National Park Service
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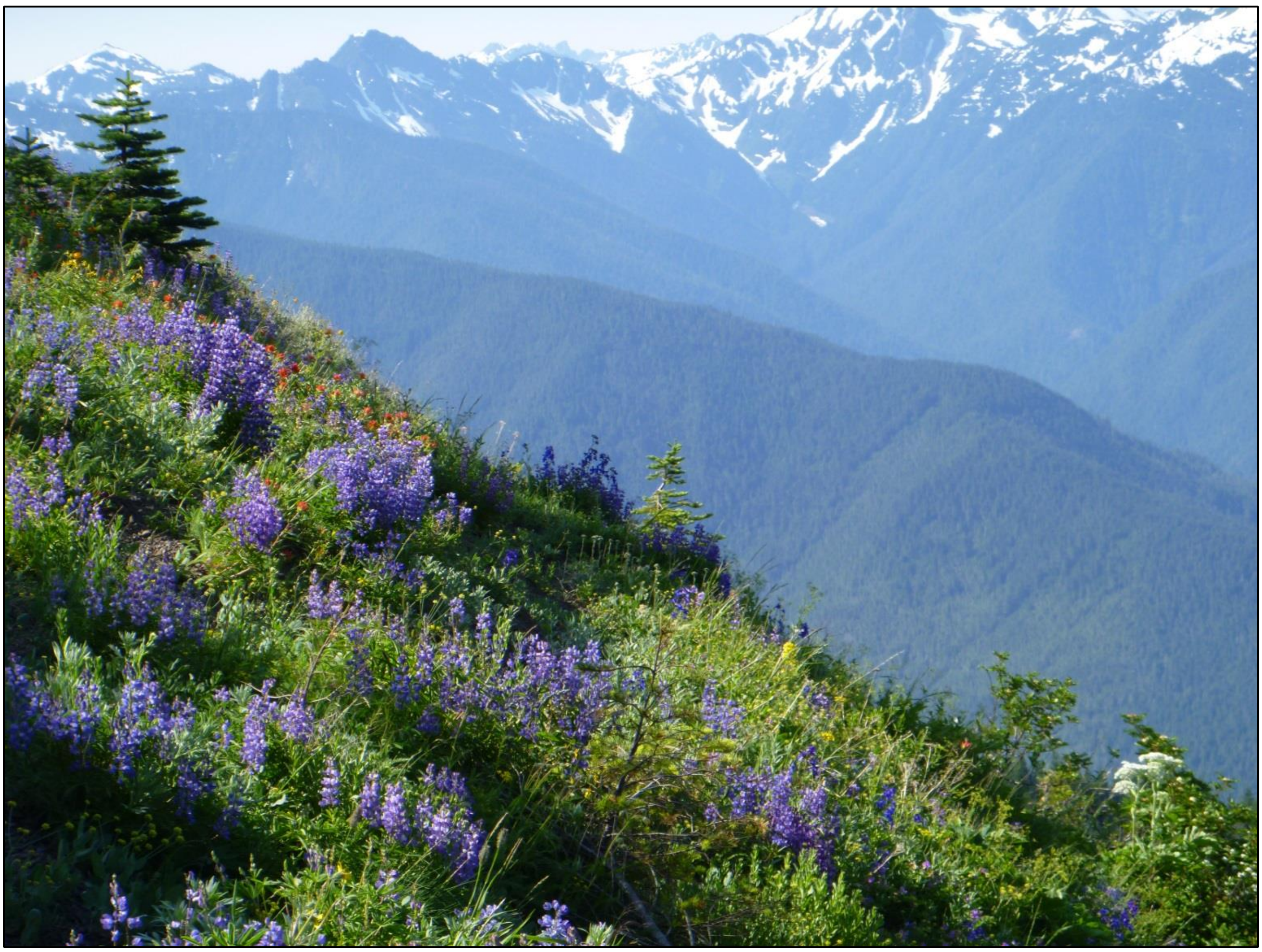
Natural Resource Stewardship and Science

Air Quality Overview

Olympic National Park

Natural Resource Report NPS/PWRO/NRR—2013/696



ON THIS PAGE
Clockwise: 1) nitrogen throughfall samplers at the Hoh Rainforest; 2) sampling winter snowpack; 3) bulk snow collector and portable ozone monitor at Hurricane Ridge; and 4) sediment sampling at Milk Lake
Photographs by: Bill Baccus & John Warrick

ON THE COVER
View from Hurricane Ridge
Photograph by: Tonnie Cummings

Air Quality Overview

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

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This report received formal peer review by subject-matter experts who were not directly involved in the collection, analysis, or reporting of the data, and whose background and expertise put them on par technically and scientifically with the authors of the information.

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Abstract

Olympic National Park, located in Northwest 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 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 1980. 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 Olympic National Park.

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 Olympic National Park is about 48 percent hazier than natural conditions. 2000-2009 data indicate a statistically significant improvement in visibility on the clearest and average days and a slight improvement on the haziest days. Currently, 36-47 percent of 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 19 percent.

There were no trends in nitrate, ammonium or sulfur concentrations in precipitation from 2000-2009. 1989-2008 data indicated a significant decrease in wet ammonium concentrations. About 25 percent of the nitrogen, and about 20 percent of the sulfur, is in the form of dry deposition at Olympic National Park.

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 Olympic National Park 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 higher average and cumulative ozone values generally occurring at higher elevations. Ozone concentrations have not reached levels known to harm human health or vegetation.

Elevated concentrations of toxic air pollutants have been detected in snowpack, vegetation, fish and sediment samples from the park. Concentrations of some pollutants, such as mercury in fish, exceeded wildlife and human health thresholds. Ongoing studies are investigating the extent of mercury contamination.

Acknowledgments

Many thanks to D. Bingham for preparing several figures for this report and to K. Pugacheva for help with formatting. My deep appreciation to B. Baccus for his insightful comments on, and contributions to, this report. Thanks, too, to T. Blett, K. Morris, E. Porter and R. Rochefort for their valuable peer review comments.

Acronyms

$\mu g/m^3$	micrograms per cubic meter
AQRV	air quality related value
ARD	Air Resources Division
CASTNET	Clean Air Status and Trends Network
dv	deciview
EPA	Environmental Protection Agency
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
km	kilometer
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
NDAMN	National Dioxin Air Monitoring Network
ng/g ww	nanograms per gram wet weight

ng/L	nanograms per Liter
NH_3	ammonia
NH_4	ammonium
NH_4NO_3	ammonium nitrate
NH_4SO_4	ammonium sulfate
NO_3	nitrate
NO_x	nitrogen oxide
NP	National Park
NPS	National Park Service
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
S	sulfur
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. 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 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 Olympic National Park (NP; Eilers et al., 1994). Since that time, substantial monitoring and research have greatly improved our 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 Olympic NP. 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 in 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 95 percent of Olympic NP, 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.). Olympic NP is one of the NPS's 48 Class I areas; all 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. The Clean Air Act sets 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 and forestry practices, land disturbance, prescribed fire and fossil fuel combustion. Olympic NP is located near Seattle, Washington; cities in British Columbia; 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, and persistent bioaccumulative toxic (PBT) compounds (e.g., mercury [Hg] and pesticides).

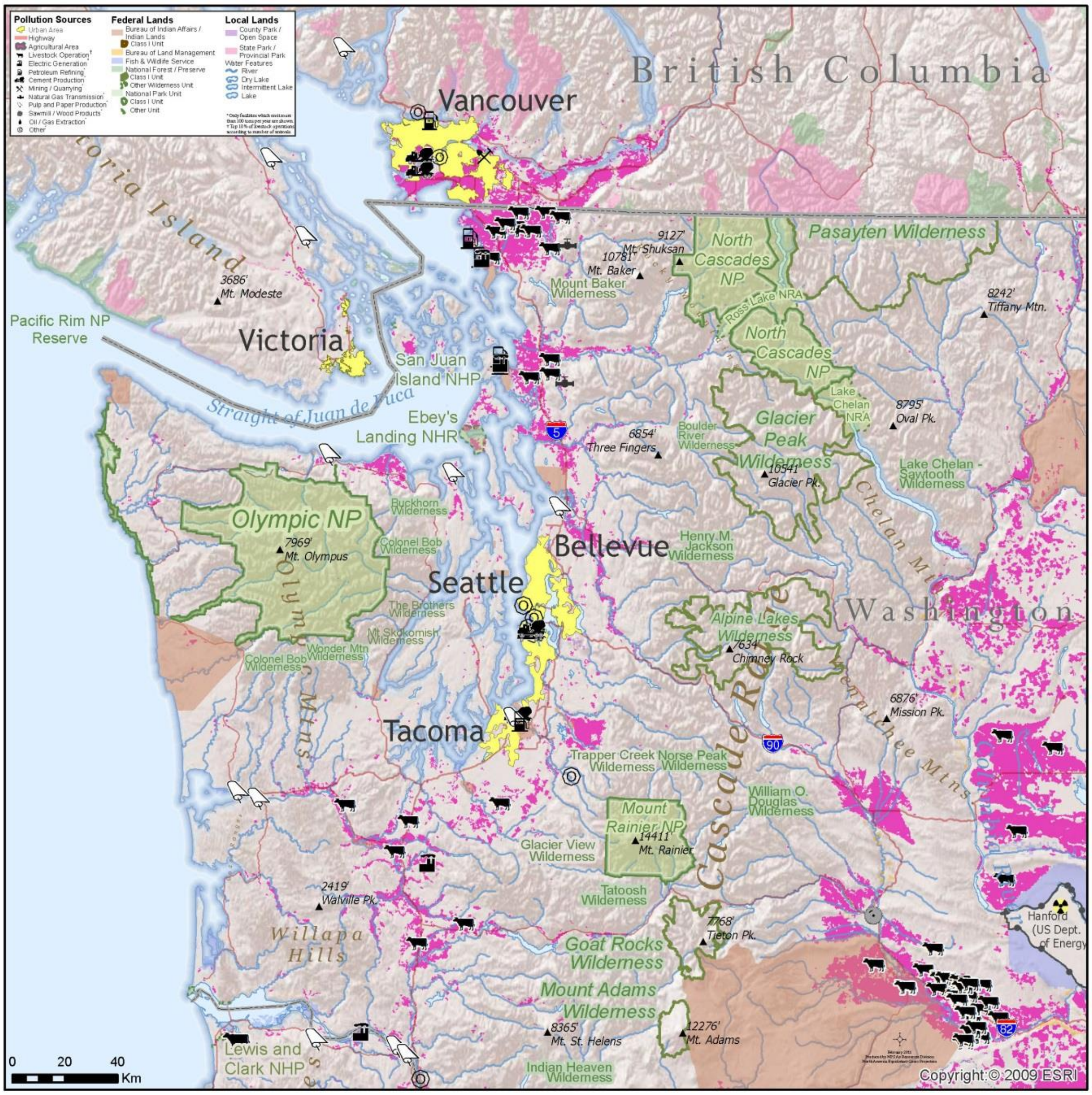

Figure 1. Pollution sources near Olympic NP (produced by NPS ARD, 2010).

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 ($PM_{2.5}$). 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, and road construction, log hauling and pile burning associated with logging. 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 approximately 100 kilometers (km) of the park that emitted more than 100 tons per year (TPY) of a single pollutant included refineries, aluminum smelters, paper mills and industrial facilities (Table 1; WDOE, 2012). TransAlta's coal-fired Centralia Power Plant, located 100 km southeast of Olympic NP, 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, there are no large point sources in Canada within 100 km of Olympic NP (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 Olympic NP (i.e., Clallam, Grays Harbor, Island, Jefferson, Kitsap and Mason), the top three sources of area emissions were marine vessels, on-road vehicles and woodstoves/fireplaces (Table 2).

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), almost six million pounds of toxic air pollutants were emitted by reporting facilities within approximately 100 km of Olympic NP (Table 3); twelve toxic chemicals were released to the air in amounts exceeding 100,000 pounds per year (lb/yr; Table 4). 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 Olympic 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) lists point sources that emit more than 10 lb/yr of Hg within approximately 100 km of the park (Table 5). In 2010, there were no large Hg sources in Canada within 100 km of Olympic NP (Environment Canada, 2012). 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).

Table 1. Emissions (in TPY), in 2005, from large point sources in Washington within approximately 100 km of Olympic NP.

Facility	Location	PM_{10}	$PM_{2.5}$	SO_2	NO_x	VOC
Alcoa Intalco Works	Ferndale	130	61	1,738	105	36
Ash Grove Cement	Seattle	51	39	34	1,581	6
Ball Metal Container	Kent	0	0	0	0	153
Boeing	Everett	0	0	0	67	231
Conoco Phillips Refinery	Ferndale	100	94	494	1,139	776
Crown Cork and Seal	Olympia	0	0	0	2	159
General Chemical	Anacortes	0	0	128	12	0
Graymont Western US	Tacoma	143	37	37	196	0
Grays Harbor Paper	Hoquiam	233	209	8	362	13
K Ply	Port Angeles	46	46	4	38	38
Kenworth Truck Company	Renton	0	0	0	7	137
Kimberly-Clark	Everett	37	36	360	767	283
Lafarge North America	Seattle	143	76	316	2,682	2
Lasco Bathware	Yelm	0	0	0	3	214
March Point Cogeneration	Anacortes	6	6	18	243	19
Moulding & Millwork	Monroe	0	0	0	0	162
Nippon Paper Industries	Port Angeles	119	108	316	222	15
Nucor Steel	Seattle	0	0	76	209	53
Olympic Panel Products	Shelton	39	24	0	0	143
Port Townsend Paper	Port Townsend	333	278	410	581	72
Premier Industries	Kent	0	0	0	0	129
Puget Sound Naval Shipyard	Bremerton	121	84	0	40	151
Puget Sound Refinery	Anacortes	212	202	4,052	1,295	578
Rexam Beverage Can	Kent	0	0	0	4	143
Saint-Gobain Containers	Seattle	90	82	183	329	46
Seattle Steam Company	Seattle	3	0	18	259	1
Sierra Pacific Cogeneration	Aberdeen	3	3	38	117	2
Simpson Tacoma Kraft	Tacoma	103	93	378	610	35
Simpson Timber	Shelton	58	106	0	72	78
Tesoro Refinery	Anacortes	652	62	5,575	2,257	1,457
TransAlta Centralia	Centralia	1,497	1,000	3,378	17,152	31
TransAlta Centralia Mining	Centralia	865	160	10	83	9
US Oil and Refining	Tacoma	8	0	9	108	130
Weyerhaeuser	Cosmopolis	313	313	286	341	29

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

Pollutant	WS/FP[1]	ROAD[2]	SHIP[3]	FIRE[4]	NRM[5]	ORM[6]	LIVE[7]	FERT[8]
PM_{10}	1,456	1,923	772					
$PM_{2.5}$	1,455		631	594				
SO_2			7,529		232	191		
NO_x			12,179		2,075	9,833		
VOC	3,847				3,644	7,704		
NH_3						383	1,236	186

[1]WS/FP = woodstoves/fireplaces
[2]ROAD = road dust
[3]SHIP = recreational boats and commercial marine vessels
[4]FIRE = wildfires
[5]NRM = land-based, non-road mobile sources (e.g., forklifts, tractors and snowmobiles)
[6]ORM = on-road mobile sources
[7]LIVE = livestock
[8]FERT = fertilizer application

Table 3. Toxic annual air emissions (in lb/yr), in 2004, by reporting facilities within approximately 100 km of Olympic NP.

County	Number of Facilities	Number of Chemicals	Emissions
Clallam	2	3	14,056
Grays Harbor	6	10	225,098
Island	0	0	0
Jefferson	1	11	523,672
Kitsap	0	0	0
King	54	32	661,544
Lewis	11	24	358,296
Mason	2	3	17,530
Pierce	25	43	962,695
San Juan	0	0	0
Skagit	6	33	990,568
Snohomish	16	28	673,379
Thurston	3	3	704,284
Whatcom	11	38	610,420
Total	137	N/A[1]	5,741,542

[1]Several chemicals were emitted in multiple counties

Table 4. Toxic chemicals with air emissions greater than 100,000 lb/yr, in 2004, by reporting facilities within approximately 100 km of Olympic NP.

Chemical	Emissions	Types of Facilities
Acetaldehyde	124,787	Paper/lumber mills
Ammonia	226,781	Paper/lumber mills, refineries, coal mining/burning
Carbonyl Sulfide	191,180	Aluminum manufacturing/smelting
Glycol Ethers	337,669	Beverage container manufacturing, paint/solvent use
Hydrochloric Acid	564,331	Paper/lumber mills, refineries, coal mining/burning
Hydrogen Fluoride	178,629	Aluminum manufacturing, brick manufacturing
Methanol	800,837	Paper/lumber mills, chemical manufacturing
N-Butyl Alcohol	359,501	Beverage container manufacturing
Styrene	880,367	Shipyards, fiberglass manufacturing
Sulfuric Acid	919,830	Paper/lumber mills, refineries
Toluene	147,773	Paint/solvent use, refineries
Xylene	151,542	Shipyards, fiberglass manufacturing, refineries

Table 5. Mercury emissions (in lb/yr), in 2004, from point sources that emit more than 10 lb/yr of Hg within approximately 100 km of Olympic NP.

Facility	Location	Hg
Ash Grove Cement	Seattle	40
LaFarge North America	Seattle	67
NuCor Steel	Seattle	63
Puget Sound Refinery	Anacortes	11
Simpson Tacoma Kraft	Tacoma	17
Tesoro Refinery	Anacortes	42
TransAlta Centralia	Centralia	107

Air Pollution Effects

This section provides a general overview of the effects of air pollution. Results from monitoring and research conducted at Olympic NP 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 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 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 may also be particularly 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, $PM_{2.5}$, PM_{10} and SO_2 (Table 6). Primary standards are intended to protect public health; secondary standards are intended to protect public welfare, including AQRVs. According to monitoring data, Olympic 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 and secondary	Annual	15 $\mu g/m^3$	annual mean, averaged over 3 years
			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 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 NO_3, NH_4 and SO_4. 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'' (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 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 Olympic NP

A great deal of air quality and AQRV monitoring and research has taken place at Olympic NP (Figure 2 and Table 7).

