



Air Quality Related Values (AQRVs) for North Coast and Cascades Network (NCCN) Parks

Effects from Ozone; Visibility Reducing Particles; and Atmospheric Deposition of Acids, Nutrients and Toxics

Natural Resource Report NPS/NCCN/NRR—2016/1173



ON THE COVER

Photograph of air quality related values within various National Park units. Wildflowers, clear views, aquatic species, and lichens may all be threatened by air pollution.

Photographs courtesy of the National Park Service

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Summary

This report describes the Air Quality Related Values (AQRVs) of the North Coast and Cascades Network (NCCN). The NCCN parks that are included in the NPS Inventory and Monitoring (I&M) Program and discussed in this report are Mount Rainier (MORA), North Cascades (NOCA), and Olympic (OLYM) national parks; Ebey's Landing National Historical Reserve (EBLA); Fort Vancouver National Historic Site (FOVA); Lewis and Clark National Historical Park (LEWI); and San Juan Island National Historical Park (SAJH). MORA, NOCA and OLYM are designated as Class I parks, giving them a heightened level of protection against harm caused by poor air quality under the Clean Air Act (CAA); the rest of the parks are Class II areas. Sullivan et al. (2011a, 2011b) and Kohut (2007) conducted risk assessments for acidification, eutrophication and ozone (O_3) for all of the NCCN parks; their results are described in this report. However, because most of the air quality and AQRV data have been collected in the three Class I areas, those parks will be the major focus of this report.

AQRVs are those resources sensitive to air quality and include streams, lakes, soils, vegetation, fish and wildlife, and visibility. This report also describes nearby air pollutant emissions and air quality within the NCCN, and their effects on AQRVs. The primary pollutants likely to affect AQRVs include nitrogen (N) and sulfur (S) compounds (nitrate [NO_3^-], ammonium [NH_4^+], and sulfate [SO_4^{2-}]); ground-level O_3 ; haze-causing particles; and airborne toxics. Background for this section can be found in "Air Quality Related Values (AQRVs) in the Inventory and Monitoring (I&M) National Parks: Status of Visibility Degradation, Ozone Effects on Vegetation, and the Effects on Natural Resources of Atmospheric Acid, Nutrient, and Toxics Deposition" (Sullivan 2016).

The air quality in the NCCN is generally very good compared to other areas of the United States. The principal air masses that impact NCCN parks are mainly derived from the atmosphere over the Pacific Ocean, and as a consequence, accumulated air pollutant concentrations are usually relatively low at most park locations. Nevertheless, local and regional sources of air pollutants impact sensitive resources in the NCCN. Pollution sources mainly include motor vehicles; power plants; industrial facilities in Portland, Seattle/Tacoma/Everett, Victoria/Vancouver/Chilliwack metro areas, and other cities along the I-5 corridor; and marine shipping traffic. MORA, NOCA, OLYM, SAJH, and EBLA are located close to the Puget Sound urban zone; FOVA is in the Portland urban zone. LEWI is on the Oregon coast and, therefore, is less influenced by urban pollution.

Air pollutants of most concern in the NCCN include N compounds and toxic airborne contaminants. Sulfur emissions, which contribute significantly to acidic deposition in the eastern United States, are relatively low upwind from NCCN parks. Nitrogen emissions, which can contribute to both acidification and eutrophication effects, are elevated in some parts of the NCCN region. Contributions to total human-caused nitrogen oxides (NO_x) emissions in the NCCN region are much higher from mobile sources than from area sources or point sources. Emissions of ammonia (NH_3) derive mainly from agricultural sources, including animal manures and fertilizer. Airborne contaminants, including pesticides and mercury (Hg) from regional sources, also affect the parks. Measurements of atmospheric O_3 , carbon monoxide (CO), hydrocarbons, and aerosol chemistry in air

arriving in the Pacific Northwest from Eurasia have shown that a variety of contaminants, including Hg, can be transported across the Pacific Ocean to the NCCN region. Such long-range transported contaminants are typically found at relatively low concentrations in the NCCN region (Jaffe et al. 2003).

Although S deposition levels are relatively low in the NCCN, some aquatic and terrestrial ecosystems in this network are potentially highly sensitive to acidification from atmospheric deposition of S, the main driver of acidification, and N. A coarse screening risk assessment concluded that the overall level of concern for acidification effects on national park units within the NCCN is very high, relative to all other I&M networks across the country (Sullivan et al. 2011b). Because S and N emissions and deposition in the NCCN region are relatively low, acidification to date has been minimal (U.S. Environmental Protection Agency (EPA) 2009). High-elevation lakes are common within the three larger parks, i.e., NOCA, MORA, and OLYM. Each of these parks also contains an extensive network of potentially acid-sensitive high-elevation and low-order streams. Lakes and streams in MORA and NOCA, which are located in the Cascade Mountains, are especially sensitive to impacts from acidic deposition because of the predominance of base-poor bedrock and thin acidic soils, large amounts of precipitation, prevalence of coniferous vegetation, steep slopes, and the dilute nature of the surface waters (Eilers et al. 1994). Each of these characteristics limits the extent to which acidic inputs are neutralized by watershed soils. Substantial portions of the NCCN contain areas of exposed bedrock, with little soil or vegetative cover to neutralize acidic inputs. As a consequence, surface waters in the Washington Cascade Mountains are among the most poorly buffered in the United States (Landers et al. 1987). Although surface water acidification has not been observed in MORA or NOCA, the high elevation aquatic habitats in these parks and other areas of the Cascade Mountains provide conditions that maintain diverse populations of aquatic organisms, but nevertheless may experience occasional episodic acidification with potential lethal consequences to aquatic biota. In contrast to MORA and NOCA, all analyses of lakes and streams in OLYM have shown them to be well buffered and relatively insensitive to stress from acidic deposition, in part due to high rates of weathering and chemical composition of the local geology (Naiman et al. 1986). Comparing acid neutralizing capacity (ANC) and pH levels between the Cascade and Olympic mountains of Washington illustrates the effect of bedrock type on streams. Bedrock in the Olympic Mountains is of marine sedimentary origin, while that in the Cascades is mostly igneous and more resistant to weathering. As a result, ANC and pH levels in water draining from the Olympic Mountains are higher than in water draining from the Cascade Mountains. Streams, lakes, and soils in the smaller and lower elevation parks in the NCCN are expected to be well-buffered and resistant to acidification.

Nitrogen pollutants can cause undesirable nutrient enrichment of natural ecosystems, leading to changes in plant species diversity. Remote oligotrophic waters are commonly N-limited, especially undisturbed northern temperate or boreal lakes that receive low levels of atmospheric N deposition. The overall level of concern for nutrient N enrichment effects on parks within the NCCN is very high relative to other I&M networks nationwide (Sullivan et al. 2011a). High-elevation lakes might be more prone than lakes at lower elevation to N-limitation (Elser et al. 2009a), and therefore potentially more susceptible to eutrophication in response to atmospheric N input. Lakes in MORA are more

likely to be N-limited than lakes in NOCA, due to lower NO_3^- concentrations in lakewater. Eutrophication effects on freshwater ecosystems from atmospheric deposition of N are of greatest concern in lakes and streams that have very low productivity and nutrient levels, such as in MORA, NOCA, and OLYM. All three of the larger parks in the NCCN also contain extensive areas of alpine and subalpine vegetation, along with some meadow and wetland vegetation, which are among the predominant vegetation types found to be sensitive to nutrient N enrichment. Of the smaller parks, much of SAJH is presumed to be highly sensitive to potential effects from N enrichment because more than one-third of this park is covered by highly sensitive prairie vegetation.

Air pollution, specifically from N, has caused lichen communities in some areas of the Pacific Northwest to lose biodiversity, but this has not been documented in NCCN parks. Among the smaller parks, modeling results suggest that lichens in FOVA, a park surrounded by urban land use, may be affected by air pollution (Geiser et al. 2010), but empirical data are not available to verify this. In urban areas, intensive agricultural zones, and areas downwind of major urban and industrial centers in the NCCN region, there are few air pollution-sensitive lichen species present. Replacement of sensitive lichens by nitrophilous (N-loving) species has undesirable ecological consequences. Lichens make important contributions to mineral cycling and soil fertility and comprise integral parts of the food web that supports mammals, insects, and birds (McCune and Geiser 1997, U.S. EPA 2005). Sensitive lichen species appear to be negatively affected by N inputs as low as 3 to 9 kilograms/hectare/year (kg/ha/yr ; Geiser et al. 2010). Available empirical data for ecoregions represented in NCCN parks suggest that the critical load (CL; lowest deposition level at which biological harm is expected) for protecting mycorrhizal fungi, herbaceous plants, and forests, and for prevention of NO_3^- leaching in various NCCN parks may be exceeded by ambient N deposition.

Ozone pollution can harm human health, reduce plant growth, and cause visible injury to foliage. Ozone concentrations in the Pacific Northwest region have occasionally exceeded National Ambient Air Quality Standards (NAAQS) intended to protect human health and welfare (including ecosystems). Maximum atmospheric O_3 concentrations are generally found downwind of urban centers in the Portland and Puget Sound areas and at higher elevations. As illustrated by the Interagency Monitoring of Protected Visual Environments Network (IMPROVE) data summarized here, the highest weekly average O_3 concentrations in western Washington were measured at the highest elevation sites in MORA. Although O_3 is of some concern with respect to air pollution effects on vegetation in national parks in the NCCN, the overall risk to vegetation does not appear to be high at the present time. The O_3 concentrations and overall O_3 risk assessment rankings (Kohut 2007) were low across all parks within the network. Among the park lands in the NCCN, MORA probably faces the highest risk from O_3 .

Particulate pollution can cause haze, reducing visibility. Visibility at the monitored parks in NCCN is impaired at times, with monitored visibility on the 20% haziest days about 5 deciviews (dv; NOCA), 7 dv (OLYM), and 8 dv (MORA) higher than estimated natural background conditions. Lower dv values represent less haze and correspond with better visibility conditions. Haze levels are generally trending downward and visibility is improving, especially at MORA, on the 20% haziest, 20%

clearest, and average days. The majority of haze in the region is attributable to SO_4^{2-} - from sulfur dioxide (SO_2) emissions and organics from fires, agriculture and other sources.

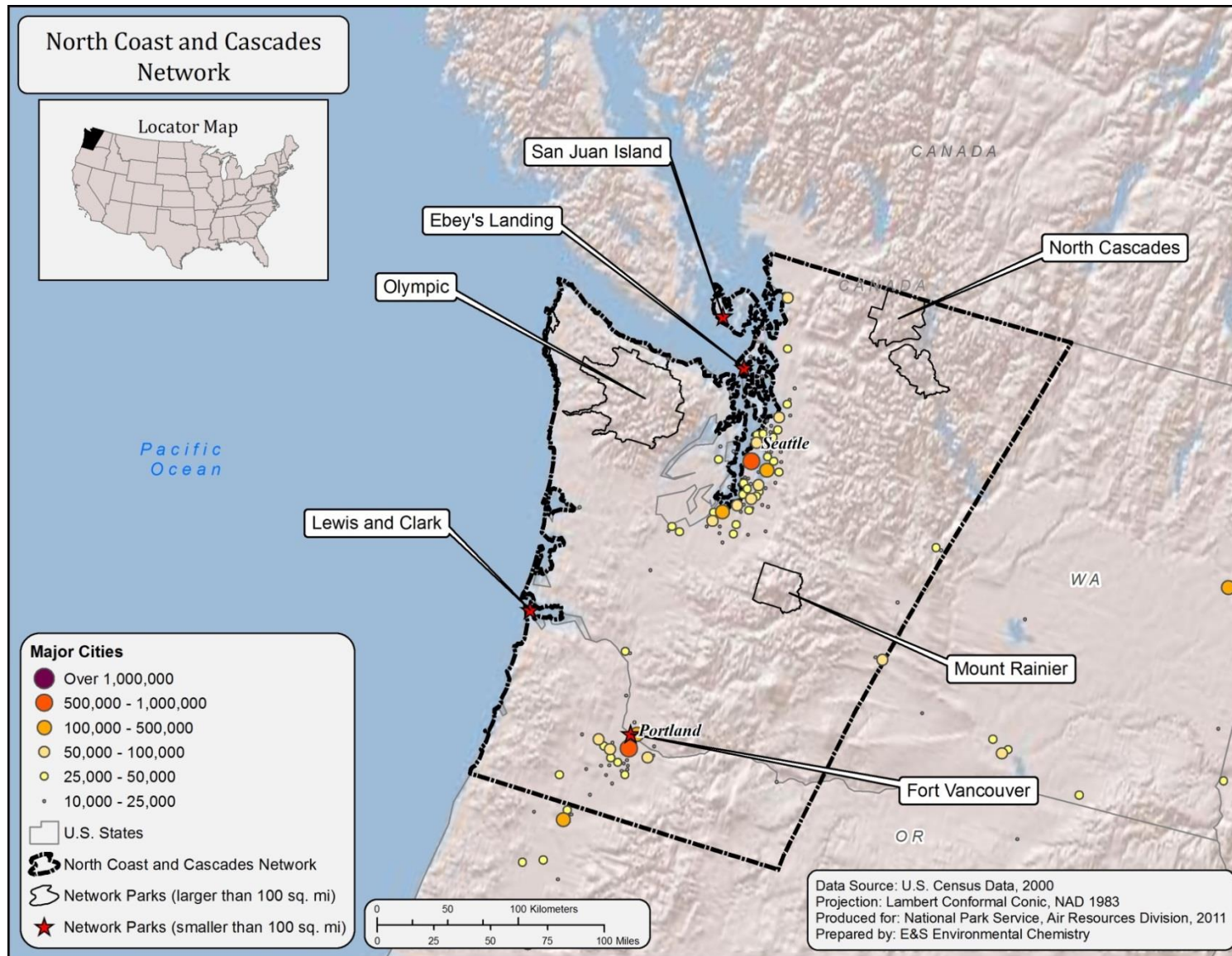
Airborne toxics can harm humans, fish, and wildlife in the NCCN. During the Western Airborne Contaminants Assessment Project (WACAP) study (Landers et al. 2010), fish and/or other environmental indicators were sampled for Hg, pesticides, and other toxics at MORA, NOCA and OLYM. Bioaccumulation of Hg was documented in some OLYM and MORA fish at levels that exceeded health thresholds for humans, mammals (otter and mink) and piscivorous birds. High Hg concentrations have also been measured in fish sampled in NOCA by the Washington Department of Ecology and U.S. Geological Survey. Reasons for these high levels of Hg contamination in fish caught in the larger NCCN parks are unclear, but are likely a combination of elevated Hg deposition from power plants and long-range transport and the presence of ecosystems, such as wetlands, that are conducive to Hg methylation, making this pollutant available for uptake by aquatic organisms. PBDEs (flame retardants) and dieldrin (a banned pesticide) were found at elevated levels in some MORA fish (Landers et al. 2010).

The WACAP study illustrated that vegetation may play an important role in collecting and depositing atmospheric semivolatile organic compounds (SOCs). The WACAP final report (Landers et al. 2010) postulated that SOC particles that are dry-deposited to vegetation likely contribute substantial contaminant loads to terrestrial ecosystems via canopy throughfall and litterfall.

Background

There are three parks larger than 100 square miles (260 km²) in the NCCN: Mount Rainier (MORA), North Cascades (NOCA), and Olympic (OLYM) national parks. NOCA is jointly managed with the Ross Lake and Lake Chelan National Recreation Areas. There are also four parks smaller than 100 square miles: Ebey's Landing National Historical Reserve (EBLA); Fort Vancouver National Historic Site (FOVA); Lewis and Clark National Historical Park (LEWI); and San Juan Island National Historical Park (SAJH). Larger parks generally have more available data with which to evaluate air pollution sensitivities and effects. In addition, the larger parks generally contain more extensive resources in need of protection against the adverse impacts of air pollution.

The major urban centers (larger than 500,000 people) in the NCCN region are Seattle, Washington, and Portland, Oregon. Vancouver, British Columbia lies just to the north of the network boundary. Map 1 shows the network boundary and the location of each national park along with human population centers with more than 10,000 people. MORA, NOCA, OLYM, SAJH, and EBLA are within about 60 miles (100 km) of emissions sources in the Seattle/Tacoma metropolitan area. OLYM, NOCA, and SAJH are all in fairly close proximity to large urban centers in Vancouver and Victoria, British Columbia, Canada. OLYM and SAJH are adjacent to busy marine shipping channels. FOVA is located in the Portland metropolitan area. LEWI is located at a coastal location, relatively remote from urban influence.



Map 1. Network boundary and locations of national parks and population centers with more than 10,000 people in the NCCN region.

Weather influences atmospheric deposition processes and ecosystem acidification. The seaward slopes of the Olympic Mountains receive more precipitation than any other place in the contiguous United States. Between 120 and 160 inches (300 and 400 cm) of precipitation fall annually in the Hoh and Queets valleys of OLYM. East of the mountains in Sequim, annual rainfall declines to only 18 inches (45 cm), in the rain shadow of the Olympic Mountains. SAJH and EBLA are also situated in the rain shadow. Elevation in OLYM ranges from sea level to 7,965 ft (2,428 m) at Mt. Olympus.

The Coast Range of Oregon and the western slopes of the Cascade Mountains in both Washington and Oregon also receive substantial precipitation, exceeding 80 to 120 in (200 to 300 cm) at many locations. At the higher elevations, much of this precipitation falls as snow. Mount Rainier is the highest of the Cascade Mountain volcanoes, at 14,410 ft (4,392 m), and the fifth tallest mountain in the contiguous United States. The mountain occupies more than one fourth of the area of MORA. Its glaciers comprise the largest mass of permanent ice in the United States outside Alaska.

The three largest parks in the NCCN contain alpine parks, glaciers, and large rivers. OLYM also includes a coastal zone. The dominant aquatic features of OLYM are the 13 major rivers flowing from the Olympic Mountains in all directions and the 648 lakes and ponds found in the park. These are generally well-buffered aquatic systems draining sedimentary bedrock and glaciers with high silt loads. There are many high-elevation lakes, some of which have been sampled for water chemistry, and several large low-elevation lakes that have been studied in some detail (Eilers et al. 1994).

OLYM has sedimentary and basaltic rocks derived from uplifted marine strata. All analyses of lakes and streams in OLYM have shown them to be well buffered and insensitive to stress from acidic deposition (Eilers et al. 1994).

Terrain in NOCA is steep and rugged, and includes numerous alpine peaks, glaciers and rivers, with strongly dissected deep forested valleys. Mountain lakes without direct glacial influence are the most susceptible to acidification. Many of the 245 natural lakes in NOCA are in subalpine and alpine settings, and are accessible only on foot. The natural lakes and stream valleys were formed by glacial action which is still evident throughout the park. Glaciers cover about 42 mi² (109 km²) in NOCA, more than any other park unit in the conterminous United States. Igneous (granitic) and metamorphic rocks form a central core in the park. The granitic rocks are mainly granodiorite and quartz diorite, which are resistant to weathering and contribute little buffering to drainage waters.

MORA has an extensive network of streams and rivers radiating from the summit and high elevation glaciers of Mt. Rainier. The park contains 35 mi² (91 km²) of snowfields and glaciers. Glacial activity has created nearly 200 lakes and ponds. The glaciers that remain on the mountain feed the streams and some of the lakes with meltwater. The lakes are distributed around the mountain and extend from montane to alpine settings. Many of the lakes are located at higher elevations and may remain ice-free only three to four months of the year.

