



Air Quality Related Values (AQRVs) for Gulf Coast Network (GULN) Parks

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

Natural Resource Report NPS/GULN/NRR—2016/1158



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 Gulf Coast Network (GULN). AQRVs are those resources sensitive to air quality and include streams, lakes, soils, vegetation, fish and wildlife, and visibility. The GULN parks that are included in the NPS Inventory and Monitoring (I&M) Program, and discussed in this report, are Big Thicket National Preserve (BITH), Gulf Islands National Seashore (GUIS), Jean Lafitte National Historical Park and Preserve (JELA), Natchez Trace Parkway (NATR), Padre Island National Seashore (PAIS), Palo Alto Battlefield National Historical Park (PAAL), San Antonio Missions National Historical Park (SAAN) and Vicksburg National Military Park (VICK).

Sullivan et al. (2011a, 2011b) and Kohut (2007) conducted risk assessments for acidification, eutrophication, and ozone (O_3) for the GULN parks; their results are described in this report. This report also describes air pollutant emissions and air quality, and their effects on AQRVs. The primary pollutants likely to affect AQRVs include nitrogen (N) and sulfur (S) compounds (nitrate [NO_3^-], ammonium [NH_4^+], and sulfate [SO_4^{2-}]); ground-level O_3 ; haze-causing particles; and airborne toxics. Background for this section can be found in “Air Quality Related Values (AQRVs) in National Parks. Effects from Ozone; Visibility Reducing Particles; and Atmospheric Deposition of Acids, Nutrients and Toxics” (Sullivan 2016).

Several of the park lands in the GULN are located on or near the coast of the Gulf of Mexico. Others are located inland. Many large population centers occur in the GULN region, including San Antonio, Houston, Memphis, and Nashville. Many large air pollution sources occur near the network area. Vehicles and other smaller sources also contribute to air pollution loading in the region.

Based on analyses by Sullivan et al. (2011b) of data collected in 2002, there are many S point sources of substantial magnitude within the GULN region, mainly coal-fired power plants and other large industrial facilities, with emissions greater than 20,000 tons per year. There are also numerous point and mobile sources of oxidized N (NO_x) throughout the GULN, including power plants, various industrial sources, and vehicles. Coal-fired power plants also constitute important sources of mercury (Hg) emissions in this network area. Agricultural, and to a lesser extent urban and industrial, development contribute emissions of reduced N (i.e., ammonia) and various pesticides and other semi-volatile organic compounds (SOCs).

Sulfur deposition throughout most of the network was fairly high in 2002, in the range of 5 to 15 kg S/ha/yr. Small areas of deposition exceeding 30 kg S/ha/yr occurred around large urban centers, such as San Antonio and Houston. Total N deposition within the network ranged from as low as 2 to 5 kg N/ha/yr near the border with Mexico to more than 15 kg N/ha/yr at some locations (Sullivan et al. 2011b). Sulfur and oxidized N deposition loads have decreased substantially at most GULN parks during the period 2001 to 2011; deposition of reduced N has increased at most of the parks.

Atmospheric N deposition may be an important nutrient stressor, especially in the coastal parks. Coastal wetlands, in particular, may be sensitive to atmospheric nutrient addition, which can favor invasive, fast-growing plant species at the expense of native species (U.S. Environmental Protection

Agency [EPA] 2008). Rare wetland species can be lost as a result. Grassland and arid ecosystems are common in some of the parks in this network. They have also been found to be sensitive to N deposition, which can alter plant species composition and reduce natural diversity.

Atmospheric deposition of Hg and Hg methylation potential are both relatively high in the GULN. As a consequence, concentrations of Hg in fish, and likely other aquatic biota and piscivorous wildlife, have been shown to be high at some locations in this region (Katner et al. 2010). This poses potential health risks to humans who consume fish and to piscivorous wildlife. Other airborne toxics, including persistent organic pollutants, have been detected in GULN ecosystems.

Although acid pollutant exposure is high at many of the park units within the GULN, there are no data that indicate high acid sensitivity for either aquatic or terrestrial park resources in this network. Thus, acidification does not appear to be an important concern.