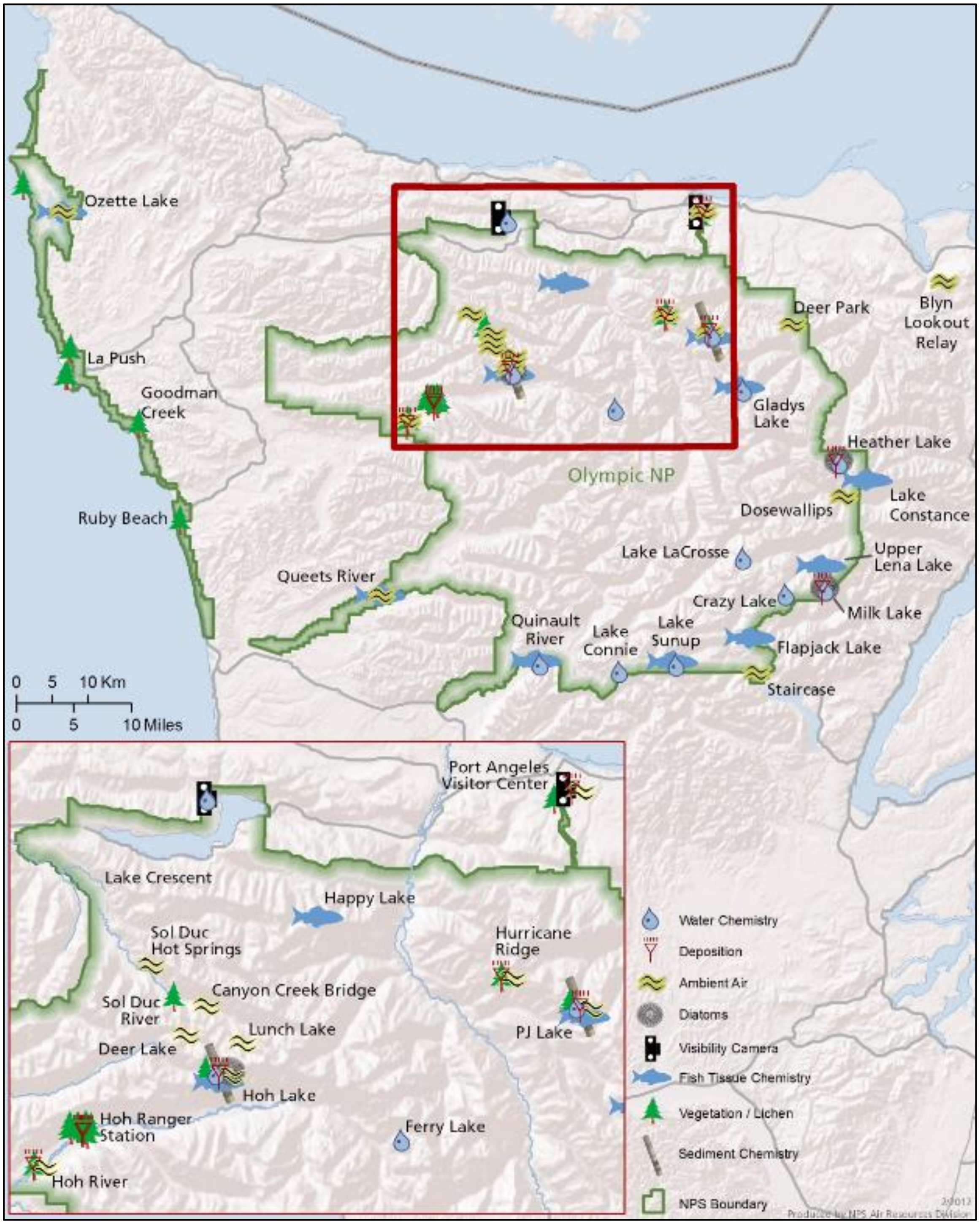

Figure 2. Locations of air quality and AQRV monitoring and research at Olympic NP (produced by NPS ARD, 2012).

Table 7. Air Quality and AQRV Monitoring and Research at Olympic NP

Parameter	Location	Investigator	Research (R)/ Monitoring (M)	Dates
Ambient Air				
35-mm camera	Port Angeles Visitor Center	NPS	M	1980 - 1991
35-mm camera	Lake Crescent	NPS	M	1985 - 1991
Digital web camera	Lake Crescent	NPS	M	2003 - present
Dioxin	Ozette Lake	NDAMN[1]	M	1999 - 2004
IMPROVE[2] - particles	Blyn Lookout Relay	NPS	M	2001 - present
Ozone - continuous	Blyn Lookout Relay	NPS	M	2005
Ozone - passive	Canyon Creek Bridge	NPS	M	1996
Ozone - passive	Deer Lake	NPS	M	1996
Ozone - passive	Deer Park	NPS	M	1995 - 1999
Ozone - portable	Deer Park	NPS	M	2009 - 2011
Ozone - passive	Dosewallips	NPS	M	1995 - 1999
Ozone - passive	Hoh River	NPS	M	1997
Ozone - passive	Hurricane Ridge	NPS	M	1995 - 2003
Ozone - continuous	Hurricane Ridge	NPS	M	1998 - 2000
Ozone - portable	Hurricane Ridge	NPS	M	2004 - 2008
Ozone - passive	Lunch Lake	NPS	M	1996
Ozone - continuous	Port Angeles Visitor Center	NPS	M	1981 - 2004
Ozone - passive	Port Angeles Visitor Center	NPS	M	1995 - 2003
Ozone - passive	Queets River	NPS	M	1997
Ozone - passive	Sol Duc Hot Springs	NPS	M	1996
Ozone - passive	Staircase	NPS	M	1995 - 1999
Passive air sampling device	Hoh Lake	WACAP[3]	R	2005 - 2006
Passive air sampling device	PJ Lake	WACAP	R	2005 - 2006
Sulfur dioxide	Port Angeles Visitor Center	NPS	M	1981 - 2004

Table 7. Air Quality and AQRV Monitoring and Research at Olympic NP (continued)

Parameter	Location	Investigator	Research (R)/ Monitoring (M)	Dates
Deposition Chemistry				
Bulk deposition	Hoh Lake	Sheibley	R	2008
Bulk deposition	Hoh Ranger Station	Fenn and Geiser	R	2005 - 2007
Bulk deposition	Hurricane Ridge	WACAP	R	2004
Bulk deposition	Hurricane Ridge	Campbell and Simonich	R	2005 – 2007
Bulk deposition	Milk Lake	Sheibley	R	2008
Bulk deposition	PJ Lake	Sheibley	R	2008
CASTNET[4] dry deposition	Port Angeles Visitor Center	NPS	M	1997 - 2005
NADP[5] wet deposition	Hoh Ranger Station	NPS	M	1980 - present
Snowpack	Hoh Lake	WACAP	R	2004
Snowpack	Hoh Lake	Campbell and Simonich	R	2006
Snowpack	Hurricane Ridge	WACAP	R	2004
Snowpack	Hurricane Ridge	Campbell and Simonich	R	2006 - 2007
Snowpack	PJ Lake	WACAP	R	2004
Throughfall deposition	Hoh River	Fenn and Geiser	R	2005 - 2007
Diatom Communities				
Diatoms	Heather Lake	Sheibley	R	2009
Diatoms	Hoh Lake	Sheibley	R	2009
Diatoms	Milk Lake	Sheibley	R	2009
Fish Tissue Chemistry				
Fish	Flapjack Lake	Moran	R	2002
Fish	Gladys Lake	Eagles-Smith	R	2011
Fish	Happy Lake	Moran	R	2002
Fish	Hoh Lake	Moran	R	2002
Fish	Hoh Lake	WACAP	R	2005
Fish	Lake Constance	Moran	R	2002
Fish	Lake Crescent	EPA	R	1999

Table 7. Air Quality and AQRV Monitoring and Research at Olympic NP (continued)

Parameter	Location	Investigator	Research (R)/ Monitoring (M)	Dates
Fish	Lake Sunup	Eagles-Smith	R	2011
Fish	Ozette Lake	WDOE	M	2004 - 2010
Fish	PJ Lake	Moran	R	2002
Fish	PJ Lake	WACAP	R	2003, 2005
Fish	Queets River	WDOE	M	2005
Fish	Quinault River	WDOE	M	2008
Fish	Upper Lena Lake	Eagles-Smith	R	2011
Lichen Communities				
Lichens	Goodman Creek	Geiser	M	2000
Lichens	Hoh Ranger Station	Geiser	M	1998, 2006
Lichens	Hoh River	Geiser	R	2006
Lichens	Ozette Lake	Geiser	M	2000
Lichens	Ruby Beach	Geiser	M	2000
Sediment Chemistry				
Sediment	Hoh Lake	WACAP	R	2005
Sediment	PJ Lake	WACAP	R	2005
Vegetation Chemistry				2004
Vegetation	Hoh Lake	WACAP	R	2004
Vegetation	Hurricane Ridge	WACAP	R	2004
Vegetation	PJ Lake	WACAP	R	2004
Vegetation	Port Angeles Visitor Center	WACAP	R	2004
Vegetation	Sol Duc River	WACAP	R	2004
Water Chemistry				
Water	Crazy Lake	NPS	M	2010 - present
Water	Ferry Lake	NPS	M	2009 - present
Water	Gladys Lake	NPS	M	2010 - present
Water	Heather Lake	NPS	M	2005 - present
Water	Heather Lake	Sheibley	R	2009

Table 7. Air Quality and AQRV Monitoring and Research at Olympic NP (continued)

Parameter	**Location**	**Investigator**	**Research (R)/ Monitoring (M)**	**Dates**
Water	Hoh Lake	WACAP	R	2005
Water	Hoh Lake	Sheibley	R	2009
Water	Lake Connie	NPS	M	2006 - present
Water	Lake Crescent	NPS	M	2006 - present
Water	Lake LaCrosse	NPS	M	2010 - present
Water	Lake Sunup	NPS	M	2006 - present
Water	Milk Lake	NPS	M	2005 - present
Water	Milk Lake	Sheibley	R	2009
Water	PJ Lake	WACAP	R	2005
Water	PJ Lake	Sheibley	R	2009
Water	Quinault River	WDOE	M	2008

[1]NDAMN = National Dioxin Air Monitoring Network
[2]IMPROVE = Interagency Monitoring of Protected Visual Environments
[3]WACAP = Western Airborne Contaminants Assessment Project
[4]CASTNET = Clean Air Status and Trends Network
[5]NADP = National Atmospheric Deposition Program

Visibility

Beginning in 1980, the NPS began monitoring visibility at Olympic NP. To provide qualitative documentation of visual conditions, pictures were taken with first a 35-mm camera at the Port Angeles Visitor Center (1980-1991) and Lake Crescent (1985-1991), and later with a digital camera (2003-present) at Lake Crescent (Figure 3; NPS, 2012). Based on an average of 2007-2011 data, on the 20 percent best visibility days, the standard visual range was 278 km and on the 20 percent worst visibility days, the standard visual range was 92 km (Bret Schichtel, NPS ARD, personal communication).

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

Atmospheric particle monitoring began in 2001 at Blyn Lookout Relay as part of the national Interagency Monitoring of Protected Visual Environments (IMPROVE) Program and includes quantitative measurements of mass, chemical elements, SO_4, NO_3, 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.

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, 2013a) evaluated visibility on the 20 percent best, annual average and 20 percent worst visibility days from 2000-2009. Data indicate visibility improved significantly on the best and worst days at Olympic NP; there was also an improvement, although not statistically significant, on the average days. 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, about 36-47 percent of the haze at Olympic NP is due to SO_4 (note: SO_4 occurs as NH_4SO_4 and NO_3 occurs as NH_4NO_3). Under natural conditions, the contribution to visibility impairment from SO_4 would be less than 19 percent. The difference between current annual average visibility and natural conditions at the park is 4.81 dv, meaning current average visibility is 48 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.

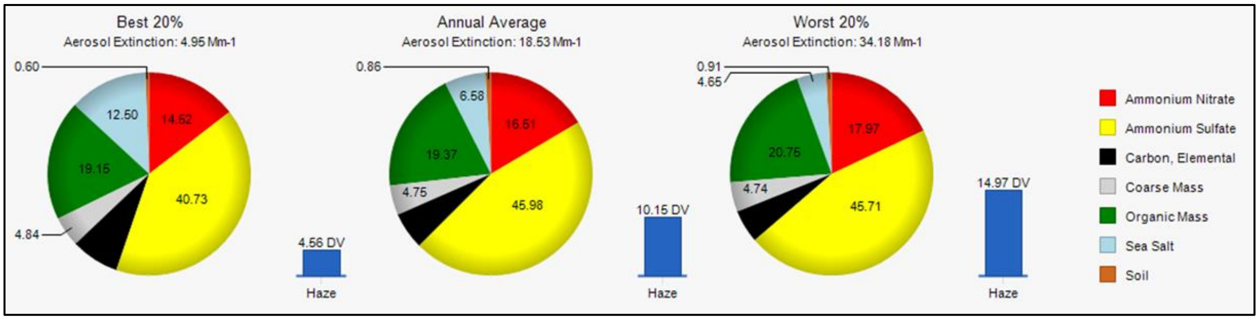

Figure 4. Current Conditions – levels of haze (bar chart) and its composition (pie chart) on the 20 percent best, annual average and 20 percent worst visibility days at Olympic NP from 2006-present (from Federal Land Manager Environmental Database, 2012).

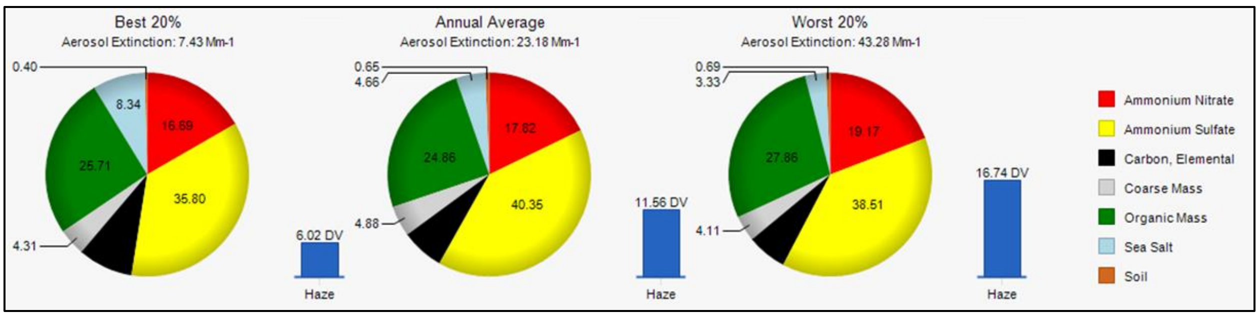

Figure 5. Baseline Conditions - levels of haze (bar chart) and its composition (pie chart) on the 20 percent best, annual average and 20 percent worst visibility days at Olympic NP during the Regional Haze Rule baseline time period 2000-2004 (from Federal Land Manager Environmental Database, 2012).

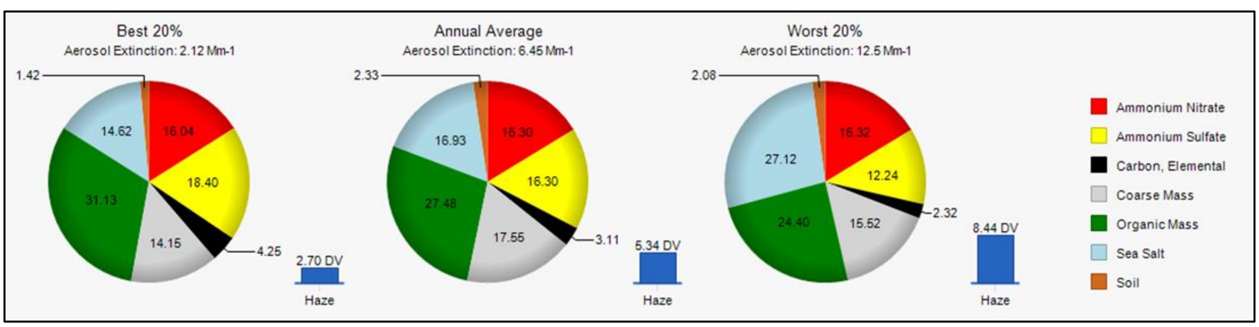

Figure 6. Natural Conditions - natural levels of haze (bar chart) and its composition (pie chart) on the 20 percent best, annual average and 20 percent worst visibility days at Olympic NP (from Federal Land Manager Environmental Database, 2012).

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 the Hoh Ranger Station (WA14) at Olympic NP since 1980 through the National Atmospheric Deposition Program (NADP). The NADP reports concentrations and annual deposition of SO_4, NO_3, NH_4 and base cations. The ARD (NPS, 2013a) evaluated 2000-2009 NADP data and found no trends in concentrations of SO_4, NO_3 or NH_4 at Olympic NP. 1989-2008 data indicated a significant decrease in wet ammonium concentrations (NPS, 2010). The NADP graphs for Olympic NP show the long term trends in annual concentration (in milligrams/liter [mg/L]), precipitation (in centimeters [cm]) and deposition (in kilograms/hectare [kg/ha]) (Figures 7-12; NADP, 2012).

