



Air Quality Related Values (AQRVs) for Mojave Desert Network (MOJN) Parks

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

Natural Resource Report NPS/MOJN/NRR—2016/1170



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 Mojave Desert Network (MOJN). AQRVs are those resources sensitive to air quality and include streams, lakes, soils, vegetation, fish and wildlife, and visibility. The MOJN parks that are included in the NPS Inventory and Monitoring (I&M) Program, and discussed in this report, are Death Valley National Park (DEVA), Great Basin National Park (GRBA), Joshua Tree National Park (JOTR), Lake Mead National Recreation Area (LAKE), Manzanar National Historic Site (MANZ), and Mojave National Preserve (MOJA). JOTR is designated as a Class I park, giving it a heightened level of protection against harm caused by poor air quality under the Clean Air Act (CAA). Data are generally lacking for Grand Canyon-Parashant National Monument (PARA), and it is not addressed in this report.

Sullivan et al. (2011a, 2011b) and Kohut (2007a) conducted risk assessments for acidification, eutrophication, and ozone (O_3) for the MOJNN parks; their results are described in this report. This report also describes air pollutant emissions and air quality in the MOJN, 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 ozone (O_3); 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 pollutant emissions vary throughout the MOJN region. Some of the parks, notably GRBA in Nevada, are quite distant from air pollutant sources and enjoy relatively good air quality. Other MOJN parks, including JOTR in southern California, experience much higher levels of air pollution.

California is the most populous state in the nation, with its largest population center located in the Los Angeles Basin. Because the prevailing winds are from the west and northwest, many of California’s national parks, including those located in the southeastern California deserts in the MOJN, are often downwind of the most populated portion of the state. Pollutant transport to the more remote regions of California has been studied extensively and urban-area and agricultural emissions are known to affect air quality in southeastern California’s national parks. Prevailing winds carry pollutants along certain transport routes into the mountains and deserts to the south and east of heavily populated areas, including the Los Angeles Basin. LAKE, located on the Arizona/Nevada border, also receives air pollutants from Las Vegas, Nevada. Ozone, N, and particulate matter (PM) are problematic air pollutants in the MOJN, and are of concern for their effects on public health, visibility and vegetation (Sullivan et al. 2001).

Atmospheric S and N pollutants can cause acidification of streams, lakes, and soils. DEVA and GRBA are potentially sensitive to acidification because of their steep slopes, which allow limited opportunity for incoming acidic deposition to be buffered by base cations in rocks and soils. Lakes in GRBA are considered to be somewhat acid-sensitive, with Baker Lake thought to be the most sensitive lake in the park (T. Cummings, NPS, personal communication, July, 2014).

Nitrogen deposition can also cause undesirable nutrient enrichment of natural ecosystems, leading to changes in plant species composition and soil nutrient cycling. Ecosystems in five of the seven parks in the MOJN are considered to be highly sensitive to nutrient N enrichment because of the preponderance of desert vegetation in the parks, which is very responsive to N inputs. Enhanced N has been found to facilitate the recently observed invasion of some exotic and invasive plant species within parts of the Mojave and Sonoran deserts (Allen and Geiser 2011).

Water availability affects plant community response to N input. Ecosystem modeling and empirical evidence suggest that N deposition of 3-9 kilograms/hectare/year (kg/ha/yr) was sufficient to increase biomass of invasive annual grasses, thereby significantly increasing fire risk, in creosote bush and pinyon-juniper communities in JOTR during average precipitation years (< 21 cm/yr). In wetter years, N deposition as low as 1.5 kg/ha/yr induced the same response (Rao et al. 2010). Modeled N deposition ranges from < 2 kg/ha/yr to in the range of 5-10 kg/ha/yr in MOJN parks, suggesting that some areas may be at risk for increased invasive grass biomass and wildfire.

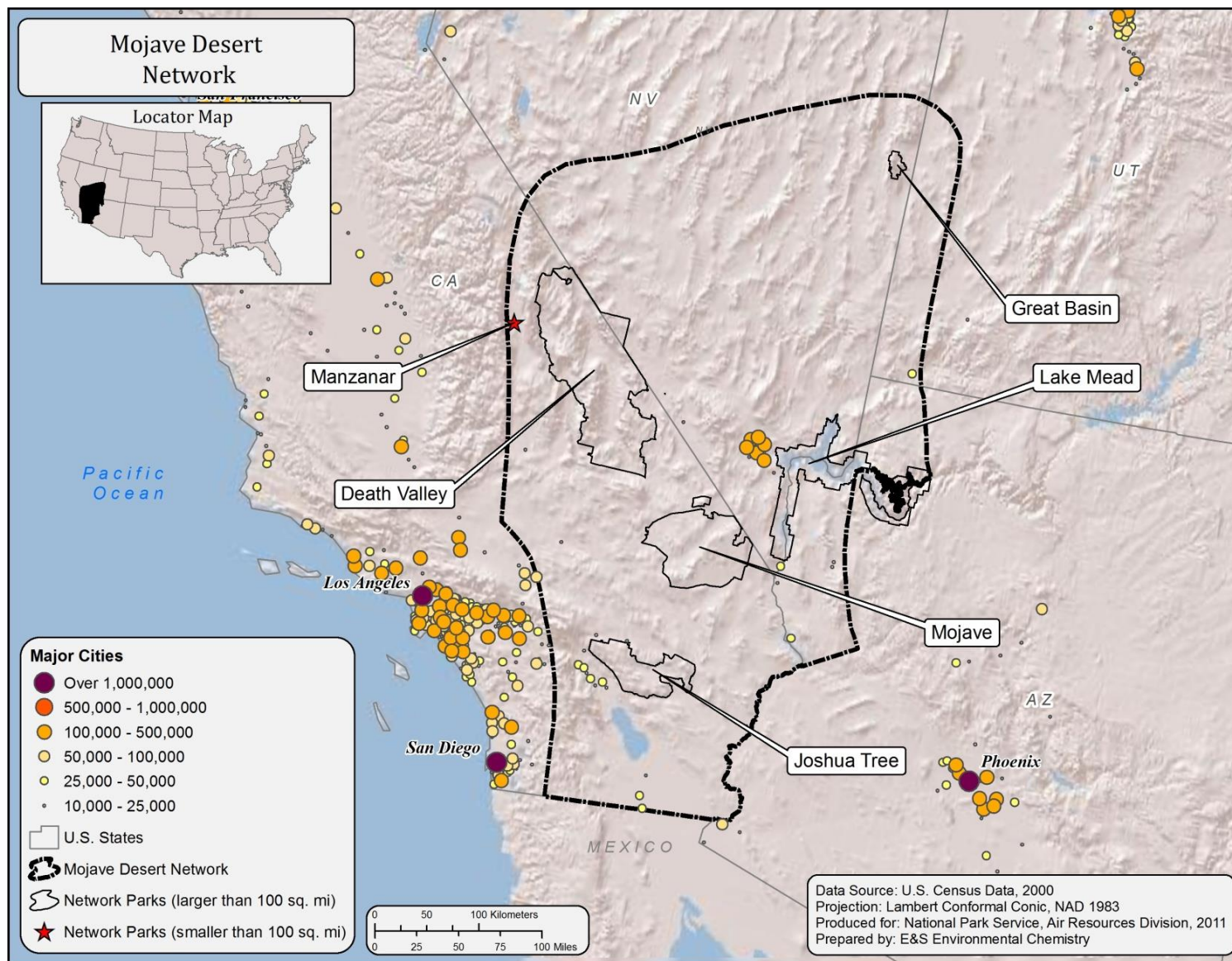
Ozone pollution can harm human health, reduce plant growth, and cause visible injury to foliage. JOTR and MOJA are located in areas designated nonattainment by EPA because O₃ concentrations violate the national O₃ standard to protect human health, and air quality is unhealthy at times. Risk to plants is assessed using metrics that reflect exposure over three or five months of the growing season. Risk to plants in MOJN parks varied from low to high in an assessment conducted for all parks nationwide (Kohut 2007a, Kohut 2007b).

Particulate and gaseous air pollution can cause haze, reducing visibility. JOTR has the highest levels of haze among the three monitored parks (DEVA, GRBA, and JOTR) in the MOJN. Haze in MOJN parks is primarily caused by SO₄²⁻, NO₃⁻, organics, and coarse mass.

Airborne toxics, including mercury (Hg) and other heavy metals, can accumulate in food webs, reaching toxic levels in top predators. Effects have been documented in some areas, including parts of California, in piscivorous fish and wildlife (Landers et al. 2010). Data on bioaccumulation of toxic substances in MOJN parks and associated effects on sensitive receptors are not generally available.

Background

There are five parks in the Mojave Desert Network (MOJN) considered in this report that are larger than 100 square miles: Death Valley National Park (DEVA), Great Basin National Park (GRBA), Joshua Tree National Park (JOTR), Lake Mead National Recreation Area (LAKE), and Mojave National Preserve (MOJA). There is one park smaller than 100 square miles: Manzanar National Historic Site (MANZ; Map 1). 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. One additional park in MOJN (Grand Canyon-Parashant National Monument) was not included in this analysis.



Map 1. Network boundary and locations of parks and population centers greater than 10,000 people.

The western Mojave Desert is impacted by air pollution that originates mainly in the Los Angeles air basin and then subsequently moves inland with the prevailing westerly winds (Allen et al. 2006, Edinger et al. 1972, Fenn et al. 2003). Inputs of atmospheric nitrogen (N) to JOTR and other park lands in the MOJN may affect plant production and distribution differentially, with non-native species, especially some invasive grasses, having higher N uptake rates and growth than many native species (Allen et al. 1998, Brooks 2003, Rao et al. 2010, Yoshida and Allen 2001, 2004).

Map 1 shows the network boundary along with locations of each park considered in this assessment and population centers with more than 10,000 people. There are several population centers larger than 100,000 people near the MOJN parks, including Los Angeles, San Diego, and Las Vegas. Air pollutants generated in the Los Angeles Basin have substantial impact on resources in the southern portion of the MOJN, especially in JOTR.

Atmospheric Emissions and Deposition

County-level emissions near the MOJN, 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 sulfur dioxide (SO₂), oxidized nitrogen (NO_x), and reduced N (NH₃), respectively. Most counties in the vicinity of MOJN parks had SO₂ emissions lower than 1 ton/mi²/yr (Map 2). Emissions of NO_x were higher, with values at some locations higher than 5 tons/mi²/yr (Map 3). Emissions of NH₃ near MOJN parks were < 2 tons/mi²/yr at most locations (Map 4).

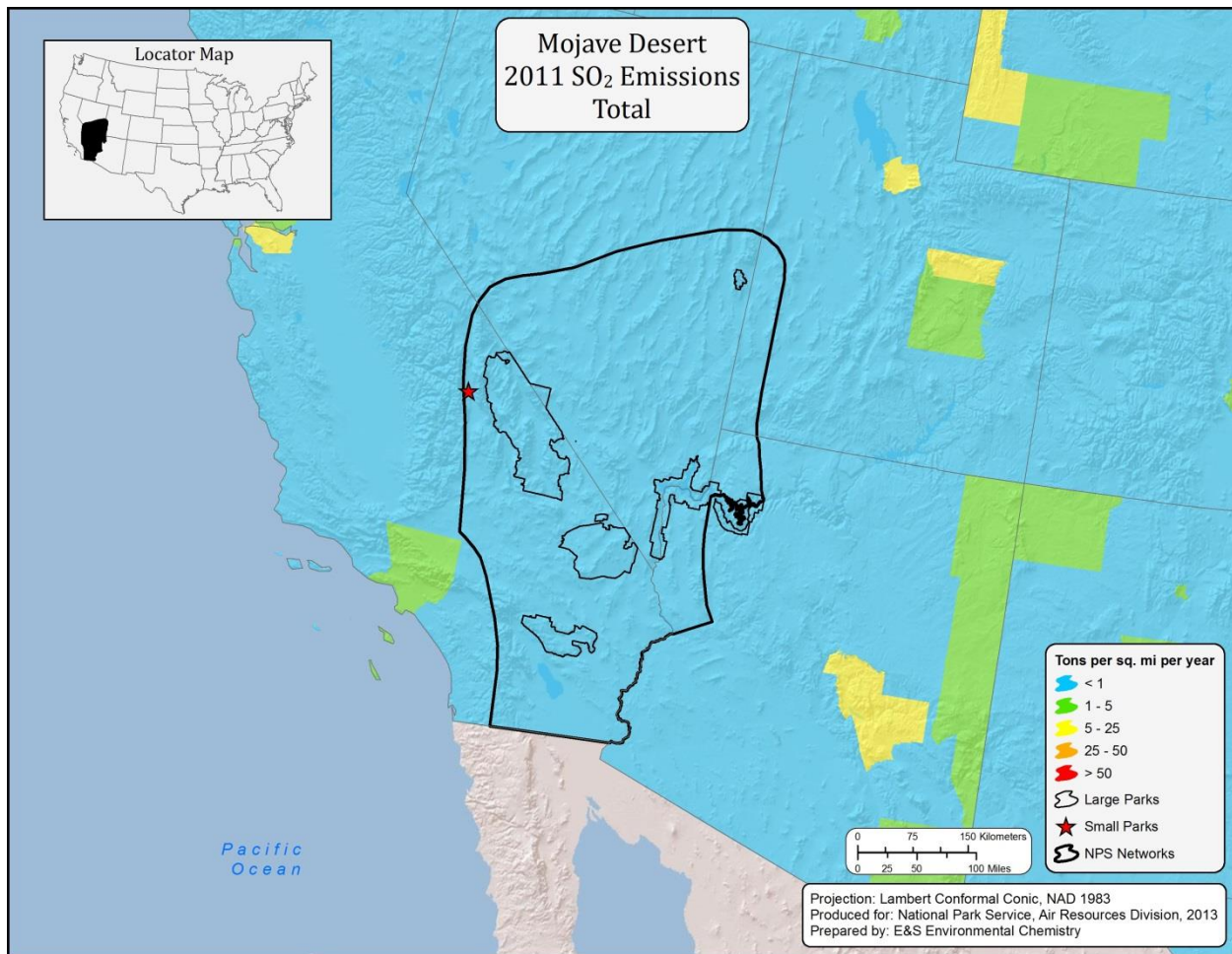
Recently, Schwede and Lear (2014) documented a hybrid approach developed by the National Atmospheric Deposition Program (NADP) Total Deposition (TDEP) Science Committee for estimating total N and S deposition. This approach combined monitoring and modeling data. Modeling was accomplished using the Community 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), N₂O₅, NO, NO₂, HONO, and organic NO₃. The total deposition estimates are considered to be dynamic, with updates planned as new information becomes available. The TDEP data reported here were developed in late 2013 and are designated version 2013.02.