Exposure of sensitive vegetation to O₃ also does not appear to be a particularly important resource concern in this network. Exposure is high at one park in the network (GUIS), based on W126 and SUM06 exposure indices, but the risk to vegetation is likely to be low at most GUIS park locations due to leaf stomatal closure caused by low soil moisture. The exception may be in riparian zones and other areas of local higher moisture availability, where O₃ uptake into leaf tissue may be more pronounced. The risk of O₃ injury to vegetation was estimated to be highest at BITH, where O₃ uptake into plant foliage may be expected to induce foliar symptoms where and when soil moisture conditions promote foliar uptake.

Visibility is not monitored directly at any park units in the GULN. Nevertheless, visibility is known to be an important resource concern at Sipsey Wilderness, which is considered representative of NATR. Sulfates are the primary components of haze at this monitoring site; organics also contribute substantially. Despite high current haze conditions, recent haze reductions suggest successful movement towards the national goal of zero human-caused haze in the year 2064 at this site.

Available data indicate substantial Hg bioaccumulation in fish and other aquatic species within the GULN. Analyses by the U.S. Geological Survey (USGS; Last modified February 20, 2015) suggested relatively high Hg methylation potential, due in part to elevated concentration of organic carbon (C) in aquatic ecosystems in this network.

Background

There are three parks in GULN that are larger than 100 square miles: Big Thicket National Preserve (BITH), Gulf Islands National Seashore (GUIS), and Padre Island National Seashore (PAIS). In addition, there are five smaller parks: Jean Lafitte National Historical Park and Preserve (JELA), Natchez Trace Parkway (NATR), Palo Alto Battlefield National Historical Park (PAAL), San Antonio Missions National Historical Park (SAAN) and Vicksburg National Military Park (VICK). 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.

Many large population centers occur within a 300-mile radius around the network, including San Antonio, Houston, Austin, Dallas, Fort Worth, Memphis, Nashville, Oklahoma City, Indianapolis, New Orleans, and Jacksonville. Baton Rouge, which is somewhat smaller, is located in proximity to some GULN parks. Map 1 shows the network boundary along with locations of each park and population centers with more than 10,000 people.

