



Air Quality Related Values (AQRVs) for San Francisco Bay Area Network (SFAN) Parks

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

Natural Resource Report NPS/SFAN/NRR—2016/1186



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

Air Quality Related Values (AQRVs) for San Francisco Bay Area Network (SFAN) Parks

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

Natural Resource Report NPS/SFAN/NRR—2016/1186

Timothy J. Sullivan
P.O. Box 609
Corvallis, OR 97339

March 2016

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

The National Park Service, Natural Resource Stewardship and Science office in Fort Collins, Colorado, publishes a range of reports that address natural resource topics. These reports are of interest and applicability to a broad audience in the National Park Service and others in natural resource management, including scientists, conservation and environmental constituencies, and the public.

The Natural Resource Report Series is used to disseminate comprehensive information and analysis about natural resources and related topics concerning lands managed by the National Park Service. The series supports the advancement of science, informed decision-making, and the achievement of the National Park Service mission. The series also provides a forum for presenting more lengthy results that may not be accepted by publications with page limitations.

All manuscripts in the series receive the appropriate level of peer review to ensure that the information is scientifically credible, technically accurate, appropriately written for the intended audience, and designed and published in a professional manner.

This report received informal peer review by subject-matter experts who were not directly involved in the collection, analysis, or reporting of the data.

Views, statements, findings, conclusions, recommendations, and data in this report do not necessarily reflect views and policies of the National Park Service, U.S. Department of the Interior. Mention of trade names or commercial products does not constitute endorsement or recommendation for use by the U.S. Government.

This report is available in digital format from the E&S Environmental Chemistry website (www.esenvironmental.com) and the Natural Resource Publications Management website (<http://www.nature.nps.gov/publications/nrpm/>). To receive this report in a format optimized for screen readers, please email irma@nps.gov.

Please cite this publication as:

Sullivan, T. J. 2016. Air quality related values (AQRVs) for San Francisco Bay Area Network (SFAN) parks: Effects from ozone; visibility reducing particles; and atmospheric deposition of acids, nutrients and toxics. Natural Resource Report NPS/SFAN/NRR—2016/1186. National Park Service, Fort Collins, Colorado.

Contents

	Page
Figures.....	iv
Tables.....	iv
Maps.....	v
Summary	vi
Background.....	1
Atmospheric Emissions and Deposition	4
Acidification	14
Nutrient Nitrogen Enrichment	16
Ozone Injury to Vegetation.....	20
Visibility Degradation.....	23
Natural Background and Monitored Visibility Conditions	23
Composition of Haze	27
Trends in Visibility.....	30
Development of State Implementation Plans	30
Toxic Airborne Contaminants.....	34
References Cited	35

Figures

	Page
Figure 1a. Three representative photos of the same view in PINN and PORE illustrating the 20% clearest visibility, 20% haziest visibility, and the annual average visibility.	25
Figure 1b. Three representative photos of the same view in PINN and PORE illustrating the 20% clearest visibility, 20% haziest visibility, and the annual average visibility	26
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 FOPO, GOGA, JOMU, MUWO, and PORE.	28
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% haziest visibility days for PINN	29
Figure 3a. Trends in monitored visibility at FOPO, GOGA, JOMU, MUWO and PORE, based on IMPROVE measurements on the 20% clearest, 20% haziest, and annual average visibility days over the monitoring period of record.....	31
Figure 3b. Trends in monitored visibility at PINN, based on IMPROVE measurements on the 20% clearest, 20% haziest, and annual average visibility days over the monitoring period of record.....	31
Figure 4a. Glideslopes to achieving natural visibility conditions by 2064 for the 20% haziest (red line) and the 20% clearest (blue line) days in FOPO, GOGA, JOMU, MUWO, and PORE	32
Figure 4b. Glideslopes to achieving natural visibility conditions by 2064 for the 20% haziest (red line) and the 20% clearest (blue line) days in PINN	33

Tables

	Page
Table 1. Average changes in S and N deposition between 2001 and 2011 across park grid cells at SFAN parks.	9
Table 2. Estimated I&M park rankings according to risk of acidification impacts on sensitive receptors	14
Table 3. Estimated park rankings according to risk of nutrient enrichment impacts on sensitive receptors	17
Table 4. Critical loads for nitrogen in the SFAN, determined by ecoregion and receptor from Pardo et al. (2011).....	19

Tables (continued)

	Page
Table 5. Ozone-sensitive and bioindicator plant species known or thought to occur in the I&M parks of the SFAN	21
Table 6. Ozone assessment results for I&M parks in the SFAN.....	22
Table 7. Estimated natural haze and measured ambient haze in SFAN parks averaged over the period 2004 through 2008.	24
Table 8. IMPROVE monitors and visibility at Class 1 areas in the SFAN.....	33

Maps

	Page
Map 1. Map showing the SFAN boundary and locations of parks and population centers with more than 10,000 people.....	2
Map 2. Total SO ₂ emissions, by county, near the SFAN for the year 2011.....	5
Map 3. Total NO _x emissions, by county, near the SFAN for the year 2011	6
Map 4. Total NH ₃ emissions, by county, near the SFAN for the year 2011	7
Map 5. Total S deposition for the three-year period centered on 2011 in and around the SFAN	10
Map 6. Total oxidized inorganic N deposition for the three-year period centered on 2011 in and around the SFAN	11
Map 7. Reduced inorganic N deposition for the three-year period centered on 2011 in and around the SFAN.....	12
Map 8. Total N deposition for the three-year period centered on 2011 in and around the SFAN	13

Summary

This report describes the Air Quality Related Values (AQRVs) of the San Francisco Bay Area Network (SFAN). The SFAN parks that are included in the NPS Inventory and Monitoring (I&M) Program, and discussed in this report, are Fort Point National Historic Site (FOPO), Golden Gate National Recreation Area (GOGA), John Muir National Historic Site (JOMU), Pinnacles National Monument (PINN), Point Reyes National Seashore (PORE), and Muir Woods National Monument (MUWO). PINN and PORE are designated as Class I, giving them a heightened level of protection against harm caused by poor air quality under the Clean Air Act (CAA).

Sullivan et al. (2011a, 2011b) and Kohut (2007) conducted risk assessments for acidification, eutrophication, and ozone (O₃) for all of the SFAN parks; their results are described in this report. This report also describes air pollutant emissions and air quality within the SFAN region, and their effects on AQRVs. The primary pollutants likely to affect AQRVs include nitrogen (N) and sulfur (S) compounds (nitrate [NO₃⁻], ammonium [NH₄⁺], and sulfate [SO₄²⁻]); ground-level O₃; haze-causing particles; and airborne toxics. Background for this section can be found in “Air quality related values (AQRVs) in national parks: Effects from ozone; visibility reducing particles; and atmospheric deposition of acids, nutrients and toxics” (Sullivan 2016).

Air pollution levels in California vary from very low along portions of the northern coast, where prevailing winds are from the Pacific Ocean and there are relatively few pollution sources, to very high in parts of central and southern California where there are large urban areas and substantial agricultural activity. Air quality in California has generally improved since the early 1980s, but is still significantly degraded in some areas, causing impacts to park visibility and ecosystems. In SFAN parks, air quality is relatively good in PORE because it is generally upwind of pollution sources, but more degraded in other parks, such as PINN which is downwind from the San Francisco Bay air basin.

Sulfur and N air pollutants can acidify streams, lakes, and soils. The SFAN parks appear to have soils and streams that are relatively well-buffered from acidification, but coastal streams in PORE have high amphibian and salmonid abundance and diversity that may be vulnerable to impacts if stream acidification occurs in the future. Nitrogen deposition can also cause undesirable nutrient enrichment of ecosystems, leading to changes in plant species diversity. A risk assessment conducted for all I&M networks nationwide suggested that JOMU and PINN may be especially sensitive to nutrient N enrichment (Sullivan et al. 2011a). The predominant vegetation types within SFAN parks that are thought to be most responsive to nutrient N enrichment are grasslands and arid and semi-arid plant communities. In the San Francisco Bay area, which receives N deposition levels of 10 to 15 kilograms N/hectare/year (kg N/ha/yr), exotic nitrophilous (nitrogen-loving) grasses have displaced native grass species, likely due to greater N availability from deposition and from the cessation of grazing, which previously exported N out of the system (Fenn et al. 2003a). Subsequent to this change in grass species composition, populations of the rare and threatened bay checkerspot butterfly (*Euphydryas editha bayensis*) have declined greatly. Empirical critical load (CL) analyses provide estimates of the levels of atmospheric N deposition that are likely to cause ecological harm, based on

observations and/or field experiments. These analyses suggest that modeled atmospheric N deposition is sufficiently high in all parks in the SFAN, except FOPO, to exceed the CL for lichens. Based on modeled deposition, the empirical CL may also be exceeded in some SFAN parks for additional AQRVs and ecological responses, including the protection of mycorrhizal fungi, herbaceous plants forests, and NO_3^- leaching.

Ozone pollution can harm human health, reduce plant growth, and cause visible injury to foliage. Ozone concentrations in the air are relatively high at some locations in the SFAN region, including at PINN, which is located in a mostly non-urban air basin that is affected by pollutant transport from the San Francisco Bay area and North Central Coast (Monterey area). Data from the O_3 monitor at PINN showed that concentrations exceeded the federal O_3 National Ambient Air Quality Standard (NAAQS) in two of six years between 1992 and 1997 and consistently violated the state standard in effect at that time. Ozone concentrations at PINN continue to exceed the more stringent NAAQS during some years.

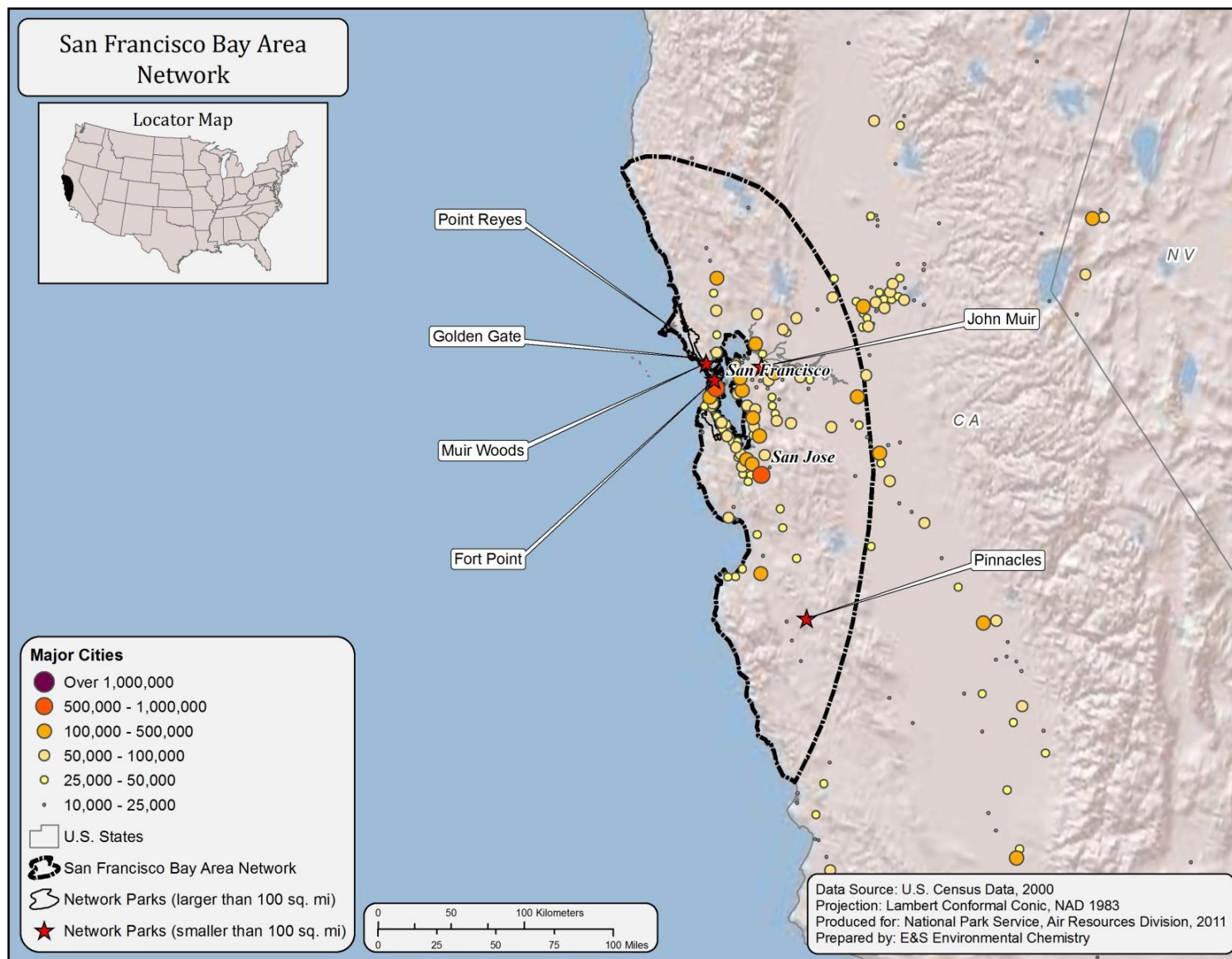
Particles and aerosols in the air can cause haze, reducing visibility. Monitoring in PINN and PORE from 2004 through 2008 indicated that current visibility was moderately worse than estimated natural visibility conditions. Sulfate is the biggest contributor to visibility degradation in these parks. Smoke from frequent forest fires may further reduce visibility during summer.

Background

There are two parks in the San Francisco Bay Area Network (SFAN) that are larger than 100 square miles: Golden Gate National Recreation Area (GOGA) and Point Reyes National Seashore (PORE). There are four smaller parks: Fort Point National Historic Site (FOPO), John Muir National Historic Site (JOMU), Pinnacles National Monument (PINN), and Muir Woods National Monument (MUWO). 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. PINN and PORE are designated as Class I, giving them a heightened level of protection against harm caused by poor air quality under the Clean Air Act (CAA).

