National Park Service
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Natural Resource Stewardship and Science

Air Quality Overview

Mount Rainier National Park

Natural Resource Report NPS/PWRO/NRR—2014/848

ON THIS PAGE
Washington State University graduate student conducting nitrogen deposition study at Mount Rainier National Park
Photograph by: Tonnie Cummings

ON THE COVER
Paradise, Mount Rainier National Park
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Air Quality Overview

Mount Rainier National Park

Natural Resource Report NPS/PWRO/NRR—2014/848

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Contents

Figures

Page

Figures (continued)

Page

Figures (continued)

Page

Tables

Page

Executive Summary

Mount Rainier National Park, located in western Washington, is designated as a Class I air quality area and is afforded special protection under the federal Clean Air Act. The park is vulnerable to air pollution from nearby urban and agricultural areas, as well as to pollution from regional and even global sources. To better understand and protect air quality, the National Park Service has monitored air quality and air pollution-sensitive resources at Mount Rainier since the early 1980s. In 1994, the National Park Service published a comprehensive review of the status of air quality and air pollution-related ecological effects in five Class I parks in the Pacific Northwest; a 2003 addendum supplied visibility analyses for the five parks. This overview provides an update on air quality and air pollution effects in and near Mount Rainier National Park. It is intended to serve as a thorough, yet concise, summary for National Park Service managers and others who are interested in air quality at the park.

Mount Rainier is currently in compliance with all the National Ambient Air Quality Standards; however, these standards do not provide adequate benchmarks for assessing ecosystem condition. To that end, in accordance with the Clean Air Act, the National Park Service has adopted the goal of no human-caused visibility impairment in parks. For ecological resources, the National Park Service uses thresholds from the scientific literature to assess potential effects from ozone and deposition of nitrogen, sulfur, and toxic air pollutants.

A 1990 study found that most of the visibility impairment at Mount Rainier was due to human-caused sources, including the coal-fired Centralia power plant located 80 kilometers west of the park. Centralia's owners installed emission controls in 2001 through 2003; in the years following installation of controls, there were noticeable decreases in some pollutants at the park. Monitoring data collected from 1988 to 2013 showed steadily improving trends in visibility at the park on the clearest and haziest days. Nevertheless, based on 2008 to 2012 data, current average visibility at Mount Rainier National Park was about 42 percent hazier than natural conditions.

Most of the atmospheric deposition at the park is in the form of wet deposition. Sulfate and nitrate concentrations have decreased in precipitation samples collected at the park's lower elevation Tahoma Woods site and in bulk deposition samples from the higher elevation Paradise site. There was no trend in ammonium concentrations in precipitation at Tahoma Woods (2000 to 2009), while ammonium concentrations at Paradise increased over a longer period of record (1989 to 2012).

Some park ecosystems are considered at high risk for both acidification and nitrogen enrichment. Critical loads for sulfur have not been developed, but nitrogen deposition at Mount Rainier appears to be below critical levels shown to affect lichen communities. Efforts are underway to determine nitrogen critical loads for other ecosystem components.

Monitoring indicates ozone concentrations vary throughout the park, with greater maximum and cumulative ozone values generally occurring at higher elevations. Ozone concentrations were higher than the current National Ambient Air Quality Standard of 75 parts per billion at Paradise in 2003; and in many years, concentrations exceeded the lower end of the range for a revised primary ozone standard proposed by the U.S. Environmental Protection Agency in 2010. An

evaluation of 2000 to 2009 data indicated a decreasing trend in ozone concentrations at Mount Rainier. Surveys conducted over several years have found little indication of ozone damage to park vegetation.

Elevated concentrations of toxic air pollutants, including mercury, have been detected in snowpack, vegetation, fish, songbird, and sediment samples from Mount Rainier. Concentrations of some pollutants exceeded wildlife and human health thresholds. Ongoing studies are investigating the extent of, and factors that contribute to, mercury contamination.

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Acronyms

µg/kg	micrograms per kilogram
µg/m^3	micrograms per cubic meter
a-HCH	hexachlorocyclohexane-alpha
AMNet	Atmospheric Mercury Network
AMoN	Ammonia Monitoring Network
AQRV	air quality related value
ARD	Air Resources Division
CASTNET	Clean Air Status and Trends Network
CMAQ	Community Multi-Scale Air Quality model
CWU	Central Washington University
DDT	dichlorodiphenyltrichloroethane
dv	deciview
EPA	U.S. Environmental Protection Agency
FHM	Forest Health Monitoring Program
FIA	Forest Inventory and Analysis Program
HCB	hexachlorobenzene
Hg	mercury
HNO_3	nitric acid
I&M	Inventory and Monitoring
IMPROVE	Interagency Monitoring of Protected Visual Environments
lb/yr	pounds per year
kg/ha/yr	kilograms per hectare per year

MDN	Mercury Deposition Network
MeHg	methylmercury
mg/L	milligrams per Liter
Mm^{-1}	inverse megameter
N	nitrogen
NAAQS	National Ambient Air Quality Standard
NADP	National Atmospheric Deposition Program
NCCN	North Coast and Cascades Network
ng/g ww	nanograms per gram wet weight
ng/L	nanograms per Liter
NH_3	ammonia
NH_4	ammonium
NO_3	nitrate
NO_x	nitrogen oxide
NP	National Park
NPS	National Park Service
PAH	polycyclic aromatic hydrocarbon
PBDE	polybrominated diphenyl ether
PBT	persistent bioaccumulative toxin
PCB	polychlorinated biphenyl
PM	particulate matter
$PM_{2.5}$	particulate matter smaller than 2.5 micrometers
PM_{10}	particulate matter smaller than 10 micrometers

ppb	parts per billion
ppm	parts per million
ppm-hrs	parts per million-hours
ppm ww	parts per million wet weight
PREVENT	Pacific Northwest Regional Visibility Experiment Using Natural Tracers
PRISM	Parameter-elevation Regressions on Independent Slopes Model
S	sulfur
SFU	stacked filter units
SO_2	sulfur dioxide
SO_4	sulfate
SOC	Semi-volatile organic compound
TPY	tons per year
USGS	U.S. Geological Survey
VOC	volatile organic compound
WACAP	Western Airborne Contaminants Assessment Project
WDOE	Washington Department of Ecology

Introduction

Air quality is a fundamental resource of all units of the National Park System. It affects human health and visitor enjoyment, and good air quality helps ensure the integrity of park resources and values. Mount Rainier National Park's (NP) draft Foundation Document discusses the significance of air quality for the park (Roger Andrascik, Mount Rainier NP, personal communication):

> "Unimpaired, clean air allows for enjoyment of the park's spectacular views and supports healthy ecosystems. Mount Rainier National Park is designated a class I area under the Clean Air Act and requires federal land managers to protect park air quality related values that include ecosystem components, functions and processes; visual and cultural resources. Policies and strategies are in place to work towards ensuring that Mount Rainier's air quality is enhanced or maintained with no significant degradation and that unimpaired views of the landscape in the park are available."

To achieve that goal, the National Park Service (NPS) works in concert with the larger air quality community to monitor air pollution and its effects, analyze and synthesize data, determine the sources of air pollution affecting parks, and share information with others. Collection of high quality data allows the NPS to contribute research and monitoring results which inform state and federal regulatory activities and park management decisions that affect air quality and resources. Perhaps most importantly, the information can be used to educate the public about the significance of air as an essential resource in national parks and of the value to humans and ecosystems in protecting and maintaining clean air.

In 1994, the NPS published a comprehensive report describing the status of air quality and air pollution-related ecological effects in five parks in the Pacific Northwest, including Mount Rainier NP (Eilers et al., 1994). A 2003 addendum summarized visibility data collected through 1999 at the five parks (Air Resource Specialists, 2003). Since that time, a substantial amount of monitoring and research have greatly improved our understanding of air quality conditions and trends in and adjacent to parks, along with an enhanced appreciation for the air pollution sensitivity of ecosystems in the Pacific Northwest. This report provides an update on air quality and air pollution effects in and near Mount Rainier NP.

The report includes a synopsis of the legal mandates for air quality protection; a description of emission sources near the park; overviews of air pollution effects, air quality standards, and pollution thresholds; discussions of air quality-related monitoring and research conducted in and near the park; and recommendations for additional research and monitoring. Much of the information is excerpted from monitoring network websites and researchers' reports and journal articles. Website links to information sources are included in the Literature Cited section of the report.

Legal Mandates

Several laws provide the basis for air quality protection in units of the National Park System. The 1916 Organic Act directs the NPS to "…conserve the scenery and the natural and historic objects and the wild life therein and to provide for the enjoyment of the same in such manner and by such means as will leave them unimpaired for the enjoyment of future generations" (16 U.S.C. 1). The Mount Rainier Wilderness was designated in 1988 and includes 97 percent of the park's 236,381 acres. The Wilderness Act contains a directive that wilderness areas be managed to preserve their natural conditions and recognizes that wilderness is "…an area where the earth and its community of life are untrammeled by man, where man himself is a visitor who does not remain" (16 U.S.C. 1131-1136). In 1997, most of the developed areas of the park, along with the 150 km Wonderland Trail and Northern Loop Trail, were designated a National Historic Landmark District. This designation supports the need to protect the park's historic structures from air pollution.

The 1977 amendments to the 1970 Clean Air Act include requirements to "preserve, protect, and enhance the air quality" in 158 mandatory Class I national parks and wilderness areas (42 U.S.C. 7470 et seq.). Mount Rainier NP is one of the NPS's 48 Class I areas; all other areas in the U.S., including other NPS units, are Class II air quality areas. The 1977 amendments give federal land managers an "affirmative responsibility" to protect the air quality related values (AQRV) in Class I areas. Park AQRVs are resources sensitive to air quality, including lakes, streams, vegetation, soils, wildlife, and visibility. Section 169A of the Clean Air Act states: **"**Congress hereby declares as a national goal the prevention of any future, and the remedying of any existing, impairment of visibility in mandatory class I Federal areas which impairment results from manmade air pollution" (42 U.S.C. 7491). Congress further stated that "the Federal land manager should assume an aggressive role in protecting the air quality values… [and in] the case of doubt the land manager should err on the side of protecting the air quality-related values for future generations" (Senate Report No. 95-127, 95th Congress, 1st Session, 1977). The 1990 Clean Air Act amendments promoted regional approaches to air pollution control. In addition, they clarified that lands added to Class I areas subsequent to the 1977 amendments also have Class I designation.

The NPS 2006 Management Policies describe agency responsibilities relative to air quality in parks. The Management Policies state the NPS will "…seek to perpetuate the best possible air quality in parks to (1) preserve natural resources and systems; (2) preserve cultural resources; and (3) sustain visitor enjoyment, human health, and scenic vistas." To accomplish these objectives the NPS "…will:

- inventory the air quality-related values associated with each park;
- monitor and document the condition of air quality and related values;
- evaluate air pollution impacts and identify causes;
- minimize air quality pollution emissions associated with park operations, including the use of prescribed fire and visitor use activities; and
- ensure healthful indoor air quality in NPS facilities."

The 2006 Management Policies also direct the NPS to work with federal, state, and local regulatory agencies to remedy existing and prevent future impacts on park resources and to use interpretive and educational programs to improve the public's understanding of park air quality issues.

Air Pollution Sources

There are many sources of air pollution; some are natural and some are anthropogenic, i.e., human-caused. The NPS focuses on reducing the impact of anthropogenic pollution on park resources. Human activities that produce air pollution include manufacturing and industrial processes, agricultural and forestry practices, land disturbance, prescribed fire, and fossil fuel combustion. Mount Rainier NP is located near the cities of Seattle and Tacoma and the urban Interstate-5 corridor (Figure 1). The air pollutants of concern include sulfur (S) and nitrogen (N) compounds, ground-level ozone, particulate matter (PM), and persistent bioaccumulative toxins (PBT) such as mercury and pesticides.

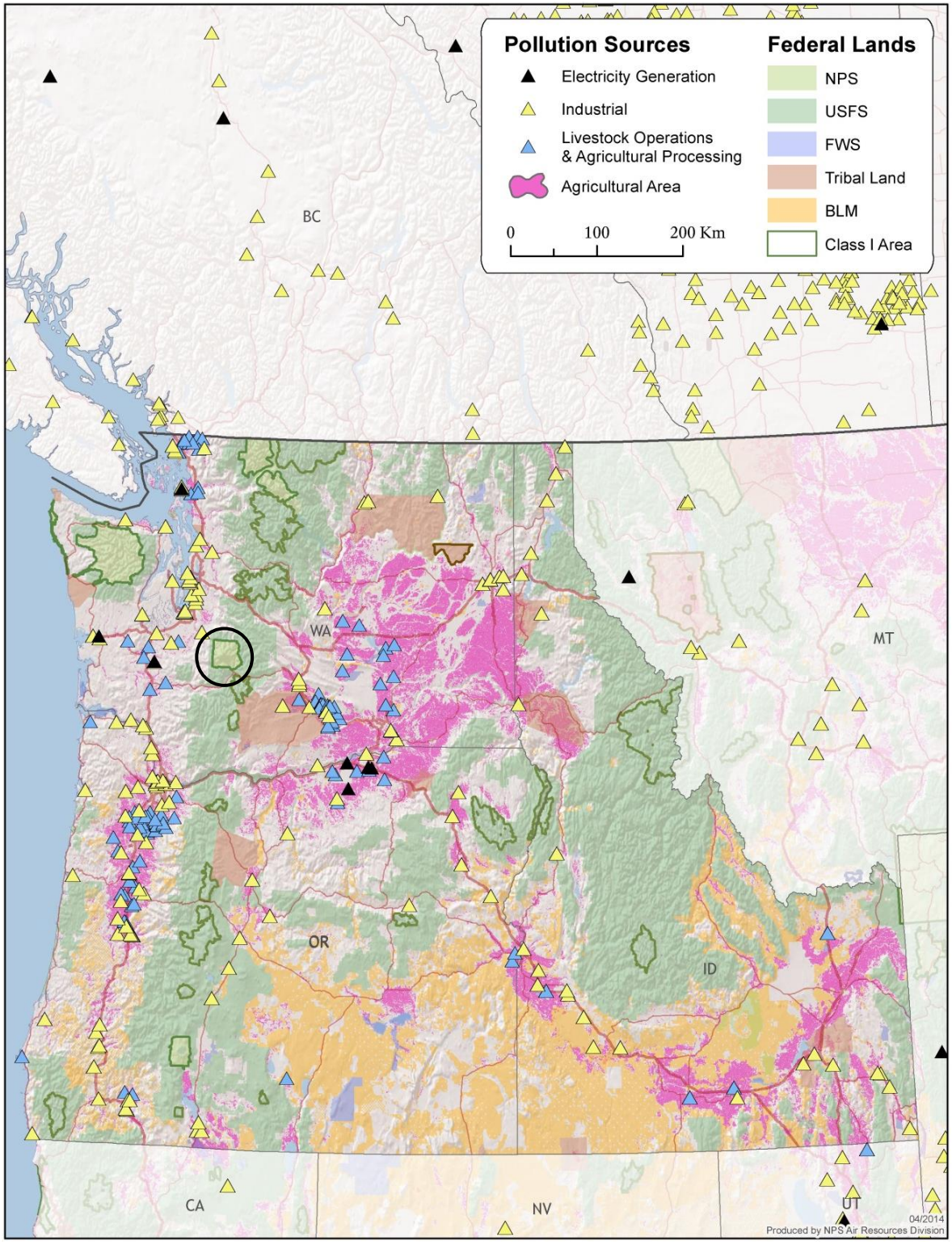

Figure 1. Public lands and air pollution sources in the Pacific Northwest (produced by NPS, 2014). Mount Rainier NP is circled on the map. Triangles designate point sources that emit greater than 100 tons per year of a single pollutant. BLM is Bureau of Land Management, FWS is U.S. Fish and Wildlife Service, NPS is National Park Service, and USFS is U.S. Forest Service.

The main source of S pollution is sulfur dioxide (SO_2) released by coal-fired power plants and industrial operations such as aluminum smelting. Sulfur dioxide oxidizes in the atmosphere to form sulfate particles. There are two types of N pollutants - oxidized compounds and reduced compounds. Oxidized N compounds, i.e., nitrogen oxides (NO_x), are formed primarily during fuel combustion and transformed in the atmosphere into nitric acid (HNO_3). Reduced N compounds, e.g., ammonia (NH_3) and ammonium (NH_4), result primarily from agricultural activities in rural areas and from vehicle emissions in urban areas. Nitric acid and ammonia can react to form particulate ammonium nitrate. Ground-level ozone is formed when volatile organic compounds (VOC) from vehicles, solvents, industry, and vegetation react with NO_x in the atmosphere. Because sunlight is necessary for the formation of ozone, ozone concentrations are usually highest during the warmer, sunnier summer months in the Pacific Northwest. There are two size-range categories of particulate matter typically measured by air quality monitoring networks, i.e., particles smaller than 10 micrometers (PM_{10}) and particles smaller than 2.5 micrometers ($PM_{2.5}$). Particulate matter is directly emitted by point sources, such as refineries and manufacturing plants, as well as from non-point (area) sources, i.e., wood-burning stoves, road dust, and construction. Many particles that affect parks are formed downwind of sources when emissions of NO_x and SO_2 react in the atmosphere to form nitrate (NO_3) and sulfate (SO_4), as noted above. Persistent organic pollutants include pesticides and byproducts of industrial processes and fuel combustion. Coal combustion, mining processes, and other industries emit mercury (Hg).

While a complete listing of anthropogenic emissions in the Pacific Northwest is beyond the scope of this report, Washington Department of Ecology's (WDOE) 2011 stationary sources emissions inventory (Stephanie Summers, WDOE, personal communication) provides insight on the types of facilities that affect air quality at Mount Rainier NP. The inventory includes information about point sources of air pollution within approximately 100 km of the park that emitted more than 100 tons per year (TPY) of a single pollutant. Those sources included an aluminum smelter, a cement plant, power plants, wood products manufacturers, and other manufacturing facilities (Table 1).

The Centralia coal-fired power plant is located 80 km west of Mount Rainier NP. In 1996, NPS, WDOE, the U.S. Environmental Protection Agency (EPA), the Southwest Clean Air Agency, and the Puget Sound Clean Air Agency negotiated with Centralia's owners to reduce emissions from the facility. At that time, Centralia had no SO_2 controls and was the largest source of SO_2 emissions in the western United States. Scrubbers were installed in 2001 through 2002, reducing SO_2 emissions from about 80,000 TPY in 1996 to about 10,000 TPY by late 2002. Combustion controls were added to the boilers; those controls reduced NO_x emissions from about 16,000 TPY in 1996 to about 10,000 TPY by the end of 2003. 2011 emissions (Table 1) reflect a reduction in power plant operating hours in recent years (Alan Newman, WDOE, personal communication). Additional controls were installed at Centralia in 2011 to 2012 to further reduce NO_x emissions by 30 percent. In 2007, Centralia's coal mine ceased operation and the power plant began burning Powder River Basin coal, which has about half the mercury content of Centralia's coal. Switching coal reduced Hg emissions to about 250 to 300 pounds per year (lb/yr). In 2011, the state legislature passed a law requiring that Centralia two boilers meet stringent greenhouse gas emission limits in 2020 and 2025, respectively. In order to comply with the law, Centralia's coal-fired boilers will likely shut down.

Washington Department of Ecology prepared a 2011 comprehensive emission inventory that provided county-by-county estimates of area emissions of PM_{10}, $PM_{2.5}$, SO_2, NO_x, VOC, and NH_3 by source category (WDOE, 2014). An analysis of the top three categories of anthropogenic area source emissions for each pollutant in the five counties near Mount Rainier NP (i.e., King, Kittitas, Lewis, Pierce, and Yakima) shows substantial emissions from construction, road dust, residential woodburning, on-road vehicles, recreational boats and commercial marine vessels, non-road vehicles (e.g., forklifts, tractors, and snowmobiles), solvents, and livestock (Table 2).

The state of Washington requires facilities that store more than 10,000 pounds of a hazardous material on-site at any one time to report toxic pollutant releases to air, water, and land. Based on the state's 2011 toxics release inventory (Stephanie Summers, WDOE, personal communication), over 4 million pounds of toxic air pollutants were emitted by reporting facilities within approximately 100 km of Mount Rainier NP (Table 3); ten toxic chemicals were released to the air in amounts exceeding 100,000 lb/yr (Table 4). The state of Washington does not track toxic emissions from area sources, such as pesticide applications. However, Hageman et al. (2010) correlated pesticide concentrations in snowpack from several national parks, including Mount Rainier, with nearby cropland intensity and wind patterns and concluded that for all studied parks, more than 75 percent of the pesticide contribution was from pesticide use beyond 150 km of the park.

The WDOE 2011 toxics release inventory lists point sources that emitted more than 10 lb/yr of Hg to the air (Table 5). After mercury 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 to10 percent of the Hg deposited in the Pacific Northwest is from local anthropogenic sources, approximately 20 percent is from emission sources in Asia, and the rest is from the global pool (National Research Council, 2009).

Table 1. 2011 emissions (in TPY) from point sources within approximately 100 km of Mount Rainier NP that emitted more than 100 TPY of a single pollutant.

Facility Name	Type of Facility	Location	PM_{10}	$PM_{2.5}$	SO_2	NO_x	VOC
Alcoa Wenatchee Works	aluminum smelter	Malaga	546	546	2,906	63	266
Ash Grove Cement	cement plant	Seattle	31	24	51	918	4
Boeing	airplane manufacturer	Auburn	0	0	0	99	130
Boeing	airplane manufacturer	Seattle	0	0	0	22	150
Boeing	airplane manufacturer	Renton	0	0	0	37	216
Cardinal FG	glass manufacturer	Winlock	10	7	56	810	19
Crown Cork and Seal	metal can manufacturer	Olympia	1	1	0	5	182
Longview Fibre	wood products manufacturer	Longview	81	81	202	1,372	219
Nucor Steel	steel mill	Seattle	0	0	79	205	0
Rexam Beverage Can	metal can manufacturer	Kent	0	0	0	5	182
Saint-Gobain Containers	glass container manufacturer	Seattle	65	60	73	299	32
Seattle Steam Company	power plant	Seattle	0	0	0	208	0
Shields Bag and Printing	packaging manufacturer	Yakima	0	0	0	3	291
Simpson Tacoma Kraft	wood products manufacturer	Tacoma	97	88	349	945	77
Centralia	power plant	Centralia	410	274	1,136	6,635	3
U.S. Navy Puget Sound	shipyard	Bremerton	18	3	0	0	142
US Oil and Refining	oil refinery	Tacoma	12	0	5	134	115
Weyerhaeuser Company	wood products manufacturer	Longview	76	67	582	2,137	422

Table 2. 2011 top three categories of anthropogenic area source emissions (in TPY), by pollutant, in the five counties near Mount Rainier NP (i.e., King, Kittitas, Lewis, Pierce, and Yakima).

	CON	ROAD	RW	ORM	SHIP	FUEL	NRM	SOL	FERT	LIVE
PM_{10}	17,433	13,244	6,382							
$PM_{2.5}$		2,284	6,380	2,388						
SO_2				283	1,839	569				
NO_x				70,761	6,669		13,188			
VOC				31,196			11,094	16,622		
NH_3				1,205					1,274	11,340

CON = construction
ROAD = road dust
RW = residential woodburning
ORM = on-road mobile sources
SHIP = recreational boats and commercial marine vessels
FUEL = commercial and residential non-wood fuel use (e.g., oil, natural gas)
NRM = land-based, non-road mobile sources (e.g., forklifts, tractors, and snowmobiles)
SOL = commercial and consumer solvents
FERT = fertilizer application
LIVE = livestock

Table 3. 2011 emissions (in lb/yr) of toxic air pollutants by reporting facilities within approximately 100 km of Mount Rainier NP.

County	Number of Facilities	Number of Chemicals	Emissions
Chelan	1	5	815,402
Clark	0	0	0
Cowlitz	6	25	1,351,190
Grays Harbor	0	0	0
Jefferson	0	0	0
King	46	32	465,356
Kitsap	1	9	72,100
Kittitas	0	0	0
Klickitat	0	0	0
Lewis	6	16	57,945
Mason	1	1	125
Pierce	20	45	1,011,215
Skamania	0	0	0
Snohomish	5	9	6,428
Thurston	3	7	282,708
Yakima	2	2	136,690
Total	91	62[1]	4,199,159

[1]Several chemicals were emitted in multiple counties

Table 4. 2011 toxic chemicals with air emissions greater than 100,000 lb/yr by reporting facilities within approximately 100 km of Mount Rainier NP.

Chemical	Emissions (lb/yr)	Types of Facilities
Acetaldehyde	167,445	Wood products manufacturing
Ammonia	455,296	Wood products manufacturing, oil refineries
Carbonyl Sulfide	477,738	Aluminum smelters
Glycol Ethers	305,521	Beverage container manufacturing, paint/solvent use
Hydrochloric Acid	568,040	Wood products manufacturing
Hydrogen Fluoride	364,603	Aluminum smelters
Methanol	936,621	Wood products manufacturing
N-Butyl Alcohol	239,100	Beverage container manufacturing, shipyards
Styrene	216,679	Fiberglass manufacturing, wood products manufacturing
Xylene	106,125	Paint/solvent manufacturing and use, shipyards

Table 5. 2011 emissions from point sources within approximately 100 km of Mount Rainier NP that emitted more than 10 lb/yr of Hg to the air.

Facility	Type of Facility	Location	Hg (lb/yr)
Ash Grove Cement	cement manufacturer	Seattle	72
NuCor Steel	steel manufacturer	Seattle	236
Centralia	coal-fired power plant	Centralia	235

Air Pollution Effects

This section provides a general overview of the effects of air pollution. Results from monitoring and research conducted in and near Mount Rainier and other national parks in the Pacific Northwest are discussed in subsequent sections of the report.

Among the experiences that visitors to national parks treasure is enjoying the breathtaking scenery – majestic mountains contrasted against a pure blue sky or a spectacular array of stars at night. Fine particles in the atmosphere absorb or scatter light, causing haze, reducing visibility and degrading scenic views. Visibility-impairing particles include ammonium sulfate, ammonium nitrate, organic and elemental carbon, fine soil, fine sea salt, and coarse mass. Fine particles are a significant human health concern because they lodge deep in the lungs and can exacerbate asthma and other respiratory diseases.

Particles in the air are eventually deposited as wet deposition (i.e., via rain, snow, clouds, and fog) or dry deposition (i.e., via settling, impaction or adsorption) onto lakes, streams, soils, and vegetation. Sulfur and N deposition change water and soil chemistry, which in turn affects algae, aquatic and terrestrial invertebrates, and soil microorganisms, and can lead to impacts higher in the food chain (Sullivan et al., 2011a; Sullivan et al., 2011b; Greaver et al., 2012). Because N is an essential plant nutrient, excess N deposition can have an unwanted fertilizing effect. Nitrogen favors certain plant species, such as invasive grasses, allowing them to out-compete native species, resulting in a loss of biodiversity. High elevation ecosystems in the Pacific Northwest are thought to be very sensitive to atmospheric deposition of S and N due to a limited ability to neutralize acid deposition and to absorb excess N (Sullivan et al., 2011c; Sullivan et al., 2011d). In nitrogen-limited lakes, excess N deposition can cause phytoplankton (e.g., diatoms) to shift from communities dominated by species adapted to low N conditions (i.e., oligotrophic) to those more typical of disturbed, high N (i.e., mesotrophic) conditions. Because lichens are nitrogen-sensitive, lichen community composition and N content serve as excellent indicators of N deposition. Alpine vegetation communities may also be particularly sensitive to excess N deposition (Sullivan et al., 2011b).

Ground-level ozone harms vegetation as well as human health (USEPA, 2006). Ozone is a respiratory irritant and can trigger a variety of health problems including chest pain, throat irritation, and congestion. Ozone causes significant harm to sensitive plant species in both managed and natural systems. 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 weights).