Atmospheric Emissions and Deposition

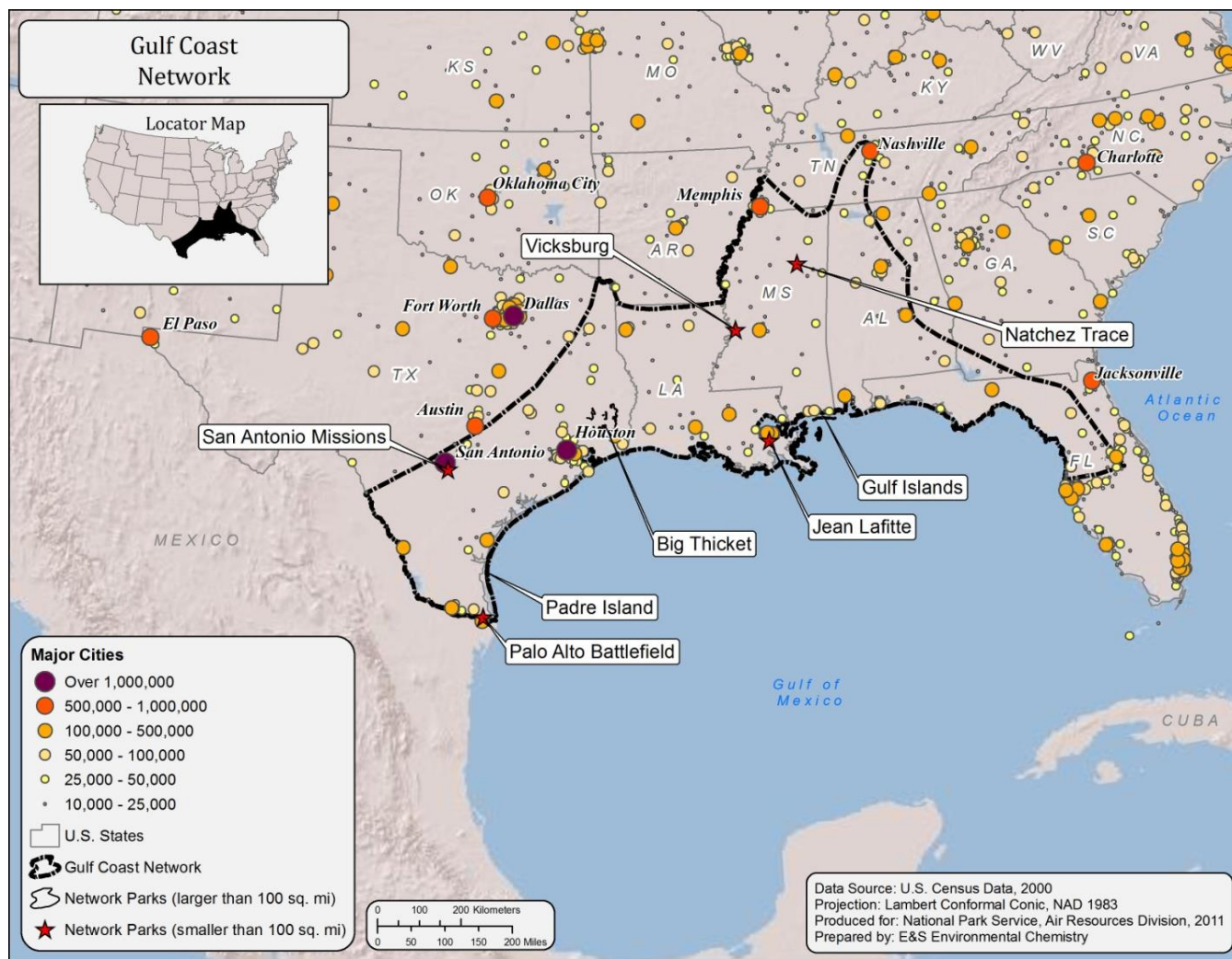
Sullivan et al. (2011a) reviewed air pollutant emissions in the GULN. In general, county sulfur (S) emissions in the GULN ranged from less than 1 to between 5 and 20 tons of sulfur dioxide (SO₂) per square mile per year (mi²/yr; Sullivan et al. 2011b). However, several counties throughout the network produced SO₂ emissions greater than 20 tons/mi²/yr, and two counties were in the range of 50 to 100 tons/mi²/yr. There were many individual SO₂ point sources of substantial magnitude within the network, mostly electricity generating units (EGUs; Sullivan et al. 2011b). Several were larger than 20,000 tons/yr, and two were larger than 40,000 tons/yr. Many other large SO₂ point sources existed outside the network boundary to the north and northeast.

In general, annual county nitrogen (N) emissions within the GULN were in the range of 1 to 20 tons/mi² in 2002. Two counties had emissions of 50 to 100 tons/mi²/yr, and several were in the range of 20 to 50 tons/mi²/yr. There were numerous N point sources throughout the GULN. Most of the larger sources (greater than 1,000 tons per year) emitted oxidized N, but there were also some relatively large point sources of reduced N. The oxidized N point sources were mainly EGUs; the reduced N point sources were mostly fertilizer or livestock production operations.

