



Air Quality Overview

North Cascades National Park Complex

Natural Resource Report NPS/PWRO/NRR—2013/657





ON THIS PAGE

National Park Service staff collect snow samples at Silver Glacier, North Cascades National Park
Photograph by: NPS photo

ON THE COVER

Water quality monitoring at Vista Lake, North Cascades National Park
Photograph by: Mike Larrabee

Air Quality Overview

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Natural Resource Report NPS/PWRO/NRR—2013/657

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Abstract

North Cascades National Park Complex, located in Northwest Washington, includes North Cascades National Park and Lake Chelan and Ross Lake National Recreation Areas. North Cascades National Park is designated as a Class I air quality area and is afforded special protection under the federal Clean Air Act. North Cascades National Park Complex 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 in the park since 1984. In 1994, the National Park Service Air Resources Division published a comprehensive review of the status of air quality and air pollution effects in five Class I parks in the Pacific Northwest. This report provides an update on air quality-related research and monitoring that has taken place at North Cascades National Park Complex.

Park air quality is currently in compliance with all the National Ambient Air Quality Standards, but these standards do not provide adequate benchmarks for assessing ecosystem condition. The National Park Service Air Resources Division has, therefore, adopted the goal of natural conditions for assessing visibility impairment and uses ecological thresholds from the scientific literature to assess potential effects from ozone and deposition of nitrogen, sulfur and toxic air pollutants.

Current average visibility at North Cascades National Park is about 34 percent hazier than natural conditions, with no significant improvement or degradation from 2000-2009. Currently, about half the visibility impairment at the park is due to sulfate particles in the atmosphere resulting from sulfur dioxide emissions from power plants and other sources. Under natural conditions, the contribution to visibility impairment from sulfate would be less than 25 percent.

Nitrate concentration in precipitation decreased significantly at the park from 2000-2009. There was also a decrease in wet ammonium concentration. While there was no trend in 2000-2009 for sulfate, longer-term data (1987-2009) indicate a decrease in wet sulfate deposition at the park. Less than 10 percent of the nitrogen, and less than 5 percent of the sulfur, is in the form of dry deposition.

Sensitive 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 North Cascades National Park Complex appears to be below critical levels shown to affect lichen communities. Efforts are underway to determine nitrogen critical loads for other ecosystem components.

Ozone concentrations are below levels thought to be harmful to human health or vegetation; however, ozone concentrations increased slightly from 1996 until monitoring was discontinued in 2007.

Elevated concentrations of toxic air pollutants have been detected in the park, including concentrations of some pollutants, such as mercury in fish, which exceeded wildlife or human health thresholds. Ongoing studies are investigating the extent of mercury contamination.

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Acronyms

µg/kg	micrograms per kilogram
µg/m ²	micrograms per square meter
µg/m ³	micrograms per cubic meter
AQRV	air quality related value
ARD	Air Resources Division
BC	British Columbia
CASTNET	Clean Air Status and Trends Network
cm	centimeter
CMAQ	Community Multi-Scale Air Quality atmospheric model
CRLA	Crater Lake National Park
DDT	dichlorodiphenyltrichloroethane
dv	deciview
EPA	Environmental Protection Agency
FOVA	Fort Vancouver National Historic Site
Hg	mercury
HNO ₃	nitric acid
I&M	Inventory and Monitoring
IMPROVE	Interagency Monitoring of Protected Visual Environments
lb	pound
lb/yr	pounds per year
kg/ha	kilograms per hectare
kg/ha/yr	kilograms per hectare per year

km	kilometer
LEWI	Lewis and Clark National Historical Park
MDN	Mercury Deposition Network
MeHg	methylmercury
mg/L	milligrams per Liter
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
NH ₄ NO ₃	ammonium nitrate
NH ₄ SO ₄	ammonium sulfate
NHP	National Historical Park
NO ₃	nitrate
NO _x	nitrogen oxide
NP	National Park
NPS	National Park Service
NRA	National Recreation Area
PAH	polycyclic aromatic hydrocarbon
PBDE	polybrominated diphenyl ether

PBT	persistent bioaccumulative toxin
PCB	polychlorinated biphenyl
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
PRISM	Parameter-elevation Regressions on Independent Slopes Model
S	sulfur
SAJH	San Juan Island National Historical Park
SO ₂	sulfur dioxide
SO ₄	sulfate
TMDL	Total Maximum Daily Load
TPY	tons per year
USGS	U.S. Geological Survey
VOC	volatile organic compound
WACAP	Western Airborne Contaminants Assessment Project
WDOE	Washington Department of Ecology
WSDOH	Washington State Department of Health

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. The vision of the National Park Service (NPS) Air Resources Division (ARD) is “...a world where people breathe easy, see far, and nature thrives.” To achieve that goal, the NPS ARD works in concert with park and regional staff, and the larger air quality community, to monitor air pollution and its effects, analyze and synthesize the data, and share information with others. Collection of high quality data empowers NPS to 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 need for air quality protection in parks.

In 1994, the NPS published a comprehensive report describing the status of air quality and air pollution effects in five parks in the Pacific Northwest, including North Cascades National Park (NP; Eilers et al., 1994). Since that time, substantial monitoring and research have greatly improved understanding of air quality conditions in parks and the sensitivity of park resources to air pollution. This report provides an update on air quality and air pollution effects in and near North Cascades NP Complex, which includes North Cascades NP, Lake Chelan National Recreation Area (NRA) and Ross Lake NRA. The overview is intended to serve as a thorough, yet concise, summary for NPS managers and others who are interested in air quality at the park.

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 at units of the National Park System. The 1916 Organic Act directs the NPS to conserve the resources and values of parks in a manner that will leave them “unimpaired for the enjoyment of future generations” (16 U.S.C. 1). The Wilderness Act, which applies to the 642,000 acre Stephen Mather Wilderness at North Cascades NP Complex, contains a similar directive that wilderness areas be managed to preserve their natural conditions (16 U.S.C. 1131-1136).

The 1977 Clean Air Act amendments include additional 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.). North Cascades NP is one of the NPS’s 48 Class I areas; all other NPS units, including Ross Lake and Lake Chelan NRAs, 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. The Clean Air Act set a specific goal for visibility protection in Class I areas: “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 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 practices, land disturbance, prescribed fire and fossil fuel combustion. North Cascades NP Complex is located near Seattle, Washington; Vancouver, British Columbia; and the urban Interstate-5 corridor. In addition, there are substantial agricultural and livestock operations north and west of the park (Figure 1). The air pollutants of concern include sulfur (S) and nitrogen (N) compounds, ground-level ozone, particulate matter, and persistent bioaccumulative toxic (PBT) compounds (e.g., mercury [Hg] and pesticides).

The main source of S pollution is sulfur dioxide (SO_2) released by coal-fired power plants and industrial operations such as aluminum smelting. 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 nitrate (NO_3) and nitric acid (HNO_3). Reduced N compounds, e.g., ammonia (NH_3) and ammonium (NH_4), result from agricultural activities and manufacturing. 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 facilitates the reaction, ozone concentrations are typically highest during the warm summer months. There are two categories of particulate matter, particles smaller than 10 micrometers (PM_{10}) and particles smaller than 2.5 micrometers ($\text{PM}_{2.5}$). Particulate matter is emitted by point sources, such as refineries and manufacturing plants, as well as from non-point (area) sources, i.e., wood-burning stoves, agriculture and road dust. Particles are also formed downwind of sources when NO_x and SO_2 react to form NO_3 and sulfate (SO_4). Persistent organic pollutants include pesticides and byproducts of industrial processes and fuel combustion. Coal combustion, mining processes and other industries emit Hg.

According to Washington Department of Ecology's (WDOE) 2005 emissions inventory, point sources of air pollution within 100 kilometers (km) of the park that emitted more than 100 tons per year (TPY) of a single pollutant included refineries, aluminum smelters, cement plants and industrial facilities (Table 1; WDOE, 2012). TransAlta's coal-fired Centralia Power Plant, located 200 km southwest of North Cascades NP Complex, is the largest point source of NO_x emissions in Washington. A 2011 state law requires Centralia's coal-fired boilers be shut down by 2025. Based on the 2010 Environment Canada emissions inventory, large point sources in British Columbia within 100 km of the park included a pulp and paper mill and a cement plant (Table 1; Environment Canada, 2012).

Washington's 2005 emissions inventory provided county-by-county estimates of area emissions by source category (WDOE, 2012). In the six counties near North Cascades NP Complex (i.e., Chelan, King, Okanogan, Skagit, Snohomish and Whatcom), the top three sources of area emissions were on-road vehicles, wildfire and non-road vehicles (e.g., forklifts, tractors and snowmobiles; Table 2). Environment Canada's 2010 emissions inventory also included information about the amount of area source emissions by province (Environment Canada, 2012). Because the emissions inventory for British Columbia covers a much greater area than

that encompassed by the six Washington counties, the Environment Canada data are reported as ranked source categories rather than TPY of emissions (Table 3).

The state of Washington requires facilities that store more than 10,000 pounds (lb) of a hazardous material on-site at any one time to report toxic pollutant releases to air, water and land. Based on the 2004 toxics release inventory (WDOE, 2006), over two million pounds of toxic air pollutants were emitted by reporting facilities within approximately 100 km of North Cascades NP Complex (Table 4); six toxic chemicals were released to the air in amounts exceeding 100,000 pounds per year (lb/yr; Table 5). Neither the state of Washington nor Environment Canada keeps track of toxic emissions from area sources, such as pesticide applications. Hageman et al. (2010) correlated pesticide concentrations in snowpack from several national parks, including North Cascades NP, with nearby cropland intensity and wind patterns and concluded that for all studied parks, less than 25 percent of the pesticide contribution was from pesticide use within 150 km of the park.

The WDOE 2004 toxics release inventory (WDOE, 2006) and Environment Canada's 2010 emissions inventory (Environment Canada, 2012) list point sources that emit more than 10 lb/yr of Hg within approximately 100 km of the park (Table 6). After Hg is emitted, it has the potential for long-range transport and joins the "global Hg pool", i.e., Hg that cycles continuously between the atmosphere, ocean, soil and living organisms. Modeling indicates 0-10 percent of the Hg deposited in the Pacific Northwest is from local anthropogenic sources, approximately 20 percent is from Asia and the rest is from the global pool (National Research Council, 2009).

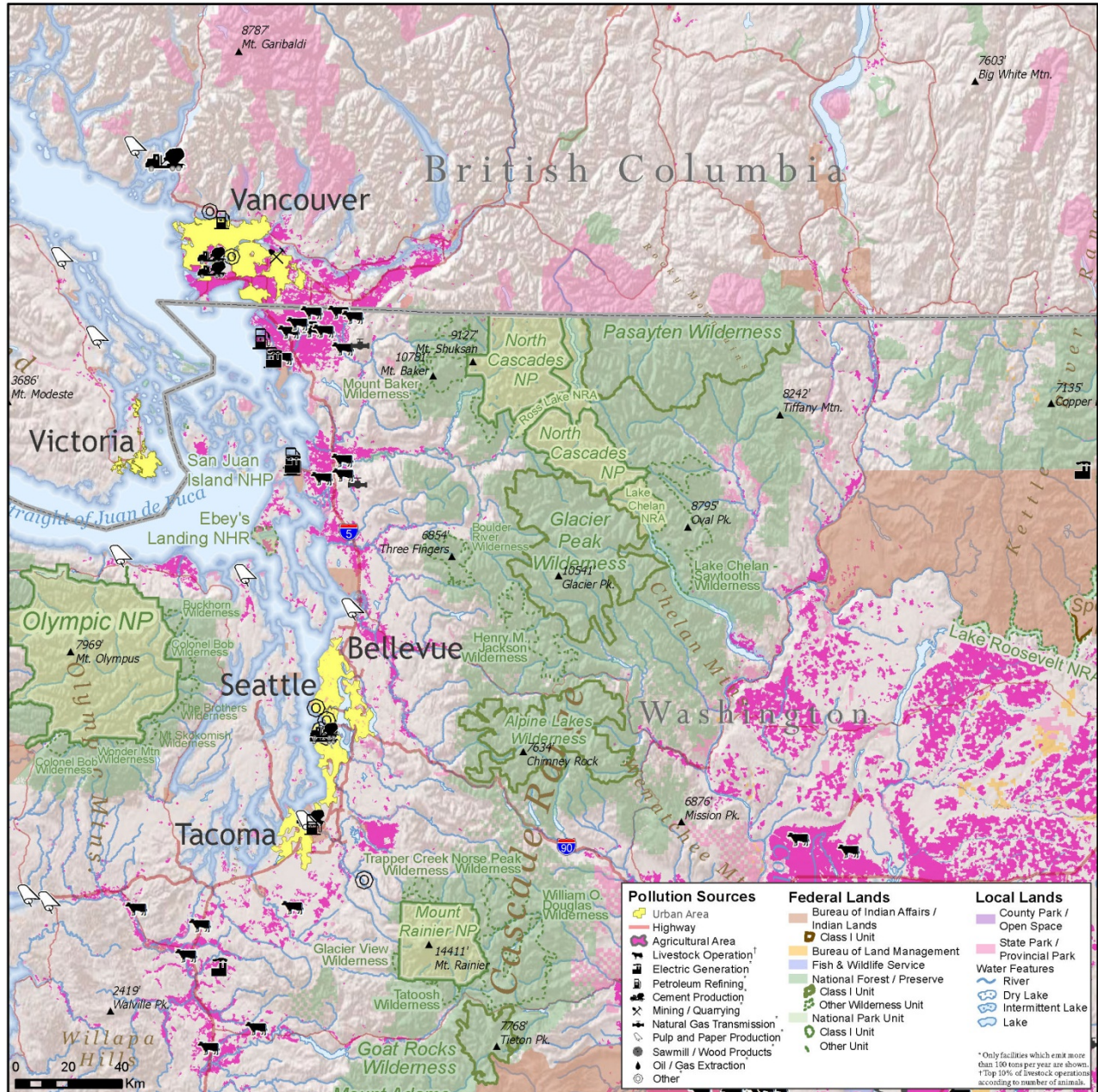


Figure 1. Pollution sources near North Cascades NP Complex (produced by NPS ARD, 2010).

Table 1. Emissions (in TPY) from large point sources in Washington (in 2005) and British Columbia (BC; in 2010) within approximately 100 km of North Cascades NP Complex.

Facility	Location	PM ₁₀	PM _{2.5}	SO ₂	NO _x	VOC
Alcoa Intalco Works	Ferndale	130	61	1,738	105	36
Alcoa Wenatchee Works	Malaga	159	115	1,607	39	6
Ash Grove Cement	Seattle	51	39	34	1,581	6
Boeing	Everett	0	0	0	67	231
BP Cherry Point Refinery	Blaine	131	131	1,397	2,179	413
Conoco Phillips Refinery	Ferndale	100	94	494	1,139	776
General Chemical	Anacortes	0	0	128	12	0
Kimberly-Clark	Everett	37	36	360	767	283
Lafarge North America	Seattle	143	76	316	2,682	2
March Point Cogeneration	Anacortes	6	6	18	243	19
Moulding & Millwork	Monroe	0	0	0	0	162
Northwest Pipeline	Sumas	2	2	3	163	10
Nucor Steel	Seattle	0	0	76	209	53
Puget Sound Refinery	Anacortes	212	202	4,052	1,295	578
Saint-Gobain Containers	Seattle	90	82	183	329	46
Seattle Steam Company	Seattle	3	0	18	259	1
Tesoro Refinery	Anacortes	652	62	5,575	2,257	1,457
TransAlta Centralia ¹	Centralia	1,497	1,000	3,378	17,152	31
Ainsworth Lumber	Vancouver, BC	78	25	0	202	625
Bulldog Bag	Richmond, BC	0	0	0	0	180
Central Heat	Vancouver, BC	2	2	0	198	0
Chevron Burnaby Refinery	Burnaby, BC	40	11	531	249	123
FLEXSTAR Packaging	Richmond, BC	0	0	0	0	214
Howe Sound Pulp & Paper	Port Mellon, BC	214	166	1,100	1,246	216
Inteplast Bags & Film	Delta, BC	0	0	0	0	186
Lehigh Cement	Delta, BC	136	58	140	1,879	61
Mainland Sand & Gravel	Abbotsford, BC	41	0	0	632	0
Metro Waste-to-Energy	Burnaby, BC	2	2	95	505	0
Weyerhaeuser	Princeton, BC	25	5	0	0	119
Weston Bakeries	Langley, BC	0	0	0	0	186
Western Concord	Delta, BC	0	0	0	0	592

¹Located 200 km from the park

Table 2. Emissions (in TPY), in 2005, for the top three area source categories in the six counties near North Cascades NP Complex.

Pollutant	Woodstoves/ Fireplaces	Road Dust	Wildfire¹	On-road Mobile	Non-road Mobile	Livestock
PM ₁₀	6,465	12,727	22,018			
PM _{2.5}	6,459		18,889		1,412	
SO ₂			1,328	1,433	1,484	
NO _x			4,848	70,290	15,906	
VOC	20,130			47,483	17,215	
NH ₃			1,016	2,516		12,529

¹Majority of wildfire emissions were from Chelan and Okanagan counties. Note that prescribed fire emissions are included under Non-residential Outdoor Burning, which is not one of the top three area source categories.

Table 3. Top three area source categories in 2010, by pollutant, in British Columbia.