Atmospheric S deposition levels have increased slightly at most MOJN parks since 2001, based on TDEP estimates (Table 1). The largest increase (23.8%) was at GRBA. Estimated total N deposition over that same time period increased at some parks and decreased at others. Reduced N deposition increased at all network parks, in all cases by considerable amounts (> 40%). Oxidized N deposition declined in all parks except GRBA.

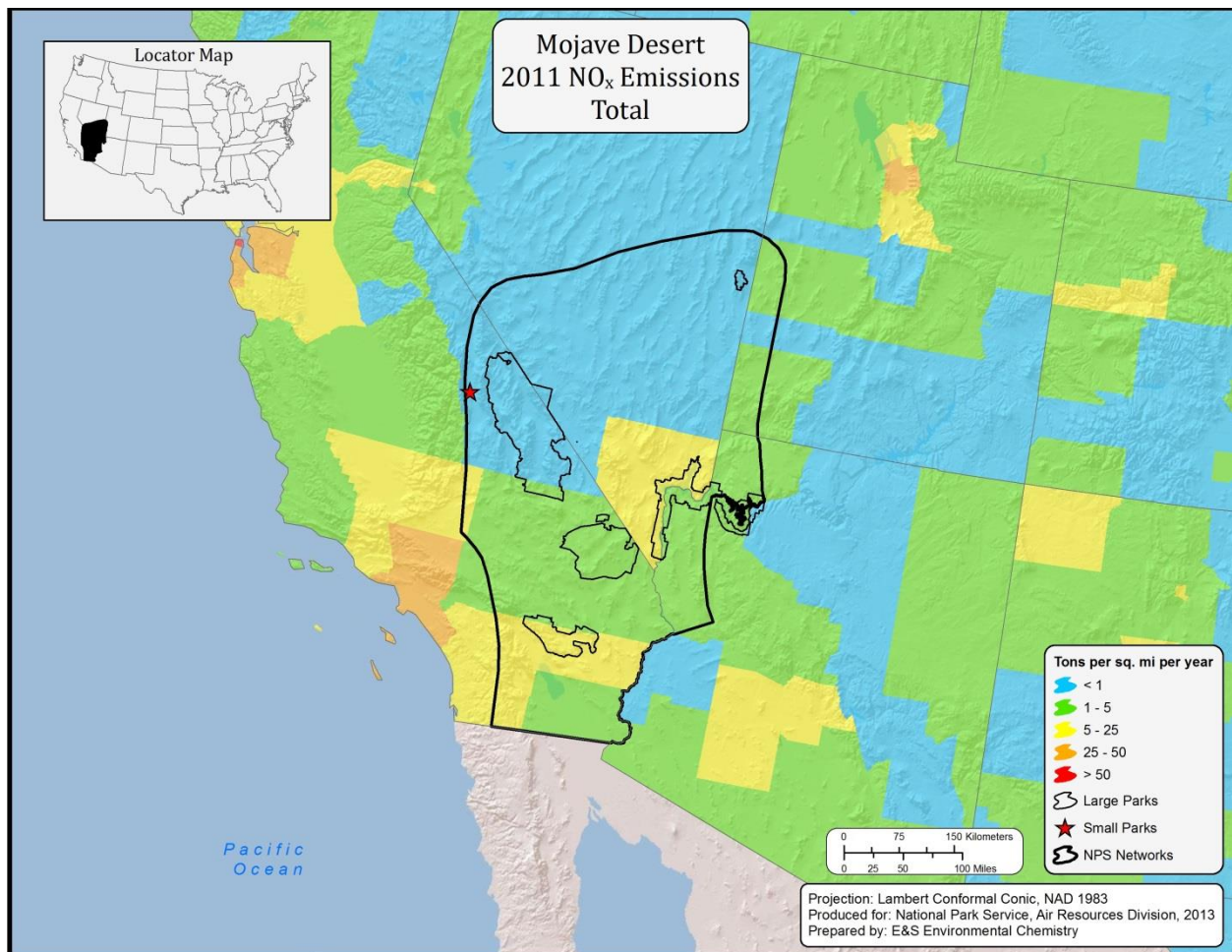
Total modeled S deposition throughout the MOJN was generally less than 2 kg S/ha/yr (Map 5). Such low levels of S deposition would not contribute to any appreciable soil or water acidification in this network.

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

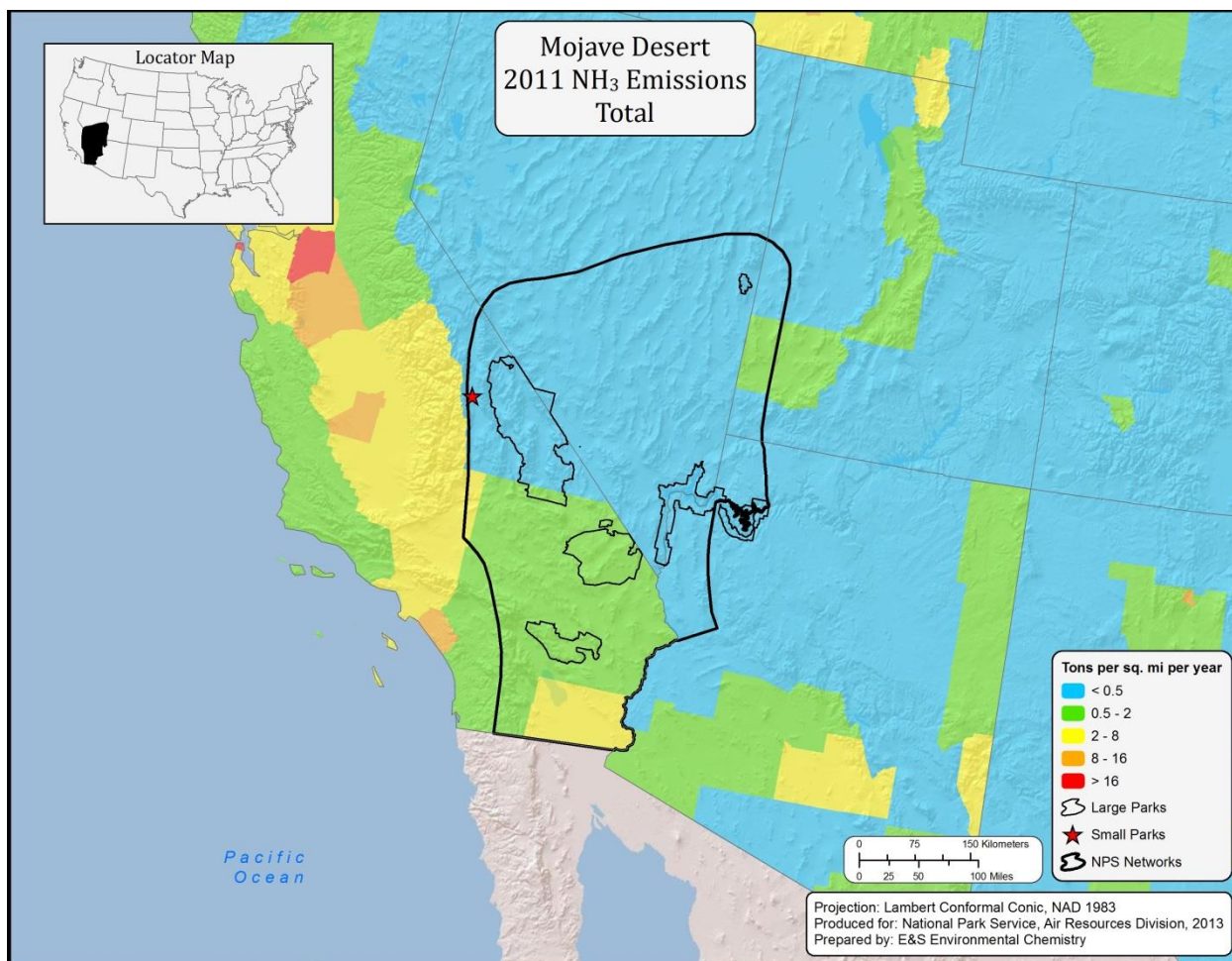
Park Code	Park Name	Parameter	2001 Average (kg/ha/yr)	2011 Average (kg/ha/yr)	Absolute Change (kg/ha/yr)	Percent Change	2011 Minimum (kg/ha/yr)	2011 Maximum (kg/ha/yr)	2011 Range (kg/ha/yr)
DEVA	Death Valley	Total S	0.45	0.49	0.05	11.5%	0.26	1.06	0.79
		Total N	3.19	3.51	0.31	9.6%	1.94	6.35	4.42
		Oxidized N	2.40	2.37	-0.03	-1.3%	1.34	4.24	2.90
		Reduced N	0.79	1.13	0.34	47.4%	0.60	2.11	1.52
GRBA	Great Basin	Total S	1.07	1.30	0.23	23.8%	0.71	1.64	0.92
		Total N	3.29	3.92	0.63	20.4%	2.47	4.72	2.25
		Oxidized N	1.97	1.99	0.02	1.7%	1.18	2.30	1.12
		Reduced N	1.32	1.93	0.61	49.0%	1.29	2.42	1.13
JOTR	Joshua Tree	Total S	0.42	0.46	0.04	9.9%	0.29	0.63	0.34
		Total N	5.62	4.87	-0.75	-13.4%	2.86	6.44	3.58
		Oxidized N	4.83	3.41	-1.42	-29.2%	2.02	4.49	2.47
		Reduced N	0.80	1.47	0.67	85.6%	0.84	2.10	1.25
LAKE	Lake Mead	Total S	0.56	0.52	-0.04	-6.8%	0.39	0.99	0.59
		Total N	3.22	2.70	-0.52	-16.0%	1.77	4.07	2.30
		Oxidized N	2.68	1.83	-0.85	-31.7%	0.79	2.66	1.87
		Reduced N	0.53	0.87	0.33	63.7%	0.69	1.46	0.78
MANZ	Manzanar	Total S	0.56	0.65	0.09	15.7%	0.65	0.65	0.00
		Total N	3.46	3.43	-0.03	-0.9%	3.43	3.43	0.00
		Oxidized N	2.51	2.09	-0.42	-16.7%	2.09	2.09	0.00
		Reduced N	0.95	1.34	0.39	40.9%	1.34	1.34	0.00
MOJA	Mojave	Total S	0.51	0.53	0.02	5.7%	0.26	0.70	0.44
		Total N	4.53	4.60	0.07	1.6%	3.02	5.66	2.64
		Oxidized N	3.77	2.99	-0.78	-20.6%	1.86	3.77	1.90
		Reduced N	0.75	1.61	0.85	114.2%	1.06	2.00	0.93