Atmospherically-deposited Hg can be transformed by ecosystem processes into a bioavailable form, methylmercury (MeHg), which accumulates in the food chain, sometimes reaching toxic levels in fish, wildlife, and humans. Certain ecosystem factors, such as predominance of wetlands and frequent changes in water level, facilitate Hg methylation. In addition, a recent study at Mount Rainier NP (Eagles-Smith, U.S. Geological Survey, in preparation) suggests *in situ* processes likely influence Hg availability. Effects of Hg and other PBTs include impacts on reproductive success, growth, behavior, neurological function, and disease susceptibility (Landers et al., 2008).

Air Quality Standards and Thresholds

The EPA established National Ambient Air Quality Standards (NAAQS) for six primary or "criteria" pollutants: carbon monoxide, lead, nitrogen dioxide, ozone, $PM_{2.5}$, PM_{10}, and SO_2 (Table 6). Primary standards are intended to protect public health; secondary standards are intended to protect public welfare, including park resources. According to monitoring data, Mount Rainier NP is in compliance with all the NAAQS.

Table 6. National Ambient Air Quality Standards.

Pollutant		Primary/ Secondary	Averaging Time	Level	Form
Carbon Monoxide		primary	8-hour	9 ppm	Not to be exceeded more than once per year
			1-hour	35 ppm	
Lead		primary and secondary	Rolling 3 month average	0.15 $\mu g/m^3$	Not to be exceeded
Nitrogen Dioxide		primary	1-hour	0.100 ppm	98th percentile, averaged over 3 years
		primary and secondary	Annual	0.053 ppm	Annual Mean
Ozone		primary and secondary	8-hour	0.075 ppm (75 ppb)	Annual fourth-highest daily maximum 8-hour concentration, averaged over 3 years
Particulate Matter	$PM_{2.5}$	primary	Annual	12 $\mu g/m^3$	annual mean, averaged over 3 years
		secondary	Annual	15 $\mu g/m^3$	annual mean, averaged over 3 years
		primary and secondary	24-hour	35 $\mu g/m^3$	98th percentile, averaged over 3 years
	PM_{10}	primary and secondary	24-hour	150 $\mu g/m^3$	Not to be exceeded more than once per year on average over 3 years
Sulfur Dioxide		primary	1-hour	0.075 ppm	99th percentile of 1-hour daily maximum concentrations, averaged over 3 years
		secondary	3-hour	0.500 ppm	Not to be exceeded more than once per year

ppb = parts per billion
ppm = parts per million
$\mu g/m^3$ = micrograms per cubic meter

Unfortunately, the NAAQS do not provide full protection of ecological resources. For example, the form of the ozone standard does not appropriately reflect the threat to vegetation, and there are no NAAQS for PBTs or secondary pollutants such as NO_3, NH_4, and SO_4. Therefore, the

NPS and other federal land managers use ecological thresholds from the scientific literature to assess potential effects from ozone and deposition of N, S, and PBTs. Consistent with Section 169A of the Clean Air Act, park visibility is compared to natural conditions.

The NPS Air Resources Division (ARD) assesses the threat from S and N deposition through the use of critical loads and target loads. Critical loads are defined as ‘‘the quantitative estimate of an exposure to one or more pollutants below which significant harmful effects on specified sensitive elements of the environment do not occur according to present knowledge’’ (Nilsson and Grennfelt, 1988). Target loads are usually based on critical loads and represent a policy or management decision about the amount of deposition that could be allowed without jeopardizing resource protection (Porter et al., 2005). In the 2012 Final Rule regarding their review of the NAAQS for NO_x and sulfur oxides, EPA used critical loads to define the extent of stream and lake acidification across the U.S. and considered setting secondary standards based on critical loads (“Secondary National Ambient Air Quality Standards for Oxides of Nitrogen and Sulfur, EPA-HQ-OAR-2007-1145; Final Rule”, 77 F.R. 64 [3 April 2012], pp. 20218-20272). The EPA deferred setting critical-load based standards in 2012, but continues to evaluate such standards for their next review. To protect lichen communities in forests of the Pacific Northwest, critical loads for total N deposition of 2.7 to 9.2 kilograms per hectare per year (kg/ha/yr) have been recommended (Geiser et al., 2010). Critical loads for other ecosystem components are under development.

The ARD uses thresholds considered by EPA in their recent review of the NAAQS to assess the threat from ground-level ozone. In January 2010, EPA proposed a stronger primary ozone standard. The agency also proposed a new secondary ozone NAAQS that better reflects vegetation response to ozone exposure, using the W126 metric (“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). The W126 is a cumulative sum of hourly ozone concentrations during a rolling three-month period, where the hourly values are weighted according to their magnitude. The proposed level of the W126 was 7 to 15 parts per million-hours (ppm-hrs). Although EPA ultimately deferred its decision on setting new standards, ARD is using the lower end of the proposed ranges, i.e., 0.060 ppm (60 ppb) for the primary NAAQS and 7 ppm-hrs for the secondary NAAQS, as thresholds that raise concern about ozone effects in NPS areas (NPS, 2013).

In lieu of NAAQS, for PBTs, the NPS 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, EPA has established a guideline of 0.3 ppm (equivalent to 300 nanograms per gram wet weight [ng/g ww]) in muscle (i.e., fillets) for safe human consumption of fish. Recommended mercury thresholds for wildlife are much lower, e.g., 90 to 270 ng/g ww in fish muscle (Eagles-Smith et al., 2014).

Air Quality-Related Monitoring and Research at Mount Rainier NP

A great deal of air quality-related monitoring and research has taken place at Mount Rainier NP (Figures 2-5 and Table 7). This work will be discussed in subsequent sections of the report.

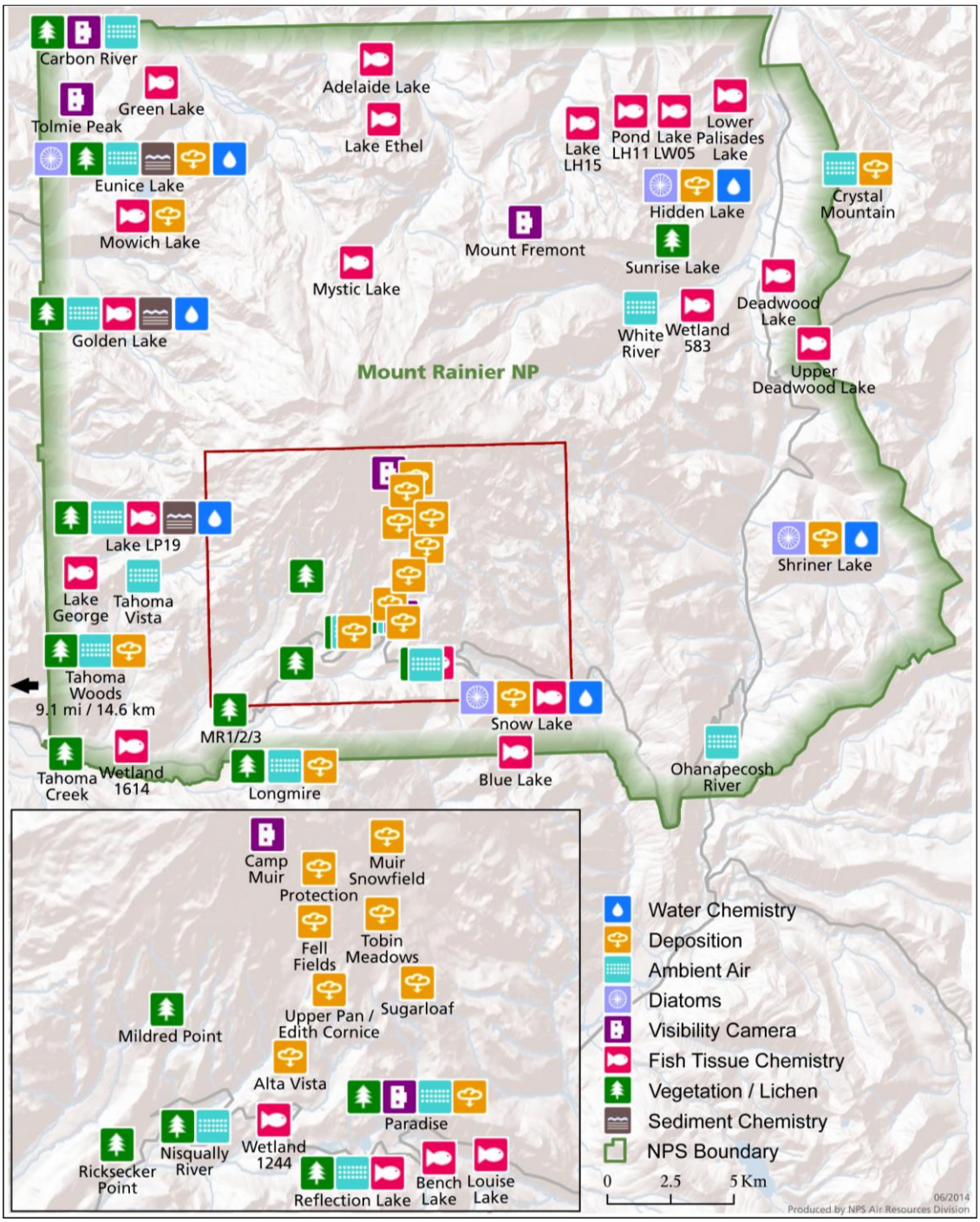

Figure 2. Locations of some of the air quality-related monitoring and research that has been conducted at Mount Rainier NP (produced by NPS, 2014).

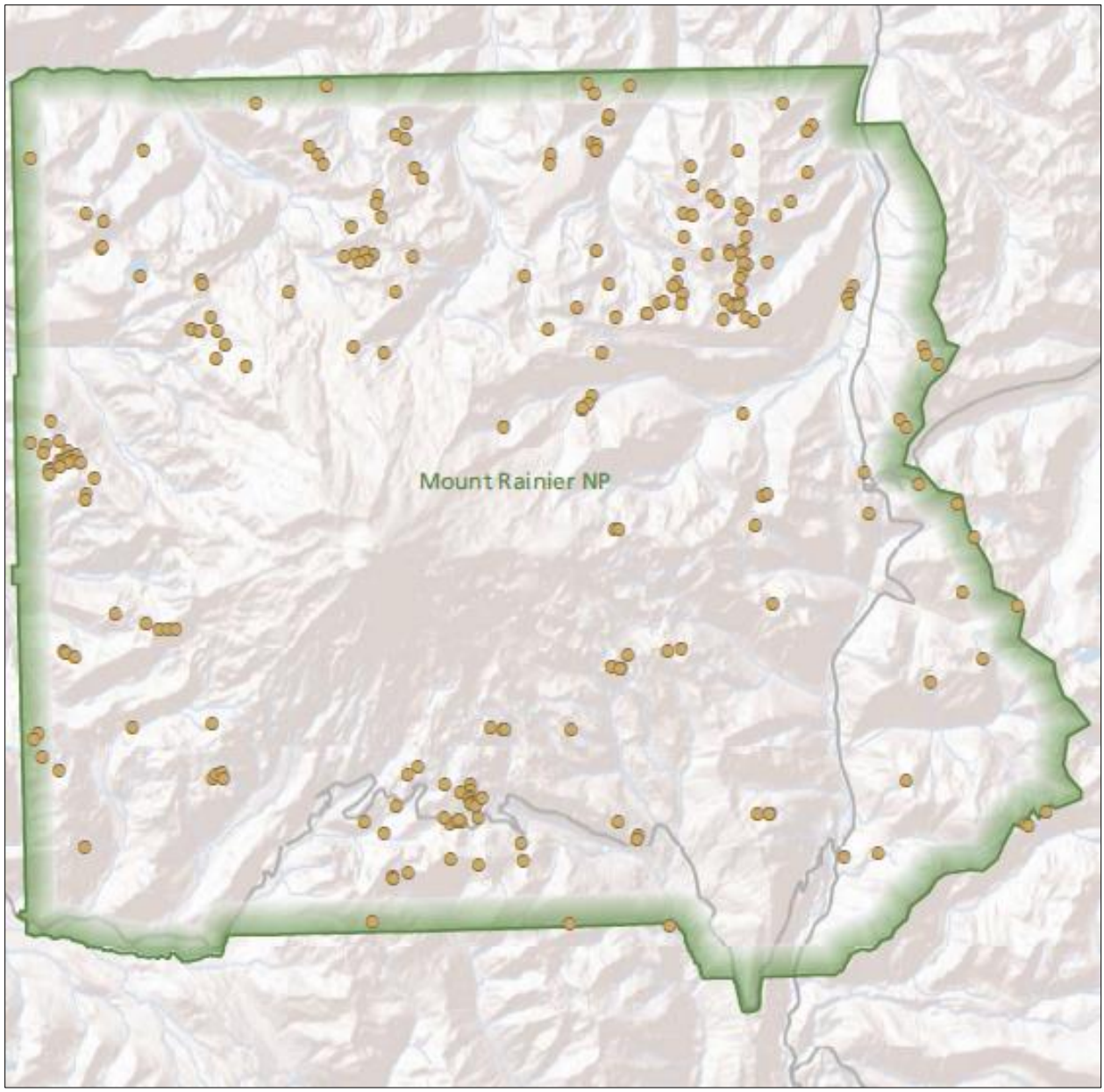

Figure 3. Spatial extent of water chemistry data collected at Mount Rainier NP from 1988 to 2013 (produced by NPS, 2013).

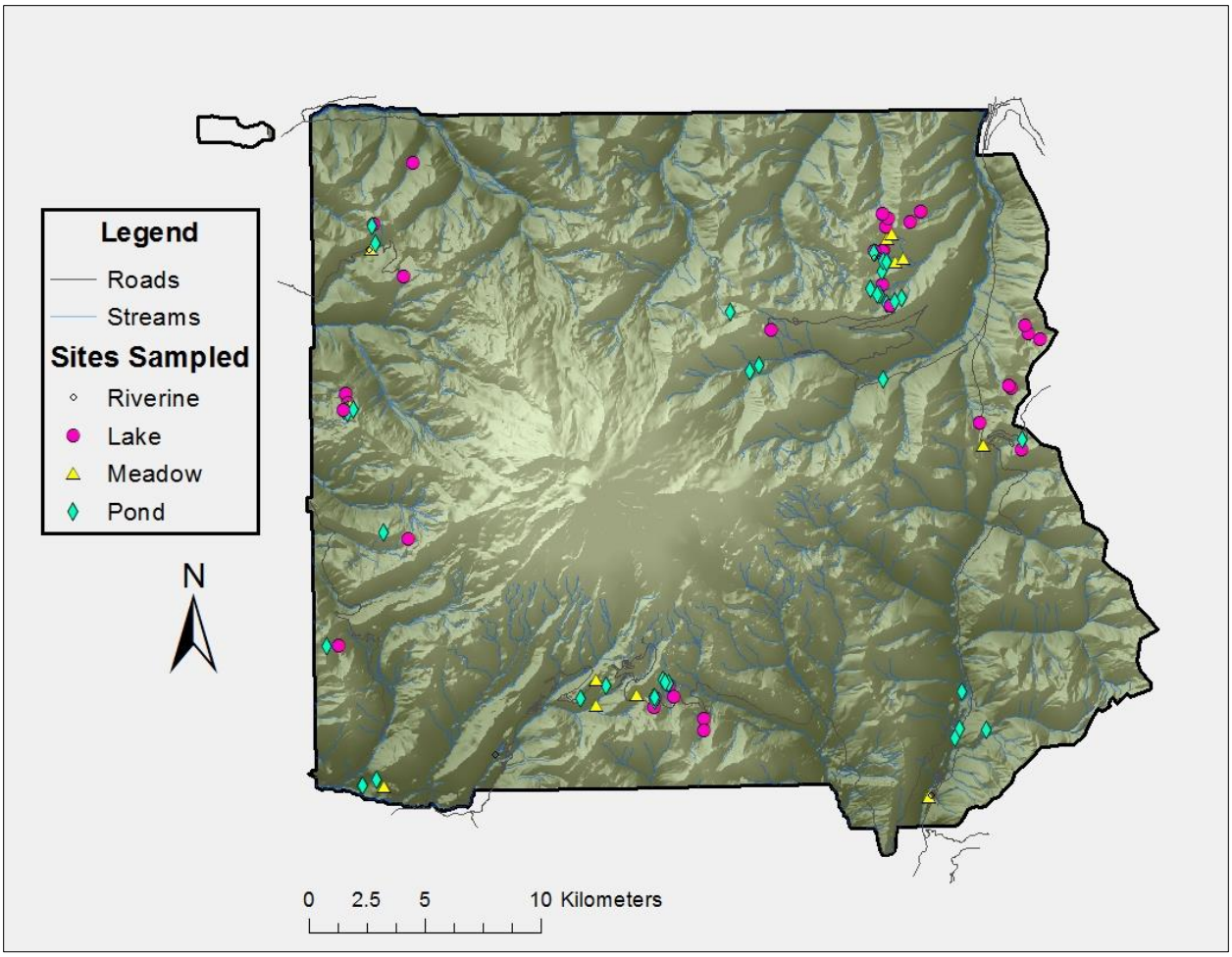

Figure 4. Spatial extent of fish, salamander, and dragonfly larvae samples collected during a 2012 mercury study at Mount Rainier NP (produced by U.S. Geological Survey, 2014).

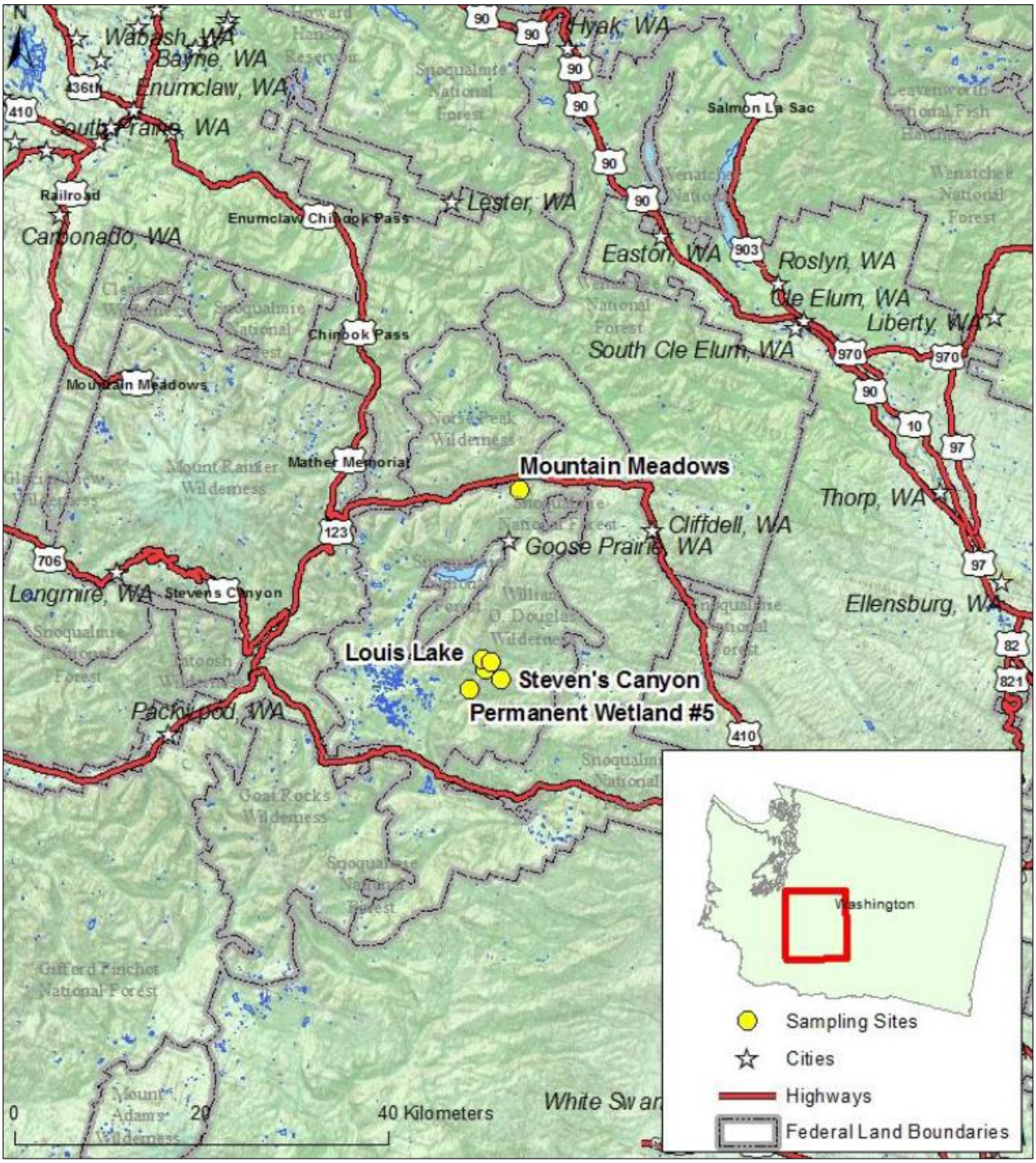

Figure 5. Locations of sampling sites for a 2012 study of mercury in songbirds at Mount Rainier NP (from Adams et al., 2013).

Table 7. Air quality-related monitoring and research at Mount Rainier NP.

Parameter	Location	Investigator	Research (R)/ Monitoring (M)	Dates
Ambient Air				
35-mm camera	Camp Muir	NPS	M	1980s
35-mm camera	Mount Fremont	NPS	M	late 1980s – early 1990s
35-mm camera	Paradise	NPS	M	1985 - 1995
35-mm camera	Tolmie Peak	NPS	M	late 1980s – early 1990s
Digital web camera	Paradise	NPS	M	2003 - present
Visibility – nephelometer	Ohanapecosh campground	NPS	M	2007
Visibility - nephelometer	Paradise	WDOE	M	1993 - 2007
Visibility - nephelometer	Tahoma Woods	NPS	M	1993 - present
Visibility – particles (EBAM monitor)	Ohanapecosh campground	NPS	M	2009, 2010, 2013
Visibility – particles (SFU)	Paradise	NPS	M	1983 - 1987
Visibility – particles (IMPROVE)	Tahoma Woods	NPS	M	1988 - present
Visibility – PREVENT	Carbon River	NPS	R	1990
Visibility - PREVENT	Crystal Mountain	NPS	R	1990
Visibility - PREVENT	Mount Fremont	NPS	R	1990
Visibility - PREVENT	Ohanapecosh	NPS	R	1990
Visibility - PREVENT	Paradise	NPS	R	1990
Visibility - PREVENT	Tahoma Woods	NPS	R	1990
Visibility – total nitrogen	Tahoma Woods	NPS	M	1986 - 1987
Ozone - continuous	Carbon River	NPS	M	1994
Ozone - continuous	Longmire	NPS	M	1987 - 1988
Ozone - continuous	Paradise	WDOE, NPS	M	1998 - present
Ozone - continuous	Tahoma Woods	NPS	M	1991 - 2013
Ozone - portable	Tahoma Vista	NPS	M	2004 - 2005

Table 7. Air quality-related monitoring and research at Mount Rainier NP. (continued)

Parameter	Location	Investigator	Research (R)/ Monitoring (M)	Dates
Ozone - passive	Carbon River drainage	Peterson et al.	M	1994 - 1995
Ozone - passive	Carbon River	NPS	M	1999 - 2005
Ozone - passive	Eunice Lake	NPS	M	2000 - 2005
Ozone - passive	Longmire	NPS	M	1999 - 2005
Ozone - passive	Nisqually River drainage	Peterson et al.	M	1994 - 1997
Ozone - passive	Nisqually River	NPS	M	1999 - 2005
Ozone - passive	Ohanapecosh River drainage	Peterson et al.	M	1995
Ozone - passive	Paradise	NPS	M	1999 - 2005
Ozone - passive	Reflection Lake	NPS	M	1999 - 2005
Ozone - passive	White River drainage	Peterson et al.	M	1994 - 1995
Passive air sampling device	Golden Lake	WACAP	R	2005 - 2006
Passive air sampling device	Lake LP19	WACAP	R	2005 - 2006
Sulfur dioxide	Tahoma Woods	NPS	M	1991 - 1995
AMoN ammonia gas	Tahoma Woods	NPS	M	2011 - present
Deposition				
Bulk deposition	Eunice Lake	Sheibley	R	2008
Bulk deposition	Hidden Lake	Sheibley	R	2008
Bulk deposition	Mowich Lake	Clow and Campbell	R	2000
Bulk deposition	Paradise	NPS, CWU	M	1989 - present
Bulk deposition	Shriner Lake	Sheibley	R	2008
Bulk deposition	Snow Lake	Sheibley	R	2008
CASTNET dry deposition	Tahoma Woods	NPS	M	1995 - 2013
NADP wet deposition	Tahoma Woods	NPS	M	1999 - present
Snowpack	Alta Vista	WACAP	R	2003
Snowpack	Crystal Mountain	Campbell and Simonich	R	2006 - 2007
Snowpack	Edith Cornice	WACAP	R	2005
Snowpack	Eunice Lake	Clow and Campbell	R	2000

Table 7. Air quality-related monitoring and research at Mount Rainier NP. (continued)

Parameter	Location	Investigator	Research (R)/ Monitoring (M)	Dates
Snowpack	Fell Fields	WACAP	R	2005
Snowpack	Mowich Lake	Clow and Campbell	R	2000
Snowpack	Mowich Lake	WACAP	R	2004
Snowpack	Mowich Lake	Campbell and Simonich	R	2006 - 2007
Snowpack	Muir Snowfield	Campbell and Simonich	R	2006 - 2007
Snowpack	Paradise	Eilers	R	1994 - 1996
Snowpack	Paradise	Clow and Campbell	R	2000
Snowpack	Paradise	WACAP	R	2004
Snowpack	Paradise	Campbell and Simonich	R	2006
Snowpack	Protection	WACAP	R	2005
Snowpack	Sugarloaf	WACAP	R	2005
Snowpack	Tobin Meadows	Campbell and Simonich	R	2006
Snowpack	Upper Pan	Campbell and Simonich	R	2006
Throughfall deposition	Longmire	Fenn and Geiser	R	2005 - 2007
Throughfall deposition	Tahoma Woods	Fenn and Geiser	R	2005 - 2007
Diatoms				
Diatoms	Eunice Lake	Sheibley	R	2009
Diatoms	Hidden Lake	Sheibley	R	2009
Diatoms	Shriner Lake	Sheibley	R	2009
Diatoms	Snow Lake	Sheibley	R	2009
Diatoms	Several lakes	Charles, Whiting, and Samora	R	1990s
Diatoms	Several lakes	Drake and Samora	Inventory	late 1990s
Diatoms	Several lakes	Eilers	R	1990s
Lichens				
Lichens	MR1, MR2, MR3	Geiser	M	2006
Lichens	Tahoma Woods	Geiser	M	2006

Table 7. Air quality-related monitoring and research at Mount Rainier NP. (continued)