Pollutant	Road Dust	Forest Fires	Mining	Residential Fuel Use	Mobile Sources	Solvents	Agriculture
PM ₁₀	1	2	3				
PM _{2.5}	1	2		3			
SO ₂			2	3	1		
NO _x		2		3	1		
VOC		2			1	3	
NH ₃			3		2		1

Table 4. Toxic annual air emissions (in lb/yr), in 2004, by reporting facilities within approximately 100 km of North Cascades NP Complex.

County	Number of Facilities	Number of Chemicals	Emissions
Chelan	1	2	1,552
Island	0	0	0
King	36	29	183,679
Okanagan	0	0	0
San Juan	0	0	0
Skagit	7	32	990,568
Snohomish	15	26	673,379
Whatcom	10	35	610,420
Total	69	N/A ¹	2,459,598

¹ Several chemicals were emitted in multiple counties

Table 5. Toxic chemicals with air emissions greater than 100,000 lb/yr, in 2004, by reporting facilities in Washington within approximately 100 km of North Cascades NP Complex.

Chemical	Emissions	Types of Facilities
Carbonyl Sulfide	191,870	Aluminum manufacturing/smelting
Hydrochloric Acid	324,239	Paper/lumber mills, refineries, coal combustion
Styrene	326,934	Shipyards, fiberglass manufacturing
Sulfuric Acid	726,231	Paper/lumber mills, refineries
Toluene	117,372	Paint/solvent use, refineries
Xylene	120,313	Shipyards, fiberglass manufacturing, refineries

Table 6. Mercury emissions (in lb/yr) from point sources in Washington (in 2004) and British Columbia (BC; in 2010) that emit more than 10 lb/yr of Hg within approximately 100 km of North Cascades NP Complex.

Facility	Location	Hg
Ash Grove Cement	Seattle	40
LaFarge North America	Seattle	67
NuCor Steel	Seattle	63
Puget Sound Refinery	Anacortes	11
Tesoro Refinery	Anacortes	42
BP Cherry Point	Blaine	13
TransAlta Centralia ¹	Centralia	107
Lehigh Cement	Delta, BC	110

¹Located 200 km from the park

Air Pollution Effects

This section provides a general overview of the effects of air pollution. Results from monitoring and research conducted at North Cascades NP Complex and other 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 anthropogenic pollutants such as ammonium nitrate (NH_4NO_3) and ammonium sulfate (NH_4SO_4) as well as natural compounds like soil and sea salt. Fine particles are also 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 through either wet deposition (i.e., rain, snow, clouds and fog) or dry deposition (i.e., particles and gases) 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; 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 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 N-limited lakes, excess N deposition can cause 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 N-sensitive, lichen community composition and N content are excellent indicators of N deposition. Alpine vegetation communities are also sensitive to excess N deposition (Sullivan et al., 2011b).

One of the most widespread air pollutants is ground-level ozone, which 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. 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 U.S. Environmental Protection Agency (EPA) established National Ambient Air Quality Standards (NAAQS) for six primary or “criteria” pollutants: carbon monoxide, lead, nitrogen dioxide, ozone, PM_{2.5}, PM₁₀ and SO₂ (Table 7). Primary standards are intended to protect public health; secondary standards are intended to protect public welfare, including AQRVs. According to monitoring data, North Cascades NP Complex is in compliance with all the NAAQS.

Table 7. 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 µg/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 and secondary	Annual	15 µg/m ³	annual mean, averaged over 3 years
			24-hour	35 µg/m ³	98th percentile, averaged over 3 years
	PM ₁₀	primary and secondary	24-hour	150 µg/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

µg/m³ = micrograms per cubic meter

Unfortunately, the NAAQS do not provide full protection of AQRVs. 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 NO₃, NH₄ and SO₄. Therefore, the NPS and other federal land managers evaluate visibility relative to natural conditions and use ecological thresholds from the scientific literature to assess potential effects from ozone and deposition of N, S, and PBTs.

To judge the threat from S and N deposition, ARD supports 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.” 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 their recent 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 has adopted 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, called the W126, that better reflects vegetation response to ozone exposure (“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 based on 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 7-15 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 trigger concern for human health and AQRVs in NPS areas (NPS, 2010).

In lieu of NAAQS, for PBTs, ARD relies on literature values indicating the concentrations of pollutants in fish tissue that are known to be a threat to fish health or to the health of humans and wildlife that eat fish. For example, for Hg, EPA has established a guideline of 0.3 ppm (equivalent to 300 nanograms per gram wet weight [ng/g ww]) for safe human consumption of fish. Mercury thresholds for piscivorous (fish-eating) wildlife are much lower, ranging from 30-100 ng/g ww (Landers et al., 2008).

Air Quality-Related Monitoring and Research at North Cascades NP Complex

A great deal of air quality and AQRV monitoring and research has taken place at North Cascades NP Complex, particularly at North Cascades NP (Figure 2 and Table 8).

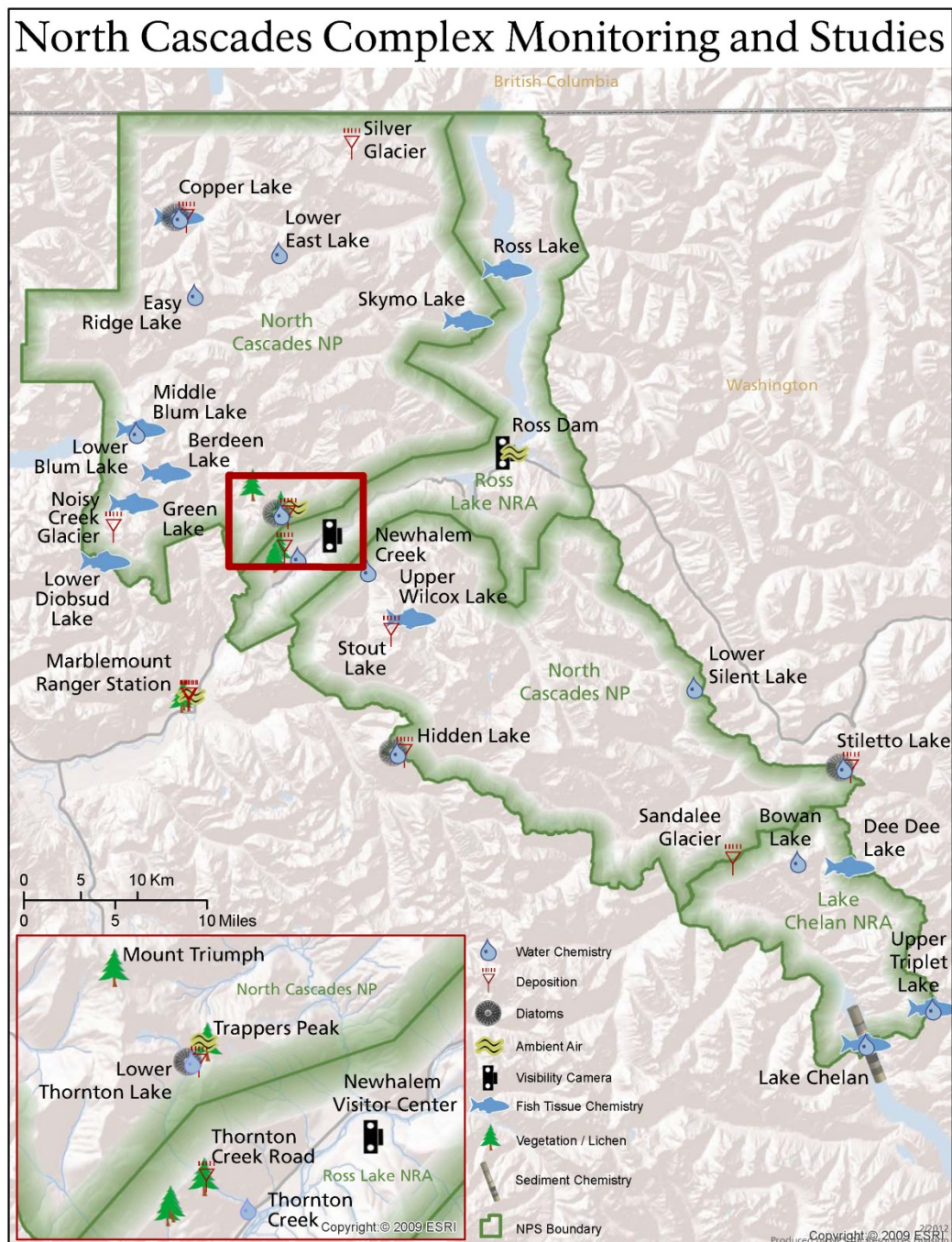


Figure 2. Locations of air quality and AQRV monitoring and research at North Cascades NP Complex (produced by NPS ARD, 2012).

Table 8. Air Quality and AQRV Monitoring and Research at North Cascades NP Complex

Parameter	Location	Investigator	Research (R)/ Monitoring (M)	Dates
Ambient Air				
35-mm camera	Ross Lake Dam	NPS	M	1985 - 1991
Digital web camera	Newhalem Visitor Center	NPS	M	2003 - present
IMPROVE ¹ - particles	Ross Lake Dam	NPS	M	2000 - present
Ozone	Marblemount Ranger Station	NPS	M	1996 - 2007
Passive air sampling device	Trappers Peak	WACAP ²	R	2005 - 2006
Deposition Chemistry				
Bulk deposition	Copper Lake	Sheibley	R	2008
Bulk deposition	Hidden Lake	Sheibley	R	2008
Bulk deposition	Marblemount Ranger Station	Fenn and Geiser	R	2005 - 2007
Bulk deposition	Lower Thornton Lake	Sheibley	R	2008
Bulk deposition	Stiletto Lake	Sheibley	R	2008
CASTNET ³ dry deposition	Marblemount Ranger Station	NPS	M	1996 - 2007
NADP ⁴ wet deposition	Marblemount Ranger Station	NPS	M	1984 - present
Snowpack	Noisy Creek Glacier	Campbell and Simonich	R	2005 - 2007
Snowpack	Sandalee Glacier	Campbell and Simonich	R	2005 - 2007
Snowpack	Silver Glacier	Campbell and Simonich	R	2005- 2006
Snowpack	Stout Lake	Campbell and Simonich	R	2005 - 2006
Throughfall deposition	Thornton Creek Road	Fenn and Geiser	R	2005 - 2007
Diatom Communities				
Diatoms	Copper Lake	Sheibley	R	2009
Diatoms	Hidden Lake	Sheibley	R	2009
Diatoms	Lower Thornton Lake	Sheibley	R	2009
Diatoms	Stiletto Lake	Sheibley	R	2009

Table 8. Air Quality and AQRV Monitoring and Research at North Cascades NP Complex (continued)

Parameter	Location	Investigator	Research (R)/ Monitoring (M)	Dates
Fish Tissue Chemistry				
Fish	Berdeen Lake	Schreck	R	2009
Fish	Copper Lake	Moran	R	2002
Fish	Dee Dee Lake	Moran	R	2002
Fish	Diobsud Lake	Schreck	R	2009
Fish	Green Lake	Moran	R	2002 - 2003
Fish	Lake Chelan	WDOE	M	1992 - 2006
Fish	Lake Chelan	EPA	R	2003
Fish	Middle Blum Lake	Schreck	R	2009
Fish	Middle Blum Lake	Eagles-Smith	R	2011
Fish	Ross Lake	WDOE	M	2003 - 2007
Fish	Skymo Lake	Moran	R	2002 - 2003
Fish	Upper Triplet Lake	Schreck	R	2009
Fish	Upper Wilcox Lake	Moran	R	2002
Fish	Upper Wilcox Lake	Schreck	R	2009
Fish	Upper Wilcox Lake	Eagles-Smith	R	2011
Lichen Communities				
Lichens	Marblemount Ranger Station	Geiser	M	1998 - 2006
Lichens	Thornton Creek Road	Geiser	R	2006
Sediment Chemistry				
Sediment	Lake Chelan	WDOE	R	2003
Vegetation Chemistry				
Vegetation	Mount Triumph	WACAP	R	2005

Table 8. Air Quality and AQRV Monitoring and Research at North Cascades NP Complex (continued)

Parameter	Location	Investigator	Research (R)/ Monitoring (M)	Dates
Water Chemistry				
Water	Bowan Lake	NPS	M	2010 - present
Water	Copper Lake	Sheibley	R	2009
Water	Easy Ridge Lake	NPS	M	2010 - present
Water	Hidden Lake	Sheibley	R	2009
Water	Lake Chelan	WDOE	R	2003
Water	Lower Blum Lake	NPS	M	2010 - present
Water	Lower East Lake	NPS	M	2010 - present
Water	Lower Silent Lake	NPS	M	2010 - present
Water	Lower Thornton Lake	Sheibley	R	2009
Water	Newhalem Creek	Clow and Campbell	R	2000 - 2006
Water	Stiletto Lake	Sheibley	R	2009
Water	Thornton Creek	Clow and Campbell	R	2000 - 2006
Water	Upper Triplet Lake	NPS	M	2010 - present

¹IMPROVE = Interagency Monitoring of Protected Visual Environments

²WACAP = Western Airborne Contaminants Assessment Project

³CASTNET = Clean Air Status and Trends Network

⁴NADP = National Atmospheric Deposition Program

Visibility

Beginning in 1985, the NPS began monitoring visibility at North Cascades NP Complex. To provide qualitative documentation of visual conditions, pictures were taken with first a 35-mm camera (1985-1991) at Ross Lake Dam, and later with a digital camera (2003-present) at Newhalem Visitor Center (Figure 3; NPS, 2012). Based on an average of 2007-2011 data, on the 20 percent best visibility days, the standard visual range was 313 km and on the 20 percent worst visibility days, the standard visual range was 110 km (B. Schichtel, NPS ARD, personal communication).



Figure 3. Examples of photographs documenting visibility conditions at North Cascades NP Complex (from NPS, 2012).

Atmospheric particle monitoring began in 2000 at Ross Lake Dam as part of the national Interagency Monitoring of Protected Visual Environments (IMPROVE) Program and includes quantitative measurements of mass, chemical elements, SO₄, NO₃, organics and elemental carbon. 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. Data from the North Cascades NP IMPROVE monitor are also used to represent visibility conditions at the nearby U.S. Forest Service Glacier Peaks Wilderness.

In 1999, EPA promulgated the Regional Haze Rule, which requires each state to develop 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, with no degradation on the clearest days. Visibility is typically reported using a haze index called the deciview (dv). To quantify the amount of visibility impairment at a park, the NPS determines the dv difference between current visibility and calculated natural visibility, i.e., the visibility that would exist without human-caused impairment.

The most recent ARD condition and trends report (NPS, in preparation) evaluated visibility on the 20 percent best, annual average and 20 percent worst visibility days from 2000-2009 and indicated no trends at North Cascades NP. To help track progress in achieving the goals of the

Regional Haze Rule, IMPROVE developed a series of bar charts showing the levels of haze, and pie charts showing its composition, associated with current (2006-present), baseline (2000-2004) and natural background conditions (Figures 4-6; Federal Land Manager Environmental Database, 2012). The baseline is the initial haze level from which progress is measured. Under current and baseline conditions, 44-57 percent of the haze at North Cascades NP Complex is due to SO₄ (note: SO₄ occurs as NH₄SO₄ and NO₃ occurs as NH₄NO₃). Under natural conditions, the contribution to visibility impairment from SO₄ would be less than 24 percent. The difference between current annual average visibility and natural conditions at the park is 3.43 dv, meaning current average visibility is about 34 percent hazier than natural conditions. The ARD considers visibility conditions that are 2-8 dv worse than natural conditions to be of moderate concern (NPS, 2010). 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.

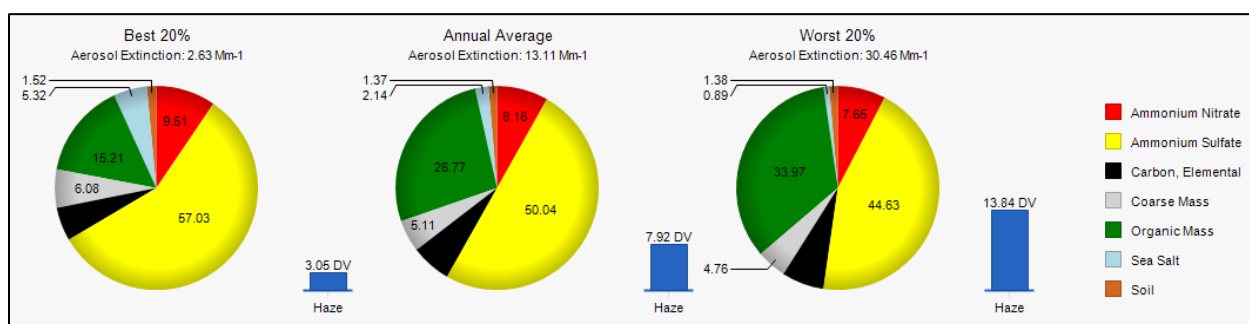


Figure 4. Current Conditions – levels of haze (bar chart) and its composition (pie chart) on the 20 percent best, annual average and 20 percent worst visibility days at North Cascades NP from 2006-present (from Federal Land Manager Environmental Database, 2012).