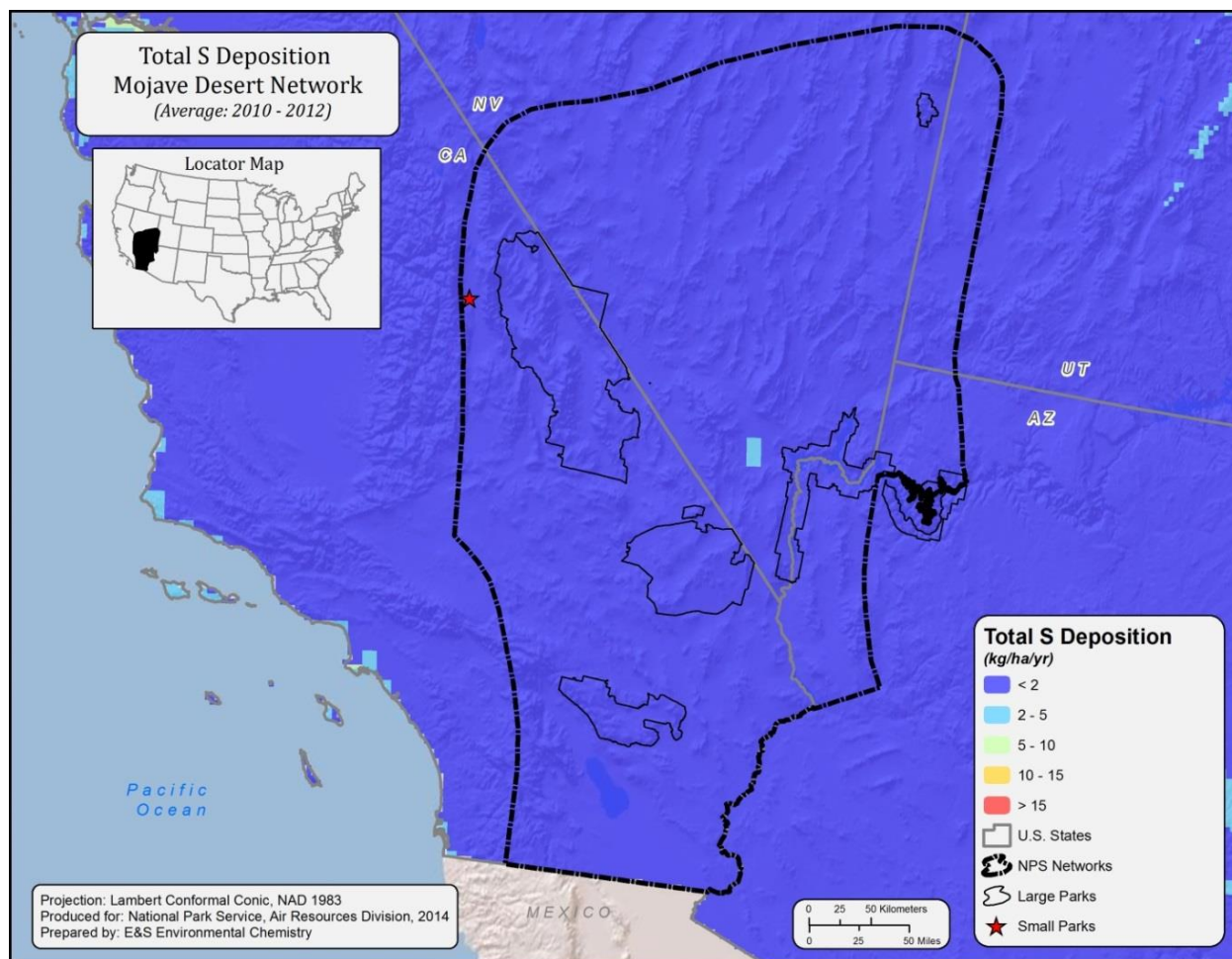
Map 2. Total SO₂ emissions, by county, near the MOJN for the year 2011. Data from EPA's National Emissions Inventory.



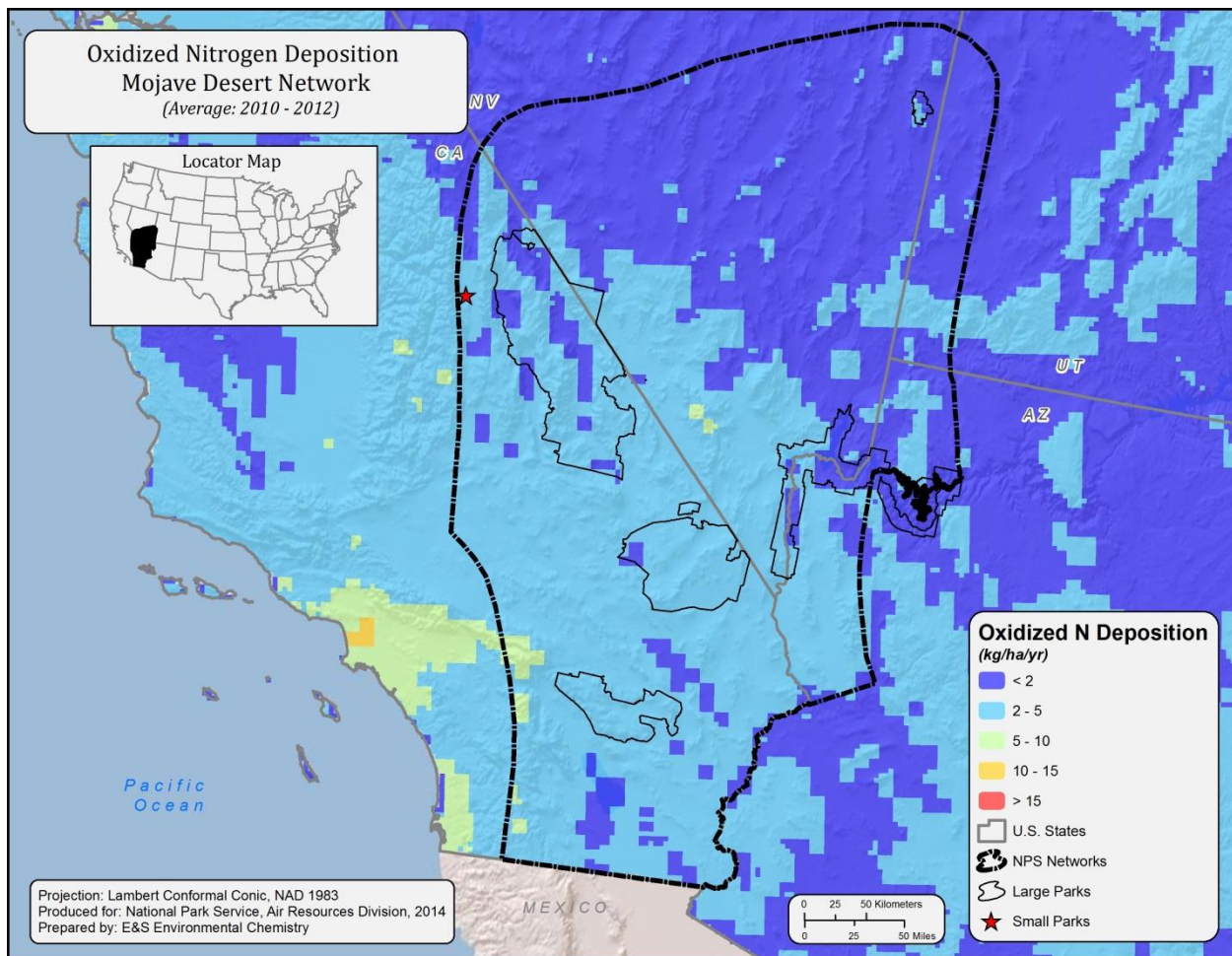
Map 3. Total NO_x emissions, by county, near the MOJN for the year 2011. Data from EPA's National Emissions Inventory.



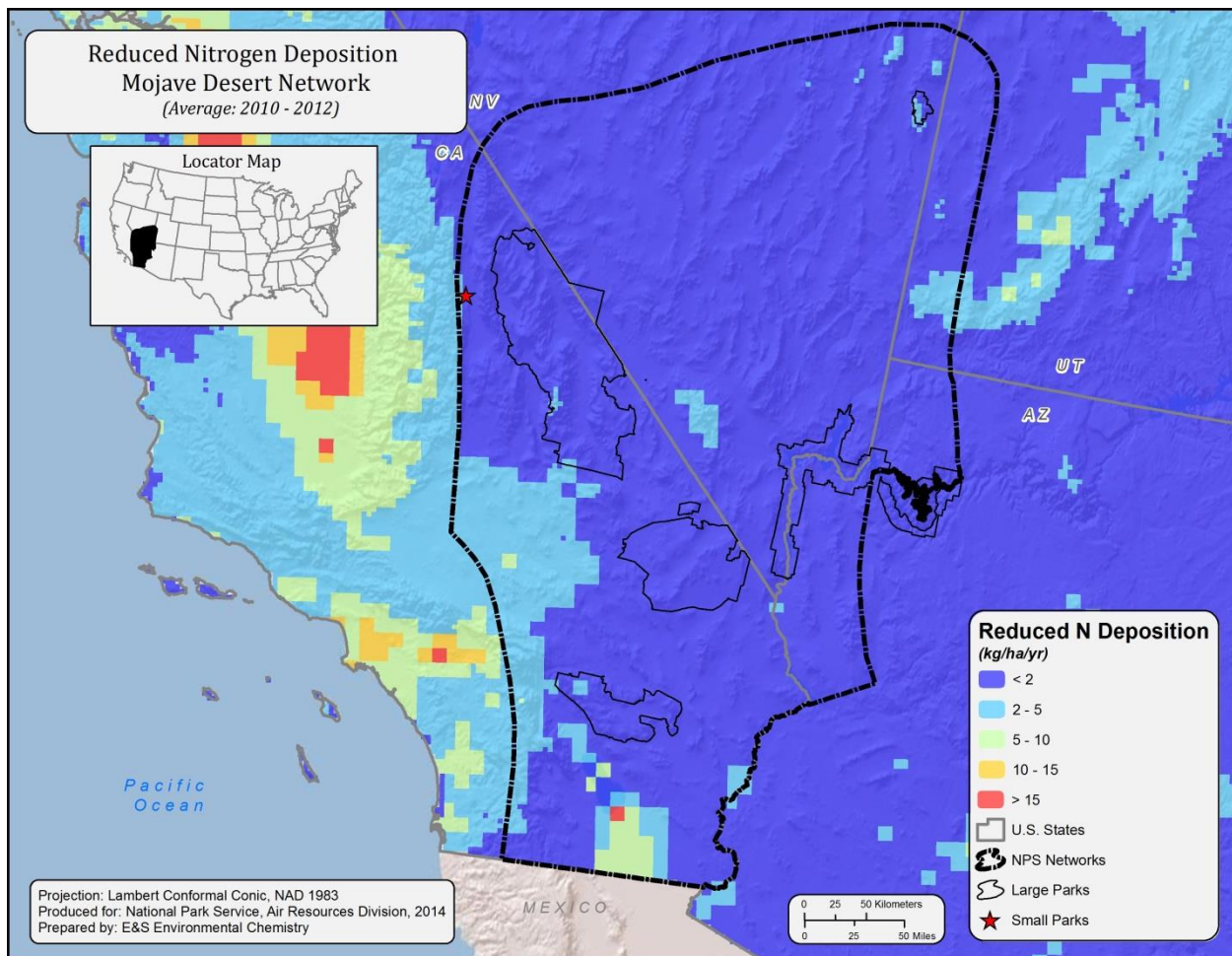
Map 4. Total NH₃ emissions, by county, near the MOJN for the year 2011. Data from EPA's National Emissions Inventory.



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



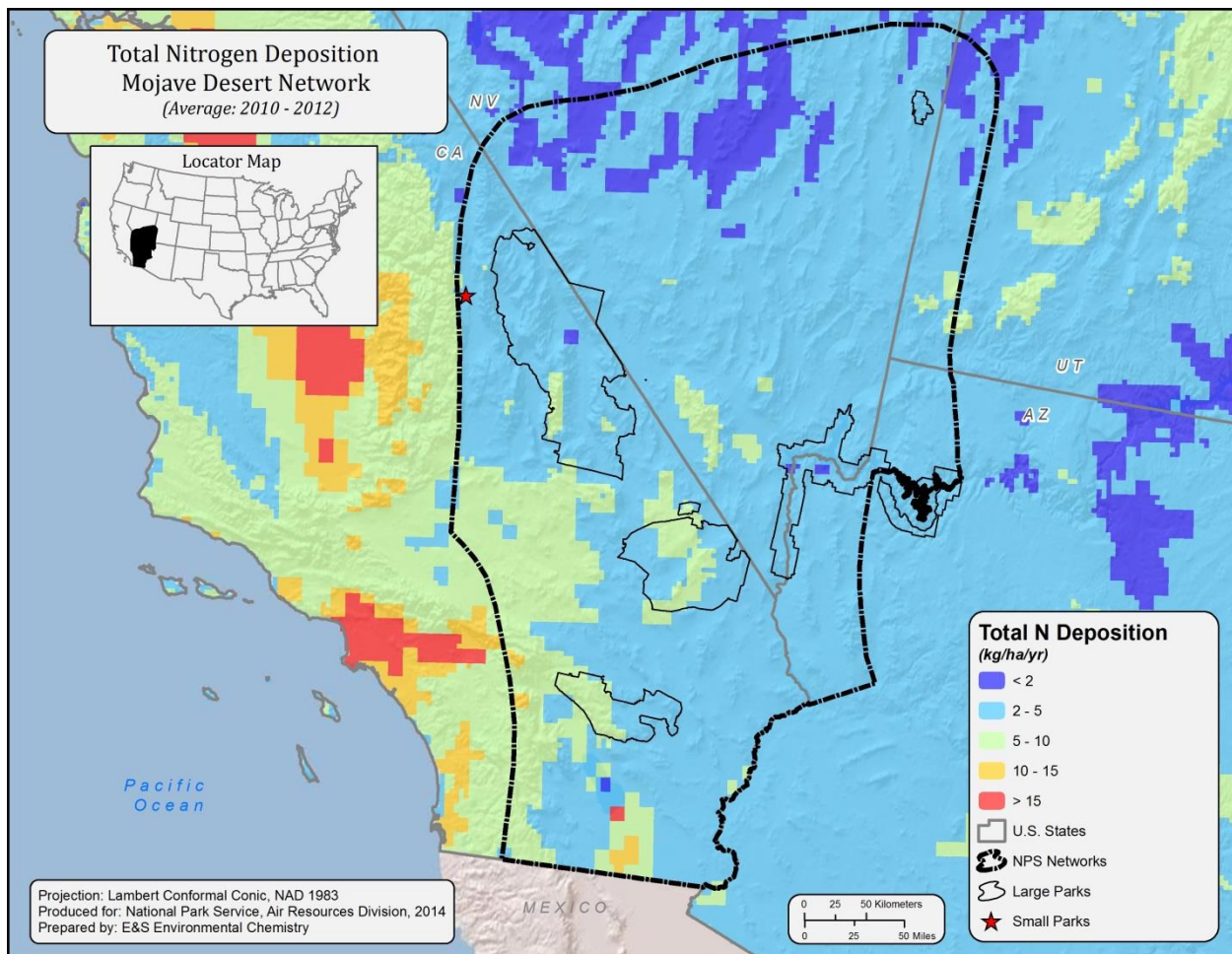
Map 6. Total oxidized inorganic N deposition for the three-year period centered on 2011 in and around the MOJN. (Source: Schwede and Lear 2014)