There is a high density of relatively large population centers in the SFAN region, but they are confined to the middle half of the region, with none in the far north or south. Map 1 shows the SFAN boundary along with locations of each I&M park and population centers with more than 10,000 people.

Point Reyes National Seashore is located in western Marin County, within the San Francisco Bay Area Air Basin, a predominantly urban air basin with substantial emissions of air pollutants. However, the park's coastal location near the northwestern edge of the air basin, combined with prevailing northwesterly winds off the Pacific Ocean, means PORE is generally upwind relative to the urbanized portions of the air basin. When prevailing winds change, especially during autumn, air



Map 1. Map showing the SFAN boundary and locations of parks and population centers with more than 10,000 people.

quality and visibility at PORE are often reduced. Other parks in the network are more often downwind of local air pollution sources.

Sullivan et al. (2001) reviewed air quality and air pollutant impacts in Class I national parks of California and concluded that there were no significant air pollution concerns in PORE at that time. Pollutant exposures were uniformly low and there were no known or suspected adverse effects on sensitive air quality related values (AQRVs). There were also no known effects of air pollution on vegetation in PINN. It should be noted, however, that until the past few years, research on the effects of air pollution on plant communities in the western United States focused mostly on visible foliar injury associated with ozone (O₃) exposure. In addition, there was limited information about the O₃ sensitivity of the shrubland vegetation that dominates PINN. Now, more information is available about nitrogen (N) deposition effects on western ecosystems, particularly plant communities.

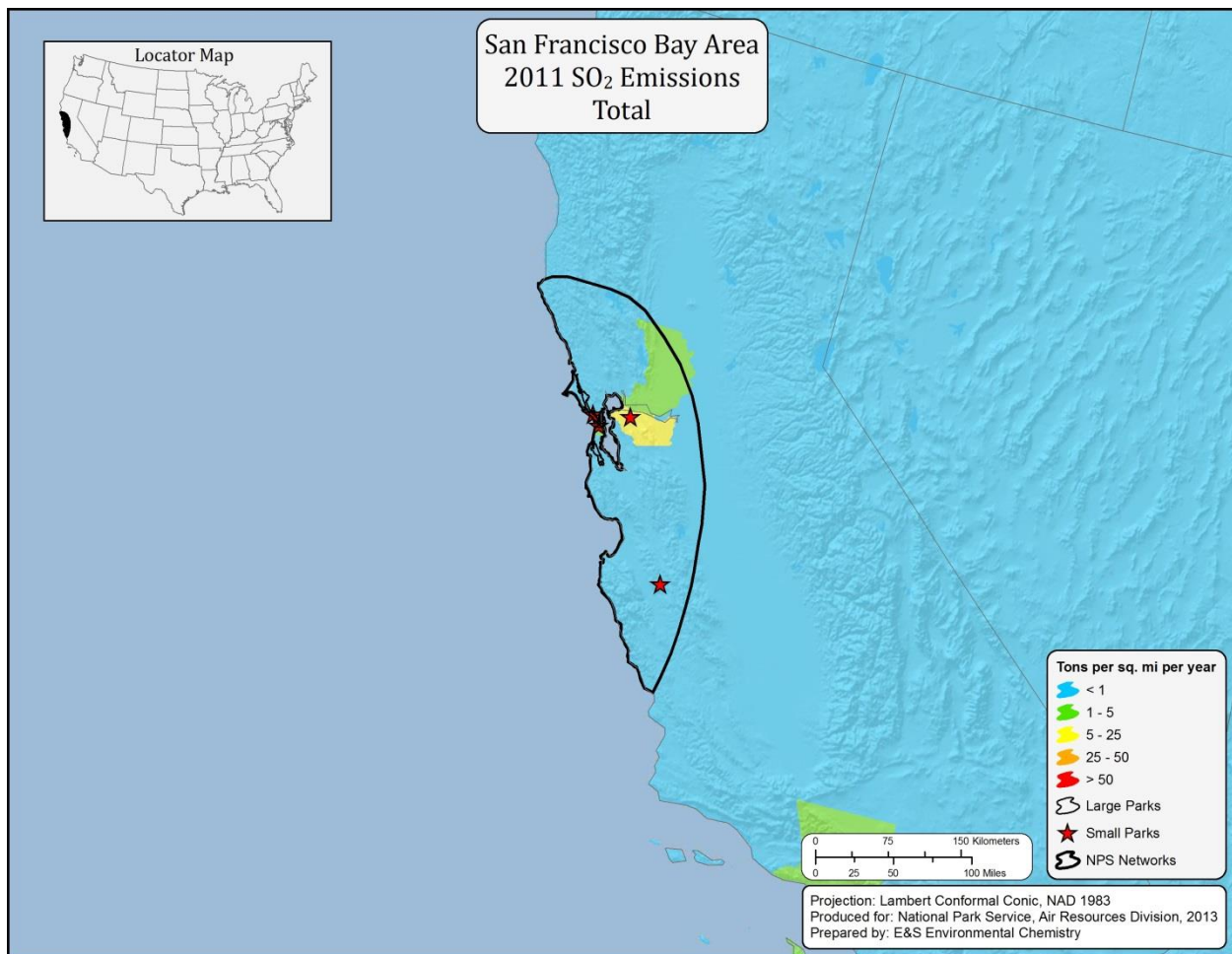
Relatively little air pollution effects information is available for rare, threatened and endangered plant species. GOGA contains more (36) federally listed endangered species than almost any other park in the NPS system (Fritzke 2011). Therefore, additional work to determine the likelihood of impacts of air pollutants (especially O₃ exposure and nutrient N input) may be warranted at that park.

Atmospheric Emissions and Deposition

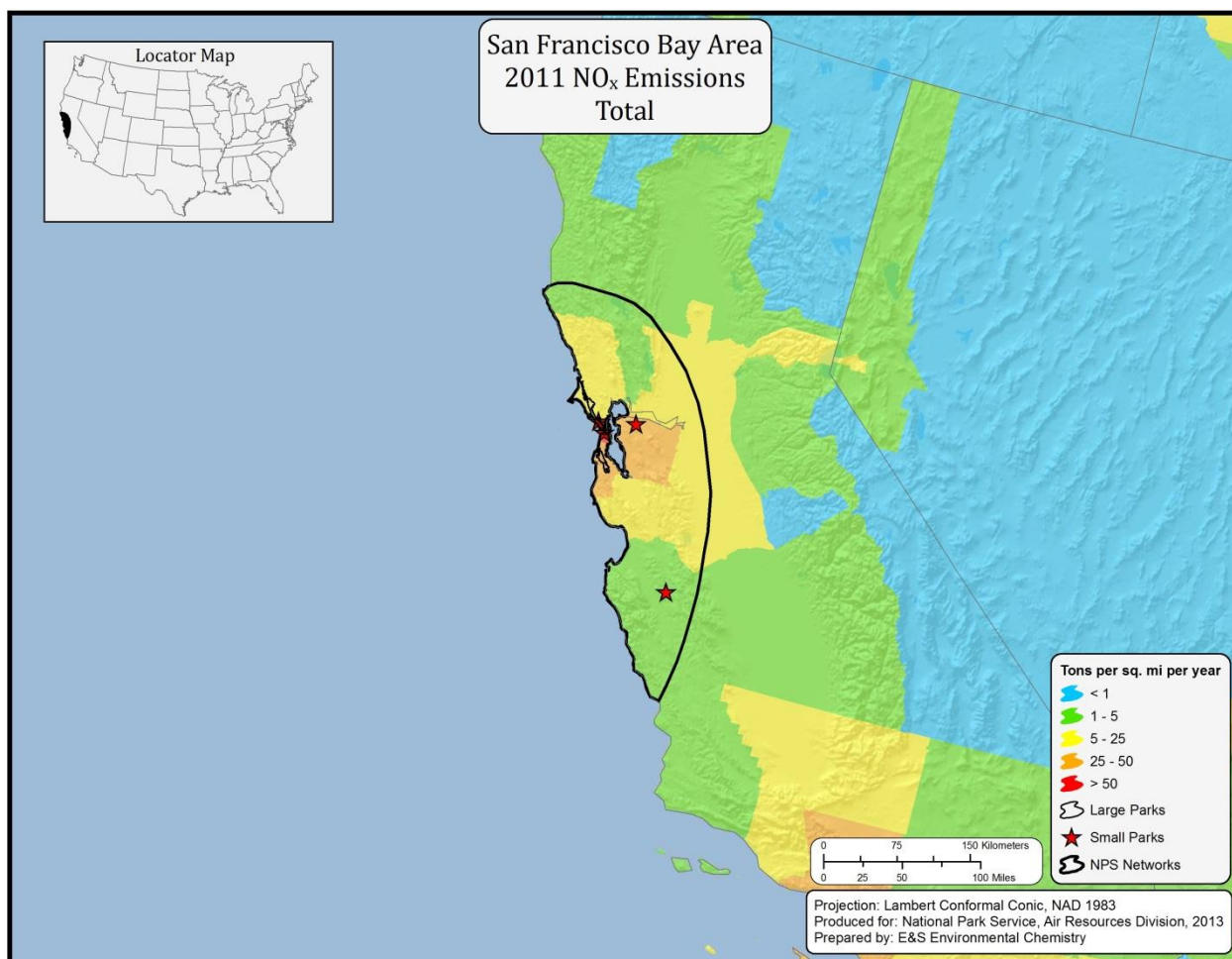
Sullivan et al (2011b) analyzed 2002 emissions and found that annual county-level sulfur dioxide (SO₂) emissions varied throughout the SFAN region, generally from less than 1 ton per square mile per year (ton/mi²/yr) to 5 to 20 tons/mi²/yr. One small area near San Francisco had SO₂ emissions of 20-50 tons/mi²/yr. There were few sulfur (S) or N point sources of any magnitude in this network, although SO₂ emissions from ocean vessels constitute an important contributor to visibility impairment¹ at coastal California parks. County-level N emissions within the SFAN region were higher, generally ranging from less than 5 tons/mi²/yr in the north and the south to 20-50 tons/mi²/yr in the central portion of the region. Some areas had N emissions more than 50 tons/mi²/yr (Sullivan et al. 2011b). The major sources of N emissions in the western United States, including within the SFAN region, are transportation, agriculture, power plants, and industry. The Central Valley of California is one of the most intensively cultivated agricultural regions of the United States and constitutes an important source of reduced N (NH₃) emissions that may impact parks in the SFAN on occasion. Prevailing winds generally transport those emissions away from SFAN parks.

County-level emissions near the SFAN, 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 SO₂, oxidized N (NO_x), and NH₃, respectively. Most counties near SFAN parks had relatively low SO₂ emissions (< 1 ton/mi²/yr; Map 2). Emissions of NO_x were higher, with highest values near PORE, GOGA, and JOMU (Map 3). Emissions of NH₃ were in the range of 0.5 to more than 16 tons/mi²/yr (Map 4).

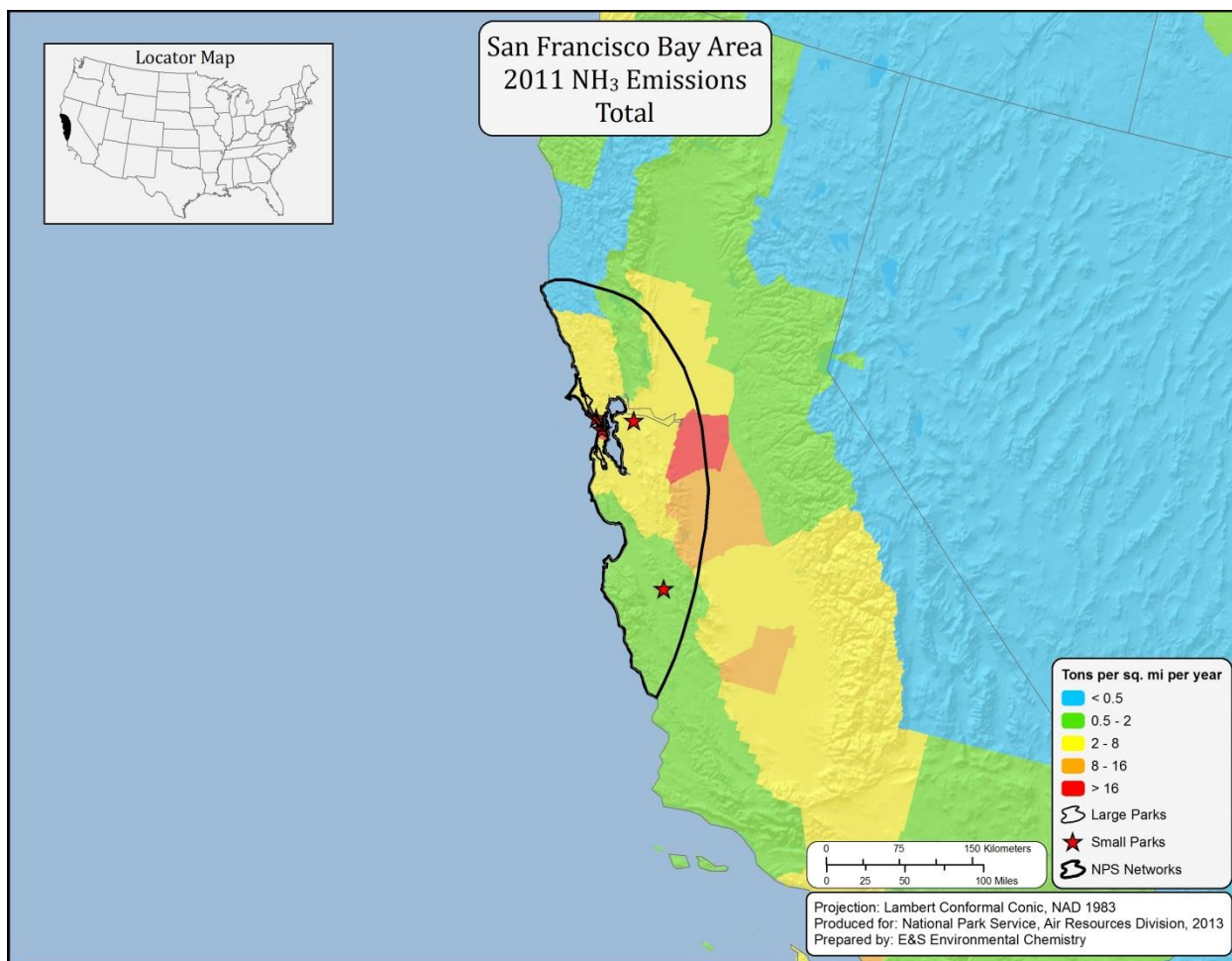
¹ *Visibility impairment* means any humanly perceptible change in visibility (light extinction, visual range, contrast, coloration) from that which would have existed under natural conditions



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



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



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

Trans-Pacific transport of N from southeast Asia is also a source of air pollutants in California, (Fenn et al. 2003b). Emissions of N and S in Asia are higher than in North America (Fenn et al. 2003b) and have increased dramatically in recent decades (Akimoto and Narita 1994, Fenn et al. 2003b).