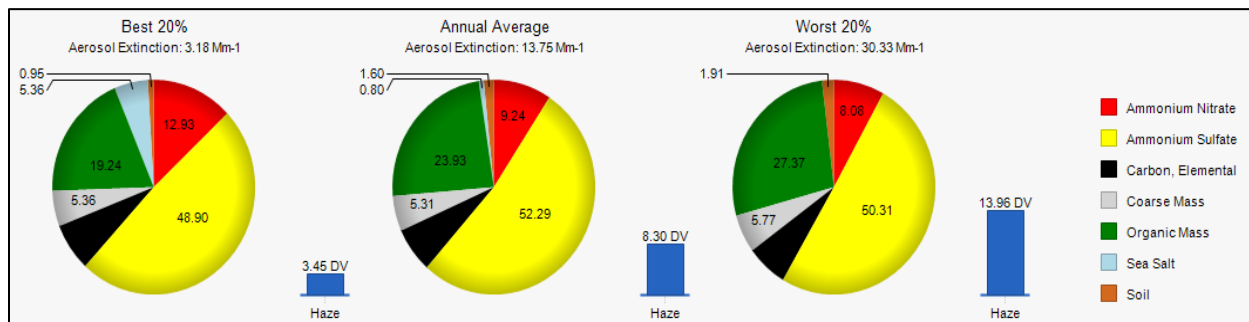


Figure 5. Baseline Conditions - levels of haze (bar chart) and its composition (pie chart) on the 20 percent best, annual average and 20 percent worst visibility days at North Cascades NP during the Regional Haze Rule baseline time period 2000-2004 (from Federal Land Manager Environmental Database, 2012).

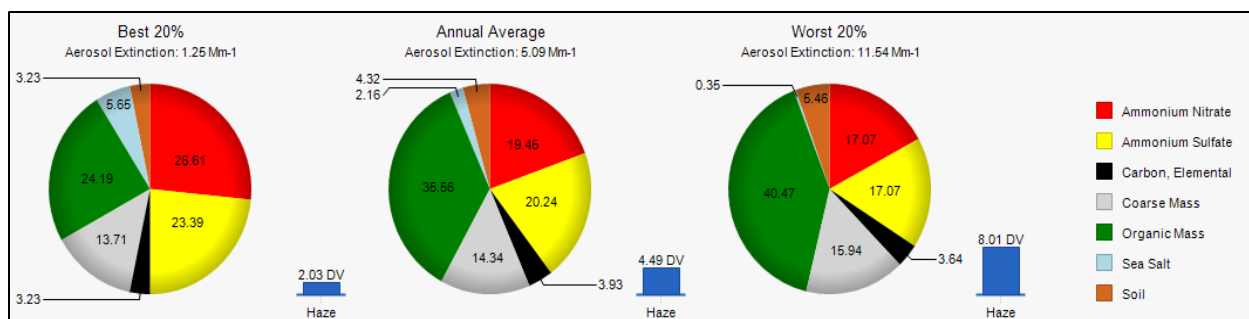


Figure 6. Natural Conditions - natural levels of haze (bar chart) and its composition (pie chart) on the 20 percent best, annual average and 20 percent worst visibility days at North Cascades NP (from Federal Land Manager Environmental Database, 2012).

Deposition

Pollutants that are either washed (wet deposition) or fall (dry deposition) out of the atmosphere can have significant impacts on park ecosystems. Wet deposition has been monitored at Marblemount Ranger Station at North Cascades NP Complex since 1984 through the National Atmospheric Deposition Program (NADP). The NADP reports concentration and annual deposition of SO_4 , NO_3 , NH_4 and base cations. The ARD (NPS, in preparation) evaluated 2000-2009 trends in NADP pollutant concentrations and found a statistically significant decrease in wet NO_3 concentration at North Cascades NP. There was a slight, but not significant, decrease in wet NH_4 concentration and no trend in wet SO_4 concentration. Data from 1989-2007 indicated significant decreases in wet ammonium and sulfate concentrations (NPS, 2010). The NADP graphs for North Cascades NP, site WA19, show the long term trends in annual concentration (in milligrams per liter [mg/L]) and deposition (in kilograms per hectare [kg/ha]) (Figures 7-11; NADP, 2012). While there is an obvious decrease in wet SO_4 concentration and deposition, long-term trends of wet N deposition are less clear.

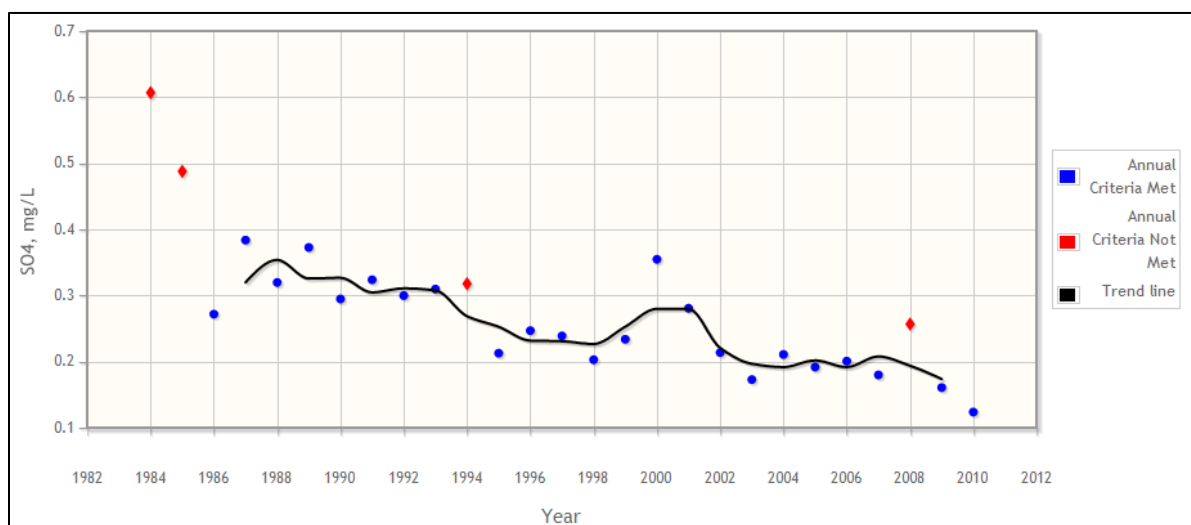


Figure 7. Trend in SO_4 concentration at NADP site WA19, North Cascades NP (from NADP, 2012). Trend line does not include years that don't meet data completeness criteria.

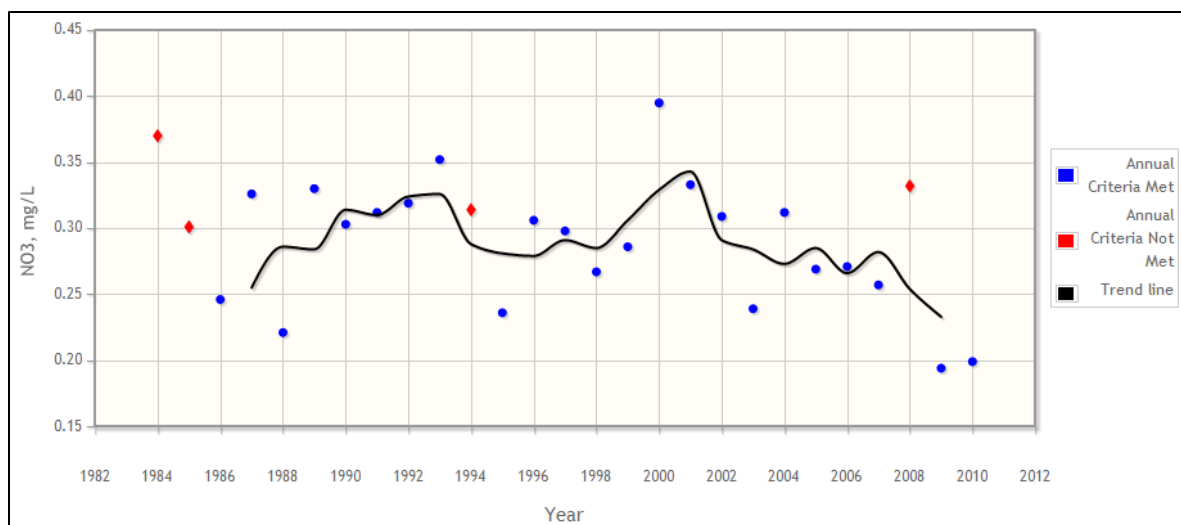


Figure 8. Trend in NO_3 concentration at NADP site WA19, North Cascades NP (from NADP, 2012). Trend line does not include years that don't meet data completeness criteria.

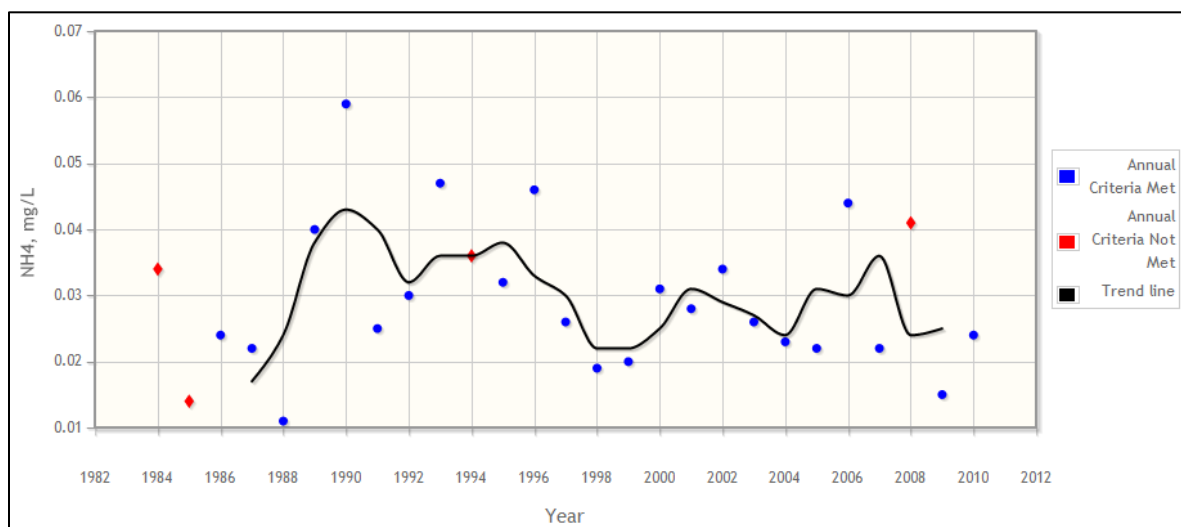


Figure 9. Trend in NH_4 concentration at NADP site WA19, North Cascades NP (from NADP, 2012). Trend line does not include years that don't meet data completeness criteria.

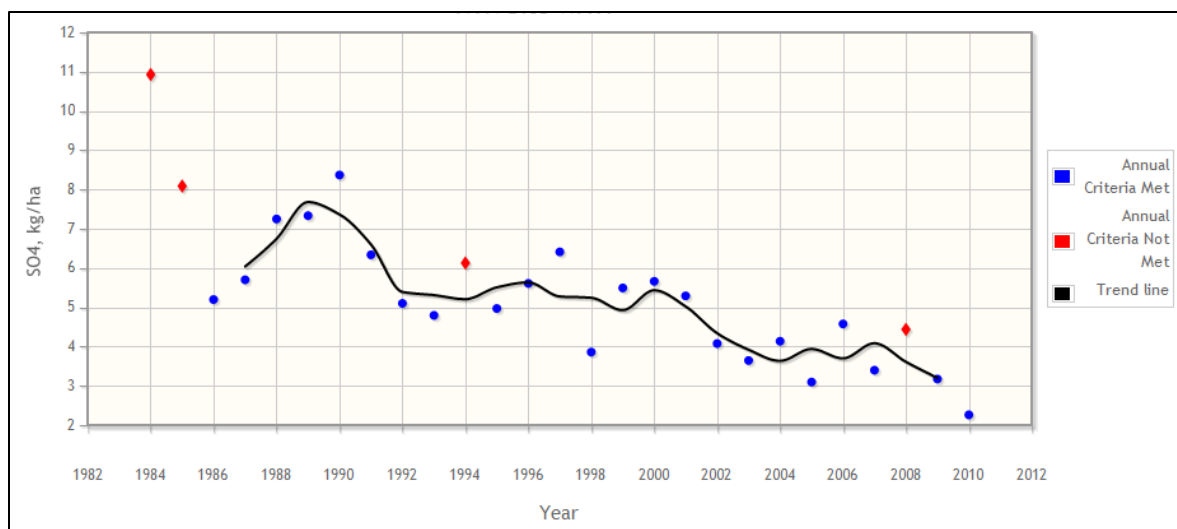


Figure 10. Trend in SO₄ deposition at NADP site WA19, North Cascades NP (from NADP, 2012). Trend line does not include years that don't meet data completeness criteria.

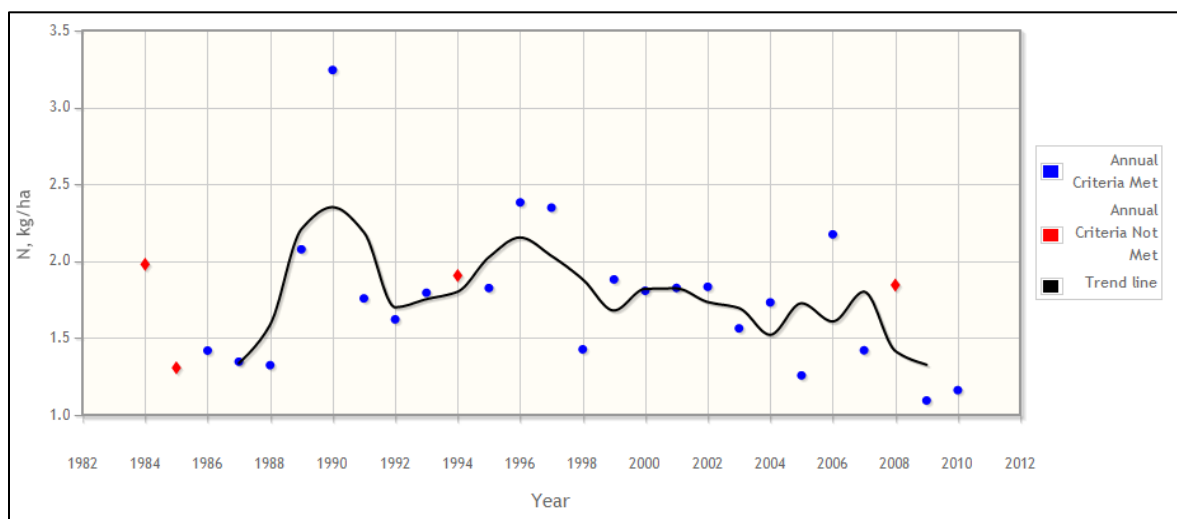


Figure 11. Trend in total N (NO₃ plus NH₄) deposition at NADP site WA19, North Cascades NP (from NADP, 2012). Trend line does not include years that don't meet data completeness criteria.

Dry deposition was monitored at the Marblemount Ranger Station from 1996-2007 through the national Clean Air Status and Trends Network (CASTNET; site NCS415). The CASTNET dry deposition values are not measured; they 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 North Cascades NP was estimated to be between 1.14 and 2.06 kg/ha/yr for years with complete data (Figure 12; CASTNET, 2012). Total N deposition ranged from 1.41 to 2.35 kg/ha/yr (Figure 13). Dry deposition accounted for about 5 percent of total S deposition and about 10 percent of total N deposition. While dry deposition is expected to be low in wet environments like the Pacific Northwest, CASTNET typically underestimates dry deposition, especially because N deposition from NH₃ is not included in the estimate.

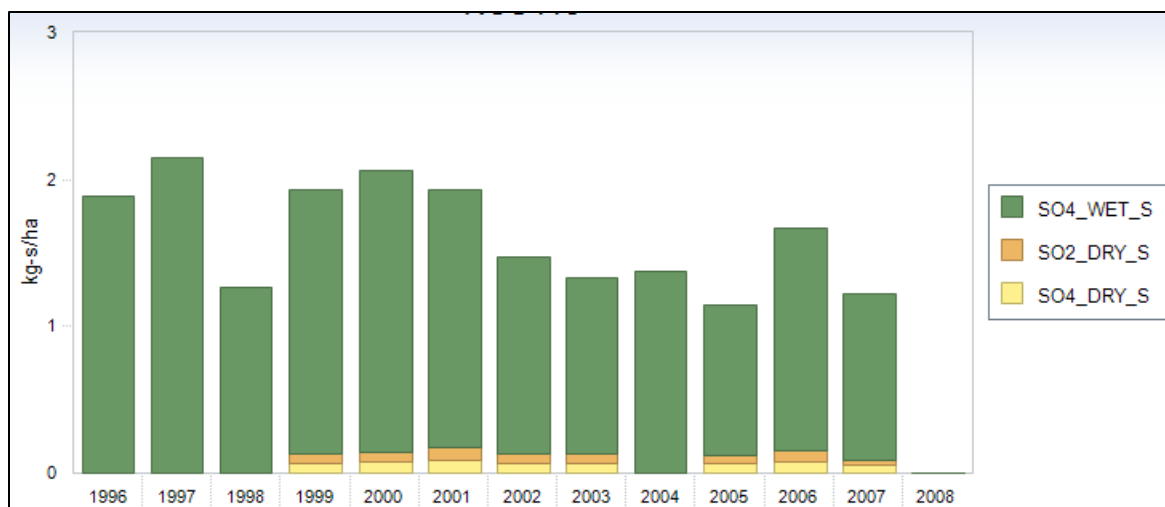


Figure 12. Total S deposition at CASTNET site NCS415, North Cascades NP (from CASTNET, 2012).