Parameter	Location	Investigator	Research (R)/ Monitoring (M)	Dates
Sediment Chemistry				
Sediment	Eunice Lake	Eilers and Sullivan	R	1998
Sediment	Golden Lake	WACAP	R	2005
Sediment	Lake LP19	WACAP	R	2005
Vegetation Chemistry				
Vegetation	Golden Lake	WACAP	R	2004
Vegetation	Lake LP19	WACAP	R	2004
Vegetation	Mildred Point	WACAP	R	2004
Vegetation	Reflection Lake	Henderson and Lesher	R	1998
Vegetation	Ricksecker Point	WACAP	R	2004
Vegetation	Sunrise Lake	Henderson and Lesher	R	1998
Vegetation	Tahoma Creek	WACAP	R	2004
Vegetation Ozone Injury				
Vegetation	Carbon River	NPS	M	1999 - 2005
Vegetation	Eunice Lake	NPS	M	2000 - 2005
Vegetation	Longmire	NPS, FHM	M	1998
Vegetation	Longmire	NPS	M	1999 - 2005
Vegetation	Nisqually River	NPS	M	1999 - 2005
Vegetation	Paradise	NPS	M	1999 - 2005
Vegetation	Reflection Lake	NPS, FHM	M	1998
Vegetation	Reflection Lake	NPS	M	1999 - 2005
Vegetation	Wonderland Trail	NPS, FHM	M	1998
Water Chemistry				
Water	Eunice Lake	Clow and Campbell	R	2000
Water	Eunice Lake	Sheibley	R	2009
Water	Golden Lake	WACAP	R	2005
Water	Hidden Lake	Sheibley	R	2009
Water	Lake LP19	WACAP	R	2005
Water	Shriner Lake	Sheibley	R	2009

Table 7. Air quality-related monitoring and research at Mount Rainier NP. (continued)

Parameter	Location	Investigator	Research (R)/ Monitoring (M)	Dates
Water	Snow Lake	Sheibley	R	2009
Water	Several lakes	NPS	M	1988 - present
Wildlife				
Songbirds	Bench Pond	BRI	R	2012
Songbirds	Louise Lake	BRI	R	2012
Songbirds	Mountain Meadows	BRI	R	2012
Songbirds	Permanent Wetland #5	BRI	R	2012
Songbirds	Reflection Lake	BRI	R	2012
Songbirds	Steven's Canyon	BRI	R	2012
Dragonfly larvae	Several locations	Eagles-Smith	R	2012
Fish	Adelaide Lake	Schreck and Kent	R	2009
Fish	Bench Lake	Eagles-Smith	R	2011 - 2012
Fish	Blue Lake	Schreck and Kent	R	2009
Fish	Deadwood Lake	Schreck and Kent	R	2008
Fish	Deadwood Lake	Eagles-Smith	R	2011 - 2012
Fish	Golden Lake	Moran	R	2002
Fish	Golden Lake	WACAP	R	2005
Fish	Golden Lake	Eagles-Smith	R	2011 - 2012
Fish	Green Lake	Moran	R	2002
Fish	Green Lake	Schreck and Kent	R	2009
Fish	Green Lake	Eagles-Smith	R	2011 - 2012
Fish	Lake Ethel	Schreck and Kent	R	2008 - 2009
Fish	Lake George	Eagles-Smith	R	2011 - 2012
Fish	Lake LH15	Schreck and Kent	R	2008
Fish	Lake LH15	Eagles-Smith	R	2011 - 2012
Fish	Lake LP19	WACAP	R	2005
Fish	Lake LW05	Eagles-Smith	R	2011 - 2012
Fish	Louise Lake	Schreck and Kent	R	2008
Fish	Louise Lake	Eagles-Smith	R	2011 - 2012

Table 7. Air quality-related monitoring and research at Mount Rainier NP. (continued)

Parameter	Location	Investigator	Research (R)/ Monitoring (M)	Dates
Fish	Lower Palisades Lake	Eagles-Smith	R	2011 - 2012
Fish	Mowich Lake	Schreck and Kent	R	2008
Fish	Mowich Lake	Eagles-Smith	R	2011 - 2012
Fish	Mystic Lake	Schreck and Kent	R	2009
Fish	Pond LH11	Eagles-Smith	R	2011 - 2012
Fish	Reflection Lake	Eagles-Smith	R	2011 - 2012
Fish	Snow Lake	Moran	R	2002
Fish	Snow Lake	Schreck and Kent	R	2009
Fish	Snow Lake	Eagles-Smith	R	2011 - 2012
Fish	Upper Deadwood Lake	Moran	R	2002
Fish	Upper Deadwood Lake	Schreck and Kent	R	2009
Fish	Upper Deadwood Lake	Eagles-Smith	R	2011 - 2012
Fish	Wetland 583	Eagles-Smith	R	2011 - 2012
Fish	Wetland 1244	Eagles-Smith	R	2011 - 2012
Fish	Wetland 1614	Eagles-Smith	R	2011 - 2012
Salamanders	Various locations	Eagles-Smith	R	2012

AMoN = Ammonia Monitoring Network
BRI = Biodiversity Research Institute
CASTNET = Clean Air Status and Trends Network
CWU = Central Washington University
FHM = Forest Health Monitoring Program
IMPROVE = Interagency Monitoring of Protected Visual Environments
NADP = National Atmospheric Deposition Program
NPS = National Park Service
PREVENT = Pacific Northwest Regional Visibility Experiment Using Natural Tracers
SFU = Stacked Filter Unit
WACAP = Western Airborne Contaminants Assessment Project
WDOE = Washington Department of Ecology

Visibility

Beginning in the 1980s, the NPS began monitoring visibility at Mount Rainier NP. Pictures were taken with a 35-mm camera at Camp Muir (1980s), Mount Fremont (1980s to 1990s), Paradise (1985 to 1995), and Tolmie Peak (1980s to 1990s). A digital camera has been operating at Paradise since 2003. The photographs provide qualitative documentation of visibility impairment. In 1995, an historical photographic archive was developed to show representative regional haze visibility conditions (Figure 6), including each slide's estimated standard visual range (i.e., the distance at which one can barely make out the presence of a large, dark object).

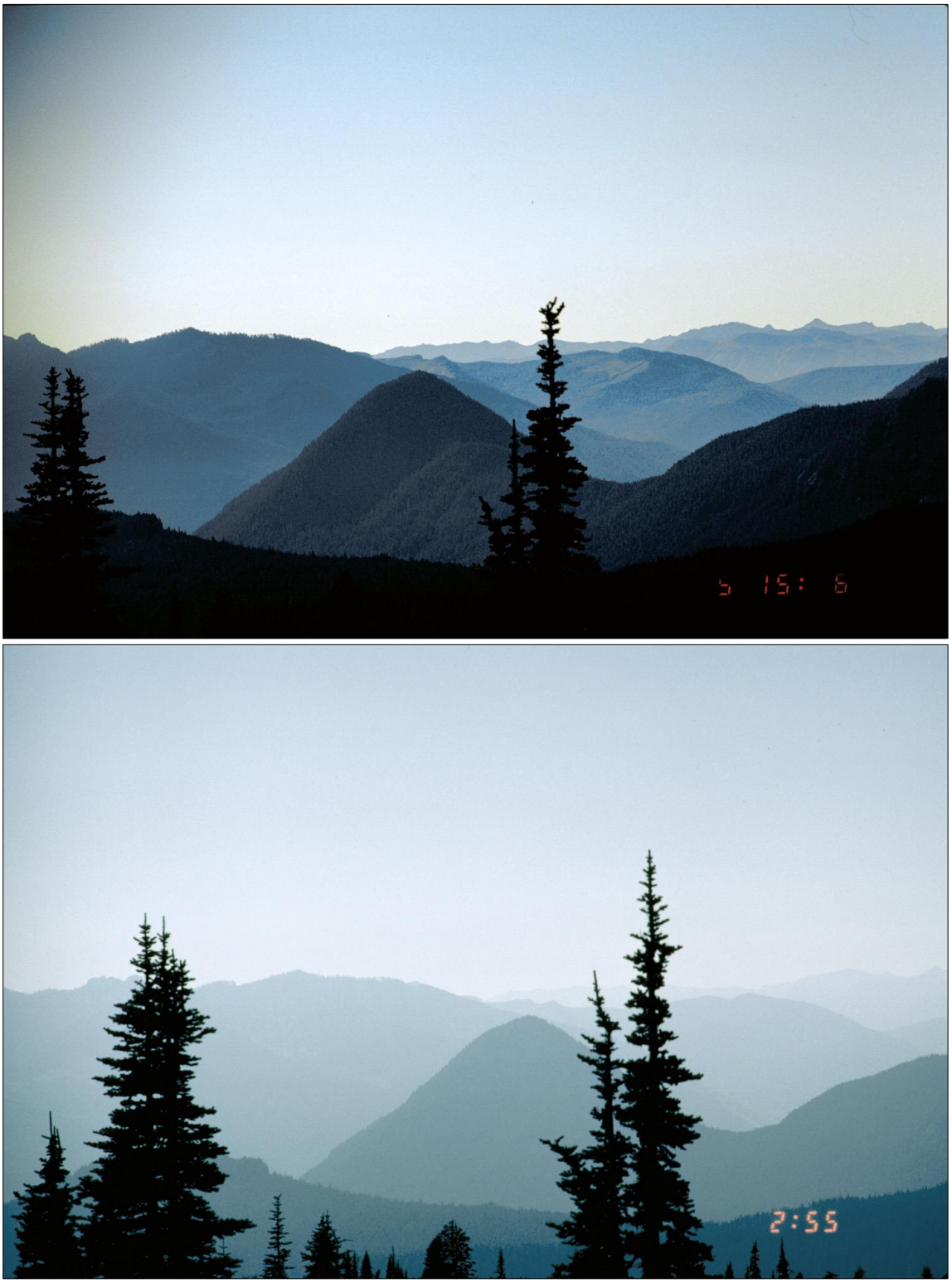

Figure 6. Representative photographs of the view from Paradise at Mount Rainier NP (from IMPROVE, 2014). The top picture, with a standard visual range of 280 km, illustrates the clearest days. The bottom picture, with a standard visual range of 60 km, illustrates the haziest days.

Atmospheric particle monitoring allows for identification of the chemical species and sources of visibility impairment in the park and is used to document long-term visibility trends. Particle monitoring was conducted with stacked filter units (SFU) at Paradise from 1983 to 1987. Since 1988, an Interagency Monitoring of Protected Visual Environments (IMPROVE) Program particle monitor has been operating at Tahoma Woods; the monitor gives quantitative measurements of mass, chemical elements, SO_4, NO_3, organics, and elemental carbon. A nephelometer provides another method of monitoring visibility by measuring the amount of light scattered by atmospheric particles and gases. Nephelometers have been operating at Paradise (1993 to 2007) and Tahoma Woods (1993 to present).

The Pacific Northwest Regional Visibility Experiment Using Natural Tracers (PREVENT) study was carried out during the summer of 1990 (Malm et al., 1994). The objectives of the study were to: determine the spatial and temporal patterns of visibility reducing particles and gases in northwest Washington, identify general source types that contribute to visibility impairment at Mount Rainier and North Cascades NPs, and develop estimates of the amount of haze that is natural versus anthropogenic. The sampling network consisted of three primary and 21 secondary sites; six sites were located at Mount Rainier (Table 8). The study indicated 80 to 90 percent of the haze was due to anthropogenic sources, with sulfates being the largest contributor to visibility impairment. At Mount Rainier NP, SO_4 concentrations were statistically linked to emissions from the Centralia coal-fired power plant and the Seattle-Tacoma urban area. Results from the PREVENT study factored into the negotiations that resulted in installation of controls at, and a significant reduction in emissions from, Centralia.

Table 8. Monitoring sites at Mount Rainier NP for the 1990 PREVENT visibility study.

Location	35-mm Camera	Nephelometer	IMPROVE
Carbon River	X	X	X
Crystal Mountain			X
Mount Fremont	X		
Ohanapecosh			X
Paradise	X	X	X
Tahoma Woods		X	X

In 1999, EPA promulgated the Regional Haze Rule, which involves each state developing a plan to improve visibility in Class I areas, with the goal of returning visibility to natural conditions by 2064. The Regional Haze Rule requires visibility to improve on the haziest days and no degradation on the clearest days. 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. To quantify the amount of visibility impairment at a site, IMPROVE determines the dv difference between monitored visibility and calculated natural conditions, i.e., the visibility that would exist without human-caused impairment.

The most recent ARD air quality conditions and trends report indicated a statistically significant improvement in visibility on the clearest and haziest days at Mount Rainier NP from 2000 to 2009 (NPS, 2013). This was consistent with steadily improving trends shown by the longer 1988 to 2013 dataset (Figure 7). To assess the visibility condition in parks, ARD calculates the

difference between average current visibility and estimated average natural visibility. For 2008 to 2012, that difference was 4.21 dv for Mount Rainier NP, meaning monitored visibility was 42 percent worse than natural conditions (NPS, 2014). The ARD considers average visibility conditions that are 2 to 8 dv worse than natural conditions to be of moderate concern (NPS, 2013). While the difference between current conditions and natural conditions is greater than 8 dv in most of the parks in the eastern U.S. and California, most parks in the western U.S. fall into the moderate concern category.

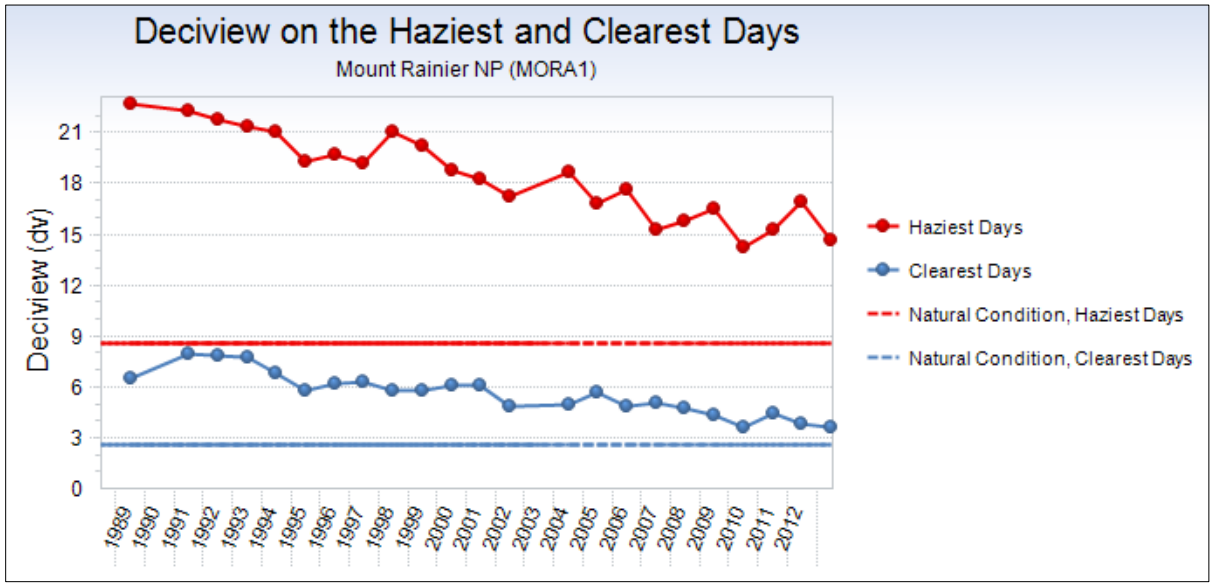

Figure 7. Deciview trends compared to natural conditions on the haziest and clearest days at Mount Rainier NP (from Federal Land Manager Environmental Database, 2014).

Visibility impairment is also reported in terms of light extinction, which is the loss in light intensity due to scattering and absorption, measured in inverse megameters (Mm-1). Similar to the dv scale, as light extinction increases, visibility degrades. The IMPROVE program provides summaries of total light extinction, by year, as well as a breakdown of each monitored pollutant's contribution to light extinction. From 1988 to 2013, on the haziest days, there was a decreasing trend in ammonium sulfate (Figure 8) at Mount Rainier NP. In general, the contribution from ammonium sulfate to visibility impairment appeared to be lower since SO2 controls were installed at the Centralia power plant in 2001 through 2002. There was no apparent trend in ammonium nitrate at the park on the haziest days; installation of NOx controls at Centralia in 2003 did not have a noticeable effect. On the clearest days at Mount Rainier NP, the improving 1988 to 2013 visibility trend appeared to be associated with a decrease in several pollutants (Figure 9).

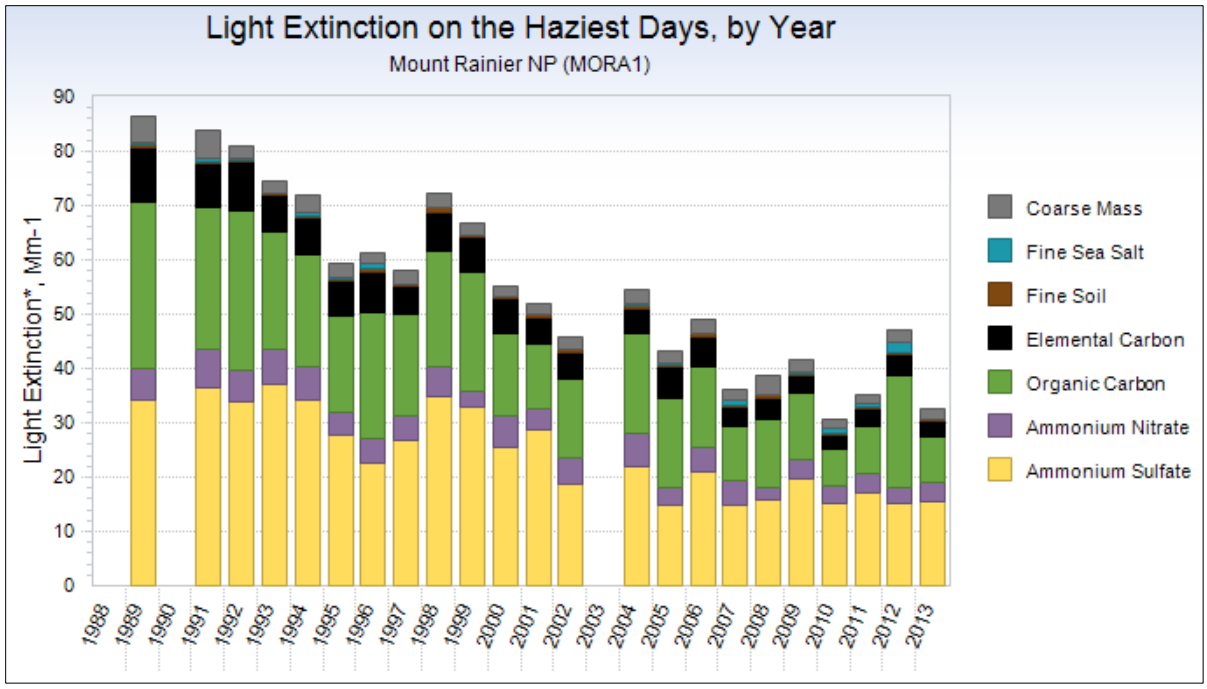

Figure 8. Light extinction on the haziest days, by year, at Mount Rainier NP (from Federal Land Manager Environmental Database, 2014).

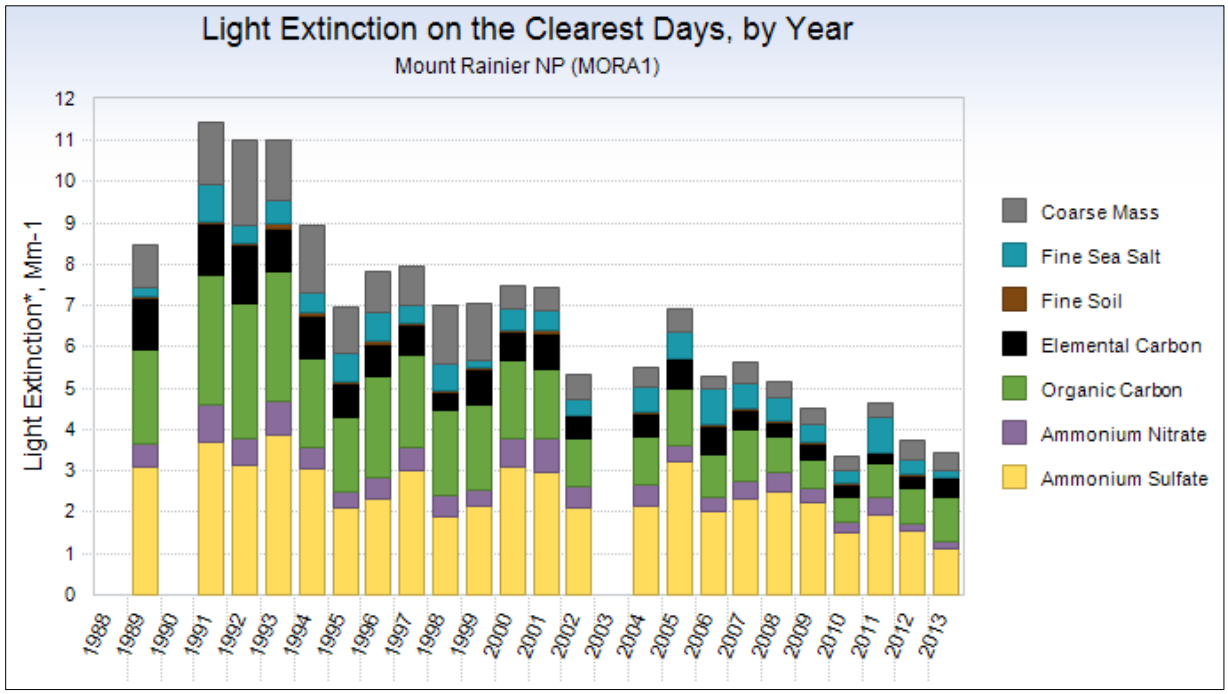

Figure 9. Light extinction on the clearest days, by year, at Mount Rainier NP (from Federal Land Manager Environmental Database, 2014).

As mentioned previously, atmospheric particles are also a human health concern. In response to visitor and employee complaints about wood smoke, particle monitoring was conducted in the Ohanapecosh campground at the park during summer through early fall of 2009, 2010, and 2013.

During the sample periods, no exceedances of the 24-hr PM2.5 NAAQS of 35 µg/m3 occurred. However, on September 12th, 2009, the 24-hr concentration reached 34 µg/m3 (Lofgren and Samora, 2010). Although no NAAQS exceedances occurred, high hourly peak concentrations were recorded on weekends during the evening hours. In 2013, the number of campfires and weather conditions were correlated with PM2.5 levels. Results indicated concentrations of particulate matter in the Ohanapecosh area do not necessarily increase with an increase in campfire activity. High concentrations were found to be more related to the presence of campfires in combination with inversions occurring on clear, cold nights and mornings in the Ohanapecosh valley (Johnson and Lofgren, in preparation).

Deposition

Pollutants in wet and dry deposition can have significant impacts on park ecosystems. Wet deposition has been monitored at Tahoma Woods (site WA99) at Mount Rainier NP since 1999 through the National Atmospheric Deposition Program (NADP). The NADP reports concentrations and deposition of SO_4, NO_3, NH_4, and base cations. The ARD evaluated 2000 to 2009 NADP data and found a statistically significant decrease in NO_3 concentrations, a decrease in SO_4 concentrations, and no trend in NH_4 concentrations at the park over that period of time (NPS, 2013). The NADP graphs for Mount Rainier NP show the long term trends in annual concentration (in milligrams/liter [mg/L]; Figure 10), precipitation (in cm; Figure 11), and deposition (in kg/ha/yr; Figure 11).

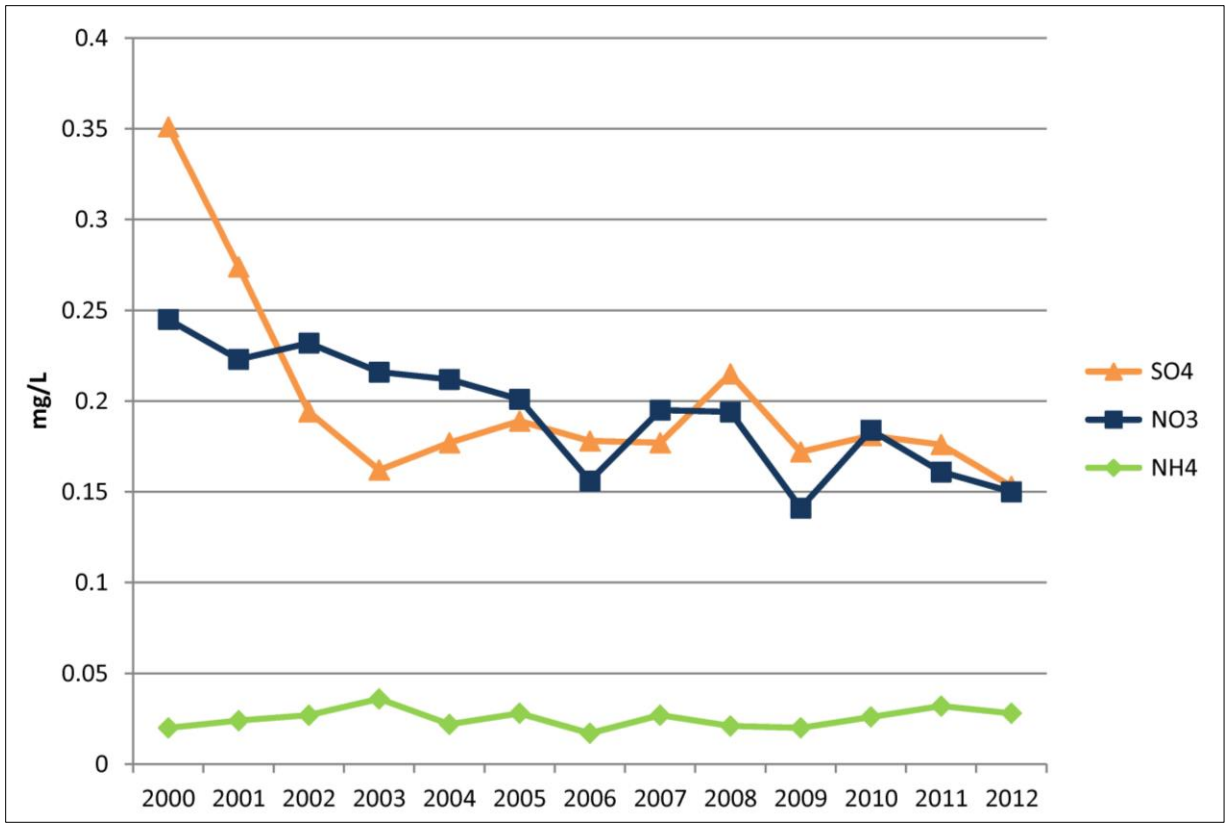

Figure 10. Trends in annual concentrations of SO_4, NO_3, and NH_4 at the Tahoma Woods NADP site (WA99) at Mount Rainier NP (produced by NPS, 2014).

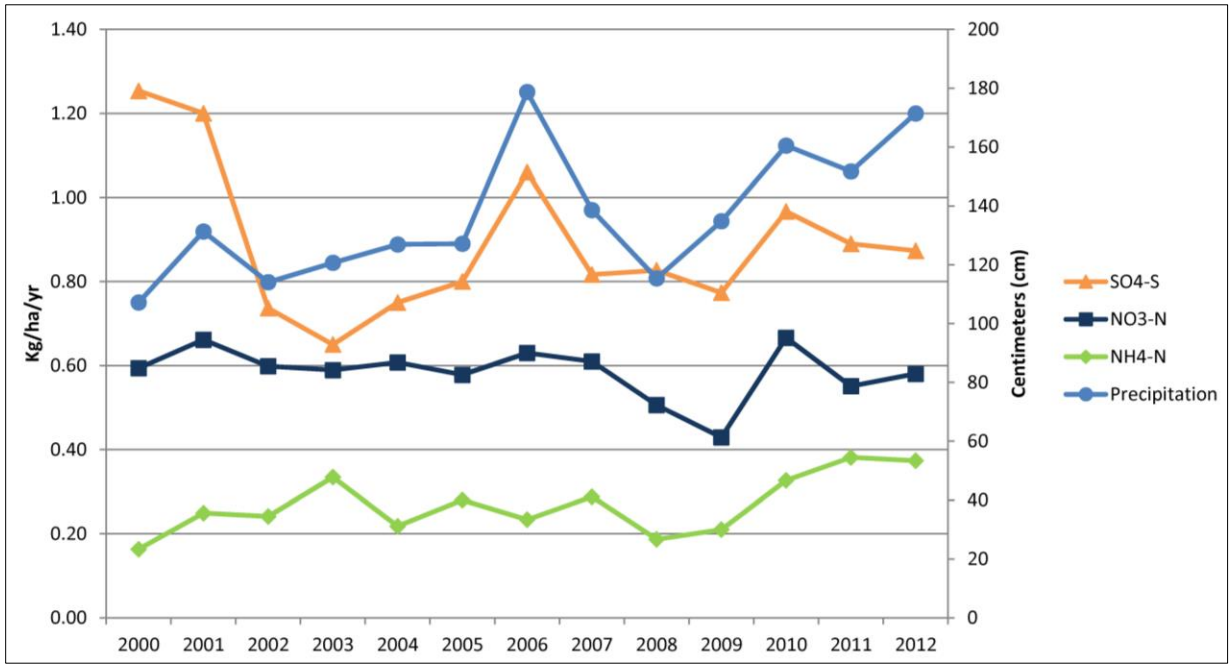

Figure 11. Trends in annual precipitation and deposition of SO_4, NO_3, and NH_4 at the Tahoma Woods NADP site (WA99) at Mount Rainier NP (produced by NPS, 2014).