Emissions of N can be transported across the Pacific Ocean from Asia as peroxyacetyl nitrate (PAN), which has a lifetime in the atmosphere of days to weeks. Because of the comparatively short lifetime of NO_x in the atmosphere (generally less than 24 hr), conversion of NO_x to a longer-lived form (such as PAN) is necessary for long-range transport of N. Once in the troposphere, PAN can be transported long distances over a period of many days and then moved back into the boundary layer, where it regenerates NO_x and nitric acid (HNO₃; Kotchenruther et al. 2001). Long-range transport of PAN from Asia to North America is well documented (Jaffe et al. 1999). Thus, it is likely that NO_x emissions in Asia contribute some, albeit an unknown amount of, N deposition to the western United States. If Asian NO_x emissions continue to increase as predicted (cf., Klimont et al. 2001, Streets and Waldhoff 2000), trans-Pacific sources of N may become more important to west coast locations of the United States, including those in the SFAN, in the future.

Jaffe et al. (2003) demonstrated that the concentration of O₃ in air masses reaching the west coast of the United States from Asia increased by about 30% (10 parts per billion [ppb]) from the mid-1980s to 2002. The study included sites at PORE and Lassen Volcanic and Redwood national parks (both to the north of the SFAN). The measured increase in O₃ at these three parks during the period of study was correlated with increasing N emissions in Asia.

Both SO₂ emissions and atmospheric sulfate (SO₄²⁻) concentrations measured at Interagency Monitoring of Protected Visual Environments (IMPROVE) visibility monitoring sites decreased during the 1990s throughout much of the western United States (Malm et al. 2002). Decreases in emissions ranged from -37% in California to -8% in Idaho. Most of the 30 national park sites in the western United States investigated by Malm et al. (2002) showed decreasing atmospheric SO₄²⁻ concentrations during the period 1989 to 1999, but the trends were statistically significant at only six sites, including PINN, where the reduction was about 40%.

Sullivan et al. (2011b) modeled S and N deposition for all I&M networks nationwide. Total modeled S deposition in 2002 in the SFAN region ranged from less than 2 kg S/ha/yr to 5-10 kg S/ha/yr (Sullivan et al. 2011b). It was generally less than 5 kg S/ha/yr at most locations, except in the heavily populated areas in the central part of the SFAN region. Total modeled N deposition in the SFAN region ranged from 2-5 kg N/ha/yr at some locations to more than 10 kg N/ha/yr (Sullivan et al. 2011b).

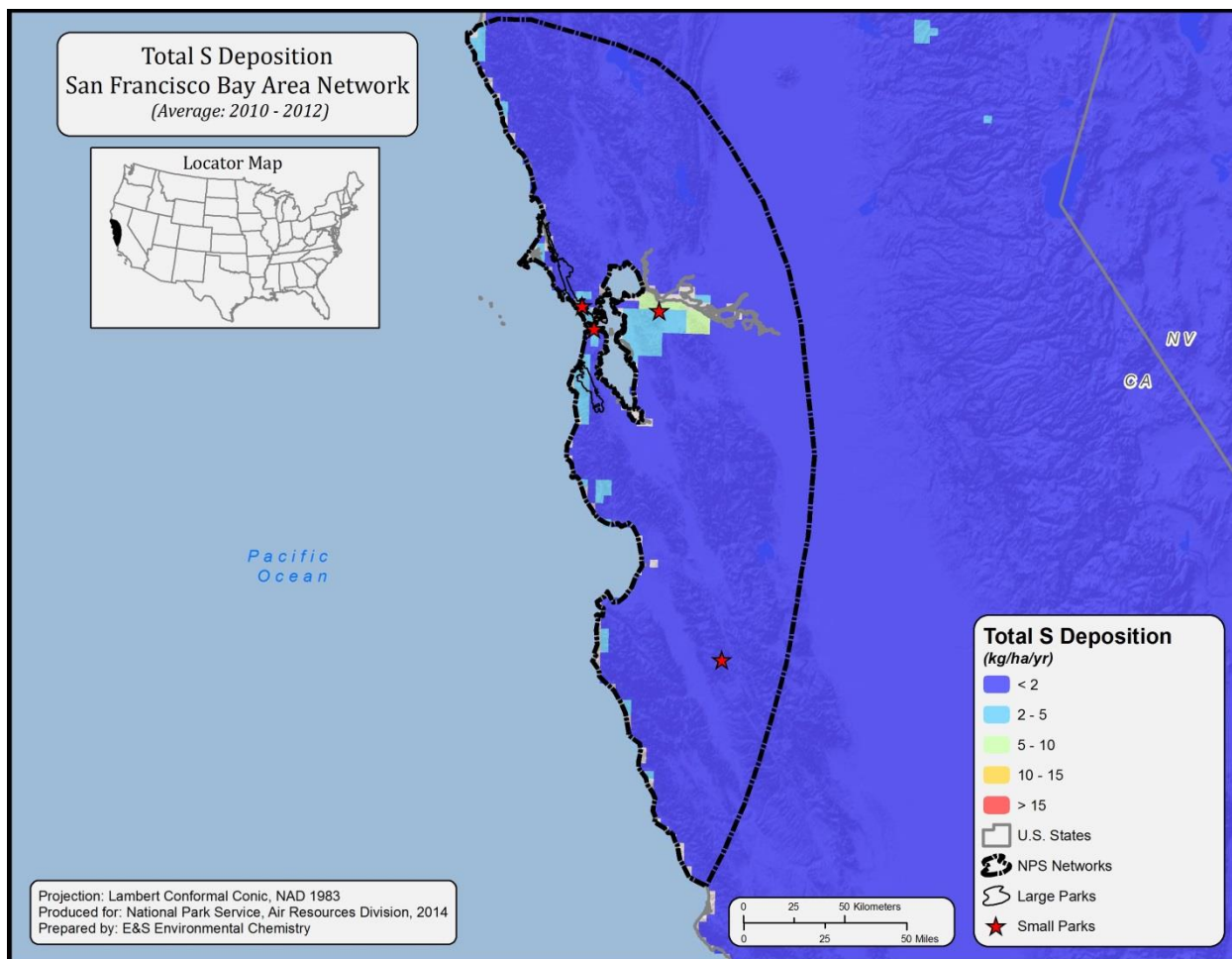
Recently, Schwede and Lear (2014) documented a hybrid approach developed by the National Atmospheric Deposition Program (NADP) Total Deposition (TDEP) Science Committee for estimating total N and S deposition. This approach combined monitoring and modeling data. Modeling was accomplished using the Community 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: PAN, N₂O₅, NO, NO₂, HONO, and organic NO₃. 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 and N deposition levels at SFAN parks have showed variable changes since 2001, based on TDEP estimates (Table 1). Changes in oxidized and reduced N have been more consistent in direction of change across parks. Oxidized and reduced N showed opposite patterns, with oxidized N decreasing and reduced N increasing at all of the parks in the network since the monitoring period 2000-2002.

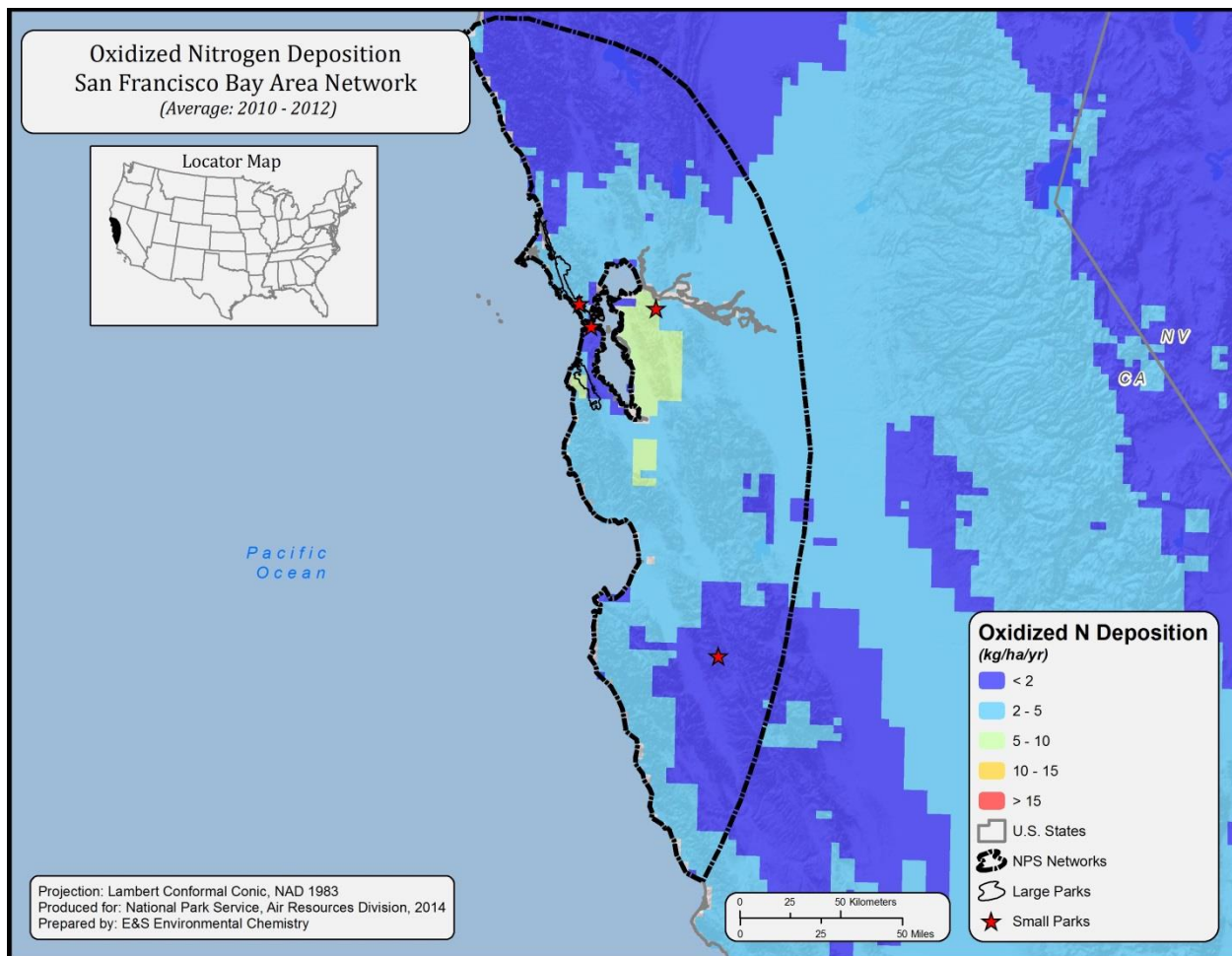
Total S deposition in and around SFAN for the period 2010-2012 was generally in the range of 2 to 5 kg S/ha/yr at park locations within the network (Map 5). Oxidized inorganic N deposition for the period 2010-2012 was variable throughout the park lands within SFAN (Map 6). Most areas received less than 10 kg N/ha/yr of reduced inorganic N from atmospheric deposition during this same period (Map 7). Total N deposition was higher than 5 kg N/ha/yr at most park locations (Map 8).

Table 1. Average changes in S and N deposition between 2001 and 2011 across park grid cells at SFAN 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.