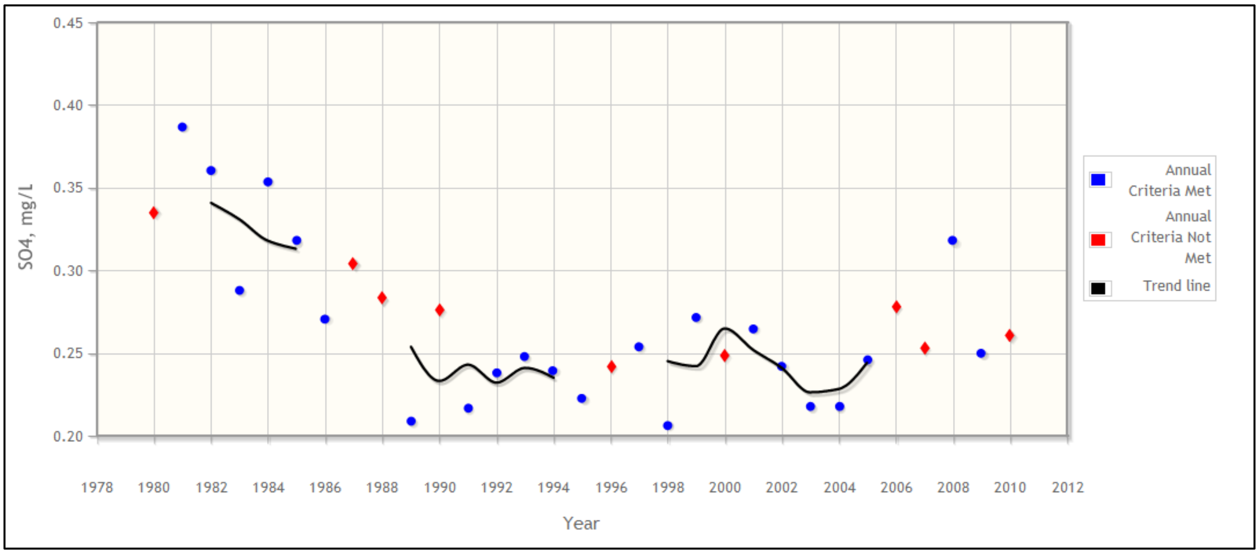

Figure 7. Trend in SO_4 concentration at NADP site WA14, Olympic NP (from NADP, 2012). Trend line does not include years that don't meet data completeness criteria.

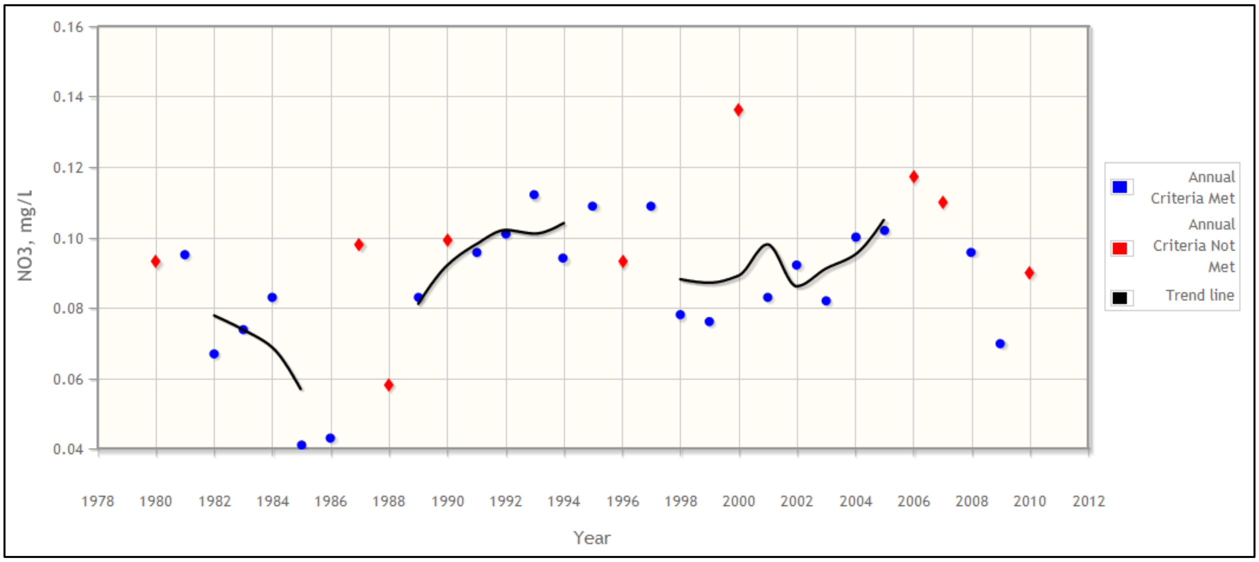

Figure 8. Trend in NO_3 concentration at NADP site WA14, Olympic NP (from NADP, 2012). Trend line does not include years that don't meet data completeness criteria.

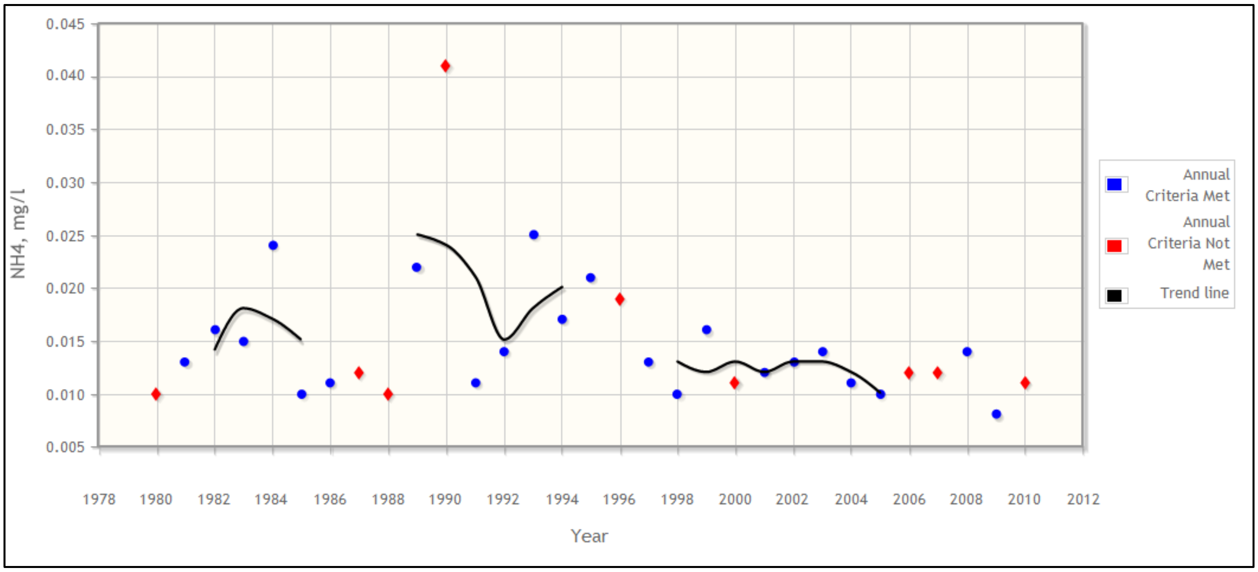

Figure 9. Trend in NH_4 concentration at NADP site WA14, Olympic NP (from NADP, 2012). Trend line does not include years that don't meet data completeness criteria.

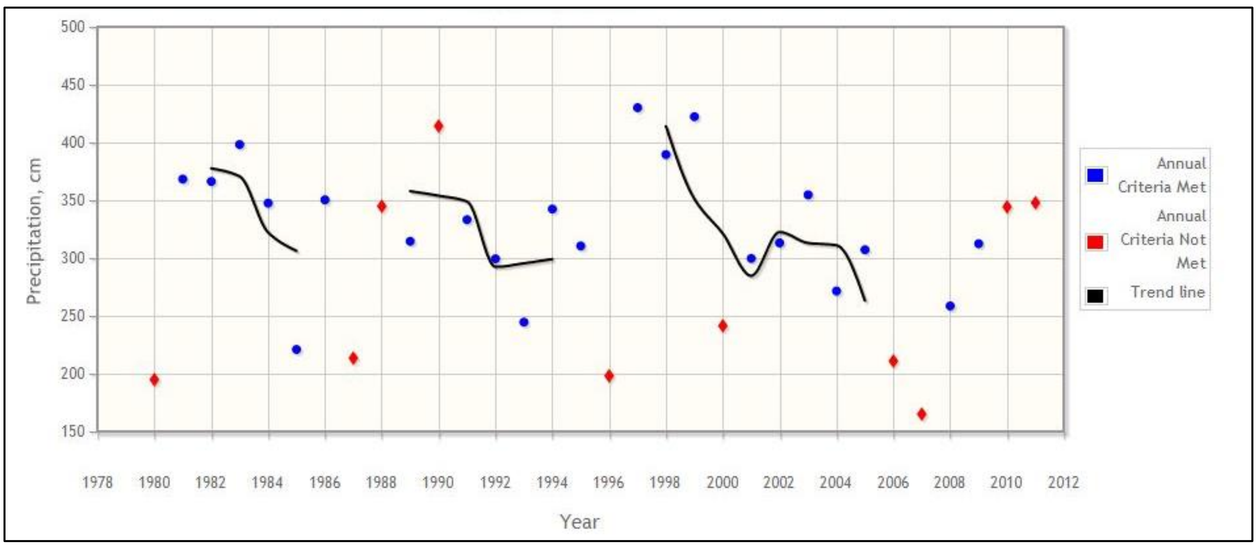

Figure 10. Trend in precipitation at NADP site WA14, Olympic NP (from NADP, 2012). Trend line does not include years that don't meet data completeness criteria.

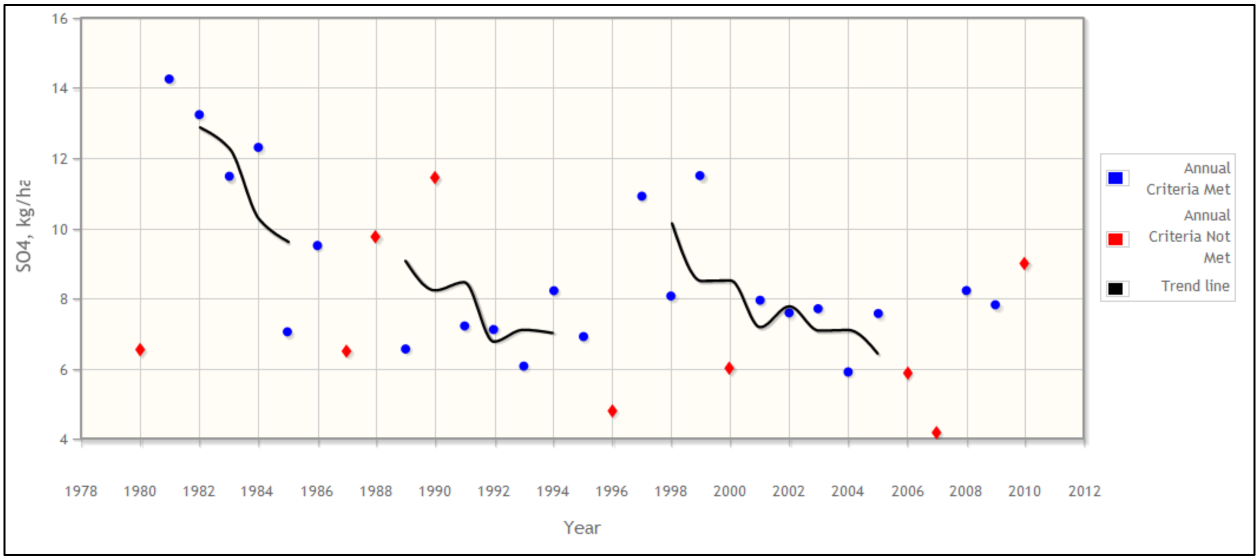

Figure 11. Trend in SO_4 deposition at NADP site WA14, Olympic NP (from NADP, 2012). Trend line does not include years that don't meet data completeness criteria.

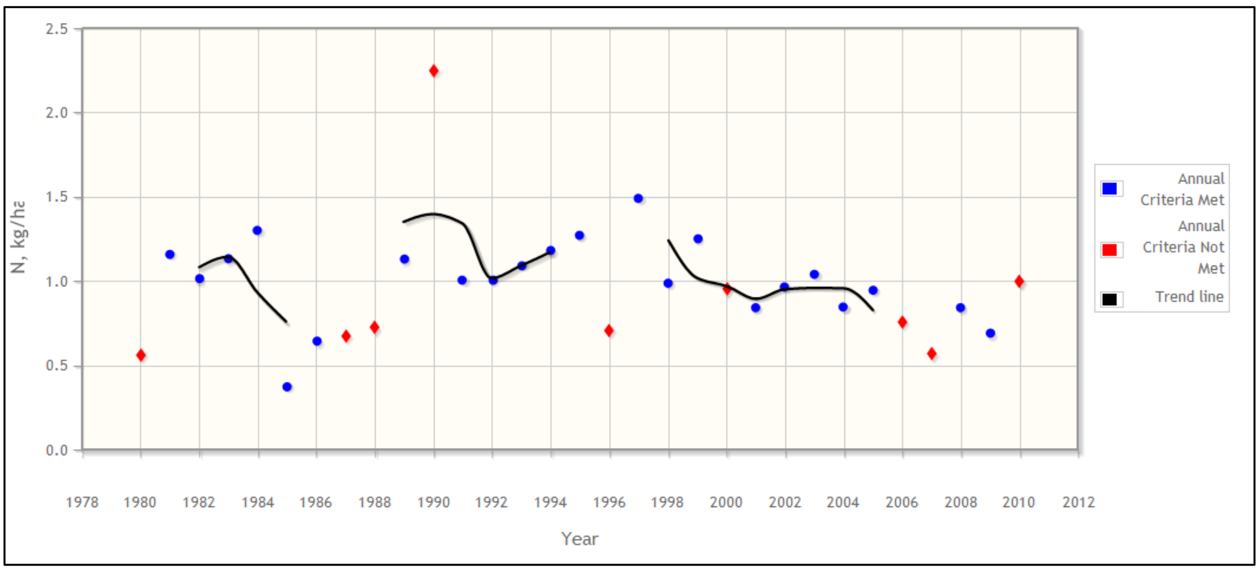

Figure 12. Trend in total N (NO_3 plus NH_4) deposition at NADP site WA14, Olympic NP (from NADP, 2012). Trend line does not include years that don't meet data completeness criteria.

Dry deposition was monitored at the Port Angeles Visitor Center from 1997-2005 through the national Clean Air Status and Trends Network (CASTNET; site OLY421). The CASTNET dry deposition values are not measured; they are calculated by multiplying measured ambient pollutant concentrations of SO_2, SO_4, HNO_3, NO_3 and NH_4 by estimated deposition velocities. By combining NADP wet and CASTNET dry deposition, total S deposition at Olympic NP was estimated to be between 2.44 and 4.58 kg/ha/yr for years with complete data (Figure 13; CASTNET, 2012). Total N deposition ranged from 1.05-1.96 kg/ha/yr for years with complete data. Dry deposition accounted for about 20 percent of total S deposition and about 25 percent of total N deposition (Figure 14). 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 NH_3 is not included in the estimate.

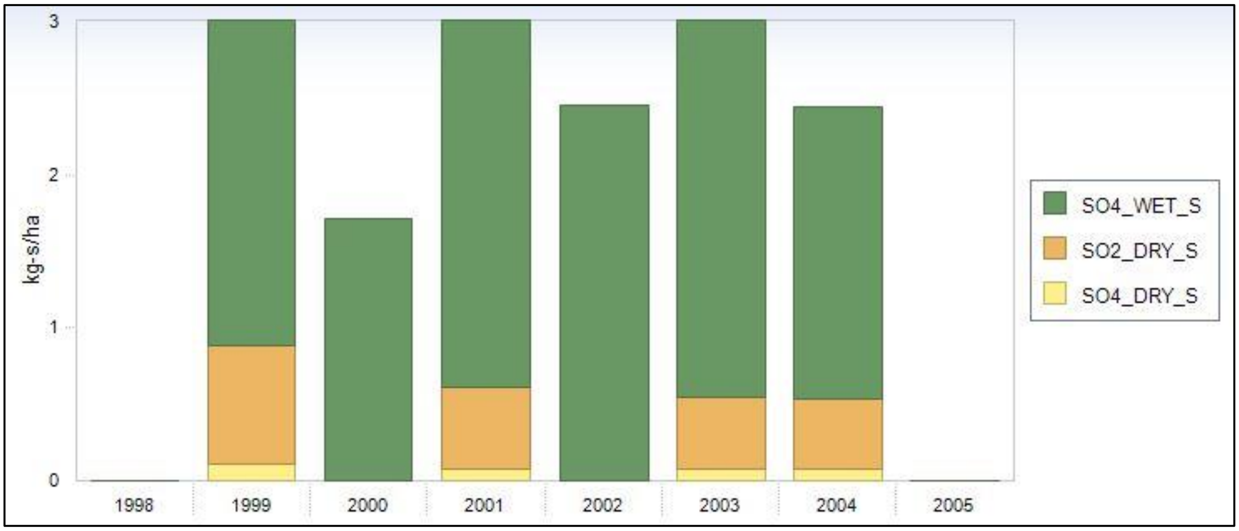

Figure 13. Total S deposition at CASTNET site OLY421, Olympic NP (from CASTNET, 2012).