Atmospheric Emissions and Deposition

Local and regional sources of air pollutants in the NCCN region include mainly motor vehicles, power plants, and industrial facilities in the Puget Sound area (Clow and Campbell 2008), the Portland metropolitan area and the eastern end of the Columbia River Gorge. Marine vessels are also a significant source of emissions that are transported to EBLA, LEWI, OLYM and SAJH. Sulfur (S) is generally emitted as sulfur dioxide (SO_2) from coal-burning power plants, smelting, and diesel engines, depositing eventually as sulfate (SO_4^{2-}). Nitrogen (N) is emitted as oxidized N (NO_x) from vehicles, power plants, industry, and fires, or as reduced N (NH_3) from agriculture and fertilizer use, eventually depositing mainly as nitrate (NO_3^-) or ammonia (NH_4^+). Toxic air pollutants include a wide variety of organic compounds and heavy metals and may be emitted from power plants, industry, and agriculture.

Emissions

In general, annual county average SO_2 emissions in 2002 were estimated at less than 5 tons per square mile ($\text{tons}/\text{mi}^2/\text{yr}$) throughout most of the NCCN region, with only one county in the 5 to 20 $\text{tons}/\text{mi}^2/\text{yr}$ range (Sullivan et al. 2011b). Most individual point sources of SO_2 were below 5,000 tons per year with only one point source, a coal-fired power plant, in the range of 5,000 to 20,000 tons/yr. Only one N point source larger than 2,500 tons per year exists in the NCCN region (TransAlta's Centralia power plant), but N emissions from this source are expected to decrease substantially, and the coal-fired boilers will be replaced by a natural gas-fired power plant by 2025 (T. Cummings, NPS, personal communication, August, 2014). Even before shutdown of the Centralia coal-fired boilers, contributions to total human-caused NO_x emissions in the Cascadia region, including the NCCN, were much higher from mobile sources than from area sources or point sources (70% vs. 12% and 18%, respectively; Barna et al. 2000).

Local emissions sources of pesticides, Hg, polycyclic aromatic hydrocarbons (PAHs), and other toxic materials also influence NCCN parks. Such emissions derive from agriculture, power plants, fire, and other point and non-point sources. To date, these sources have not been well quantified.

County-level emissions near NCCN, based on data from the EPA's National Emissions Inventory (NEI) during a recent time period (2011), are depicted in Maps 2 through 4 for SO_2 , NO_x , and NH_3 , respectively. Many counties near the NCCN parks had SO_2 emissions in the range of 1 to 5 $\text{tons}/\text{mi}^2/\text{yr}$ (Map 2). Patterns in NO_x emissions were generally higher, at many locations higher than 5 $\text{tons}/\text{mi}^2/\text{yr}$ (Map 3). Emissions of NH_3 near NCCN parks were mostly below 2 $\text{tons}/\text{mi}^2/\text{yr}$ (Map 4).

Deposition

Atmospheric pollutants can be deposited as wet (rain and snow), dry (dryfall and aerosols), or occult (cloud and fog) deposition. Wet deposition appears to be higher than dry deposition in NCCN parks, and it was estimated to make up more than 70% of total wet plus dry N and S deposition, based on Community Multiscale Air Quality (CMAQ) atmospheric deposition model simulations (Sullivan et al. 2011b). The contribution from occult deposition is unknown.

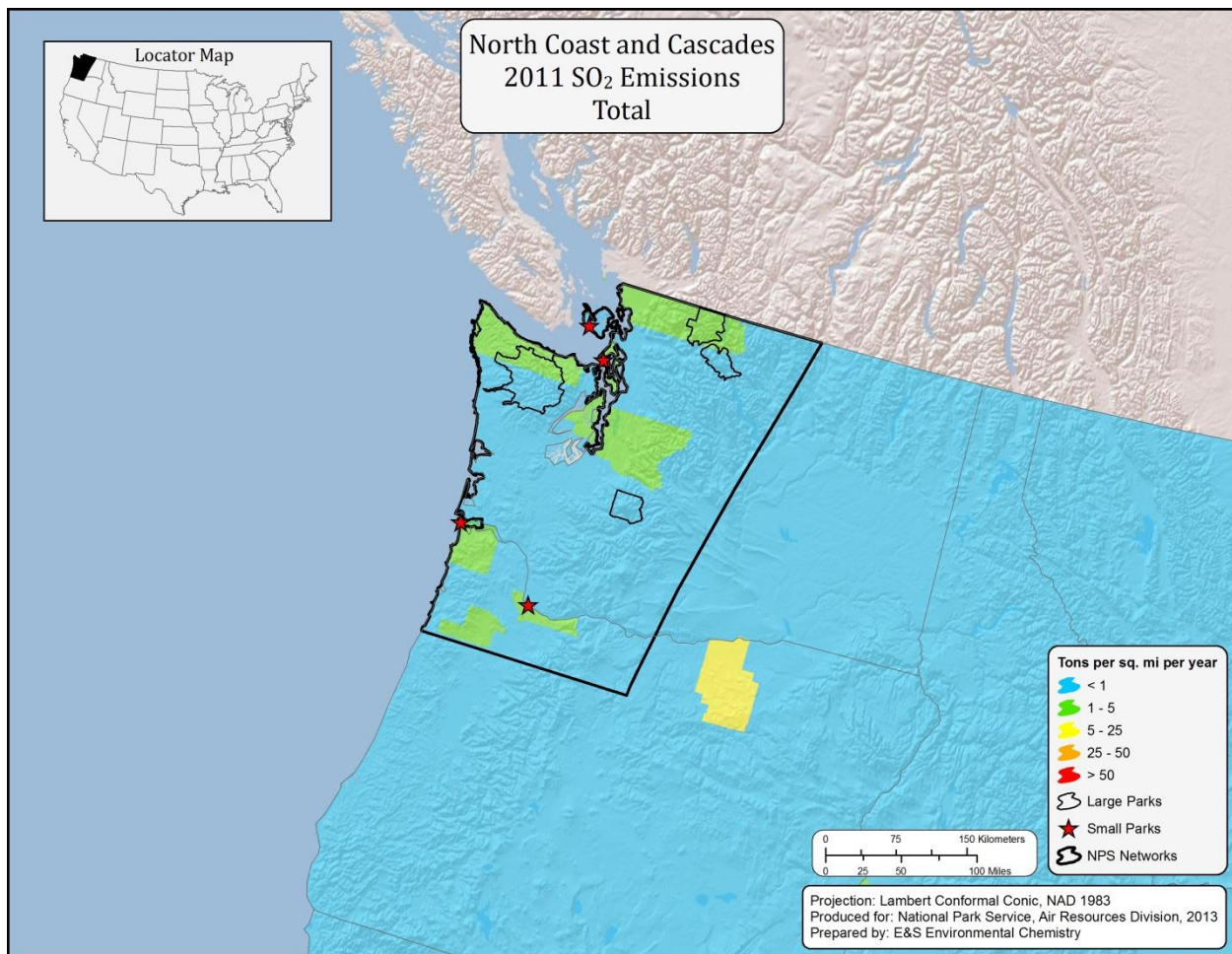
Recently, Schwede and Lear (2014) documented a hybrid approach developed by the National Atmospheric Deposition Program (NADP) Total Deposition (TDEP) Science Committee for estimating total N and S deposition. This approach combined monitoring and modeling data. Modeling was accomplished using the Community Multiscale Air Quality (CMAQ) model (Byun and Schere 2006). Priority was given to measured data near the locations of the monitors and to modeled data where monitoring data were not available. In addition, CMAQ data were used for N species that are not routinely measured in the monitoring programs: peroxyacetyl nitrate (PAN), N_2O_5 , NO, NO_2 , HONO, and organic NO_3 . The total deposition estimates are considered to be dynamic, with updates planned as new information becomes available. TDEP data reported here were developed in late 2013 and are designated version 2013.02.

Atmospheric S deposition levels have declined at all NCCN parks except EBLA since 2001, based on TDEP estimates (Table 1). Decreases in total S deposition over the previous decade for the parks in this network have mostly been larger than 25%. Estimated total N deposition over that same time period decreased at some NCCN parks and increased at others. Oxidized N decreased at all parks except EBLA. Reduced N deposition increased at all network parks, in many cases by substantial amounts.

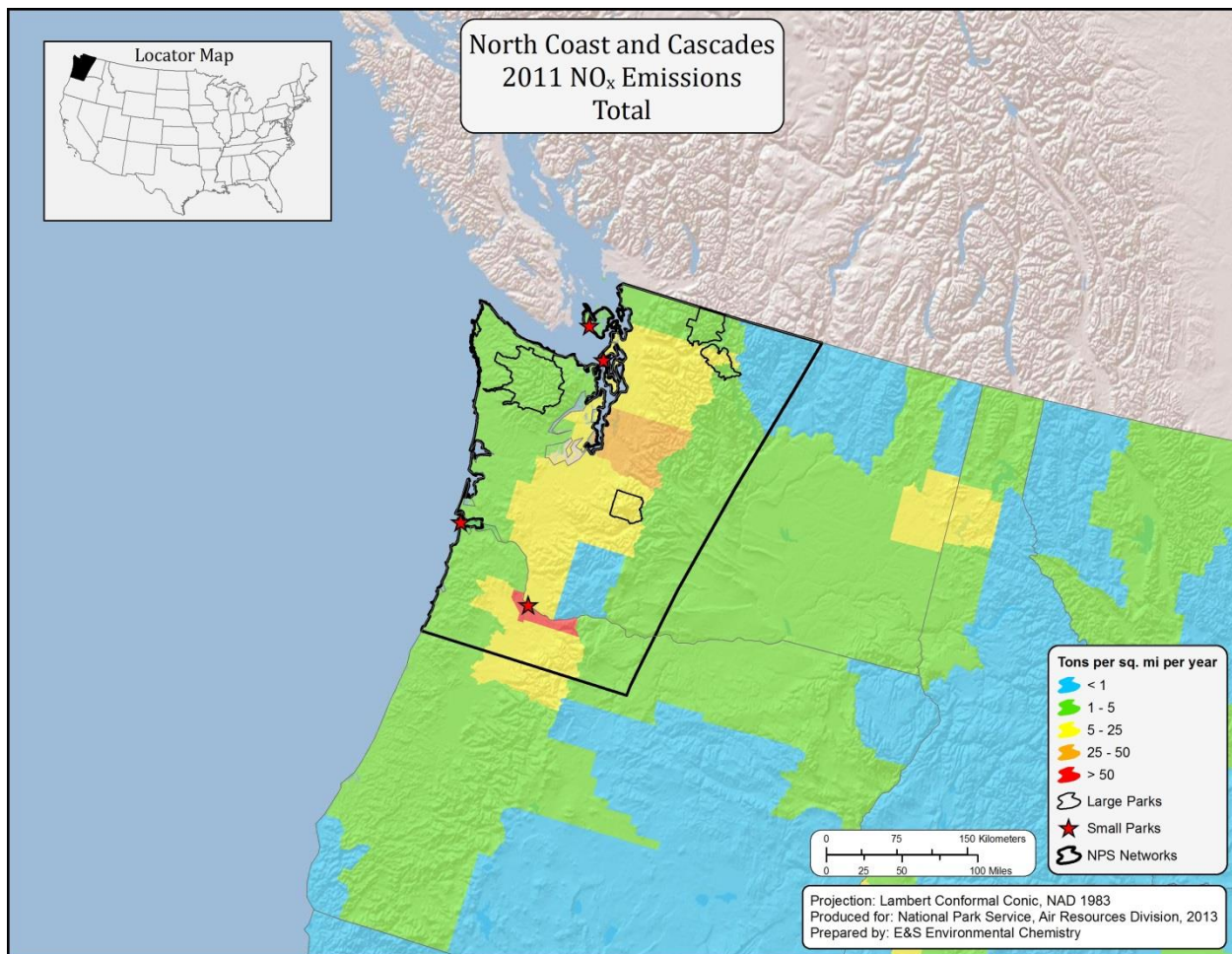
Total S deposition in and around NCCN for the period 2010-2012 was generally < 5 kg S/ha/yr at park locations (Map 5). Oxidized inorganic N deposition for the period 2010-2012 was less than 5 kg N/ha/yr throughout the park lands within NCCN (Map 6). Most areas received less 2 kg N/ha/yr of reduced inorganic N from atmospheric deposition during this same period (Map 7); a few areas received higher amounts. Total N deposition was less than 5 kg N/ha/yr at most park locations (Map 8); Some areas were estimated to have received higher amounts, up to 10 kg N/ha/yr.

Recently, the NADP produced estimates for wet S and N deposition that account for elevational differences in precipitation (<http://nadp.sws.uiuc.edu/>). Generally, higher elevation areas experience higher precipitation and, as a consequence, higher wet deposition of both S and N.

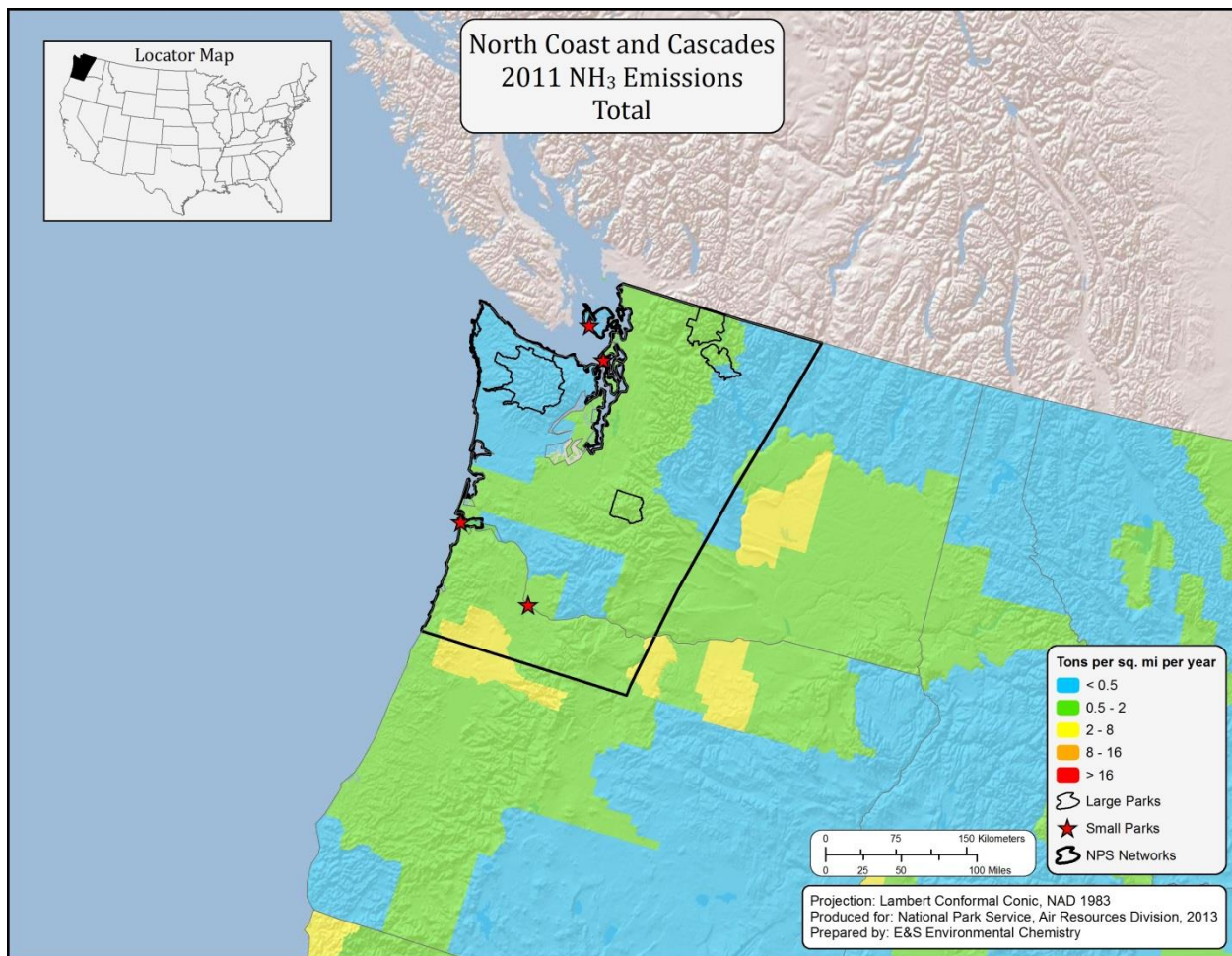
Data from a U.S. Geological Survey study in MORA and NOCA suggested that, during the 1986 to 2005 period, wet S deposition declined significantly while wet N deposition remained relatively stable (Clow and Campbell 2008). Decreases in S deposition were more pronounced after 2001 when emissions controls were added to TransAlta's Centralia power plant (Clow and Campbell 2008). Sulfur deposition in the NCCN region has never been high, compared to areas in the eastern United States, for example, and these relatively low deposition levels have been further reduced over the past two decades in response to emissions controls.



Map 2. Total SO₂ emissions, by county, near NCCN for the year 2011. Data from EPA's National Emissions Inventory.



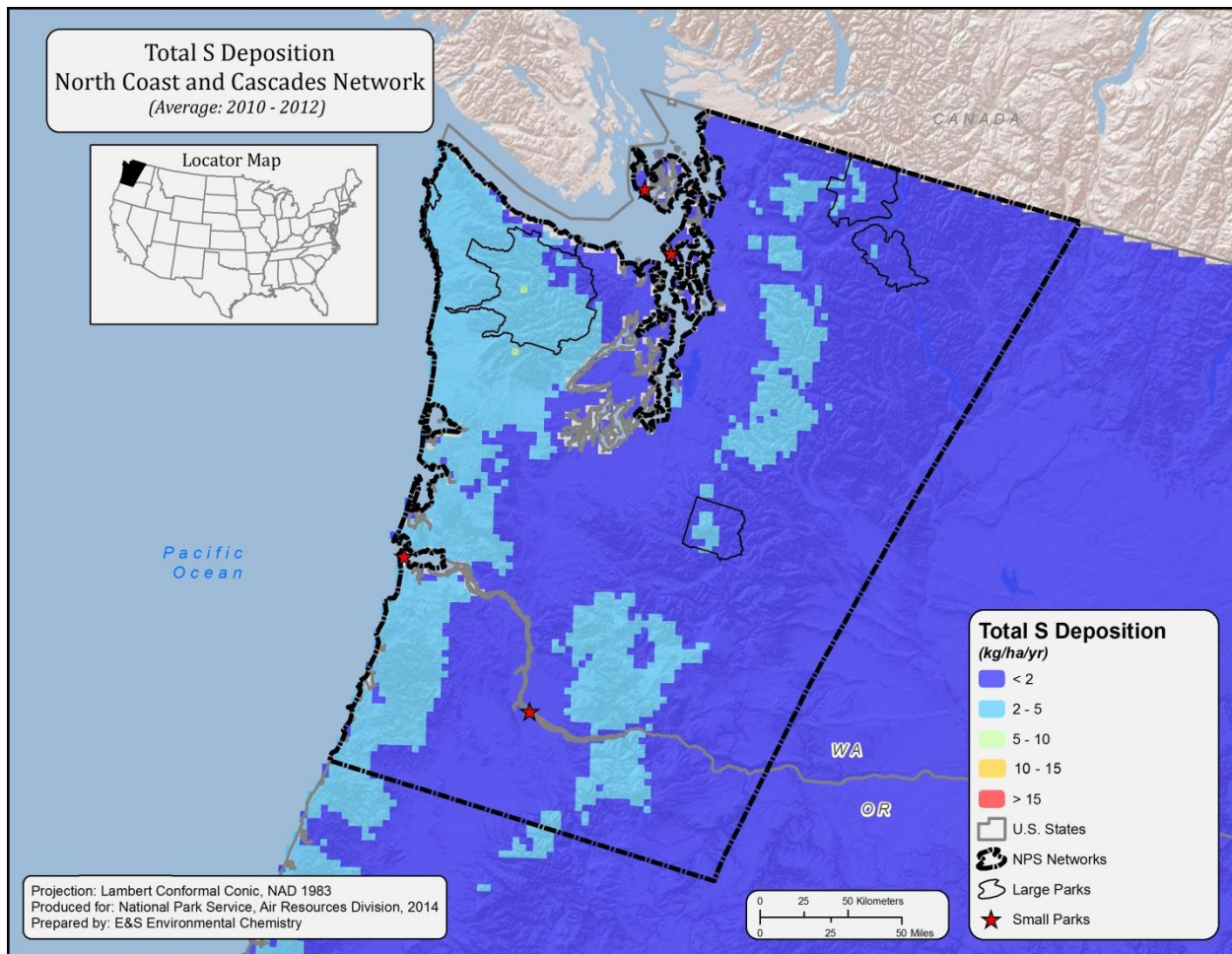
Map 3. Total NO_x emissions, by county, near NCCN for the year 2011. Data from EPA's National Emissions Inventory.