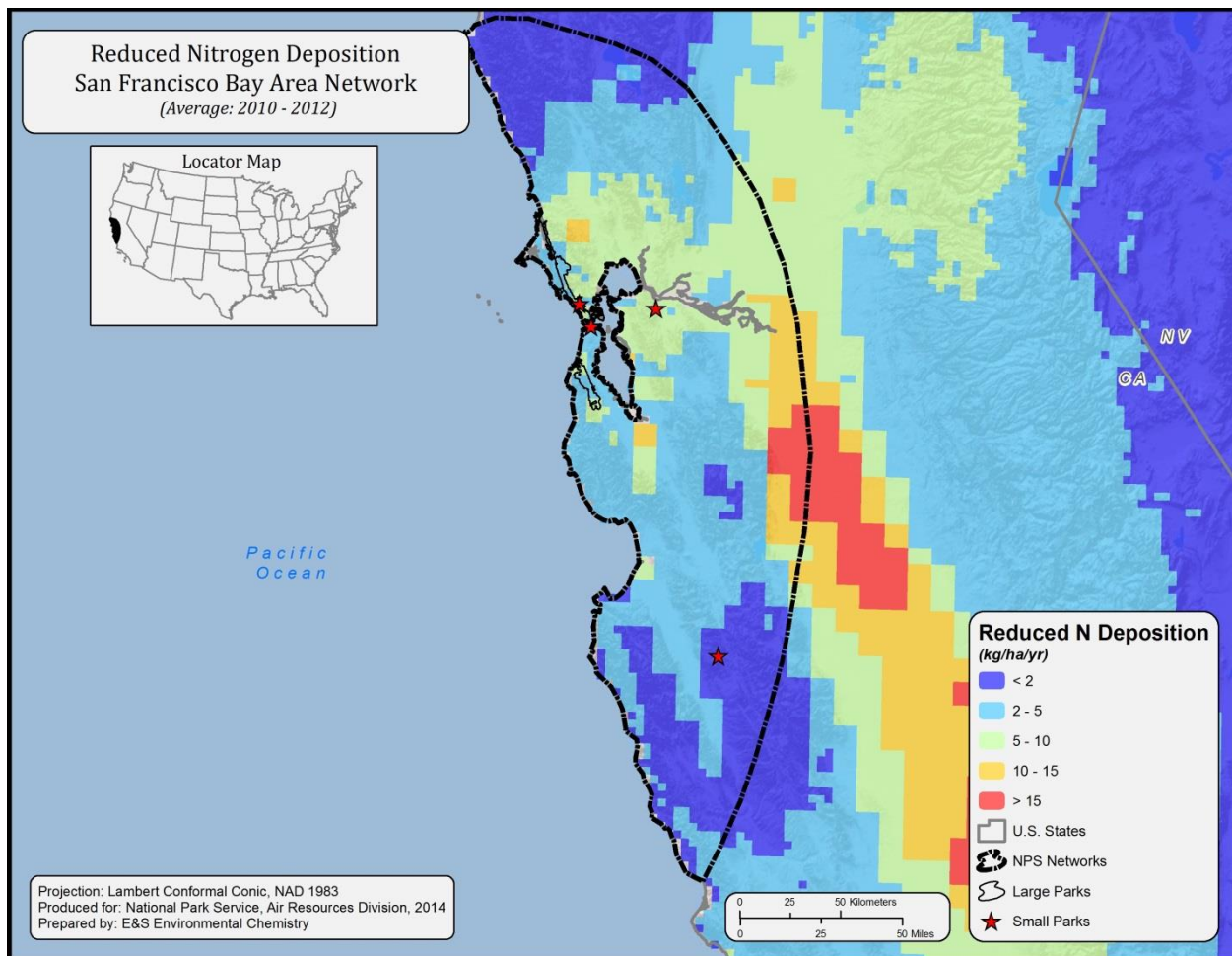
Park Code	Park Name	Parameter	2001 Average (kg/ha/yr)	2011 Average (kg/ha/yr)	Absolute Change (kg/ha/yr)	Percent Change	2011 Minimum (kg/ha/yr)	2011 Maximum (kg/ha/yr)	2011 Range (kg/ha/yr)
FOPO	Fort Point	Total S	2.20	2.00	-0.19	-8.8%	2.00	2.00	0.00
		Total N	12.97	5.71	-7.26	-56.0%	5.71	5.71	0.00
		Oxidized N	9.53	1.46	-8.07	-84.7%	1.46	1.46	0.00
		Reduced N	3.44	4.25	0.81	23.5%	4.25	4.25	0.00
GOGA	Golden Gate	Total S	2.23	2.15	-0.08	-4.1%	1.12	4.29	3.17
		Total N	10.70	7.93	-2.78	-24.8%	3.94	12.99	9.05
		Oxidized N	7.26	3.16	-4.10	-54.8%	1.18	5.21	4.03
		Reduced N	3.44	4.77	1.33	37.3%	2.66	8.09	5.43
JOMU	John Muir	Total S	1.59	4.61	3.01	189.6%	4.28	6.50	2.22
		Total N	9.24	11.12	1.88	21.0%	10.84	12.74	1.90
		Oxidized N	6.22	5.62	-0.60	-9.3%	5.39	5.65	0.26
		Reduced N	3.02	5.51	2.49	82.0%	5.19	7.35	2.16
MUWO	Muir Woods	Total S	3.05	2.24	-0.81	-25.9%	1.86	3.73	1.86
		Total N	10.46	9.34	-1.12	-10.7%	8.23	10.33	2.10
		Oxidized N	6.21	3.54	-2.67	-42.8%	3.28	3.81	0.53
		Reduced N	4.25	5.80	1.55	36.6%	4.95	6.52	1.57
PINN	Pinnacles	Total S	0.61	0.63	0.02	2.5%	0.58	0.66	0.08
		Total N	4.08	3.59	-0.50	-12.1%	3.18	3.71	0.52
		Oxidized N	2.81	1.82	-0.98	-35.0%	1.70	1.87	0.17
		Reduced N	1.28	1.76	0.49	38.4%	1.48	1.84	0.36
PORE	Point Reyes	Total S	1.88	1.79	-0.09	-4.4%	1.21	2.34	1.13
		Total N	7.27	5.55	-1.72	-23.8%	3.43	7.52	4.09
		Oxidized N	4.41	2.29	-2.12	-48.5%	1.21	3.49	2.28
		Reduced N	2.86	3.26	0.40	14.9%	2.22	6.00	3.78



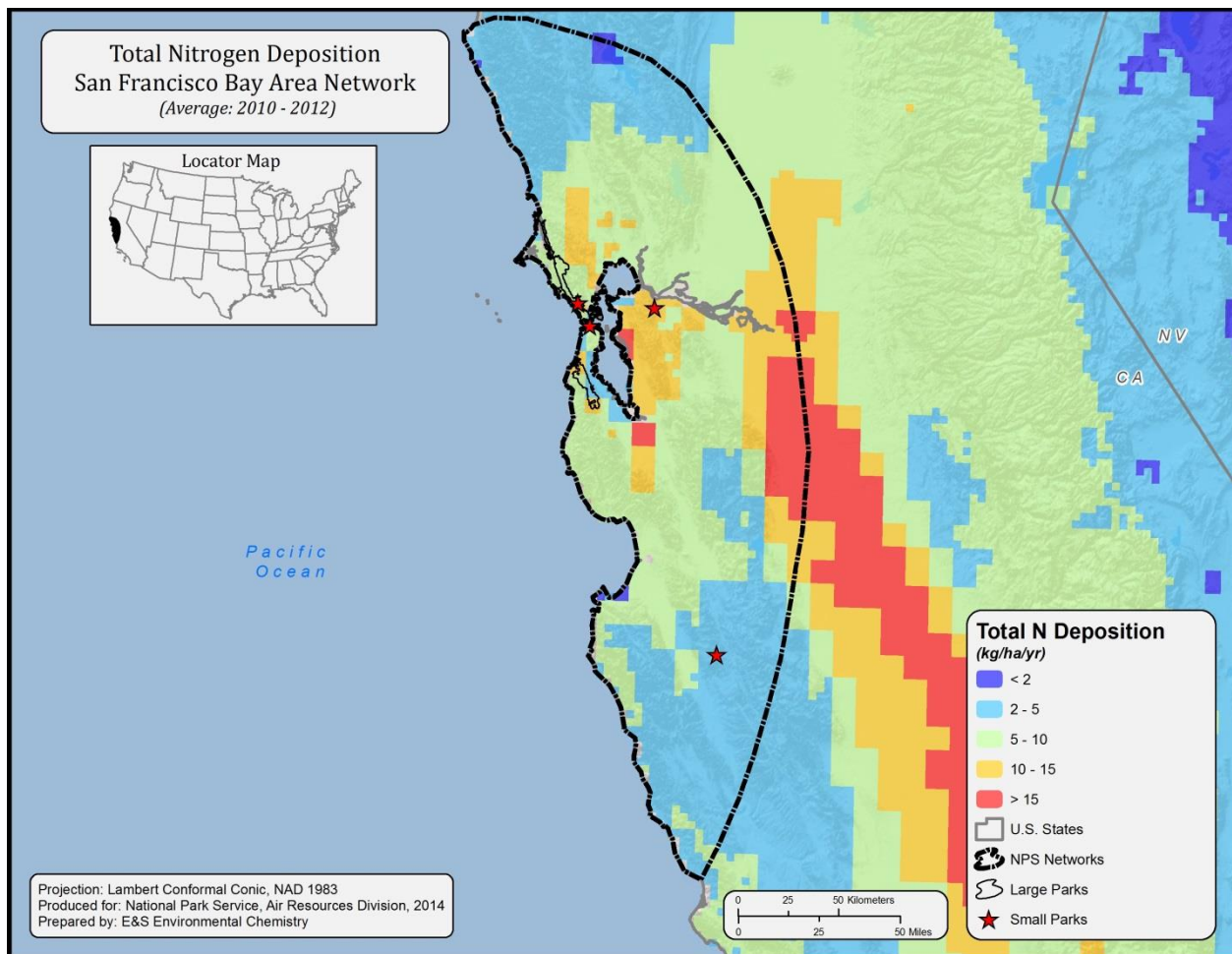
Map 5. Total S deposition for the three-year period centered on 2011 in and around the SFAN. (Source: Schwede and Lear 2014)



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



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



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

Acidification

Sullivan et al. (2011a) conducted a coarse screening assessment to evaluate relative risk of acidification for all I&M networks nationwide. The network rankings reported by Sullivan et al. (2011b) for acid Pollutant Exposure, Ecosystem Sensitivity to acidification, and Park Protection yielded an overall network acidification Summary Risk ranking for the SFAN that was near the middle of the distribution among all I&M networks. The overall level of concern for acidification effects on parks within the SFAN was judged by Sullivan et al. (2011b) to be Moderate relative to other I&M networks.

Three of the parks in the SFAN (JOMU, MUWO and PORE), were ranked by Sullivan et al. (2011b) in the second highest quintile (High) among I&M parks in acid Pollutant Exposure, due largely to their proximity to emissions source areas (Table 2). Because PORE is generally upwind of San

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
Fort Point	FOPO	Moderate	Low
Golden Gate	GOGA	Moderate	High
John Muir	JOMU	High	Low
Muir Woods	MUWO	High	Moderate
Pinnacles	PINN	Moderate	High
Point Reyes	PORE	High	Moderate

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.

Francisco Bay area emissions, however, the actual pollutant exposure is much less at this park than is indicated by this ranking. The other three parks were ranked Moderate for this theme. For Ecosystem Sensitivity to acidification, the rankings varied: two parks (GOGA and PINN) were ranked High, two parks (MUWO and PORE) were ranked Moderate, and two parks (FOPO and JOMU) were ranked Low (Table 2). Ecosystem sensitivity to acidification rankings take into account elevation and land slope, which often influence the degree of acid neutralization provided by soils and bedrock within the watershed. Slope is general fairly steep in the parks in the SFAN, generally between about 20° and 30°. The terrain in the northern part of PORE is less steep, with average slope between 10° and 20°, suggesting decreased potential for acid sensitivity of aquatic ecosystems. While rankings are an indication of risk, park-specific data, particularly data on ecosystem sensitivity, are needed to fully evaluate risk from acidification.

Modeled N and S deposition at PORE are low and, based on existing water chemistry data, the streams do not appear to be highly sensitive to acidification (Sullivan et al. 2001). Aquatic acidification is not an important concern at the present time. Nevertheless, coastal streams in PORE

have high amphibian and salmonid abundance and diversity. These aquatic organisms may be adversely affected if stream acidification occurs in the future. PINN exhibits some of the characteristics typically associated with acid-sensitive surface waters, such as steep slopes and numerous low-order streams, and were therefore ranked High by Sullivan et al. (2011b) in Ecosystem Sensitivity to acidification. Nevertheless, existing water chemistry data for PINN, although limited, do not reinforce the suggestion of a high degree of acid sensitivity (Sullivan et al. 2001).

Nutrient Nitrogen Enrichment

Atmospheric N deposition in recent years ranged from about 1 to 5 kg N/ha/yr throughout most of the western United States, essentially acting as a low-level fertilizer to western plant communities. For most western ecosystems, these low-level N additions probably serve to slightly increase N availability and plant growth. However, some sensitive species, including lichens, can be adversely affected by deposition inputs as low as 3 to 8 kg N/ha/yr (Fenn et al. 2003a). Nitrogen enrichment changes lichen species composition because some species are better able to use the additional N than others. Levels of N deposition can be much higher than the broad-scale regional average, and there can be more pronounced effects on ecosystems near depositional hot spots such as metropolitan, industrial, or agricultural centers or large point sources of pollution (Fenn et al. 2003a). This may be the case in park lands located in proximity to the San Francisco Bay Area.

The network rankings developed by Sullivan et al. (2011a) for nutrient N Pollutant Exposure, Ecosystem Sensitivity to nutrient enrichment, and Park Protection yielded an overall network nutrient N Summary Risk ranking for the SFAN that was in the second highest quintile (High) among all I&M networks nationwide. Parks in the SFAN were ranked Moderate to High in nutrient N Pollutant Exposure (Table 3). Ecosystem sensitivity to nutrient N enrichment appeared to be more variable, with highest sensitivity estimated for JOMU, PINN, and PORE. 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.

The predominant vegetation types within the SFAN parks that are thought to be most responsive to nutrient N enrichment effects are arid and semi-arid plant communities, and lichens in forests. From studies of N additions in tallgrass prairie, Lane and BassiriRad (2002) suggested that increasing N deposition levels could cause species-specific growth and plant tissue quality changes, which in turn could lead to changes in ecosystem dynamics and community structure. Grasses are well known to respond to increased N availability. Under high N supply, grasses will often out-compete other herbaceous species, and cause changes in plant community composition.