Dry deposition was monitored at Tahoma Woods from 1995 to 2013 through the national Clean Air Status and Trends Network (CASTNET; site MOR409). The CASTNET dry deposition values are calculated by multiplying measured ambient pollutant concentrations of SO2, SO4, HNO3, NO3, and NH4 by estimated deposition velocities. By combining NADP wet and CASTNET dry deposition, total S deposition at Tahoma Woods was estimated to range from about 0.8 to 1.7 kg/ha/yr (Figure 12) and total N deposition ranged from about 0.76 to 1.28 kg/ha/yr (Figure 13). The Tahoma Woods site showed a substantial decrease in S deposition following installation of SO2 emission controls at the Centralia power plant in 2001 through 2002; a decrease in N deposition occurred after NOx controls were installed at Centralia in 2003.

Dry deposition was estimated to account for 7 to 26 percent of total S deposition and 10 to 35 percent of total N deposition at Tahoma Woods. While dry deposition is expected to be low in wet environments like the Pacific Northwest, CASTNET typically underestimates dry deposition, especially because N from NH3 is not included in the total. To improve understanding of the contribution of NH3 to total N deposition, NADP established the Ammonia Monitoring Network (AMoN) in 2010; an AMoN site (WA99) has been operating at Tahoma Woods since 2011 (NADP, 2014).

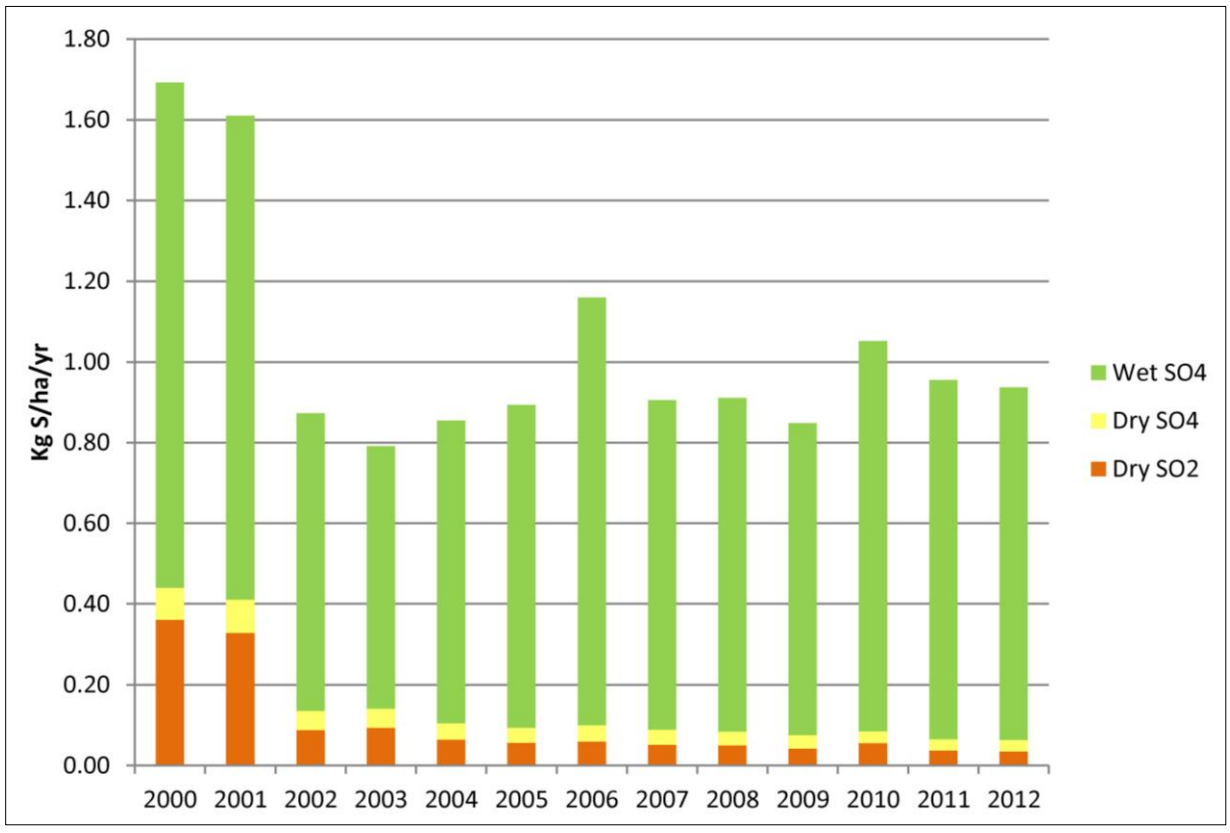

Figure 12. Total S deposition at Tahoma Woods at Mount Rainier NP based on NADP (site WA99) wet deposition and CASTNET (site MOR409) dry deposition data (produced by NPS, 2014).

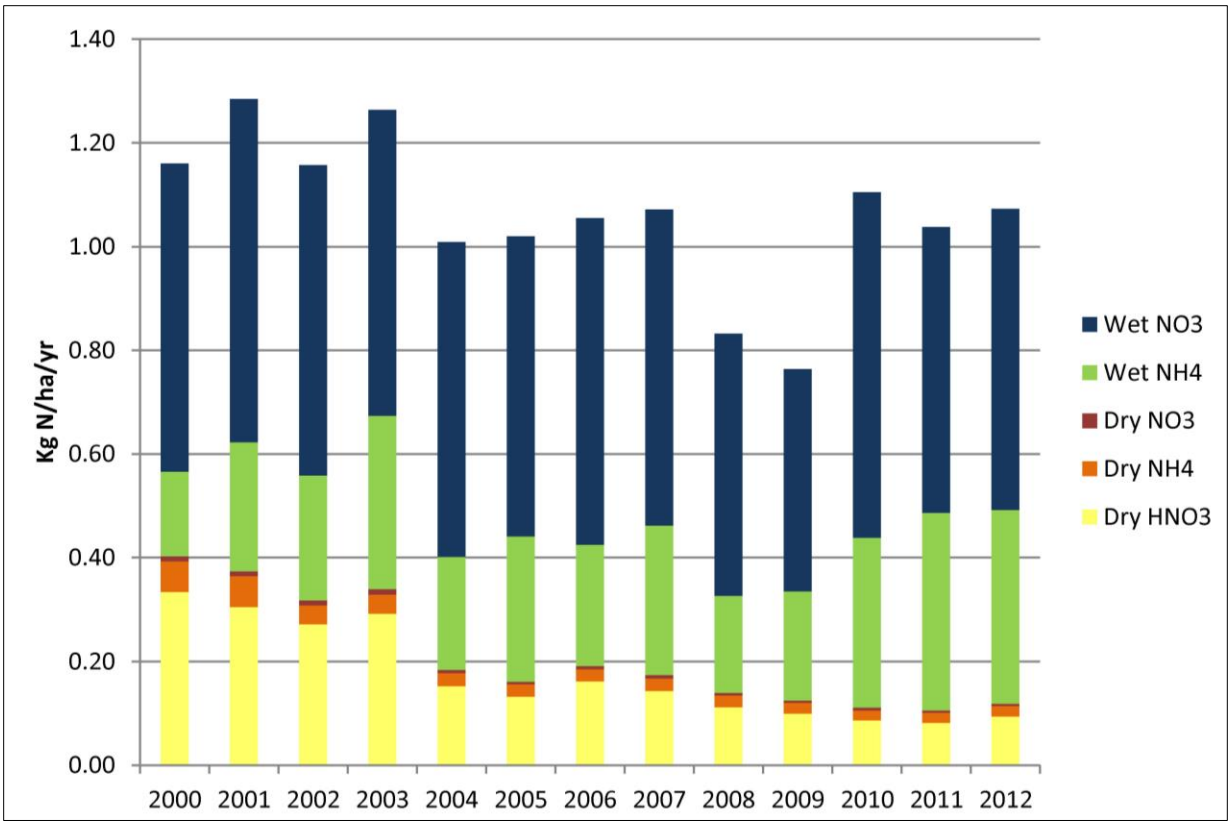

Figure 13. Total N deposition at Tahoma Woods at Mount Rainier NP based on NADP (site WA99) wet deposition and CASTNET (site MOR409) dry deposition data (produced by NPS, 2014).

Mount Rainier NP staff have been monitoring bulk, i.e., wet plus some dry, deposition at Paradise since 1989 and the samples have been analyzed by the Central Washington University Chemistry Lab. Agren et al. (2013) reported decreasing trends in SO_4 and NO_3 concentrations and an increasing trend in NH_4 concentrations at the Paradise site from 1989 to 2012. Agren et al. compared 1999 to 2012 data from the Tahoma Woods NADP site (at 421 m) and the Paradise bulk deposition site (at 1,654 m) to determine if differences in elevation resulted in different chemical characteristics at the two sites. While they found no significant difference in the SO_4 and NH_4 concentrations, the NO_3 concentrations were significantly higher at Paradise.

Fog events occur frequently in the Pacific Northwest; however, fog deposition is not measured routinely by either the NADP or CASTNET networks. In an attempt to capture fog deposition, Fenn et al. (2013) conducted throughfall sampling at Mount Rainier, North Cascades and Olympic NPs from 2005 to 2007. Throughfall is a bulk deposition measurement that incorporates wet deposition with the wash-off of dry particles and gases from the leaf surface. The researchers concluded total S deposition to the forest floor was 0.9 to 1.5 times greater than combined NADP wet and CASTNET dry deposition. Average wet plus dry deposition was 2.1 kg/ha/yr compared to throughfall S deposition of 2.5 kg/ha/yr. Throughfall N deposition at the parks was unexpectedly low because approximately 90 percent of wet-deposited nitrate-N was taken up by the forest canopy. High canopy uptake limits the usefulness of the throughfall method for monitoring total N deposition. Fenn et al. (2013) used the S:N ratios in wet deposition and throughfall S deposition to estimate a range of total N deposition of 1.3 to 2.1

kg/ha/yr in park forests. They concluded this range was comparable to the NADP wet N deposition range of 0.9 to 2.0 kg/ha/yr.

As part of the air quality related values inventory for NPS's Inventory and Monitoring (I&M) Program, Sullivan et al. conducted risk assessments for acidification from S and N deposition (Sullivan et al., 2011a) and for nutrient enrichment from N (Sullivan et al., 2011b). Both assessments considered pollutant exposure, occurrence of ecosystems known or suspected to be sensitive to acidification or N enrichment, and mandates for park protection (Class I parks and parks with wilderness areas were ranked high for park protection; all other parks were ranked moderate). Relative risk was assessed for all 32 NPS I&M Networks as well as for all NPS areas larger than 100 square miles. Mount Rainier, North Cascades and Olympic NPs, as well as a number of smaller historic park units, are part of I&M's North Coast and Cascades Network (NCCN). Although S and N deposition is relatively low compared to parks in the eastern U.S., the NCCN is considered at high risk for both acidification (Figure 14; Sullivan et al., 2011c) and N enrichment (Figure 15; Sullivan et al., 2011d) relative to other I&M Networks, based on the suspected sensitivity of high elevation ecosystems in the three large parks. Similarly, Mount Rainier NP is considered at high risk in both assessments (Figures 16 and 17). Sullivan et al. (2011c and 2011d) used GIS data to produce maps showing the extent of likely sensitive high elevation surface waters (Figures 18 and 19) and vegetation (Figure 20) in the park (note: data used for the assessment are available from the NPS Data Store at https://irma.nps.gov/App/Portal/Home).

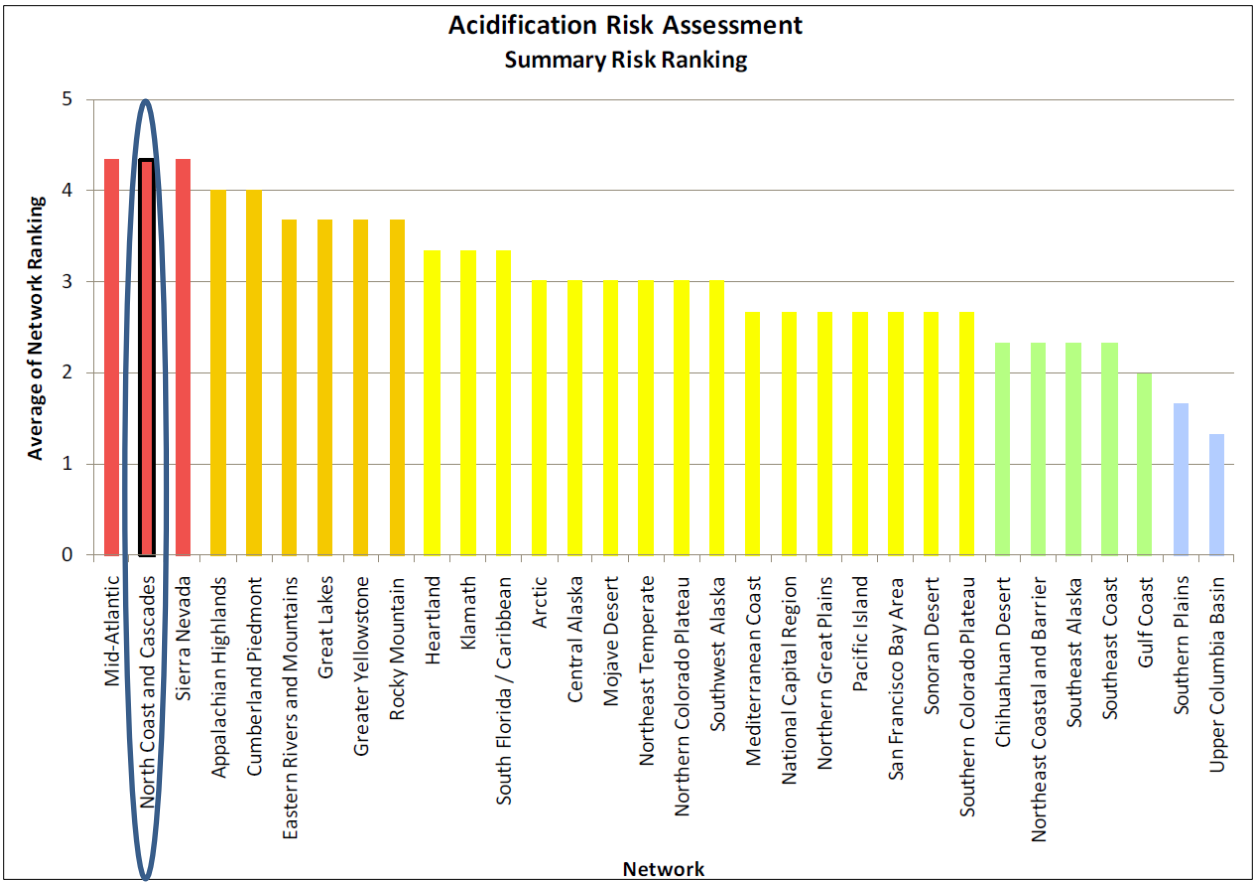

Figure 14. Summary risk ranking of acidification due to S and N deposition for the 32 NPS I&M Networks (from Sullivan et al., 2011c). Network rankings are divided into color-coded quintiles, with red indicating the highest risk and blue reflecting the lowest risk.

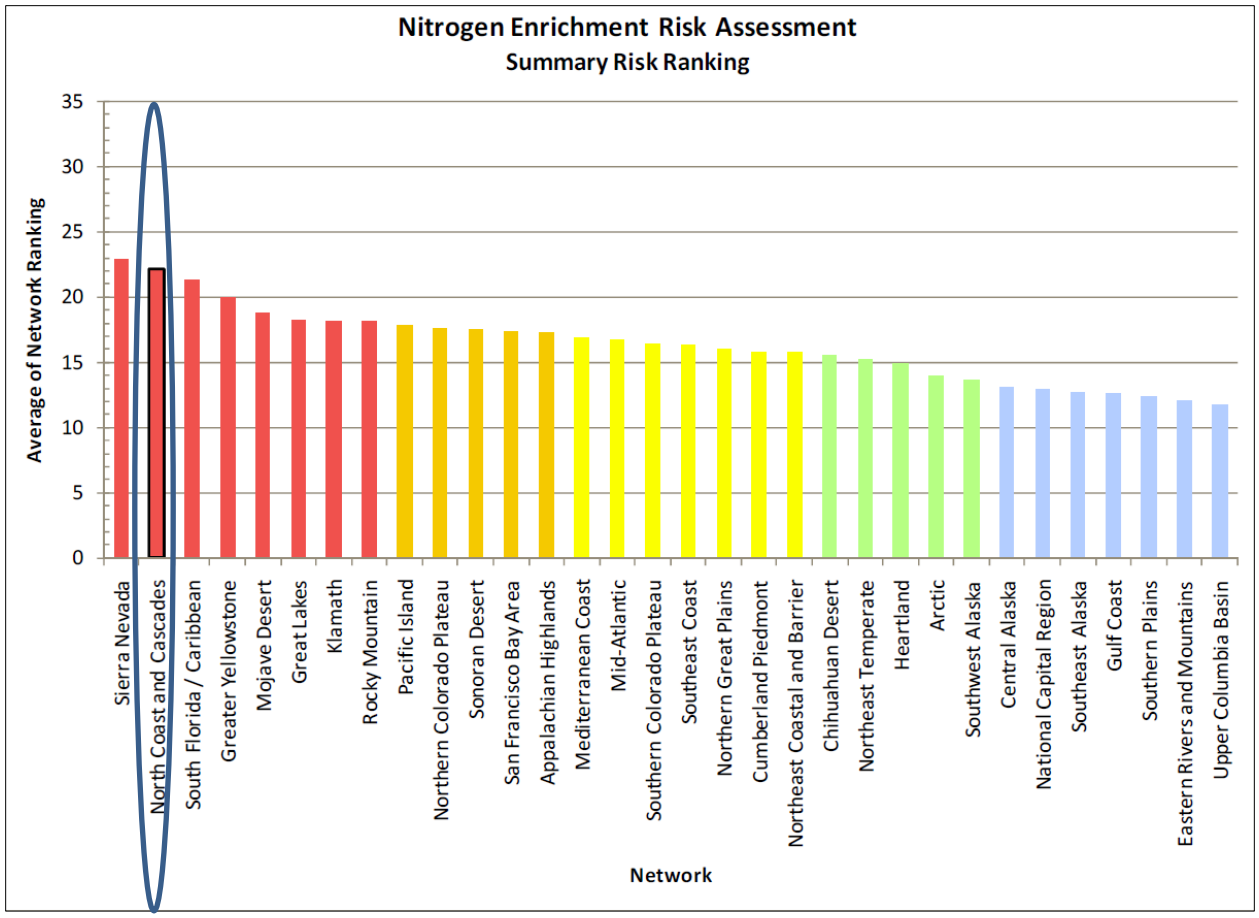

Figure 15. Summary risk ranking of atmospheric N enrichment for the 32 I&M Networks (from Sullivan et al., 2011d). Network rankings are divided into color-coded quintiles, with red indicating the highest risk and blue reflecting the lowest risk.

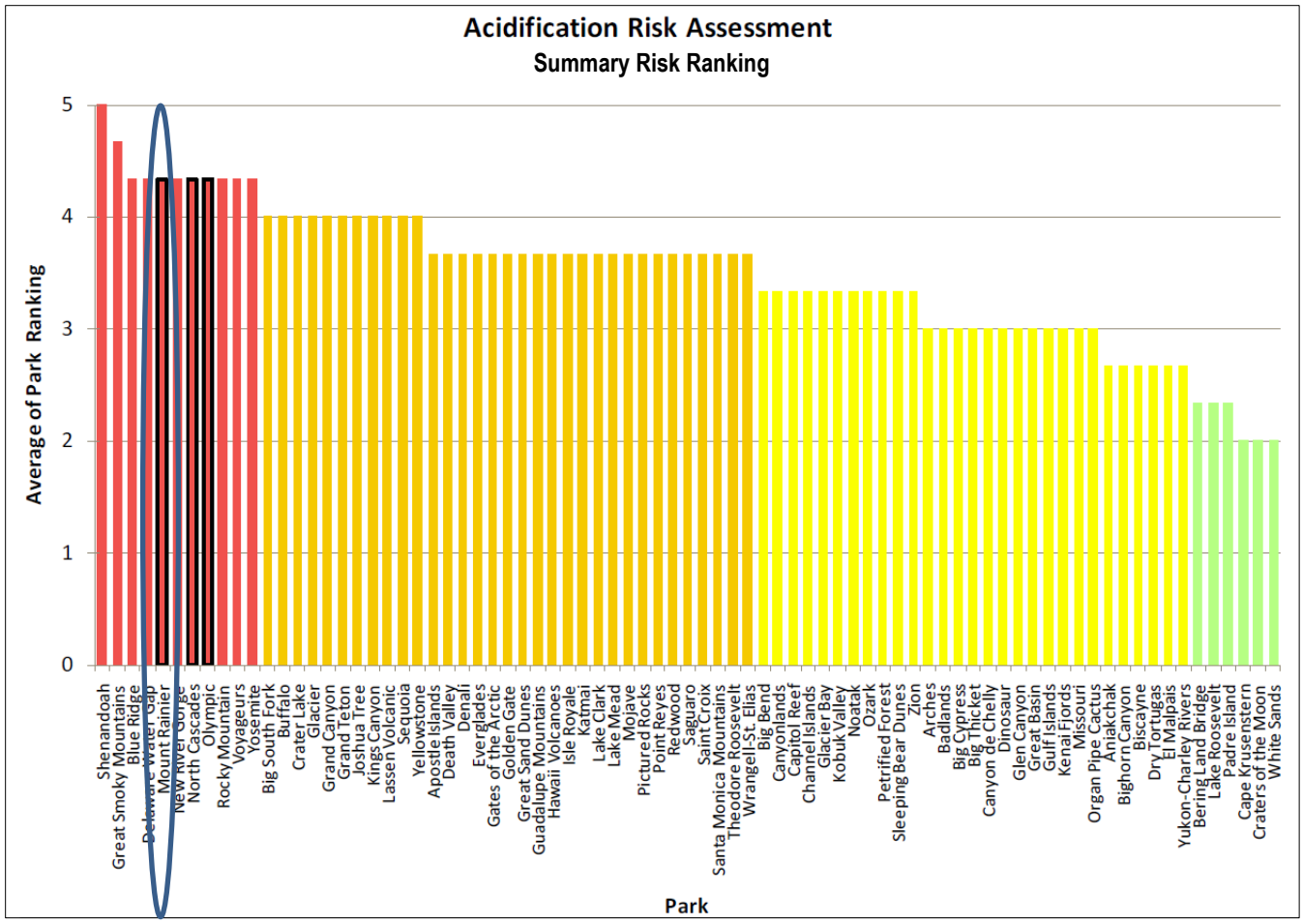

Figure 16. Summary risk ranking of acidification due to S and N deposition for all NPS areas larger than 100 square miles (from Sullivan et al., 2011c). Park rankings are divided into color-coded quintiles, with red indicating the highest risk and blue reflecting the lowest risk.

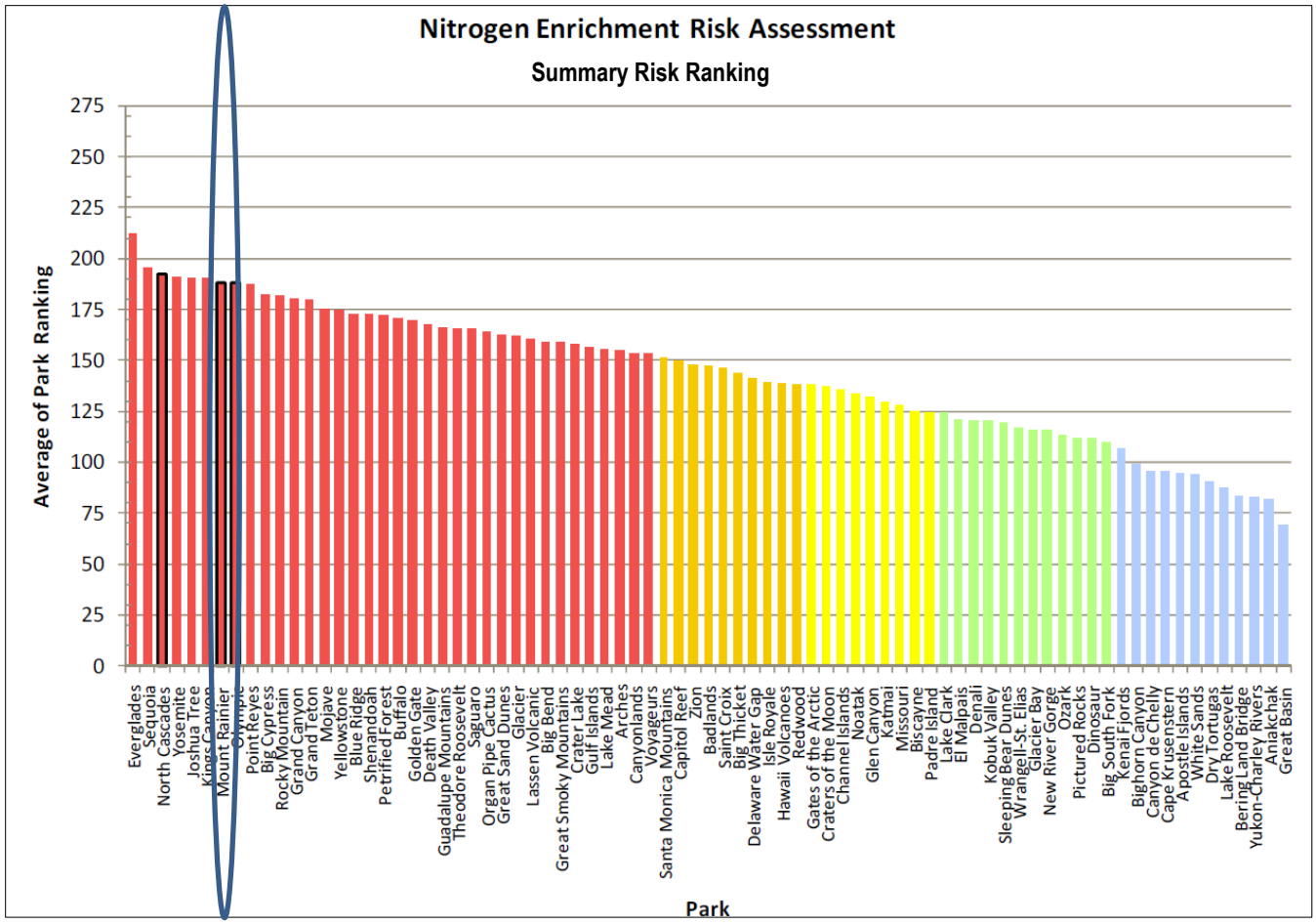

Figure 17. Summary risk ranking of atmospheric N enrichment for all NPS areas larger than 100 square miles (from Sullivan et al., 2011d). Park rankings are divided into color-coded quintiles, with red indicating the highest risk and blue reflecting the lowest risk.