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

Oxidized inorganic N deposition for the period 2010-2012 was less than 5 kg N/ha/yr throughout the park lands within the MOJN (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 modeled N deposition ranged from less than 5 kg N/ha/yr at most park locations to the range of 5 to 10 kg N/ha/yr in parts of several parks, most notably JOTR and MOHA (Map 8).

Dry deposition predominates in arid ecosystems, such as are prevalent in the MOJN. Dry deposition is difficult to quantify, however, in large part because the deposition is influenced by a multitude of factors, including the mix of air pollutants present, surface characteristics of soil and vegetation, and meteorological conditions (Weathers et al. 2006). Fenn et al. (2009) developed a soil plate sampler for estimating dry deposition fluxes of N to exposed soil in arid ecosystems. This approach could be used to better quantify dry and total N deposition in desert environments.



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

Because the vegetation is sparse in arid ecosystems, soil surfaces are potentially exposed to substantial direct dry deposition of atmospheric pollutants. Padgett et al. (1999) found that inorganic N can accumulate on the soil surface of coastal sage scrub vegetation communities in southern California during dry smoggy periods. Upon onset of the rainy season, the concentration of nitrate (NO_3^-) in the surface soil decreased and was leached down the soil profile (Padgett et al. 1999, Padgett and Bytnerowicz 2001). Allen et al. (2006) measured throughfall (water from precipitation that has dripped through the vegetation canopy prior to reaching the ground surface) N at two sites (Covington Flat and Pine City) in the western portion of JOTR. Under pinyon pine (*Pinus edulis*), throughfall N deposition measurements were 36.2 and 23.1 kg N/ha/yr. Assuming 27% and 20% tree cover, respectively, at the two sites, estimated stand-level N deposition averages were 12.4 and 6.2 kg N/ha/yr.

Emerging atmospheric deposition issues at GRBA concern deposition of dust and other contaminants to the snowpack during winter and early spring. Dust deposited on the snowpack can alter local hydrology by increasing spring runoff and evaporation/sublimation from the snowpack. Dust

deposition cannot only alter hydrology, but also affect delivery of contaminants and nutrients to plants and to surface waters. To date, research has not been conducted on these issues in GRBA (Ben Roberts, NPS, personal communication, November, 2013).

The Los Angeles Basin is not the only source of air pollutants that travel from outside the network boundaries to park lands within the MOJN. Based on Western Regional Air Partnership (WRAP) analyses (Suarez-Murias et al. 2009), emissions of SO_4^{2-} from ocean vessels constitute an important contributor to visibility impairment¹ at coastal California Class I areas and may influence air quality at parks in the MOJN.

As a follow-up to the Western Airborne Contaminant Project (WACAP), Wright et al. (2014) conducted an investigation of Hg deposition inputs to national parks in the western United States. This research focused on dry deposition of gaseous oxidized Hg (GOM). Surrogate surfaces (reflective of dry depositional input) and passive samplers (reflective of atmospheric concentrations) were installed during the period 2010 to 2013 at sites from coastal California to eastern Nevada. Assessment of meteorological data, back trajectory modeling, and O_3 measurements suggested highest Hg deposition at a high-elevation coastal site (1279 m) and at GRBA (2062 m). Dry deposition of Hg was three to four times higher than wet deposition at the two high-elevation sites. Lowest Hg deposition (0.2 to 0.4 $\text{ng/m}^2/\text{hr}$) occurred at low-elevation coastal sites. Highest deposition values (0.5 to 2.4 $\text{ng/m}^2/\text{hr}$) were recorded in GRBA 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 $\text{ng/m}^2/\text{hr}$).

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

Acidification

A coarse screening assessment for all Inventory and Monitoring (I&M) Program networks and parks for acid Pollutant Exposure, Ecosystem Sensitivity to acidification, and Park Protection yielded an overall network acidification Summary Risk ranking for the MOJN that was near the middle of the distribution among all networks. The overall level of concern for acidification effects on I&M parks within this network was judged by Sullivan et al. (2011b) to be Moderate. While rankings are an indication of risk, park-specific data, particularly data on ecosystem sensitivity, are needed to fully evaluate risk from acidification.

The five I&M parks within the MOJN that are larger than 100 square miles were distributed across the lower half of the spectrum among all I&M parks for acid Pollutant Exposure, from the middle quintile (JOTR) to the lowest quintile (DEVA and GRBA; Table 2). MANZ, which is less than 100 square miles, was also ranked in the lowest quintile. Ecosystem Sensitivity to acidification for two of the six I&M parks (DEVA and GRBA) was ranked in the highest quintile, due largely to the presence of very steep slopes and many low-order and high- elevation streams. The three other large parks (LAKE, MOJA, and JOTR) were ranked as High, while the small park, MANZ, was ranked Very Low. Ecosystem sensitivity to acidification rankings take into account land slope, which often influences the degree of acid neutralization provided by soils and bedrock within the watershed. Much of the park land in the MOJN is moderately steep. Some areas in DEVA, JOTR, and LAKE have Hydrologic Unit Codes (HUCs) with average slope more than 30°. GRBA is entirely greater than 40° in slope, with one watershed having average slope greater than 50°. Although surface water resources are generally scarce in the parks in the MOJN, GRBA has several high elevation lakes that are fairly low in acid neutralizing capacity (ANC). These lakes were surveyed in 1986 as part of EPA's Western Lakes Survey. All of the sampled lakes in the park were considered acid-sensitive (ANC less than 200 microequivalents per liter [$\mu\text{eq/L}$]), according to EPA's classification criteria at that time (Landers et al. 1987). The most sensitive lake included in the study was Baker Lake at 3,238 m (10,620 feet), with an ANC of 73 $\mu\text{eq/L}$. Recent conductivity measurements and correlation analysis suggest that the ANC of Baker Lake is, at times, less than 50 $\mu\text{eq/L}$, a level considered to be very acid-sensitive. Nevertheless, the overall risk of acidification is probably low in view of the very low levels of S deposition to GRBA. Depletion of ANC increases the risk to lakes and streams in the park from episodic or chronic acidification. Baker Lake has a listed population of Lahontan cutthroat trout (*Onchorhynchus clarki henshawi*), as well as other fish and invertebrates, that could be negatively affected by acidification.

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
<i>Death Valley</i>	DEVA	Very Low	Very High
<i>Great Basin</i>	GRBA	Very Low	Very High
<i>Joshua Tree</i>	JOTR	Moderate	High
<i>Lake Mead</i>	LAKE	Low	High
Manzanar	MANZ	Very Low	Very Low
<i>Mojave</i>	MOJA	Low	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.

Nutrient Nitrogen Enrichment

Risk Ranking

The network rankings developed in a coarse screening analysis by Sullivan et al. (2011a) for nutrient N Pollutant Exposure, Ecosystem Sensitivity to nutrient N enrichment, and Park Protection yielded an overall network nutrient N enrichment Summary Risk ranking for MOJN that was in the top quintile among all networks. 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. 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 five I&M parks within this network that are larger than 100 square miles were distributed across the lower half of the spectrum for nutrient N Pollutant Exposure, from the middle quintile (JOTR and MOJA) to the lowest quintile (GRBA; Sullivan et al. 2011a; Table 3).

Ecosystem Sensitivity to nutrient N enrichment for most of the I&M parks in MOJN was ranked in the highest quintile due to the preponderance of desert vegetation, which is presumed to be highly sensitive to nutrient N enrichment. GRBA has cheatgrass (*Bromus tectorum*; a non-native invasive annual grass) at low elevations. This species is very sensitive to N enrichment. If N levels increase in the future, we might expect to see higher cheatgrass densities and expansion into currently unoccupied areas, perhaps contributing to a cascade of ecological changes.

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
<i>Death Valley</i>	DEVA	Low	Very High
<i>Great Basin</i>	GRBA	Very Low	Low
<i>Joshua Tree</i>	JOTR	Moderate	Very High
<i>Lake Mead</i>	LAKE	Low	Very High
Manzanar	MANZ	Low	Very High
<i>Mojave</i>	MOJA	Moderate	Very 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.

Some arid ecosystems in southern California receive very high levels of atmospheric N deposition. For these arid ecosystems, however, it is not appropriate to establish critical loads (CLs) based on NO₃⁻ leaching or soil acidification. This is because most deposited N leaches deep into the soil profile (Walvoord et al. 2003), and soils are generally not acidic. The N CL is more appropriately set to prevent eutrophication for these southwestern arid ecosystems.

Field Studies

Studies in desert environments have indicated possible plant community changes resulting from elevated nutrient N input. A fertilization experiment in the Chihuahuan desert, with inputs of 100 kg N/ha/yr over about a decade, resulted in a 30% increase in cover of warm season grasses and a 52% reduction in cover of legumes (Báez et al. 2007). Somewhat similar responses might be expected in the MOJN. From 1989 to 2004, Baez et al. (2007) observed a 43% increase in ambient N deposition, from 1.71 to 2.45 kg N/ha/yr, resulting in an additional 5.88 kg N/ha deposition over that time period. These increases in N deposition may result in significant plant community changes, as indicated by fertilization studies of blue grama (*Bouteloua gracilis*) and black grama (*B. eriopoda*). With additions of 20 kg N/ha in one season, blue grama was favored over black grama, the previously dominant species (Báez et al. 2007).

Plant productivity on arid land typically increases with both increasing precipitation (Bowers 2005, Romney et al. 1978) and N availability (Allen et al. 2009, Rao et al. 2010, Salo et al. 2005). In desert ecosystems, water is generally more limiting than N. Brooks (2003) found that plant responses were influenced by specific rainfall events rather than by average annual rainfall, with the annual plants thriving in a year when high rainfall events triggered germination. In the Mojave desert, the shrub creosote bush (*Larrea tridentata*) showed no increased growth response to experimental N additions (at 10 and 40 kg N/ha/yr as calcium nitrate ($\text{Ca}(\text{NO}_3)_2$), but did respond to increased water (Barker et al. 2006). Conversely, invasive annuals showed a greater response to elevated N than did native species.

Fertilization experiments by Brooks (2003) in the Mojave desert showed that increased levels of N deposition could favor the establishment of non-native species where non-natives were already prevalent (Brooks 2003). At very high N application rates of 32 kg N/ha/yr over two years, both density and biomass of non-native plants increased. Non-native biomass increased 54% while native species biomass declined by about 39%.