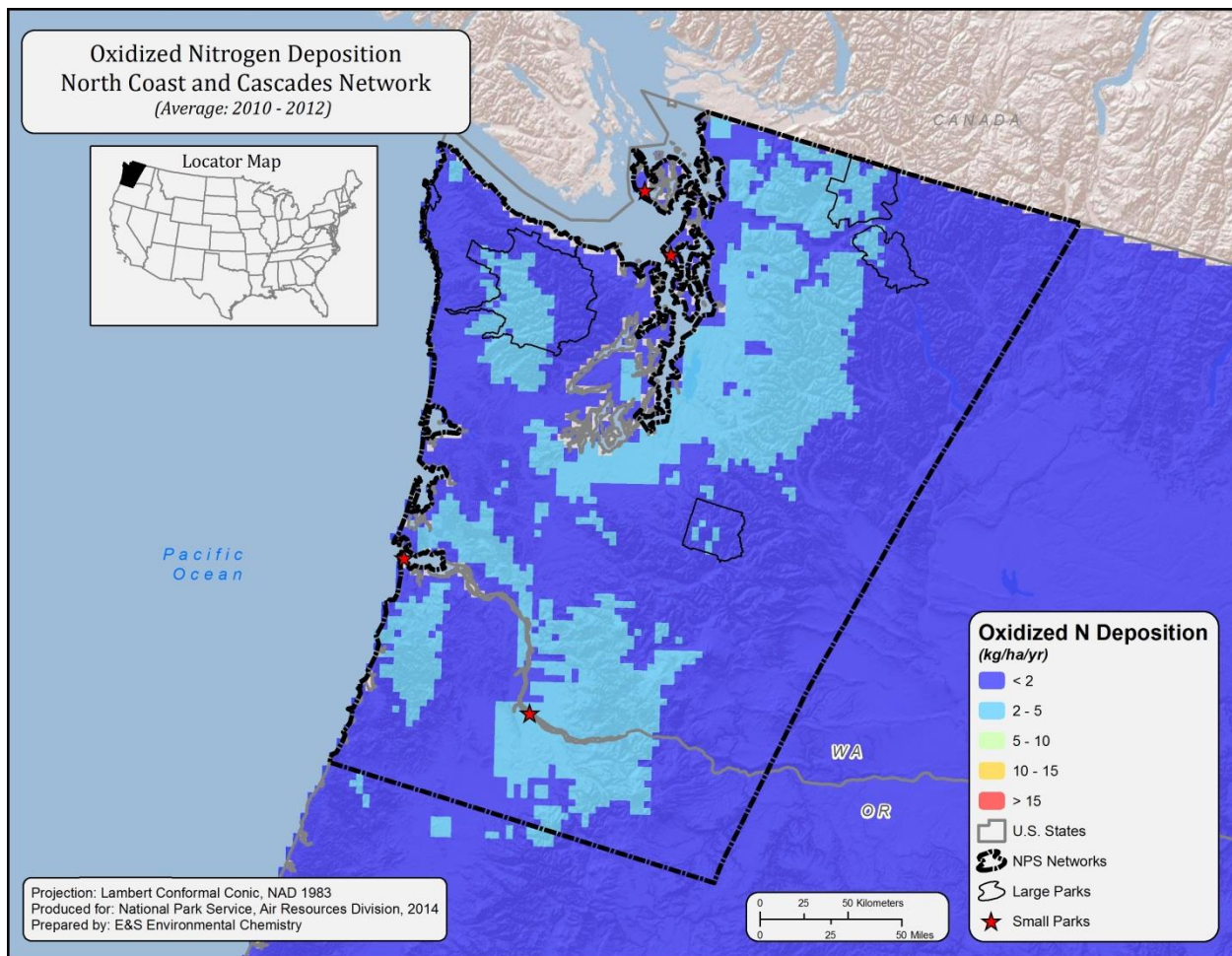
Map 4. Total NH₃ emissions, by county, near NCCN for the year 2011. Data from EPA's National Emissions Inventory.

Table 1. Average changes in S and N deposition between 2001 and 2011 across park grid cells at NCCN parks. Deposition estimates were determined by the Total Deposition Project, TDEP, based on three-year averages centered on 2001 and 2011 for all ~4 km grid cells in each park. The minimum, maximum, and range of 2011 S and N deposition within each park are also shown.

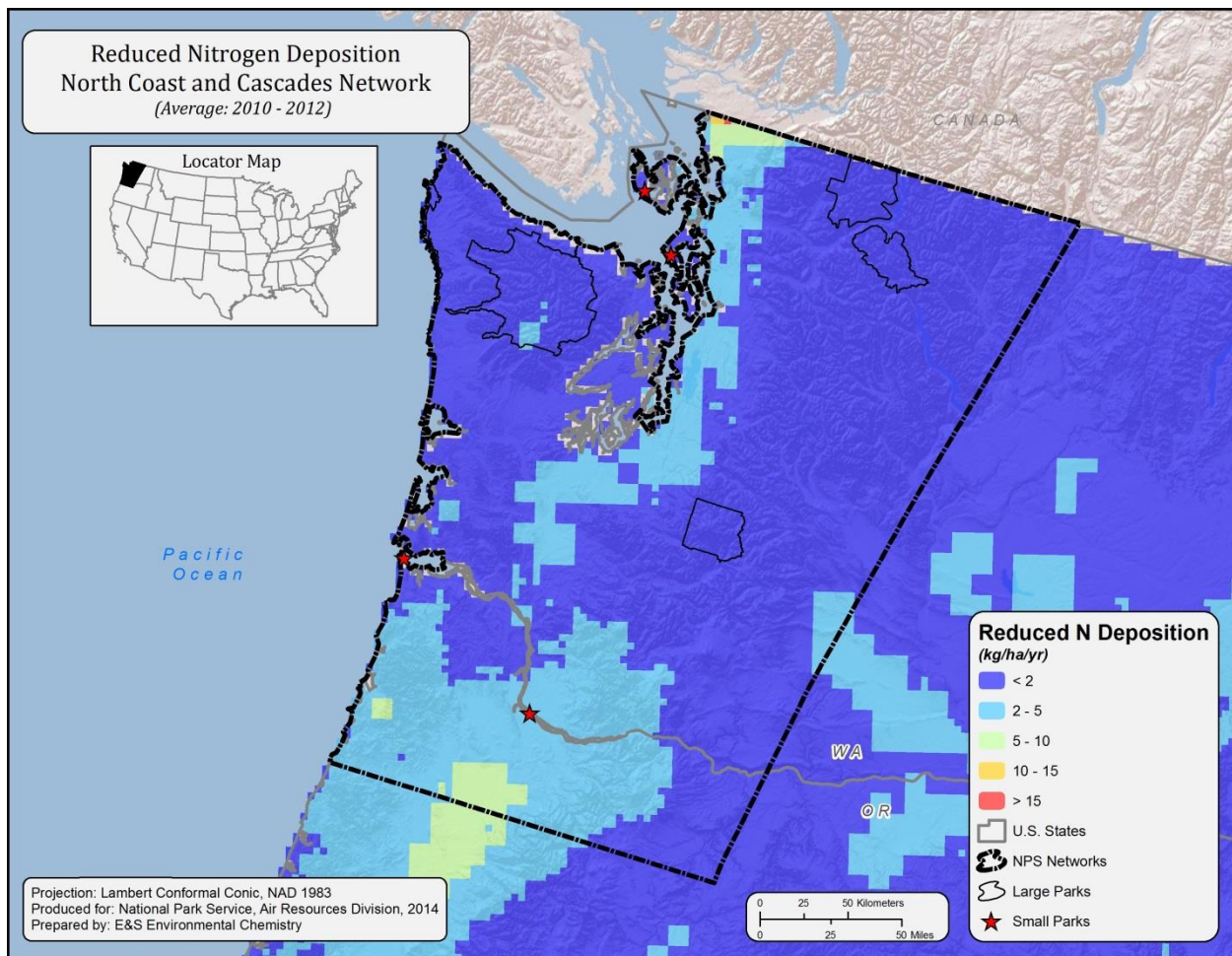
Park Code	Park Name	Parameter	2001 Average (kg/ha/yr)	2011 Average (kg/ha/yr)	Absolute Change (kg/ha/yr)	Percent Change	2011 Minimum (kg/ha/yr)	2011 Maximum (kg/ha/yr)	2011 Range (kg/ha/yr)
EBLA	Ebey's Landing	Total S	1.20	1.32	0.11	9.2%	1.27	1.34	0.08
		Total N	1.10	2.51	1.40	127.5%	2.49	2.52	0.03
		Oxidized N	0.75	1.18	0.44	58.6%	1.18	1.20	0.02
		Reduced N	0.36	1.32	0.97	272.8%	1.29	1.34	0.05
FOVA	Fort Vancouver	Total S	1.81	1.36	-0.45	-25.1%	1.27	1.62	0.35
		Total N	5.65	5.44	-0.21	-3.7%	5.40	5.57	0.17
		Oxidized N	3.71	2.56	-1.15	-31.1%	2.41	2.97	0.56
		Reduced N	1.94	2.89	0.95	48.9%	2.60	2.99	0.39
LEWI	Lewis and Clark	Total S	3.30	2.25	-1.05	-31.5%	1.74	2.54	0.80
		Total N	3.66	3.01	-0.65	-18.0%	2.06	3.73	1.66
		Oxidized N	2.50	1.58	-0.92	-36.9%	1.09	2.12	1.02
		Reduced N	1.16	1.43	0.26	22.5%	0.97	1.61	0.64
MORA	Mount Rainier	Total S	4.19	1.86	-2.33	-55.1%	1.34	2.63	1.29
		Total N	4.08	3.16	-0.91	-21.7%	2.61	4.27	1.65
		Oxidized N	3.06	1.83	-1.23	-40.0%	1.52	2.43	0.91
		Reduced N	1.02	1.34	0.32	34.3%	1.08	1.84	0.75
NOCA	North Cascades	Total S	2.21	1.56	-0.65	-29.4%	0.84	2.32	1.47
		Total N	3.07	2.92	-0.16	-5.2%	1.84	4.33	2.49
		Oxidized N	2.41	1.99	-0.42	-17.6%	1.23	2.74	1.51
		Reduced N	0.67	0.93	0.27	39.9%	0.57	1.85	1.28
OLYM	Olympic	Total S	6.46	2.98	-3.48	-53.6%	1.03	5.19	4.16
		Total N	2.92	2.99	0.07	3.9%	1.49	5.23	3.74
		Oxidized N	2.24	1.87	-0.38	-15.0%	1.03	3.09	2.06
		Reduced N	0.68	1.12	0.45	67.6%	0.46	2.37	1.91
SAJH	San Juan Island	Total S	1.45	1.00	-0.44	-32.0%	0.68	1.70	1.01
		Total N	1.22	1.36	0.14	6.3%	0.86	2.45	1.58
		Oxidized N	0.79	0.76	-0.03	-5.7%	0.52	1.28	0.76
		Reduced N	0.43	0.60	0.18	28.7%	0.35	1.17	0.82



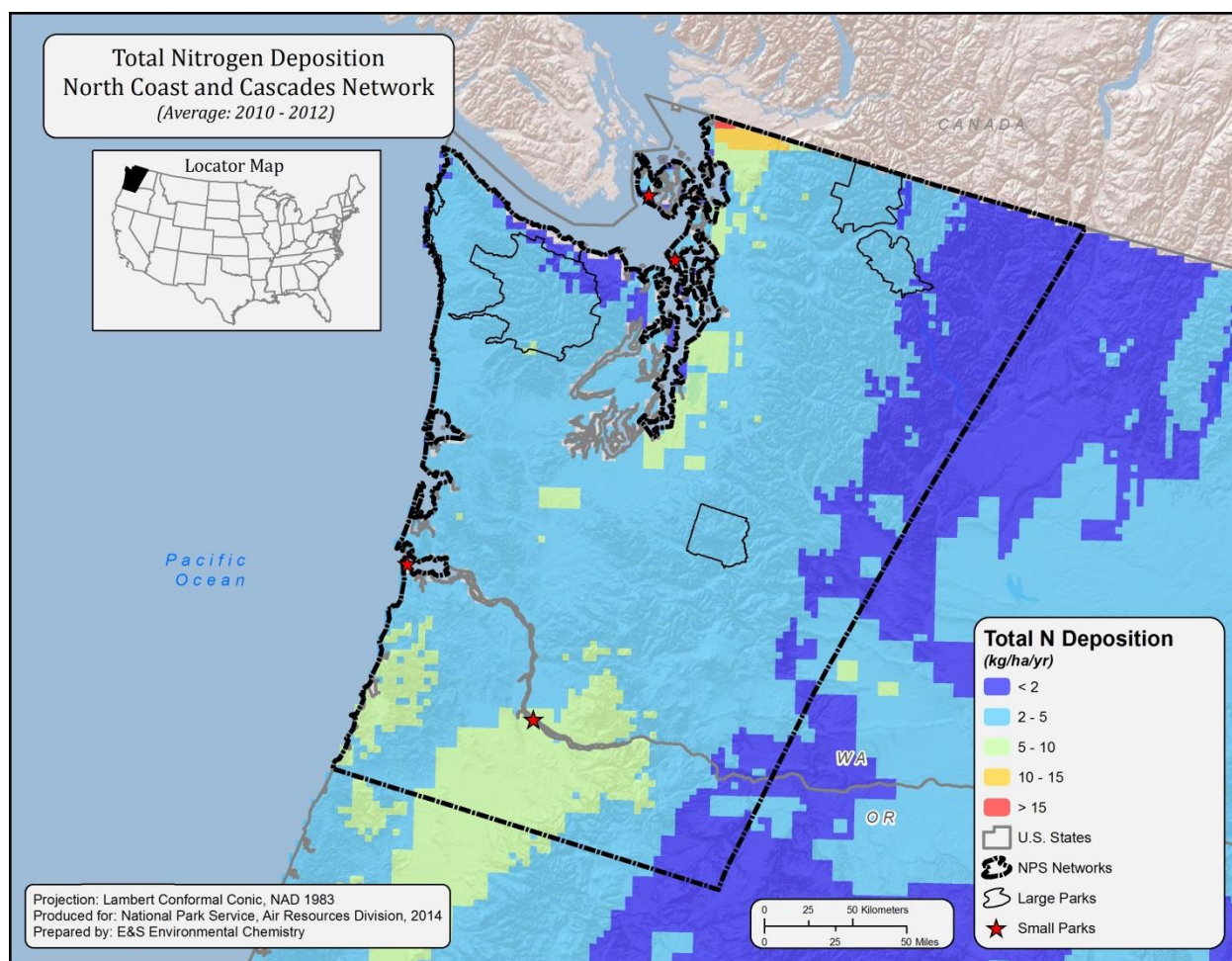
Map 5. Total S deposition for the three-year period centered on 2011 in and around NCCN. (Source: Schwede and Lear 2014)



Map 6. Total oxidized inorganic N deposition for the three-year period centered on 2011 in and around NCCN. (Source: Schwede and Lear 2014)



Map 7. Reduced inorganic N deposition for the three-year period centered on 2011 in and around NCCN. (Source: Schwede and Lear 2014)



Map 8. Total N deposition for the three-year period centered on 2011 in and around NCCN. (Source: Schwede and Lear 2014)

At the Paradise atmospheric sample site at 5,427 (1,654 m) elevation in MORA, contaminant levels (N and S) in precipitation were between lower levels observed at Hoh in OLYM and higher levels observed at Marblemount in NOCA (located east of Puget Sound; Rybka et al. 2009). There are few point sources of N or S of any magnitude near NOCA.

Clouds and fog are relatively common throughout the NCCN region. Cloudwater chemistry sampled by Basabe et al. (1994) in western Washington was relatively acidic, and similar to acidity values reported in California, the Midwest, and the Northeast. Fog at low elevation contained higher ammonium (NH_4^+) concentrations than fog at high elevation, reducing its acidity. High-elevation clouds on the Olympic Peninsula and in the North Cascades were less acidic than high-elevation clouds nearer the greater Seattle area, in closer proximity to the major regional S and N emissions sources (Basabe et al. 1994). Unquantified cloud and fog deposition of S and N to sensitive high-elevation and coastal receptors in the NCCN region increases impacts caused by wet- and dry-deposited materials.

Atmospheric deposition of air toxics is an important air pollution concern in NCCN parks. The Western Airborne Contaminants Assessment Project (WACAP) studied airborne contaminants in a number of national parks of the western United States, including OLYM, MORA and NOCA from 2002 to 2007. The dominant semivolatile organic compounds (SOCs) detected in environmental samples collected in these parks in the WACAP study included current and historic-use (banned) pesticides, fungicides, and combustion by-products (Landers et al. 2010).

Measurements of atmospheric ozone (O_3), carbon monoxide, hydrocarbons, and aerosol chemistry in air arriving in the Pacific Northwest from Eurasia have shown that a variety of contaminants can be transported across the Pacific Ocean (Jaffe et al. 2003). There is a high degree of variability, however, in the chemistry of the trans-Pacific episodes of atmospheric pollution transport.

Acidification

Both N and S deposition can contribute to acidification of soils, lakes, and streams in the NCCN, with possible effects on biota. If deposition is sufficiently high to acid-sensitive resources, these effects can include loss of acid-sensitive fish and macroinvertebrates, disruption of soil nutrient cycling, and loss of aquatic, terrestrial, and wetland ecosystem biodiversity.

Risk Analysis Results

In a coarse screening analysis (Sullivan et al. 2011b), all parks and networks in the NPS Inventory and Monitoring (I&M) Program were ranked according to their relative risk of acidification from atmospheric deposition. The analysis considered three major factors: pollutant exposure, ecosystem sensitivity, and park protection mandates. The Summary Risk ranking for the NCCN was among the highest of all networks (Sullivan et al. 2011b). Although estimated relative risk varied by park, the overall level of concern for acidification effects on I&M parks within this network was judged by Sullivan et al. (2011b) to be Very High.

All of the I&M parks within the NCCN were ranked by Sullivan et al. (2011b) in the third quintile (Moderate) in acid Pollutant Exposure (Table 2). The three large parks were all ranked in the highest quintile in Ecosystem Sensitivity to acidification. The smaller parks were lower in Ecosystem Sensitivity to acidification, ranging from Very Low (EBLA, FOVA, and SAJH) to Low (LEWI; Table 2). While rankings are an indication of risk, park-specific data, particularly data on ecosystem sensitivity, are needed to fully evaluate risk from acidification.