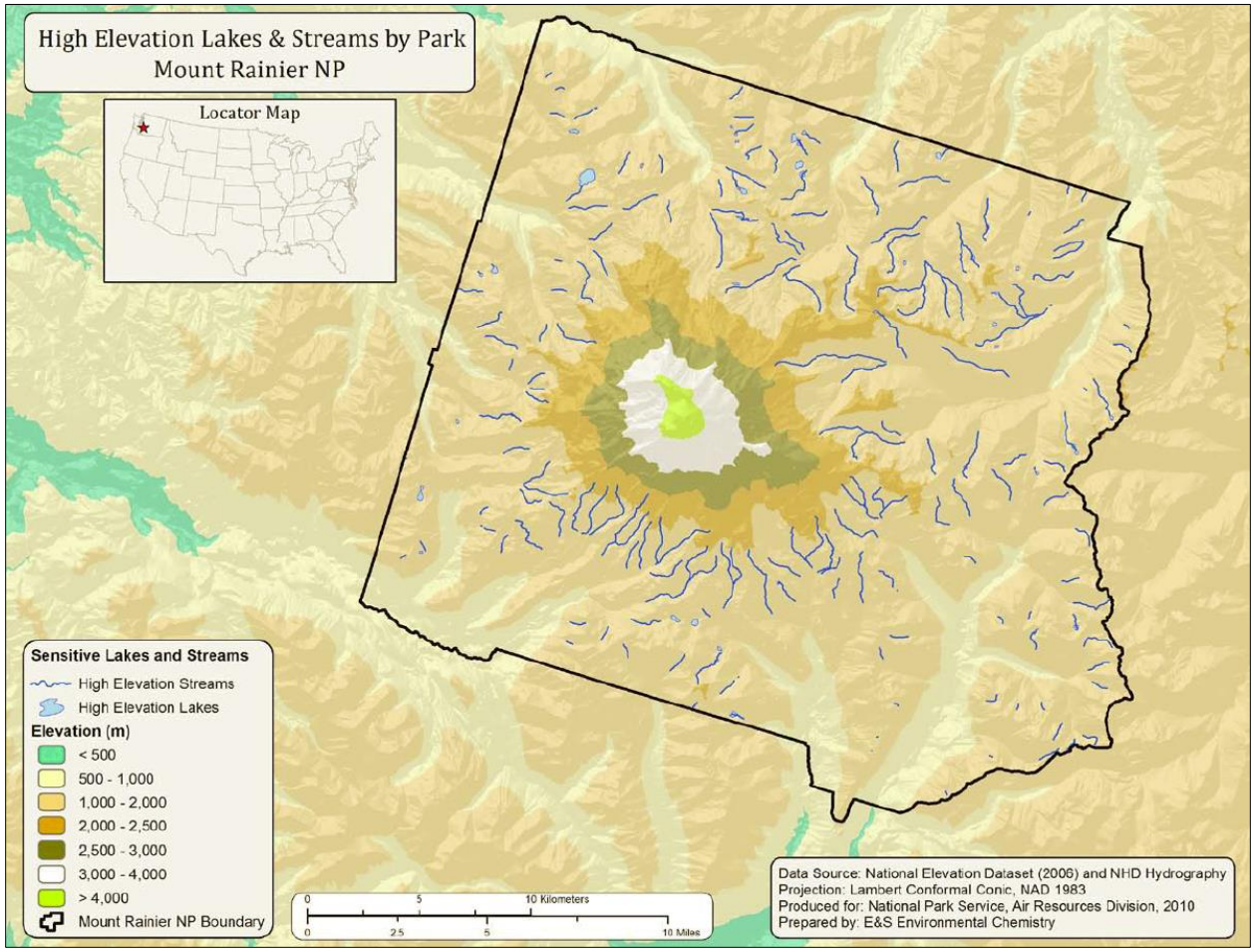

Figure 18. Spatial extent of high elevation lakes and streams at Mount Rainier NP likely sensitive to acidification (from Sullivan et al., 2011c).

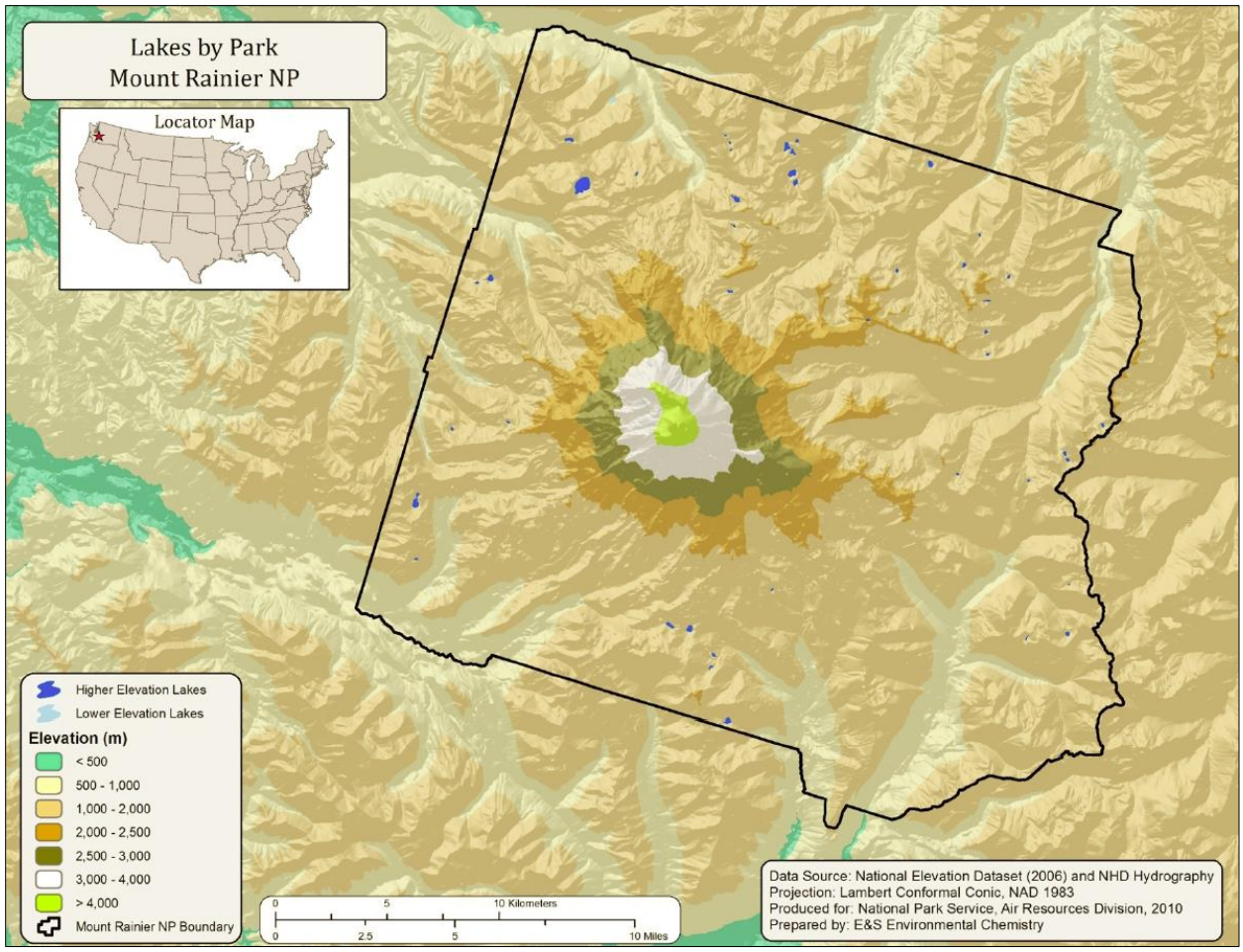

Figure 19. Spatial extent of high elevation lakes at Mount Rainier NP likely sensitive to atmospheric N enrichment (from Sullivan et al., 2011d).

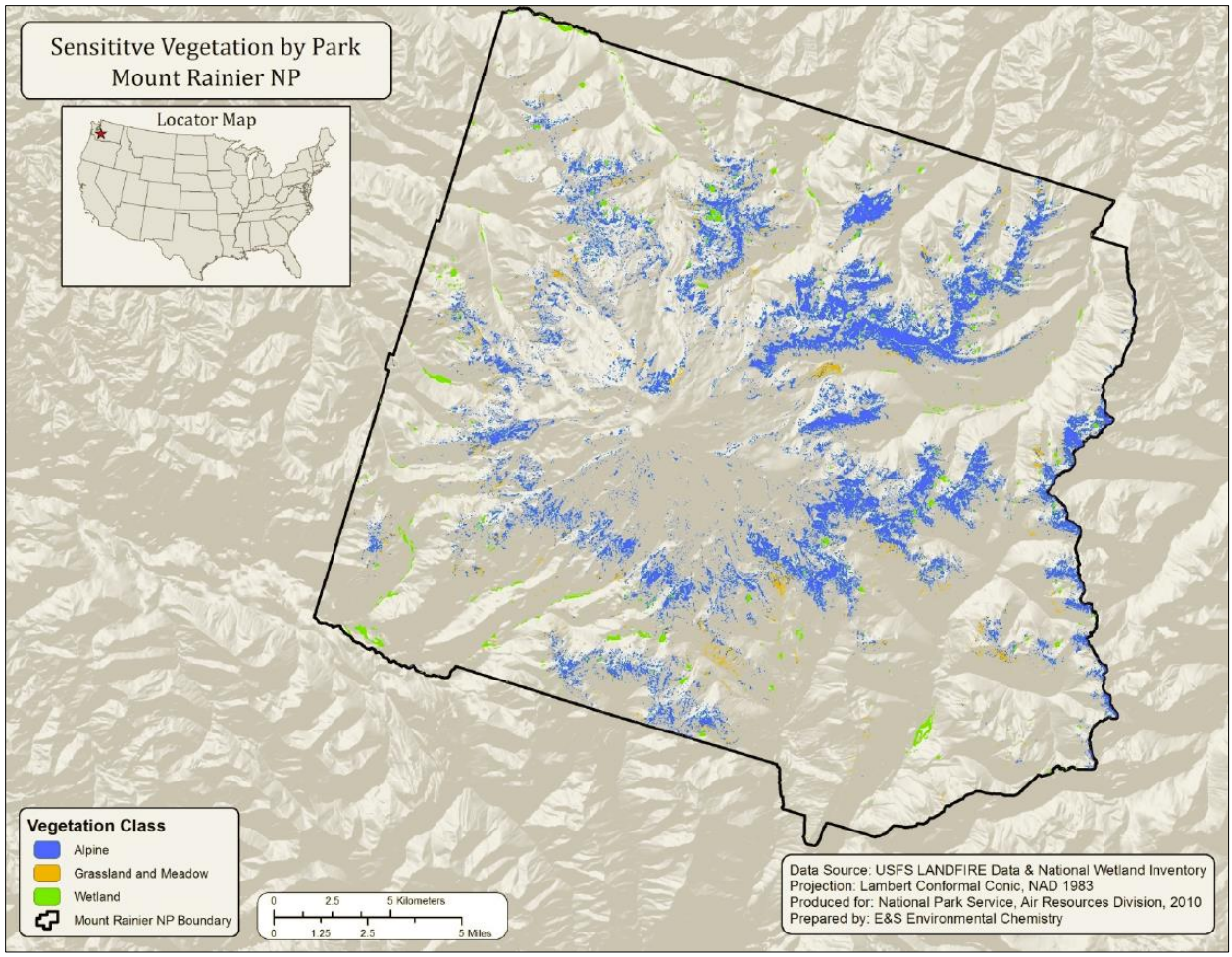

Figure 20. Spatial extent of vegetation types in Mount Rainier NP likely sensitive to atmospheric N enrichment (from Sullivan et al., 2011d).

Water chemistry has been monitored at several locations in Mount Rainier NP since 1988 (Babara Samora, Mount Rainier NP, unpublished data; Figure 3). A recent analysis of the data indicates park lakes are generally low in productivity, have low nutrient and ion concentrations, and tend to be poorly buffered (Hoffman et al., in review). High-elevation lake sampling in Mount Rainier, North Cascades, and Olympic NPs has been incorporated into the NCCN long-term monitoring program (Fradkin et al., 2012). This monitoring will continue to assess the effects of pollutants, climate change, and other stressors on the chemistry and biota of park lakes.

Clow and Campbell (2008) studied the effects of atmospheric deposition on surface water chemistry at two sites each at Mount Rainier and North Cascades NPs in 2000 and 2005 to 2006. Stream NO_3 concentrations at North Cascades NP were somewhat elevated compared to the Eunice Lake and Lake Louise study sites at Mount Rainier NP. The researchers indicated the higher NO_3 concentrations were consistent with higher atmospheric deposition at North Cascades NP, but pointed out the presence of N-fixing red alder (*Alnus rubra*) at the study sites confounded the results in lower-elevation watersheds. They recommended future monitoring of N deposition effects in the Pacific Northwest focus on high elevation areas without alder. Clow and Campbell found evidence of episodic acidification associated with spring snowmelt at

Eunice Lake. They concluded rain-on-snow events and spring snowmelt could cause episodic acidification of high-elevation lakes and streams in the Cascade Mountains.

Black carbon concentrations in snowpack and snowmelt are being measured at several locations in Washington, including sites at Mount Rainier and North Cascades NPs, by Kaspari and Delaney of Central Washington University. 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).

Nitrogen Critical Loads

A critical load is the threshold for ecosystem sensitivity to air pollution. In general, as deposition increases, additional resources are affected and ecological effects become more pronounced. Given concern about the likely sensitivity of high elevation ecosystems in the NCCN, the NPS and others are conducting studies to determine the critical loads for high elevation lakes, soils, and vegetation. The studies are focusing on N deposition because, although both N and S deposition are relatively low in most areas of the western U.S., certain ecosystems respond to very low levels of N. Cummings et al. (2014) summarized the current state of knowledge about N deposition, effects, and critical loads in the Pacific Northwest (i.e., Idaho, Oregon, and Washington). While the authors identified cumulative potential adverse ecological effects in the region (Figure 21), they determined that, with the exception of lichens, N critical loads have not been well established for the Pacific Northwest. Cummings et al. (2014) discussed current research efforts and prioritized additional data needed to improve understanding of N effects on sensitive resources in the region's national parks and national forests. The goal is to identify N critical loads for a number of ecosystem components because some may be more sensitive than others.

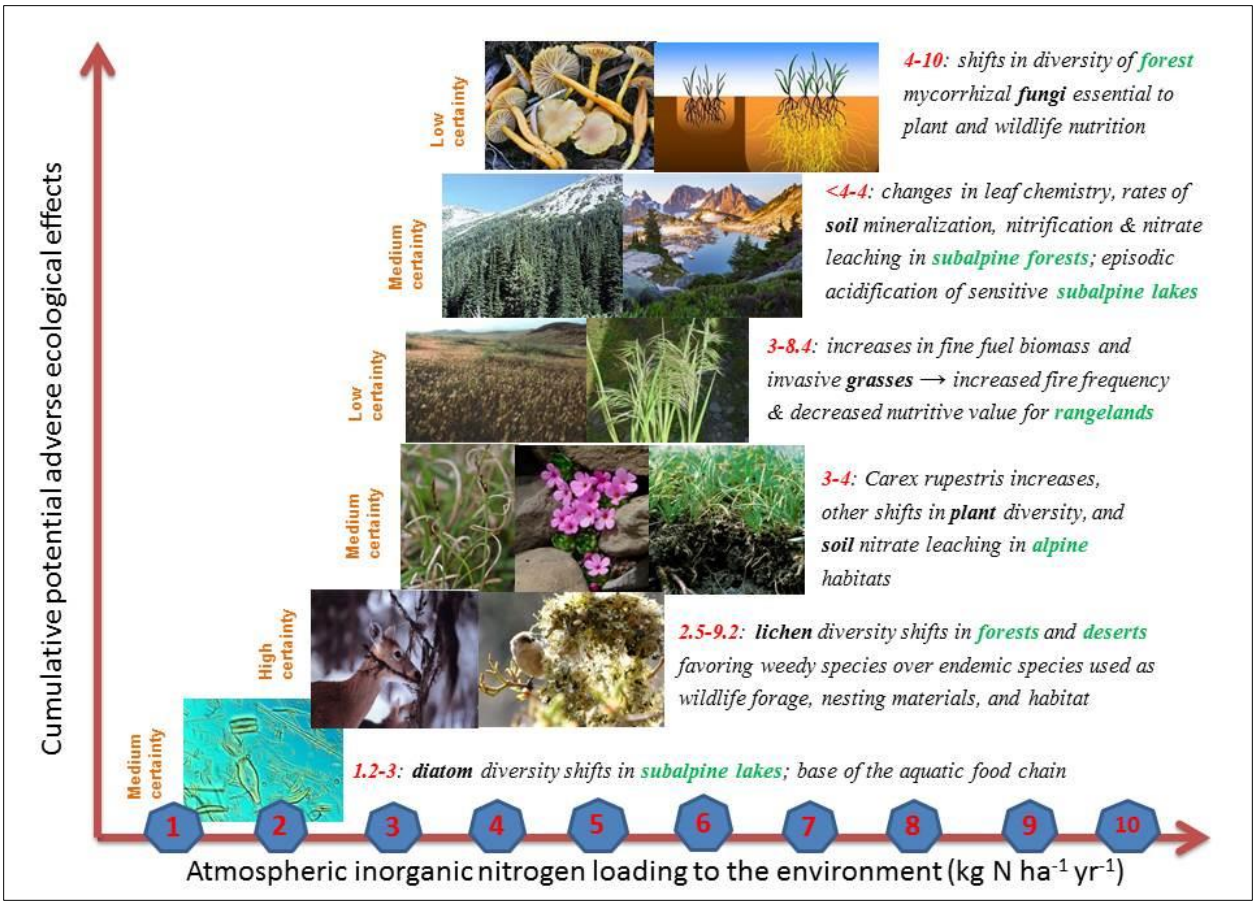

Figure 21. Cumulative potential adverse ecological effects associated with atmospheric N deposition in the Pacific Northwest (from Cummings et al., 2014). The reliability assessments are as follows: High Certainty when a number of published papers of various studies show comparable results, Medium Certainty 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.

In 2006, the U.S. Forest Service sampled lichens in and near Mount Rainier NP. Sample sites included low elevation forested areas at Tahoma Woods and near the Nisqually River. Combining the results from sites in the park with those from over 1,400 lichen plots in western Oregon and Washington, Geiser and Neitlich (2007) developed air quality scores based on lichen community data. Specifically, they focused on the percentage of oligotrophic species, i.e., species adapted to unpolluted, low nutrient conditions. The researchers considered plots with scores higher than 0.21, the point at which oligotroph contribution to species richness declined by about 33 to 43 percent, to have exceeded the N critical load. None of the plots in or near Mount Rainier NP exceeded the critical load; plots in the two park locations had scores below -0.11, indicating best condition (Figure 22).

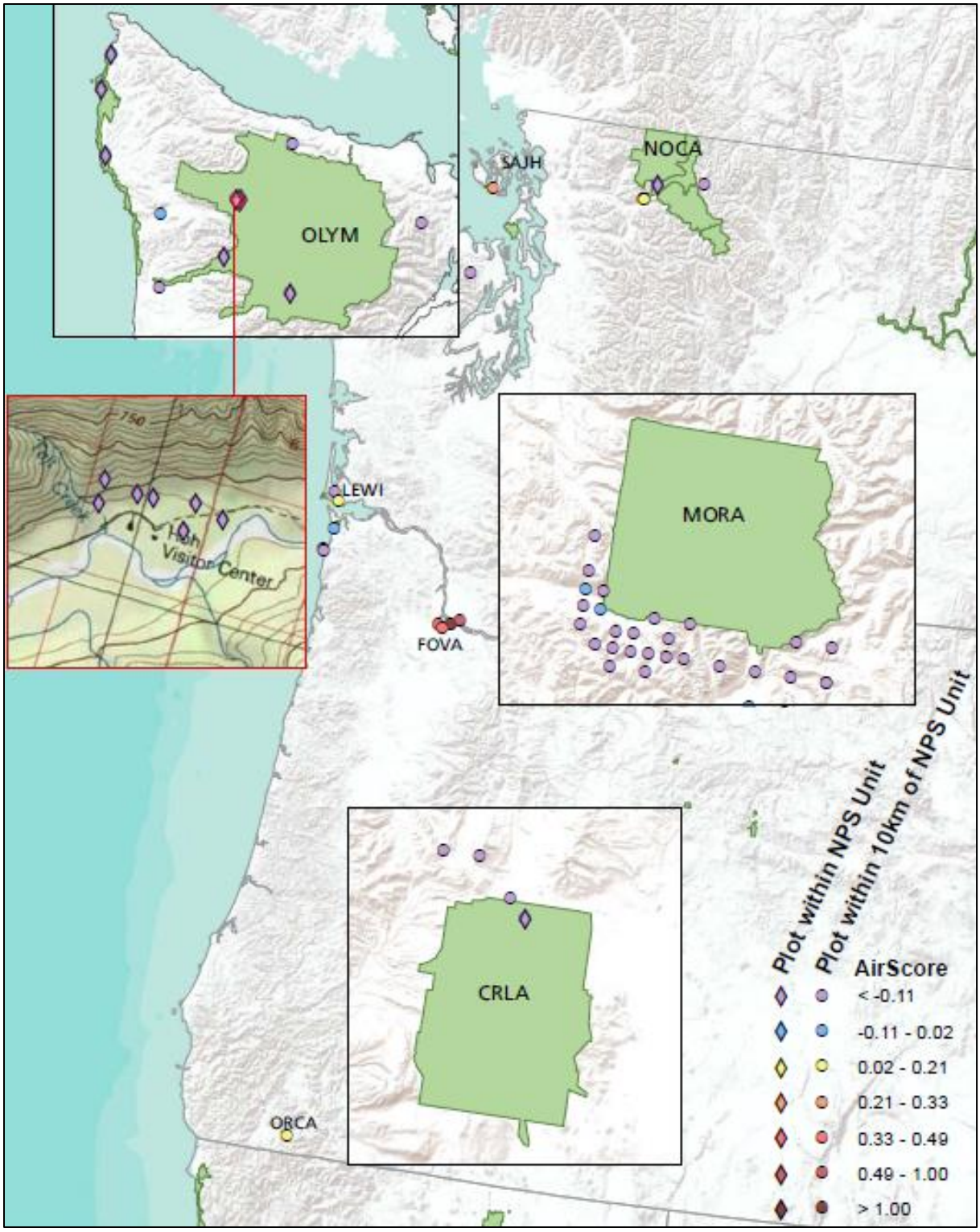

Figure 22. Air quality scores for lichen plots in and near NPS units in western Oregon and Washington (produced by U.S. Forest Service, 2012). Scores of 0.21-0.33 or greater exceeded the N critical load. CRLA is Crater Lake NP, FOVA is Fort Vancouver National Historic Site, LEWI is Lewis and Clark National Historical Park (NHP), MORA is Mount Rainier NP, NOCA is North Cascades NP, OLYM is Olympic NP, and SAJH is San Juan Island NHP.

Geiser et al. (2010) identified critical loads across western Oregon and Washington by correlating lichen scores with N deposition derived from a number of methods. For example, they determined total N deposition estimated with the Community Multi-Scale Air Quality (CMAQ) atmospheric model corresponded to a critical load of 2.7 to 9.2 kg/ha/yr. The researchers concluded critical loads in Oregon and Washington were only exceeded in and around major cities, in the Puget Sound Trough, on the valley floor of the Columbia River Gorge, and along the Interstate-5 corridor (Figure 23). In a recent report that identified N critical loads for the ecoregions of the continental U.S. (Pardo et al., 2011), critical loads for the Northwestern Forested Mountains ecoregion, which includes Mount Rainier NP, were based on the Geiser et al. (2010) values. Following those methods, the lichen community-based critical loads at Mount Rainier NP are 3.9 to 9.3 kg/ha/yr of total N deposition (Figure 24). Using CMAQ deposition estimates, higher critical loads values are most applicable for wetter areas and/or naturally N-rich hardwood forests growing on valley floors. Given some of the assumptions that go into the model, CMAQ tends to over- or under-predict deposition in complex terrain. Preliminary results from other models indicate the high end of the N critical loads range for lichens in Oregon and Washington will likely be lowered (Cummings et al., 2014). Using the critical loads recommended by Geiser et al. (2010) for lichens in the Pacific Northwest, Ellis et al. (2013) conducted atmospheric modeling and concluded N critical loads may be exceeded at Mount Rainier, North Cascades, and Olympic NPs. However, because of uncertainties inherent in modeled estimates, predictions need to be assessed with better measurements of deposition, emissions, and ecosystem responses.

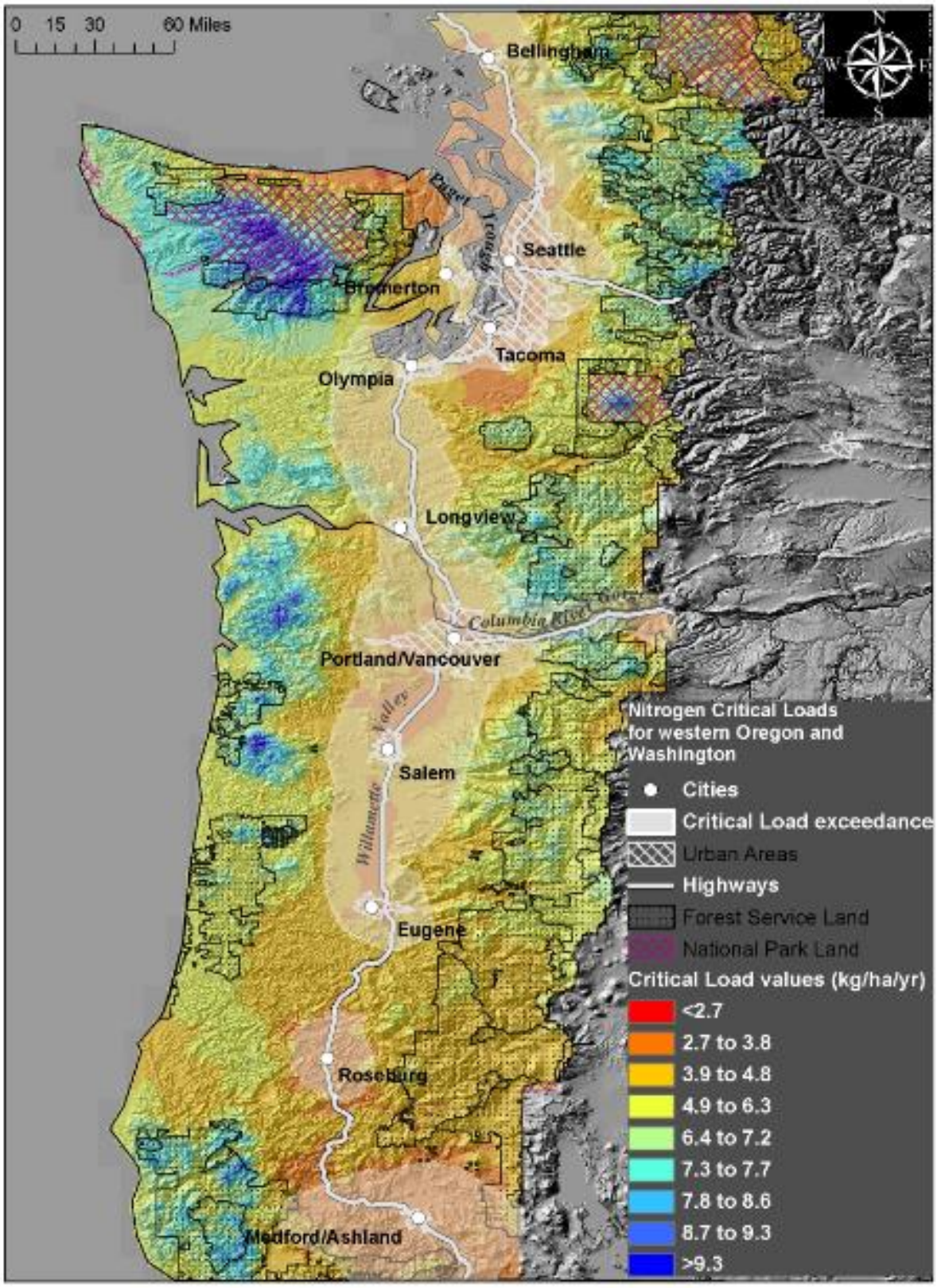

Figure 23. Map of lichen community-based critical loads for total N deposition in western Oregon and Washington (produced by U.S. Forest Service, 2012).