Fire risk in desert vegetation communities is largely controlled by interactions among water and N availability, soil texture, and the presence of invasive grasses. Grasses create a continuous fire fuel bed in the interspaces between shrubs. Exotic grass litter breaks down slowly, creating a highly flammable spatially continuous fire fuel load during the dry season (Brooks and Minnich 2006). Because of the historical rarity of fire in arid ecosystems, arid land shrubs are typically not fire adapted and experience high mortality and slow re-establishment subsequent to fire (Brown and Minnich 1986). Slow recovery of shrubs after fire, and fast recovery of grasses contribute to increased fire frequency and a shift from shrub-dominated to exotic grass-dominated vegetation (Brooks et al. 2004, D'Antonio and Vitousek 1992, Rao et al. 2010, Steers 2008). Soil texture also affects fire frequency by modifying soil water holding capacity, infiltration, and hydraulic conductivity (Austin et al. 2004, Rao et al. 2010, Schwinning et al. 2004)

Allen et al. (2009) measured reactive N in the air and soils along an N deposition gradient at JOTR to determine effects on invasive and native plant species. Because invasive plant species such as Mediterranean spelt grass (*Schismus barbatus*), red brome (*Bromus rubens*), and stork's bill (*Erodium cicutarium*) had become widespread over the preceding two decades, it was postulated that

increasing N deposition might influence invasive plant range expansion. Nitrogen fertilization was added at levels of 5 and 30 kg N/ha/yr for each of two years, in addition to about 3 to 12 kg N/ha/yr of ambient atmospheric deposition (Allen and Geiser 2011, Tonnesen et al. 2007). Non-native grass biomass increased significantly upon addition of 30 kg N/ha/yr at three of four treatment sites but not at the lower application level. Native forb species richness declined at a site with high non-native grass cover, but richness and cover of native forbs increased in response to N addition at a site having low non-native grass cover (Allen et al. 2009).

The Allen et al. (2009) study also suggested that the response of desert vegetation to added N varied by wetness condition. During 2003, which was a dry year, vegetation biomass remained unchanged. During 2004, a moderate precipitation year, two of four experimental plots showed increased biomass of non-native invasive grasses at addition of 30 kg N/ha/yr, but not at 5 kg N/ha/yr. During the wettest year (2005), invasive grass biomass increased at both N treatment levels (Allen et al. 2009). Productivity of native forbs decreased in response to N addition at these sites, but increased at another treatment site that had only sparse invasive grass cover.

Some native species are also able to use added N. For example, greasewood (*Sarcobatus vermiculatus*), a native desert shrub found in the Great Basin Desert, demonstrated a twofold to threefold increase in stem growth, a 2.5- to 4-fold increase in viable seed production, and a 17% to 35% increase in leaf N with N additions at sites around Mono Lake, CA (Drenovsky and Richards 2005).

The studies by Allen et al. (2009) at JOTR suggested that the critical load of N to protect desert vegetation in this park against invasive grass biomass increase due to N enrichment during wet years may be as low as about 8 kg N/ha/yr (Allen and Geiser 2011). Modeling results using the daily Century biogeochemical model (DayCent; Allen and Geiser 2011, Brooks and Matchett 2006) were similar, suggesting a critical load less than 8.2 kg N/ha/yr for low elevation desert dominated by invasive Mediterranean grass, and a critical load less than 5.7 kg N/ha/yr at higher elevation sites dominated by invasive red brome (Rao et al. 2010). The model results further suggested that, at higher N input levels above these critical loads, fire risk is controlled more by precipitation than by grass productivity as influenced by N input (Allen and Geiser 2011).

Pardo et al. (2011b) compiled data on empirical CL for protecting sensitive resources in Level I ecoregions across the conterminous United States against nutrient enrichment effects caused by atmospheric N deposition. Data on empirical CL for nutrient N deposition applicable to MOJN parks are limited. Pardo et al. (2011b) only reported empirical CL values in the North American Deserts ecoregion for the protection of lichens and herbaceous plants (Table 4). The lower end of the reported range was 3 kg N/ha/yr for both of these sensitive receptors. Modeled ambient N deposition reported by Pardo et al. (2011b) was higher than the estimated CL at four parks in the network: DEVA, JOTR, LAKE and MOJA. This suggests the CL for protection of terrestrial plant communities against adverse effects associated with nutrient N enrichment may have been exceeded at these parks.

Modeling Studies

The DayCent model was applied to plant communities in the deserts of southern California by Rao et al. (2009, 2010). Invasive non-native grass production was simulated from 2003 to 2008 under varying levels of N input and precipitation, resulting in predictions of changing fire frequency. Simulated fire risk increased above N deposition of 3 kg N/ha/yr. The simulated risk leveled off at N deposition above 5.7 kg N/ha/yr in pinyon-juniper and at 8.2 kg N/ha/yr in creosote bush scrub (Rao et al. 2010).

Table 4. Empirical critical loads for nitrogen in the MOJN, 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	N Deposition (kg N/ha/yr)	Critical Load (kg N/ha/yr)	
			Lichen	Herbaceous Plant
Death Valley NP	North American Deserts	3.8	3	3 - 8.4
Great Basin NP	North American Deserts	1.8	3	3 - 8.4
Joshua Tree NP	North American Deserts	7.0	3	3 - 8.4
Lake Mead NRA	North American Deserts	4.8	3	3 - 8.4
Manzanar NHS	North American Deserts	1.7	3	3 - 8.4
Mojave NPres	North American Deserts	4.0	3	3 - 8.4

Rao et al. (2010) applied DayCent to estimate critical loads of N deposition in JOTR to control its effects on fire risk in two different arid land vegetation types, creosote bush and pinyon-juniper. Fire risk was expressed as the probability that annual biomass production exceeded the general fire threshold of 1000 kg/ha. Critical loads were calculated as the amount of N deposition at the point along the deposition continuum where modeled fire risk began to increase exponentially. The mean estimated CL for all soil types, under annual precipitation less than 21 cm/yr, were 3.2 and 3.9 kg N/ha/yr for creosote bush and pinyon-juniper plant communities, respectively. Critical loads decreased (more nutrient-sensitive) with decreasing soil clay content and increasing precipitation. The wettest areas with clay content of 6% to 14% had estimated critical loads as low as 1.5 kg N/ha/yr (Rao et al. 2010). These values fall at the lower end of the CL range identified by Pardo et al. (2011) for herbaceous vegetation in North American Deserts. Fire risks in the two vegetation types were highest under N deposition of 9.3 and 8.7 kg N/ha/yr, respectively; above these deposition levels, fire risk was driven by precipitation amount.

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 (Geiser et al. 2010). 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 for DEVA, GRBA, and JOTR in the range of 3-8.4 kg N/ha/yr for protection of herbaceous plants.

Ozone Injury to Vegetation

The O₃-sensitive plant species that are known or thought to occur within the parks in the MOJN are listed in Table 5. Those considered to be bioindicators, because they exhibit distinctive symptoms when injured by O₃ (e.g., dark stipple), are designated by an asterisk. Each of the parks in this network contains at least four O₃ sensitive species.

Ozone Exposure Indices and Levels

Experimental studies using controlled exposures have identified desert plant species that are potentially sensitive to O₃ (Temple 1989, Thompson et al. 1984a, Thompson et al. 1984b, Thompson et al. 1980). Bytnerowicz et al. (1988) developed an open-air exposure system for measuring O₃ exposure in the desert. They then exposed 16 Mojave Desert winter annual plant species to a range of O₃ exposure conditions. Of the species studied, *Camissonia claviformis*, *C. hirtella*, and *Erodium cicutarium* were the most sensitive to O₃ exposures. In a major air-pollutant screening effort, Thompson et al. (1984a, 1984b) used controlled exposures to determine the sensitivity of 49 Mojave Desert species to O₃ and SO₂. They found considerable variation in sensitivity, with evening primrose (*Oenothera* spp.) and catseye (*Cryptantha* spp.) having some of the highest levels of injury in response to exposure to O₃ and SO₂.

Temple (1989) tested the sensitivity of the woody perennials catclaw acacia (*Acacia greggii*), desert willow (*Chilopsis linearis*), skunkbush sumac (*Rhus trilobata*), and Goodding's willow (*Salix gooddingii*) to controlled exposures of O₃ ranging up to 200 parts per billion (ppb) over four-hour periods. This study found that skunkbush sumac exhibited foliar injury at concentrations as low as 100 ppb, while Goodding's willow exhibited foliar injury at 200 ppb; other species had no injury symptoms. Surprisingly, skunkbush sumac exposed to elevated levels of O₃ also grew faster, but the fact that it had such clear foliar symptoms at relatively low exposures indicates high sensitivity and good potential as a bioindicator. There appears to be high potential for vegetation injury caused by O₃, although injury symptoms are known for relatively few desert plant species and can be difficult to diagnose (Sullivan et al. 2001).

Table 5. Ozone sensitive and bioindicator plant species known or thought to occur in the I&M parks of the MOJN. (Data Source: E. Porter, National Park Service, pers. comm., August 30, 2012; lists are periodically updated at <https://irma.nps.gov/NPSpecies/Report>).

Species	Common Name	Park ¹					
		<i>DEVA</i>	<i>GRBA</i>	<i>JOTR</i>	<i>LAKE</i>	<i>MANZ</i>	<i>MOJA</i>
<i>Ailanthus altissima</i> *	Tree-of-heaven	x				x	
<i>Apocynum androsaemifolium</i> *	Spreading dogbane		x				
<i>Apocynum cannabinum</i>	Dogbane, Indian hemp		x	x	x	x	x
<i>Artemisia douglasiana</i> *	Mugwort	x					
<i>Artemisia ludoviciana</i> *	Silver wormwood	x	x		x		
<i>Pinus ponderosa</i> *	Ponderosa pine		x		x		
<i>Populus tremuloides</i> *	Quaking aspen		x				
<i>Prunus virginiana</i>	Choke cherry		x		x		
<i>Rhus trilobata</i> *	Skunkbush		x	x	x		x
<i>Robinia pseudoacacia</i>	Black locust	x				x	x
<i>Salix gooddingii</i>	Gooding's willow	x		x	x	x	x
<i>Sambucus mexicana</i> *	Blue elderberry	x		x			x

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

* 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 (2007a) O₃ risk ranking. The two ranking systems differ. The NPS ranking system (NPS 2010) is a quick assessment of O₃ condition. It ranks O₃ exposure levels according to injury thresholds from the literature (Heck and Cowling 1997), using a 5-year average of the W126 or the SUM06 metrics over a 3-month period. The W126 was classified as Moderate at values between 7 and 13 parts per million-hours (ppm-hr) as defined by NPS (2010). 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, respectively. Using these criteria, O₃ exposure at all of the MOJN parks was rated High.

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.

Table 6. Ozone assessment results for parks in the MOJN based on estimated average 3-month W126 and SUM06 ozone exposure indices for the period 2005-2009 and Kohut's (2007a) 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	
Death Valley	DEVA	28.96	High	40.96	High	Low
Great Basin	GRBA	15.55	High	21.20	High	Low
Joshua Tree	JOTR	29.53	High	39.95	High	High
Lake Mead	LAKE	19.58	High	28.46	High	Low
Manzanar	MANZ	40.46	High	52.46	High	High
Mojave	MOJA	25.92	High	36.49	High	High

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.

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 considered more recent O₃ conditions (2005-2009), but not environmental conditions.

Kohut (2007b) assessed the risk of foliar injury from O₃ exposure in MOJN parks, with three parks (DEVA, GRBA, and JOTR) assessed based on in-park monitoring data and the others based on kriging of data from surrounding monitoring stations. In addition, data for 2000-2004 were analyzed for DEVA and GRBA. The SUM06 index generally exceeded the threshold for foliar injury in DEVA and GRBA during the initial monitoring period (1995-1999), and more definitively exceeded the threshold in the other parks (including DEVA and GRBA) for the monitoring period 2000-2004. The threshold for the W126 index was exceeded in JOTR, MANZ and MOJA, but generally not in the other parks. There was an apparent relationship between O₃ concentrations and soil moisture, whereby when O₃ exposure was high, soil moisture was low. This would be expected to reduce O₃ uptake and therefore the likelihood of foliar injury. This observed relationship was most pronounced for JOTR and MOJA. Kohut (2007b) classified JOTR, MANZ and MOJA as having High risk of foliar injury, and the remaining three parks as having Low risk. For JOTR, MANZ and MOJA, there were many hours each year during the monitoring period having O₃ exposure greater than 100 ppb. During some years, drought would significantly restrict O₃ uptake and therefore foliar injury. During other years (e.g., 1995, 1998), however, O₃ exposure was high and soil moisture was normal. The hours of exposure to O₃ concentrations at DEVA that were greater than 60 ppb increased over the full period of record (1995-2004), and exposure to concentrations greater than 80 ppb increased slightly

(Kohut 2007b). Although the W126 index was substantially higher than the threshold in DEVA, there were only two hours of exposure greater than 100 ppb over the nine-year period of record. Therefore, the W126 criteria were not met. Frequent drought in this park further constrained O₃ uptake and reduced the likelihood of foliar injury.

During more recent years (2000-2009), no significant trends in O₃ concentration were detected in monitored parks in this network (DEVA, GRBA, JOTR, LAKE; NPS-ARD 2013). EPA has set national standards for O₃ to protect both human and plant health. The current standard is set at 75 ppb for protecting both humans and plants, based on an 8-hour average. JOTR and MOJA are both located in areas designated nonattainment by EPA because O₃ concentrations violate this standard, and air quality is considered unhealthy at times. EPA has recognized that the 8-hour form for the standard is probably not appropriate to protect plants, which respond to longer-term O₃ exposures. In 2010, EPA proposed a new secondary O₃ standard to protect plant health (Federal Register Vol. 75, No. 11, 40 CFR Parts 50 and 58, National Ambient Air Quality Standards for Ozone, Proposed Rules, January 19, 2010, p. 2938). It was based on an index of the total plant O₃ exposure, the W126. For the W126 index, hourly values are weighted according to magnitude and then summed for daylight hours over three months, approximately a growing season. EPA proposed to set the level of the new standard in the range of 7-15 ppm-hr. There were 17 parks that exceeded the upper end of this range in 2008. The highest values were reported for Sequoia-Kings Canyon National Parks (57 ppm-hr), JOTR (53 ppm-hr), Yosemite National Park (34 ppm-hr), and DEVA (29 ppm-hr), all in California. The standard was not finalized, but EPA is considering the W126 standard again in its ongoing review of the secondary O₃ standard.