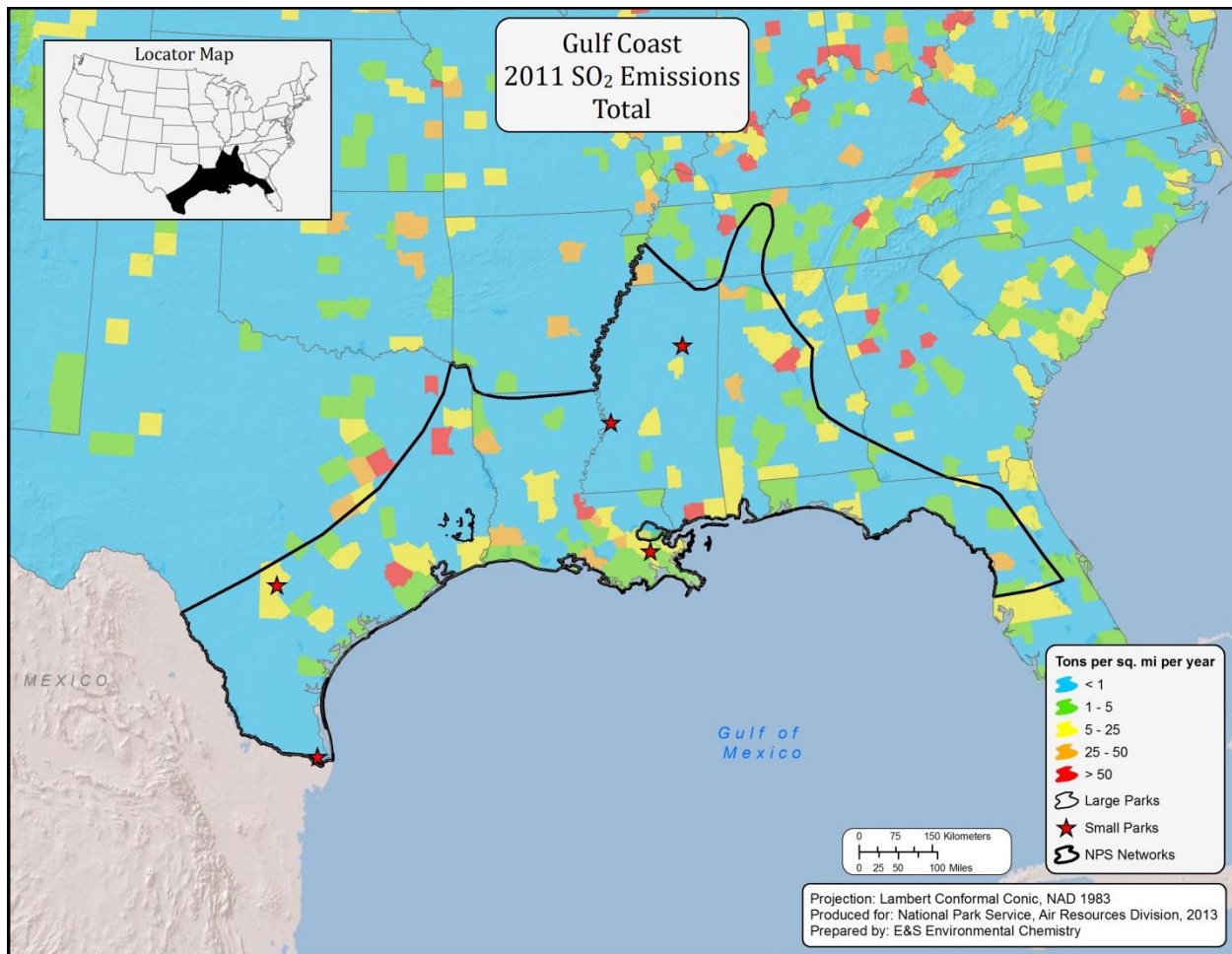
County-level emissions near GULN, based on data from the EPA's National Emissions Inventory (NEI) during a recent time period (2011), are depicted in Maps 2 through 4 for SO₂, oxidized N (NO_x), and reduced N (NH₃), respectively. Many counties to the north of GULN parks had relatively high SO₂ emissions (> 50 tons/mi²/yr; Map 2). Spatial patterns in NO_x emissions were generally similar, with highest values to the north of GULN parks (Map 3). Emissions of NH₃ near GULN parks were somewhat lower, with most counties showing emissions levels below 8 tons/mi²/yr (Map 4).

Mercury (Hg) emissions from power plants are substantial in and to the north of the network boundary. Power plant Hg emissions are disproportionately associated with coal burning EGUs. There are also some natural gas and oil burning power plant emissions of Hg (CEC 2011). In addition, Hg deposited from anthropogenic sources can be re-emitted by fires. This contribution is substantial in the GULN and throughout portions of the southwestern United States (Wiedinmyer and Friedli 2007).