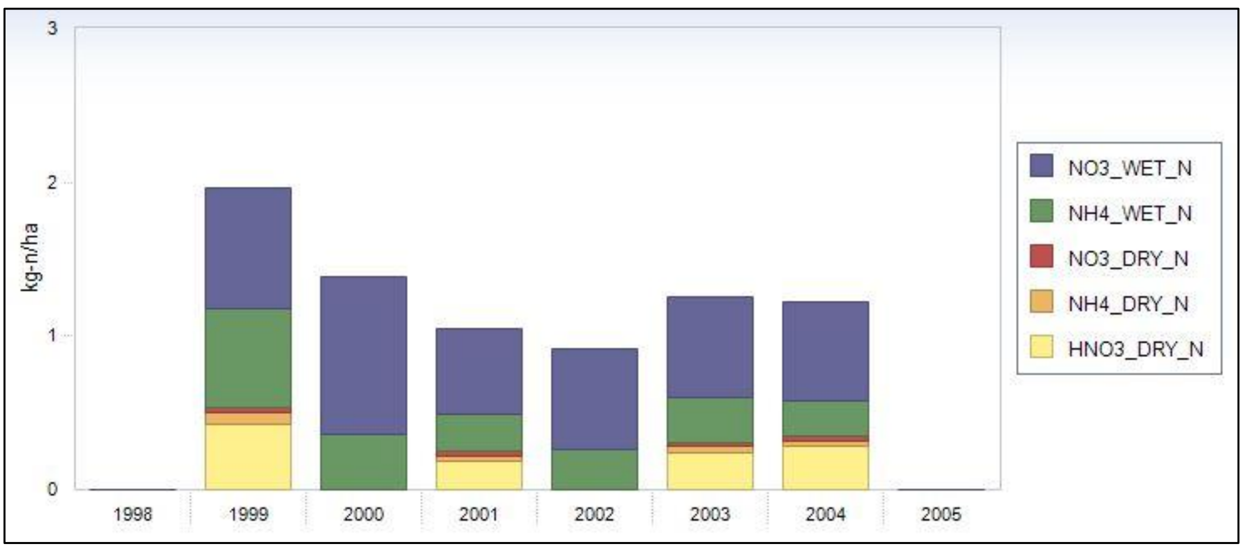

Figure 14. Total N deposition at CASTNET site OLY421, Olympic NP (from CASTNET, 2012).

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 Olympic, North Cascades and Mount Rainier 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 NO_3-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 NPS I&M Networks as well as for all NPS areas larger than 100 square miles. Olympic, North Cascades and Mount Rainier 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 15; Sullivan et al., 2011c) and N enrichment (Figure 16; Sullivan et al., 2011d) relative to other I&M Networks, based on the sensitivity of high elevation ecosystems in the three large parks. Accordingly, Olympic NP is considered at high risk in both assessments (Figures 17 and 18). Sullivan et al. (2011c and 2011d) used GIS data to produce maps showing areas of likely sensitive surface waters (Figure 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).

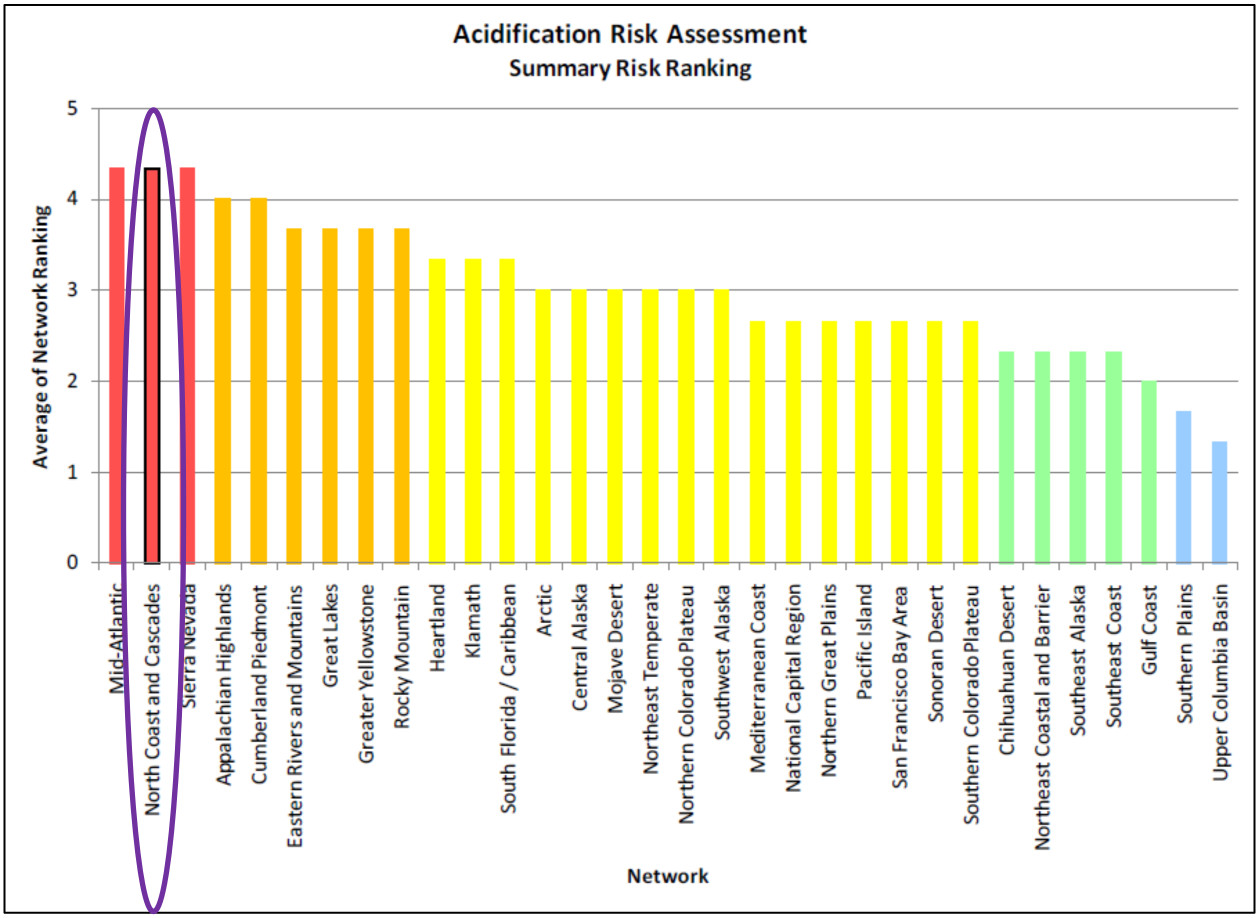

Figure 15. Summary risk ranking of acidification due to S and N deposition for the 32 I&M Networks (from Sullivan et al., 2011c).

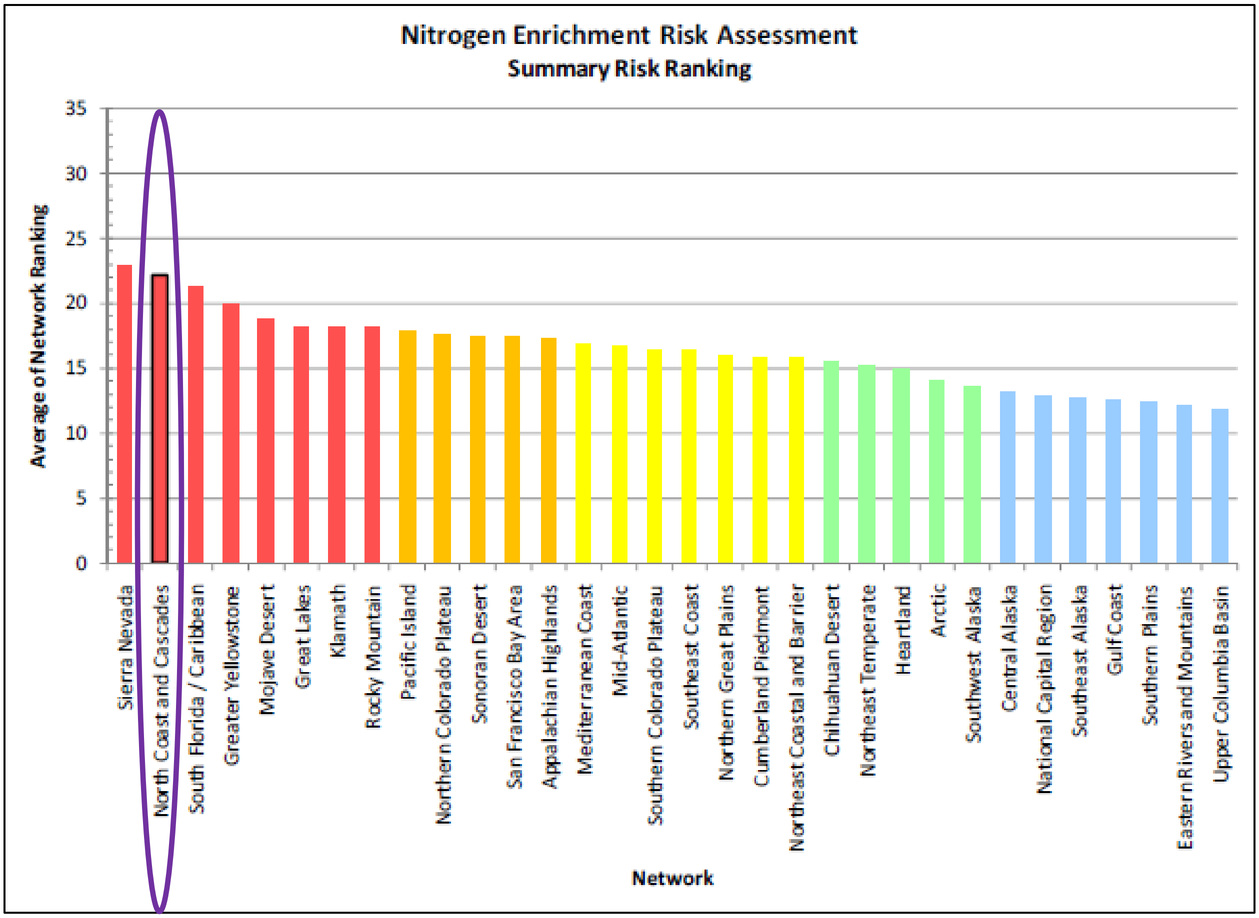

Figure 16. Summary risk ranking of atmospheric N enrichment for the 32 I&M Networks (from Sullivan et al., 2011d).

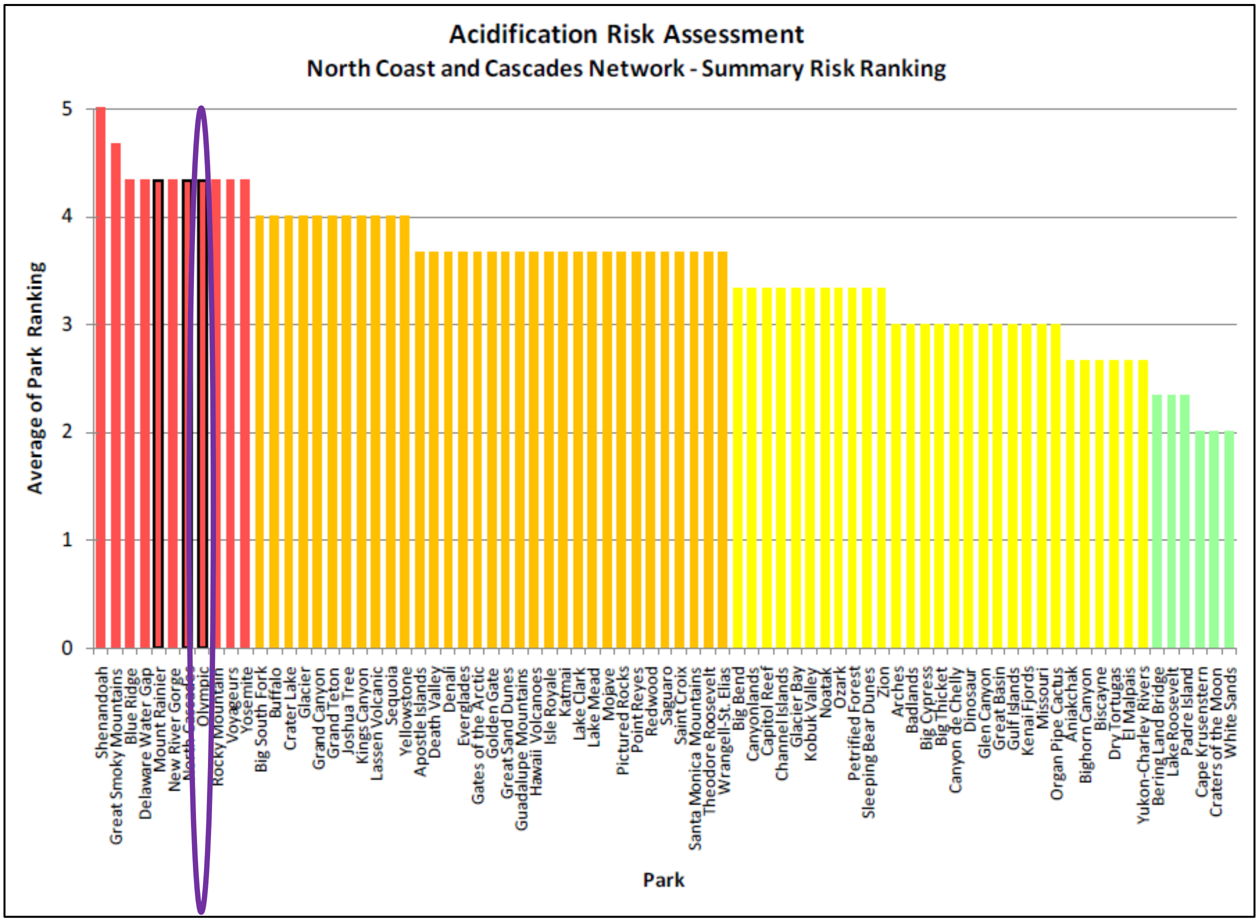

Figure 17. Summary risk ranking of acidification due to S and N deposition for all NPS areas larger than 100 square miles (from Sullivan et al., 2011c).

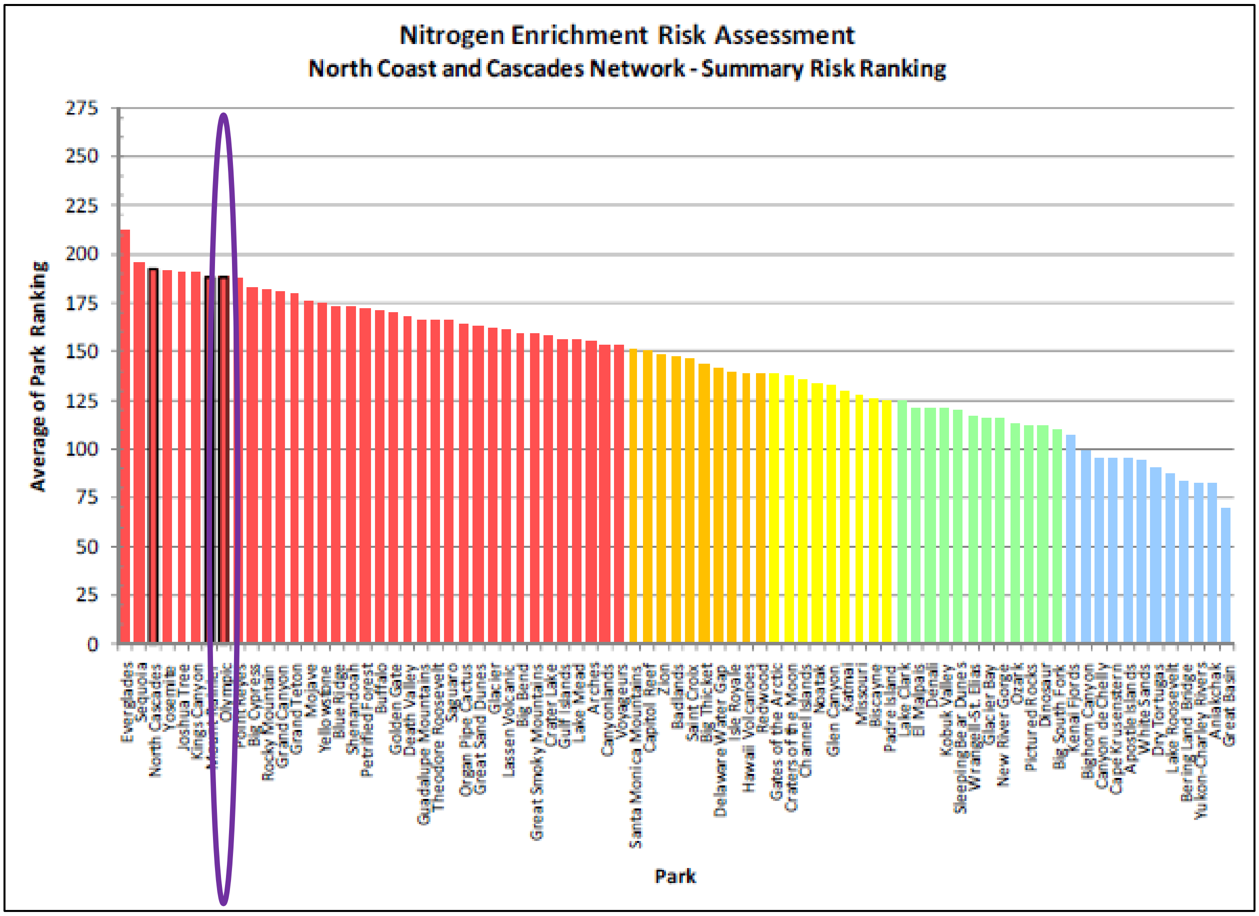

Figure 18. Summary risk ranking of atmospheric N enrichment for all NPS areas larger than 100 square miles (from Sullivan et al., 2011d).