In European grasslands, changes in species composition in response to N deposition have been observed regardless of soil type. Such effects have been found in calcareous, neutral, and acidic environments, species-rich heaths, and montane-subalpine grasslands (Bobbink et al. 1992, Bobbink et al. 1998, Stevens et al. 2004).

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
Fort Point	FOPO	Moderate	Low
Golden Gate	GOGA	High	Moderate
John Muir	JOMU	High	High
Muir Woods	MUWO	High	Low
Pinnacles	PINN	Moderate	High
Point Reyes	PORE	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.

In the San Francisco Bay area, which receives relatively high N deposition levels of 10 to 15 kg N/ha/yr, exotic nitrophilous (N-loving) grasses have displaced native grass species, likely due to greater N availability from deposition and from the cessation of grazing, which previously exported N out of the system (Fenn et al. 2003a). Since this change in plant species composition, populations of the rare and threatened bay checkerspot butterfly (*Euphydryas editha bayensis*) have declined greatly (Fenn et al. 2003a). It has been hypothesized that the response of the butterfly has been due to the vegetative changes.

Zavaleta et al. (2003) investigated the effects of changing climate and N deposition on natural grassland communities at the Jasper Ridge Biological Preserve, south of San Francisco. Treatment plots received combinations of elevated carbon dioxide (CO₂), warming, increased N input, and increased precipitation. Responses for the 10 most common plant species were not strong, but were sufficiently consistent within functional groups to determine patterns of response. Annual grasses and forbs exhibited production and abundance responses. After three years of treatment, N deposition decreased plant diversity, forb production, and forb abundance; in contrast, grass production increased. Combinations of changes in the various drivers had small effects on plant diversity, but more pronounced effects on the relative dominance of forbs and grasses. Such shifts in plant species composition could have important impacts on ecosystem processes and nutrient cycling (Zavaleta et al. 2003). Increased N deposition (70 kg N/ha/yr over three years) led to a decline in total species richness. Specifically, soft brome (*Bromus hordeaceus*) abundance increased while slender oat (*Avena barbata*) declined during the experiment.

In a greenhouse experiment with native shrubs and exotic grasses from the California coastal sage scrub (CSS) ecosystem, N was added to obtain soil N concentrations of 2, 20, 40, and 80 micrograms per gram (µg/g). The grasses demonstrated a 1.5- to 2.5-fold growth increase when soil N levels increased from 20 to 40 µg/g. To achieve a comparable growth increase, shrubs required higher soil N levels (between 20 and 80 µg/g; Padgett and Allen 1999). These lab experiments agreed with

observations in the field, where exotic grasses replaced native shrubs under elevated N deposition (Padgett and Allen 1999).

Serpentine grassland near San Jose, California was estimated by Fenn et al. (2011) to have a CL of about 6 kg N/ha/yr, based on identification of the location along a roadside N depositional gradient where the cover of non-native invasive annual grasses became visibly diminished (Fenn et al. 2010, Weiss 1999).

Changes in plant root-to-shoot growth ratios with increasing nutrient N enrichment were observed in studies of the CSS community, which is composed largely of the drought-resistant deciduous shrubs California sagebrush (*Artemisia californica*), brittlebush (*Encelia farinose*), and eastern Mojave buckwheat (*Eriogonum fasciculatum*). The CSS community in California has been declining in land area and in shrub density over about the past 60 years and is being replaced in many areas by Mediterranean annual grasses (Padgett and Allen 1999, Padgett et al. 1999). Nitrogen deposition is considered a possible cause or contributor to this ecosystem alteration. Egerton-Warburton and Allen (2000) discerned a shift in mycorrhizal fungi community composition with decreased species richness and diversity in CSS ecosystems along a deposition gradient (2 to 57 $\mu\text{g N/g}$ as soil NO_3^-). Larger-spored species were displaced as smaller-spored species proliferated. These shifts in mycorrhizal fungal communities may facilitate the observed replacement of native CSS plant communities by Mediterranean annual grasslands. The CSS community is of particular interest because it contains about 200 sensitive plant species and several federally listed threatened or endangered animal species.

Eutrophic (nutrient-rich) lichen species richness and abundance have been shown to decrease with NH_3 emissions and N deposition in the Central Valley (Jovan and McCune 2005, Jovan 2008). Fenn et al. (2011) reported that, of the 53 lichen survey sites in California that had relative clean air scores, only three occurred in locations where modeled deposition was greater than 5.5 kg of total N/ha/yr. Modeled N deposition in the SFAN is greater than this amount in some locations so there may currently be adverse effects on lichen community composition.

Pardo et al. (2011) identified the CLs that would protect sensitive resources in Level I ecoregions across the conterminous United States against effects caused by atmospheric N deposition (Table 4). 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, so CLs for the same receptor may vary within a park (e.g., lichens at GOGA). Table 4 suggests that CLs for lichens may be exceeded by current deposition in most SFAN parks; CLs for mycorrhizal fungi, forests, and nitrate leaching may also be exceeded at some areas. In some cases, estimated ambient N deposition exceeded both the lower and the upper end of Pardo et al.'s (2011) estimated CL range, mainly for protection of lichens.

Table 4. Critical loads for nitrogen in the SFAN, determined by ecoregion and receptor from Pardo et al. (2011). Ambient N deposition reported by Pardo et al. (2011) 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
Fort Point NHS	Mediterranean California	2.4	7.8 - 9.2	3.1 - 6	6 - 33	17 - 39	10 - 17
Golden Gate NRA	Marine West Coast Forests	11.1	5 - 5	2.7 - 9.2	NA	5 - 5	NA
Golden Gate NRA	Mediterranean California	11.1	7.8 - 9.2	3.1 - 6	6 - 33	17 - 39	10 - 17
John Muir NHS	Mediterranean California	8.0	7.8 - 9.2	3.1 - 6	6 - 33	17 - 39	10 - 17
Muir Woods NM	Mediterranean California	5.4	7.8 - 9.2	3.1 - 6	6 - 33	17 - 39	10 - 17
Pinnacles NM	Mediterranean California	5.4	7.8 - 9.2	3.1 - 6	6 - 33	17 - 39	10 - 17
Point Reyes NS	Mediterranean California	5.6	7.8 - 9.2	3.1 - 6	6 - 33	17 - 39	10 - 17
Presidio of San Francisco	Mediterranean California	11.1	7.8 - 9.2	3.1 - 6	6 - 33	17 - 39	10 - 17

Ozone Injury to Vegetation

The O₃-sensitive plant species that are known or thought to occur within the I&M parks in the SFAN are listed in Table 5. Those considered to be bioindicators, that is, they display visible and easily recognizable O₃ injury symptoms, are designated by an asterisk. Each park in this network contained at least one 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 6, along with Kohut's (2007) O₃ risk ranking. The NPS and Kohut ranking systems differ. The NPS ranking system (NPS 2010) 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 exposure at values between 7 and 13 ppm-hr. Values higher than 13 ppm-hr were classified as High exposure, and values lower than 7 ppm-hr were classified as Low exposure. NPS (2010) classified the SUM06 as Moderate at values between 8 and 15 ppm-hr. Higher and lower values were classified as High and Low, respectively.

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 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. Kohut's more robust approach rated the parks from Low to High risk, with JOMU and PINN at high risk.

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 concentrations (2005-2009), but not environmental conditions.

Table 5. Ozone-sensitive and bioindicator plant species known or thought to occur in the I&M parks of the SFAN. (Data 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					
		FOPO	GOGA	JOMU	MUWO	PINN	PORE
<i>Ailanthus altissima</i> *	Tree-of-heaven			x			
<i>Alnus rubra</i> *	Red alder		x		x		x
<i>Apocynum cannabinum</i>	Dogbane, Indian hemp					x	
<i>Artemisia douglasiana</i> *	Mugwort		x	x	x	x	x
<i>Oenothera elata</i> spp. <i>Hookeri</i> *	Evening primrose		x				
<i>Philadelphus coronarius</i>	Sweet mock orange			x			
<i>Physocarpus capitatus</i> *	Ninebark						x
<i>Pinus ponderosa</i> *	Ponderosa pine			x			
<i>Pinus radiata</i>	Monterey pine		x	x	x		x
<i>Quercus kelloggii</i>	California black oak			x			
<i>Robinia pseudoacacia</i>	Black locust			x			x
<i>Rubus parviflorus</i>	Thimbleberry		x		x		x
<i>Salix scouleriana</i> *	Scouler's willow		x				
<i>Sambucus mexicana</i> *	Blue elderberry		x	x	x	x	
<i>Sambucus nigra</i> spp. <i>canadensis</i> *	Blue elderberry						x
<i>Sambucus racemosa</i> *	Red elderberry	x	x				
<i>Spartina alterniflora</i>	Smooth cordgrass		x				x
<i>Symphoricarpos albus</i> var. <i>laevigatus</i> *	Common snowberry			x			
<i>Symphoricarpos albus</i> *	Common snowberry		x				
<i>Vitis vinifera</i> *	European wine grape			x			

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

* Bioindicator species

Table 6. Ozone assessment results for I&M parks in the SFAN. NPS risk ranking is based on estimated average 3-month W126 and SUM06 ozone exposure indices for the period 2005-2009. Risk to vegetation is based on several factors that contribute to injury in plants, including ozone exposure and environmental variables (Kohut 2007)¹.

Park Name ²	Park Code	W126		SUM06		Kohut O ₃ Risk Ranking
		Value (ppm-hr)	Ranking	Value (ppm-hr)	Ranking	
Fort Point	FOPO	2.39	Low	2.34	Low	No Rank
<i>Golden Gate</i>	GOGA	2.30	Low	2.34	Low	Low
John Muir	JOMU	4.90	Low	5.64	Low	High
Muir Woods	MUWO	2.34	Low	2.26	Low	Moderate
Pinnacles	PINN	7.36	Moderate	8.81	Moderate	High
<i>Point Reyes</i>	PORE	1.81	Low	1.93	Low	Low

¹ Parks are classified into one of three ranks (Low, Moderate, High), based on comparison with other I&M parks.

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

Air pollution damage to plants in California, especially damage associated with exposure of sensitive plants to O₃, varies from virtually none in PORE to substantial in parts of southern California (Sullivan et al. 2001). In the SFAN air basins, O₃ concentrations declined from the early 1980s through 1997 (Sullivan et al. 2001). Ozone measurements within PORE reported by Sullivan et al. (2001) were available only from 1989 to 1992. During that period, O₃ concentrations were low in PORE relative to other parks within California, and did not exceed the California or the federal O₃ standards.

Pinnacles NM experiences seasonal to chronic periods of poor air quality, especially high O₃ (Sullivan et al. 2001). The park is located in a mostly non-urban air basin. Nevertheless, pollutant transport from the San Francisco Bay Area and North Central Coast (Monterey area) Air Basins occurs (Sullivan et al. 2001). Data from the O₃ monitor in the park showed that O₃ concentrations exceeded the federal maximum daily 1-hr hourly O₃ standard in effect at that time (120 ppb) for two of the six years between 1992 and 1997 and consistently violated the state maximum hourly standard in effect at that time (90 ppb). Ozone concentrations at PINN continue to exceed the more stringent 8-hr NAAQS of 75 ppb in some recent years. Ozone injury surveys have not been conducted at PINN.

Visibility Degradation

Natural Background and Monitored Visibility Conditions

The Clean Air Act set a specific goal for visibility protection in Class I areas: “the prevention of any future, and the remedying of any existing, impairment of visibility in mandatory Class I federal areas which impairment results from manmade air pollution” (42 U.S.C. 7491). 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. Natural background visibility assumes no human-caused pollution, but varies with natural processes such as windblown dust, wildfire, volcanic activity and biogenic (vegetation) emissions. Visibility is monitored by the IMPROVE Network and typically reported using the haze index called the deciview² (dv). Lower dv values correspond with lower haze and better visibility conditions.

Natural background visibility has been estimated by IMPROVE for PINN and PORE and is reported in Table 7. The data from PORE are considered to be representative of visibility conditions in all of the other SFAN parks (except PINN). 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 of that area. PINN had moderately lower natural background visibility in comparison with all I&M parks for the 20% clearest days (3.4 dv). For the 20% haziest days and the average days, natural background visibility in PINN was also moderate (8.0 and 5.6 dv, respectively; Table 7). Point Reyes NS, FOPO, GOGA, JOMU, and MUWO had relatively high background haze and low natural background visibility on the 20% clearest (4.8 dv), 20% haziest (15.8 dv), and average days (10.0 dv), compared with other monitored I&M parks.

Monitored visibility reflects current pollution levels and was 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). Only parks with representative IMPROVE monitors were used in generating the baseline visibility ranking. Table 7 gives the relative park haze rankings on the 20% clearest, 20% haziest, and average days.

Measured ambient haze values in the monitored parks in SFAN for the period 2004 through 2008 were only moderately higher than the estimated natural condition, and the relative rankings varied. Measured visibility in PINN was ranked High for the 20% clearest days and Moderate for the 20% haziest and average days. The rest of the parks were ranked High for all groups based on PORE data (20% haziest, 20% clearest, and average days; Table 7).

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 selected vistas under three different visibility conditions are shown in Figure 1 for PINN and PORE. Photos were selected to correspond with the clearest 20% visibility conditions, haziest 20% visibility conditions, and annual average visibility conditions at each location. IMPROVE data from PINN suggest that pollution has reduced average natural visual range from 140 miles (226 km) to 60 miles (87 km). On the haziest days, visual range has been reduced from 110 miles (177 km) to 35 miles (56 km). Severe haze episodes occasionally reduce visibility to 10 miles (16 km). At PORE, air pollution has reduced average natural visual range from 80 miles (129 km) to 40 miles (64 km). On the haziest days, visual range has been reduced from 50 miles (80 km) to 20 miles (32 km). Severe haze episodes occasionally reduce visibility to 5 miles (8 km).