Ecosystem Sensitivity was rated substantially higher in NOCA, MORA, and OLYM, in large part because high-elevation lakes and low-order streams that do not receive substantial glacial meltwater inputs are common within these parks. High-elevation lakes that do not have glacial meltwater inputs tend to be more acid-sensitive than lower-elevation lakes because they typically receive low contributions of base cations in runoff that influences lake chemistry. Each of these parks also contains an extensive network of potentially acid-sensitive high-elevation and low-order streams. Ecosystem Sensitivity to acidification rankings also take into account land slope, which often influences the degree of acid neutralization provided by soils and bedrock within the watershed. Terrain in NOCA, MORA and OLYM is steep, with large portions of all of all three parks having average slope above 40°. These steep slopes suggest areas with high potential for acid sensitivity of aquatic ecosystems. Part of OLYM along the coast and the smaller parks in this network are much less steep, with average slopes below 20°.

Table 2. Estimated I&M park rankings¹ according to risk of acidification impacts on sensitive receptors. (Source: Sullivan et al. 2011b)

Park Name ²	Park Code	Estimated Acid Pollutant Exposure	Estimated Ecosystem Sensitivity to Acidification
Ebey's Landing	EBLA	Moderate	Very Low
Fort Vancouver	FOVA	Moderate	Very Low
Lewis and Clark	LEWI	Moderate	Low
<i>Mount Rainier</i>	MORA	Moderate	Very High
<i>North Cascades</i>	NOCA	Moderate	Very High
<i>Olympic</i>	OLYM	Moderate	Very High
San Juan Island	SAJH	Moderate	Very Low

¹ Relative park rankings are designated according to quintile ranking, among all I&M Parks, from the lowest quintile (Very Low risk) to the highest quintile (Very High risk).

² Park names are printed in bold italic for parks larger than 100 mi².

Acidification of Terrestrial Ecosystems

Although soil acidification sensitivity may be high in some areas, soil acidification is not expected to be an important concern in the NCCN, given the relatively low levels of acidic deposition. Eilers et al. (1994) concluded that acidic deposition was a potential threat to terrestrial resources in NOCA, but they reported an absence of research to determine effects on terrestrial resources in that park. With regard to ambient air quality near MORA, NOCA, and OLYM, S and N deposition presently are probably too low to cause much concern about acidification effects on terrestrial resources. The smaller parks occur at lower elevation and are also not expected to be highly sensitive to terrestrial acidification. Regionally, the largest potential cause of air quality damage to terrestrial resources from atmospheric deposition in the NCCN is probably associated with N deposition (a key plant nutrient) near industrialized urban areas and agricultural areas (Eilers et al. 1994). Given the relatively low levels of acidic deposition, terrestrial effects of acidification are not expected to be an important concern in the NCCN.

Acidification of Aquatic Ecosystems

Chronic Acid-Base Chemistry

The U.S. EPA's Western Lakes Survey (WLS) indicated that the Cascade Mountains, including within the NCCN region, are among the western mountain ranges with the greatest numbers of acid-sensitive streams and lakes (Landers et al. 1987). Lakes in this mountain range are especially sensitive to impacts from acidic deposition because of the predominance of base-poor bedrock and thin acidic soils, large amounts of precipitation, prevalence of coniferous vegetation, and the dilute nature of the lakes (Nelson 1991). Surface waters in this range are among the most poorly buffered surface waters in the United States (Landers et al. 1987, Nelson 1991). The acid base chemistry of lake and stream waters in the NCCN is primarily a function of the interactions among several key parameters and associated processes: atmospheric deposition, bedrock geology, the depth and composition of surficial deposits and associated hydrologic flowpaths, and the occurrence of soils, tundra, and forest vegetation (Sullivan 2000). Substantial portions of the NCCN contain areas of exposed bedrock, with little soil cover to neutralize acidic inputs. However, the percentage of

exposed bedrock in a watershed does not always indicate acid-sensitivity. If the bedrock contains even small deposits of calcareous minerals or if physical weathering such as that caused by glaciers causes a high production of base cations within the watershed (Drever and Hurcomb 1986), surface waters may be alkaline and not sensitive to acidification from acidic deposition.

Highest NO_3^- concentrations in surface waters in this network are generally found at high elevation, where biological activity, and therefore NO_3^- uptake, by terrestrial and aquatic biota is lowest (Gibson et al. 1983). The most sensitive (to N-driven acidification) aquatic resources likely include high-elevation lakes that are ice-covered more than eight or nine months of the year. These lakes may not achieve water temperatures $> 10^\circ \text{C}$ during the brief summer, and biological activity is limited. Therefore, they may be sensitive to accumulating N throughout the growing season (Eilers et al. 1994). Lakes and streams receiving glacial meltwater are not likely to be acid sensitive receptors because of the high physical weathering rates associated with glacial action. Weathering contributes calcium and other base cations that buffer acidity.

The National Acid Precipitation Assessment Program (NAPAP) State of Science and Technology Reports and the Integrated Assessment (NAPAP, 1991) provided only a cursory treatment of aquatic acidification effects issues in the western United States, largely because it was well known that atmospheric deposition of S and N were generally low compared to areas in the eastern United States (Sullivan 2000). Results from the WLS (Landers et al. 1987) concluded that there were virtually no acidic (acid neutralizing capacity $[\text{ANC}] \leq 0$) lakes in the West. Both MORA and NOCA contain lakes and streams that have $\text{ANC} \leq 50 \mu\text{eq/L}$ (Larson et al. 1994, Larson et al. 1999); ANC below 50 to $100 \mu\text{eq/L}$ indicates acid-sensitivity. These low- ANC waters are considered to be highly sensitive to acidification (Clow and Campbell 2008).

Sampling of high-elevation lakes by Brakke (1984, 1985), Landers et al. (1987), and Liss et al. (1991) showed that very low- ANC ($\sim 10 \mu\text{eq/L}$) lakes were present and presumably highly sensitive to acidic deposition. Eilers et al. (1994) stated that headwater streams in the high-elevation areas were also presumed to be acid-sensitive, although data were not available to confirm this. Water chemistry has been studied at Thornton and Newhalem Creeks in NOCA (Clow and Campbell 2008). These watersheds are steep and densely forested and are located at elevations below about 1500 m; alpine and subalpine vegetation occurs at higher elevation. Volume-weighted average ANC in both streams is about $100 \mu\text{eq/L}$ (Clow and Campbell 2008), suggesting only moderate acid-sensitivity. Volume-weighted NO_3^- concentrations in these two streams were somewhat elevated (3.4 and $5.7 \mu\text{eq/L}$) and about six fold higher than those measured in Lake Louise and Eunice Lake in MORA. The relatively high NO_3^- concentrations in the streams in NOCA could be due to the presence of N-fixing bacteria associated with red alder trees (Edmonds 1980). Clow and Campbell (2008) suggested that monitoring and assessment of effects of atmospheric N deposition in NOCA should focus on high-elevation ecosystems to avoid confounding effects of N-fixation associated with alder trees.

Some lakes throughout MORA, especially those on the west side, are considered highly sensitive to acidification from atmospheric deposition (Eilers et al. 1994). Eunice Lake and Lake Louise have been well studied (cf., Clow and Campbell 2008). These are small, shallow, high-elevation, acid-sensitive lakes with fast hydrologic flushing, steep slopes, and thin coarse soils. Volume-weighted

average ANC was determined by Clow and Campbell (2008) to be between 25 and 50 $\mu\text{eq/L}$ in both lakes.

The NCCN Mountain Lakes Monitoring Protocol includes monitoring the chemistry of 20 reference lakes in MORA, NOCA, and OLYM. The reference lakes are small (most smaller than about 3 ha in surface area). Study watersheds differ in their ability to buffer acidic atmospheric inputs. None of the eight monitoring lakes in OLYM has $\text{ANC} < 100 \mu\text{eq/L}$. The other two parks contain two (MORA) and three (NOCA) such lakes (Fradkin et al. 2012).

Summit Lake, located at 5,413 ft (1,650 m) in the western Washington Cascades, was sampled by Landers et al. (1987) and again in 1993 by the Mt. Baker-Snoqualmie National Forest. It had lake ANC about 1 $\mu\text{eq/L}$, with nonmarine SO_4^{2-} concentration of 7 $\mu\text{eq/L}$. Because the nonmarine base cation concentrations (those not attributable to marine aerosol contributions) were very low (about 10 $\mu\text{eq/L}$) and could largely be attributed to atmospheric deposition, there appeared to be little watershed contribution of S to the lake. Therefore, the lakewater SO_4^{2-} concentration was assumed to be of atmospheric origin. Summit Lake is close to local and regional sources of atmospheric S emissions and it is conceivable that the lake has lost up to 7 $\mu\text{eq/L}$ of ANC in response to human-caused acidic deposition (Sullivan and Eilers 1994). It is possible that some of the other high-elevation lakes in NCCN parks have been similarly affected.

Temporal Variability in Water Chemistry

The acid-base chemistry of Cascade Mountain lakes varies seasonally, with lowest ANC during the spring snowmelt when accumulated acid anions are released from the melting snowpack, increasing to higher values during fall. For example, the ANC of Gertrude Lake, located at 5,702 ft (1,738 m) elevation in the Goat Rocks wilderness in Washington varied seasonally from a minimum of about 10 $\mu\text{eq/L}$ to a maximum of 91 $\mu\text{eq/L}$ (Eilers and Vaché 1998).

Most surface waters exhibit seasonally lower ANC and pH values than would be captured by monitoring or trend analysis that considers only summer or fall chemistry data. This is important because lakes and streams can exhibit water chemistry that is suitable for aquatic biota most of the time, but nevertheless experience occasional episodic acidification with lethal consequences (cf., Wigington et al. 1993). Episodic acidification is an especially important concern for surface waters throughout mountainous areas in the NCCN. A number of factors pre-dispose such systems to potential episodic effects (Peterson et al. 1998, Sullivan 2000), including:

1. the common occurrence of dilute lakes which exhibit very low concentrations of base cations, and therefore ANC, throughout the year;
2. poorly developed soils that lack buffering capacity;
3. large snowpack accumulation, thus contributing to episodic acidification via the natural process of base cation dilution; and
4. short hydraulic retention times for many of the upland drainage lakes, thus enabling snowmelt to flush lake basins with dilute meltwater.

The NCCN parks contains widespread high-elevation watersheds with steep topography, extensive areas of exposed bedrock, deep snowpack accumulation, and shallow, base-poor soils. These conditions help to determine the pathway followed by snowmelt and stormflow water through the watershed and, therefore, the extent of acid neutralization provided by the soils and bedrock. Conditions within the NCCN predispose the surface water to be highly sensitive to episodic acidification because they receive an elevated proportion of flow that is derived from water that has moved laterally through the surface soil without infiltration to deeper soil horizons (Sullivan 2000, Wigington et al. 1990); in general, more subsurface contact contributes to higher surface water ANC (Turner et al. 1990).

Episodic acidification due to human-caused acidic deposition is most commonly associated with N deposition, and effects tend to be most pronounced during snowmelt. However, snowmelt can flush into surface waters not only N that was deposited from the atmosphere to the snowpack, but also N that was mineralized within the soil under the snowpack during winter (Campbell et al. 1995). A substantial component of the NO_3^- that moves into drainage water may have been derived from mineralization of naturally occurring organic N (Ley et al. 2004). Much of the N released from the snowpack during the melting period is retained in underlying soils and only a component of that is flushed to surface waters. Where soils are sparse, as at high elevation in the NCCN, much of the snowpack N can be flushed to surface waters, and this can cause temporary acidification of surface waters (Campbell et al. 2002, Williams and Tonnessen 2000).

The NCCN has not demonstrated clear pattern of change in lake or stream acid-base chemistry over time. Water chemistry in acid-sensitive watersheds, such as are commonly found in NCCN parks, changes on both intra-annual and inter-annual time scales in response to changes in environmental conditions. Because of this variability, many years of data are required to establish the existence of trends in surface water chemistry. Assignment of causality to changes that are found to occur is even more difficult. Nevertheless, even low to moderate concentrations of NO_3^- in high-elevation NCCN lakes might be significant in view of: (1) the low base cation concentrations in many lakes; (2) potential for continuing N deposition to eventually exhaust natural assimilative capabilities; and (3) the fact that available data are mostly based on fall or summer sampling. Synoptic lake surveys, such as those conducted in the NCCN by the WLS (Landers et al. 1987) and some more localized studies, have typically been conducted during the summer or autumn "index period," during which time lakewater chemistry generally exhibits low temporal variability. Although either summer or autumn can be an ideal time for surveying lakewater chemistry in terms of minimizing variability, lakewater samples collected at these times provide little relevant data on episodic processes, and in particular on the dynamics or importance of N as an agent of acidification. Nitrate concentrations in lakewater are elevated during the summer and autumn seasons only in lakes having watersheds that exhibit fairly advanced symptoms of N saturation (Stoddard 1994).

Most research in the United States on episodic processes has been conducted on stream systems; data from intensive study sites suggest that episodic depression of ANC and pH may be more pronounced for streams than for lakes. However, there are no available systematic stream chemistry data within the NCCN region with which to assess sensitivity of streams to acidic deposition (Sullivan 2000).

Most acid-base chemistry data collected in the NCCN region have been collected from lakes. Spatial variability can be considerable in lakes, and this complicates efforts to quantify the magnitude of episodic effects (Gubala et al. 1991).

Although many Cascade Mountain lakes are highly sensitive to potential acidic deposition effects (Nelson 1991), it does not appear that chronic acidification has occurred to any significant degree. Episodic acidification has likely occurred in some surface waters but has not been quantified. The data that would be needed for determining the extent and magnitude of episodic acidification have not been collected to a sufficient degree in acid-sensitive waters in the NCCN to support regional assessment of episodic acidification (Sullivan 2000). Nevertheless, episodic acidification likely occurs in the NCCN and it remains an important potential stressor in the high-elevation parks in this network.

Some high-elevation lakes in the NCCN may receive N deposition sufficiently high to cause some limited chronic NO_3^- leaching. What little information has been collected suggests that acidification from NO_3^- is probably not occurring to any substantial degree (Eilers et al. 1994), and any biological effects that have occurred would be expected to have been minimal.

Based on data available within the parks in the NCCN and results of more detailed studies elsewhere, Eilers et al. (1994) offered a preliminary evaluation of critical load (CL) of atmospheric S deposition in the NCCN, below which sensitive resources will be protected from adverse effects. For protection of sensitive lakes and streams in MORA and NOCA, they recommended an interim nonmarine S deposition guideline of 20 meq/m²/yr (equal to about 3 kg S/ha/yr; 9 kg SO_4^{2-} /ha/yr). At this time, data do not exist to suggest that the estimate of Eilers et al. (1994) is no longer appropriate. The recommended CL for S should probably be adjusted upward, however, to account for precipitation greater than 39 in (1 m), especially in OLYM and portions of the west slope of the Cascade Mountains. For example, areas which receive 78 in (2 m) of annual precipitation might require double the annual S load to experience surface water concentrations comparable to similar areas receiving only 39 in (1 m) of precipitation (Eilers et al. 1994).

Data from over 12,500 streams and lakes were used by the Critical Loads of Atmospheric Deposition Science Committee (CLAD) of the NADP (<http://nadp.sws.uiuc.edu/committees/clad/>) to develop steady-state critical loads for acidity of surface waters based on multiple approaches for estimating base cation weathering; modified F-factor, regional regression model, and MAGIC model. Water quality data were obtained from a variety of sources including EPA Long Term Monitoring (LTM) sites, lake surveys, EMAP Assessments, and National Stream Surveys; USGS; NPS Vital Signs program; and USFS air program. The average water quality measurements from the most recent five years of data were used for sites with long-term water monitoring records. The CLAD database included CL estimates for six sites in each of MORA and OLYM and seven sites in NOCA. All modeled CL estimates were high (> 3000 eq S/ha/yr) in OLYM. Both MORA and especially NOCA had some sites with modeled CL = 0 eq S/ha/yr. At NOCA, the 25th percentile CL estimate was 0 eq S/ha/yr.

Nutrient Nitrogen Enrichment

In a coarse screening study, Sullivan et al. (2011a) ranked all I&M networks nationwide for relative risk of nutrient N enrichment. The network rankings for nutrient N Pollutant Exposure, Ecosystem Sensitivity to nutrient N enrichment, and Park Protection yielded an overall network nutrient enrichment Summary Risk ranking for the NCCN that was among the highest of all NPS networks (Sullivan et al. 2011a). The overall level of concern for nutrient N enrichment effects on I&M parks within this network was judged by Sullivan et al. (2011a) to be Very High.

All of the I&M parks within the NCCN except SAJH were ranked in the third quintile (Moderate) in nutrient N Pollutant Exposure (Sullivan et al. 2011a; Table 3). SAJH was ranked High, in part due to its proximity to Seattle. The three large parks were all ranked in the highest quintile (Very High) in Ecosystem Sensitivity to nutrient N enrichment. The smaller parks were ranked lower for this theme, ranging from Low (EBLA) to High (SAJH; Table 3). These high rankings for Ecosystem Sensitivity to nutrient N enrichment resulted from the presence of vegetation and lake elevations that are expected to be sensitive to added N. SAJH received a ranking of High for Ecosystem Sensitivity to nutrient N enrichment because about 37% of this small (2.7 mi² [7 km²]) park is covered by prairie vegetation, which is expected to be highly sensitive to nutrient N enrichment. Although rankings provide an indication of risk, park-specific data, particularly regarding nutrient-enrichment sensitivity, are needed to fully evaluate risk from nutrient N addition.

Lichens are known to be highly sensitive to N input (Geiser et al. 2010). Lichen communities in many areas in the Pacific Northwest are exposed to sufficient levels of air pollution such that they are beginning to show signs of air pollution damage (Fenn et al. 2003, Geiser and Neitlich 2007). Although the Pacific Northwest retains widespread populations of air pollution-sensitive lichens in some areas (Fenn et al. 2003), there are few sensitive lichen species in urban areas, intensive

Table 3. Estimated park rankings¹ according to risk of nutrient enrichment impacts on sensitive receptors (Source: Sullivan et al. 2011a)

Park Name ²	Park Code	Estimated Nutrient N Pollutant Exposure	Estimated Ecosystem Sensitivity to Nutrient N Enrichment
Ebey's Landing	EBLA	Moderate	Low
Fort Vancouver	FOVA	Moderate	Moderate
Lewis and Clark	LEWI	Moderate	Moderate
<i>Mount Rainier</i>	MORA	Moderate	Very High
<i>North Cascades</i>	NOCA	Moderate	Very High
<i>Olympic</i>	OLYM	Moderate	Very High
San Juan Island	SAJH	High	High

¹ Relative park rankings are designated according to quintile ranking, among all I&M Parks, from the lowest quintile (Very Low risk) to the highest quintile (Very High risk).

² Park names are printed in bold italic for parks larger than 100 mi².

agricultural zones, or downwind of major urban and industrial centers. Various factors influence lichen community composition, but research has found strong correlations between elevated N deposition and changes in lichen diversity. Indicators of clean sites and polluted sites (Table 4) were used by Geiser and Neitlich (2007) to identify six lichen zones of air quality within the region, from worst (all sensitive species absent) to best (all sensitive species present). Geiser et al. (2010) developed empirical N critical loads (CLs) for forests in western Washington and Oregon, based on observed relationships between epiphytic lichens and total N deposition estimates derived from the CMAQ model. Estimated total N deposition equal to 3 to 9 kg N/ha/yr was associated with declines in sensitive lichen species of 20 to 40%. Sensitivity varied with precipitation amount. Geiser et al. (2010) concluded that no single lichen CL is appropriate across land areas that receive varying amounts of precipitation. A model was developed with which to predict N CLs at any desired lichen community composition, expressed as the percent composition by oligotrophic (low nutrient) versus eutrophic (high-nutrient) lichen species. In addition, high N concentrations have been measured in lichen tissue collected in areas of relatively high N deposition within the NCCN region (Fenn et al. 2003). With N enrichment, especially around urban and agricultural areas, there is a shift towards weedy, nitrophilous (N-loving) lichen species (Fenn et al. 2003). Replacement of sensitive lichens by nitrophilous species has undesirable ecological consequences. In late-successional, naturally N-limited forests of the Coast Range and western Cascade Mountains, for example, lichens make important contributions to mineral cycling and soil fertility (Pike 1978, Sollins et al. 1980). Large, pollution-sensitive lichens comprise integral parts of the food web for mammals, insects, and birds (McCune and Geiser 1997, U.S. EPA 2005). Sensitive lichen species appear to be negatively affected by N inputs as low as 3 to 8 kg/ha/yr (Fenn et al. 2003).