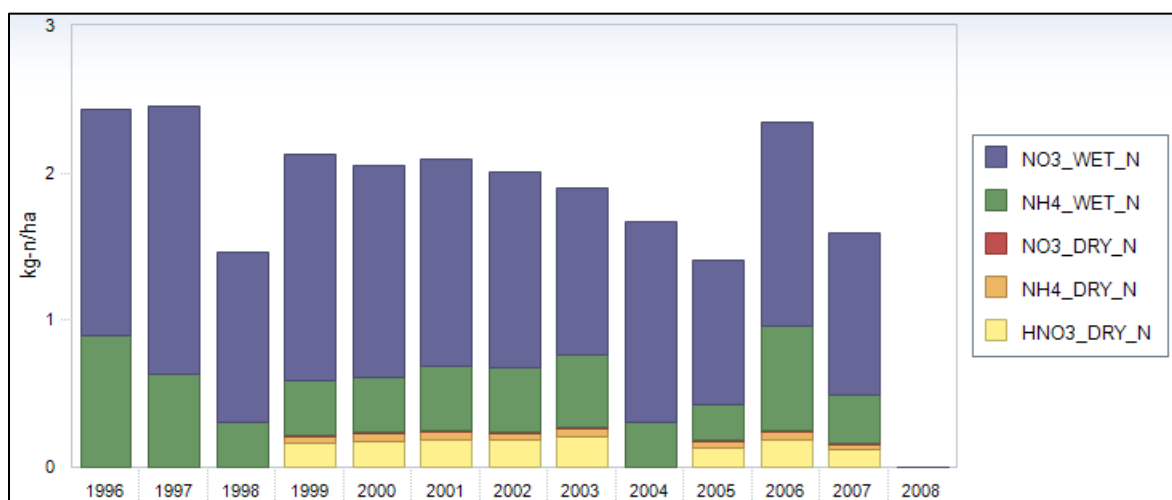


Figure 13. Total N deposition at CASTNET site NCS415, North Cascades NP (from CASTNET, 2012).

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 North Cascades, Mount Rainier and Olympic NPs from 2005-2007. Throughfall is a bulk (i.e., total) deposition measurement that incorporates wet deposition with the wash-off of dry particles and gases from the leaf surface. Fenn et al. 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 $\text{NO}_3\text{-N}$ 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. used the S:N ratios in wet deposition and throughfall S deposition to estimate a range of total N deposition of 1.3-2.1 kg/ha/yr in forest stands in the parks.

As part of the AQRV 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 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 I&M Networks as well as for all NPS areas larger than 100 square miles. North Cascades, Mount Rainier, and Olympic NPs, as well as a number of smaller historic park units, are part of the 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 sensitivity of high elevation ecosystems in the three large parks. Accordingly, North Cascades 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 areas of likely sensitive surface waters (Figure 18) and vegetation (Figure 19) in the park (note: data used for the assessment are available from the NPS Data Store at <https://irma.nps.gov/App/Portal/Home>).

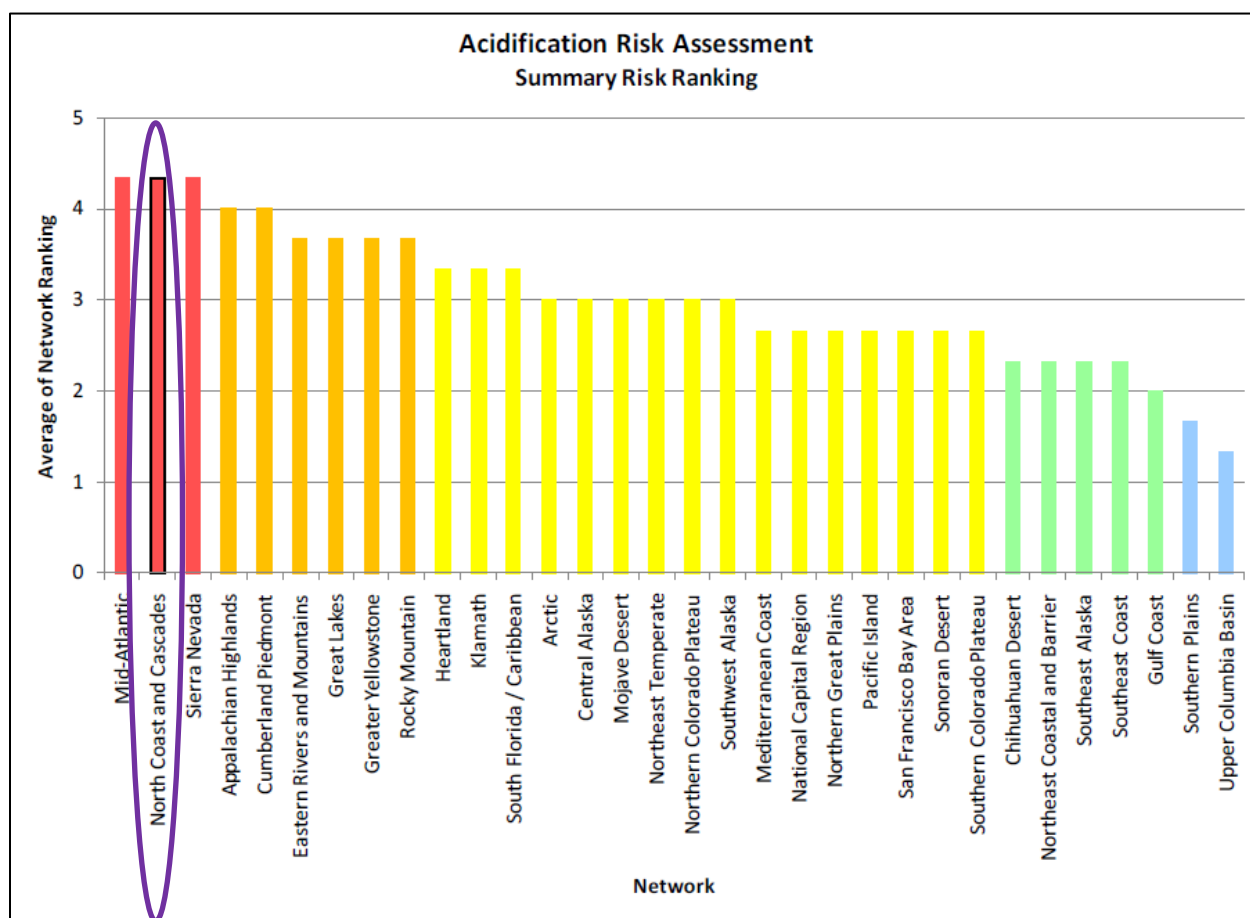


Figure 14. Summary risk ranking of acidification due to S and N deposition for the 32 I&M Networks (from Sullivan et al., 2011c).

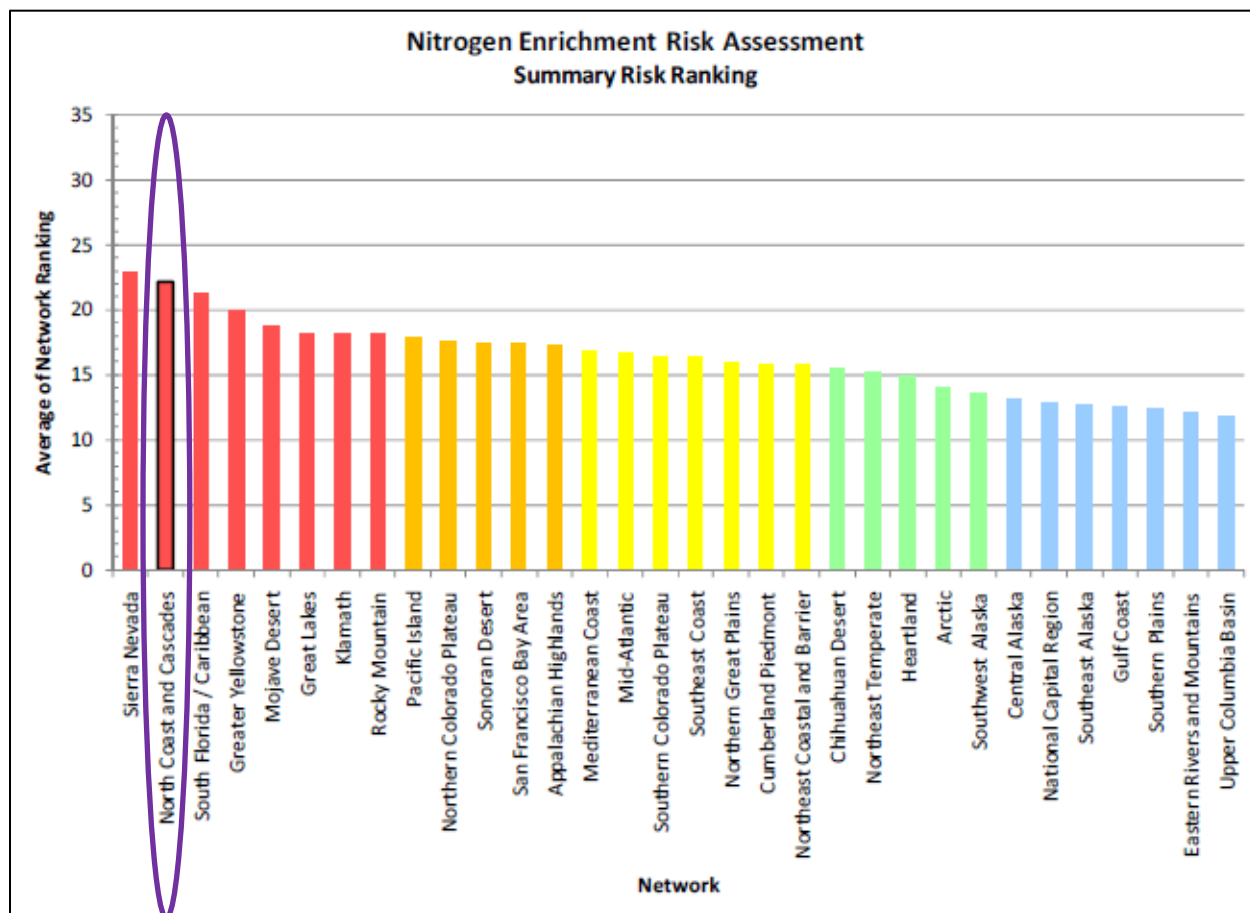


Figure 15. Summary risk ranking of atmospheric N enrichment for the 32 I&M Networks (from Sullivan et al., 2011d).

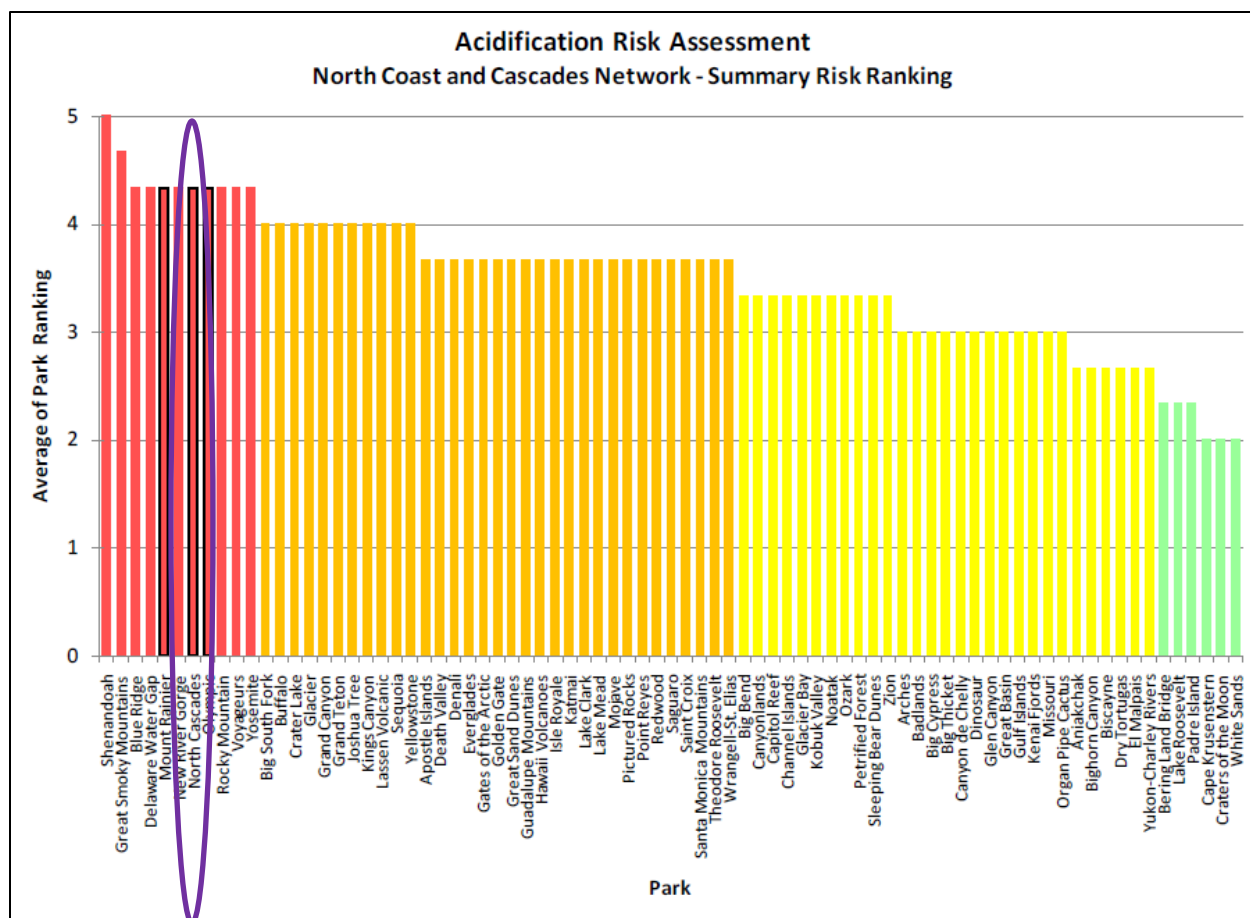


Figure 16. Summary risk ranking of acidification due to S and N deposition for all NPS areas larger than 100 square miles (from Sullivan et al., 2011c).

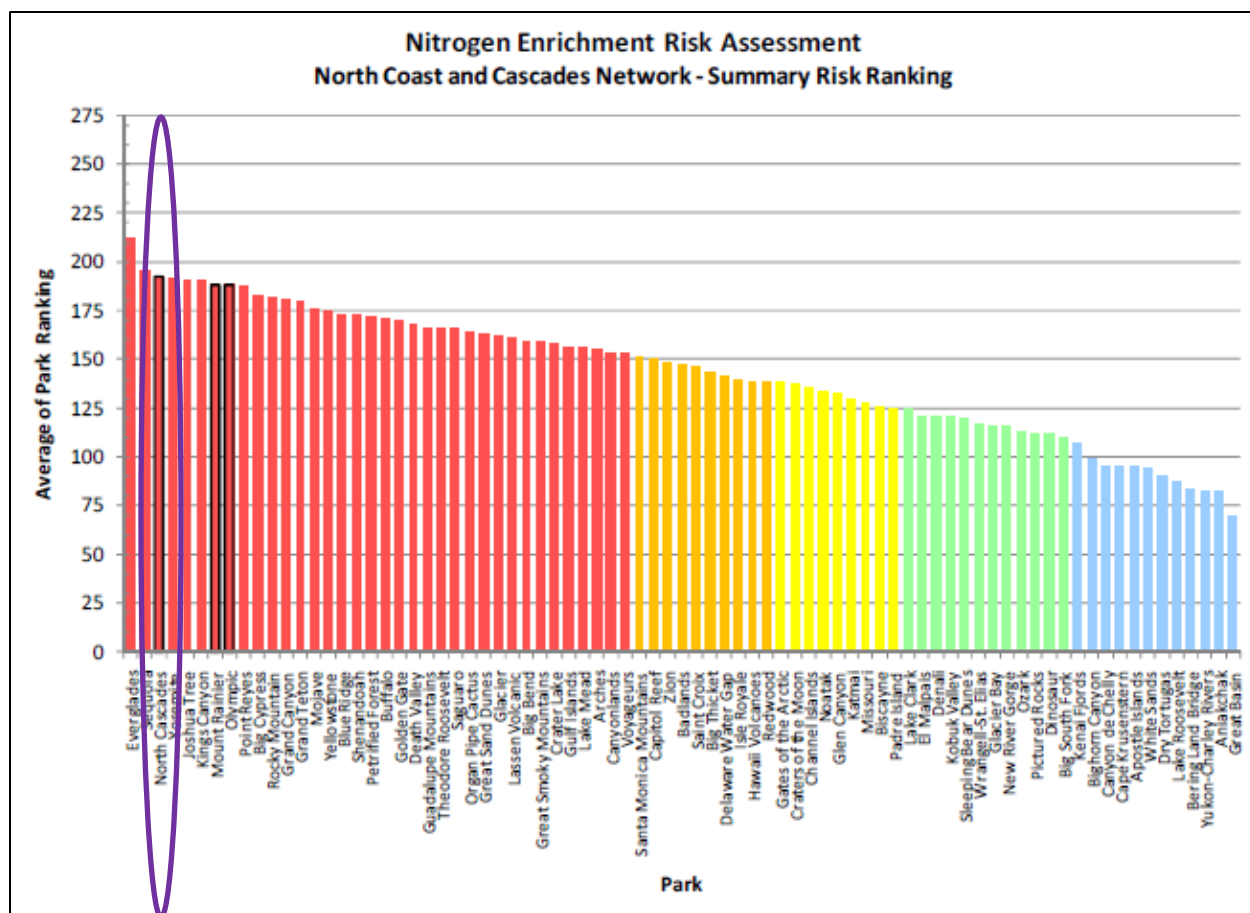


Figure 17. Summary risk ranking of atmospheric N enrichment for all NPS areas larger than 100 square miles (from Sullivan et al., 2011d).