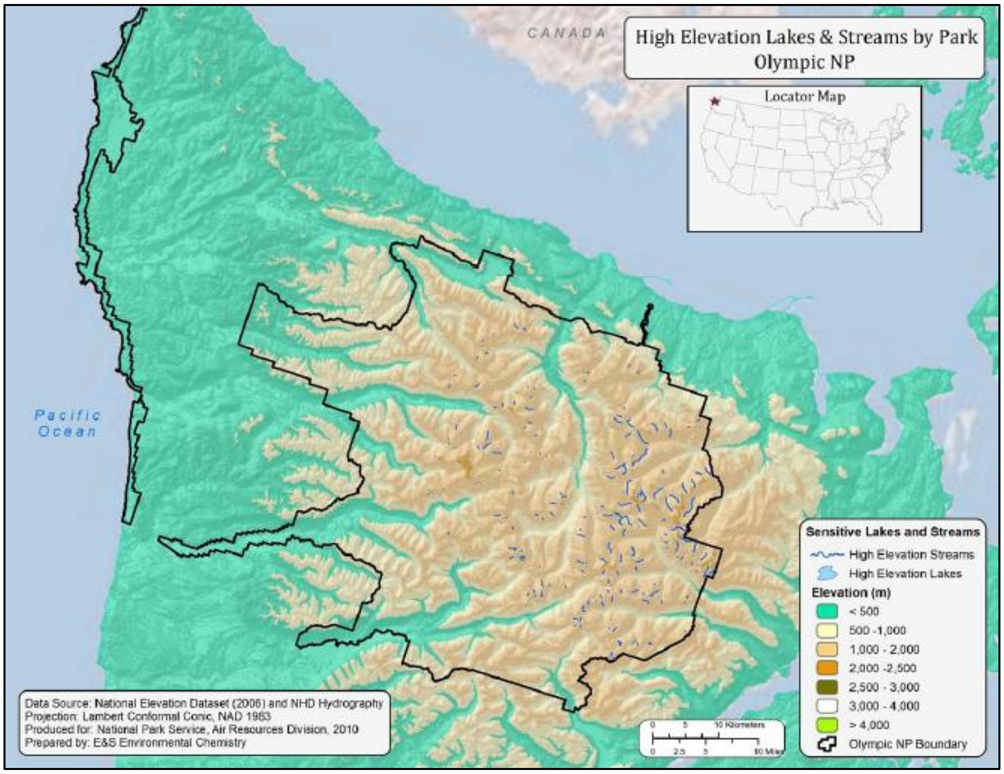

Figure 19. High elevation lakes and streams at Olympic NP likely sensitive to acidification (from Sullivan et al., 2011c).

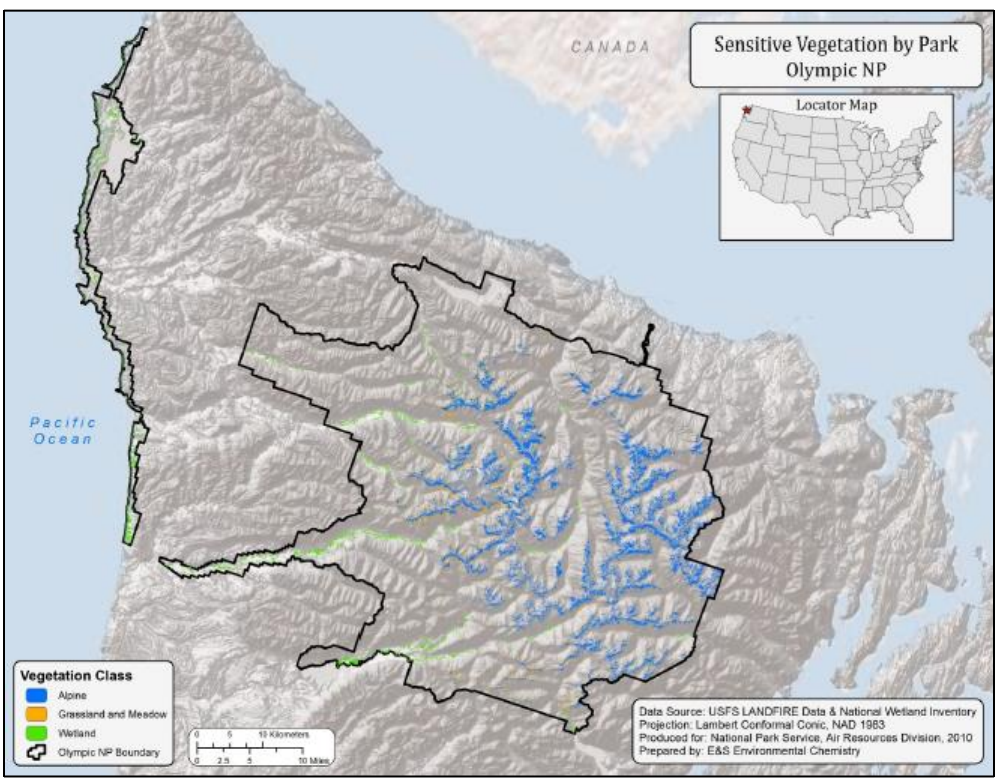

Figure 20. Vegetation types in Olympic NP likely sensitive to atmospheric N enrichment (from Sullivan et al., 2011d).

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 NO_3 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 NO_3 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. Episodic acidification may also be a concern at Olympic NP.

As part of the NCCN I&M Program, long term monitoring is being conducted at eight mountain lakes in Olympic NP (i.e., Connie, Crazy, Ferry, Heather, Gladys, LaCrosse, Milk and Sunup Lakes), as well as at six lakes each in North Cascades 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. Results to-date indicate sedimentary bedrock causes lakes at Olympic NP to be less acid-sensitive than lakes at the other two parks.

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 because some may be more sensitive than others.

Geiser sampled lichens from coastal areas near Goodman Creek, La Push, Ozette Lake and Ruby Beach in 2000 and near the Hoh River valley in 1998 and 2006. Combining the Olympic NP 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 higher than 0.21, the point at which oligotroph contribution to species richness declined by about 33-43 percent, to have exceeded the N critical load. None of the plots in or near Olympic NP exceeded the critical load; all plots in the park had scores below -0.11 (indicating best condition; Figure 21). 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 the authors, 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 22). 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 Olympic NP, were based on the Geiser et al. (2010) values. Following the methods of Geiser et al., the lichen community-based critical loads at Olympic NP are 3.9 to 9.3 kg/ha/yr of total N deposition (Figure 23).

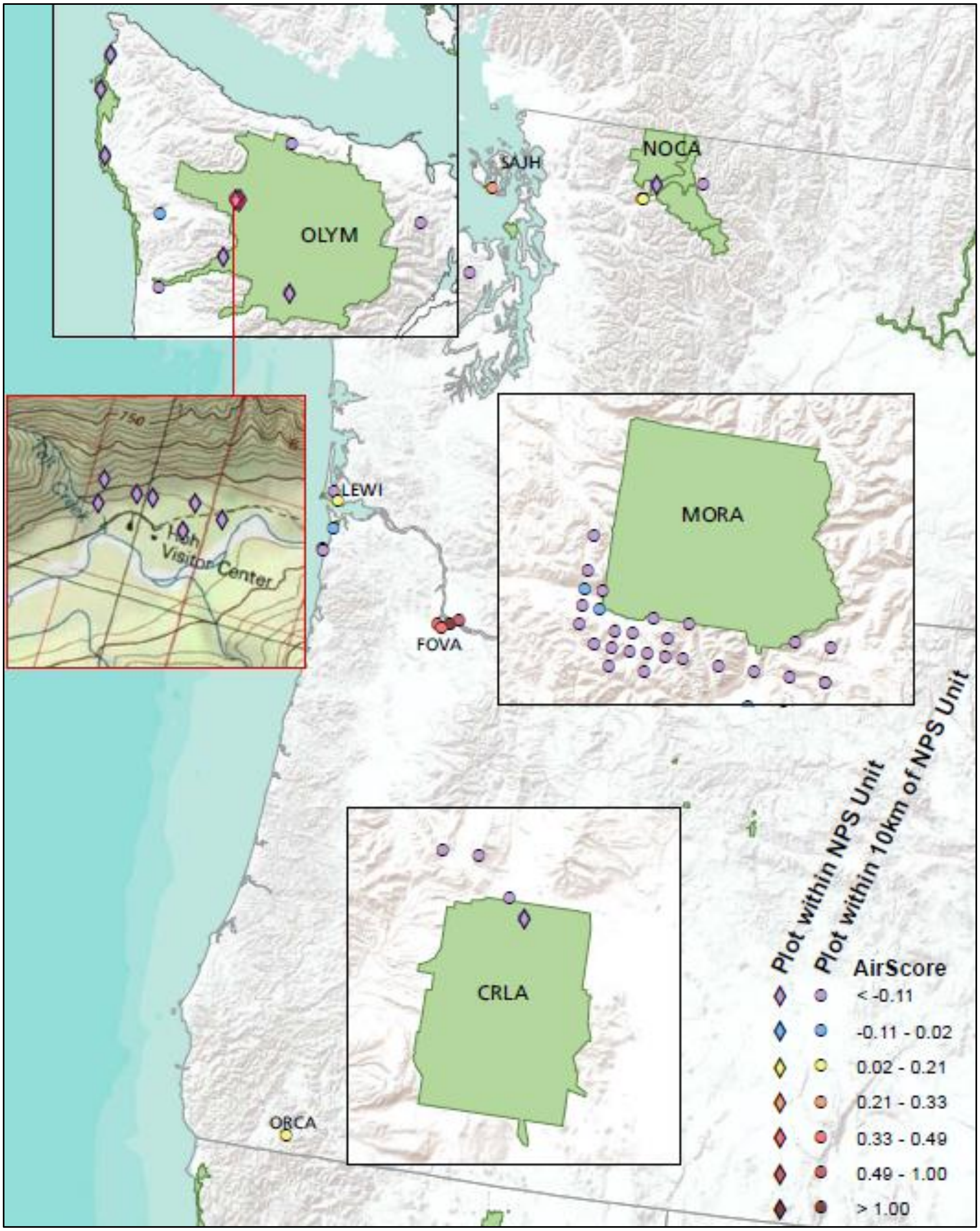

Figure 21. Air quality scores for lichen plots in and near NPS units in western Oregon and Washington. Scores of 0.21-0.33 or greater exceeded the critical load. CRLA is Crater Lake NP, FOVA is Fort Vancouver National Historic Site, LEWI is Lewis and Clark National Historical Park (NHP), MORA is Mount Rainier NP, NOCA is North Cascades NP, OLYM is Olympic NP, and SAJH is San Juan Island NHP (produced from U.S. Forest Service, 2012).

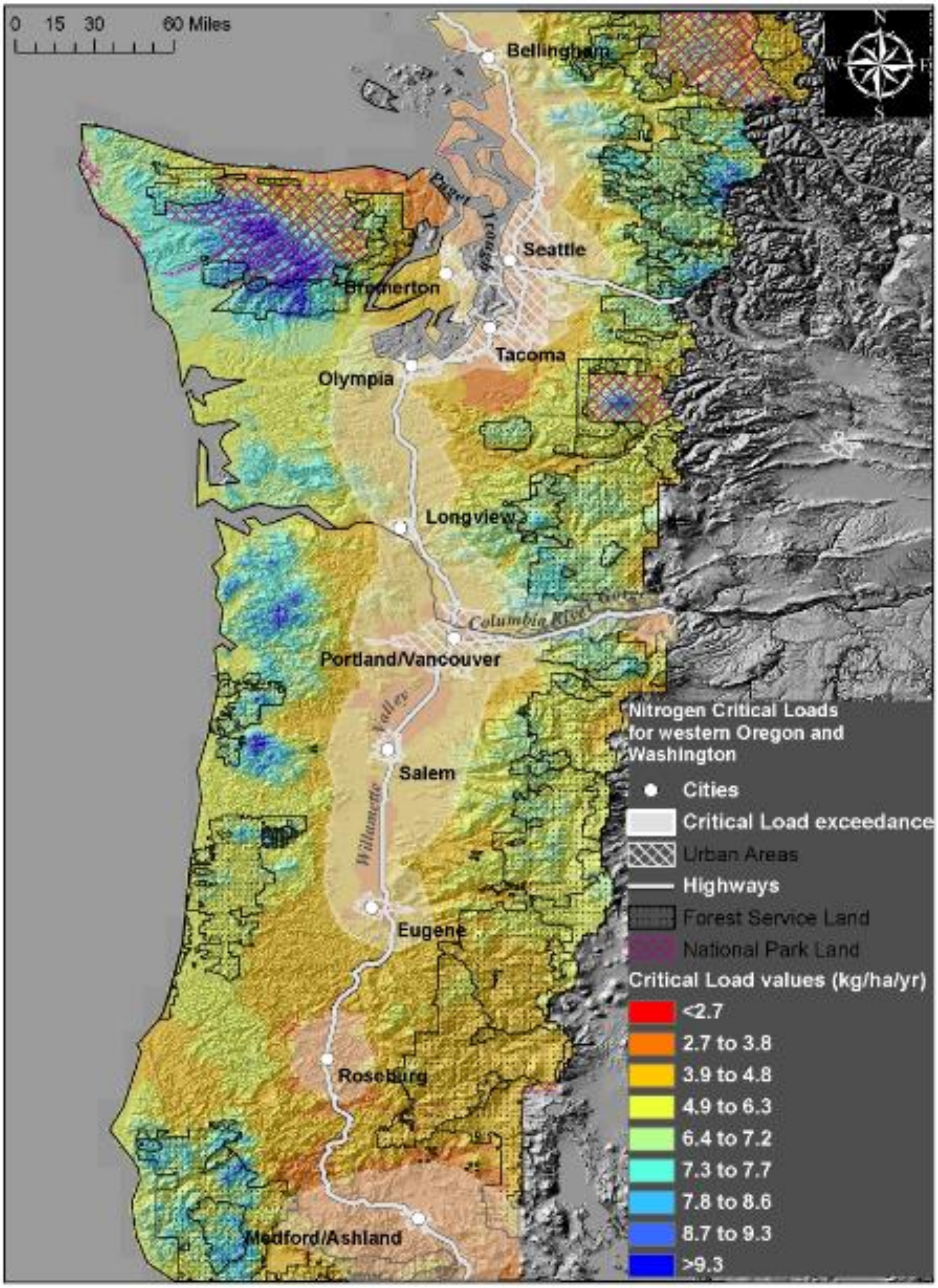

Figure 22. Map of lichen community-based critical loads for total N deposition in western Oregon and Washington (produced by Geiser and Glavich, 2012).

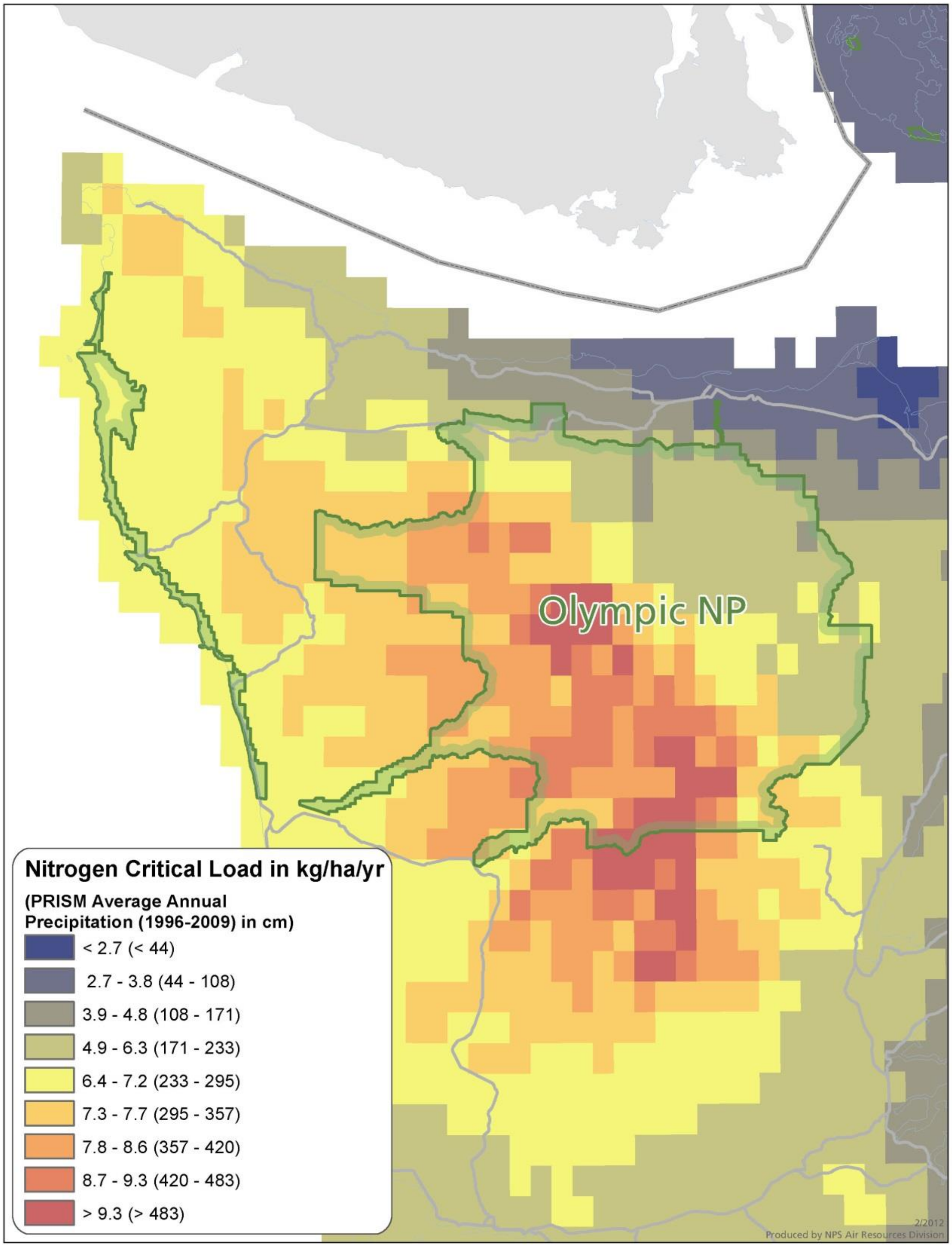

Figure 23. Map of lichen community-based critical loads for total N deposition in Olympic NP (produced by NPS ARD, 2013). PRISM is the Parameter-elevation Regressions on Independent Slopes Model.