Visibility Degradation

Estimated Natural Background Visibility and Monitored Visibility Conditions

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 deciview² (dv). Lower dv values correspond with better visibility conditions. Although JOTR is the only Class I area in the MOJN (the rest are classified as Class II by the CAA), visibility is also monitored in DEVA and GRBA. Improvements required by the RHR are anticipated to benefit both Class I and Class II parks.

The JOTR IMPROVE monitor (JOSH1) is considered by EPA to be representative of MOJA because it’s located within 60 mi (100 km) and 425 ft (130 m) elevation of MOJA. Natural background visibility assumes no human-caused pollution, but varies with natural processes such as windblown dust, fire, volcanic activity, and natural biogenic emissions from vegetation. Estimated natural haze was relatively low in DEVA and GRBA, compared with MOJA, JOTR, and other I&M parks (Table 7).

Monitored visibility reflects recent 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 across the United States. Given the substantially greater amount of human-caused emissions in the eastern United States and environmental factors such as generally higher humidity in the East, visibility tends to be much better at western parks than at eastern parks. Relative rankings range from very low haze (very good visibility) to very high haze (very poor visibility). Only parks with on-site or representative IMPROVE monitors were used to generate the visibility ranking. Table 7 gives the relative park visibility rankings on the 20% clearest, 20% haziest and average days.

Measured visibility for the period 2004 through 2008 was somewhat worse at each of the monitored parks than the estimated natural condition. Measured visibility impairment in DEVA and GRBA was considered Low and Very Low, respectively, for all groups (20% clearest days, 20% haziest days and average days). JOTR and MOJA were ranked Moderate for all groups, and had the worst visibility among the four monitored parks in the MOJN (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.

Table 7. Estimated natural background visibility and measured visibility in I&M parks in the MOJN averaged over the period 2004 through 2008¹.

Park Name ²	Park Code	Site ID	Estimated Natural Background Visibility		
			20% Clearest Days	20% Haziest Days	Average Days
			dv	dv	dv
<i>Death Valley</i>	DEVA	DEVA1	2.22	7.90	4.68
<i>Great Basin</i>	GRBA	GRBA1	0.85	6.24	3.18
<i>Joshua Tree</i>	JOTR	JOSH1	1.68	7.19	4.17
<i>Lake Mead</i>	LAKE	No Site			
Manzanar	MANZ	No Site			
<i>Mojave</i> ³	MOJA	JOSH1	1.68	7.19	4.17

Park Name	Park Code	Site ID	Measured Visibility (For Years 2004 through 2008)					
			20% Clearest Days		20% Haziest Days		Average Days	
			dv	Ranking	dv	Ranking	dv	Ranking
<i>Death Valley</i>	DEVA	DEVA1	4.69	Low	15.41	Low	9.63	Low
<i>Great Basin</i>	GRBA	GRBA1	2.06	Very Low	10.71	Very Low	5.94	Very Low
<i>Joshua Tree</i>	JOTR	JOSH1	5.51	Moderate	18.29	Moderate	11.87	Moderate
<i>Lake Mead</i>	LAKE	No Site						
Manzanar	MANZ	No Site						
<i>Mojave</i>	MOJA	JOSH1	5.51	Moderate	18.29	Moderate	11.87	Moderate

¹ Parks are classified into one of five ranks (Very Low, Low, Moderate, High, Very High), based on a relative comparison of visibility conditions at all monitored parks.

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

³ Data from the JOTR IMPROVE monitor are used to represent conditions at MOJA. A monitoring site is considered to be representative if it is within 60 mi (100 km) and 425 ft (130 m) in elevation of that area.

Representative photos of a selected vista under three different visibility conditions are shown in Figure 1 for GRBA. Photos were selected to correspond with the clearest 20% of visibility conditions, haziest 20% of visibility conditions and average visibility conditions at that location. This series of photos provides a graphic illustration of the visual effect of haze.

IMPROVE data allow estimation of visual range (VR), i.e., how far a person can see. Data indicate that at the DEVA monitoring site (DEVA1), air pollution has reduced average VR from 150 to 80 miles (241 to 129 km). On the haziest days, VR has been reduced from 110 to 50 miles (177 to 80 km). Severe haze episodes occasionally reduce visibility to 19 miles (30 km). At the GRBA monitoring site (GRBA1), air pollution has reduced average VR from 170 to 120 miles (274 to 193 km). On the haziest days, VR has been reduced from 130 to 85 miles (209 to 137 km). Severe haze episodes occasionally reduce visibility to 16 miles (26 km). At the JOTR monitoring site (JOSH1), also representative of MOJA, air pollution has reduced average VR from 160 to 90 miles (257 to 145 km). On the haziest days, VR has been reduced from 120 to 35 miles (193 to 56 km). Severe haze episodes occasionally reduce visibility to 13 miles (21 km).

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 that are derived from natural and human-caused sources. NO_x emissions are from combustion sources including vehicles, 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. 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 DEVA, GRBA, JOTR and MOJA (values for MOJA are based on JOTR data). The figure illustrates that SO₄²⁻ is the primary component of current haze at all four parks on the 20% clearest days, when human-caused emissions are relatively low. Some of that SO₄²⁻ is likely derived from marine sources. On the 20% haziest days, organics contribute the most to haze in DEVA and GRBA. In JOTR and MOJA, the largest contribution is from NO₃⁻. For the average days, SO₄²⁻ is the largest contributor to haze in DEVA, JOTR and MOJA; organics is the largest contributor in GRBA.

Analyses conducted by the 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 MOJN. In addition, air pollution sources outside the western United States, 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).

Park staff at JOTR have noted that visibility impairment frequently occurs at the park, particularly during summer (Sullivan et al. 2001). Winter visibility conditions seem to be better when the prevailing airflows are not from the Los Angeles Basin.

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. The average difference between measured visibility and estimated natural condition was 8.3 dv, but several western parks had measured dv on the haziest days well (more than 8 dv) above estimated natural conditions. Such large differences between ambient and estimated natural haze are reflected in the 2004-2008 monitoring results shown in Table 7 for JOTR and MOJA. All monitored parks in the MOJN show some evidence of improvement in visibility in recent years on the 20% clearest days, 20% haziest days, and annual average condition (Figure 3). Such improvements are most pronounced on the haziest days for JOTR and MOJA.

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 (Air Resource Specialists 2007).

Source apportionment 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 Apportionment Technology (PSAT) algorithm was used for WRAP model analysis.

Great Basin

Best Days

Taken: 9:00 AM

Haze = 2 dv

$B_{\text{ext}} = 12 \text{ Mm}^{-1}$

VR = 320 km



Worst Days

Taken: 9:00 AM

Haze = 10 dv

$B_{\text{ext}} = 26 \text{ Mm}^{-1}$

VR = 150 km



Average Days

Taken: 9:00 AM

Haze = 6 dv

$B_{\text{ext}} = 18 \text{ Mm}^{-1}$

VR = 220 km



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

DEVA

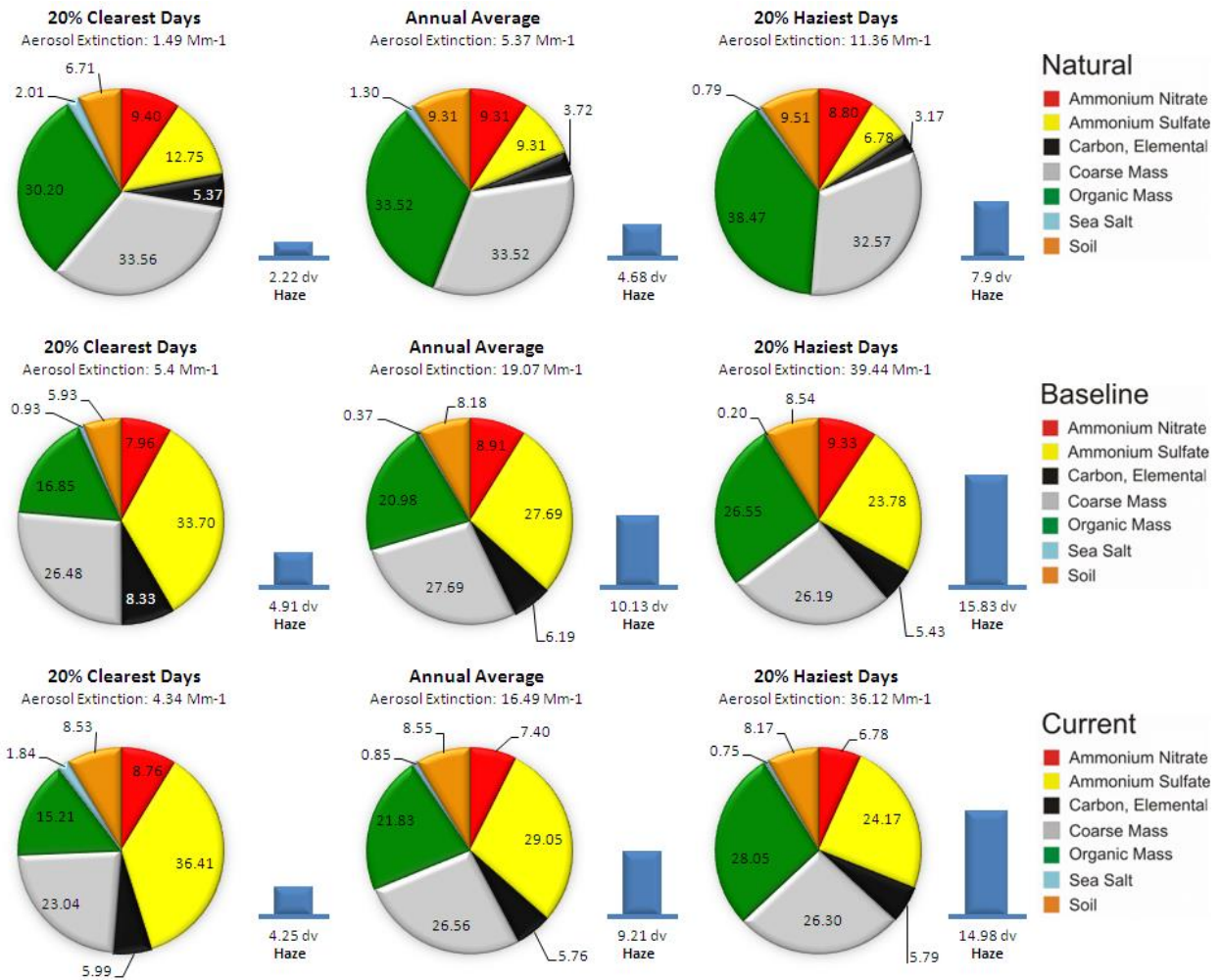


Figure 2a. Estimated natural (pre-industrial), baseline (2000-2004), and current (2006-2010) levels of haze (blue columns) and its composition (pie charts) on the 20% clearest, annual average and 20% haziest days for DEVA. Data for MOJA were taken from a representative site (JOSH1). DEVA has no data for the years 2000 or 2003; JOTR and MOJA have no data for the year 2000. Data Source: NPS-ARD