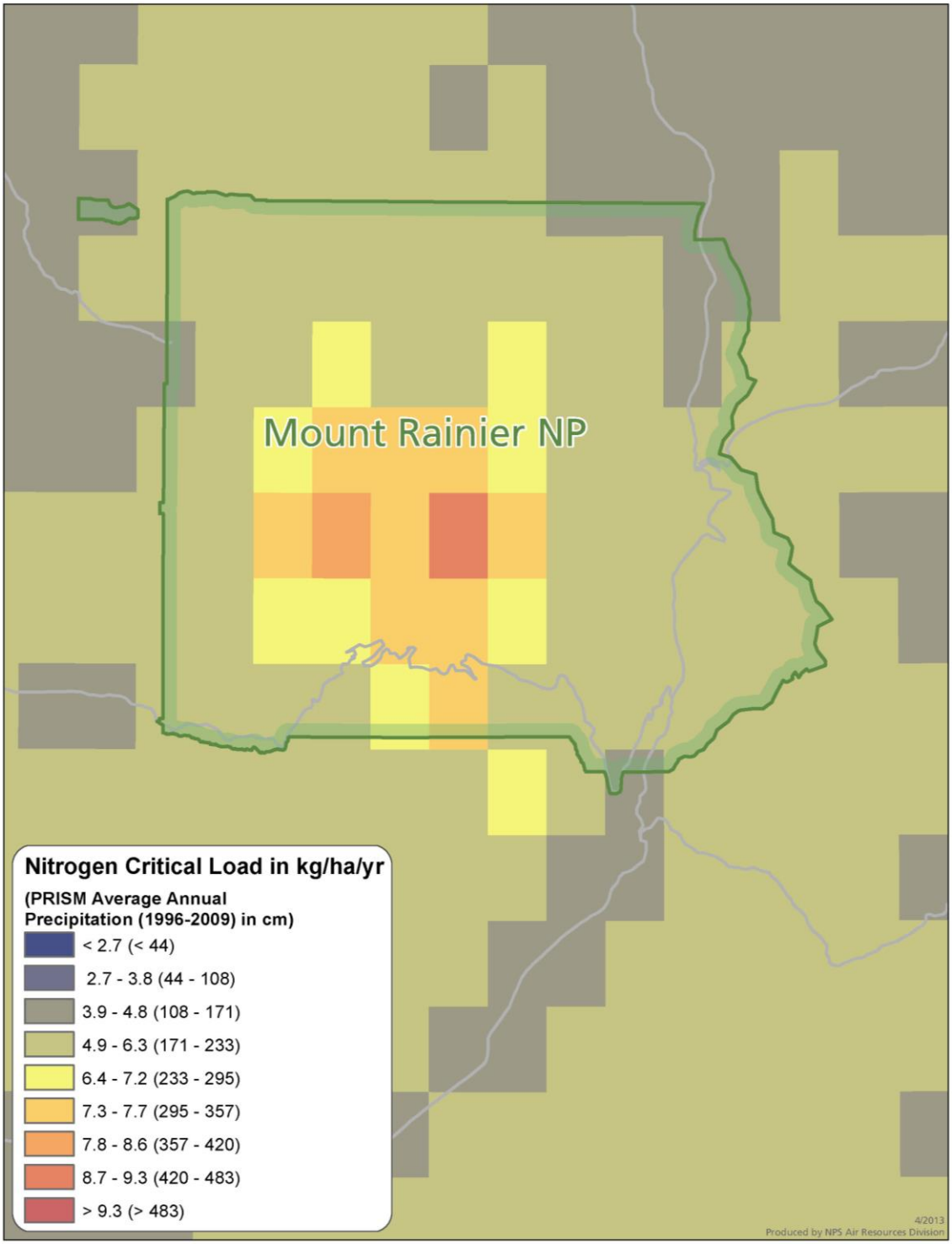

Figure 24. Map of lichen community-based critical loads for total N deposition in Mount Rainier NP (produced by NPS, 2013). The critical loads are correlated with precipitation quantities derived from the Parameter-elevation Regressions on Independent Slopes Model (PRISM).

From 2008 to 2010, the U.S. Geological Survey (USGS) conducted a study to determine critical loads of N deposition for lake diatoms. The USGS collected bulk deposition and water quality data at four high-elevation lakes each in Mount Rainier, North Cascades, and Olympic NPs. Because of their locations, N inputs to the lakes are primarily from atmospheric deposition. The study sites in Mount Rainier NP were Eunice, Hidden, Shriner, and Snow Lakes. Park-averaged bulk deposition of S and N was lowest at Olympic NP, intermediate at Mount Rainier NP, and highest at North Cascades NP (Sheibley et al., 2012). All the study lakes at Mount Rainier and North Cascades NPs had acid neutralizing capacity less than 100 microequivalents per liter, indicating the lakes are acid-sensitive. Sheibley et al. (2014) collected and evaluated sediment cores from ten of the 12 lakes in an attempt to identify changes in diatom community structure resulting from historic increases in N deposition rates. Nitrogen-sensitive species that are used as an indicator of N deposition effects in the Rocky Mountains were only found in one Pacific Northwest lake, Hoh Lake at Olympic NP. The researchers estimated a critical load of 1.0 to 1.2 kg/ha/yr wet N deposition for Hoh Lake. For the other examined lakes, it is not clear if historic N deposition rates have not been sufficient to elicit a change in community structure; if phytoplankton growth was historically phosphorus-limited, causing lakes to be insensitive to N enrichment effects; or if diatom communities in Pacific Northwest lakes respond differently to N than lakes in the Rocky Mountains. A 2013 to 2015 nutrient enrichment study by Williams and Beutel (Washington State University) will further explore the response of diatoms to N deposition in high elevation lakes in Mount Rainier, North Cascades, and Olympic NPs.

In 2012, Simpson, Zabowski, and Edmonds (University of Washington) began a three-year study assessing the effects of N deposition on high elevation plant and soil communities in Mount Rainier, North Cascades, and Olympic NPs. The researchers fertilized plots with different amounts of N and are monitoring changes in plant and soil N concentrations and soil fungi. Poinsatte and Evans (Washington State University) began a two-year study at Mount Rainier in 2013 to investigate how three subalpine vegetation communities respond to elevated N deposition from snowmelt. They are measuring how much N is stored in plant tissue and soils compared to how much is lost from the soil through nitrous oxide emissions or N leaching to the watershed. These two studies will provide information that can be used to establish N critical loads for alpine/subalpine soils and vegetation in the Cascade and Olympic Mountains.

Ozone

Over the years, ozone data have been collected at many locations in Mount Rainier NP. A portable monitor was used at Tahoma Vista in 2004 to 2005. Continuous monitors operated for a short time at Carbon River (1994) and Longmire (1987 to 1988) and have operated long-term at Paradise (1998 to present) and Tahoma Woods (1991 to 2013). Results indicate ozone concentrations are often somewhat higher at Paradise (1,615 m in elevation) than at Tahoma Woods (423 m; Figure 25). In 2003, ozone was higher than the current NAAQS, i.e., the annual fourth-highest daily maximum 8-hour ozone concentration of 75 ppb, at Paradise. Concentrations at both Paradise and Tahoma Woods frequently exceeded the lower end of the range for a revised ozone NAAQS proposed by EPA in 2010, i.e., 60 ppb. An evaluation of 2000 to 2009 data indicated a decreasing trend in ozone concentrations at the park (NPS, 2013). The reason for the decline is unclear; while it might be due to a change in weather patterns, it is more likely due to a reduction in emissions of ozone precursors throughout the region (Brian Lamb, Washington State University, personal communication).

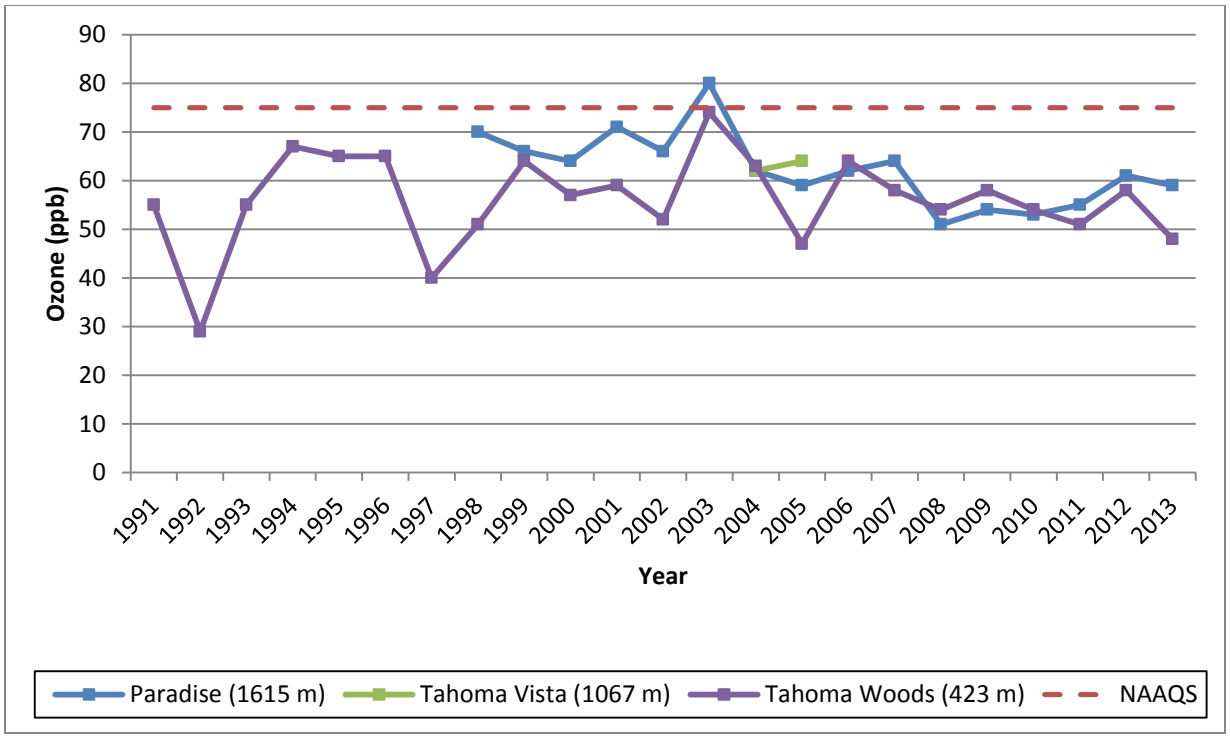

Figure 25. Annual 4th highest daily maximum 8-hour ozone concentrations (in ppb) measured with continuous and portable monitors at Mount Rainier NP between 1991 and 2013 (produced by NPS, 2013).

Brace and Peterson (1998) evaluated ozone concentrations in the Puget Sound region, including at Mount Rainier, during the summers of 1994 and 1995. They found concentrations generally increased with distance from Seattle and that Paradise had the highest monthly mean concentrations of all monitored sites. On high ozone days, concentrations decreased at night at sites near Seattle but remained elevated at Paradise. Brace and Peterson (1998) used passive samplers in 1994 to 1995 to measure summertime ozone concentrations across an elevation gradient of 420 to 2,100 m in the Carbon, Nisqually, Ohanapecosh and White River drainages in Mount Rainier NP. In all but the Ohanapecosh River drainage, ozone concentrations increased with elevation, with highest average weekly concentrations recorded at the highest elevation sites. Concentrations were significantly higher on the west side of the park. Subsequent monitoring in the Nisqually River drainage during the summers of 1995 to 1997 also showed ozone concentrations increased with elevation (Peterson et al., 1999).

The NPS used passive samplers to monitor ozone at six locations (i.e., Carbon River, Eunice Lake, Longmire, Nisqually Bridge, Paradise, and Reflection Lake) during the summers of 1999 to 2005 (Figure 26). In general, the results confirmed the findings by Brace and Peterson (1998) that ozone concentrations were greater at higher elevations and in the northwest corner of the park.

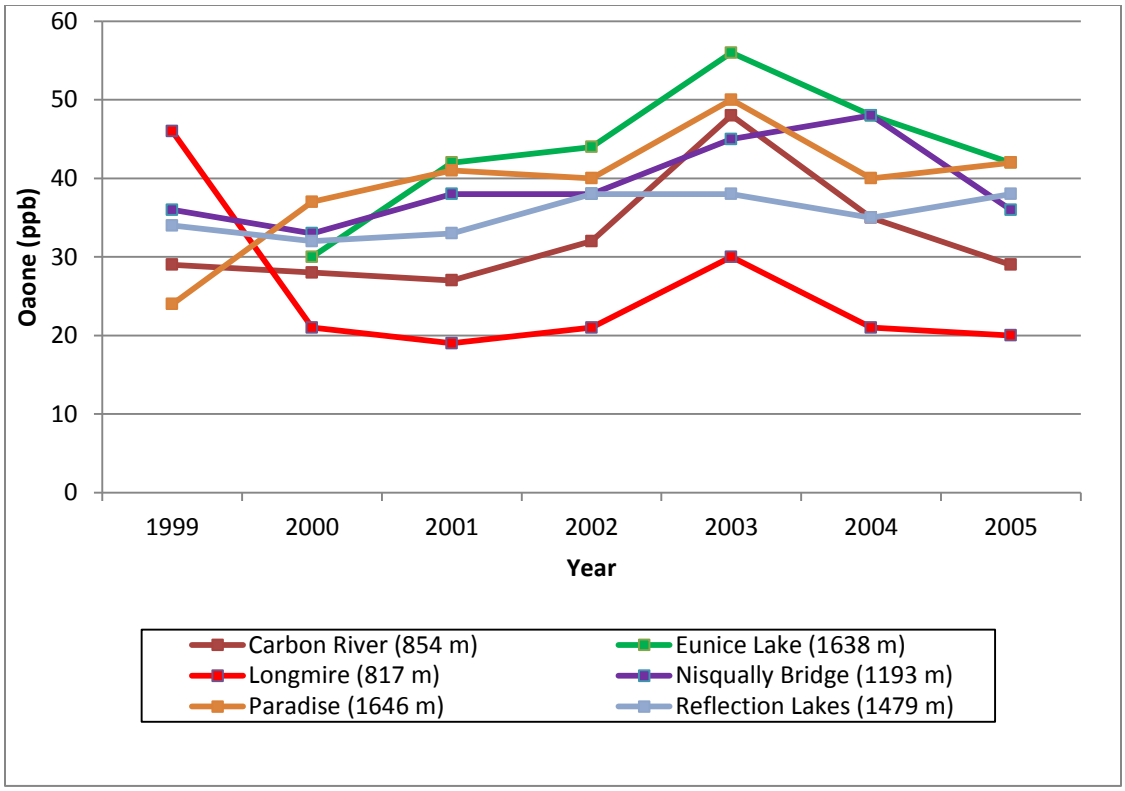

Figure 26. Maximum one-week cumulative ozone concentrations (in ppb) measured with passive samplers at six sites in Mount Rainier NP between 1999 and 2005 (produced by NPS, 2013).

Jaffe and Ray (2007) analyzed 1987 to 2004 ozone data from nine rural and remote sites in the western U.S. and two sites in Alaska; their analysis did not include Mount Rainier NP. At seven of the nine sites in the western U.S., there was a statistically significant, but very small, increase in ozone. The authors speculated the trends were due to increased regional emissions, changes in the regional distribution of emissions, increased biomass burning or increased global background ozone associated with higher Asian emissions.

Kohut (2007) assessed the risk of ozone-induced foliar injury at all NPS I&M parks based on species sensitivity, ozone concentrations, and soil moisture (which influences ozone uptake). To evaluate injury thresholds, he compared ozone concentrations to a number of exposure indices that reflect vegetation response to ozone, including the W126 metric proposed by EPA for the secondary ozone standard. While Kohut (2004) determined several species at Mount Rainier NP are ozone-sensitive (Table 9), given the relatively low ozone concentrations at the park (e.g., between 1995 and 1999, 5-month W126 values ranged from 0.9 to 5.4 ppm-hrs compared to the 3-month 7 to 15 ppm-hrs range proposed by EPA in 2010), he concluded there was low risk of ozone injury at the park.

Table 9. Ozone-sensitive species at Mount Rainier NP (from February 11, 2014, search of the NPSpecies database at https://irma.nps.gov/NPSpecies/).

Latin Name	Common Name	Family
Alnus rubra	Red alder	Betulaceae
Apocynum androsaemifolium	Spreading dogbane	Apocynaceae
Artemisia douglasiana	Douglas' mugwort	Asteraceae
Physocarpus capitatus	Ninebark	Rosaceae
Pinus ponderosa	Ponderosa pine	Pinaceae
Salix scouleriana	Scouler's willow	Saliaceae
Symphoricarpos albus	Common snowberry	Caprifoliaceae
Vaccinium membranaceum	Thin leaf huckleberry	Ericaceae

The U.S Forest Service Forest Health Monitoring Program, now called the Forest Inventory and Analysis (FIA) Program, evaluated a total of 60 thin leaf huckleberry (*Vaccinium membranaceum*), thimbleberry (*Rubus parviflorus*), red elderberry (*Sambucus racemosa*), and Scouler's willow (*Salix scouleriana*) plants for ozone injury at Longmire, Reflection Lake, and a location on the Wonderland Trail in Mount Rainier NP during the summer of 1998 (Campbell et al., 2000). Two thin leaf huckleberry plants displayed injury that was possibly due to ozone. Along with the 1999 to 2005 passive ozone sampling, the NPS examined red alder (*Alnus rubra*), Scouler's willow, and thin leaf huckleberry plants for ozone injury. No injury was detected (Barbara Samora, Mount Rainier NP, personal communication). The FIA Program evaluated thin leaf huckleberry, Scouler's willow, and red alder plants for ozone injury at three plots in Mount Rainier from 2000 to 2009. Again, no injury was detected (Sarah Jovan, FIA Program, personal communication).

Persistent Bioaccumulative Toxic Compounds

Persistent bioaccumulative toxic compounds are highly toxic, long-lasting substances that can build up in the food chain to levels that are harmful to human and ecosystem health. These pollutants include heavy metals such as Hg, cadmium, and zinc; current and historic use pesticides; industrial chemicals; and by-products of fuel combustion. Several studies in the past decade have detected PBTs in remote areas of Mount Rainier and other national parks in the Pacific Northwest, with atmospheric deposition being the only feasible source of pollution. Many of the past and ongoing studies in Mount Rainier NP focus on Hg.

Ambient Monitoring

The NADP Mercury Deposition Network (MDN) monitors Hg concentrations in precipitation and produces national maps of annual Hg concentration (in nanograms per liter [ng/L]) and deposition (in micrograms per square meter [$\mu g/m^2$]; Figures 27 and 28). The NADP Atmospheric Mercury Network (AMNet) measures air concentrations of three Hg species at only a handful of sites, mostly in the eastern U.S. (NADP, 2014). There are no other national monitoring networks for PBTs.

While there are a number of MDN monitors in the eastern U.S., coverage in the west is sparse, leading to greater uncertainty about Hg deposition estimates in western parks. There are two MDN sites in Washington, one in Seattle (site WA18) that has been operating since 1996, and one at the Makah fish hatchery (site WA03), on the northwestern tip of the Olympic Peninsula,

that has been operating since 2007. There was a decrease in Hg concentration and deposition at WA18 from 1996 to 2000, possibly because of emission reductions from power plants and other sources in the region; Hg levels have been relatively constant since 2000 (Figures 29 and 30). It is unlikely that either MDN site fully represents conditions at Mount Rainier NP.

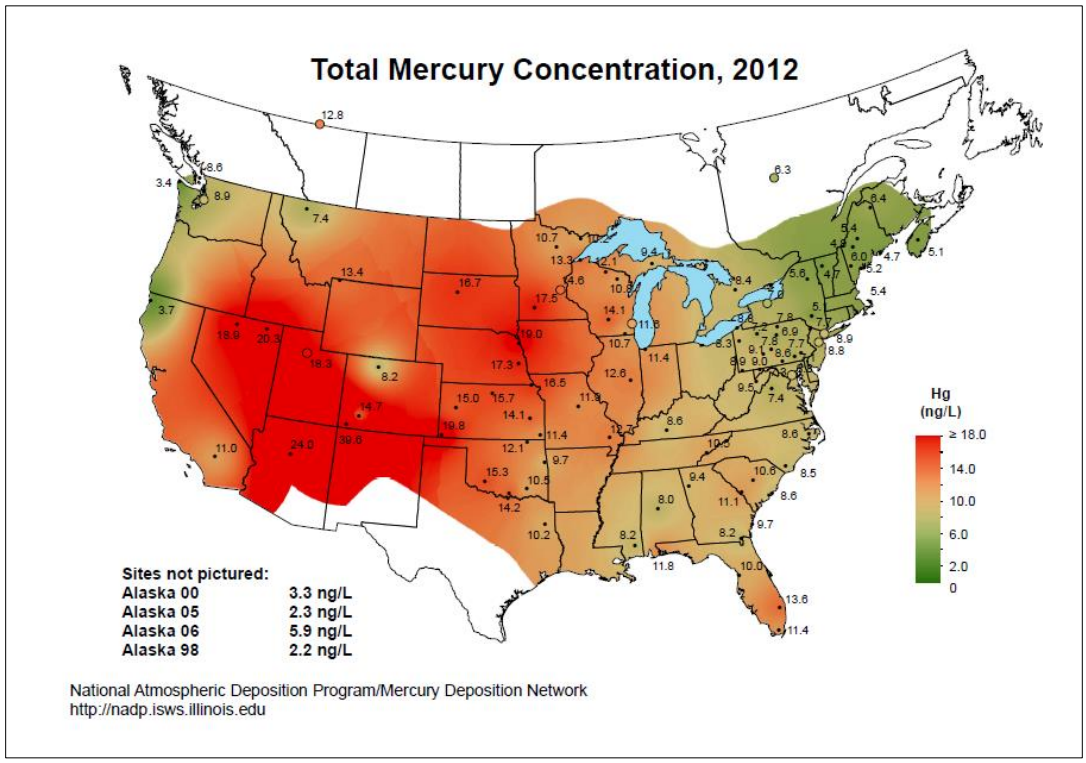

Figure 27. Map of total Hg concentration in precipitation based on 2012 MDN data (from NADP, 2014).

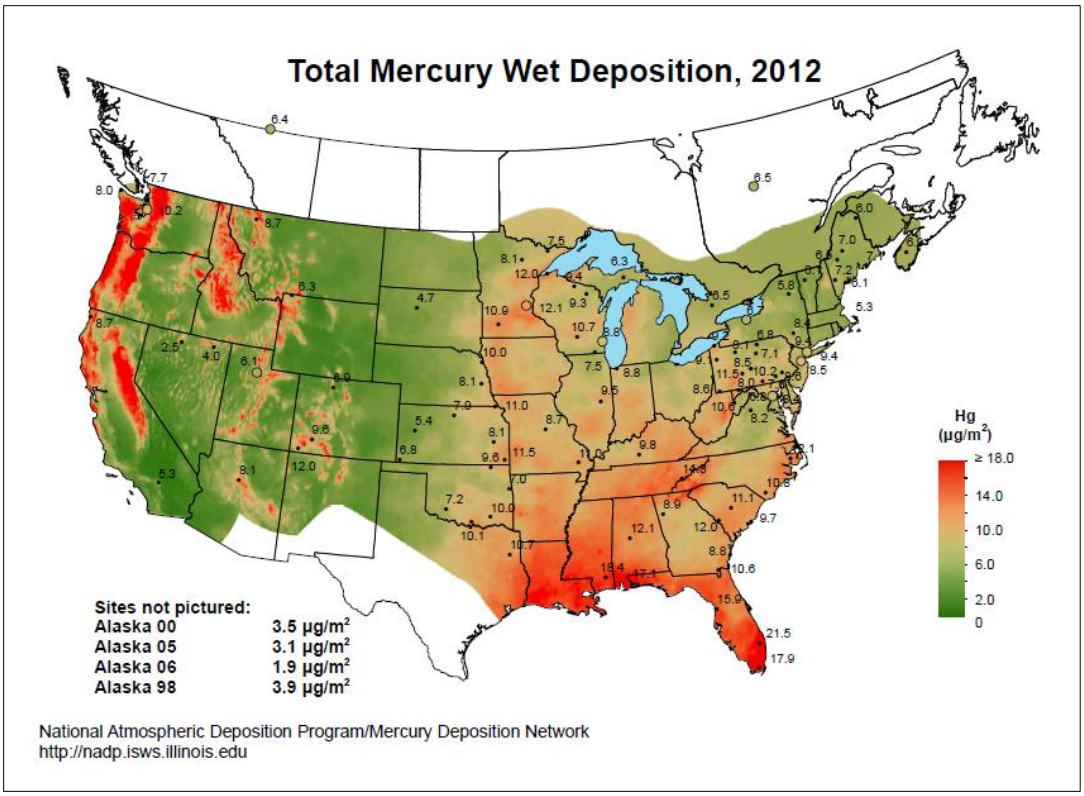

Figure 28. Map of total Hg deposition in precipitation based on 2012 MDN data (from NADP, 2014).