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 higher-elevation lakes each in Olympic, North Cascades and Mount Rainier NPs. Because of their locations, N inputs to the lakes are primarily from atmospheric deposition. The study sites in Olympic NP were Heather, Hoh, Milk and PJ Lakes. In general, bulk deposition of S and N was lower at Olympic than at the other two parks (Sheibley et al., 2012). Sheibley et al. (in review) 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. The authors estimated a critical load of 1.0-1.2 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 2013-2015 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 Olympic, North Cascades and Mount Rainier 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 Olympic, North Cascades 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

Over the years, ozone data have been collected at many locations in Olympic NP. Ozone concentrations were measured with passive samplers during the ozone season, i.e., approximately May-September, at six sites in the park between 1995 and 2003. Continuous monitoring was conducted at the Port Angeles Visitor Center in 1981-2004, Hurricane Ridge in 1998-2000 and Blyn Lookout Relay in 2005. Portable monitors were used during the ozone season at Hurricane Ridge in 2004-2008 and Deer Park in 2009-2011.

The passive samplers showed ozone values vary throughout the park, with higher maximum one-week cumulative ozone concentrations generally occurring at higher elevations (Figures 24 and 25). A trend analysis was performed for the three park sites where passive ozone data were collected every year from 1995-2003, i.e., Hurricane Ridge, Hurricane Ridge Road and the Port Angeles Visitor Center. Data from Hurricane Ridge Road indicated an increasing ozone trend ($p \leq 0.15$); there were no trends at the other two sites (John Ray, NPS ARD, personal communication). A 1995 comparison of passive ozone data showed concentrations at Olympic NP were low relative to other NPS areas (Figure 26).

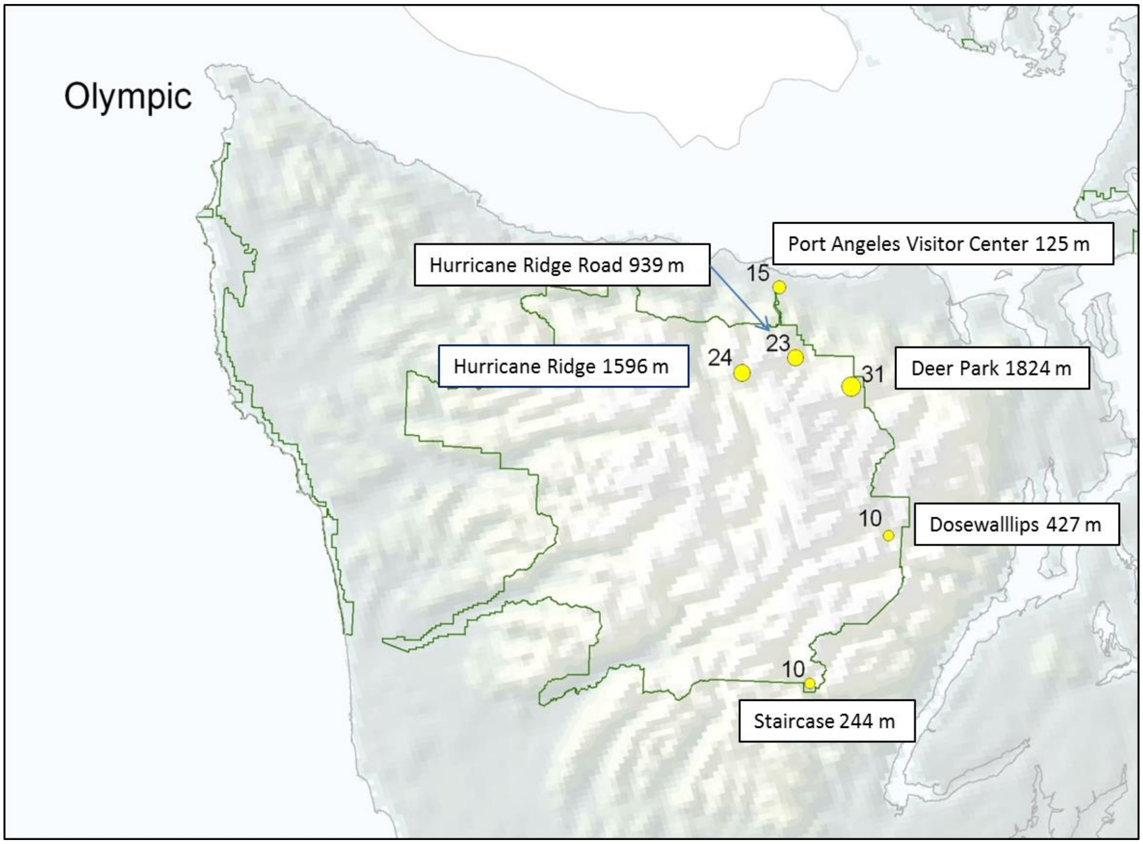

Figure 24. Maximum one-week cumulative ozone concentrations (in ppb) measured with passive samplers at Olympic NP in 1995 (NPS ARD, unpublished data).

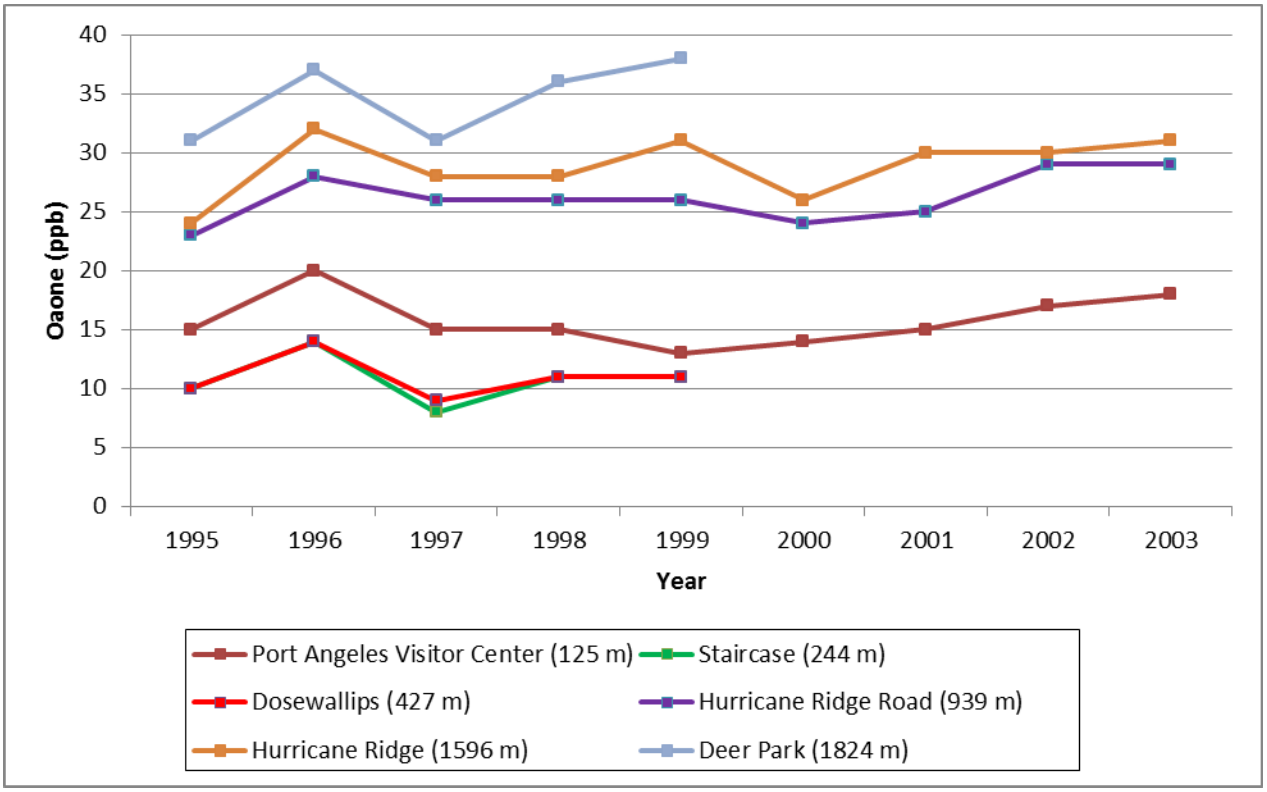

Figure 25. Maximum one-week cumulative ozone concentrations (in ppb) measured with passive samplers at six sites in Olympic NP between 1995 and 2003 (produced from NPS ARD, unpublished data).

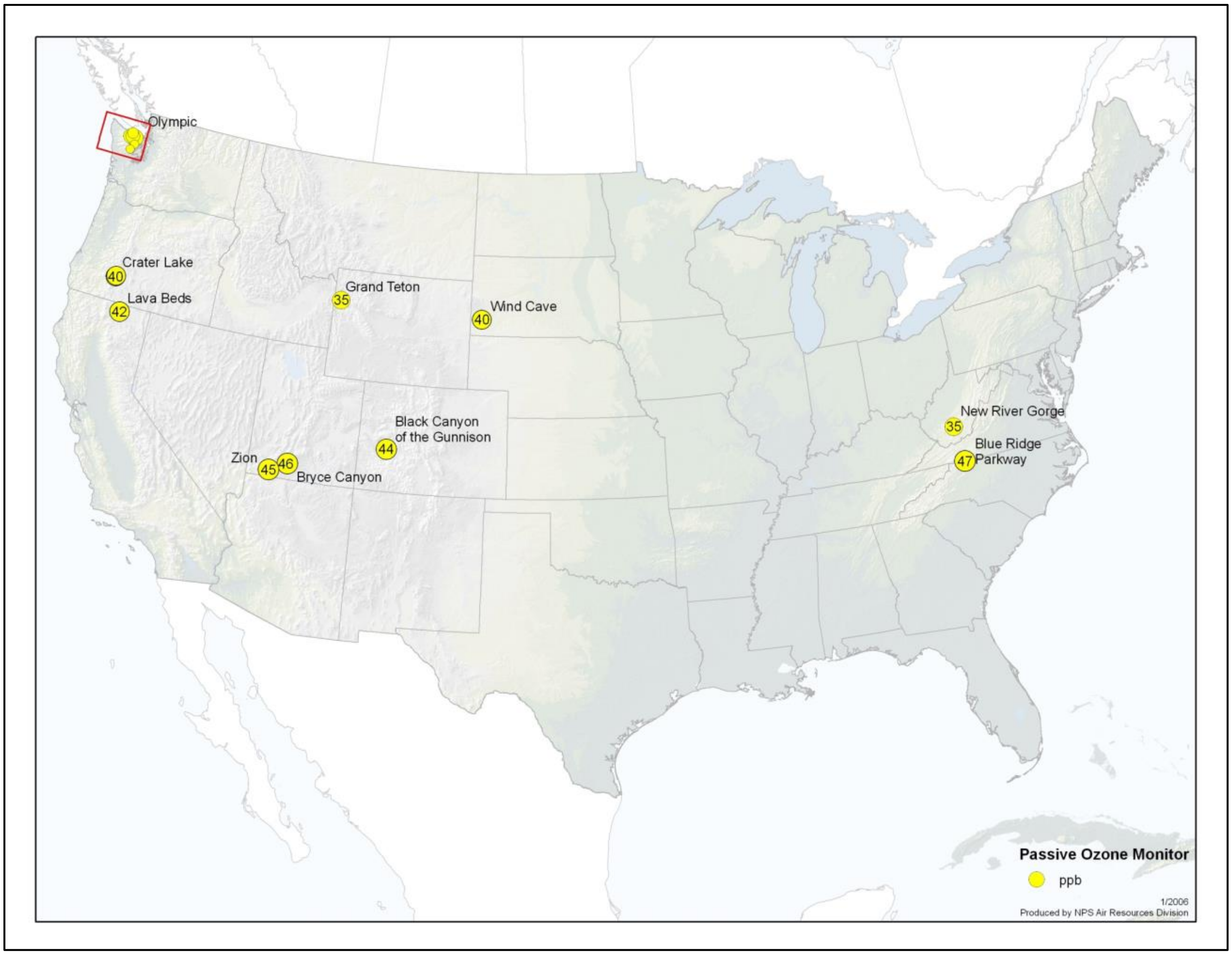

Figure 26. Maximum one-week cumulative ozone concentrations (in ppb) measured with passive samplers at 10 NPS areas in 1995; see Figure 24 for concentrations at Olympic NP sites (NPS ARD, unpublished data).

Continuous and portable monitors showed no exceedances of the ozone NAAQS of 75 ppb; the highest annual 4th high daily maximum 8-hr concentration was 50 ppb at the Port Angeles Visitor Center, 54 ppb at Deer Park (note: Deer Park data have not been validated) and 59 ppb at Hurricane Ridge (Figure 27).

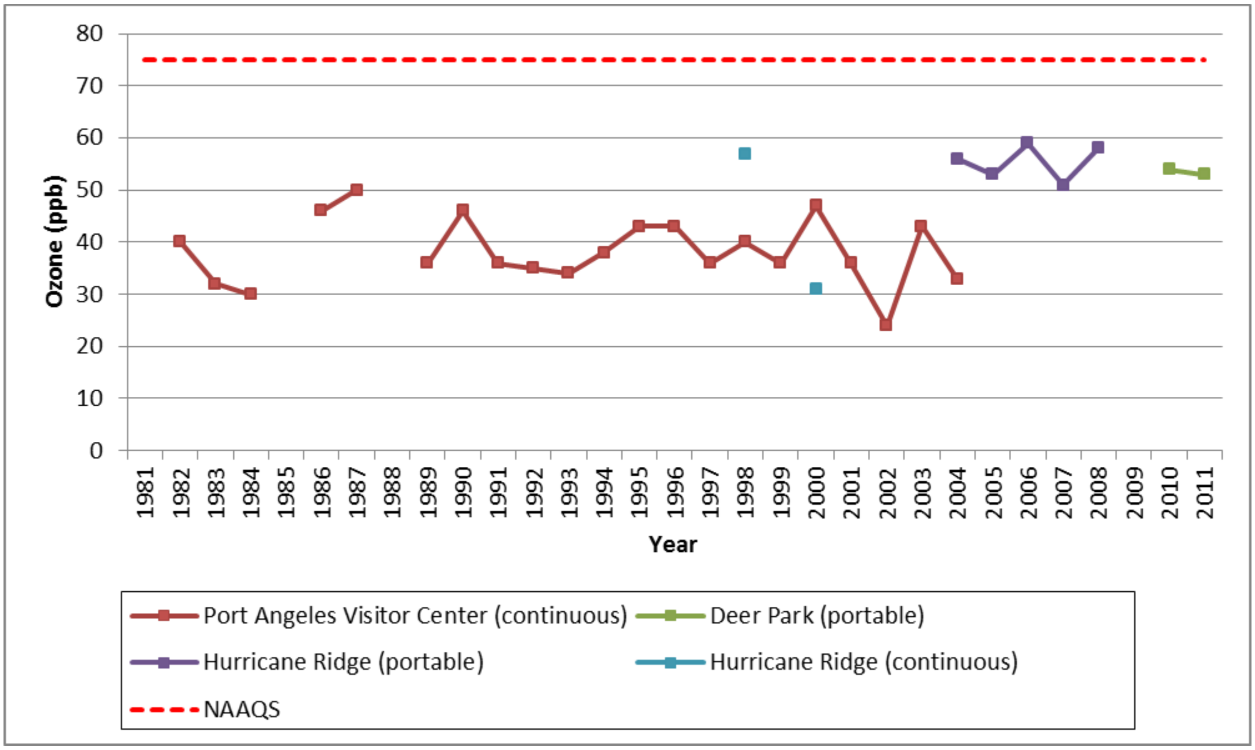

Figure 27. Annual 4th highest daily maximum 8-hr ozone concentrations measured with continuous and portable monitors at Olympic NP between 1981 and 2011. Only sites and years with sufficient data are included (produced from NPS, 2013b).

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 Olympic 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 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 a few species at Olympic NP are ozone-sensitive (Table 8), given the low ozone concentrations at the park (e.g., between 1996 and 1999, W126 values ranged from 1.1-1.9 ppm-hrs compared to the proposed range of 7-15 ppm-hrs), he concluded there was low risk of ozone injury at the park. Since 2001, the U.S. Forest Service Forest Inventory and Analysis (FIA) Program has examined plants for ozone injury at a monitoring plot in Olympic NP. No injury was detected during 2001-2009 surveys of red alder (*Alnus rubra*), scouler's willow (*Salix scouleriana*), red elderberry (*Sambucus racemosa*) and thin leaf huckleberry (*Vaccinium membranaceum*; Sarah Jovan, FIA Program, personal communication).

Table 8. Ozone-sensitive species at Olympic NP (from Kohut, 2004).

Latin Name	Common Name	Family
Alnus rubra	Red alder	Betulaceae
Physocarpus capitatus	Ninebark	Rosaceae
Populus tremuloides	Quaking aspen	Salicaceae
Robinia pseudoacacia	Black locust	Fabaceae
Salix scouleriana	Scouler's willow	Saliaceae

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. As part of EPA's National Dioxin Air Monitoring Network (NDAMN), atmospheric concentrations of dioxins and other chlorinated pollutants were monitored at Ozette Lake from 1999-2004 (Cleverly et al., 2007). Pollutant concentrations at the 31 rural and remote sites were low compared to the three urban monitoring sites. Concentrations of dioxin-like compounds at remote sites, such as Ozette Lake, were in the range of $1\text{-}5 \times 10^{-10}$ $\mu g/m^3$. At all sites, there was little variability in mean annual concentrations. Cleverly et al. hypothesized urban areas are regional sources of dioxins that affect concentrations in rural and remote locations in the United States.