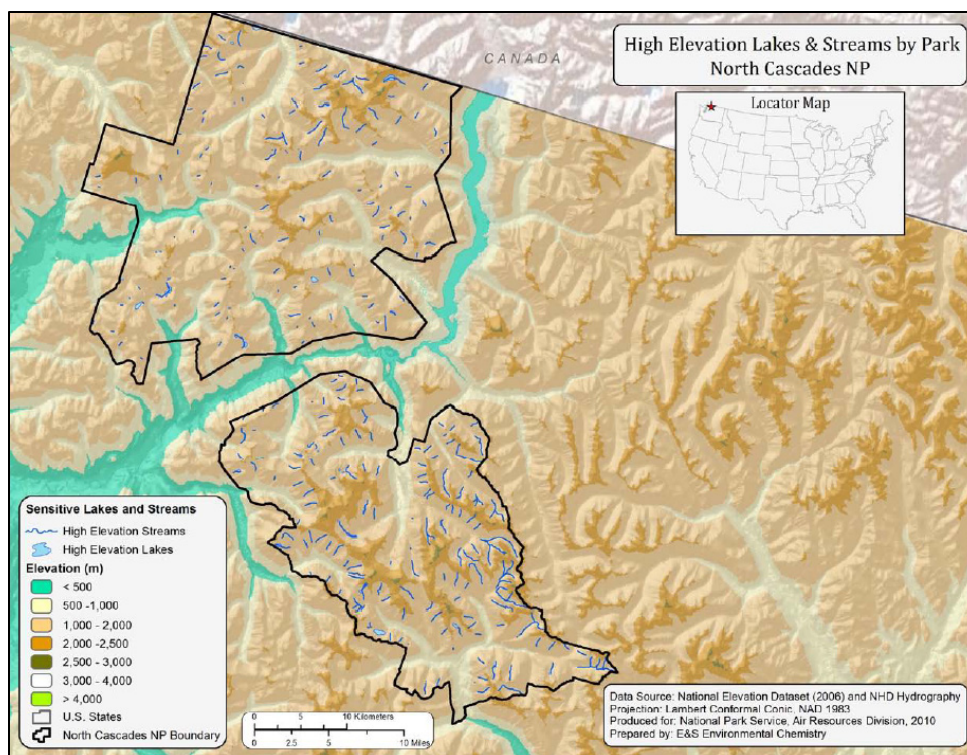


Figure 18. High elevation lakes and streams at North Cascades NP likely sensitive to acidification (from Sullivan et al., 2011c).

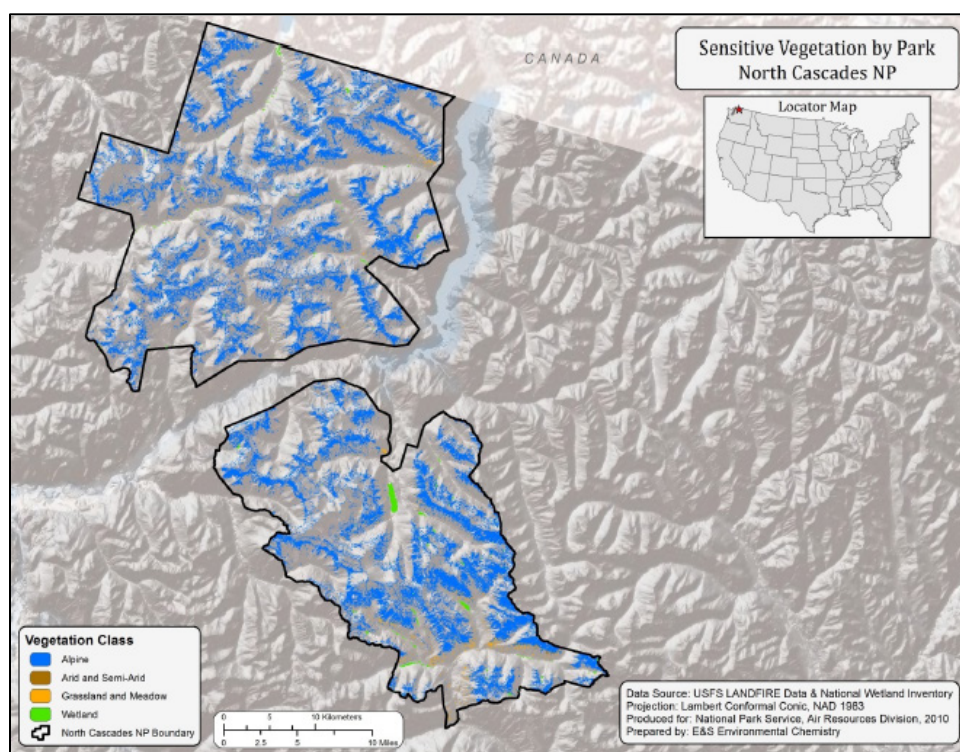


Figure 19. Vegetation types in North Cascades NP likely sensitive to atmospheric N enrichment (from Sullivan et al., 2011d).

Clow and Campbell (2008) studied the effects of atmospheric deposition on surface water chemistry at North Cascades and Mount Rainier NPs in 2000 and 2005-2006. Stream NO₃ concentrations at Thornton and Newhalem Creeks in North Cascades NP were somewhat elevated compared to study sites at Mount Rainier NP. The authors indicated the higher NO₃ concentrations were consistent with higher atmospheric deposition at North Cascades NP, but the presence of N-fixing red alder (*Alnus rubra*) at North Cascades NP confounded the results in lower-elevation watersheds. They recommended future monitoring of N deposition effects focus on high elevation areas without alder. Clow and Campbell concluded that rain-on-snow events and spring snowmelt could cause episodic acidification of high-elevation lakes and streams in the Cascade Mountains.

As part of the NCCN I&M Program, long term monitoring is being conducted at Bowan, Easy Ridge, Lower Blum, Lower East, Lower Silent and Upper Triplet Lakes in North Cascades NP Complex, as well as at six to eight lakes each in Olympic and Mount Rainier NPs (Fradkin et al., 2012). This monitoring will assess the effects of pollutants, climate change and other stressors on the chemistry and biota of park lakes.

Critical Loads

Given concern about the 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, i.e., the amounts of pollution that will harm those resources. 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. The goal is to identify N critical loads for a number of ecosystem components since some may be more sensitive than others.

Geiser sampled lichens near the NADP monitor at North Cascades NP in 1998 and again in 2006. Combining the park results 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 authors considered plots with scores of 0.21, the point at which oligotroph contribution to species richness declined by about 33-43 percent, to have exceeded the N critical load. The authors' analysis included one lichen plot in North Cascades NP and two plots within 10 km of the park (Figure 20). Two of the plots had scores below -0.11 (indicating best condition); the other plot had a score of 0.02-0.21 (indicating fair condition). 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 lichen critical loads are based on precipitation quantities derived from the Parameter-elevation Regressions on Independent Slopes Model (PRISM), and the critical load increases as precipitation increases. According to Geiser et al., 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 21). 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 Marine West Coast Forest ecoregion, which includes North Cascades NP Complex, were based on the Geiser et al. (2010) values. Following the methods of Geiser et al. (2010), the

lichen community-based critical loads at North Cascades NP Complex are 2.7 to 7.7 kg/ha/yr (Figure 22).

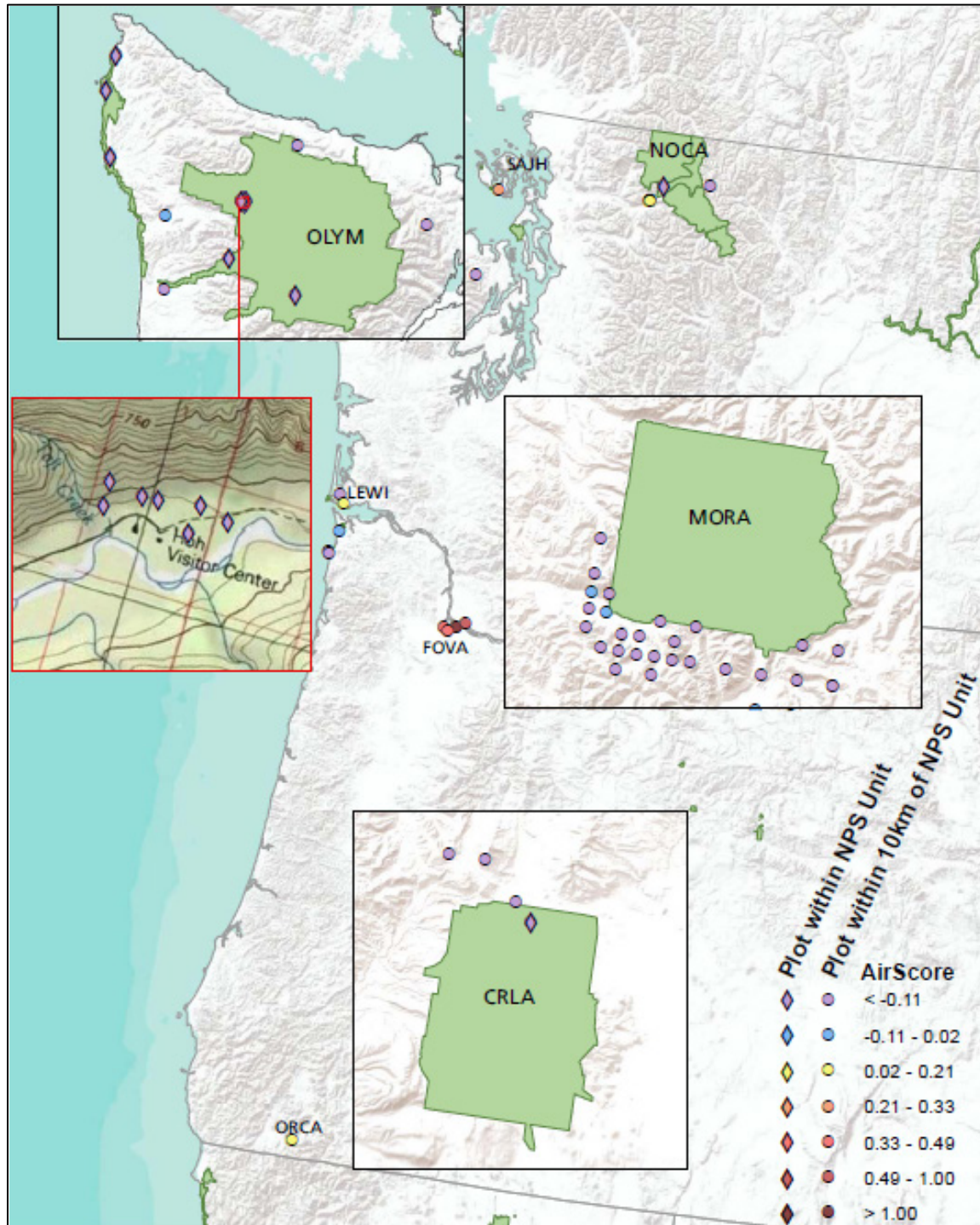


Figure 20. Air quality scores for lichen plots in and near NPS units in western Oregon and Washington. Scores of 0.21-0.33 or greater exceeded the critical load. CRLA is Crater Lake NP, FOVA is Fort Vancouver National Historic Site, LEWI is Lewis and Clark National Historical Park (NHP), MORA is Mount Rainier NP, NOCA is North Cascades NP, OLYM is Olympic NP, and SAJH is San Juan Island NHP (produced by U.S. Forest Service, 2012).

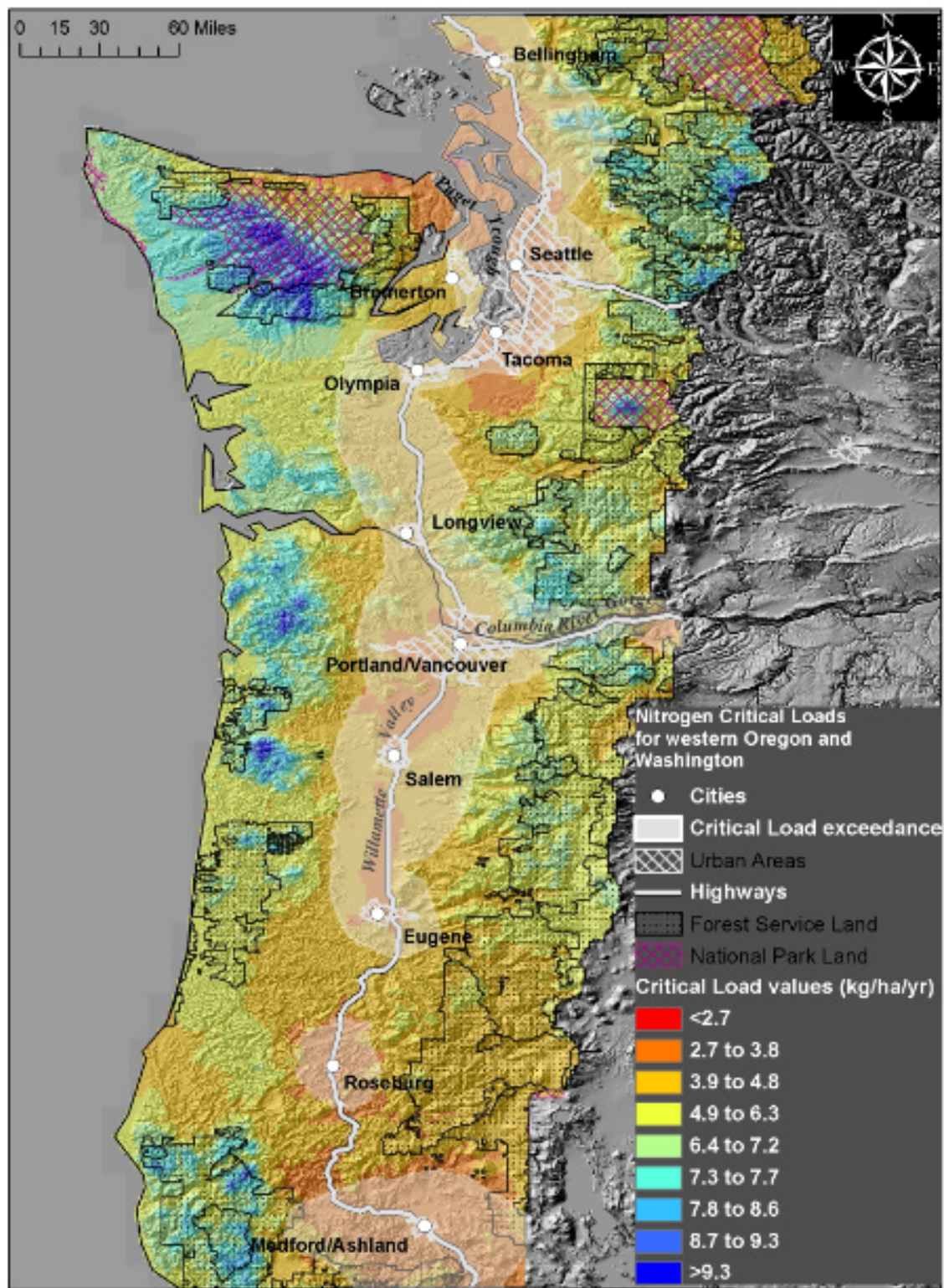


Figure 21. Map of lichen community-based critical loads for N in western Oregon and Washington (produced by Geiser and Glavich, 2012).