Cummings et al. (2014) recently summarized the state of knowledge regarding thresholds for protecting ecosystems in the NCCN from impacts caused by atmospheric N deposition. Critical loads information for this network is fairly limited. The report also summarizes ongoing research and the use of the data by NPS in planning and regulatory arenas.

Table 4. Principal air quality indicator lichen species in Oregon and Washington.¹

Group	Sub-Group	Indicator Species
Clean Air	Regional distribution	<i>Bryoria capillaris</i> , <i>Lobaria oregana</i> , <i>Sphaerophorus globosus</i> , <i>Usnea filipendula</i> , <i>Usnea scabrata</i>
	Sub-regional distribution	<i>Ahtiana pallidula</i> , <i>Alectoria sarmentosa</i> , <i>Bryoria fuscescens</i> , <i>Hypogymnia enteromorpha</i> , <i>Nephroma bellum</i> , <i>Nodobryoria oregana</i>
Polluted Air	Regional nitrophyles	<i>Candelaria concolor</i> , <i>Physcia adscendens</i> , <i>Xanthoria polycarpa</i>

¹ Includes only species with highest indicator value, used by Geiser and Neitlich (2007) to define air quality zones. Source: (Geiser and Neitlich 2007)

Geiser and Neitlich (2007) found that air pollution was associated more with effects on community composition of lichens, rather than species richness (number of species). The most widely observed effects included paucity of sensitive, endemic species, and enhancement of nitrophilous and non-native species (Geiser and Neitlich 2007). The strongest relationship was found with wet NH_4^+ deposition, consistent with findings in California (Jovan and McCune 2005) and Europe (van Dobben et al. 2001). The zone of worst air quality was associated with an absence of sensitive lichen species, enhancement of nitrophilous lichens, mean wet NH_4^+ deposition > 0.06 mg N/L in precipitation, and lichen tissue N concentration $> 0.6\%$.

Pardo et al. (2011b) identified the CLs that would protect sensitive resources in Level I ecoregions across the conterminous United States against effects caused by atmospheric N deposition. If current deposition is lower than the CL for a given receptor, one would not expect harmful effects to occur. If current deposition exceeds the CL, the risk of harmful effects increases. Some parks may be included in more than one ecoregion, and therefore CLs for the same receptor may vary within a park. Empirical data suggested the lower end of the CL for resource protection in the NCCN region was about 2.5 kg N/ha/yr (Table 5). Estimated N deposition reported by Pardo et al. (2011b) was higher than the CL at some places in the NCCN region, especially at MORA and NOCA, and to a lesser extent at OLYM. These CL exceedances were reported for protection of mycorrhizal fungi, lichens, herbaceous plants, and forest vegetation and also prevention of NO_3^- leaching to drainage water. Some CL exceedances were also noted in FOVA and LEWI (Table 5).

Table 5. Critical loads for nitrogen in the NCCN, determined by ecoregion and receptor from Pardo et al. (2011b). Ambient N deposition reported by Pardo et al. (2011b) is compared to the lowest critical load for a receptor to identify potential exceedance, indicated by graying. A critical load exceedance suggests that the receptor is at increased risk for harmful effects.

NPS Unit	Ecoregion	Modeled N Deposition (kg N/ha/yr)	Critical Load (kg N/ha/yr)				
			Mycorrhizal Fungi	Lichen	Herbaceous Plant	Forest	Nitrate Leaching
Ebey's Landing NHR	Marine West Coast Forests	2.2	5	2.7 - 9.2	NA	5	NA
Fort Vancouver NHS	Marine West Coast Forests	10.1	5	2.7 - 9.2	NA	5	NA
Lewis and Clark NHP	Marine West Coast Forests	4.5	5	2.7 - 9.2	NA	5	NA
Mount Rainier NP	Northwestern Forested Mountains	6.0	5 - 10	2.5 - 7.1	4 - 10	4 - 17	4 - 17
North Cascades NP	Northwestern Forested Mountains	7.2	5 - 10	2.5 - 7.1	4 - 10	4 - 17	4 - 17
Olympic NP	Marine West Coast Forests	4.3	5	2.7 - 9.2	NA	5	NA
Olympic NP	Northwestern Forested Mountains	4.3	5 - 10	2.5 - 7.1	4 - 10	4 - 17	4 - 17

Conventional wisdom previously held that most lakes and streams in the United States are phosphorous (P)-, rather than N-limited. However, more recent research suggests that this may not

always be the case. There is increasing evidence from surveys and paleolimnological research suggesting N limitation is common in many lakes, or was common prior to human settlement (U.S. EPA 2008). Surveys of the literature on fertilization experiments and lake studies found that remote oligotrophic waters are commonly N-limited, especially undisturbed northern temperate or boreal lakes that receive relatively low levels of atmospheric N deposition (Bergström et al. 2005, Elser et al. 2009a, Elser et al. 2009b). Based on current understanding, eutrophication effects on freshwater ecosystems from atmospheric deposition of N are of greatest concern in lakes and streams that have very low productivity and nutrient levels and that are located in remote areas, such as in the national park units in the NCCN. In more productive and less remote fresh waters, nutrient enrichment from N deposition does not necessarily stimulate productivity or community changes because P is more commonly the limiting nutrient. Also, in many places with even minor levels of human disturbance, nutrient enrichment with both N and P from non-atmospheric human-caused sources is common.

High-elevation lakes are common within NOCA, MORA, and OLYM. Some of those lakes might be prone N-limitation (Table 6), and therefore potentially more susceptible to eutrophication in response to atmospheric N input. Each of these parks also contains extensive areas of alpine vegetation, along with some meadow and wetland vegetation, which are among the predominant vegetation types presumed to be sensitive to nutrient N enrichment. Examination of WLS data (Eilers et al. 1987) found enhanced NO_3^- concentrations in high elevation lakes in this region adjacent to and downwind of urban centers (Fenn et al. 2003).

A survey of 62 lakes that were the subject of N-enrichment studies reported a mean increase in phytoplankton biomass of 79% in response to N-enrichment (average of 46.3 $\mu\text{eq/L}$ N; Elser et al. 2009a, Elser et al. 2009b). A meta-analysis of lakes from 42 regions of Europe and North America concluded that atmospheric N deposition was responsible for increased concentrations of N in lake

Table 6. Proportion of lakes in three nutrient limitation classes (N limited, P limited, and N and P co-limited) based on ratios of dissolved inorganic nitrogen (DIN; $\text{NO}_3^- + \text{NH}_4^+$) to total phosphorus (TP) in the Cascade and Sierra Nevada Mountains. Data are from the Western Lakes Survey (Landers et al. 1987), conducted in the fall of 1985. (Source: Baron et al. 2011)

Region	Number of Lakes ¹	Number of N Limited Lakes (%) ²	Number of P Limited Lakes (%) ³	Number of Lakes with Co-limited N:P (%) ⁴
Sierra/Cascades	4,155	1,468 (35%)	1,958 (47%)	729 (18%)

¹ The Western Lakes survey was a stratified random samples of lakes; estimates of the number of lakes are based on the target population sizes for each survey.

² Lakes with DIN:TP ratios (by weight) less than four were characterized as N limited, based on the work of Morris and Lewis (1988).

³ Lakes with DIN:TP ratios (by weight) greater than 12 were characterized as P limited, based on the work of Morris and Lewis (1988).

⁴ Lakes with DIN:TP ratios (by weight) between 4 and 12 could not be assigned to nutrient limitation class, and are characterized as either co-limited or limited by something other than N or P.

water, and elevated phytoplankton biomass (Bergström and Jansson 2006). Bergström and Jansson (2005) found a consistent pattern of nutrient limitation showing N limitation for watersheds receiving N deposition below approximately 2.5 kg N/ha/yr, co-limitation of N and P for N deposition between ~2.5 and 5.0 kg N/ha/yr, and P limitation in areas with N deposition greater than 5.0 kg N/ha/yr. Thus, some of the lake watersheds in the NCCN parks might be expected to correspond with the N-limited and N+P-limited groups.

Sheibley et al. (2014) investigated N deposition CLs to protect lakes in NOCA, MORA, and OLYM against changes in the diatom community caused by nutrient N enrichment. They collected lake sediment cores using two gravity corers from 12 high-elevation lakes (above the treeline), four in each park. All study lakes were dilute and oligotrophic. Calculated dissolved inorganic N to total P ratios suggested N limitation or N and P co-limitation at all of the lakes. Nine study lakes showed a lack of response of the diatom community to changes in atmospheric N input. This result suggests that the nutrient N CL for these lakes is not exceeded under existing levels of N deposition.

At Hoh Lake in OLYM, there was a shift in the relative abundances of *Asterionella formosa* and *Fragilaria tenera*, two species that are indicative of N enrichment, beginning during the time period 1969-1975. This information was used together with estimates of past N deposition to derive an empirical CL of 1.0 to 1.2 kg N/ha/yr for this lake. There was no information suggesting that the shift in diatom relative abundance was caused by disturbance such as fire or by fish stocking. The authors hypothesized that increased N deposition at OLYM might be due, at least in part, to transpacific pollutant transport from Asia and regional marine shipping.

Ellis et al. (2013) estimated the CL for nutrient-N deposition to protect the most sensitive ecosystem receptors in 45 national parks. The lowest terrestrial CL of N was generally estimated for protection of lichens. Changes to lichen communities may signal the beginning of other changes to the ecosystem that might affect structure and function (Pardo et al. 2011a). Ellis et al. (2013) estimated the N CL in the range of 2.5-7.1 kg N/ha/yr for protection of lichens in MORA and NOCA. For protection of lichens in OLYM, the estimated N CL was in the range of 2.7-9.2 kg N/ha/yr.

Ozone Injury to Vegetation

Ozone is of concern with respect to air pollution effects on vegetation in NCCN parks, mainly due to expanding urban centers and vehicular traffic. Ozone has the potential to cause visible foliar symptoms on sensitive plants and reduce growth and reproduction. Among the parks in NCCN, MORA probably faces the highest risk, followed by FOVA and LEWI. Nevertheless, O₃ exposures are generally low in the NCCN parks (http://www.nature.nps.gov/air/Maps/AirAtlas/IM_materials.cfm), and surveys have not found O₃ injury symptoms (Campbell et al. 2007). Kohut (2007) rated vegetation in all NCCN parks at low risk from O₃ injury.

Maximum O₃ concentrations observed at park locations in NCCN have been downwind of urban centers in the Portland and Puget Sound areas (Barna et al. 2000) and at higher elevation within the region (Peterson et al. 1999). Brace and Peterson (1998) measured highest O₃ concentrations in MORA at high elevation. Concentrations were higher in the western portion of the park, as compared with the eastern portion. The highest weekly average O₃ concentrations in western Washington were measured at the two highest elevation sites in MORA (Peterson et al. 1999).

Brace et al. (1999) fumigated common NCCN forest species with O₃ at exposure levels that were somewhat above typical ambient conditions. Photographs of O₃ injury symptoms compiled in this study can be used to identify O₃ injury in NCCN parks and to distinguish it from other pathological disorders. Ozone symptoms may sometimes be similar to those caused by insects and disease.

The O₃-sensitive plant species that are known or thought to occur in NCCN parks are listed in Table 7. Those considered to be bioindicators are designated by an asterisk. Each NCCN park contains at least five O₃-sensitive and/or bioindicator species.

The W126 (a measure of cumulative O₃ exposure that preferentially weights higher concentrations) and SUM06 (a measure of cumulative exposure that includes only hourly concentrations over 60 ppb O₃) exposure indices calculated by NPS staff are given in Table 8, along with Kohut's (2007) O₃ risk ranking. The NPS and Kohut ranking systems differ. The NPS (2010) ranking system is a quick assessment of O₃ condition that ranks O₃ exposure levels according to injury thresholds from the literature (Heck and Cowling 1997), using a 5-year average of either the W126 or SUM06 index. Both metrics are calculated over a 3-month period. NPS (2010) classified the W126 as Moderate at values between 7 and 13 parts per million-hours (ppm-hr). Values higher than 13 ppm-hr were classified as High, and values lower than 7 ppm-hr were classified as Low. The SUM06 was classified as Moderate at values between 8 and 15 ppm-hr. Higher and lower values were classified as High and Low.

Kohut's approach constitutes a more rigorous assessment of potential risk to plants. It considers both O₃ exposure and environmental conditions (soil moisture). Kohut also used injury thresholds from the literature, but evaluated a different O₃ metric (after Lefohn et al. 1997), the W126 over a 5-month period in conjunction with the N100 (number of hours over 100 ppb [parts per billion] O₃). The

rationale for the N100 statistic is that higher O₃ concentrations are most likely to cause plant injury). Kohut examined five individual years of O₃ exposure and soil moisture data and considered the effects of low soil moisture on O₃ uptake each year when assigning risk. Soil moisture is important because dry conditions induce stomatal closure in plants, which has the effect of limiting O₃ uptake and injury. In areas where low soil moisture levels correspond with high O₃ exposure, uptake and injury are limited by stomatal closure even when exposures are relatively high. Each of these O₃ exposure variable rankings ranged from Low to High (three classes) for this analysis, based on comparison with other I&M parks. The W126 and SUM06 indices, as well as Kohut's (2007) risk ranking, were ranked Low across all parks within the NCCN.

Table 7. Ozone-sensitive and bioindicator plant species known or thought to occur in NCCN parks . (Source: E. Porter, National Park Service, pers. comm., August 30, 2012; lists are periodically updated and available at <https://irma.nps.gov/NPSpecies/Report>)

Species	Common Name	Park ¹						
		EBLA	FOVA	LEWI	MORA	NOCA	OLYM	SAJH
<i>Ailanthus altissima</i> *	Tree-of-heaven		x					
<i>Alnus rubra</i> *	Red alder	x		x	x	x	x	x
<i>Amelanchier alnifolia</i>	Saskatoon serviceberry	x				x		
<i>Amelanchier alnifolia</i> var. <i>semiintegrifolia</i>	Saskatoon serviceberry				x		x	
<i>Apocynum androsaemifolium</i> *	Spreading dogbane				x	x		
<i>Apocynum androsaemifolium</i> spp. <i>androsaemifolium</i> var. <i>androsaemifolium</i> *	Spreading dogbane						x	
<i>Artemisia douglasiana</i> *	Mugwort				x	x		
<i>Artemisia ludoviciana</i> *	Silver wormwood					x		
<i>Artemisia ludoviciana</i> spp. <i>Candicans</i> *	Silver wormwood						x	
<i>Parthenocissus quinquefolia</i>	Virginia creeper					x		
<i>Physocarpus capitatus</i> *	Ninebark			x	x	x	x	
<i>Pinus ponderosa</i> *	Ponderosa pine		x		x	x		
<i>Populus tremuloides</i> *	Quaking aspen					x	x	x
<i>Robinia pseudoacacia</i>	Black locust		x				x	
<i>Rubus parviflorus</i>	Thimbleberry	x		x		x		x
<i>Rubus parviflorus</i> var. <i>parviflorus</i>	Thimbleberry				x		x	
<i>Rudbeckia laciniata</i> *	Cutleaf coneflower					x		
<i>Salix scouleriana</i> *	Scouler's willow	x	x		x	x	x	x
<i>Sambucus racemosa</i> *	Red elderberry			x				x
<i>Sambucus racemosa</i> spp. <i>pubens</i> var. <i>arborescens</i> *	Red elderberry						x	
<i>Sambucus racemosa</i> var. <i>racemosa</i> *	Red elderberry	x						
<i>Symphoricarpos albus</i> *	Common snowberry	x	x	x	x	x		
<i>Symphoricarpos albus</i> var. <i>laevigatus</i> *	Common snowberry						x	x
<i>Vaccinium membranaceum</i> *	Huckleberry				x	x	x	

¹ Park acronyms are printed in bold italic for parks larger than 100 mi².

* Bioindicator species

The results of both ranking systems should be considered when evaluating the potential for O₃ injury to park vegetation. The Kohut approach considered environmental conditions that significantly affect plant response to O₃, but exposures have likely changed since the time of the assessment (1995-1999). The NPS approach considers more recent O₃ conditions (2005-2009), but not environmental conditions.

Table 8. Ozone assessment results for I&M parks in NCCN based on estimated average 3-month W126 and SUM06 ozone exposure indices for the period 2005-2009 and Kohut's (2007) ozone risk ranking for the period 1995-1999¹.

Park Name ²	Park Code	W126		Sum06		Kohut O ₃ Risk Ranking
		Value (ppm-hr)	Ranking	Value (ppm-hr)	Ranking	
Ebey's Landing	EBLA	1.16	Low	1.31	Low	Low
Fort Vancouver	FOVA	2.63	Low	3.18	Low	Low
Lewis and Clark	LEWI	2.67	Low	3.07	Low	Low
<i>Mount Rainier</i>	MORA	3.02	Low	3.10	Low	Low
<i>North Cascades</i>	NOCA	1.42	Low	1.16	Low	Low
<i>Olympic</i>	OLYM	1.57	Low	1.71	Low	Low
San Juan Island	SAJH	1.04	Low	1.10	Low	Low

¹ Parks are classified into one of three ranks (Low, Moderate, High).

² Park names are printed in bold italic for parks larger than 100 mi².

Studies by Hogsett et al. (1989) suggested that, among the tree species studied in the Pacific Northwest, ponderosa pine (*Pinus ponderosa*) is the most sensitive to damage from O₃ exposure. Once weakened by O₃ stress, ponderosa pine trees are more susceptible to root rot (*Fomes annosis*) and pine beetle (*Dendroctonus brevicornis*) infestation (Cobb and Stark 1970). These stresses can increase tree mortality. Within the NCCN region, ponderosa pine is especially sensitive to potential damage from O₃ exposure and is at risk of injury if O₃ concentrations in the atmosphere increase in this region in the future (Schoettle et al. 1999).

On the dry sites of the lower eastern foothills of NOCA, O₃-sensitive ponderosa pine predominates. This portion of the park is further away, however, from the principal sources of O₃ precursors which are located on the west side of the park. In addition, dry conditions on the east side of the park tend to inhibit O₃ uptake by plant stomata. The climate at moderate elevations on the eastern slope of the Cascade Mountains, with its typical summer drought, limits foliar uptake of C and O₃ in ecosystems that contain ponderosa pine. For example, Panek and Goldstein (2001) compared diurnal foliar patterns in young ponderosa pine trees in mixed conifer watered and control (natural drought) plots at moderate elevation 4,265-4,920 ft (1300-1500 m) in the Sierra Nevada. When plant stomata are closed, O₃ flux into the leaf is reduced, even if ambient O₃ exposure remains high. Thus, increased rainfall enhances vulnerability to O₃ damage (Panek and Goldstein 2001). Estimated O₃ uptake by trees in the ambient drought stress plot was about 40% less than in the watered plot. Panek and Goldstein (2001) speculated that an important implication of this research is that increased soil water

availability, which is predicted to occur in the Pacific Northwest with ongoing climate change, could make ponderosa pine trees vulnerable to O₃ damage at exposure levels that previously did not cause damage.

Visibility Degradation

Natural Background Visibility and Monitored Visibility Conditions

The air quality and visibility in the NCCN are generally very good compared to other areas of the United States (Eilers et al. 1994). The principal air masses that impact parks in this network are derived from the atmosphere over the Pacific Ocean. Nevertheless, air quality is degraded periodically and visibility is impaired¹.