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 28 and 29). 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 30; NADP, 2012). Trend data are not yet available for the WA03 site. The Makah fish hatchery site likely reflects conditions on the west side of Olympic NP, but it is unlikely that either site fully represents conditions on the east side of the park.

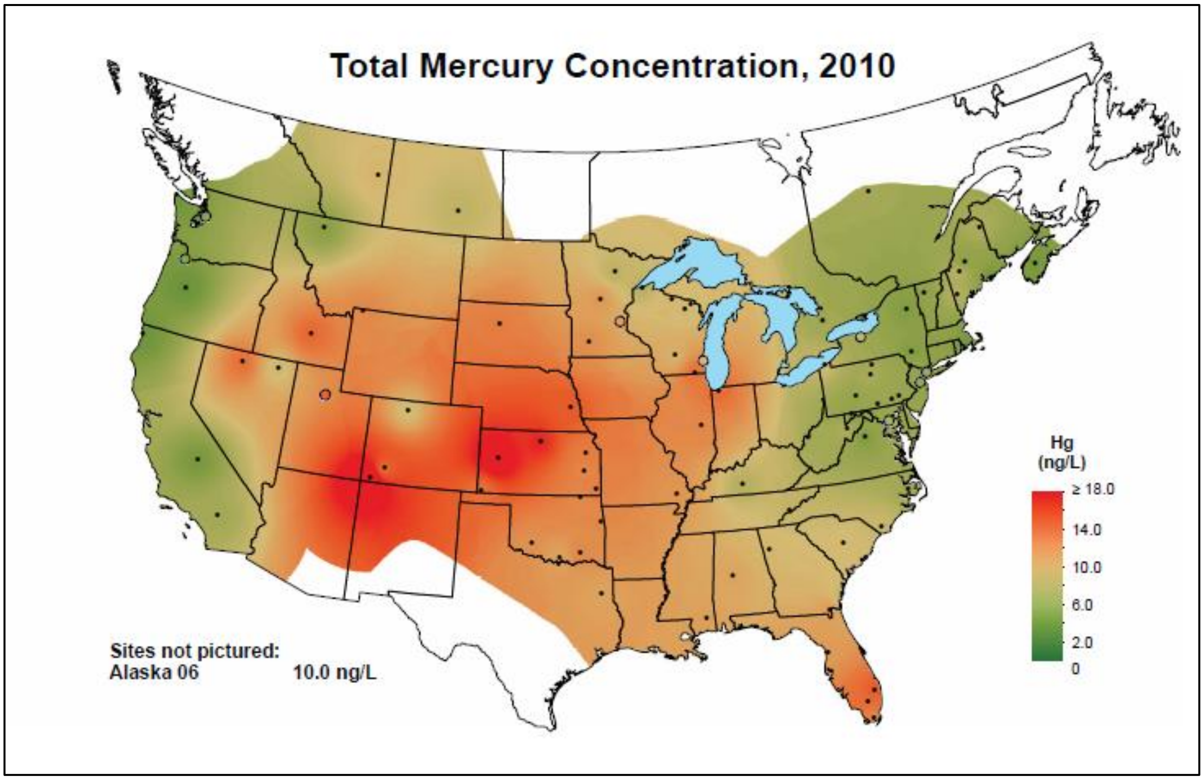

Figure 28. Map of total Hg concentration in precipitation based on 2010 MDN data (from NADP, 2012).

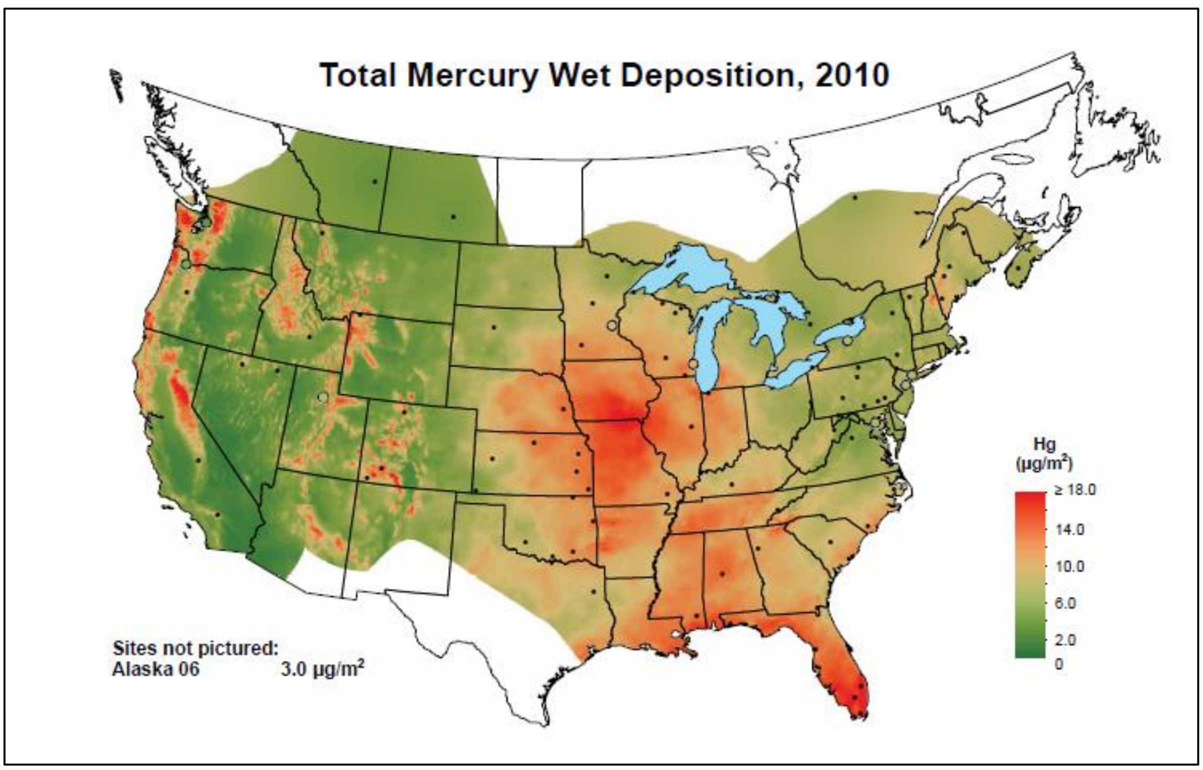

Figure 29. Map of total Hg deposition in precipitation based on 2010 MDN data (from NADP, 2012).

Figure 30. 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 (Dave Krabbenhoft and Michelle Lutz, USGS, in preparation). The assessment evaluates water quality and landscape variables such as pH, SO_4, 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 Olympic, North Cascades and Mount Rainier NPs should have low to moderate concentrations of MeHg (Figure 31). 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 at Olympic NP. 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 9). The thresholds are based on sublethal effects on health, growth and reproduction.

In 1999, fish were collected from Lake Crescent 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. Mercury, polychlorinated biphenyls (PCBs) and several pesticides were detected in fish from Lake Crescent.

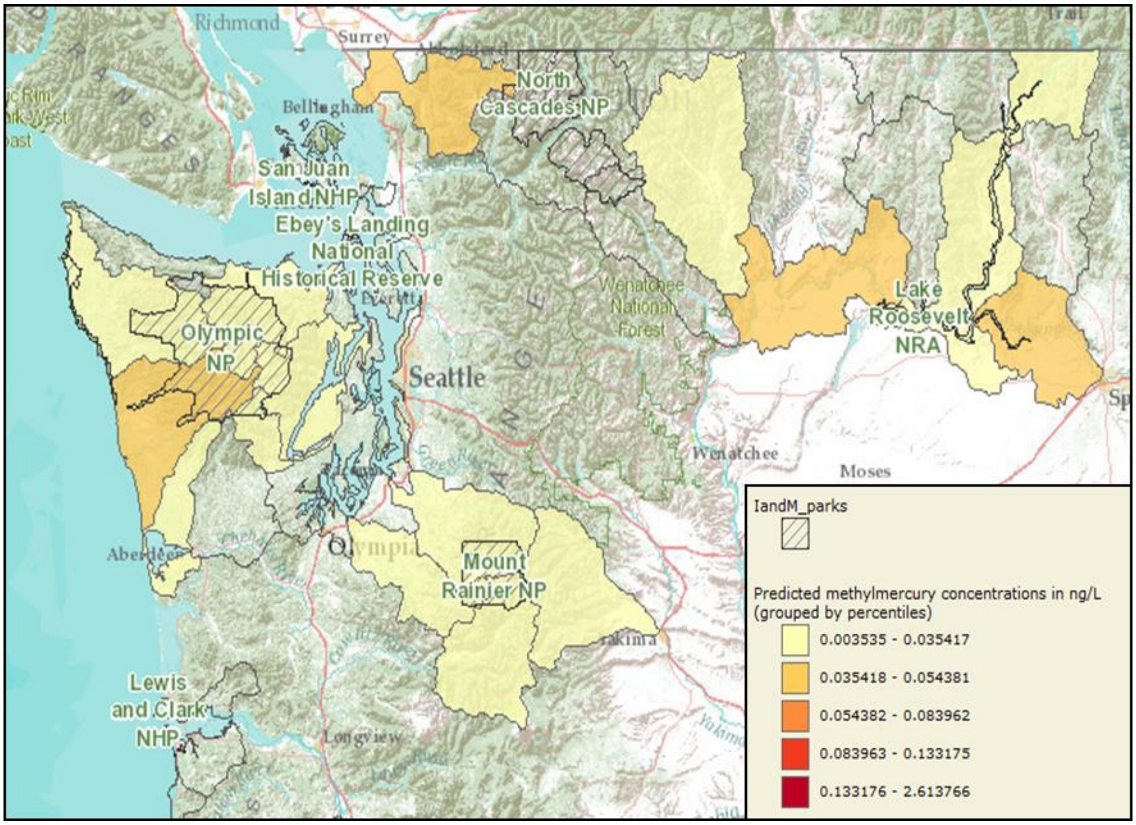

Figure 31. Predicted methylmercury concentrations, in ng/L, in watersheds in and near Olympic, North Cascades and Mount Rainier NPs (from Krabbenhoft and Lutz, in preparation).

Table 9. Fish contaminant health thresholds for piscivorous wildlife (in ng/g ww). Data from 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[1]	20	360	490
Total Chlordanes	4.5	830	1,140
Dieldrin	360	20	30

[1]dichlorodiphenyltrichloroethane

In 2002-2003, Moran et al. (2007) collected cutthroat trout (*Oncorhynchus clarki*) from five lakes in Olympic NP, five lakes in North Cascades NP and four lakes in Mount Rainier NP. The lakes at Olympic NP were Flapjack, Happy, Hoh, Constance and PJ. 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 32). The highest Hg concentration at Olympic NP was in a fish from Hoh Lake with 63 ng/g ww. All fish from Olympic NP had Hg concentrations greater than 30 ng/g ww, the health threshold for piscivorous birds (Landers et al., 2008). 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 that tissue Hg concentrations could affect gene expression in fish. Moran et al. (2007) also detected low concentrations of two organochlorines in fish from all sampled lakes in North Cascades and Mount Rainier NPs (Figure 32).

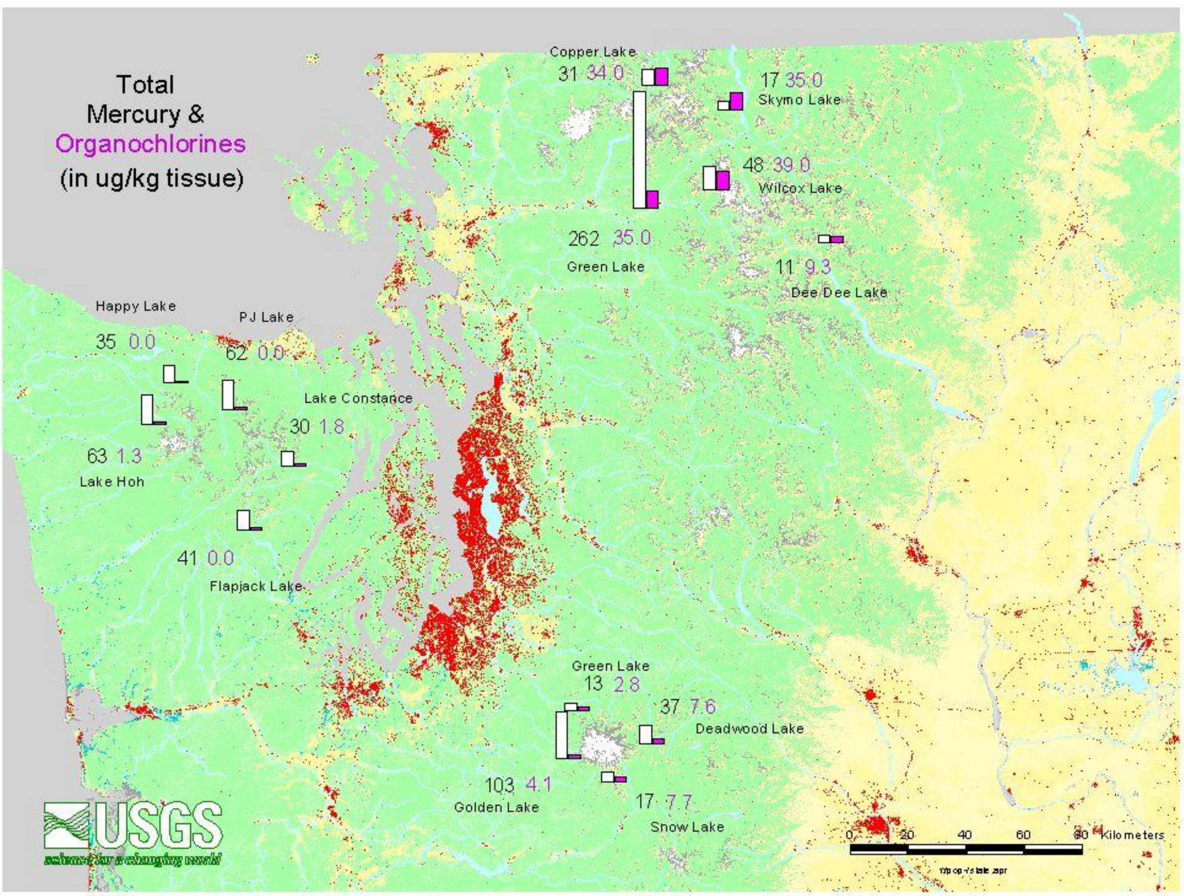

Figure 32. Concentrations of Hg and organochlorines, in micrograms per kilogram (µg/kg; equivalent to ng/g ww), in fish collected from lakes at Olympic, North Cascades and Mount Rainier NPs (produced by USGS, date unknown).

Schreck and Kent (2013) analyzed fish collected in 2008-2009 from North Cascades, Mount Rainier and nine 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. None of the 57 male fish from five lakes at North Cascades NP or the 48 male fish from twelve lakes at Mount Rainier NP exhibited intersex. While some of the female fish collected in the parks had signs of male cells in their ovaries, the authors concluded those were likely false positives due to sample contamination. Relatively high rates of intersex in male fish occurred only in lakes in Rocky Mountain parks.

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 Olympic NP (Figure 33; Landers et al., 2008). The authors used passive air sampling devices, and snow, conifer needle, lichen, surface water, sediment and fish tissue samples, to assess PBTs in the Hoh and PJ Lake watersheds at Olympic 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 involved in the WACAP study (from Landers et al., 2008).

The passive air sampling device data indicated concentrations of semi-volatile organic compounds (SOC) were similar at Hoh Lake on the west side of the park and PJ Lake on the east side of the park. Mercury deposition in snowpack, i.e., flux, (Figure 34) was higher than expected. Mercury and SOC concentrations in vegetation were at mid- to upper ranges compared to concentrations at other parks. The vegetation samples were collected along an elevational transect. While some SOCs, such as PCBs and pesticides, increased in vegetation with elevation, concentrations of polycyclic aromatic hydrocarbons (PAH) decreased with elevation (Figure 35). Landers et al. 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 pesticides in fish from Olympic NP were low to average compared to concentrations at other parks. Fish Hg concentrations were among the highest of all parks, with some fish from both Hoh and PJ Lakes exceeding the human health threshold (Figure 36). Sediment profiles from both lakes showed enrichment toward the surface (present time) of Hg, cadmium and lead beginning in the late 1800s (Figure 37).