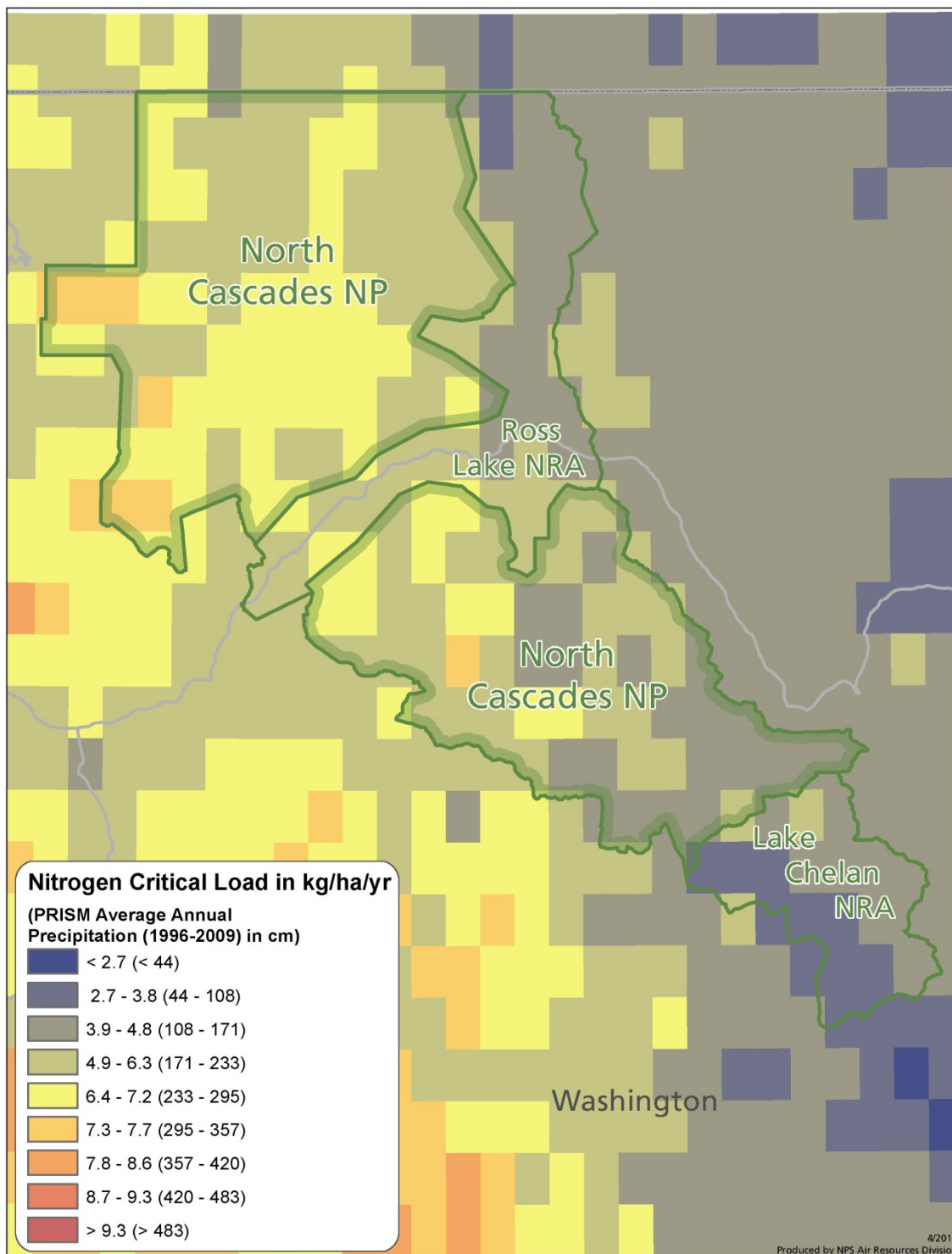


Figure 22. Map of lichen community-based critical loads for N at North Cascades NP Complex (produced by NPS ARD, 2013).

From 2008-2010, 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 North Cascades, Mount Rainier and Olympic NPs. Because of their locations, N inputs to the lakes are primarily from atmospheric deposition. The study sites in North Cascades NP Complex were Copper, Hidden, Lower Thornton and Stiletto Lakes. Bulk deposition of S and N at Stiletto Lake was lower than at the other three sites in the park (Sheibley et al., 2012). In general, bulk deposition of S and N was higher at North Cascades NP than at either Mount Rainier or Olympic NPs. Sheibley et al. (in preparation) 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, at Olympic NP. A historic change in diatom community structure was observed and thus a critical load was estimated for that 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 2013-2015 nutrient enrichment study by Dr. Mark Beutel and Jason Williams, Washington State University, will further explore the response of diatoms to N deposition in high elevation lakes in North Cascades, Mount Rainier and Olympic NPs.

In 2012, Dr. Darlene Zabowski and Dr. Robert Edmonds, University of Washington, began a three-year study assessing the effects of N deposition on high elevation plant and soil communities in North Cascades, Olympic and Mount Rainier NPs. The researchers fertilized plots with different amounts of N and will monitor changes in plant and soil N concentrations and soil fungi. National Park Service staff intend to continue monitoring the plots long term to evaluate changes in plant species composition over time. The study will provide information that can be used to establish N critical loads for alpine soils and vegetation in the Cascade and Olympic Mountains.

Ozone

Ozone was monitored at Marblemount Ranger Station from 1996-2007. Because concentrations were relatively low, and funding for the site was lost, monitoring was discontinued at that time. Based on 2003-2007 data, the 4th-highest 8-hr ozone concentration at North Cascades NP Complex was 0.054 ppm (54 ppb) and the W126 was 2.0 ppm-hrs, both of which are below the proposed primary and secondary ozone NAAQS of 0.060 ppm (60 ppb) and 7 ppm-hrs, respectively. In 2009, ARD evaluated 1998-2007 ozone data for 161 parks (NPS, 2009). North Cascades was one of only 13 parks with a worsening trend in ozone. The 1996-2007 park data also showed slightly increasing ozone concentrations (Figure 23). Jaffe and Ray (2007) analyzed 1987-2004 ozone data from nine rural and remote sites in the western U.S. and two sites in Alaska; their analysis did not include North Cascades 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.

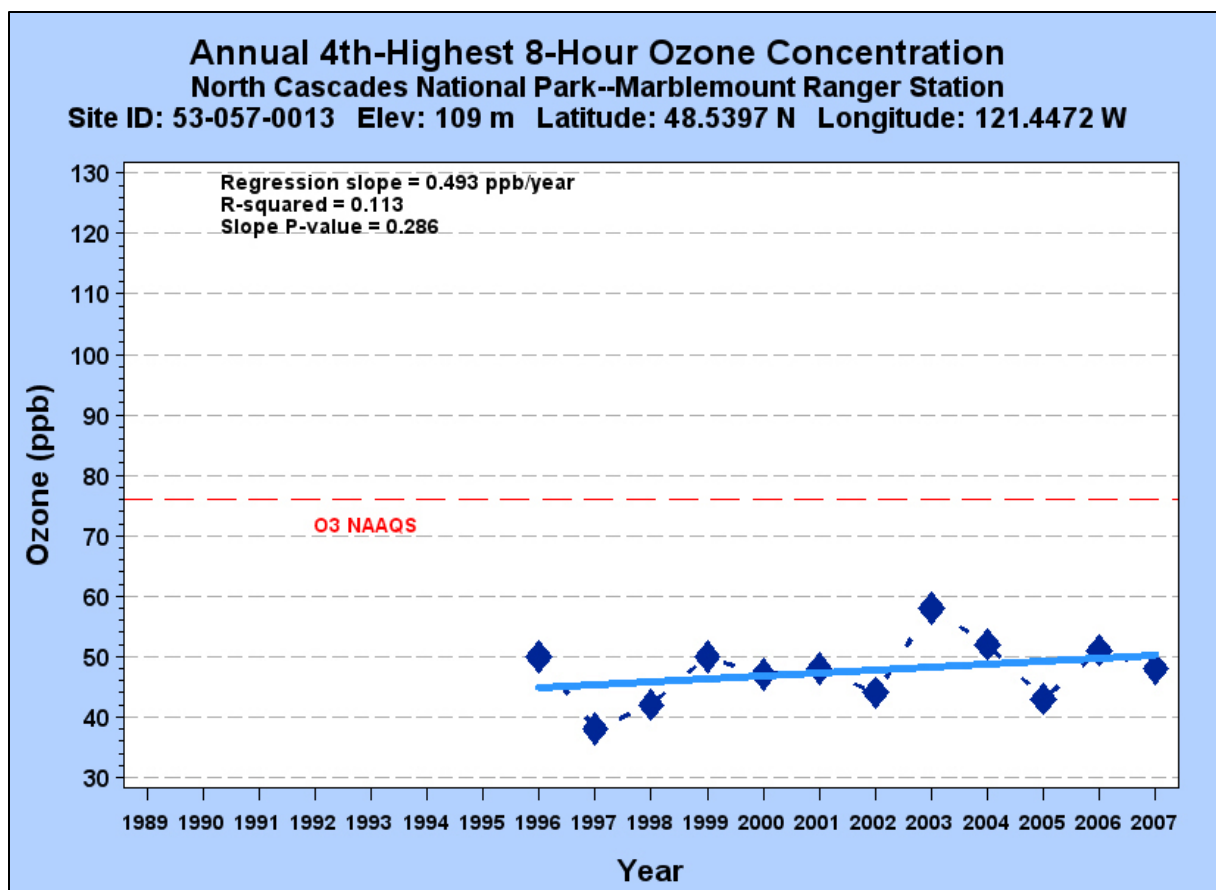


Figure 23. 1996-2007 ozone concentrations at North Cascades NP (produced by NPS ARD, 2012).

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. Kohut (2004) determined a number of species at North Cascades NP are ozone-sensitive (Table 8). However, given the low ozone concentrations, e.g., between 1996 and 1999, W126 values ranged from 0.4-2.1 ppm-hrs, Kohut concluded there was low risk of ozone injury at the park.

Table 9. Ozone-sensitive species at North Cascades NP (from Kohut, 2004).

Latin Name	Common Name	Family
<i>Alnus rubra</i>	Red alder	Betulaceae
<i>Amelanchier alnifolia</i>	Saskatoon serviceberry	Rosaceae
<i>Apocynum androsaemifolium</i>	Spreading dogbane	Apocynaceae
<i>Artemisia douglasiana</i>	Mugwort	Asteraceae
<i>Parthenocissus quinquefolia</i>	Virginia creeper	Vitaceae
<i>Physocarpus capitatus</i>	Ninebark	Rosaceae
<i>Pinus ponderosa</i>	Ponderosa pine	Pinaceae
<i>Populus tremuloides</i>	Quaking aspen	Salicaceae
<i>Rudbeckia laciniata</i>	Cut-leaf coneflower	Asteraceae
<i>Salix scouleriana</i>	Scouler's willow	Saliaceae
<i>Symphoricarpos albus</i>	Common snowberry	Caprifoliaceae

Persistent Bioaccumulative Toxic Compounds

Persistent bioaccumulative toxic compounds include Hg and other heavy metals, current and historic use pesticides, industrial chemicals and by-products of fuel combustion. 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 [$\mu\text{g}/\text{m}^2$]) (Figures 24 and 25). Mercury deposition and concentration values are useful in showing relative amounts of Hg over space or time. There are no national monitoring networks for other PBTs.

While there are a number of MDN monitors in the eastern U.S., coverage in the west is sparse, leading to greater uncertainty of Hg deposition estimates in western parks. There are two MDN sites in Washington, one in Seattle (WA18) that has been operating since 1996, and one at the Makah fish hatchery (WA03), on the northwestern tip of the Olympic Peninsula, that has been operating since 2007. There was a significant decrease in Hg concentration and deposition at WA18 from 1996-2000, possibly because of emission reductions from power plants and other sources in the region; Hg levels have been relatively constant since 2000 (Figure 26; NADP, 2012). Trend data are not yet available for the WA03 site. However, it is unlikely that either site fully represents conditions at North Cascades NP Complex.

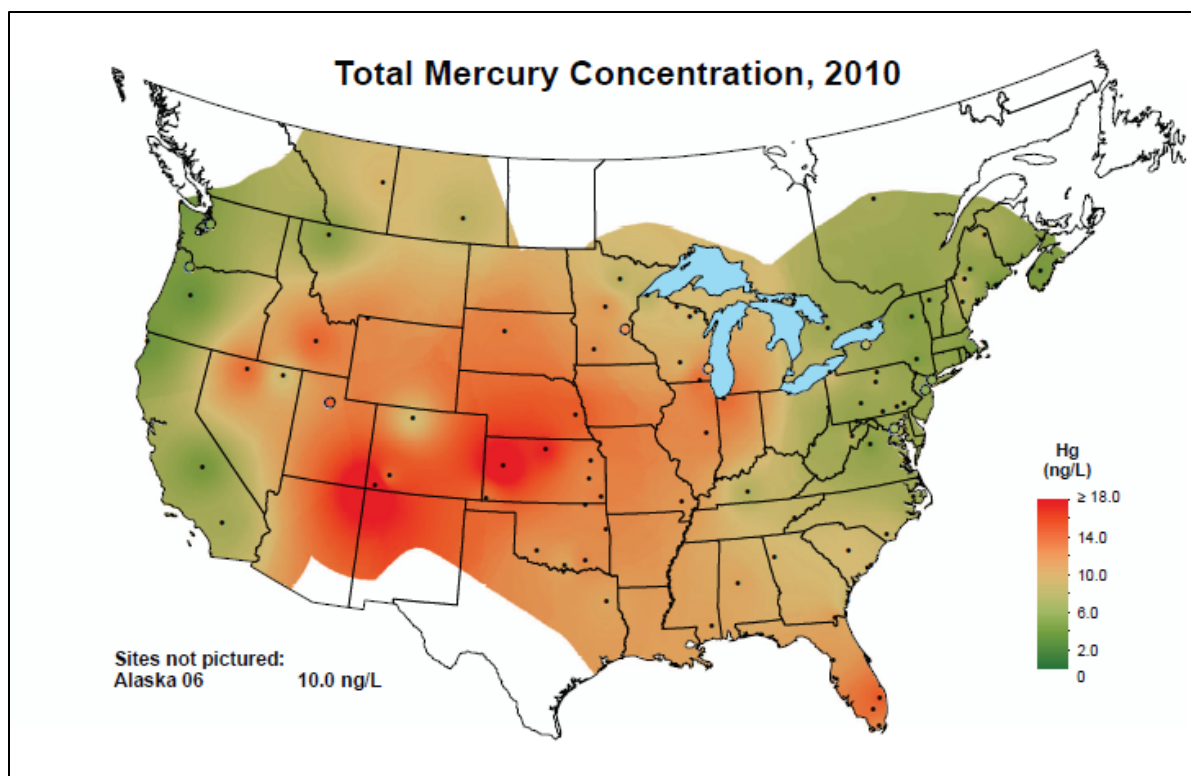


Figure 24. Map of total Hg concentration in precipitation based on 2010 MDN data (from NADP, 2012).

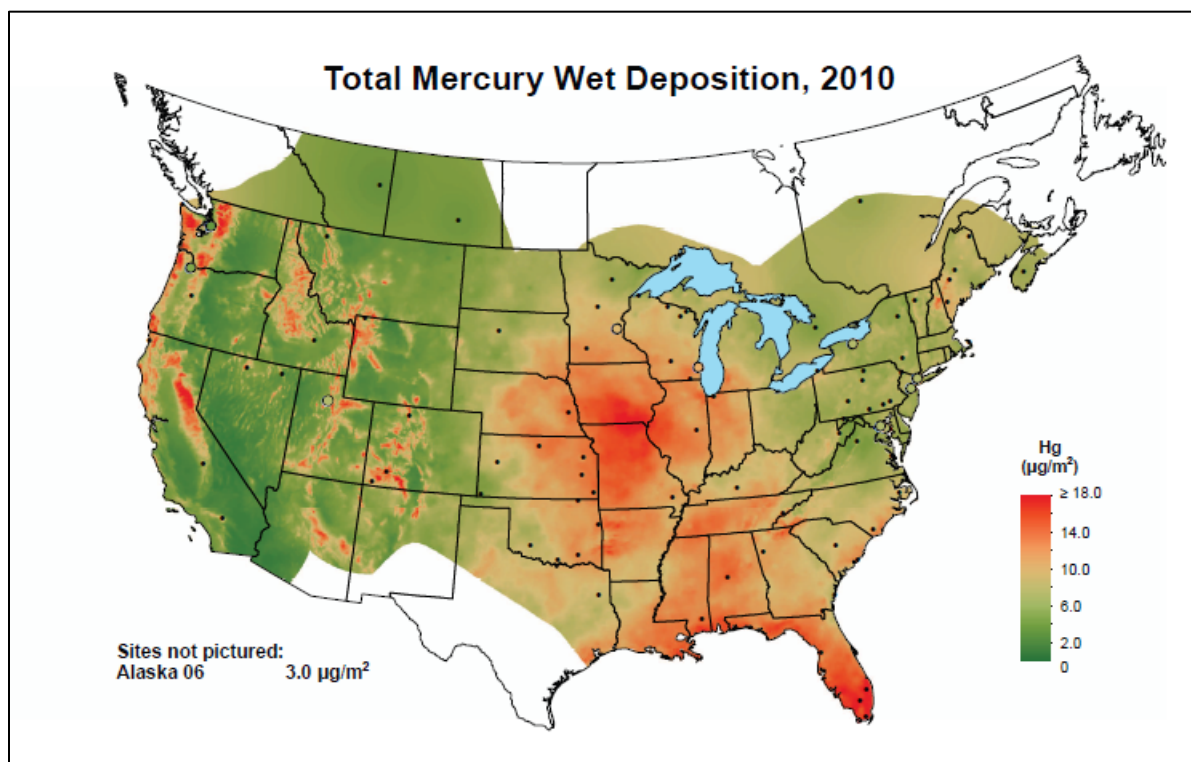


Figure 25. Map of total Hg deposition in precipitation based on 2010 MDN data (from NADP, 2012).