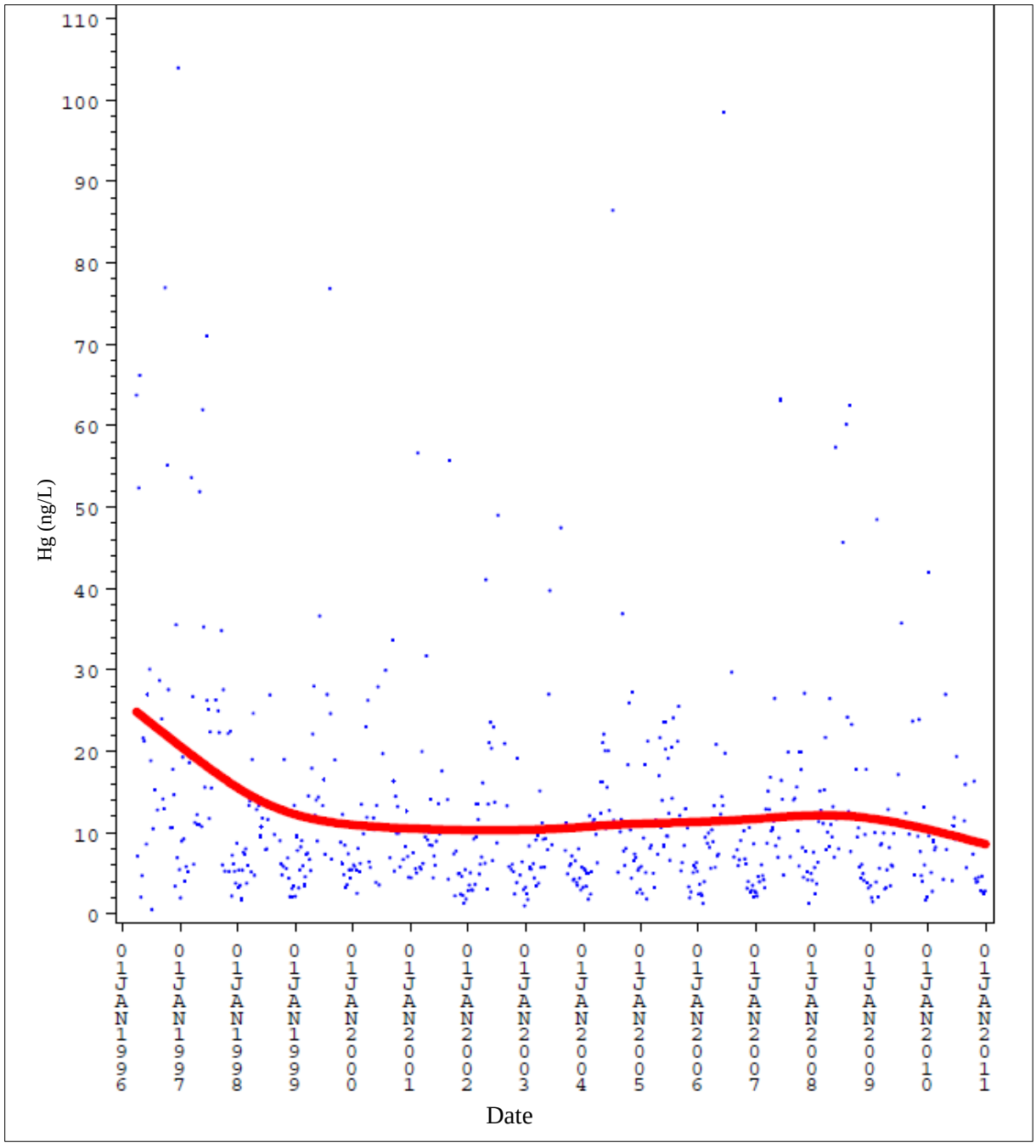

Figure 29. Trend in 1996 to 2011 annual Hg concentration at MDN site WA18 in Seattle, Washington (produced by NADP, 2012).

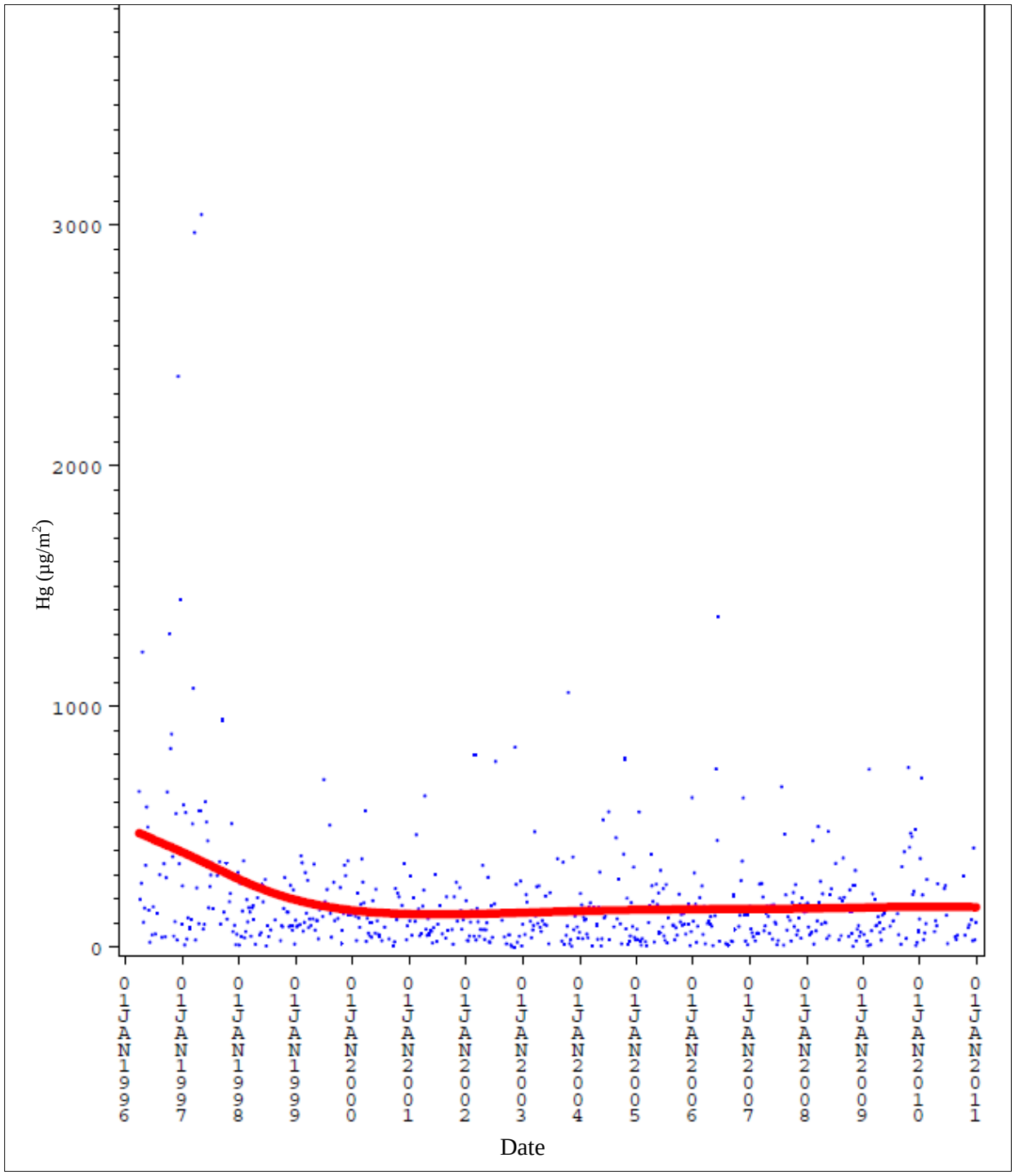

Figure 30. Trend in 1996 to 2011 annual Hg deposition at MDN site WA18 in Seattle, Washington (produced by NADP, 2012).

Risk Assessment and Health Thresholds

After Hg is deposited, biological processes convert it into toxic methylmercury (MeHg). Certain environmental factors enhance methylation, so it is useful to perform risk assessments to determine where MeHg concentrations are likely to be elevated. An Hg methylation risk

assessment is being completed for all NPS I&M parks (Krabbenhoft and Lutz, USGS, in preparation). The assessment evaluates water quality and landscape variables such as pH, SO4, total organic carbon, and percent wetlands to determine the likelihood that atmospherically-deposited Hg will be converted to MeHg in a specific watershed. Preliminary results indicate watersheds in and near Mount Rainier, North Cascades and Olympic NPs should have low to moderate concentrations of MeHg (Figure 31). The USGS assessment is intended to be used as a screening tool to indicate where ecosystem Hg data should be collected if they are not available. Existing data clearly show elevated Hg levels in fish and other biota from the three NCCN parks (see discussion below).

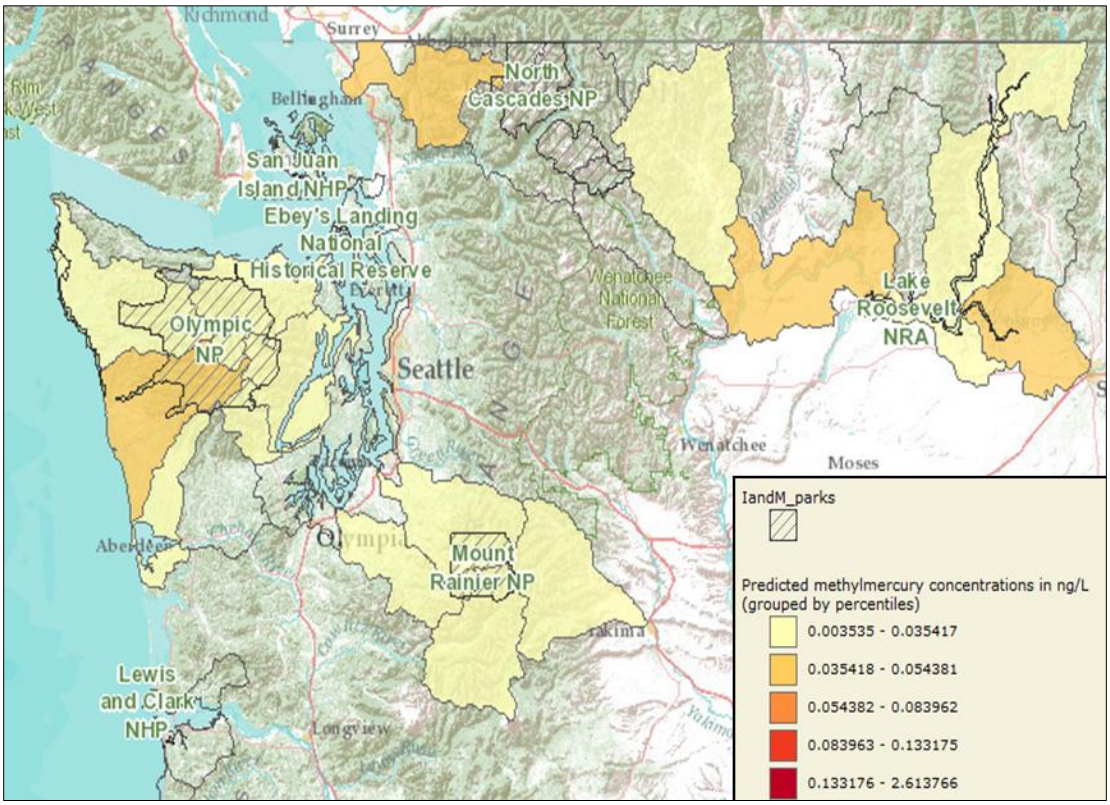

Figure 31. Predicted methylmercury concentrations (in ng/L) in watersheds in and near Mount Rainier, North Cascades, and Olympic NPs (from Krabbenhoft and Lutz, in preparation).

Measuring contaminant concentrations in fish and other wildlife provides a direct assessment of pollutant threats to individuals, populations, and multi-species communities. Studies have compared pollutant concentrations in fish muscle or whole fish to recommended thresholds for protection of fish health and the health of humans and wildlife that eat fish. For example, the EPA has established an Hg guideline of 300 ng/g ww, in muscle (fillets), for safe human consumption of fish. This is equivalent to 185 ng/g ww in analyses of whole fish. The Washington Department of Health recently lowered the state's Hg consumption criteria to 100 ng/g ww in fish fillets (Dave McBride, Washington Department of Health, personal communication). Based on a literature review, Landers et al. (2008) reported thresholds in whole fish for effects on fish-eating (i.e., piscivorous) birds and mammals for a limited number of PBTs, including Hg (Table 10). The thresholds are based on sublethal effects on health, growth, and reproduction. More recently, Eagles-Smith et al. (2014) compared Hg

concentrations of fish collected in national parks to several human health and wildlife risk benchmarks, including the EPA guideline for human consumption and 90-270 ng/g ww in fish muscle for piscivorous birds.

Table 10. Fish contaminant health thresholds for piscivorous wildlife (in ng/g ww of whole fish; based on Landers et al., 2008).

Pollutant	Belted kingfisher (*Ceryle alcyon*)	Mink (*Mustela vison*)	River otter (*Lutra canadensis*)
Total Mercury	30	70	100
Total PCBs	440	130	180
Total DDTs	20	360	490
Total Chlordanes[1]	4.5	830	1,140
Dieldrin[1]	360	20	30

PCBs = polychlorinated biphenyls, which are combustion by-products
DDTs = dichlorodiphenyltrichloroethanes, which are pesticides
[1]Chrlordanes and Dieldrin are pesticides

Studies

In 2002 to 2003, Moran et al. (2007) analyzed cutthroat trout (Oncorhynchus clarki) from Golden, Green, Snow, and Upper Deadwood Lakes in Mount Rainier and from five lakes each in North Cascades and Olympic NPs for Hg and 28 organochlorine pesticides. Mercury was detected in trout from all lakes sampled and low concentrations of two organochlorines were found in fish from all lakes in Mount Rainier and North Cascades NPs (Figure 32). Of all the sampled lakes, the highest concentration, 262 ng/g ww, was in a fish from Green Lake in North Cascades NP. The highest Hg concentration at Mount Rainier NP, 103 ng/g ww, was in a fish sample from Golden Lake. Fish from two lakes in North Cascades NP with different Hg concentrations (Wilcox Lake with 48 ng/g ww and Skymo Lake with 17 ng/g ww) 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. The researchers speculated that tissue Hg concentrations could affect gene expression in fish.

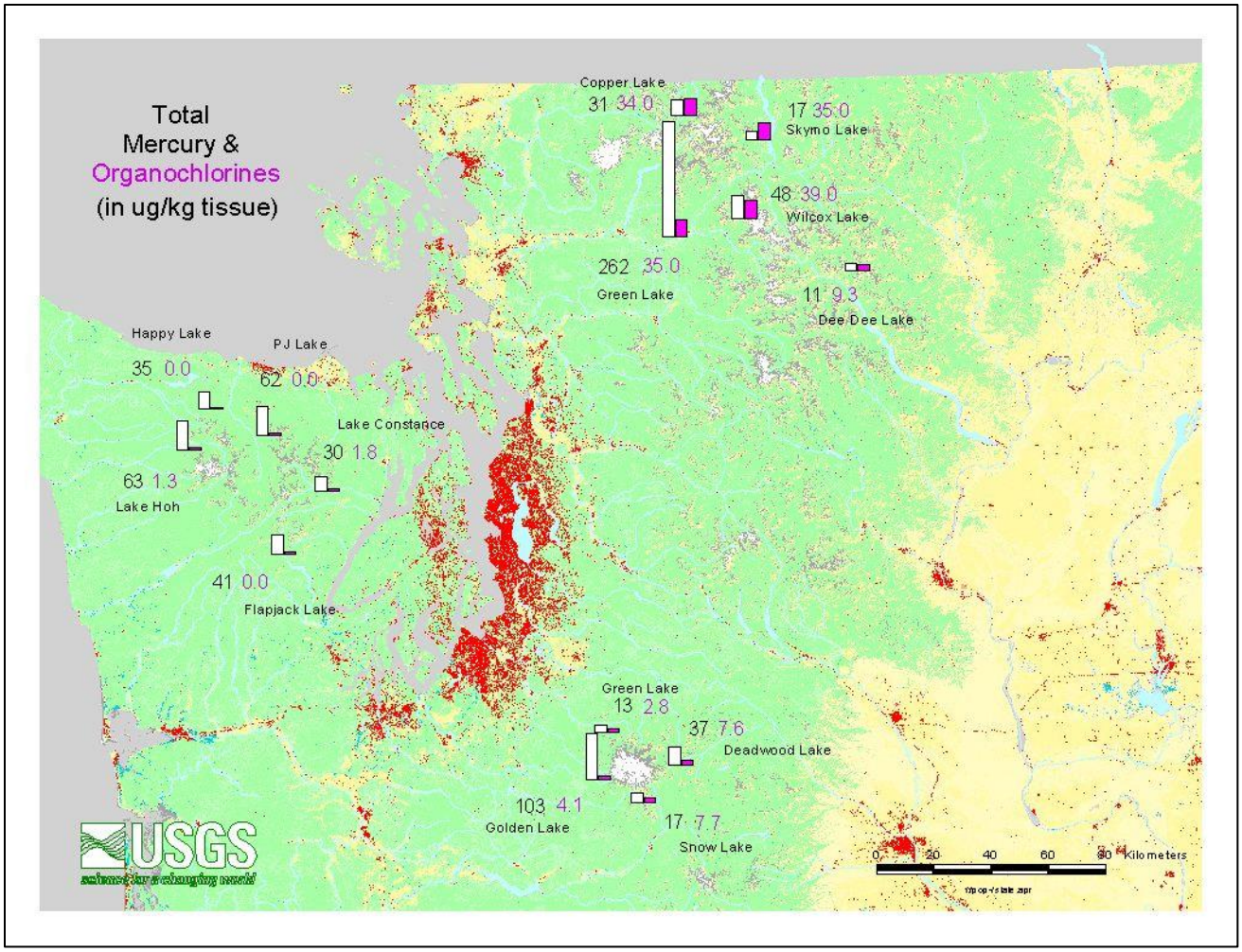

Figure 32. Concentrations of Hg and organochlorines, in micrograms per kilogram (µg/kg; equivalent to ng/g ww), in fish collected from lakes at Mount Rainier, North Cascades, and Olympic NPs (produced by USGS, date unknown).

The NPS spearheaded a multi-agency study called the Western Airborne Contaminants Assessment Project (WACAP) in 2002 to determine the risk from airborne contaminants to ecosystems and food webs in 20 national parks in the western U.S., including Mount Rainier (Figure 33; Landers et al., 2008). The researchers used passive air sampling devices, and snow, conifer needle, lichen, surface water, sediment, and fish tissue samples, to assess PBTs in the Golden Lake and Lake LP19 watersheds at Mount Rainier NP. A number of PBTs typically associated with agriculture, fuel combustion, and industry were detected in samples from the park.

Figure 33. Map of parks included in the WACAP study (from Landers et al., 2008).

The primary semi-volatile organic compounds (SOC) detected with the passive air sampling devices at Mount Rainier were the following pesticides: endosulfans, hexachlorobenzene (HCB) and hexachlorocyclohexane-alpha (a-HCH). Given the high amounts of winter precipitation, contaminant flux (deposition) was moderate to high in snowpack (Figure 34) although concentrations were mid-range compared to other parks. Predominant SOCs in vegetation at Mount Rainier NP were polycyclic aromatic hydrocarbons (PAH), which are combustion byproducts, and some pesticides (i.e., endosulfans, HCB, a-HCH and dacthal). The vegetation samples were collected along an elevational transect. While some SOCs, such as pesticides and polychlorinated biphenyls (PCB; industrial compounds), increased in vegetation with elevation, concentrations of PAH decreased with elevation (Figure 35). Mercury and SOC concentrations in vegetation at Mount Rainier were at or above concentrations for other parks. Landers et al. (2008) hypothesized that due to high forest productivity, pesticide accumulation in vegetation may contribute significant contaminant loads to the ecosystem via canopy throughfall and needle litter-fall.

Concentrations of contaminants in fish from Mount Rainier NP were generally mid-range compared to other parks; the exception was polybrominated diphenyl ethers (PBDE; industrial

compounds) in fish from Golden Lake which were the highest among all fish from all parks (Figure 36; Landers et al., 2008). Concentrations of the pesticide dieldrin in some fish from both lakes at Mount Rainier NP exceeded contaminant health thresholds for subsistence fishers. Mercury concentrations in all fish from both lakes exceeded contaminant health thresholds for piscivorous birds (e.g., kingfishers), and some fish exceeded thresholds for piscivorous mammals (e.g., otter and mink). Mercury concentrations in some fish from Lake LP19 exceeded contaminant health thresholds for humans. These Hg values indicate favorable conditions for methylation and subsequent bioaccumulation. Many of the sediment SOCs were below detection limits; PAHs and PCBs showed the highest deposition. Mercury and lead had both increased in sediments from the two lakes since about 1900, suggesting a common emissions source (Figure 37).

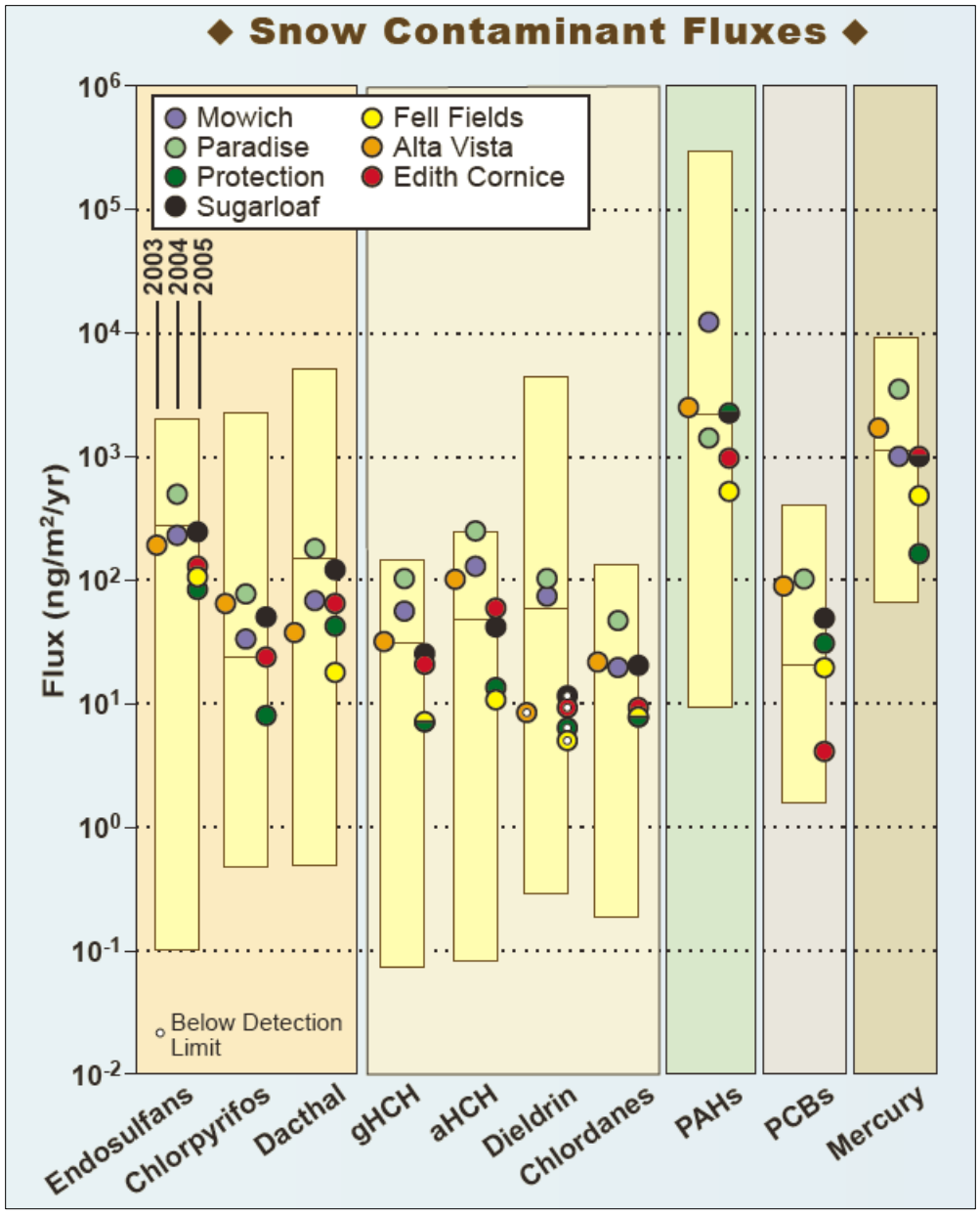

Figure 34. Flux (deposition) of PBTs in snowpack collected at Mount Rainier NP in 2003 to 2005 as part of the WACAP study (from Landers et al., 2008). Horizontal lines in boxes indicate median values. From left to right, pollutant categories represented by large shaded boxes are Current-Use Pesticides, Historic-Use Pesticides, Combustion By-products, Industrial Compounds, and Metals.

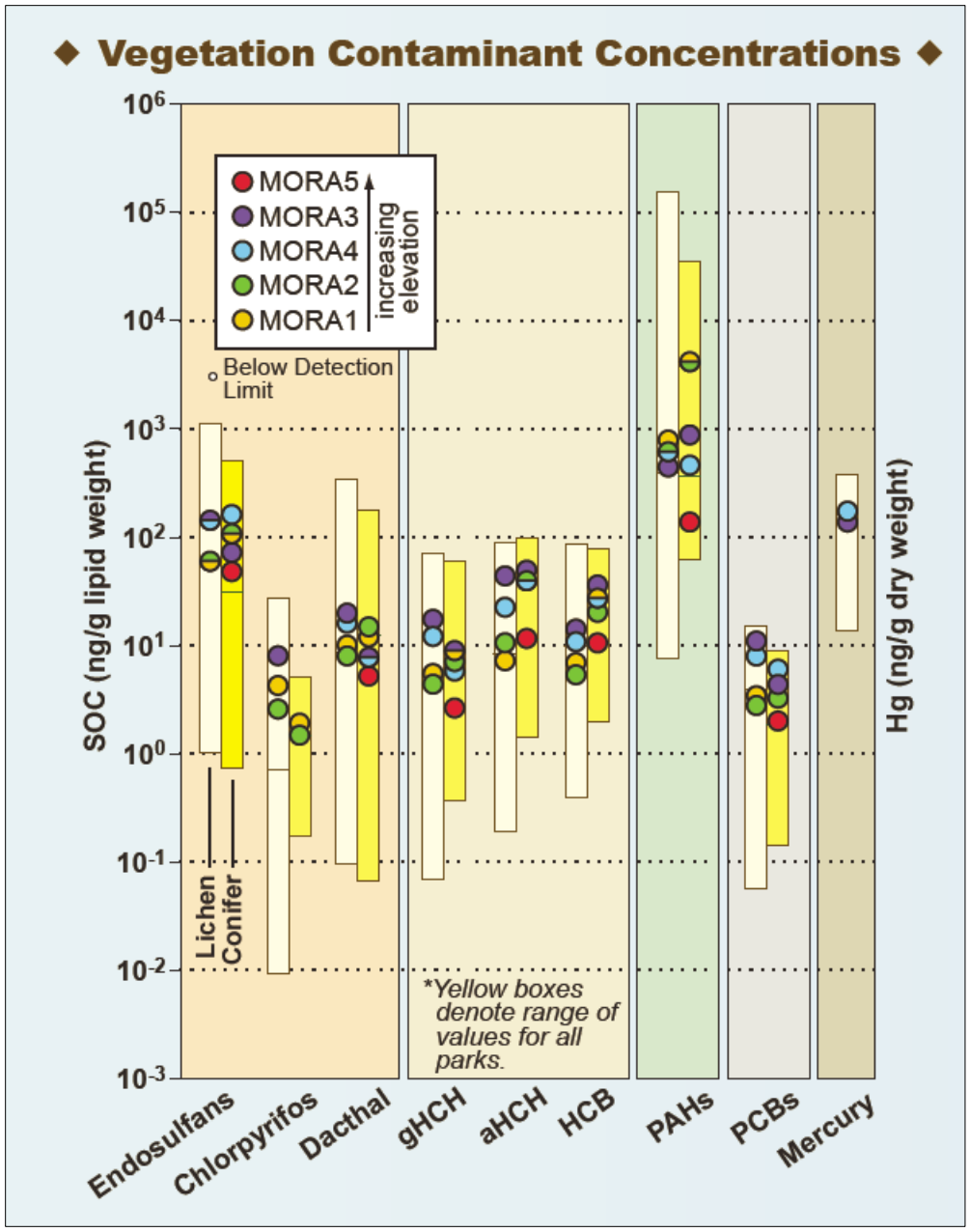

Figure 35. Concentrations of PBTs detected in vegetation along an elevation gradient in Mount Rainier NP in 2004 as part of the WACAP study (from Landers et al., 2008). Horizontal lines in boxes indicate median values. From left to right, pollutant categories represented by large shaded boxes are Current-Use Pesticides, Historic-Use Pesticides, Combustion By-products, Industrial Compounds, and Metals.