The Clean Air Act (CAA) 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). In 1999, EPA passed the Regional Haze Rule (RHR), 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. Visibility is monitored by the Interagency Monitoring of Protected Visual Environments Network (IMPROVE) and typically reported using the haze index called the deciview² (dv). Lower dv values correspond with better visibility conditions. Natural background conditions are those that would occur without human-caused air pollution.

Within the NCCN, natural background and ambient, or current, visibility conditions have been estimated by IMPROVE for MORA, NOCA, and OLYM for the 20% clearest visibility days, the 20% haziest visibility days, and average days (Table 9). Data are also available that are considered to be representative of visibility conditions in EBLA, based on measured values at an alternative IMPROVE site (PUSO1) operated by the Forest Service and located within 60 miles (100 km) and 425 ft (130 m) elevation of EBLA. Natural background visibility, the goal of the CAA, assumes no human-caused pollution, but varies with natural processes such as windblown dust, fire, volcanic activity and natural biogenic emissions from vegetation.

Current visibility estimates reflect current pollution levels and were used to rank conditions at parks in order to provide park managers with information on spatial differences in visibility and air pollution. Rankings range from very low haze (very good visibility) to very high haze (very poor visibility; Table 8). Only parks with on-site or representative IMPROVE monitors were used in generating the baseline visibility ranking.

¹ Visibility impairment means any humanly perceptible change in visibility (light extinction, visual range, contrast, coloration) from that which would have existed under natural conditions.

² The *deciview* visibility metric expresses uniform changes in haziness in terms of common increments across the entire range of visibility conditions, from pristine to extremely hazy conditions. Because each unit change in deciview represents a common change in perception, the deciview scale is like the decibel scale for sound. A one deciview change in haziness is a small but noticeable change in haziness under most circumstances when viewing scenes in Class I areas.

Representative photos of a selected vista in MORA under three different visibility conditions are shown in Figure 1. Photos were selected to correspond with the clearest 20% visibility conditions, haziest 20% visibility conditions, and annual average visibility conditions at that location.

IMPROVE data from MORA and OLYM show that pollution has reduced average visual range (VR), i.e., how far a person can see, from 140 miles to about 70 miles (225 km to 113 km); at NOCA average VR has been reduced from 150 to 80 miles (242 to 130 km). On the haziest days, VR at MORA and OLYM has been reduced from 100 to 45 miles or less (161 to 73 km); at NOCA, VR on the haziest days has been reduced from 100 to 35 miles (161 to 56 km). Severe haze episodes occasionally reduce visibility to just over 20 miles (32 km) in all three parks.

Table 9. Estimated natural background visibility (top panel) and ambient visibility conditions in NCCN parks averaged over the period 2004 through 2008 (bottom panel)¹.

Park Name ¹	Park Code	Site ID	Estimated Natural Background Visibility (dv)					
			20% Clearest Days	20% Haziest Days	Average Days			
Ebey's Landing ²	EBLA	PUSO1	4.53	10.38	7.02			
Fort Vancouver	FOVA	No Site						
Lewis and Clark	LEWI	No Site						
<i>Mount Rainier</i>	MORA	MORA1	2.56	8.54	5.46			
<i>North Cascades</i>	NOCA	NOCA1	1.93	8.39	4.44			
<i>Olympic</i>	OLYM	OLYM1	2.70	8.44	5.34			
San Juan Island	SAJH	No Site						
Park Name	Park Code	Site ID	Baseline Visibility (For Years 2004 through 2008)					
			20% Clearest Days		20% Haziest Days		Average Days	
			dv	Ranking	dv	Ranking	dv	Ranking
Ebey's Landing	EBLA	PUSO1	12.55	Very High	25.15	High	18.57	High
Fort Vancouver	FOVA	No Site						
Lewis and Clark	LEWI	No Site						
<i>Mount Rainier</i>	MORA	MORA1	5.04	Low	16.81	Moderate	10.95	Moderate
<i>North Cascades</i>	NOCA	NOCA1	3.19	Low	13.20	Low	7.88	Very Low
<i>Olympic</i>	OLYM	OLYM1	5.54	Moderate	15.44	Low	10.81	Moderate
San Juan Island	SAJH	No Site						

¹ Park names are printed in bold italic for parks larger than 100 mi².

² Representative data from a nearby site are used for EBLA. A monitoring site is considered by IMPROVE to be representative if it is within 60 mi (100 km) and 425 ft (130 m) in elevation.

Composition of Haze

Various pollutants make up the haze that causes visibility degradation. IMPROVE measures these pollutants and reports them as ammonium sulfate, ammonium nitrate, elemental carbon, coarse mass, organic mass, sea salt, and soil. Sulfates form in the atmosphere from SO₂ emissions from coal-burning power plants, smelters, and other industrial facilities. Nitrates form in the atmosphere from NO_x emissions from combustion sources including vehicles, shipping traffic, power plants, industry, and fires. Organic compounds are emitted from a variety of both natural (biogenic) and human-caused sources, including agriculture, industry, and fires. Atmospheric sea salt concentrations are

higher in coastal areas. Soil can enter the atmosphere through both natural processes and human disturbance.

Figure 2 shows estimated natural (pre-industrial), baseline (2000-2004), and current (most recent available five-year period; 2006-2010) levels of haze and its composition for MORA, NOCA, OLYM, and EBLA. The RHR requires at least three years of valid data out of a five-year period to calculate the five-year average for the baseline period (2000-2004). The figure illustrates that sulfates are the primary components of haze at all four parks on the 20% clearest, annual average, and 20% haziest visibility days. Organics and nitrates also contribute significantly to haze at these parks.

Analyses conducted by the Western Regional Air Partnership (WRAP) indicated that organics from natural emissions sources, including wildfire and biogenic sources (vegetation), contribute to substantial visibility impairment throughout the western United States, including within the NCCN region. In addition, air pollution sources outside the WRAP domain, including international off-shore shipping and sources from Mexico, Canada, and Asia, can in some cases be substantial contributors to haze (Suarez-Murias et al. 2009).

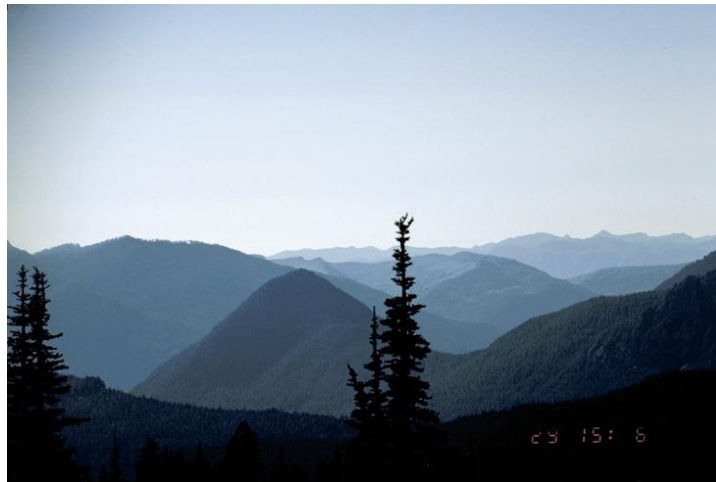
Mount Rainier

20% Clearest Days

Taken: 3:00 PM

Haze = 6 dv

VR = 137 mi (220 km)



20% Haziest Days

Taken = 3:00 PM

Haze = 17 dv

VR = 47 mi (75 km)



Average Days

Taken = 3:00 PM

Haze = 11 dv

VR = 84 mi (135 km)

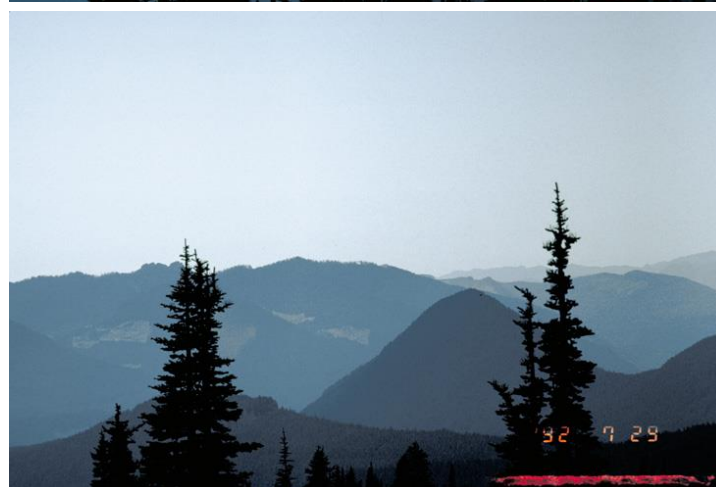


Figure 1. Three representative photos of the same view in MORA illustrating the 20% clearest visibility days, the 20% haziest visibility days and the annual average visibility. VR is the visual range.

MORA

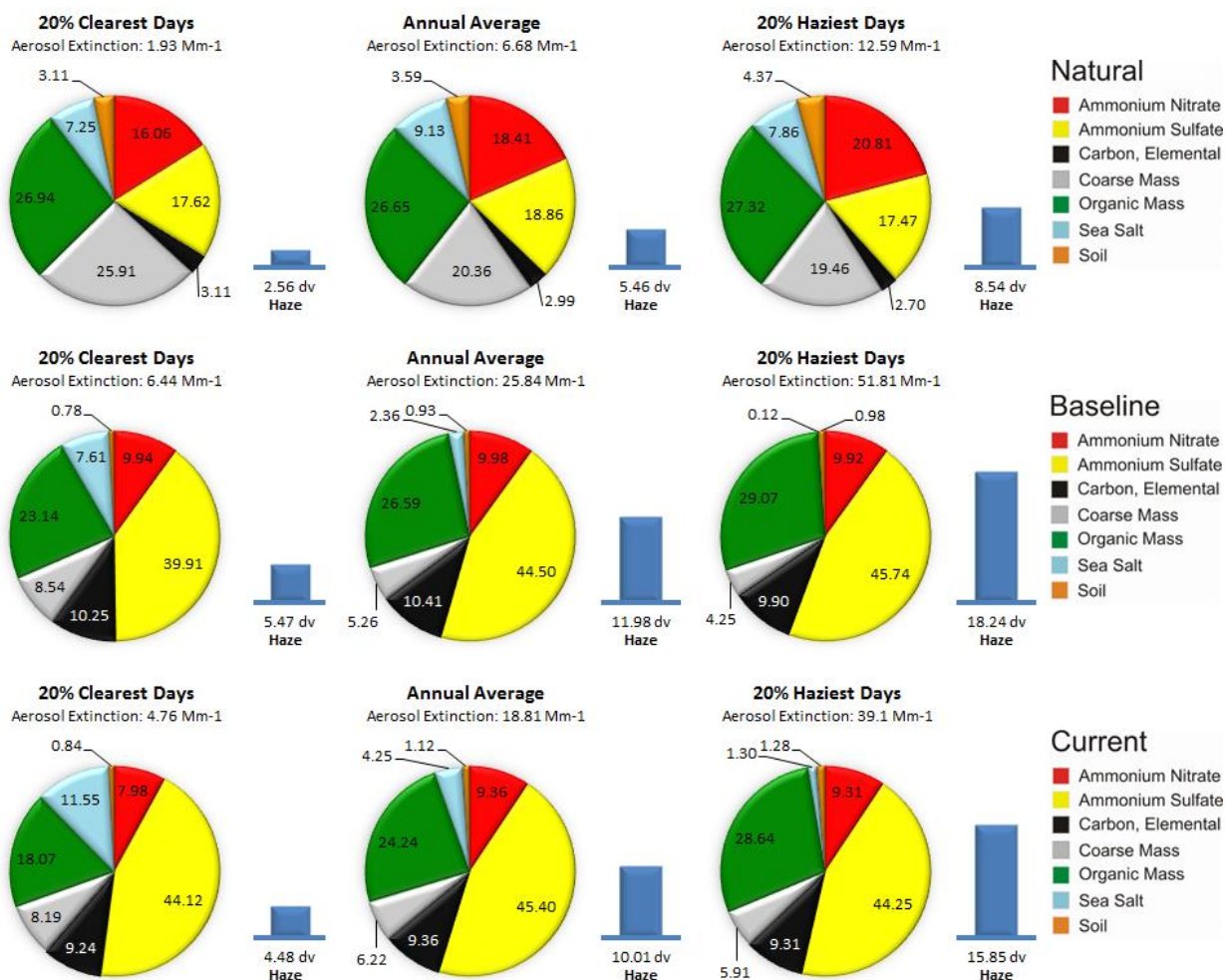


Figure 2a. Estimated natural (pre-industrial), baseline (2000-2004), and current (2006-2010) levels of haze (blue columns) and its composition (pie charts) on the 20% clearest, annual average, and 20% haziest visibility days for MORA. The latter IMPROVE site is considered representative of conditions at EBLA. The baseline figures for NOCA use the RHR2_VS method of calculation since the years 2003 and 2004 were not valid years for this park. Source: NPS-ARD

NOCA

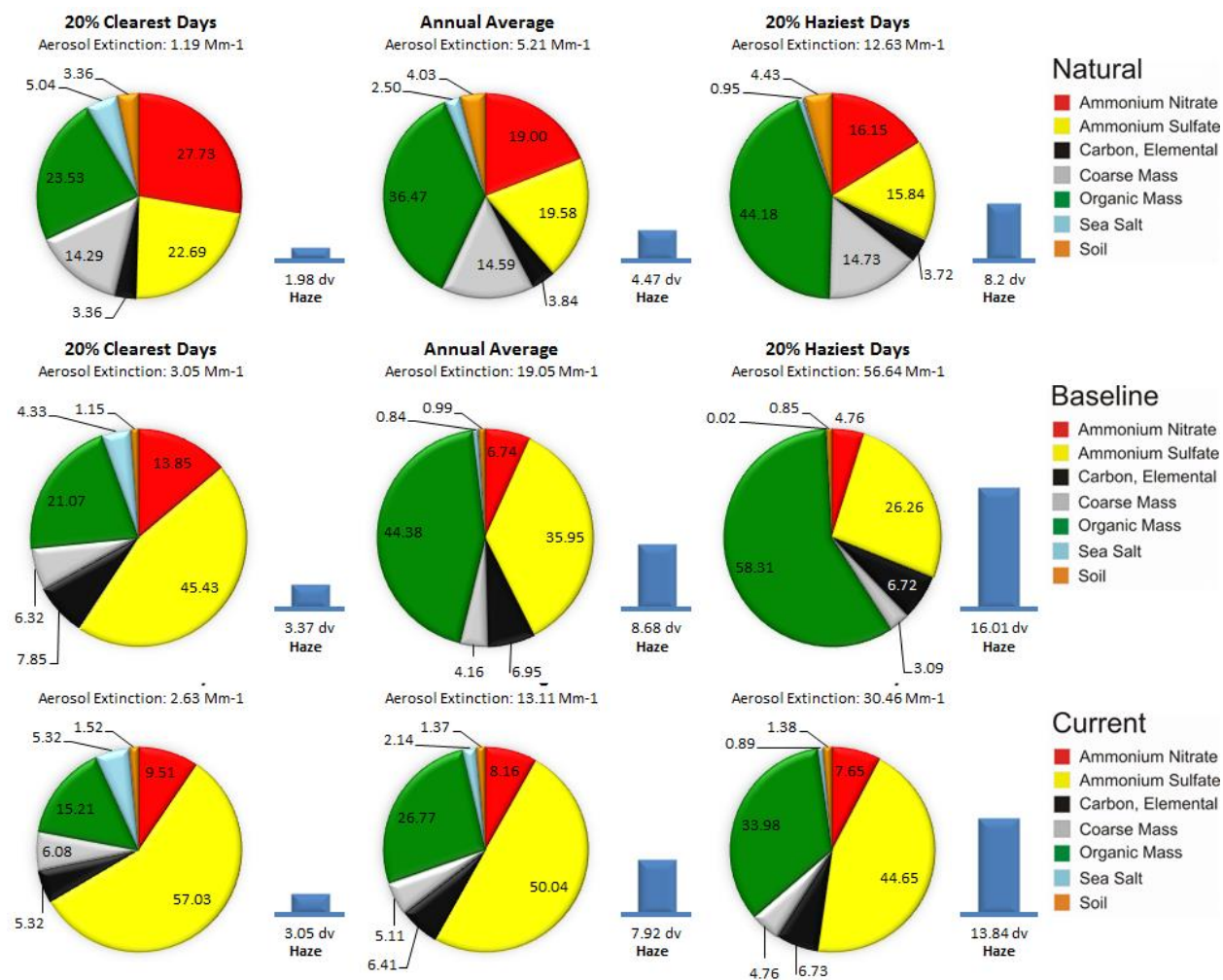


Figure 2b. Estimated natural (pre-industrial), baseline (2000-2004), and current (2006-2010) levels of haze (blue columns) and its composition (pie charts) on the 20% clearest, annual average, and 20% hazeiest visibility days for NOCA. The latter IMPROVE site is considered representative of conditions at EBLA. The baseline figures for NOCA use the RHR2_VS method of calculation since the years 2003 and 2004 were not valid years for this park. Source: NPS-ARD

OLYM

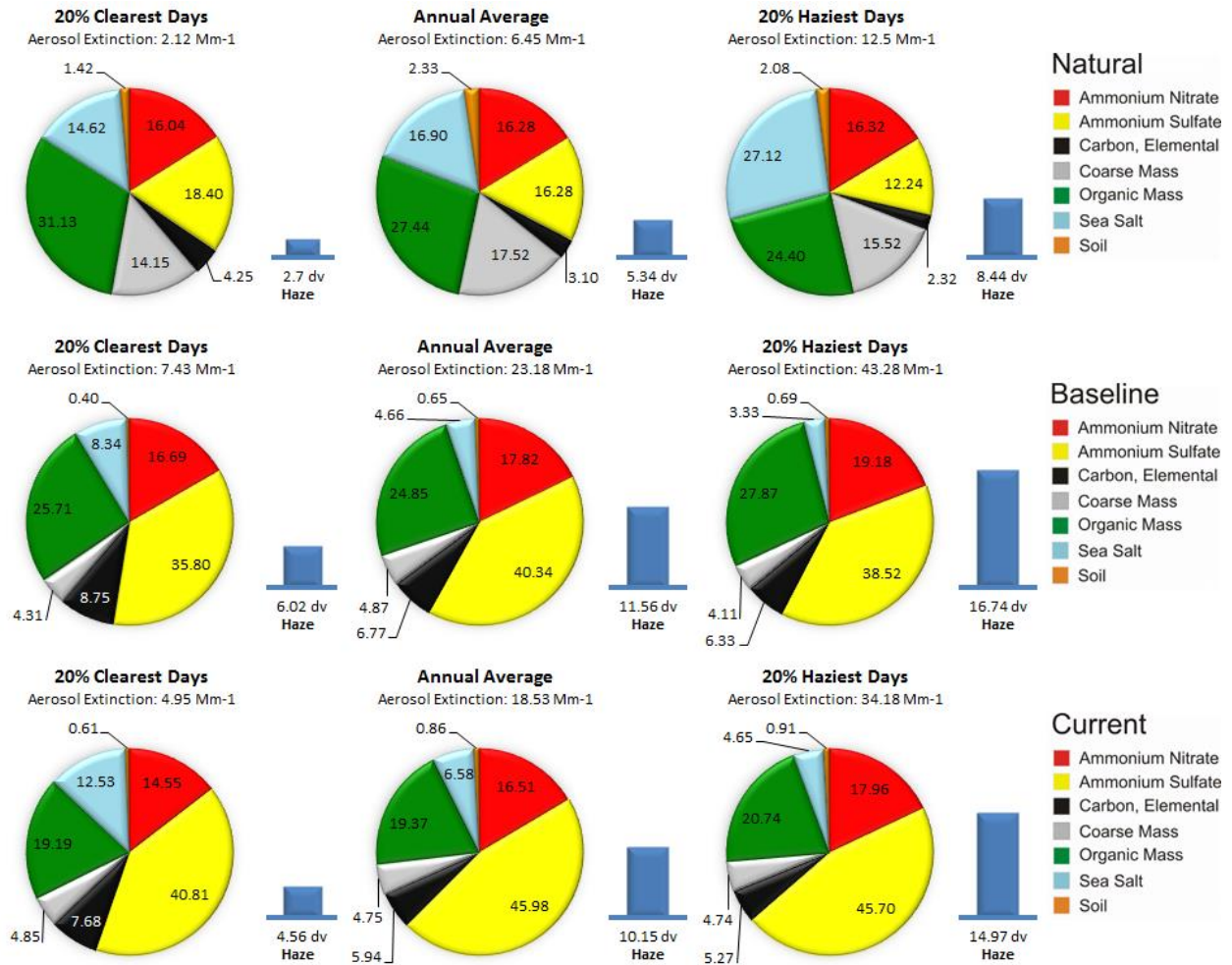


Figure 2c. Estimated natural (pre-industrial), baseline (2000-2004), and current (2006-2010) levels of haze (blue columns) and its composition (pie charts) on the 20% clearest, annual average, and 20% haziest visibility days for OLYM. The latter IMPROVE site is considered representative of conditions at EBLA. The baseline figures for NOCA use the RHR2_VS method of calculation since the years 2003 and 2004 were not valid years for this park. Source: NPS-ARD