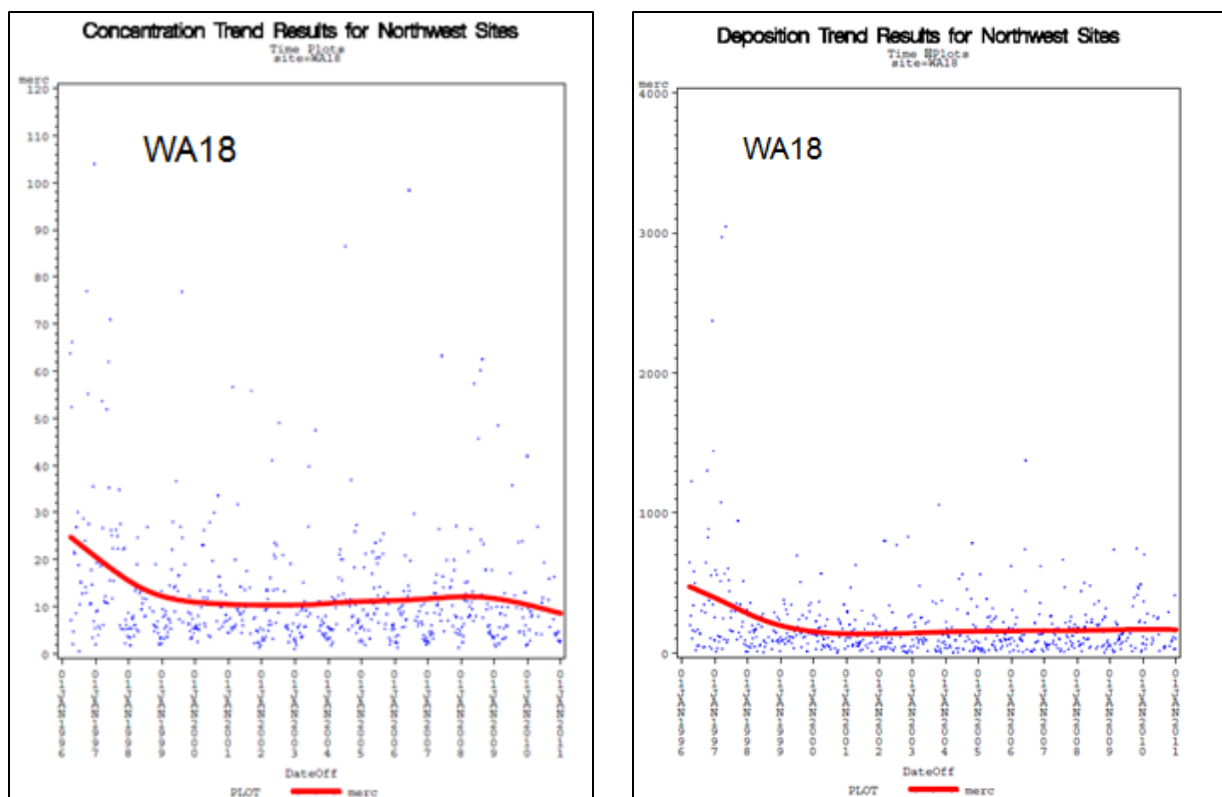


Figure 26. Trends in 1996-2011 annual Hg concentration and deposition at MDN site WA18 in Seattle, Washington (produced by NADP, 2012).

After Hg is deposited, biological processes convert it into toxic MeHg. Certain environmental factors enhance methylation, so it is useful to perform risks assessments to determine where MeHg concentrations are likely to be elevated. An Hg risk assessment is being completed for all I&M parks (Krabbenhoft and Lutz, 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 North Cascades, Olympic and Mount Rainier NPs should have low to moderate concentrations of MeHg (Figure 27). The risk assessment is limited by data availability, and in this case, preliminary results do not reflect elevated Hg levels detected in fish from the parks (see discussion below). Ideally, the final project report will discuss discrepancies between predicted methylation risk and results of Hg studies.

Measuring contaminant concentrations in fish and other wildlife provides a direct assessment of pollutant threats to individuals, populations and multi-species communities. Several studies have investigated PBTs in biota, mostly fish, at North Cascades NP Complex. The EPA has established an Hg guideline of 300 ng/g ww, in fillets, for safe human consumption of fish. This is equivalent to 185 ng/g ww in analyses of whole fish. Based on a literature review, Landers et al. (2008) reported thresholds for piscivorous wildlife for a limited number of pollutants (Table 10). The thresholds are based on sublethal effects on health, growth and reproduction.

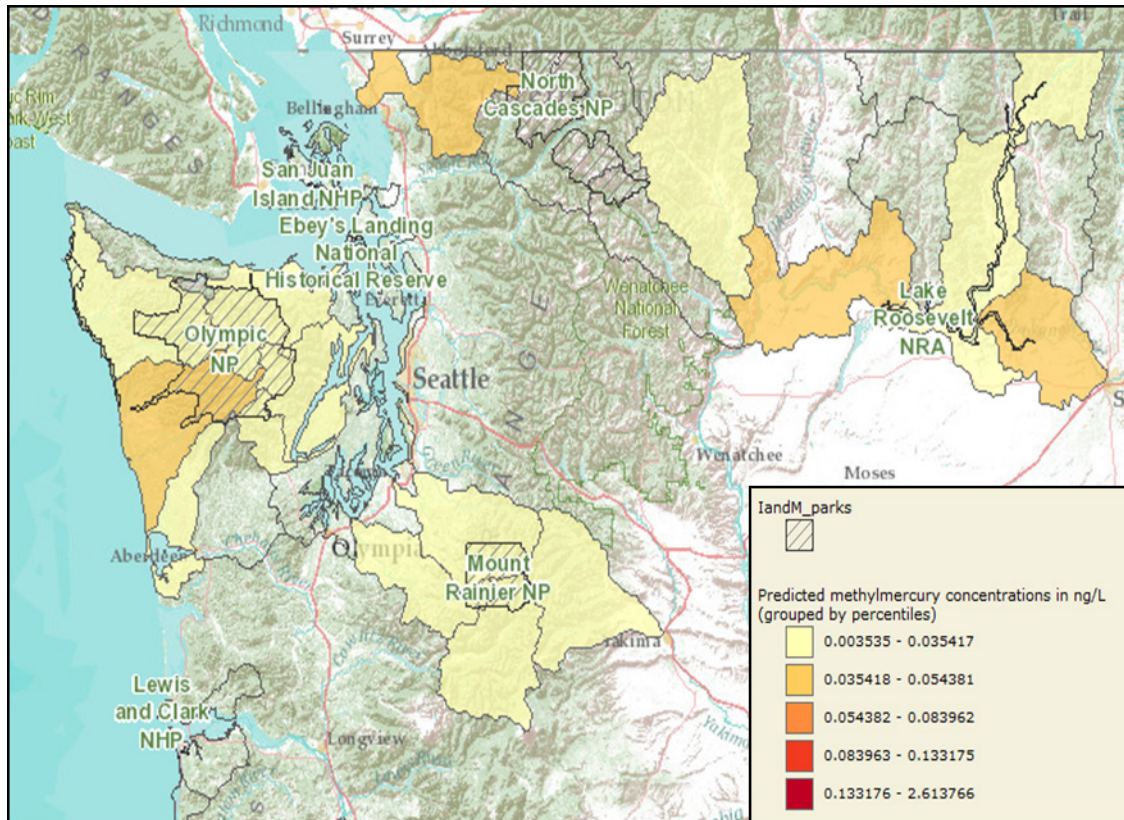


Figure 27. Predicted methylmercury concentrations, in ng/L, in watersheds in and near North Cascades, Olympic and Mount Rainier NPs (from Krabbenhoft and Lutz, in preparation).

Table 10. Fish contaminant health thresholds for piscivorous wildlife (in ng/g ww). Data from Landers et al. (2008).

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

Washington Department of Ecology sampled fish in Lake Chelan in 1992 (Davis and Johnson, 1994) and 1994 (Davis and Serdar, 1996) as part of a statewide monitoring program. Samples were screened for a total of 43 pesticides and other analytes, twelve of which were found in fish from Lake Chelan. Concentrations of total dichlorodiphenyltrichloroethanes (DDT), a class of chlorinated pesticides, and total polychlorinated biphenyls (PCB), a class of industrial contaminants, exceeded human health screening values. Total DDT concentrations in fish from Lake Chelan ranged from 56-397 ng/g ww compared to WDOE's screening value of 32 ng/g ww. Concentrations of total PCBs ranged from 16-99 ng/g ww compared to a screening value of 1.4 ng/g ww. As a result, WDOE added Lake Chelan to the state's 1996 list of impaired water bodies.

In 2008, WDOE developed a Water Quality Implementation Plan, also called a water clean-up plan or Total Maximum Daily Load (TMDL), for Lake Chelan to reduce concentrations of these pollutants in fish tissue to acceptable levels (Anderson and Peterschmidt, 2008). Because both DDTs and PCBs are legacy pollutants, i.e., their use was banned in the U.S. in 1972 and 1978, respectively, WDOE concluded high concentrations in fish were due to the chemicals persisting in lake sediments and upland soil. The TMDL's clean-up actions included removing remaining sources of DDTs and PCBs, such as old dump sites and caches of unused pesticides; reducing erosion on agricultural lands; and allowing time for the natural breakdown of the pollutants. The goal of the TMDL is to meet DDT and PCB water quality standards by 2055. The TMDL also called for monitoring of contaminants in fish from Lake Chelan at regular intervals, with the next round of monitoring due in 2013. After reviewing the TMDL results, Washington State Department of Health (WSDOH) issued a fish consumption advisory for Lake Chelan (WSDOH, 2010). The advisory recommended restricting meals of lake trout (*Salvelinus namaycush*) because of high DDT and also included Lake Chelan in a statewide Hg advisory for smallmouth bass (*Micropterus dolomieu*), largemouth bass (*Micropterus salmoides*) and northern pike minnow (*Ptychocheilus oregonensis*).

In 2003, fish were collected from Lake Chelan as part of a national EPA study of pollutants in fish (USEPA, 2009). Fish collected from 500 lakes in the lower 48 states over a four-year period were analyzed for 268 pollutants, including Hg and numerous pesticides. Elevated levels of Hg, PCBs and several pesticides were detected in fish from Lake Chelan. In 2005, WDOE collected fish from 36 lakes and rivers in Washington, including Lake Chelan, and tested them for polybrominated diphenyl ether (PBDE) flame retardants (Johnson et al., 2006). Fish from Lake Chelan had very low concentrations of PBDEs.

In 2002-2003, Moran et al. (2007) collected cutthroat trout (*Oncorhynchus clarki*) from five lakes in North Cascades NP Complex, five lakes in Olympic NP and four lakes in Mount Rainier NP. The lakes at North Cascades NP were Copper, Dee Dee, Green, Skymo and Upper Wilcox. Mercury was detected in trout from all lakes sampled, with the highest tissue Hg concentration, 262 ng/g ww, in a fish from Green Lake in North Cascades NP (Figure 27). The concentration was significantly greater than the health thresholds described by Landers et al. (2008) for piscivorous wildlife and human anglers. At North Cascades NP, only fish from Skymo Lake had Hg concentrations lower than 30 ng/g ww, the health threshold for kingfishers. 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 (Moran et al., 2007). The authors speculated tissue Hg concentrations could affect gene expression in fish. Moran et al. also detected low concentrations of two persistent organic pollutants in fish from all sampled lakes in North Cascades and Mount Rainier NPs (Figure 28).

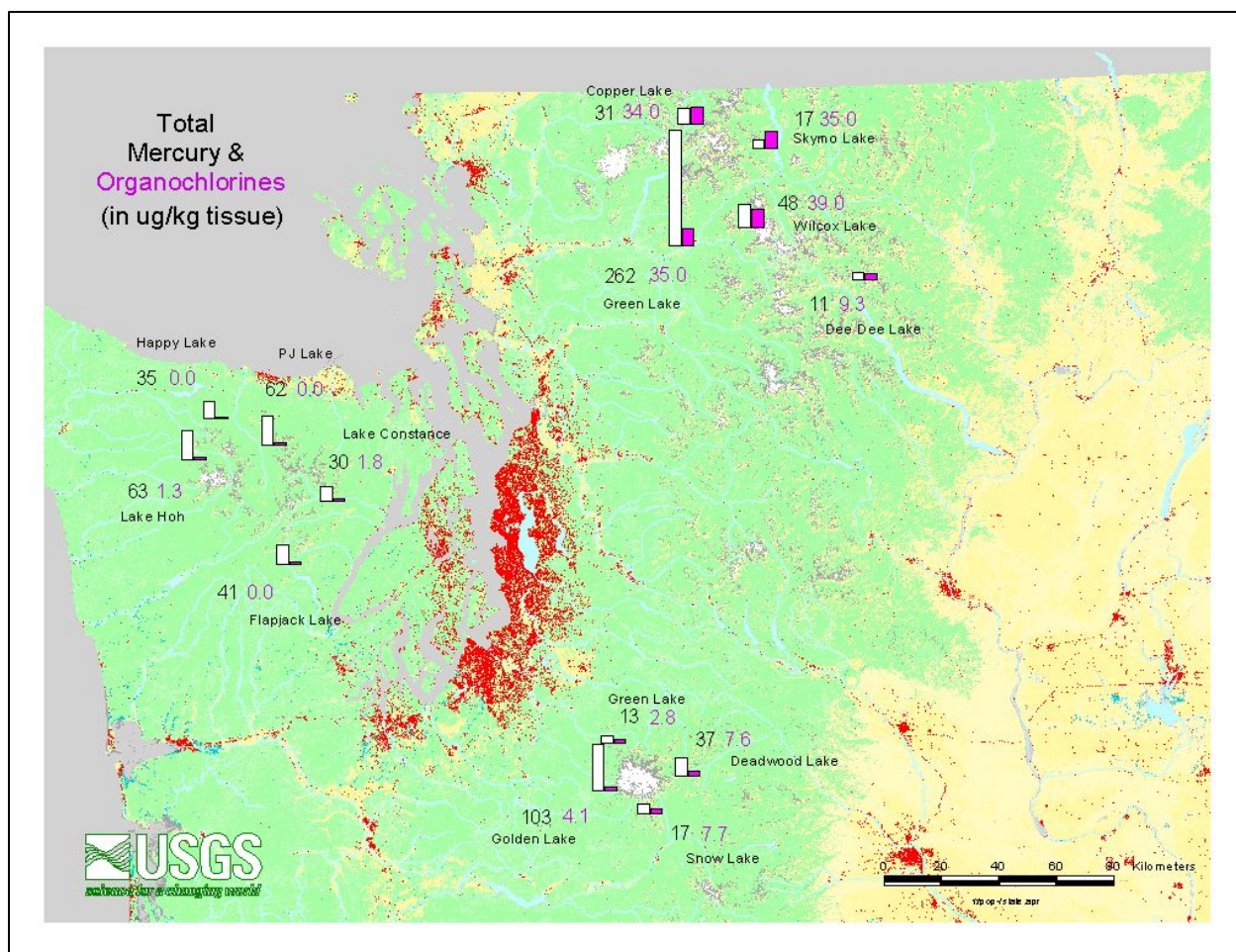


Figure 28. Concentrations of Hg and organochlorines, in micrograms per kilogram ($\mu\text{g/kg}$; equivalent to ng/g ww), in fish collected from lakes at North Cascades, Mount Rainier and Olympic NPs (from USGS, date unknown).

Also in 2002, the NPS spearheaded a multi-agency study called the Western Airborne Contaminants Assessment Project (WACAP) to determine the risk from airborne contaminants to ecosystems and food webs in 20 national parks in the western U.S., including North Cascades NP (Figure 29; Landers et al., 2008). In 2005, the authors used passive air sampling devices, and snow, conifer needle and lichen samples, to assess PBTs in the Thornton Creek watershed at North Cascades NP. A number of PBTs typically associated with agriculture, fuel combustion and industry were detected in vegetation samples from the park (Figure 30). The vegetation samples were collected along an elevational transect. Analysis of the WACAP lichen data combined for all parks indicated concentrations of PCBs and several pesticides increased with elevation, while concentrations of polycyclic aromatic hydrocarbons (PAH), which are combustion by-products, decreased with elevation.



Figure 29. Map of parks included in the WACAP study (from Landers et al., 2008).

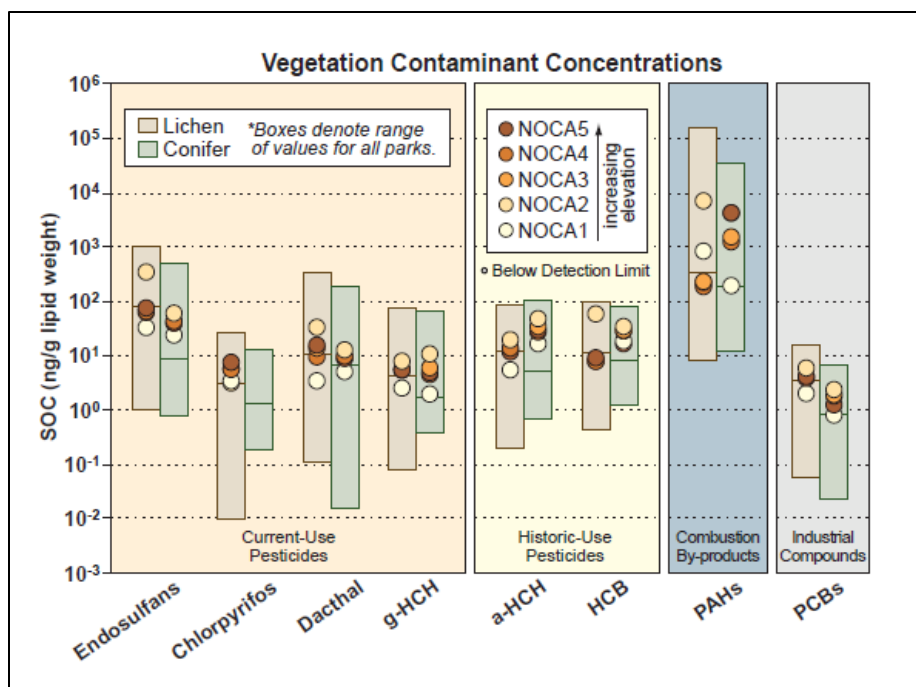


Figure 30. Concentrations of PBTs in vegetation collected from five sites (NOCA1-NOCA5) along an elevational gradient in the Thornton Creek watershed at North Cascades NP in 2005 as part of the WACAP study (from Landers et al., 2008). Horizontal lines in boxes indicate median values.