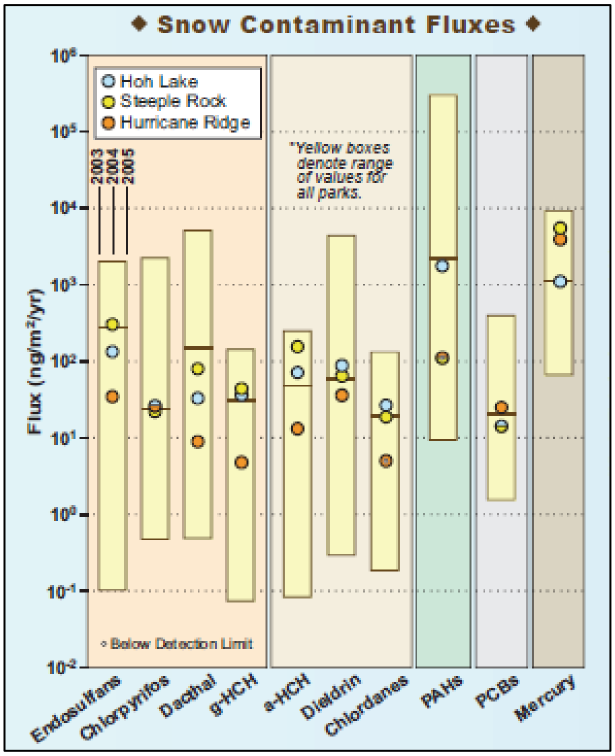

Figure 34. Flux of PBTs in snowpack collected at Olympic NP in 2003-2005 as part of the WACAP study (from Landers et al., 2008). Horizontal lines in boxes indicate median values. From left to right, pollutant categories represented by large shaded boxes are Current-Use Pesticides, Historic-Use Pesticides,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

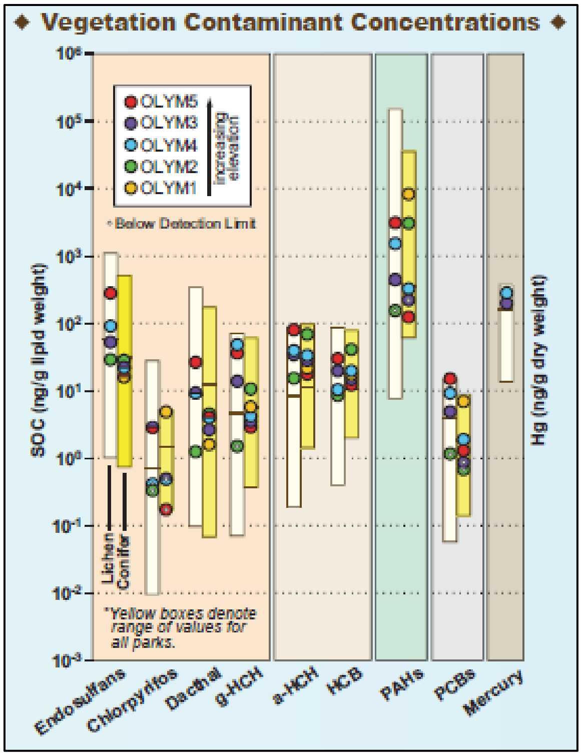

Figure 35. Concentrations of PBTs detected in vegetation along an elevation gradient in Olympic NP in 2004 as part of the WACAP study (from Landers et al., 2008). Horizontal lines in boxes indicate median values. From left to right, pollutant categories represented by large shaded boxes are Current-Use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

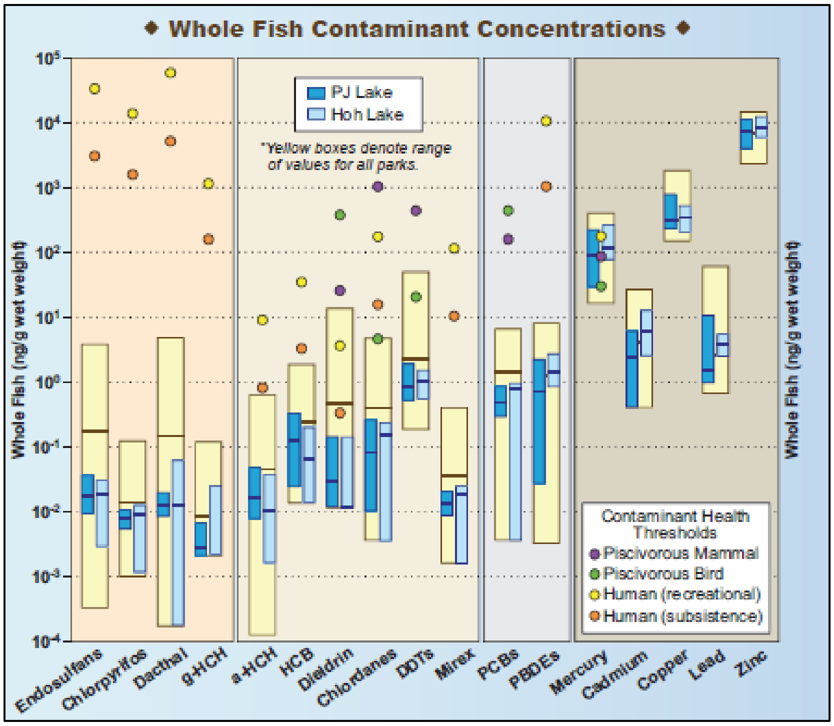

Figure 36. Concentrations of PBTs detected in fish collected from PJ and Hoh Lakes in Olympic NP in 2005 as part of the WACAP study (from Landers et al., 2008). Horizontal lines in boxes indicate median values. . From left to right, pollutant categories represented by large shaded boxes are Current-Use Pesticides, Historic-Use Pesticides, Combustion By-products and Metals.

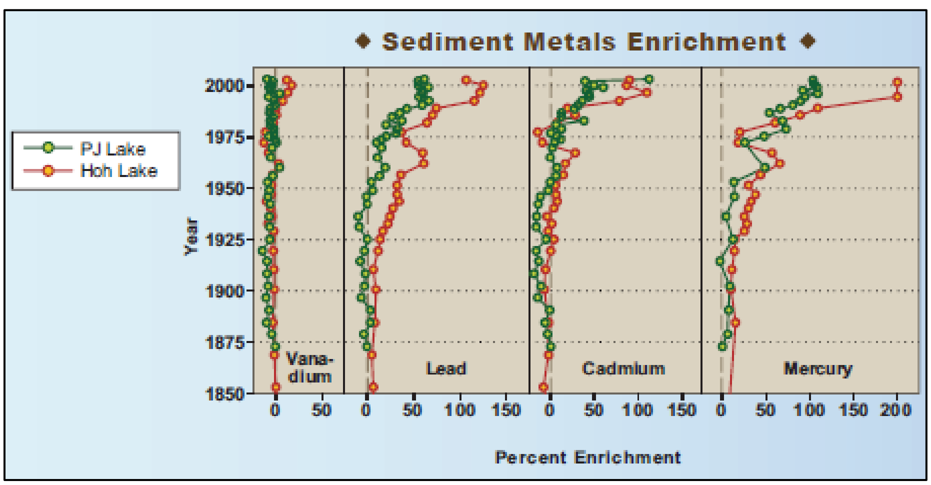

Figure 37. Percent enrichment of metals in sediment cores collected from PJ and Hoh Lakes in Olympic NP in 2005 as part of the WACAP study (from Landers et al., 2008).

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

As part of a statewide toxics monitoring program, WDOE sampled fish from Ozette Lake in 2004 (Seiders et al., 2007) and 2007 (Seiders and Deligeannis, 2009a). Based on a 2004 largemouth bass (*Micropterus salmoides*) sample, Ozette Lake was placed on the state's Impaired Waterbodies list for Hg. A northern pikeminnow (*Ptychocheilus oregonensis*) collected from the lake in 2007 had a Hg concentration of 1,600 ng/g ww (Seiders and Deligeannis, 2009a) and a largemouth bass collected the same year had a concentration of 1,800 ng/g ww (Furl and Meredith, 2008). A 2010 study found much lower Hg concentrations in Ozette Lake sockeye salmon (*Oncorhynchus nerka*), i.e., 24-50 ng/g ww, than in other species (Furl, 2011). Sediment cores were collected at Ozette Lake and nearby Lake Dickey (outside the park) to assess the sources and pathways of Hg to the lakes. Sediment core data showed Hg concentrations correlated strongly with increased sedimentation from logging in the watersheds (Furl et al., 2010). Washington Department of Ecology sampled fish from the Quinault River in 2008; the highest Hg concentration detected was 147 ng/g ww (Seiders and Deligeannis, 2009b). Because of high Hg concentrations, fish consumption advisories are in effect for Hoh, Ozette and PJ Lakes (Brenkman, 2012).

The 2004-2008 WDOE studies detected dioxins, furans and PCBs in fish from Ozette Lake and the Quinault River (Seiders and Deligeannis, 2009a; Seiders and Deligeannis, 2009b). The Quinault River was also sampled in 2008 as part of a statewide survey of perfluorinated compounds in lakes and rivers. Concentrations in both surface water and fish tissue from the Quinault River were less than the laboratory detection levels (Furl and Meredith, 2010). Washington Department of Ecology collected water and fish samples from Ozette Lake and the Queets River in 2005 as part of a statewide survey for polybrominated diphenyl ether flame retardants. Concentrations from both locations were at or below the limit of detection (Johnson et al., 2006).

Olympic NP is included in three current efforts to evaluate the extent of Hg contamination in national parks. In 2011 and 2012, Eagles-Smith, USGS, analyzed Hg concentrations in fish from lakes spanning more than 20 western national parks (Figure 38). Fish samples from Gladys, Sunup and Upper Lena Lakes were included in the analysis. Also in 2012, Eagles-Smith studied the food webs of the eight Olympic NP lakes included in the NCCN I&M long term monitoring project, plus Hoh Lake, to determine if competition from introduced fish causes native larval salamanders to alter their diet, thereby increasing salamander Hg concentrations. Reports for both projects will be available in 2013.

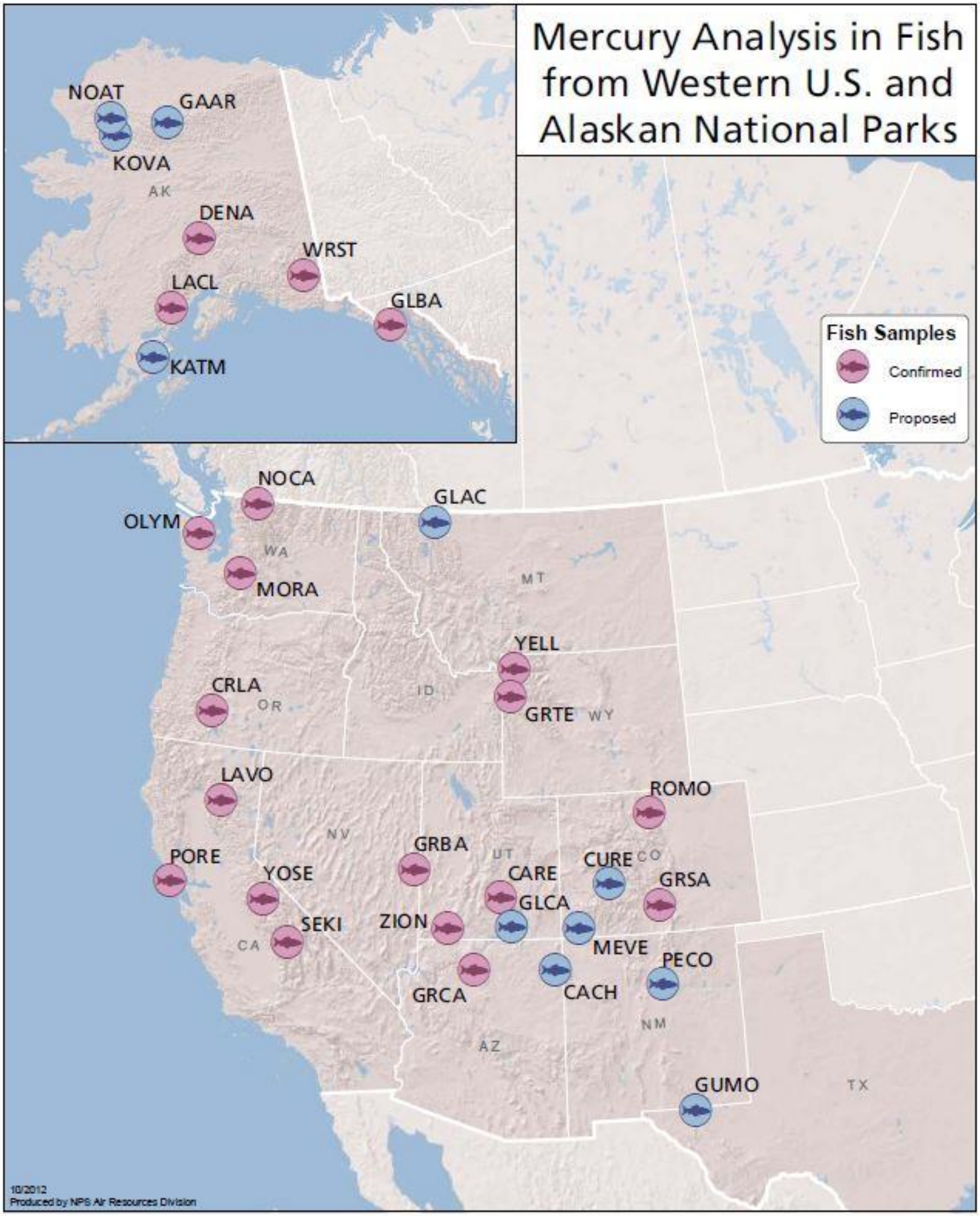

Figure 38. Map of parks with fish Hg concentrations analyzed by the USGS in 2011-2012 (produced by NPS ARD, 2012). OLYM is Olympic NP.

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 39). 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 Olympic NP.

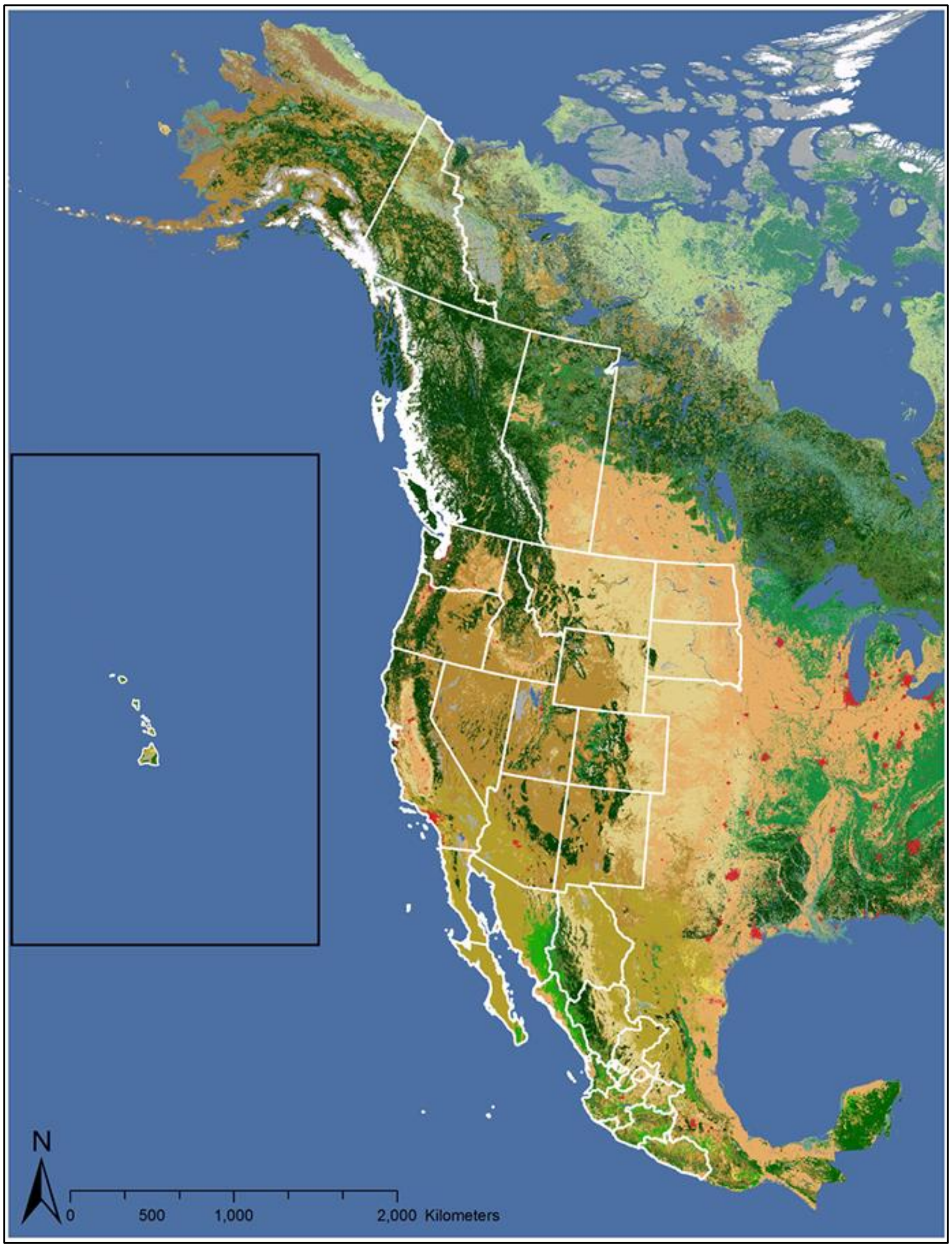

Figure 39. Map showing geographic area of the Western North America Mercury Synthesis Project (Biodiversity Research Institute, 2012).

Conclusions

Olympic 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 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 1980. Park air quality is in compliance with all the NAAQS. Nevertheless, park resources have been affected by air pollution.

Current average visibility at the park is about 48 percent hazier than natural conditions; however visibility improved on the best, average and worst days from 2000-2009. Currently, 36-47 percent of the haze at the park is due to SO_4. Under natural conditions, the contribution to visibility impairment from SO_4 would be less than 19 percent.

There were no significant trends in NADP wet S or N concentrations from 2000-2009, but NH_4 concentrations in precipitation decreased significantly from 1989-2008. Most of the N and S deposited in the park is in the form of wet deposition.

Sensitive Olympic NP 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 and Olympic 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 Olympic NP. Efforts are underway to define N critical loads for other ecosystem components.

Ozone has been monitored at several locations in the park. Concentrations generally increase with elevation, but do not reach levels known to harm human health or vegetation. 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 at Olympic, Mount Rainier and North Cascades NPs are trying to identify watershed characteristics that enhance Hg methylation and to determine the extent of Hg contamination in fish, amphibians and invertebrates.

Continued monitoring and research are critical for assessing trends in air quality and improving understanding of air pollution effects on AQRVs. 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 are:

- 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 Olympic NP site is uniquely situated to collect precipitation chemistry data that reflect global background conditions.
- 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.
- More information is needed about the occurrence and extent of PBTs and their effects on park biota. Also, because wildlife heath 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 glacial melting.

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