PUSO (for EBLA)

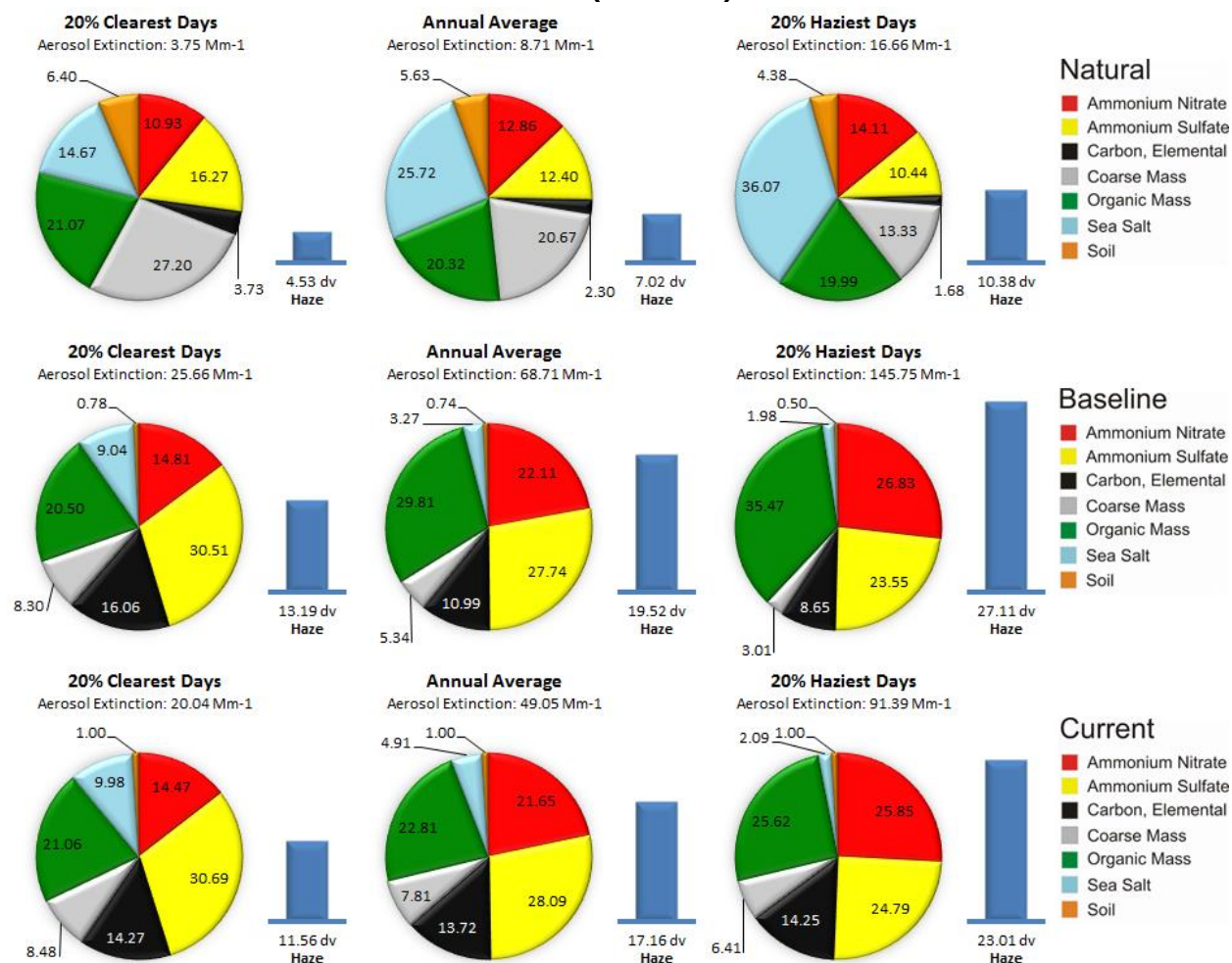


Figure 2d. Estimated natural (pre-industrial), baseline (2000-2004), and current (2006-2010) levels of haze (blue columns) and its composition (pie charts) on the 20% clearest, annual average, and 20% hazeiest visibility days for PUSO. The latter IMPROVE site is considered representative of conditions at EBLA. The baseline figures for NOCA use the RHR2_VS method of calculation since the years 2003 and 2004 were not valid years for this park. Source: NPS-ARD

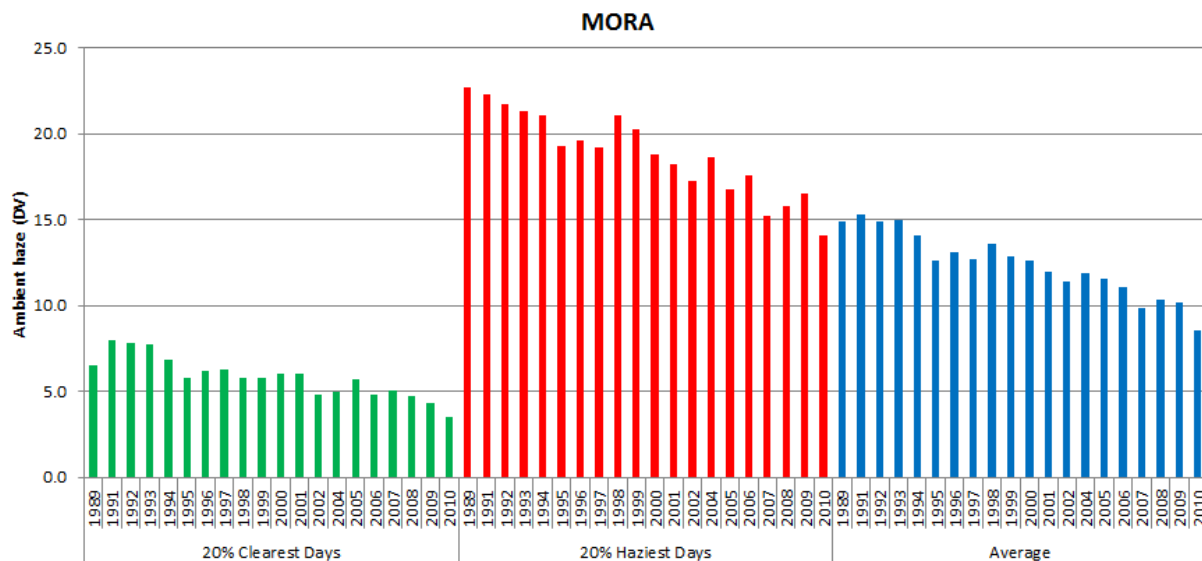


Figure 3a. Trends in monitored visibility at MORA, based on IMPROVE measurements on the 20% clearest, 20% haziest, and annual average visibility days over the monitoring period of record. NOCA used the RHR2_VS method of calculation for the years 2003 and 2004. Data from nearby PUSO1 are used to represent EBLA. Data Source:

<http://views.cira.colostate.edu/fed/Tools/FileExplorer.aspx?pathid=ImproveDataWarehouse&title=IMPROVE>

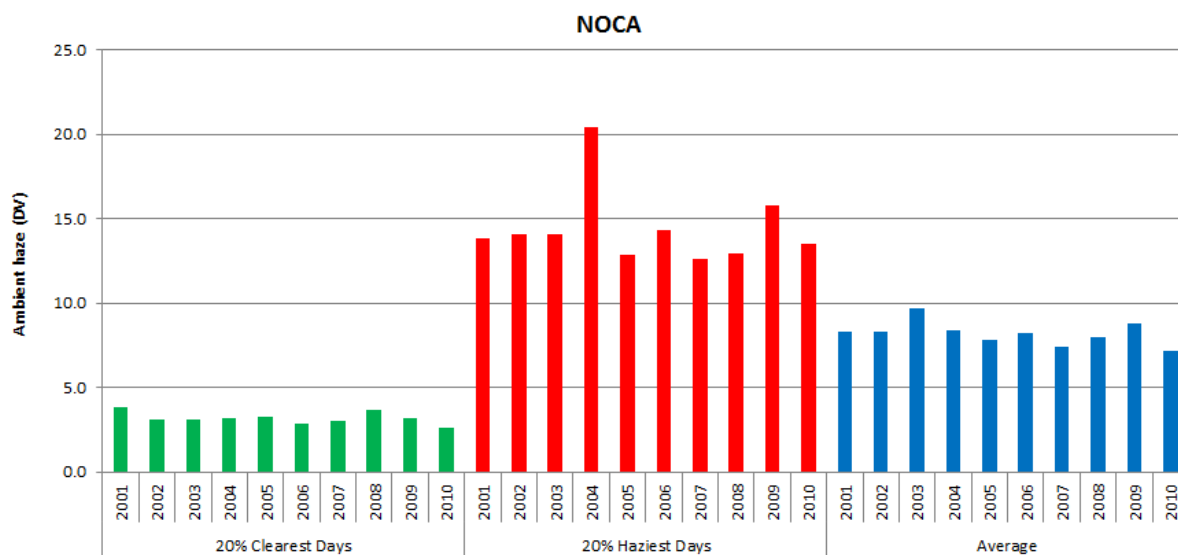


Figure 3b. Trends in monitored visibility at NOCA, based on IMPROVE measurements on the 20% clearest, 20% haziest, and annual average visibility days over the monitoring period of record. NOCA used the RHR2_VS method of calculation for the years 2003 and 2004. Data from nearby PUSO1 are used to represent EBLA. Data Source:

<http://views.cira.colostate.edu/fed/Tools/FileExplorer.aspx?pathid=ImproveDataWarehouse&title=IMPROVE>

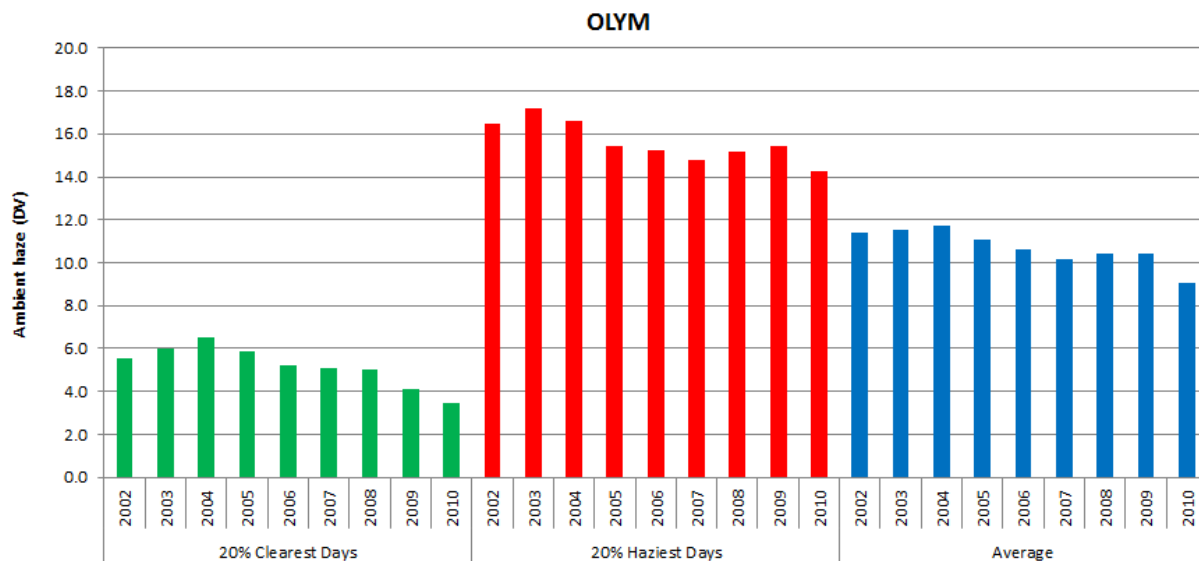


Figure 3c. Trends in monitored visibility at OLYM, based on IMPROVE measurements on the 20% clearest, 20% haziest, and annual average visibility days over the monitoring period of record. NOCA used the RHR2_VS method of calculation for the years 2003 and 2004. Data from nearby PUSO1 are used to represent EBLA. Data Source:

<http://views.cira.colostate.edu/fed/Tools/FileExplorer.aspx?pathid=ImproveDataWarehouse&title=IMPROVE>

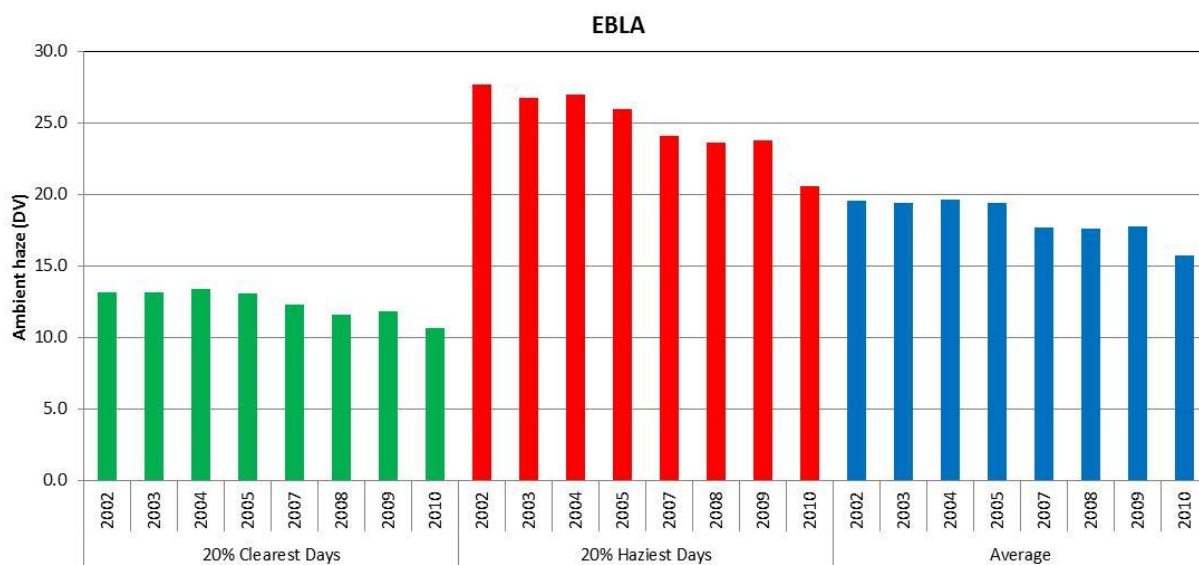


Figure 3d. Trends in monitored visibility at MORA, NOCA and OLYM, based on IMPROVE measurements on the 20% clearest, 20% haziest, and annual average visibility days over the monitoring period of record. NOCA used the RHR2_VS method of calculation for the years 2003 and 2004. Data from nearby PUSO1 are used to represent EBLA. Data Source:

<http://views.cira.colostate.edu/fed/Tools/FileExplorer.aspx?pathid=ImproveDataWarehouse&title=IMPROVE>

Trends in Visibility

NPS (2010) reported long-term trends in visibility on the clearest and haziest 20% of days at monitoring sites in 29 national parks. Twenty-seven parks showed statistically significant ($p \leq 0.05$) visibility improvement on the clearest days for 11 to 20 year monitoring periods through 2008. Ten parks showed statistically significant visibility improvement on the haziest days, with the greatest improvements reported for MORA (-0.38 dv/yr), based on 18 years of monitoring (Figure 3). Improvements at OLYM and NOCA were less pronounced and included fewer years of monitoring data (Figure 3). The IMPROVE site that showed the largest improvements in visibility for the West Coast region over the two-decade period 1992-2011 on the 20% haziest days was MORA (-3.5%/yr; $p \leq 0.01$; Hand et al. 2014).

State of Washington Regional Haze SIP

Washington Department of Ecology published their proposed Regional Haze State Implementation Plan (SIP) in 2010 (http://www.ecy.wa.gov/programs/air/globalwarm_RegHaze/regional_haze.html). The SIP summarized natural conditions (the 2064 goal of the CAA) and baseline conditions (2000-2004) for the clearest and haziest visibility days at MORA, NOCA and OLYM (Table 10).

Table 10. Summary of visibility baseline conditions averaged over the period 2000-2004, natural background conditions that must be achieved by 2064 to comply with the Regional Haze Rule, and difference between natural conditions and the baseline. (Source: Washington Department of Ecology 2010).

National Park	20% Clearest Days			20% Haziest Days		
	2000-2004 Baseline (dv)	2064 Natural Conditions (dv)	Difference (dv)	2000-2004 Baseline (dv)	2064 Natural Conditions (dv)	Difference (dv)
MORA	5.47	2.56	2.91	18.24	8.54	9.70
NOCA ¹	3.37	1.93	1.44	16.01	8.39	7.62
OLYM	6.02	2.7	3.32	16.74	8.44	8.30
EBLA ²	13.19	4.53	8.66	27.11	10.38	16.73

¹ RHR2_VS method of calculation was used to generate the baseline values.

² Data for PUSO1 are used to represent conditions at EBLA.

The SIP presented glideslopes to illustrate how visibility would be gradually improved over time from baseline conditions to estimated natural conditions in the three parks (Figure 4). The State is required to periodically demonstrate progress in visibility improvement. As part of Washington's SIP, the contributions to haze at Class I areas were modeled, and results suggested that a wide range of sources were important.

Modeled impacts from major SO₂ emission sources in the state suggested that reducing point source emissions would likely improve visibility at Washington's Class I areas. Emissions of SO₂ in Washington are projected to decline almost 40% from the baseline period (2000-2004) used in the SIP analyses. This projected emissions decline is expected to result from reduced point and mobile

source emissions. Washington Department of Ecology (2010) concluded that improved progress toward the natural visibility goal in the future will require emissions reductions from Canadian and Pacific offshore, as well as Washington, sources.

Toxic Airborne Contaminants

Environmental indicators were sampled and analyzed for Hg, pesticides, and other toxics at MORA, NOCA, and OLYM in the WACAP study (Landers et al. 2010). Only ambient air and vegetation were sampled at NOCA. Additional sampling, including fish, was conducted at MORA and OLYM. The WACAP study revealed that there were relatively high concentrations of SOC in vegetation at NOCA, OLYM, and MORA compared to other western U.S. parks that were part of the WACAP study. Concentrations of all SOC in NOCA vegetation were above the median for WACAP parks, and were similar to those found in MORA and OLYM. The primary SOC detected in the NCCN were PAHs, followed by varying concentrations of endosulfans, hexachlorocyclohexane- α , hexachlorobenzenes, and dacthal. There were low concentrations of chlorpyrifos, trifluralin, and polychlorinated biphenyls (PCBs). The OLYM vegetation also had relatively high Hg concentrations.