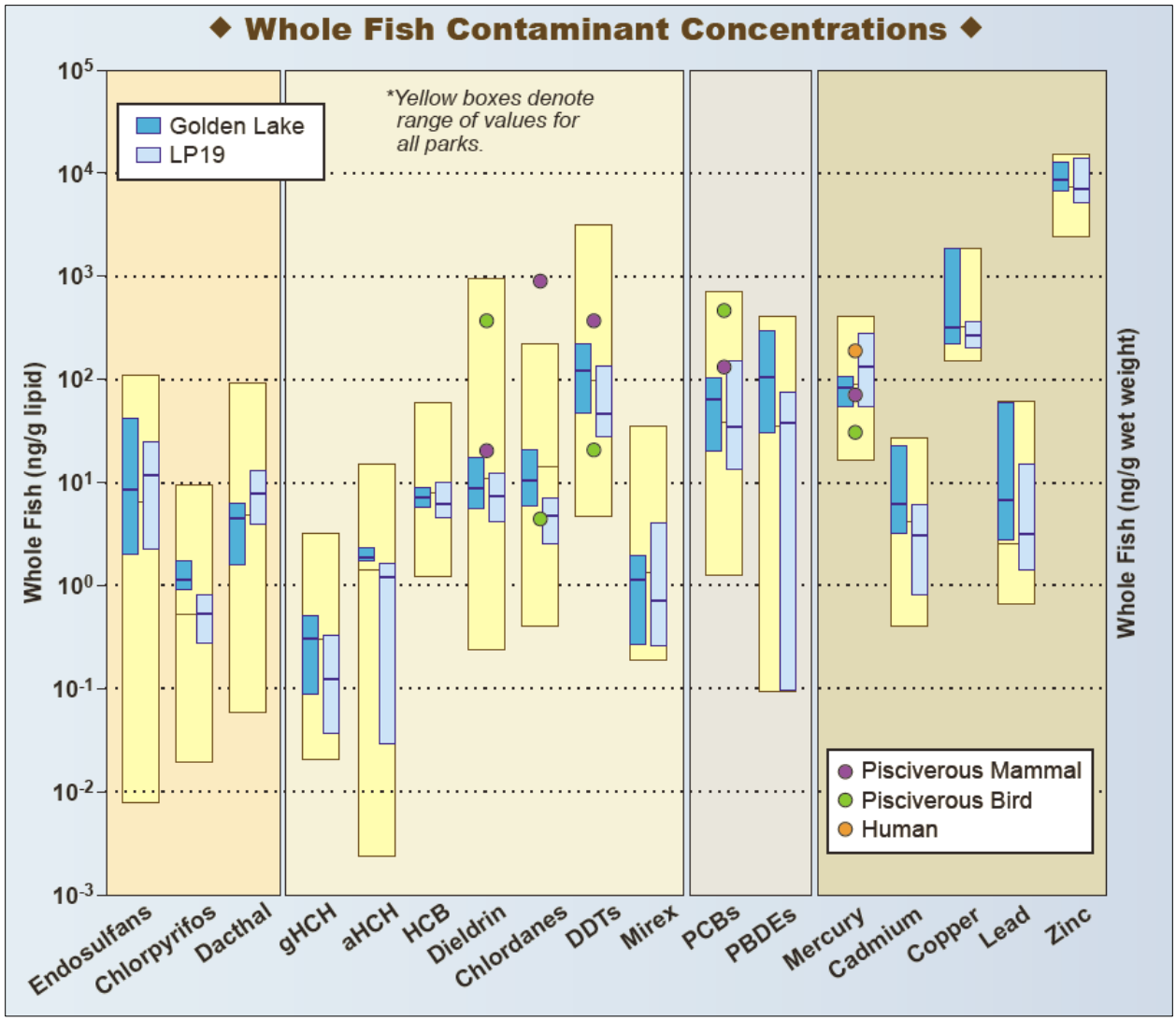

Figure 36. Concentrations of PBTs detected in fish collected from Golden Lake and Lake LP19 in Mount Rainier NP in 2005 as part of the WACAP study (from Landers et al., 2008). Horizontal lines in boxes indicate median values. From left to right, pollutant categories represented by large shaded boxes are Current-Use Pesticides, Historic-Use Pesticides, Industrial Compounds, and Metals.

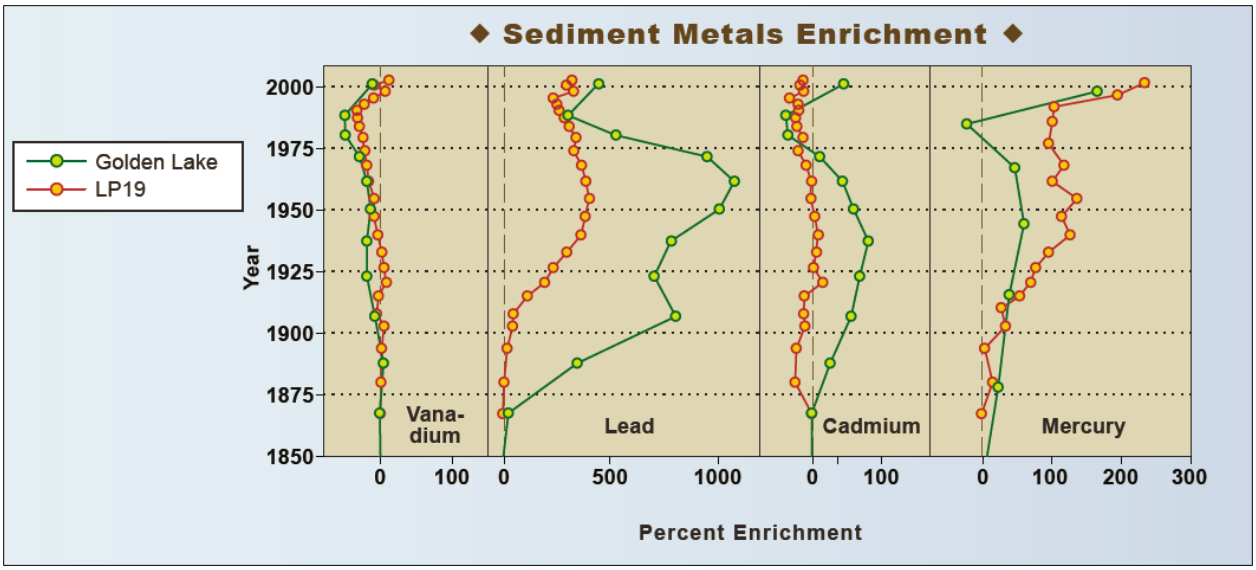

Figure 37. Percent enrichment of metals in sediment cores collected from Golden Lake and Lake LP19 in Mount Rainier NP in 2005 as part of the WACAP study (from Landers et al., 2008).

In a follow-up to the WACAP study, Simonich et al. (2012) collected snowpack samples at Mount Rainier, North Cascades, and Olympic NPs in 2005 to 2007 for additional analysis of contaminants. In Mount Rainier and North Cascades NPs, the study looked at spatial distribution of contaminants, with some sample sites near agricultural areas and others closer to industrial activity. No significant differences were observed, indicating impacts from local sources were not greater than those from regional sources. At Mount Rainier NP, samples were also collected along an elevation gradient on the south side of Mount Rainier from Paradise to Camp Muir. Results showed highest contaminant deposition occurred at an elevation of 1,500 to 2,000 m and generally decreased at higher elevations. In Olympic NP, the study focused on the temporal variability in contaminant deposition. Concentrations of current use pesticides generally increased in late winter and spring; there were no seasonal patterns in concentrations of historic use pesticides.

Some PBTs are endocrine-disrupting compounds that can impair reproduction. Schreck and Kent (2013) analyzed fish collected in 2008 to 2009 from Mount Rainier, North Cascades, and nine other western parks to study the occurrence of intersex (i.e., both male and female reproductive structures in an individual). None of the 48 male fish from twelve lakes at Mount Rainier NP or the 57 male fish from five lakes at North Cascades NP exhibited intersex. While some of the female fish collected in the parks had signs of male cells in their ovaries, the researchers concluded those were likely false positives due to sample contamination. Relatively high rates of intersex in male fish occurred only in lakes from parks in the Rocky Mountains.

Given concern about elevated levels of Hg detected in national parks, several follow-up efforts have been initiated since 2011 to determine the extent of contamination and the factors that contribute to high Hg levels in fish and other biota. Eagles-Smith et al. (2014) analyzed Hg concentrations in fish collected between 2008 and 2012 from 21 western national parks (Figure 38). Samples included fish collected from 17 sites at Mount Rainier in 2012 as part of a focused study that examined a range of food web components. To enable a better spatial comparison,

Eagles-Smith et al. (2014) normalized Hg concentrations to control for the influence of size and species. Based on the normalized concentrations, fish were assigned to one of three size classes, i.e., 50 mm, 200 mm, or 400 mm. Results for the 200 mm size class at Mount Rainier NP showed the site with the highest average Hg concentration was nearly 23-fold higher than the site with the lowest average Hg concentration (Figure 39). This extreme variation indicates local factors play an important role in influencing Hg accumulation. Two percent of the fish samples from Mount Rainier exceeded the EPA Hg human health consumption guideline of 300 ng/g ww, one percent exceeded the 200 ng/g ww concentration above which Hg exposure may affect fish health, and 15 percent exceeded the Hg concentration of 90 ng/g ww that is thought to pose a risk to birds with high sensitivity to Hg (Eagles-Smith et al., 2014). Fish from several Mount Rainier NP lakes exceeded the Washington Department of Health Hg criteria of 100 ng/g ww (Collin Eagles-Smith, USGS, personal communication).

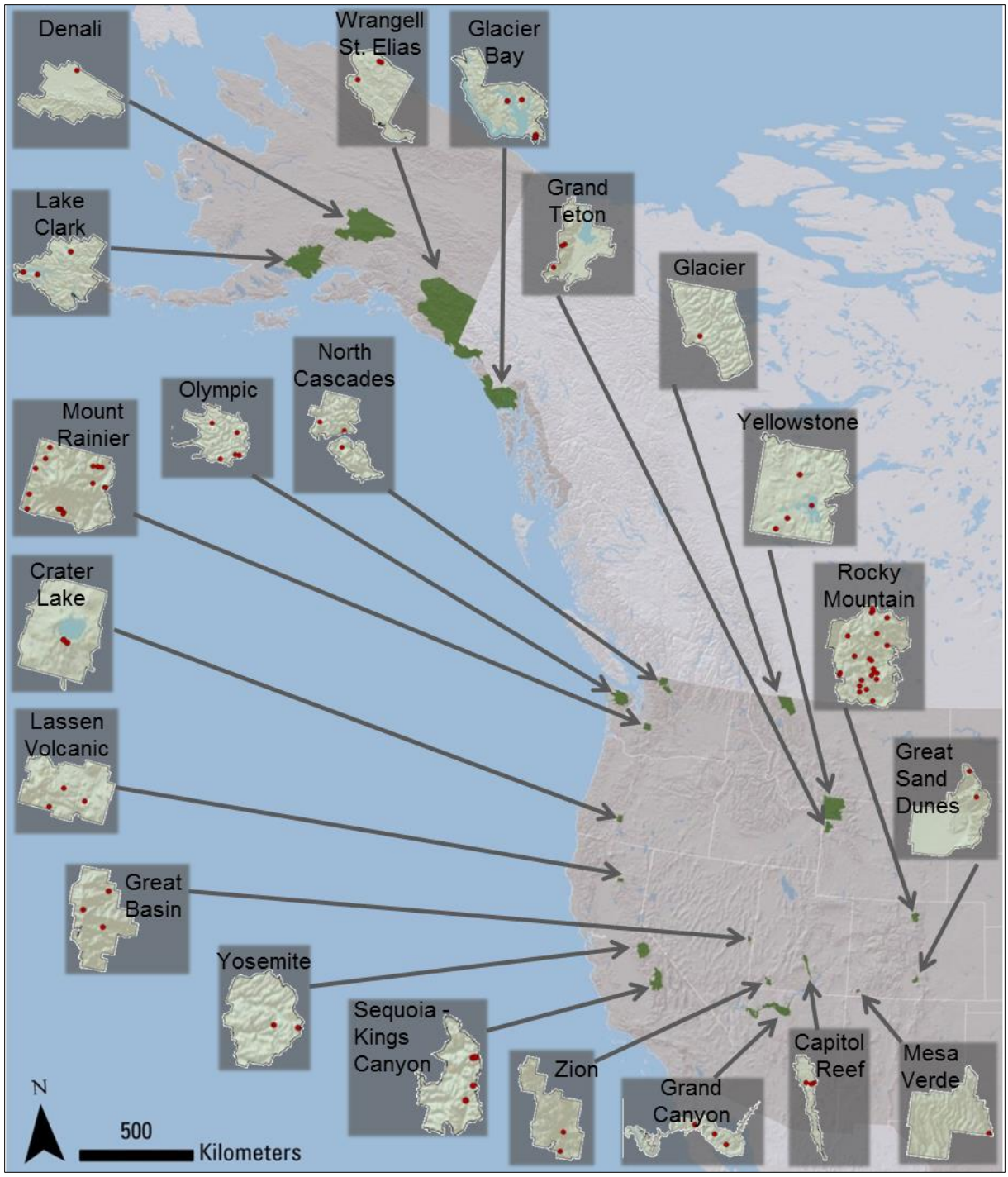

Figure 38. Map of 21 western national parks with fish collected in 2008 to 2012 for Hg analysis (from Eagles-Smith et al., 2014).

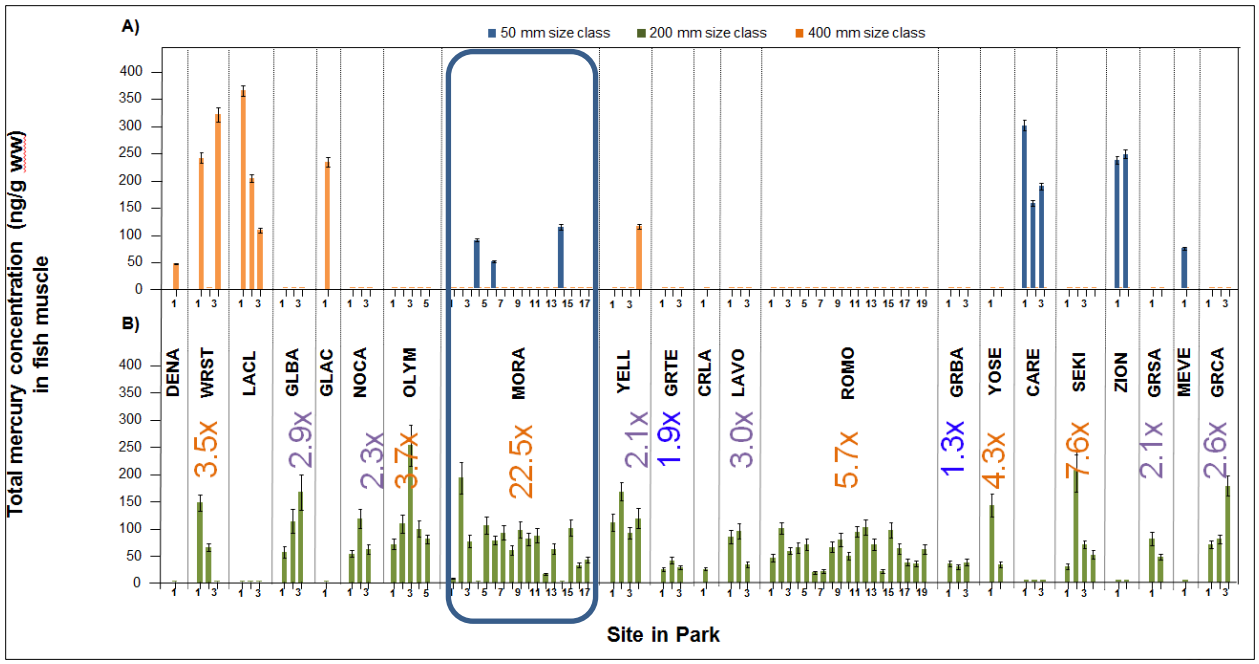

Figure 39. Least-square mean (whiskers=standard error) total Hg concentrations in fish muscle from individual sites in 21 western national parks (from Eagles-Smith et al., 2014). Concentrations are normalized for three fish size classes. MORA is Mount Rainier NP.

In 2012, Eagles-Smith analyzed Hg concentrations in invertebrates, fish, and amphibians collected from several lakes and ponds in Mount Rainier to assess the extent of Hg contamination in wetlands throughout the park and identify the key landscape, catchment, and habitat factors responsible for Hg cycling and bioaccumulation. Results showed substantial variation in bioaccumulation among habitats and along elevation gradients suggesting that *in situ* processes in the park's wetlands likely influence Hg availability and ecological risk (Collin Eagles-Smith, USGS, personal communication).

Six of the sites that were part of the 2012 Eagles-Smith study at Mount Rainier were included in a preliminary evaluation of Hg concentrations in songbirds at three western national parks (Adams et al., 2013). Although the sample size at Mount Rainier NP was low, average Hg concentrations in songbird blood were higher at Mount Rainier (0.167 parts per million wet weight [ppm ww]) than at Grand Teton NP (0.084 ppm ww) or Yosemite NP (0.110 ppm ww). Birds sampled in the wet meadow habitat at Mount Rainier NP had higher levels of Hg than those sampled in wet meadows at the other parks. With the exception of two birds from Mount Rainier, a Varied Thrush (*Ixoreus naevius*) and a Hermit Thrush (*Catharus guttatus*), Hg concentrations were below threshold levels thought to affect reproduction in songbirds.

In 2012, the Biodiversity Research Institute initiated the Western North America Mercury Synthesis, a three-year effort to synthesize information on Hg emissions, transport, and deposition, as well as MeHg production, bioaccumulation, and risk across the western U.S., Canada, and Mexico (Figure 40). This project follows two other regional efforts that resulted in several publications for the Northeastern U.S. and the Great Lakes region. The current effort will provide a synthesis of existing data, identify gaps, and contribute to understanding of Hg cycling in the West, including at Mount Rainier NP.

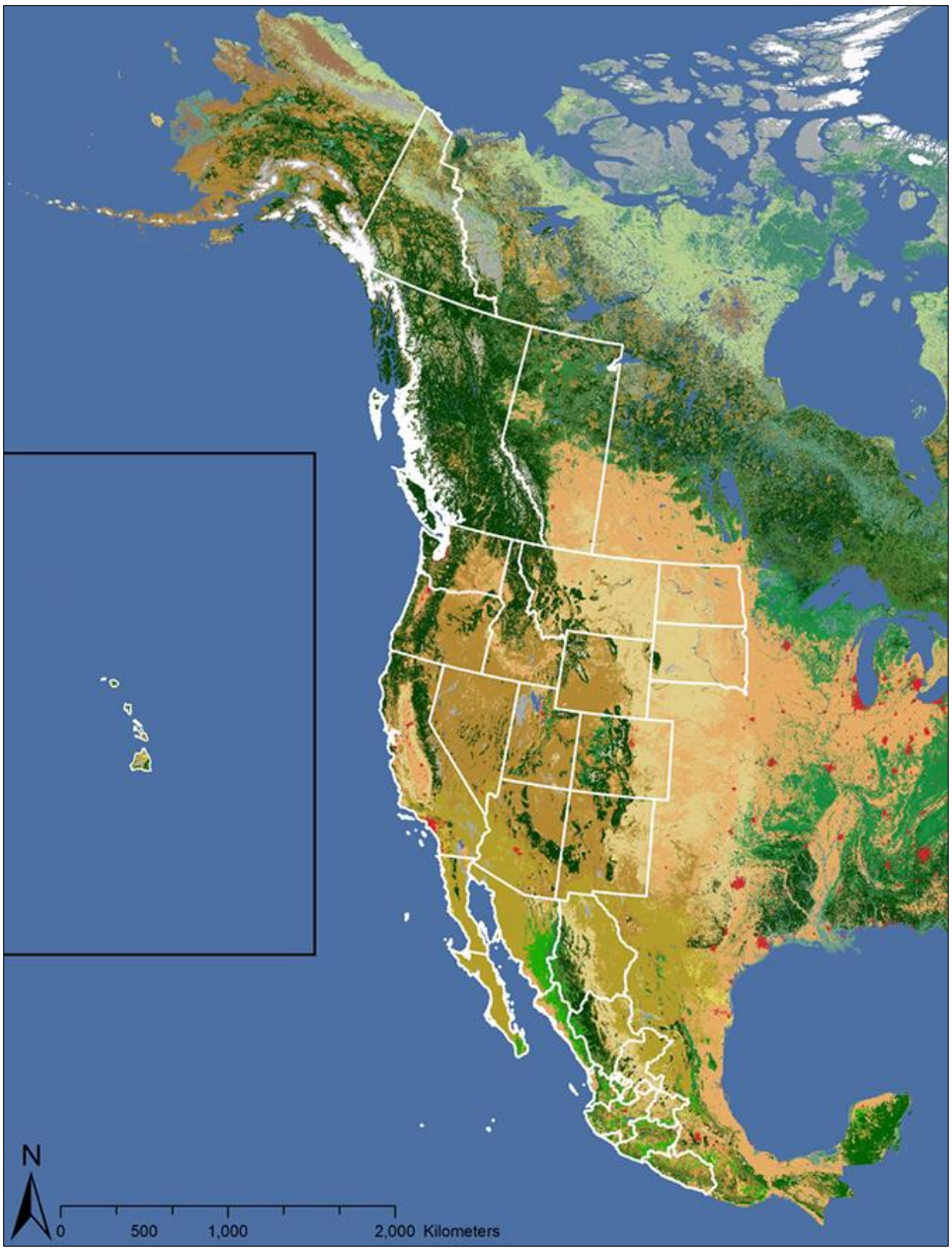

Figure 40. Map showing geographic area of the Western North America Mercury Synthesis Project (Biodiversity Research Institute, 2012).

Summary and Recommendations

Mount Rainier NP is a Class I area and is, therefore, afforded the highest degree of air quality protection under the Clean Air Act. The park is vulnerable to air pollution from nearby urban and agricultural areas, as well as to pollution from regional and even global sources. The NPS and others have monitored air quality and studied pollutant effects on park resources since the 1980s. Park air quality is currently in compliance with all the NAAQS. Nevertheless, park resources have been affected by air pollution.

Regional air pollution sources include stationary facilities such as manufacturing plants and paper mills, as well as area sources like motor vehicles, road dust, and construction. Railroads are not currently a large source of area emissions; however, emissions would likely increase if the bulk oil and coal export terminals proposed in the Pacific Northwest are constructed. Sulfur dioxide and NO_x emissions decreased substantially when emission controls were installed at the Centralia power plant in 2001 through 2003.

Visibility at Mount Rainier NP improved on the clearest and haziest days from 2000 to 2009; however, based on 2008 to 2012 data, current average visibility at the park is about 42 percent hazier than natural conditions. The contribution of ammonium sulfate to visibility impairment at Mount Rainier has declined since SO_2 controls were installed at Centralia; installation of NO_x controls at the power plant did not have a noticeable effect on visibility.

Most of the N and S deposited at the park is in the form of wet deposition. A 2000 to 2009 analysis of the Tahoma Woods NADP wet deposition data found a decrease in NO_3 and SO_4 concentrations but no trend in NH_4 concentrations. At the Paradise bulk deposition sampling site, there were decreasing trends in SO_4 and NO_3 concentrations and an increasing trend in NH_4 concentrations from 1989 to 2012. Sulfur and N deposition decreased at the park in the years following installation of emission controls at Centralia.

Some ecosystems at Mount Rainier NP are considered at high risk for both acidification and N enrichment. Results from a study at Eunice Lake indicate rain-on-snow events and spring snowmelt could cause episodic acidification of high-elevation lakes and streams in the Cascade Mountains. Critical loads for S have not been developed, but lichen community-based N critical loads have been determined for western Oregon and Washington. The limited number of lichen samples collected at Mount Rainier NP did not indicate N critical loads exceedances; however, additional sampling at higher elevations and in other parts of the park would confirm this. Efforts are underway to define N critical loads for other ecosystem components.

Ozone has been monitored at several locations in the park and results show concentrations generally increase with elevation. Ozone concentrations were higher than the current NAAQS at Paradise in 2003, and in many years, concentrations at Paradise and Tahoma Woods exceeded the lower end of the range for a revised primary ozone standard proposed by EPA in 2010. An evaluation of 2000 to 2009 data indicated a decreasing trend in ozone concentrations at Mount Rainier NP. The decrease in ozone is likely due to a regional decline in precursor emissions. Vegetation surveys conducted over several years have found little indication of ozone-induced foliar injury in the park.

Elevated concentrations of Hg and other PBTs have been detected in the park, with levels in some fish exceeding wildlife or human health thresholds. High Hg levels have also been reported for songbirds at Mount Rainier. There is a great deal of variability in Hg concentrations in samples collected across the park. Ongoing studies are investigating watershed characteristics that enhance Hg methylation and determining the extent of Hg contamination in fish, amphibians, and invertebrates.

Continued monitoring and research are critical for assessing trends in air quality and to improve understanding of air pollution effects on resources. Park staff have done an excellent job of coordinating research to reduce duplication of efforts and ensure projects complement each other. Recommendations for future research and monitoring include:

- Continue monitoring visibility in the park. The NPS, WDOE and EPA will rely on IMPROVE data to gauge progress in achieving the goals of the Regional Haze Rule. The web camera is a highly effective means of engaging public interest in park air quality.
- Continue deposition monitoring at the park. The long term NADP dataset provides valuable information about deposition trends both within the park and nationally when combined with data from other NADP sites across the country. Paradise is the only long-term high-elevation deposition monitoring site in the Pacific Northwest.
- The NPS should continue to support efforts by NADP and others to improve estimates of total N and S deposition. 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 throughout the region, particularly at higher elevations.
- At present, there are only enough Pacific Northwest-specific data to establish critical loads for N for lichens. The NPS, U.S. Forest Service, and USGS have identified and prioritized data needed to improve understanding of N critical loads in the region.
- Given that ozone concentrations at Mount Rainier NP sometimes exceed the lower limit of the revised primary ozone NAAQS proposed by EPA in 2010, ozone monitoring should continue.
- More information is needed about the amount of, and trends in, deposition of Hg and other PBTs at the park.
- Based on elevated levels of Hg detected in fish, park staff should continue to coordinate with Washington Department of Health in development of human health consumption advisories.
- Studies to evaluate the risk of Hg methylation in different habitats and measurements of Hg concentrations in fish, amphibians, aquatic invertebrates, and songbirds should continue. For example:
    - Eagles-Smith (USGS, personal communication) advises future alterations in wetland hydrology and structure associated with climate change could result in enhanced Hg risk to some communities in the park. He recommends quantifying the landscape factors that influence Hg levels in aquatic and terrestrial indicator species, evaluating the potential effects of climate change on Hg availability and subsequent exposure in park wildlife, and investigating whether current wildlife exposure to Hg is causing toxicological responses to sensitive hormones associated with endocrine disruption.

    - Adams et al. (2013) suggest Hg monitoring of songbirds would provide a better understanding of the geographic regions, habitats, and species that are at greatest risk from Hg exposure.
- Information is needed about wildlife health thresholds and sensitive life stages for a number of pesticides and other PBTs; at present, data are limited to a handful of chemicals and species.
- It is critical to understand how climate change will affect air pollution concentrations and effects on Pacific Northwest ecosystems. A recent comparison of 1993 to 2001 and 2003 to 2009 plot surveys indicated increasing temperature and lower relative humidity have already changed Pacific Northwest lichen communities (Linda Geiser, U.S. Forest Service, unpublished data). Changes in precipitation amount and timing could affect deposition and concentrations of S, N, and PBTs. 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).
- Further research is needed regarding the effects of black carbon on snowpack and glaciers in the park.

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