Table 7. Estimated natural haze and measured ambient haze in SFAN parks averaged over the period 2004 through 2008¹.

Park Name ²	Park Code	Site ID	Estimated Natural Haze (dv)					
			20% Clearest Days	20% Haziest Days	Average Days			
Fort Point ³	FOPO	PORE1	4.82	15.77	10.04			
Golden Gate ³	GOGA	PORE1	4.82	15.77	10.04			
John Muir ³	JOMU	PORE1	4.82	15.77	10.04			
Muir Woods ³	MUWO	PORE1	4.82	15.77	10.04			
Pinnacles	PINN	PINN1	3.45	7.99	5.55			
Point Reyes	PORE	PORE1	4.82	15.77	10.04			
Park Name	Park Code	Site ID	Measured Ambient Haze (For Years 2004 through 2008)					
			20% Clearest Days		20% Haziest Days		Average Days	
			dv	Ranking	dv	Ranking	dv	Ranking
Fort Point ³	FOPO	PORE1	9.66	High	22.34	High	15.82	High
Golden Gate ³	GOGA	PORE1	9.66	High	22.34	High	15.82	High
John Muir ³	JOMU	PORE1	9.66	High	22.34	High	15.82	High
Muir Woods ³	MUWO	PORE1	9.66	High	22.34	High	15.82	High
Pinnacles	PINN	PINN1	8.29	High	18.43	Moderate	13.31	Moderate
Point Reyes	PORE	PORE1	9.66	High	22.34	High	15.82	High

¹ Parks are classified into one of five haze ranks (Very Low, Low, Moderate, High, or Very High haze).

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

³ Data are from a nearby representative IMPROVE site. 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 of that area.

Pinnacles

20% Clearest Days

Taken: 3:00 PM

Haze = 8 dv

$B_{\text{ext}} = 23 \text{ Mm}^{-1}$

VR = 170 km



20% Haziest Days

Taken: 3:00 PM

Haze = 19 dv

$B_{\text{ext}} = 65 \text{ Mm}^{-1}$

VR = 60 km



Average Days

Taken: 3:00 PM

Haze = 12 dv

$B_{\text{ext}} = 33 \text{ Mm}^{-1}$

VR = 120 km



Figure 1a. Three representative photos of the same view in PINN and PORE illustrating the 20% clearest visibility, 20% haziest visibility, and the annual average visibility. B_{ext} is total particulate light extinction; VR is the visual range.

Point Reyes

20% Clearest Days

Taken: 9:00 AM

Haze = 10 dv

$B_{\text{ext}} = 28 \text{ Mm}^{-1}$

VR = 140 km



205 Haziest Days

Taken: 9:00 AM

Haze = 23 dv

$B_{\text{ext}} = 98 \text{ Mm}^{-1}$

VR = 40 km



Average Days

Taken: 9:00 AM

Haze = 16 dv

$B_{\text{ext}} = 49 \text{ Mm}^{-1}$

VR = 80 km



Figure 1b. Three representative photos of the same view in PINN and PORE illustrating the 20% clearest visibility, 20% haziest visibility, and the annual average visibility. B_{ext} is total particulate light extinction; VR is the visual range.

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 SO_2 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, power plants, industry, and fires. Organic compounds are emitted from a variety of both natural (biogenic) and anthropogenic 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 (2006-2010) levels of haze and its composition for the parks in the SFAN. Based on PORE data, sea salt is the largest contributor to extinction (b_{ext}) in FOPO, GOGA, JOMU, MUWO, and PORE on the 20% haziest days (30.5%) and annual average days (32%); SO_4^{2-} and NO_3^- also contribute appreciably. On the 20% clearest days, SO_4^{2-} is the largest contributor to haze (42.8%), followed by sea salt (24.4%). In PINN, SO_4^{2-} contributes about 30% of the haze on the 20% clearest, 20% haziest and average days. Organics and NO_3^- are also significant contributors.

Data from IMPROVE monitors in the northern and central coastal locations in California, including at Redwood National Park (REDW), PORE and PINN, for the baseline period of 2000 to 2004 suggested that visibility-degrading emissions on the 20% haziest visibility days came from SO_4^{2-} , NO_3^- , and sea salt (Suarez-Murias et al. 2009). The sea salt component was especially high at REDW and PORE, which are both located along the coast. Seasonality in the contributions of SO_4^{2-} and sea salt was much less pronounced at PORE compared to REDW to the north, although NO_3^- showed a strong peak during winter, likely due to buildup of atmospheric NO_3^- in the Bay Area under the prevailing winter offshore winds.

A study of airborne particles and visibility in the SFAN by Savig and Morse (2001) was consistent with these results. Sulfates have been shown to contribute strongly to visibility impairment in PORE (Savig and Morse 2001). Savig and Morse (2001) concluded that visibility impairment at PINN could be approximately evenly attributed to sulfates, nitrates, organics, light absorbing carbon, and coarse mass. Reconstructed extinction generated from aerosol data showed that the average annual visual range at PINN was 56 miles (90 km). During summer, the seasonal average visual range was 54 miles (87 km). The haziest conditions occurred during autumn, when the seasonal average visual range was 52 miles (84 km). The best seasonal average visual range (70 miles [113 km]) occurred during winter. Savig and Morse (2001) suspected that smoke from frequent fires contributed to reducing visibility during summer.

Visibility monitoring data collected during the 1990s showed that visibility impairment at PORE at that time was largely due to sulfates, nitrates and coarse mass (Savig and Morse 2001). Only a small fraction of light extinction could be attributed to light absorbing carbon.

FOPO, GOGA, JOMU, MUWO, and PORE

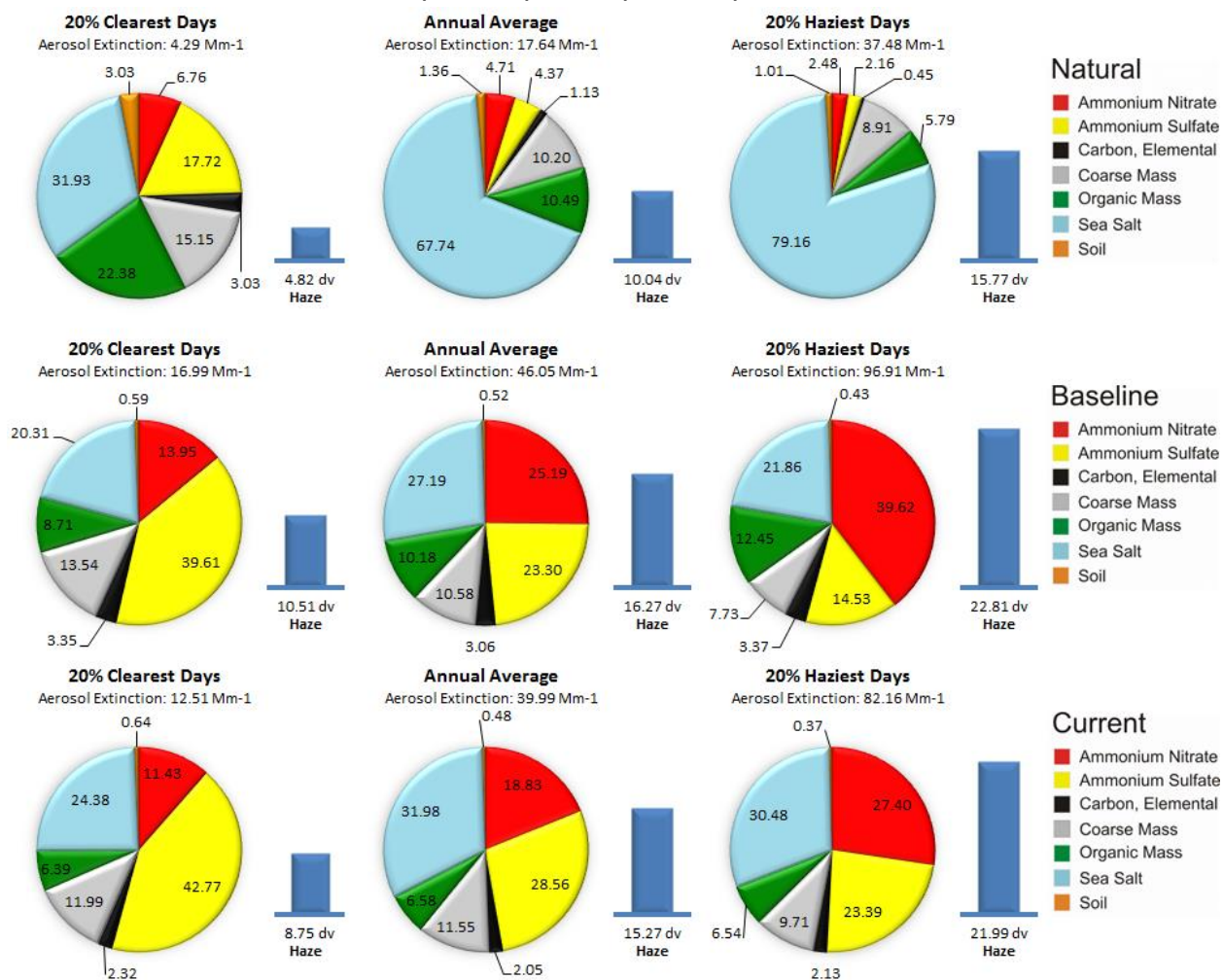


Figure 2a. Estimated natural (pre-industrial), baseline (2000-2004), and current (2006-2010) levels of haze (blue columns) and its composition (pie charts) on the 20% clearest, annual average, and 20% haziest visibility days for FOPO, GOGA, JOMU, MUWO, and PORE. Data for all of these parks except PINN are based on PORE data. PINN has no data for the year 2001. PORE has no data for the years 2001 and 2003. Source: NPS-ARD.

PINN

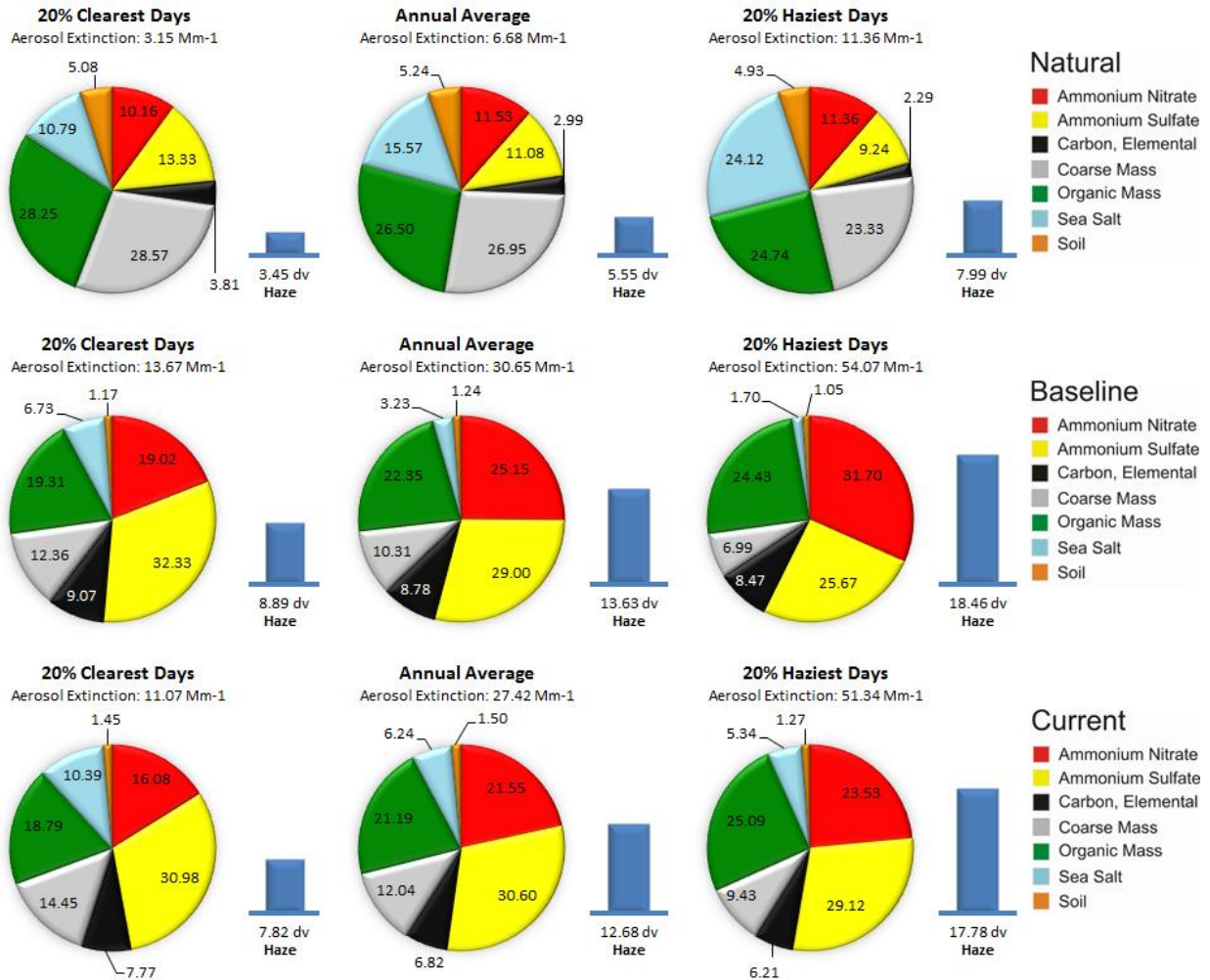


Figure 2b. Estimated natural (pre-industrial), baseline (2000-2004), and current (2006-2010) levels of haze (blue columns) and its composition (pie charts) on the 20% clearest, annual average, and 20% haziest visibility days for PINN. Data for all of these parks except PINN are based on PORE data. PINN has no data for the year 2001. PORE has no data for the years 2001 and 2003. Source: NPS-ARD.