In vegetation at MORA, concentrations were especially high for Hg, PAHs, endosulfans, hexachlorocyclohexane- α , hexachlorobenzene, and dacthal. As forest productivity is relatively high in NOCA, OLYM and MORA, significant transfer of contaminants to the soil in these parks likely arises from canopy throughfall and needle litterfall (Landers et al. 2008). Based on analyses conducted in WACAP, current-use pesticide concentrations were generally lowest in surveyed parks in the Pacific Northwest (OLYM, MORA) and Alaska (Denali National Park and Preserve and Noatak National Preserve; Ackerman et al. 2008) compared to other WACAP parks.

Contaminant concentrations detected in snow in MORA were mid-range among WACAP study sites. Snow samples collected near PJ Lake on the east side of OLYM had fairly high Hg concentrations compared to Hoh Lake on the west side of OLYM and to sites in other WACAP parks. Because there are few local Hg emission sources around OLYM, and none to the west of the park, most deposited Hg is likely transported to OLYM by wind from source areas to the east (Landers et al. 2008). Sources in Asia are also believed to contribute some Hg deposition to coastal areas in the Pacific Northwest (Landers et al. 2008).

Concentrations of pesticides and other SOC in fish in MORA were generally mid-range among WACAP sites, with the notable exception of polybrominated diphenyl ethers (PBDEs), which were higher in fish from Golden Lake in MORA than in fish from any other WACAP lake. One male fish from Golden Lake had elevated concentrations of vitellogenin (Vtg), a blood protein that is a useful biomarker for environmental estrogen exposure. Dieldrin concentrations in fish from both MORA study lakes exceeded health thresholds for subsistence fishers. The Hg levels in fish also exceeded thresholds for piscivorous birds (kingfishers) and mammals (otter and mink), and human health thresholds were exceeded by some fish from Lake LP19 at MORA. As compared to fish collected at other WACAP study lakes, fish in OLYM showed low concentrations of dieldrin, mirex, and chlordanes, and average concentrations of other pesticides.

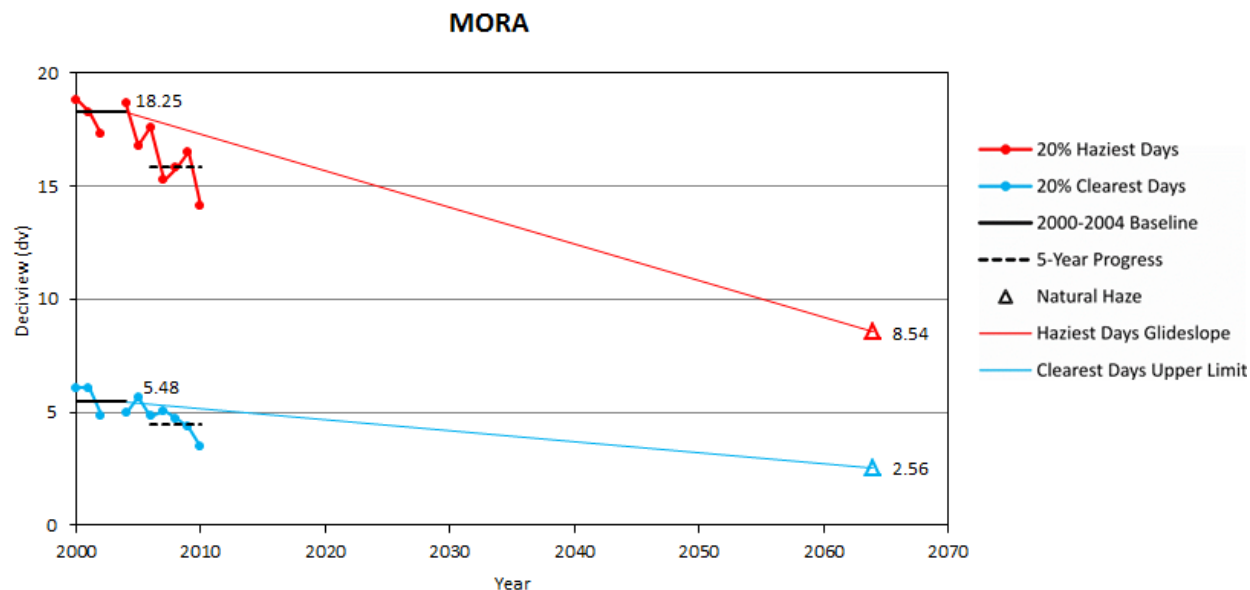


Figure 4a. Glideslopes to achieving natural visibility conditions by 2064 for the 20% hazeiest (red line) and the 20% clearest (blue line) days in MORA, NOCA and OLYM. In the Regional Haze Rule, the clearest days do not have a uniform rate of progress glideslope; the Rule only requires that the clearest days do not get any worse than the baseline period. Also shown are measured values during the period 2000 to 2010. For NOCA, the RHR2_VS method of calculation was used to generate values for the baseline period of 2000-2004. Data from PUSO are used to represent conditions for EBLA. Data Sources: http://vista.cira.colostate.edu/improve/Data/IMPROVE/summary_data.htm

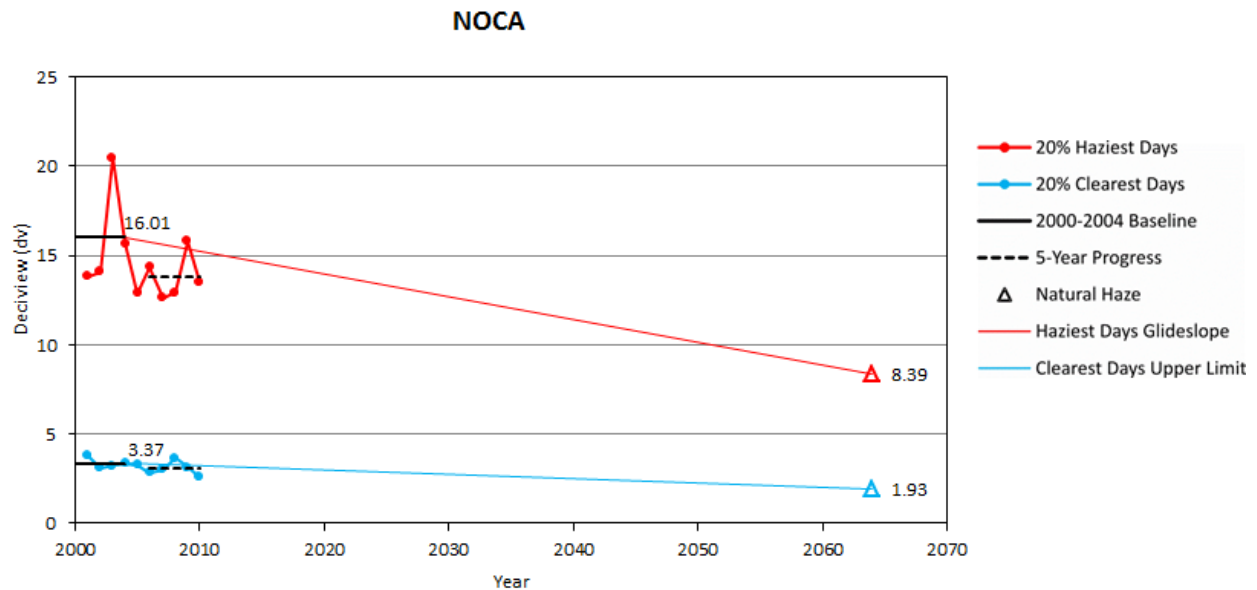


Figure 4b. Glideslopes to achieving natural visibility conditions by 2064 for the 20% haziest (red line) and the 20% clearest (blue line) days in MORA, NOCA and OLYM. In the Regional Haze Rule, the clearest days do not have a uniform rate of progress glideslope; the Rule only requires that the clearest days do not get any worse than the baseline period. Also shown are measured values during the period 2000 to 2010. For NOCA, the RHR2_VS method of calculation was used to generate values for the baseline period of 2000-2004. Data from PUSO are used to represent conditions for EBLA. Data Sources: http://vista.cira.colostate.edu/improve/Data/IMPROVE/summary_data.htm

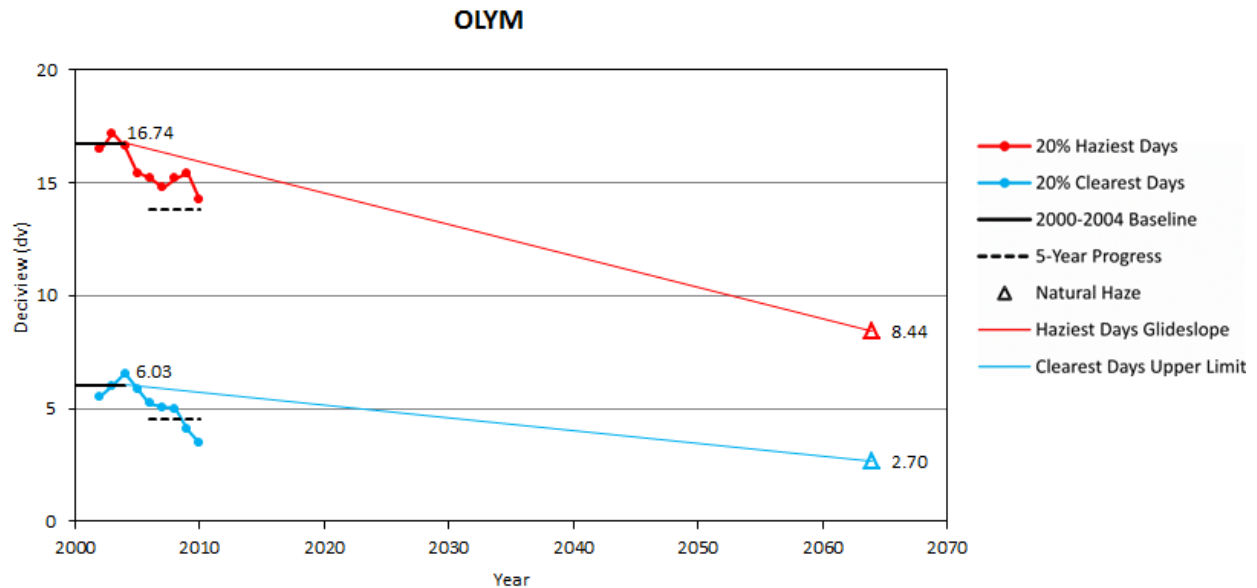


Figure 4c. Glideslopes to achieving natural visibility conditions by 2064 for the 20% haziest (red line) and the 20% clearest (blue line) days in MORA, NOCA and OLYM. In the Regional Haze Rule, the clearest days do not have a uniform rate of progress glideslope; the Rule only requires that the clearest days do not get any worse than the baseline period. Also shown are measured values during the period 2000 to 2010. For NOCA, the RHR2_VS method of calculation was used to generate values for the baseline period of 2000-2004. Data from PUSO are used to represent conditions for EBLA. Data Sources: http://vista.cira.colostate.edu/improve/Data/IMPROVE/summary_data.htm

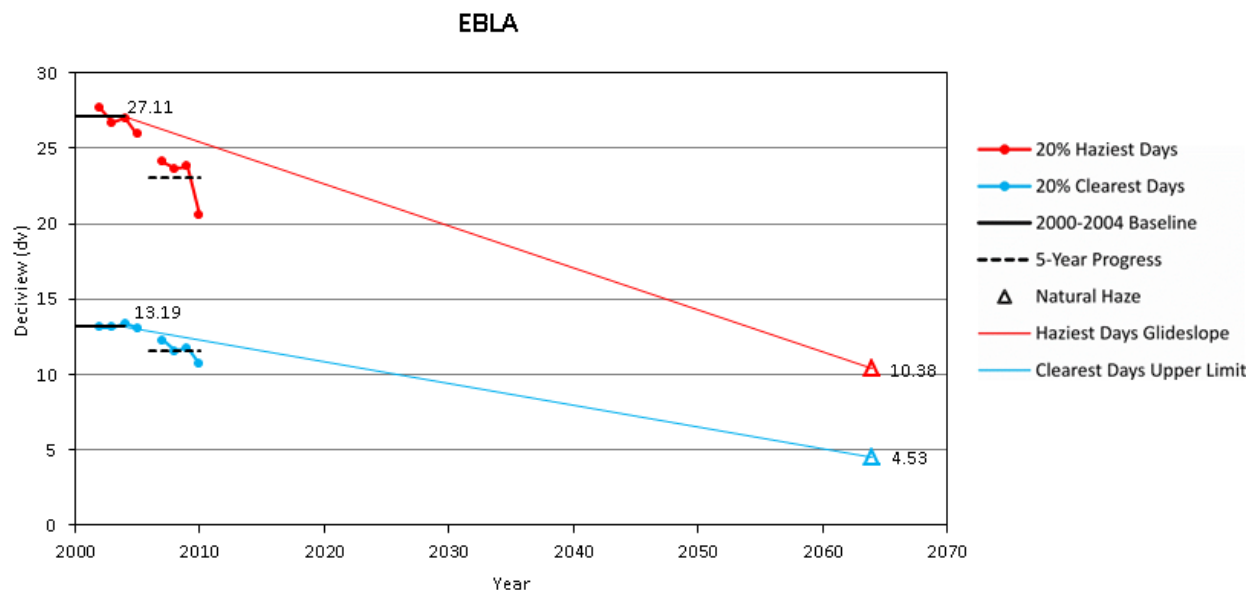


Figure 4d. Glideslopes to achieving natural visibility conditions by 2064 for the 20% haziest (red line) and the 20% clearest (blue line) days in MORA, NOCA and OLYM. In the Regional Haze Rule, the clearest days do not have a uniform rate of progress glideslope; the Rule only requires that the clearest days do not get any worse than the baseline period. Also shown are measured values during the period 2000 to 2010. For NOCA, the RHR2_VS method of calculation was used to generate values for the baseline period of 2000-2004. Data from PUSO are used to represent conditions for EBLA. Data Sources: http://vista.cira.colostate.edu/improve/Data/IMPROVE/summary_data.htm

Moran et al. (2007) sampled non-native cutthroat trout (*Oncorhynchus clarkia*) from lakes in OLYM, MORA and NOCA for Hg and organochlorine contaminants. Of the 28 organochlorine compounds analyzed, only PCBs and *p,p'*-dichlorophenylethylene (DDE) were detected, and they were in low concentrations. Mercury, however, was found in fish tissue from all the lakes sampled. The highest fish tissue Hg concentration was measured in a trout collected from Green Lake in NOCA, well above human and wildlife health thresholds. Evidence from gene expression studies comparing fish from a lake with high contaminant loads to fish from a lake with low contaminant loads led the authors to speculate that Hg plays a role in disrupting reproduction and metabolic pathways in fish from the study lakes and perhaps other high elevation lakes in western Washington (Moran et al. 2007).

Concentrations of Hg in lake sediments in MORA have increased since the 1900s, with a rapid spike in enrichment near the surface of the sediment, suggesting relatively high present-day Hg inputs. This may be a result of coal-fired power plant emissions, increasing global background levels associated with climate change, and/or emissions in Asia and trans-Pacific atmospheric transport of Hg (Landers et al. 2008).

In 1992 and 1994, Davis and Serdar (1996) collected fish from Lake Chelan in NOCA that exceeded human health screening values for some SOCs. Subsequently, the Washington Department of Ecology developed a Total Maximum Daily Load for Lake Chelan to reduce high concentrations of DDT and PCBs in fish (Anderson and Peterschmidt 2008). Lake Chelan has also been sampled for polybrominated diphenyl ether (PBDE) flame retardants in fish, but measured concentrations in fish tissue were low (Johnson et al. 2006).

Furl et al. (2010) documented high concentrations of Hg in largemouth bass collected from two lakes in and adjacent to OLYM. The two study lakes were judged to be relatively unaffected by local and regional point sources of Hg. However, sediment core data suggested recent increases in sedimentation and Hg flux from the watersheds to the lakes. These results were attributed by the authors to erosion from logging, and perhaps road building, in the portions of the study watersheds that are outside park boundaries.

Ozette Lake in OLYM was placed on the Washington State List of Impaired Water Bodies because of high concentrations of Hg in northern pike minnow (*Ptychocheilus oregonensis*; Seiders and Deligeannis 2009) and largemouth bass (*Micropterus salmoides*; Furl and Meredith 2010). Fish consumption advisories have been issued for Hoh, Ozette, and PJ lakes in OLYM (Brenkman 2011).

A study by Frenzel et al. (1990) found higher concentrations of heavy metals in lichens at MORA as compared with lichens at OLYM, presumably due to the close proximity of a copper smelter to MORA. At that time, heavy metal concentrations were not in the range considered toxic to plants. However, the authors suggested the potential for greater contamination with increasing industrialization and development in the Puget Sound area (Frenzel et al. 1990).

Hageman et al. (2010) reported results of pesticide analyses of snowpack at remote alpine, arctic, and subarctic sites in eight national parks, including OLYM, NOCA, and MORA. Various current use

pesticides (CUPs; dacthal, chlorpyrifos, endosulfans, and γ -hexachlorocyclohexane [HCH]) and historic-use pesticides (HUPs; dieldrin, α -HCH, chlordanes, and hexachlorobenzene) were measured at OLYM in 2004 and NOCA in 2005. The pesticide concentration profiles were unique for individual parks, suggesting the importance of regional, rather than distant, sources.

The distributions of CUPs among the parks were explained, using mass back trajectory analysis, based on the mass of individual CUPs used in regions located one-day upwind of the parks. For most pesticides and parks, more than 75% of the snowpack pesticide burden was attributed to regional transport. The authors concluded that the majority of pesticide contamination is U.S. national parks is due to regional, rather than distant, pesticide applications.

Eagles-Smith et al. (2014) sampled fish in 21 national parks and analyzed them for Hg concentrations in tissue. Results varied substantially by park and by water body. The concentrations of Hg in fish collected from five lakes in OLYM were highly variable. Concentrations in fish from Hoh Lake (253 ng/g ww) were more than three-fold higher than fish from Gladys Lake (71.5 ng/g ww). Model estimates suggested that Hoh Lake fish Hg levels likely approached or exceeded the EPA criterion for protecting human health and the avian benchmark for reproductive impairment in fish longer than 180 mm. These results were similar to those reported by Landers et al. (2008), who also found high Hg concentrations in fish from Hoh Lake. Fish were sampled from 17 locations in MORA, many more than in most other parks in the study. Observed variation in Hg concentrations in fish collected in this park was very high, suggesting that local factors are important in determining the ecological risk of Hg bioaccumulation. Fish were sampled from three locations in NOCA. Concentrations of Hg were generally low in this park. Ecological risk appeared to be low.

Organochlorine chemicals can be estrogenic (Garcia-Reyero et al. 2007), contributing to the occurrence of intersex fish, and can accumulate in the aquatic food chains of remote mountain ecosystems (Blais et al. 1998). Biomarkers of exposure to estrogenic chemicals suggest the likelihood of reproductive dysfunction (Harries et al. 1997). Organochlorines are likely transported as atmospheric contaminants to high-elevation sites (Hageman et al. 2006). Work by Schreck and Kent (2013) followed up on some of the work performed in the WACAP Study. They expanded the range of coverage to additional western parks, including MORA and NOCA within NCCN. No intersex fish were found in either of the study parks in NCCN.

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