In a follow-up to the WACAP study, Simonich et al. (2012) collected snowpack samples at North Cascades, Olympic and Mount Rainier NPs in 2005-2007 for additional analysis of contaminants. In North Cascades and Mount Rainier NPs, the study focused on 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. Data from Mount Rainier NP also showed an elevational gradient in contaminant deposition. In Olympic NP, the study looked at 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.

Washington Department of Ecology collected fish from Ross Lake and 15 other Washington lakes in 2007 (Seiders and Deligeannis, 2009). The fish were tested for a number of pollutants including Hg, pesticides, PCBs and PBDEs. While some contaminants were detected in fish from Ross Lake, the levels did not exceed state water quality standards for fish consumption.

Schreck and Kent (2013) analyzed fish collected in 2008-2009 from North Cascades and ten other western parks to study the occurrence of intersex (i.e., both male and female reproductive structures in an individual) in fish with elevated PBT concentrations. Sampled lakes included Berdeen, Diobsud, Middle Blum, Upper Triplet and Upper Wilcox at North Cascades NP Complex. None of the 57 male fish from the park were intersex. While some of the 59 female fish collected in the park had signs of male cells in their ovaries, the authors concluded those were likely false positives due to sample contamination.

North Cascades NP is involved in several current efforts to evaluate the extent of Hg contamination in national parks. In 2011 and 2012, Dr. Collin Eagles-Smith, USGS, analyzed Hg concentrations in fish from lakes spanning more than 20 western national parks (Figure 31). Frozen fish samples collected in 2008-2009 from Middle Blum and Upper Wilcox Lakes at North Cascades NP were included in the analysis. The park recently entered into a cooperative effort with WSDOH to analyze Hg in fish from three park lakes each year (D. McBride, WSDOH, personal communication). In 2012, fish were collected from Ross, Lower Thornton and Battalion Lakes. Also in 2012, North Cascades NP was part of a citizen-science effort led by the University of Maine to collect dragonfly larvae for Hg analysis. Four eastern national parks were involved in the project in 2011; ten additional parks participated in 2012 (Figure 32). North Cascades NP will again participate in the dragonfly study in 2013. Reports for the USGS and University of Maine projects will be available in late 2013.

Finally, 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 methylmercury production, bioaccumulation, and risk across the western U.S., Canada and Mexico (Figure 33). 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 in many national parks such as North Cascades NP Complex.

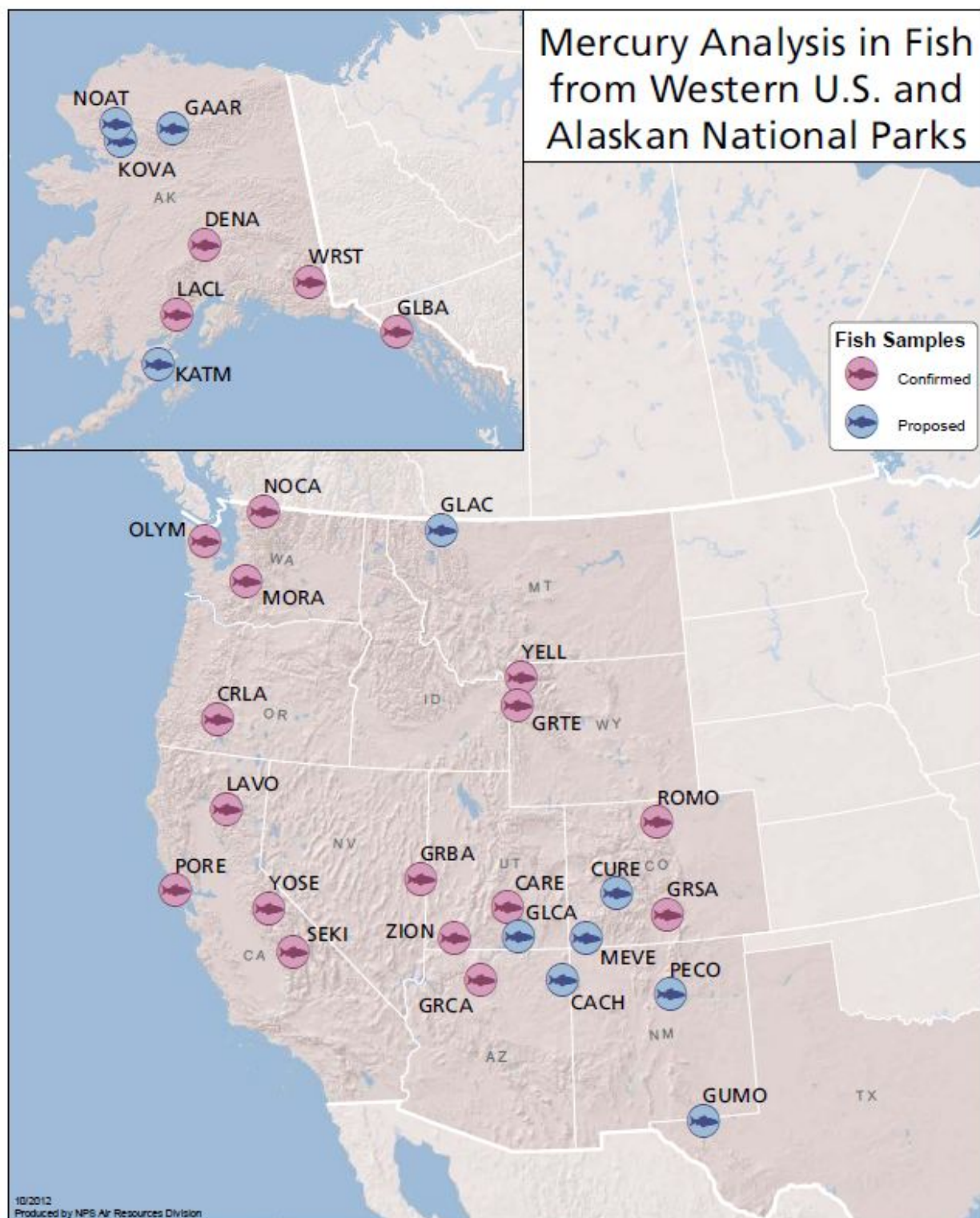


Figure 31. Map of parks with fish Hg concentrations analyzed by the USGS in 2011-2012 (produced by NPS ARD, 2012).

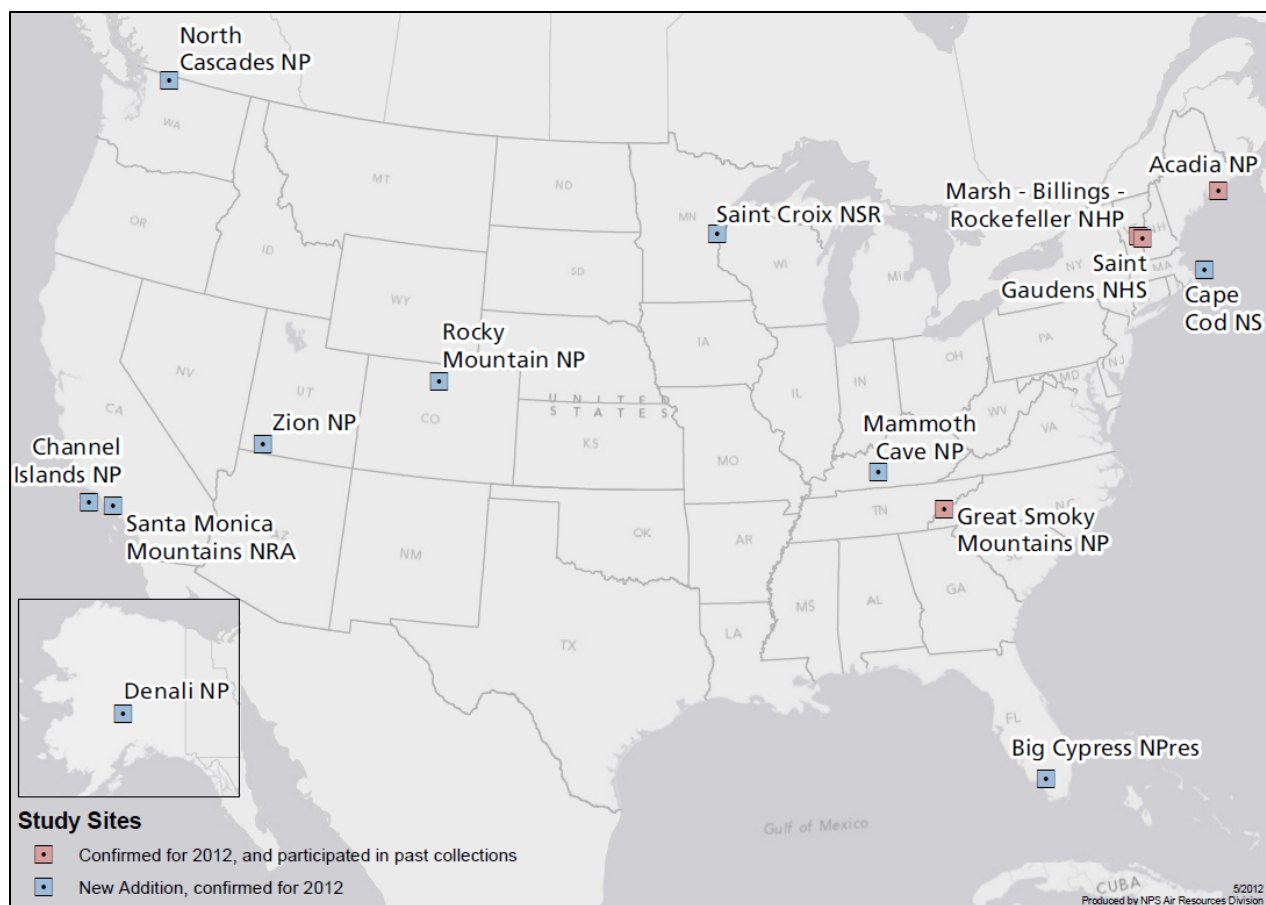


Figure 32. Map of parks that collected dragonfly larvae for Hg analysis in 2012 (produced by NPS ARD, 2012).

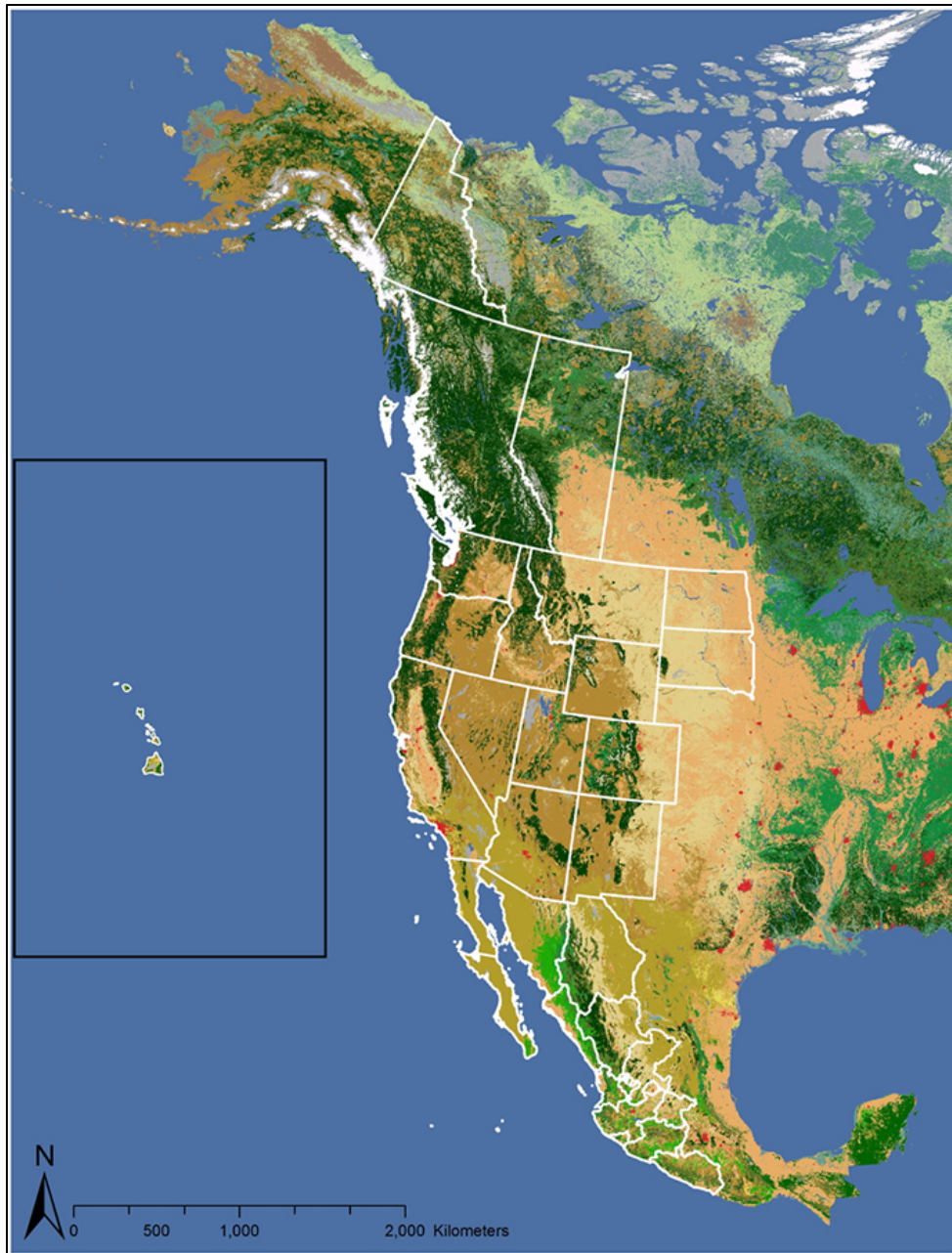


Figure 33. Map showing geographic area of the Western North America Mercury Synthesis (Biodiversity Research Institute, 2012).

Conclusions

North Cascades NP is a Class I area and is, therefore, afforded the highest degree of air quality protection under the Clean Air Act. All units in North Cascades NP Complex including Ross Lake and Lake Chelan NRAs are provided air quality protection by the NPS Organic Act and management policies. The park is vulnerable to air pollution from nearby urban and agricultural areas, as well as to pollution from regional and even global sources. Since 1984, the NPS and others have monitored air quality and studied pollutant effects on park resources. Park air quality is in compliance with all the NAAQS. Nevertheless, park resources have been affected by air pollution.

Current average visibility at North Cascades NP is about 34 percent hazier than natural conditions with no significant improvement or degradation in visibility from 2000-2009. Currently, 44-57 percent of the haze at the park is due to SO₄. Under natural conditions, the contribution to visibility impairment from SO₄ would be less than 25 percent.

Wet NO₃ deposition decreased significantly at the park from 2000-2009. There was also a decrease in wet NH₄ deposition, although the change was not statistically significant. There was no trend in wet SO₄ deposition from 2000-2009 but longer-term data (1987-2009) indicate a decrease in wet SO₄ concentration and deposition. Most of the N and S deposited in the park is in the form of wet deposition.

Sensitive park ecosystems are considered at high risk for both acidification and N enrichment. Although surface water acidification has not been documented in the park, research indicates 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 lichen N critical loads have not been exceeded at North Cascades NP Complex. Efforts are underway to define N critical loads for other ecosystem components.

Ozone concentrations are below levels thought to be harmful to human health or vegetation; however, ozone concentrations increased slightly from 1996 until monitoring was discontinued in 2007. Elevated concentrations of Hg and other PBTs have been detected in the park, with Hg levels in some fish exceeding wildlife or human health thresholds. Ongoing studies are investigating the extent of Hg contamination.

Continued monitoring and research are critical for assessing trends in air quality and improving understanding of air pollution effects on sensitive 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 NADP wet deposition monitoring in the park. The long term dataset provides valuable information about deposition trends both within the park and nationally when combined with data from other NADP sites across the country. In addition, the NPS

should continue to support efforts by NADP and others to improve estimates of total N and S deposition.

- It is a high priority to support research that leads to identification of N critical loads for numerous ecosystem components and processes. In particular, critical loads information is needed for aquatic ecosystems.
- Because ozone concentrations increased slightly from 1996 until monitoring was discontinued in 2007, it would be prudent to re-visit ozone monitoring in the park. Operating a portable monitor for a couple of ozone seasons would be a cost-effective way to determine if more intensive monitoring is warranted.
- More information is needed about the occurrence and extent of PBTs and their effects on park biota. Also, because wildlife health thresholds are known for only a handful of air toxics, NPS should support studies that determine thresholds for additional pollutants that have been found in the park. The NPS should work with regulatory agencies and others to identify and minimize sources of PBTs.
- The NPS should encourage research that investigates the interactions between air quality and climate change, e.g., the effect of black carbon (soot) on snowpack and glacial melting.

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