Air quality at PORE is generally good due to the prevailing westerly marine air flows. However, during periods when atmospheric conditions displace the east Pacific high pressure system, air flows from the San Francisco Bay area can degrade the air quality at PORE. This mainly occurs during the late summer and early fall, when the major atmospheric systems undergo a seasonal change. During this time, PORE can be impacted by a general haze, which significantly impairs visibility.

Analyses conducted by the Western Regional Air Partnership (WRAP) indicated that natural emissions sources contribute to substantial visibility impairment throughout the western United States, including in the SFAN region. These natural sources include wildfire and biogenic emissions from vegetation. In addition, air pollution sources outside the western U.S., including international

off-shore shipping and sources from Mexico, Canada, and Asia, can in some cases be substantial contributors (Suarez-Murias et al. 2009).

Trends in Visibility

Available IMPROVE monitoring data suggest that haze levels are decreasing at both monitored parks in the SFAN, especially at PINN (Figure 3). Visibility improvement at this park is most pronounced on the 20% haziest days.

The visibility data summarized for PINN by Savig and Morse (2001) showed a decreasing trend in particulates and dv , suggesting improving visibility over the 10 year period analyzed. Malm et al. (2000) also reported a decreasing trend in the long term 5-year average dv at PINN.

Development of State Implementation Plans

According to the RHR, states and tribes must establish and meet reasonable progress goals for each federal Class I area to improve visibility on the 20% haziest days and to prevent visibility degradation on the 20% clearest days. The national goal is to return visibility in Class I areas to natural background levels by 2064. States must evaluate progress by 2018 (and every 10 years thereafter) based on a baseline period of 2000 to 2004 (ARS 2007). The Class I parks in California requiring the least amount of visibility improvement to meet the national goal are REDW and PORE. These two parks are both coastal and are relatively unaffected by land-based air pollution sources in California.

Emissions of SO_4 from ocean vessels constitute an important contributor to visibility impairment at coastal California Class I areas. Source appointment analyses were conducted for the California Regional Haze Plan (Suarez-Murias et al. 2009), using regional-scale, three-dimensional air quality models that simulate emissions, chemical transformations, and transport of criteria air pollutants and fine particulate matter. Effects on visibility in Class I areas in California were then evaluated for organic C, SO_4^{2-} , and NO_3^- , which are the three major drivers of haze in California. The PM Source Appointment Technology (PSAT) algorithm was used for WRAP model analysis. Directly emitted anthropogenic organic C was estimated to contribute half or less of the organic C in most areas of California except PORE (67%) and PINN (73%), where organic C was substantially more important. Anthropogenic sources of NO_x contributed at least half of the NO_3^- in the Class I areas in the SFAN. The anthropogenic SO_4^{2-} contribution ranged from 1 to 35% at various Class I areas, with lowest contributions in northern California. The primary drivers of haze in California derive mostly from natural sources (organic C), mobile sources (NO_3^-), and off-shore and non-WPAP regional sources (SO_4^{2-} ; Suarez-Murias et al. 2009).

Modeling at IMPROVE monitoring site locations suggested that visibility will need to improve by 31% at PORE and 57% at PINN in order to meet RHR goals of no human-caused visibility impairment by 2064 (Table 8). Progress to date in meeting the national visibility goal is illustrated in Figure 4 using a uniform rate of progress glideslope. It is unclear, based on the available data, to what extent haze on the 20% haziest days at PINN is decreasing sufficiently to comply with the glideslope required by the RHR. Trends at PORE are more encouraging. Additional data are needed.

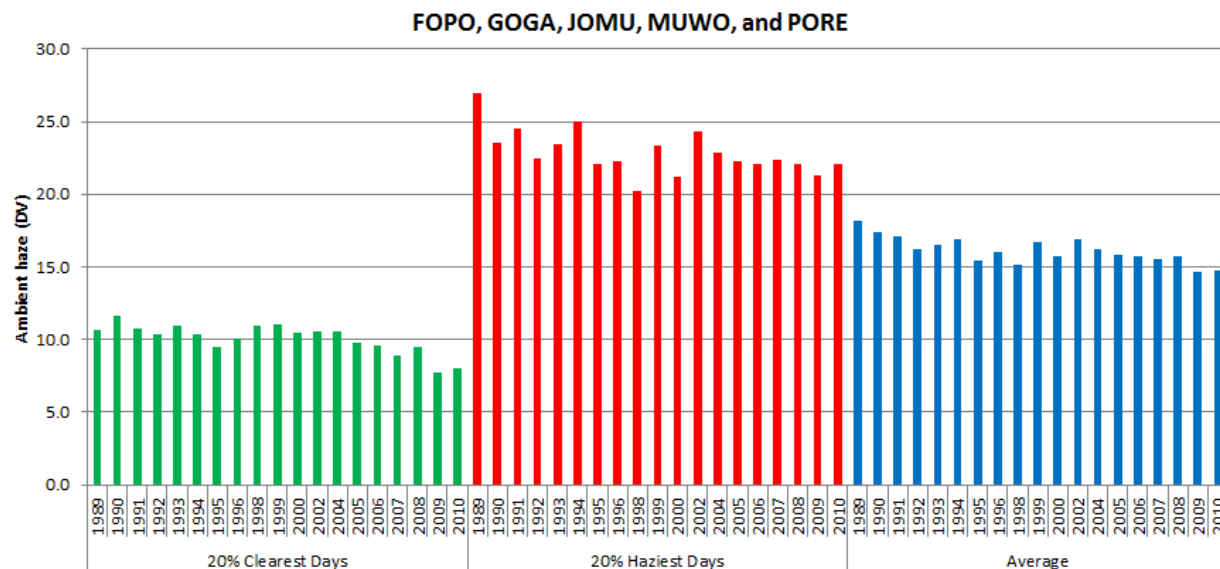


Figure 3a. Trends in monitored visibility at FOPO, GOGA, JOMU, MUWO and PORE, based on IMPROVE measurements on the 20% clearest, 20% hazeiest, and annual average visibility days over the monitoring period of record. Data for FOPO, GOGA, JOMU, and MUWO were taken from a nearby site (PORE1). Data Source: http://vista.cira.colostate.edu/improve/Data/IMPROVE/summary_data.htm

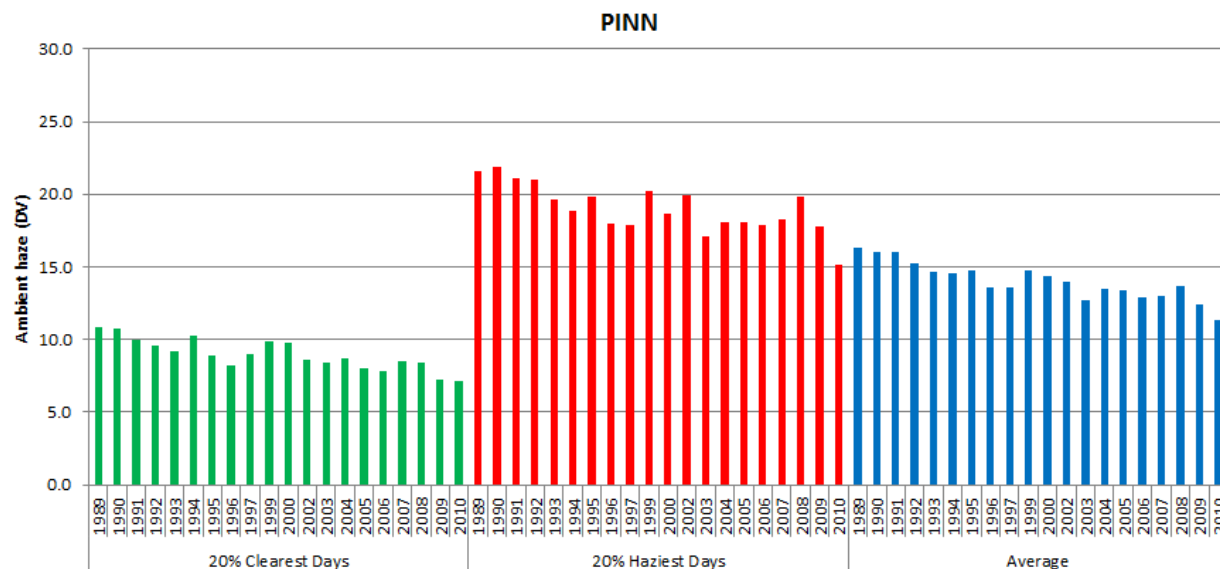


Figure 3b. Trends in monitored visibility at PINN, based on IMPROVE measurements on the 20% clearest, 20% hazeiest, and annual average visibility days over the monitoring period of record. Data for FOPO, GOGA, JOMU, and MUWO were taken from a nearby site (PORE1). Data Source: http://vista.cira.colostate.edu/improve/Data/IMPROVE/summary_data.htm

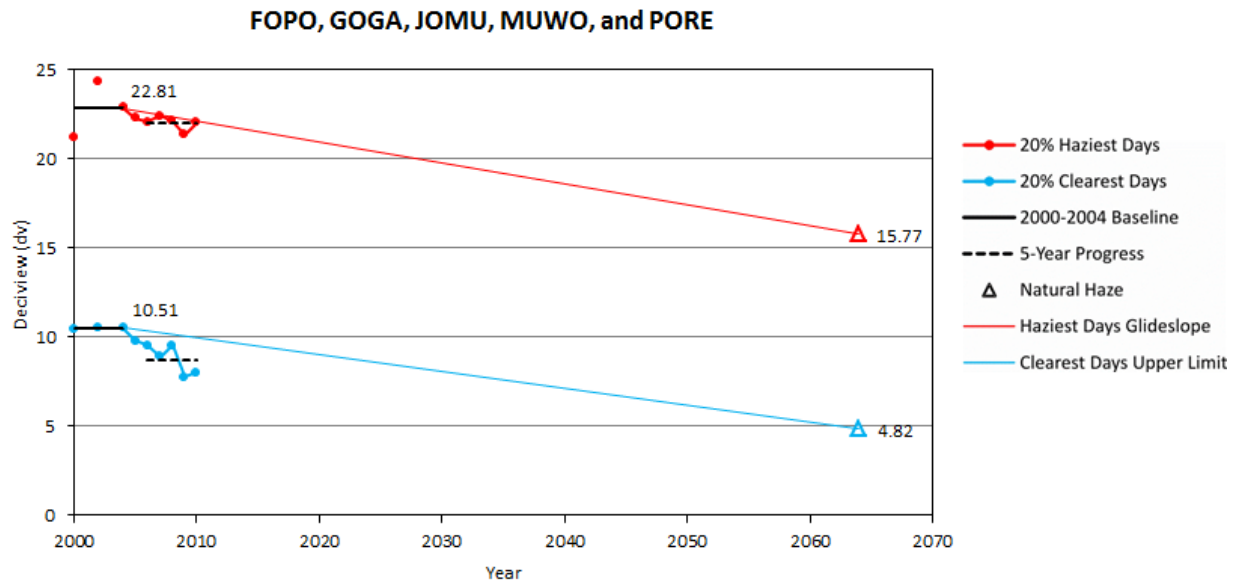


Figure 4a. Glideslopes to achieving natural visibility conditions by 2064 for the 20% haziest (red line) and the 20% clearest (blue line) days in FOPO, GOGA, JOMU, MUWO, and PORE. In the Regional Haze Rule, the clearest days do not have a uniform rate of progress glideslope; the Rule only requires that the clearest days do not get any worse than the baseline period. Also shown are measured values during the period 2000 to 2010. Data for FOPO, GOGA, JOMU, and MUWO are from a PORE. PINN has no data for the year 2001. PORE has no data for the years 2001 and 2003. Data Source: http://vista.cira.colostate.edu/improve/Data/IMPROVE/summary_data.htm

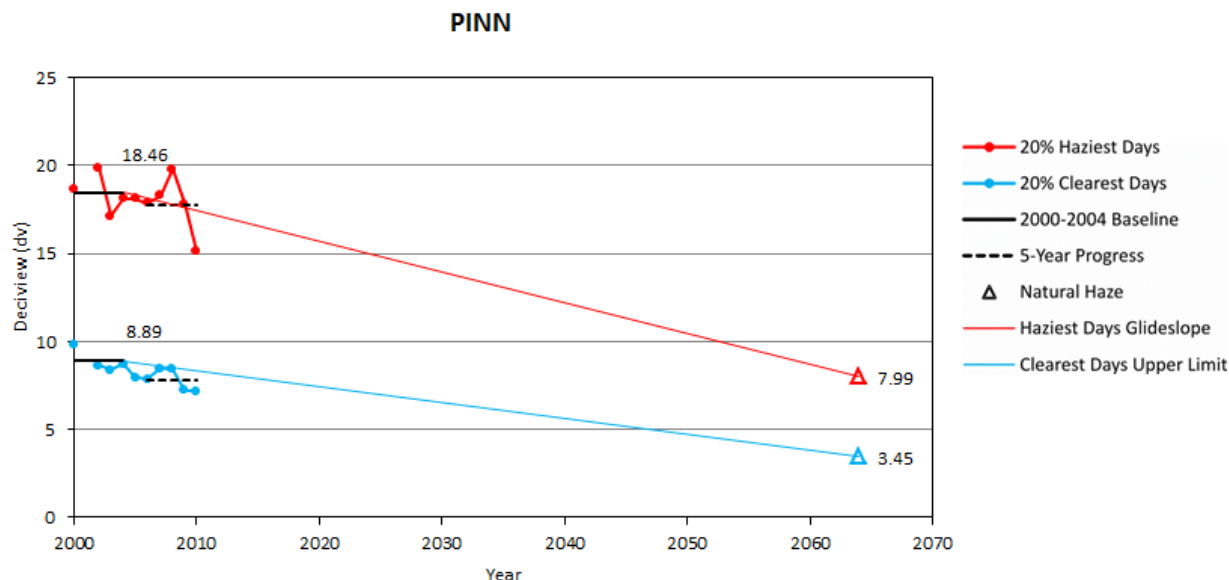


Figure 4b. Glideslopes to achieving natural visibility conditions by 2064 for the 20% hazyest (red line) and the 20% clearest (blue line) days in PINN. In the Regional Haze Rule, the clearest days do not have a uniform rate of progress glideslope; the Rule only requires that the clearest days do not get any worse than the baseline period. Also shown are measured values during the period 2000 to 2010. Data for FOPO, GOGA, JOMU, and MUWO are from a PORE. PINN has no data for the year 2001. PORE has no data for the years 2001 and 2003. Data Source:

http://vista.cira.colostate.edu/improve/Data/IMPROVE/summary_data.htm

Table 8. IMPROVE monitors and visibility at Class 1 areas in the SFAN. (Source: Suarez-Murias et al. 2009)