GRBA

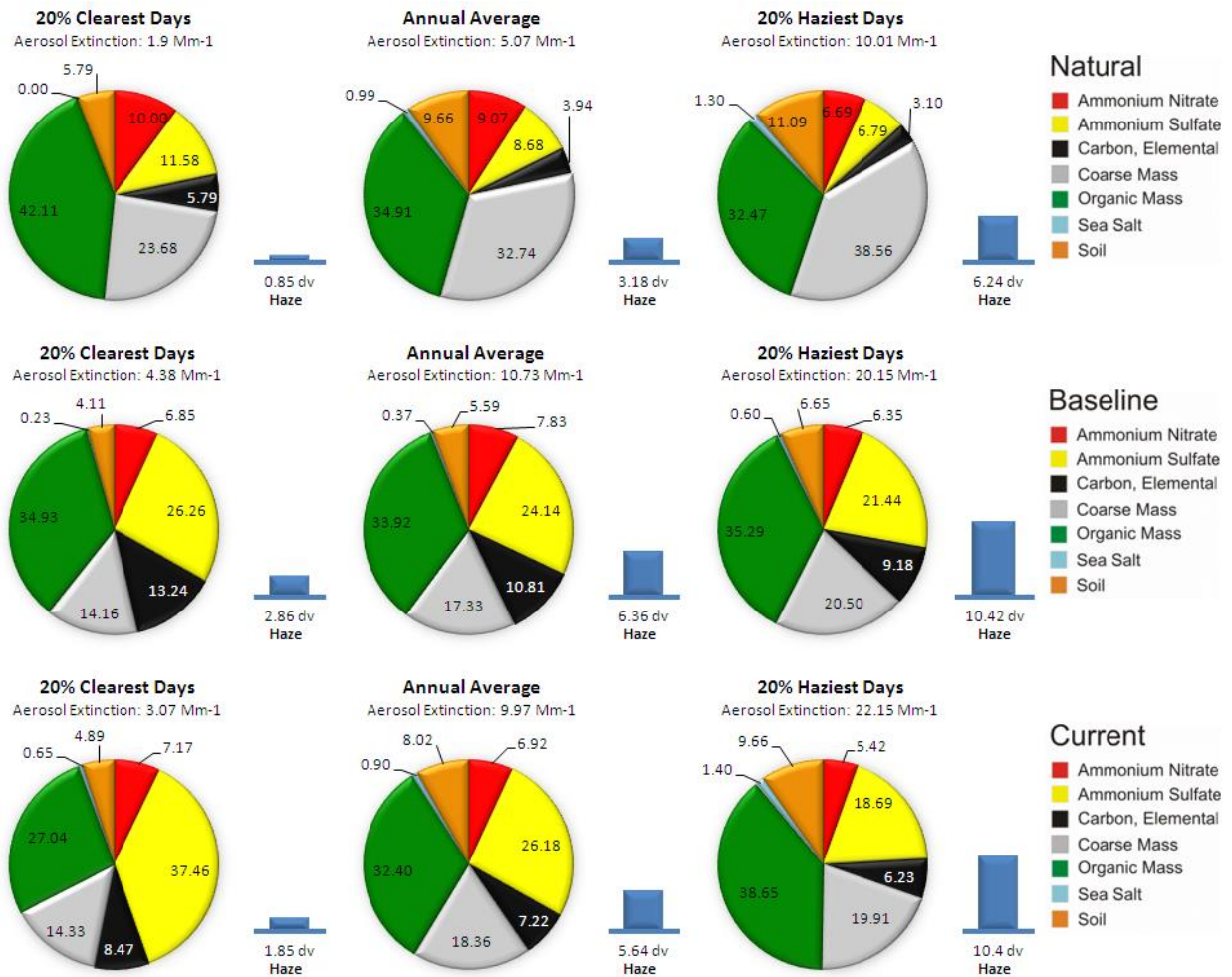


Figure 2b. Estimated natural (pre-industrial), baseline (2000-2004), and current (2006-2010) levels of haze (blue columns) and its composition (pie charts) on the 20% clearest, annual average and 20% haziest days for GRBA. Data for MOJA were taken from a representative site (JOSH1). DEVA has no data for the years 2000 or 2003; JOTR and MOJA have no data for the year 2000. Data Source: NPS-ARD

JOTR and MOJA

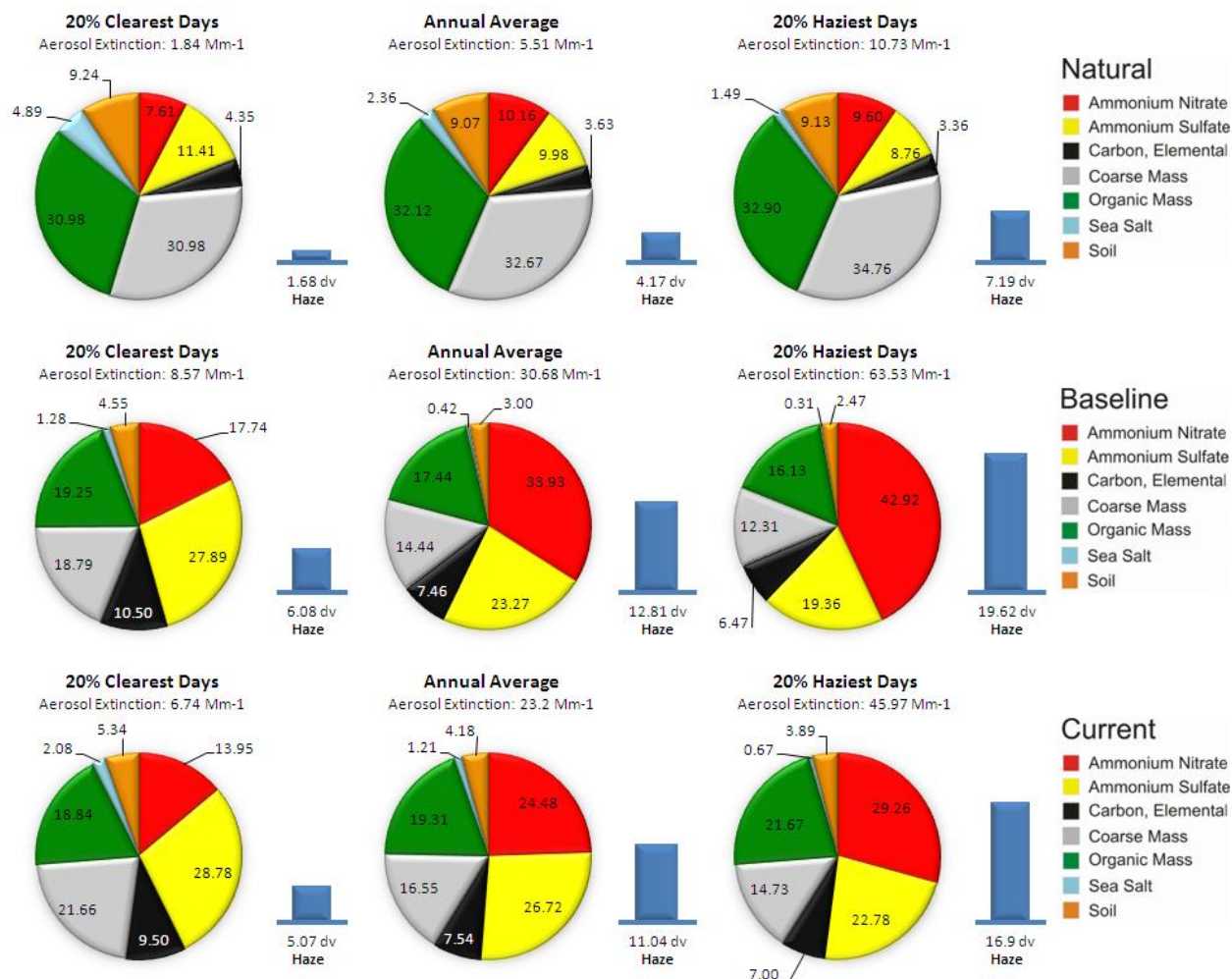


Figure 2c. Estimated natural (pre-industrial), baseline (2000-2004), and current (2006-2010) levels of haze (blue columns) and its composition (pie charts) on the 20% clearest, annual average and 20% hazeiest days for JOTR and MOJA. Data for MOJA were taken from a representative site (JOSH1). DEVA has no data for the years 2000 or 2003; JOTR and MOJA have no data for the year 2000. Data Source: NPS-ARD

Directly emitted anthropogenic organic C was estimated to contribute half or less of the organic C in most areas of California except Point Reyes National Seashore (67%) and Pinnacles National Park (73%), both well to the northwest of the MOJN. Anthropogenic sources of NO_x contributed at least half of the NO₃⁻ in all Class I areas in California except Redwood National Park (where it contributed only 7%). The anthropogenic SO₄²⁻ contribution ranged from 1 to 35% at various Class I areas, with highest contributions in southern California. The primary drivers of haze in California derive from a variety of sources including organic C, mobile sources of NO₃⁻, and off-shore regional sources of SO₄²⁻ (Suarez-Murias et al. 2009). Modeling results generated by Suarez-Murias et al. (2009) for JOTR and the U.S. Forest Service Agua Tibia Wilderness suggested that a 63% improvement would be needed in haze-forming atmospheric pollutants at JOTR in order to comply with the national visibility goal of no human-caused visibility impairment by 2064 (Table 8). The California Regional

Haze Plan (Suarez-Murias et al. 2009) also concluded that urban emissions were key sources of haze throughout the South Coast Air Basin and the central and western portions of the Mojave Desert Air Basin, which includes JOTR. Emissions from offshore shipping and international transport were also judged to be important.

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

			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)	Improvement from Current Visibility on Worst Days
Improve Monitor (name and elevation in meters)		Class I Area(s)					
AGTI (508 m)	Aqua Tibia	Agua Tibia	23.5	9.6	7.6	15.9	69%
JOSH (1,235 m)	Joshua Tree	Joshua Tree National Park	19.6	6.1	7.2	12.4	63%

Glideslope analyses shown in Figure 4 suggest that improvements on the haziest days at the monitored parks in the MOJN are progressing along (or perhaps even better than) the trajectories needed for attaining natural visibility by 2064. Results to date for DEVA and GRBA are less encouraging.

Toxic Airborne Contaminants

Little information is available regarding possible effects of air toxics deposition on sensitive park resources in the MOJN. However, elevated levels of both banned and current-use pesticides and industrial contaminants were found in vegetation, fish, snow and sediments in Sequoia-Kings Canyon National Parks to the west of the MOJN during the WACAP (Landers et al. 2008). Analyses and modeling suggested that intensive regional agriculture was at least partly responsible for these contaminants and it is possible that MOJN parks have also received airborne toxic deposition.

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. Concentrations of Hg in brook trout (*Salvelinus fontinalis*) sampled from two streams and one lake in GRBA were very low compared with other parks included in the study.

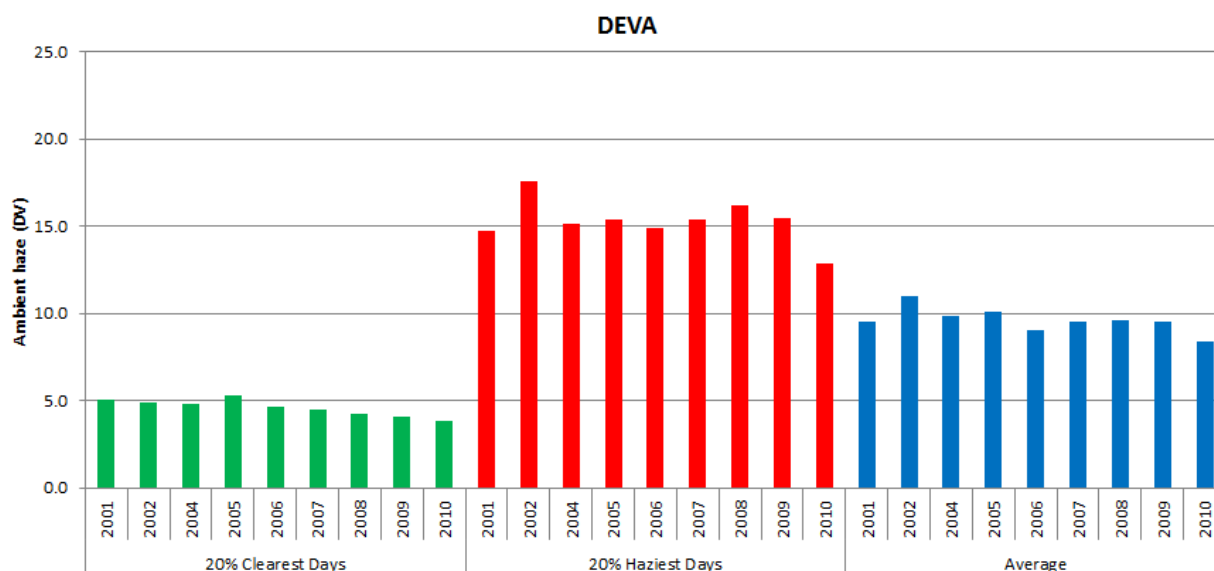


Figure 3a. Trends in monitored visibility at DEVA, based on IMPROVE measurements on the 20% clearest, 20% haziest, and annual average visibility days over the monitoring period of record. Data for MOJA were taken from a representative site (JOSH1). Data Source: http://vista.cira.colostate.edu/improve/Data/IMPROVE/summary_data.htm

