.
Forest Health: Whitebark Pine and White Pine Blister Rust	• The park would benefit from continuing to monitor blister rust infection rates and the prevalence of Mountain Pine Beetles, as well as identify blister rust-resistant genotypes of Whitebark Pine that may be used for restoration in the future.

Table 59. Recommendations for critical information and data needs (continued).

Resource Category	Primary Information and Data Needs
Forest Health: Air Quality Effects	• 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	• Development of models for climate, fire, and insect interactions relevant to NOCA. • Development of climate adaptation strategies, especially for dry-forests on the east-side of NOCA. • Park could benefit from continuing to collect fire severity data through MTBS.
Biodiversity: Exotic Plants	• 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. • Periodic analysis of exotic plant data that incorporates Exotic Plant Management Team efforts such as was conducted for the EA will apprise park staff of management success.
Biodiversity: Wetlands	• Park could benefit from producing an updated, complete map of wetlands for the entire complex. • Continue collaboration with UW researchers to develop remote-sensing methods to improve spatial documentation of monitored wetlands. • Describe the distribution of rare wetland plant associations tracked by WNHP. • Repeated inventories of wetland resources, including spatial extent, wetland class and assessment of ecological integrity, are warranted given the importance of wetlands to supporting park biodiversity and the potential for climate change to dramatically alter wetlands.
Biodiversity: Subalpine Vegetation	• Ground-based monitoring is required to provide early warning of changes to alpine and subalpine composition, structure, and extent. • Monitoring the duration and extent of annual snowpack would provide valuable information to supplement temperature and precipitation data for understanding alpine and subalpine responses to climate change.
Biodiversity: Sensitive Vegetation Species	• Surveys could be conducted of relevant habitats for species that have been reported in the park but not relocated in the NPS inventory effort. • Forecasts of where relevant habitats of sensitive species may migrate due to changing climate would be useful. • 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.
Amphibians	• Reasonable inventories for all amphibians present in NOCA have been completed. Additional surveys for terrestrial salamanders might be warranted, but any new locations would simply represent minor additions to the distribution of 2 broadly distributed species that are not thought to be declining, Ensatina and the Western Red-backed Salamander. NOCA is marginal for these 2 species.

Table 59. Recommendations for critical information and data needs (continued).

Resource Category	Primary Information and Data Needs
Land Birds	• 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 is lacking for species that are difficult to detect or occur too infrequently to monitor effectively at the spatial scale of the park – focused surveys could help provide some of this information. • Survey and monitoring information for management of some special status species, such as Marbled Murrelet and Harlequin Duck, would be useful data to collect.
Fish	• Conducting additional focused-surveys of potentially sensitive species such as Bull Trout and anadromous salmon would be beneficial. • Surveys could be initiated for species reported to be present in NOCA but not observed in the 2001 through 2003 surveys (Zyskowski 2007) and for whom occurrence and distribution are relatively unknown. • Surveys designed to elucidate the potential presence of Nooksack Dace, as well as the critically-imperiled and state-monitored Salish Sucker (as differentiated from the Longnose Sucker) in NOCA streams would be beneficial. • The park should continue to monitor salmon stocks that spawn in NOCA tributaries because of their important genetic distinctiveness. • Surveying and sampling NOCA Bull Trout populations will contribute to better understanding their life history characteristics, habitat requirements, and population dynamics. • Continued monitoring of Westslope Cutthroat Trout populations above and below Stehekin River passage barriers, focusing on maintaining genetically pure native Westslope Cutthroat Trout above the barriers is warranted. • Compiling an electronic database for 1980s–1990s era stream fish surveys should be considered.
Mammalian Fauna	• It would be valuable to conduct research and monitoring that would improve our present level of knowledge of the current status and trends of mammal populations in the park.
Mammalian Carnivores	• It would be useful to test for temporal trends in the occupancy rate of surveyed mammalian carnivore species in NOCA by repeating the methods used by Christophersen et al. (2005) and Christophersen (2006). • Radio-telemetry based studies that identify corridors and important habitat features for carnivores at the regional scale would be useful in focusing interagency conservation strategies.
Hoary Marmot and American Pika	• Repeat surveys based on methods used by Christophersen (2013) and by Bruggeman (2010) would be useful for monitoring future changes in species occupancy patterns, although the sample sizes of surveyed sites should be reconsidered, depending on the desired monitoring goals of the NPS. • Expansion of the sampling frame to include all potential habitats of marmots and pika, although more costly, would permit parkwide inference.

Table 59. Recommendations for critical information and data needs (continued).

Resource Category	Primary Information and Data Needs
Bats	• 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 NOCA would provide useful new information to this program. • Long distance migration routes for the Hoary Bat and Silver-haired Bat are not well known in this area, and this knowledge would help identify what wind turbine facilities pose risks to migratory bat species that use NOCA.
Glaciers	• Continued monitoring of all aspects of glacial change is highly recommended, including, but not limited to, glacial area and extent, and cumulative and net mass balance. Support research and monitoring of the distribution and diversity of glacier biota such as ice worms and near-glacier biota such as the stonefly (*L. borealis*). Research link should be pursued between the effects of seasonal glacier melting and long-term glacier recession on stream temperature.
Soundscapes	• Continued monitoring of natural and anthropogenic sound production in the park is recommended, and, if possible, research dedicated to the effects of chronic noise exposure on wildlife.
Dark Night Skies	• Potential impacts from light trespass in the Stehekin Valley should be investigated. • Copper Ridge monitoring site would provide a "worst case" data point for the park area re: anticipated sky glow from external communities.

6.5 Concluding Remarks

North Cascades National Park Service Complex was established by Congress in 1968. The purpose of the enabling legislation was to: "…preserve for the benefit, use, and inspiration of present and future generations certain majestic mountain scenery, snowfields, glaciers, alpine meadows, and other unique natural features in the North Cascade Mountains of the State of Washington…" and to "…provide for the public outdoor recreation use and enjoyment … [and] for the conservation of the scenic, scientific, historic, and other values contributing to public enjoyment of such lands and waters…" Since its beginning, park management has been ever vigilant in maintaining its commitment to the preservation and persistence of NOCA'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 NOCA landscape is being affected by perturbations associated 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, to name only a few. These threats and emerging issues will most likely compromise the health and integrity of NOCA 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 inventory and monitoring efforts and programs, and by enhancing those efforts with new innovative programs and strategies.

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