Improve Monitor (Name and Elevation in Meters)			Current Conditions (2000-2004 Baseline)		Future Natural Conditions (2064 Goals)		
			Worst Days	Best Days (Maintain in Future Years)	Natural Worst Days	Deciview Hurdle (Baseline to 2064)	Regional Improvement from Current Visibility on Worst Days
PORE (97m)	Point Reyes	Point Reyes National Seashore	22.8	10.5	15.8	7.0	31%
PINN (302 m)	Pinnacles	Pinnacles Wilderness Vertana Wilderness	18.5	8.9	8	10.5	57%

Toxic Airborne Contaminants

Only limited data are available with which to evaluate possible effects of airborne toxics on sensitive resources in the national parks in the SFAN. Wright et al. (2014) used surrogate artificial deposition surfaces, passive samplers, and temporal changes in Hg deposition and atmospheric concentrations to improve understanding of sources of Hg to remote western United States locations. Lowest Hg deposition (0.2 to 0.4 $\text{ng}/\text{m}^2/\text{hr}$) occurred at low-elevation coastal sites (including PORE). Highest deposition values (0.5 to 2.4 $\text{ng}/\text{m}^2/\text{hr}$) were recorded in Great Basin National Park in the Mojave Desert Network and at a high-elevation (1279 m) coastal site. Intermediate deposition values were recorded at Yosemite and Sequoia/Kings Canyon national parks in the adjacent Sierra Nevada Network (0.9 to 1.2 $\text{ng}/\text{m}^2/\text{hr}$).

References Cited

- Air Resource Specialists. 2007. VISTAS Conceptual Description Support Document. Report prepared for Visibility Improvement State and Tribal Association of the Southeast. Fort Collins, CO.
- Akimoto, H. and H. Narita. 1994. Distribution of SO₂, NO_x, and CO₂ emissions from fuel combustion and industrial activities in Asia with 1° x 1° resolution. *Atmos. Environ.* 28(213-225).
- Bobbink, R., D. Boxman, E. Fremstad, G. Heil, A. Houdijk, and J. Roelofs. 1992. Critical loads for nitrogen eutrophication of terrestrial and wetland ecosystems based upon changes in vegetation and fauna. *In* P. Grennfelt and E. Thörmelöf (Eds.). *Critical loads for nitrogen*. Nord 92:41. Nordic Council of Ministers, Copenhagen, pp. 111-159.
- Bobbink, R., M. Hornung, and J.G.M. Roelofs. 1998. The effects of air-borne nitrogen pollutants on species diversity in natural and semi-natural European vegetation. *J. Ecol.* 86:717-738.
- Byun, D. and K.L. Schere. 2006. Review of the governing equations, computational algorithms, and other components of the Models-3 Community Multiscale Air Quality (CMAQ) modeling system. *Applied Mechanics Reviews* 59:51-77.
- Egerton-Warburton, L. and E.B. Allen. 2000. Shifts in Arbuscular mycorrhizal communities along an anthropogenic nitrogen deposition gradient. *Ecol. Appl.* 10(2):484-496.
- Fenn, M.E., J.S. Baron, E.B. Allen, H.M. Rueth, K.R. Nydick, L. Geiser, W.D. Bowman, J.O. Sickman, T. Meixner, D.W. Johnson, and P. Neitlich. 2003a. Ecological effects of nitrogen deposition in the western United States. *BioScience* 53(4):404-420.
- Fenn, M.E., R. Haeuber, G.S. Tonnesen, J.S. Baron, S. Grossman-Clark, D. Hope, D.A. Jaffe, S. Copeland, L. Geiser, H.M. Rueth, and J.O. Sickman. 2003b. Nitrogen emissions, deposition, and monitoring in the western United States. *BioScience* 53(4):391-403.
- Fenn, M.E., E.B. Allen, S.B. Weiss, S. Jovan, L. Geiser, G.S. Tonnesen, R.F. Johnson, L.E. Rao, B.S. Gimeno, F. Yuan, T. Meixner, and A.A. Bytnerowicz. 2010. Nitrogen critical loads and management alternatives for N-impacted ecosystems in California. *J. Environ. Manage.* 91:2404-2423.
- Fenn, M.E., E.B. Allen, and L.H. Geiser. 2011. Mediterranean California. *In* L.H. Pardo, M.J. Robin-Abbott and C.T. Driscoll (Eds.). *Assessment of Nitrogen Deposition Effects and Empirical Critical Loads of Nitrogen for Ecoregions of the United States*. General Technical Report NRS-80. pp. 143-170.

- Fritzke, S. 2011. Restoration of endangered habitat, including dunes and serpentine grasslands, within a fragmented urban environment. Abstract. George Wright Society Conference on Parks, Protected Areas, & Cultural Sites. New Orleans, LA, March 14-18, 2011.
- Heck, W.W. and E.B. Cowling. 1997. The need for a long term cumulative secondary ozone standard - an ecological perspective. *Ecological Manager*:22-33.
- Jaffe, D., T. Anderson, D.S. Covert, R. Kotchenruther, B. Trost, J. Danielson, W. Simpson, T. Berntsen, S. Karlsdottir, D. Blake, J. Harris, G. Carmichael, and I. Uno. 1999. Transport of Asian Air Pollution to North America. *Geophys. Res. Lett.* 26:711-714.
- Jaffe, D., H. Price, D. Parrish, A. Goldstein, and J. Harris. 2003. Increasing background ozone during spring on the west coast of North America. *Geophys. Res. Lett.* 30(12):4.
- Jovan, S. and B. McCune. 2005. Air quality bioindication in the greater central valley of California, with epiphytic macrolichen communities. *Ecol. Appl.* 15(5):1712-1726.
- Jovan, S. 2008. Lichen Bioindication of Biodiversity, Air Quality, and Climate: Baseline Results from Monitoring in Washington, Oregon, and California. General Technical Report PNW-GTR-737. U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station, Portland, OR.
- Klimont, Z., J. Cofala, W. Schöpp, M. Amann, D.G. Streets, Y. Ichikawa, and S. Fujita. 2001. Projections of SO₂, NO_x, NH₃, and VOC emissions in East Asia up to 2030. *Water Air Soil Pollut.* 130:193-198.
- Kohut, R. 2007. Assessing the risk of foliar injury from ozone on vegetation in parks in the U.S. National Park Service's Vital Signs Network. *Environ. Pollut.* 149:348-357.
- Kotchenruther, R.A., D.A. Jaffe, and L. Jaegle. 2001. Ozone photochemistry and the role of peroxyacetyl nitrate in the springtime northeastern Pacific troposphere: Results from the PHOEBEA campaign. *J. Geophys. Res.* 106:28731-28741.
- Lane, D.R. and H. BassiriRad. 2002. Differential responses of tallgrass prairie species to nitrogen loading and varying ratios of NO₃⁻ to NH₄⁺. *Funct. Plant Biol.* 29:1227-1235.
- Lefohn, A.S., W. Jackson, D.S. Shadwick, and H.P. Knudson. 1997. Effect of surface ozone exposures on vegetation grown in the Southern Appalachian Mountains: Identification of possible areas of concern. *Atmos. Environ.* 31(11):1695-1708.
- Malm, W.C., R. Ames, S. Copeland, D. Day, K. Gebhart, M. Pitchford, M. Scruggs, and J. Sisler. 2000. IMPROVE Report, Spatial and Seasonal Patterns and Temporal Variability of Haze and its Constituents in the United States: Report III. ISSN: 0737-5352-47. Cooperative Institute for Research in the Atmosphere (CIRA), Colorado State University, Ft. Collins, CO.

- Malm, W.C., B.A. Schichtel, R.B. Ames, and K.A. Gebhart. 2002. A 10-year spatial and temporal trend of sulfate across the United States. *J. Geophys. Res.* 107(D22, 4627).
- National Park Service (NPS). 2010. Air Quality in National Parks: 2009 Annual Performance and Progress Report. Natural Resource Report NPS/NRPC/ARD/NRR-2010/266. National Park Service, Air Resources Division, Denver, CO.
- Padgett, P. and E.B. Allen. 1999. Differential responses to nitrogen fertilization in native shrubs and exotic annuals common to Mediterranean coastal sage scrub of California. *Plant Ecol.* 144:93-101.
- Padgett, P.E., E.B. Allen, A. Bytnerowicz, and R.A. Minnich. 1999. Changes in soil inorganic nitrogen as related to atmospheric nitrogenous pollutants in southern California. *Atmos. Environ.* 33:769-781.
- Pardo, L.H., M.J. Robin-Abbott, and C.T. Driscoll (Eds.). 2011. Assessment of Nitrogen Deposition Effects and Empirical Critical Loads of Nitrogen for Ecoregions of the United States. General Technical Report NRS-80. U.S. Forest Service, Newtown Square, PA.
- Savig, K. and D. Morse. 2001. Visibility Sections. NPS D-1454. U.S. Department of the Interior, National Park Service, Air Resources Division.
<http://www.nature.nps.gov/air/Pubs/pdf/reviews/ca/CAreport.pdf>.
- Schwede, D.B. and G.G. Lear. 2014. A novel hybrid approach for estimating total deposition in the United States. *Atmos. Environ.* 92:207-220. <http://dx.doi.org/10.1016/j.atmosenv.2014.04.008>.
- Stevens, C.J., N.B. Dise, O.J. Mountford, and D.J. Gowing. 2004. Impact of nitrogen deposition on the species richness of grasslands. *Science* 303:1876-1878.
- Streets, D.G. and S.T. Waldhoff. 2000. Present and future emissions of air pollutants in China: SO₂, NO_x, and CO. *Atmos. Environ.* 34:363-374.
- Suarez-Murias, T., J. Glass, E. Kim, L. Melgoza, and T. Najita. 2009. California Regional Haze Plan. California Environmental Protection Agency, Air Resources Board.
- Sullivan, T.J., D.L. Peterson, C.L. Blanchard, K. Savig, and D. Morse. 2001. Assessment of air quality and air pollutant impacts in Class I national parks of California. NPS D-1454. U.S. Department of the Interior, National Park Service, Air Resources Division.
<http://www.nature.nps.gov/air/Pubs/pdf/reviews/ca/CAreport.pdf>.
- Sullivan, T.J., T.C. McDonnell, G.T. McPherson, S.D. Mackey, and D. Moore. 2011a. Evaluation of the Sensitivity of Inventory and Monitoring National Parks to Nutrient Enrichment Effects from Atmospheric Nitrogen Deposition. Natural Resource Report NPS/NRPC/ARD/NRR—2011/313. U.S. Department of the Interior, National Park Service, Denver.
<http://www.nature.nps.gov/air/permits/aris/networks/n-sensitivity.cfm>.

- Sullivan, T.J., G.T. McPherson, T.C. McDonnell, S.D. Mackey, and D. Moore. 2011b. Evaluation of the Sensitivity of Inventory and Monitoring National Parks to Acidification Effects from Atmospheric Sulfur and Nitrogen Deposition. U.S. Department of the Interior, National Park Service, Denver. <http://nature.nps.gov/air/Permits/ARIS/networks/acidification-eval.cfm>.
- Sullivan, T.J. 2016. Air quality related values (AQRVs) in national parks: Effects from ozone; visibility reducing particles; and atmospheric deposition of acids, nutrients and toxics. Natural Resource Report NPS/NRSS/ARD/NRR—2016/1196. National Park Service, Fort Collins, CO.
- Weiss, S.B. 1999. Cars, cows, and checkerspot butterflies: nitrogen deposition and management of nutrient-poor grasslands for a threatened species. *Conserv. Biol.* 13:1476-1486.
- Wright, G., M.S. Gustin, P. Weiss-Penzias, and M.B. Miller. 2014. Investigation of mercury deposition and potential sources at six sites from the Pacific Coast to the Great Basin, USA. *Sci Total Environ* 470-471:1099-1113. 10.1016/j.scitotenv.2013.10.071.
- Zavaleta, E.S., M.R. Shaw, N.R. Chiariello, B.D. Thomas, E.E. Cleland, C.B. Field, and H.A. Mooney. 2003. Grassland responses to three years of elevated temperature, CO₂, precipitation, and N deposition. *Ecol. Monogr.* 73(4):585-604.

The Department of the Interior protects and manages the nation's natural resources and cultural heritage; provides scientific and other information about those resources; and honors its special responsibilities to American Indians, Alaska Natives, and affiliated Island Communities.

NPS 963/132184, March 2016

National Park Service
U.S. Department of the Interior



Natural Resource Stewardship and Science
1201 Oakridge Drive, Suite 150
Fort Collins, CO 80525

www.nature.nps.gov

2016

National Park Service.
CENTENNIAL

EXPERIENCE YOUR AMERICA™