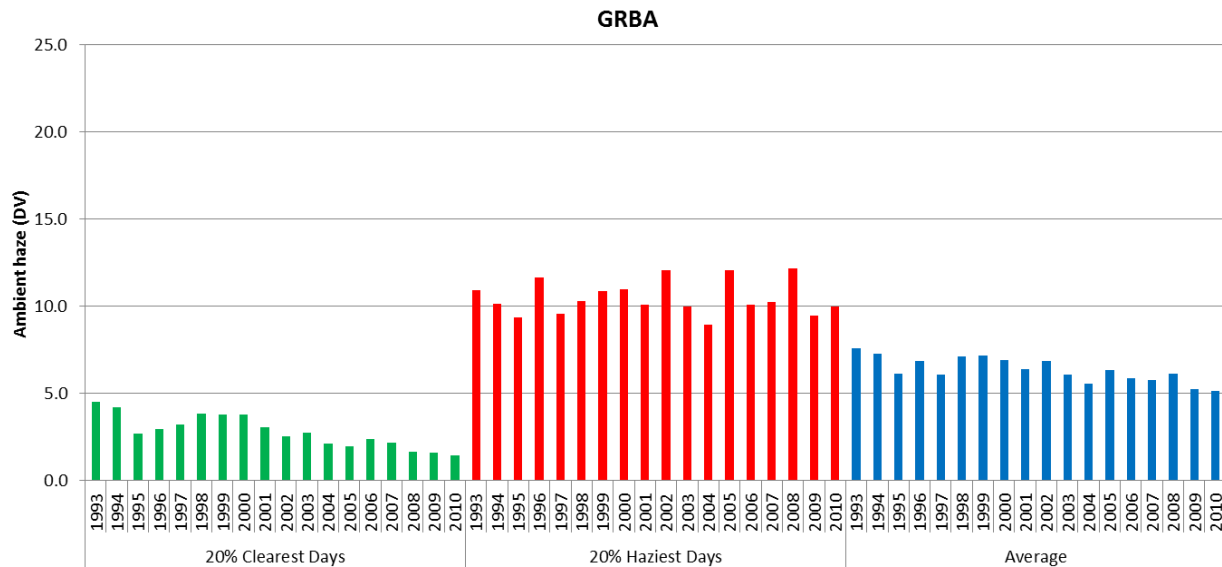


Figure 3b. Trends in monitored visibility at GRBA, based on IMPROVE measurements on the 20% clearest, 20% haziest, and annual average visibility days over the monitoring period of record. Data for MOJA were taken from a representative site (JOSH1). Data Source: http://vista.cira.colostate.edu/improve/Data/IMPROVE/summary_data.htm

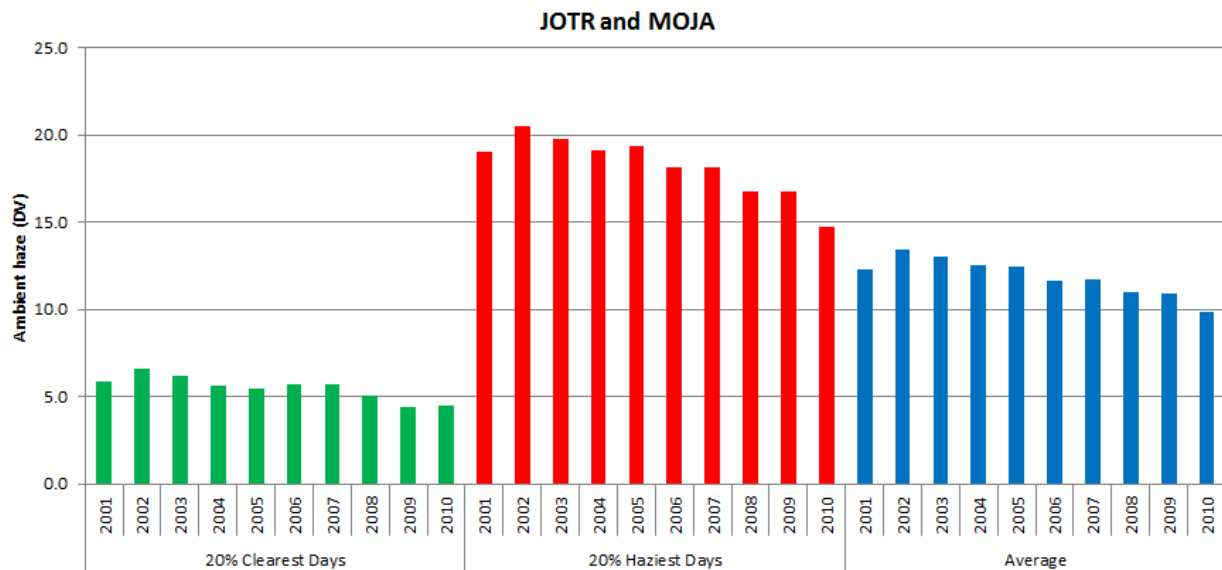


Figure 3c. Trends in monitored visibility at JOTR and MOJA, based on IMPROVE measurements on the 20% clearest, 20% haziest, and annual average visibility days over the monitoring period of record. Data for MOJA were taken from a representative site (JOSH1). Data Source: http://vista.cira.colostate.edu/improve/Data/IMPROVE/summary_data.htm

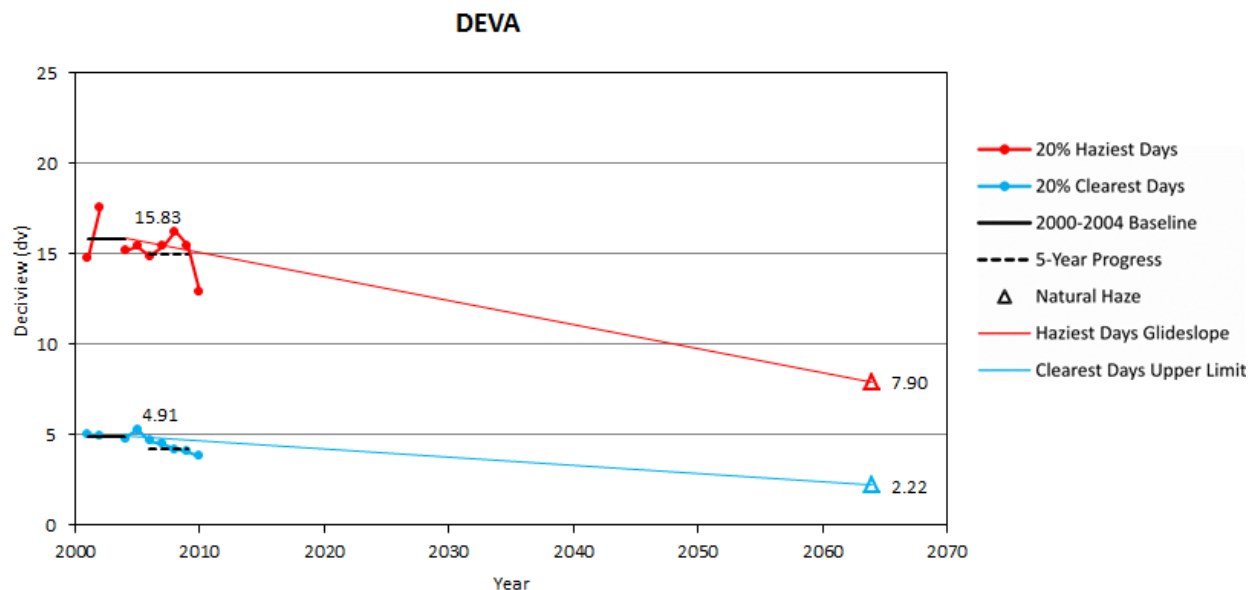


Figure 4a. Glideslopes to achieving natural visibility conditions by 2064 for the 20% hazeiest (red line) and the 20% clearest (blue line) days in DEVA. In the Regional Haze Rule, the clearest days do not have a uniform rate of progress glideslope; the Rule only requires that the clearest days do not get any worse than the baseline period. Also shown are measured values during the period 2000 to 2010. Data for MOJA were taken from a nearby site (JOSH1). DEVA has no data for the years 2000 or 2003; JOTR and MOJA have no data for the year 2000. Data Source:

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

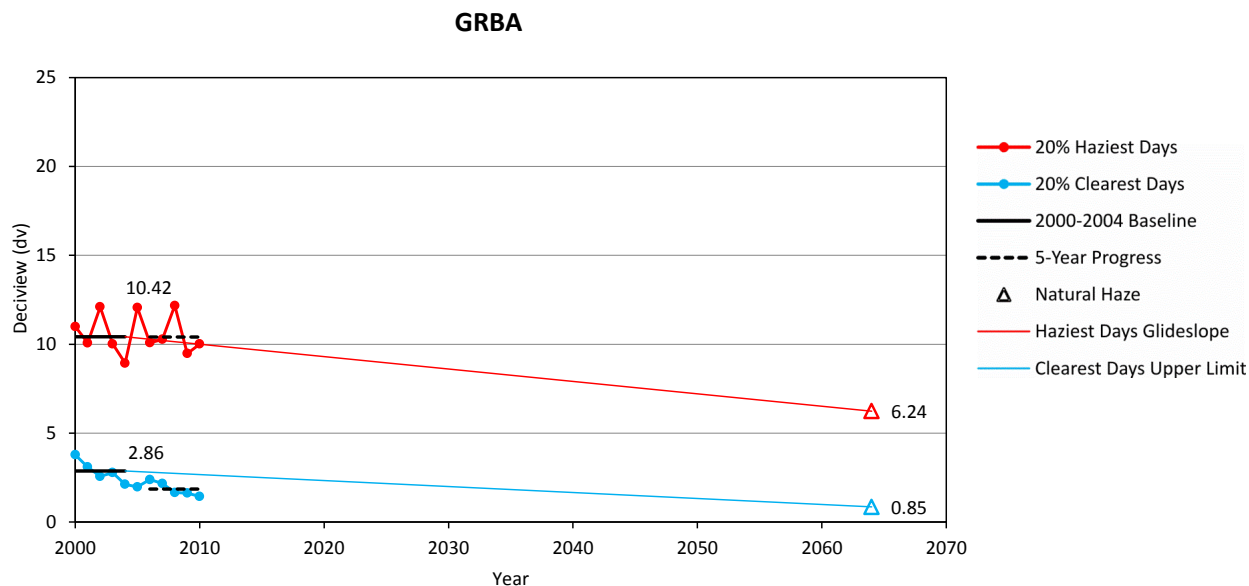


Figure 4b. Glideslopes to achieving natural visibility conditions by 2064 for the 20% hazeiest (red line) and the 20% clearest (blue line) days in GRBA. In the Regional Haze Rule, the clearest days do not have a uniform rate of progress glideslope; the Rule only requires that the clearest days do not get any worse than the baseline period. Also shown are measured values during the period 2000 to 2010. Data for MOJA were taken from a nearby site (JOSH1). DEVA has no data for the years 2000 or 2003; JOTR and MOJA have no data for the year 2000. Data Source:

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

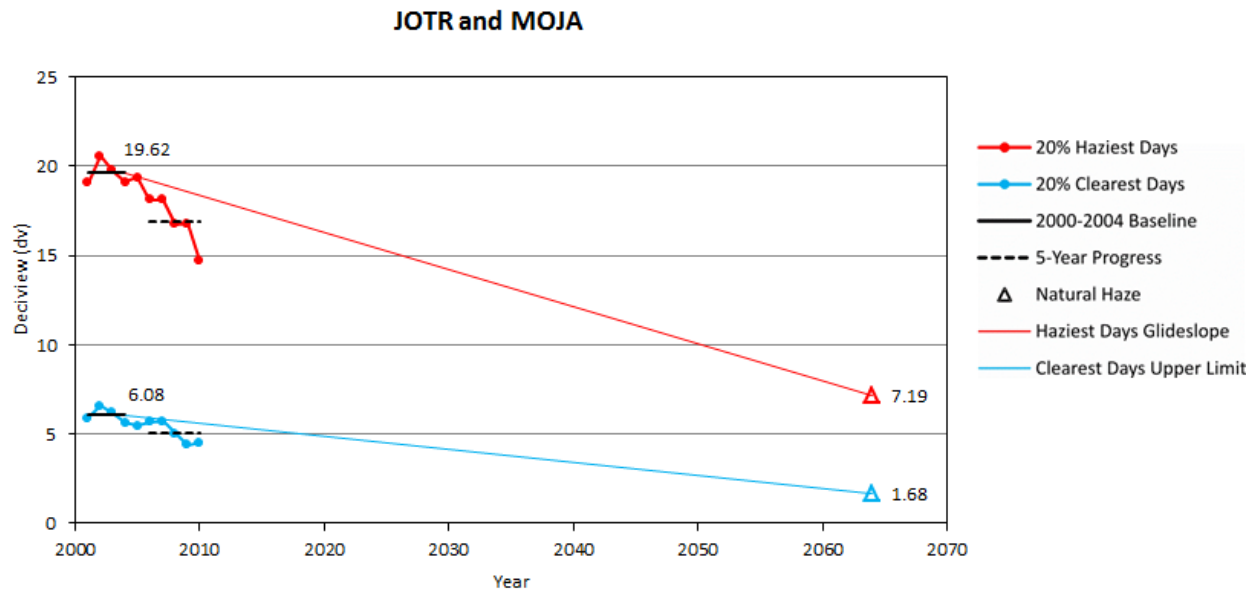


Figure 4c. Glideslopes to achieving natural visibility conditions by 2064 for the 20% haziest (red line) and the 20% clearest (blue line) days in JOTR and MOJA. In the Regional Haze Rule, the clearest days do not have a uniform rate of progress glideslope; the Rule only requires that the clearest days do not get any worse than the baseline period. Also shown are measured values during the period 2000 to 2010. Data for MOJA were taken from a nearby site (JOSH1). DEVA has no data for the years 2000 or 2003; JOTR and MOJA have no data for the year 2000. Data Source:

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

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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 963/132071, March 2016

National Park Service
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