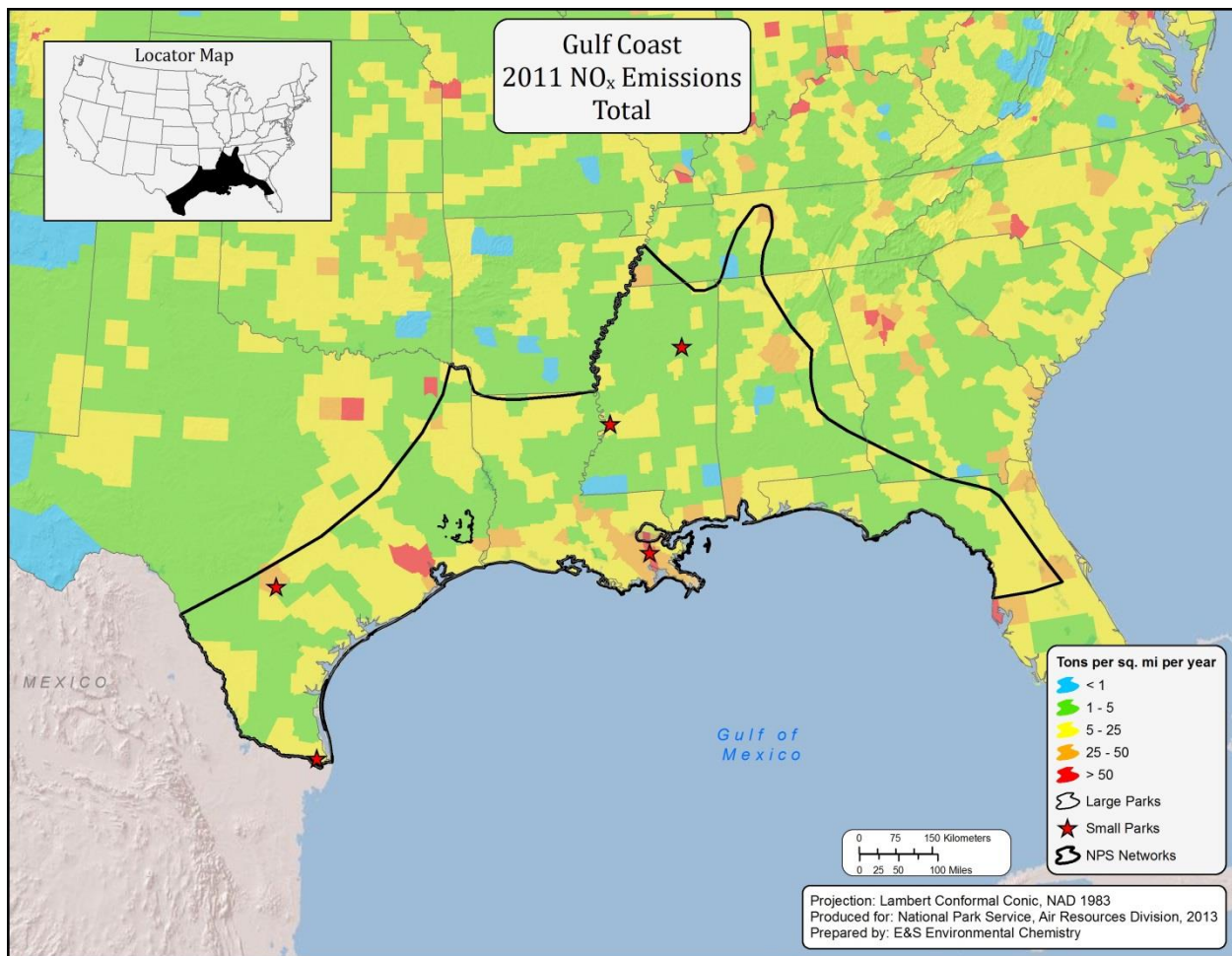
Based on Community Multiscale Air Quality (CMAQ) model estimates for 2002, atmospheric S deposition in the GULN generally ranges from about 2 to 5 kg/ha/yr at the far eastern and western ends of the network, and between about 5 and 10 kg/ha/yr at many locations elsewhere (Sullivan et al. 2011b). There are also several hot spots of higher S deposition, in some places above 15 kg S/ha/yr, mainly in southeastern Louisiana and southeastern Texas. Total atmospheric N deposition is also highest (in some places higher than 15 kg N/ha/yr) in the vicinity of San Antonio and southeastern Louisiana. Throughout most of the network, however, estimated total N deposition is in the range of about 5 to 10 kg N/ha/yr. Wet Hg deposition is also relatively high in the Gulf region (~ 10-14 $\mu\text{g}/\text{m}^2$).



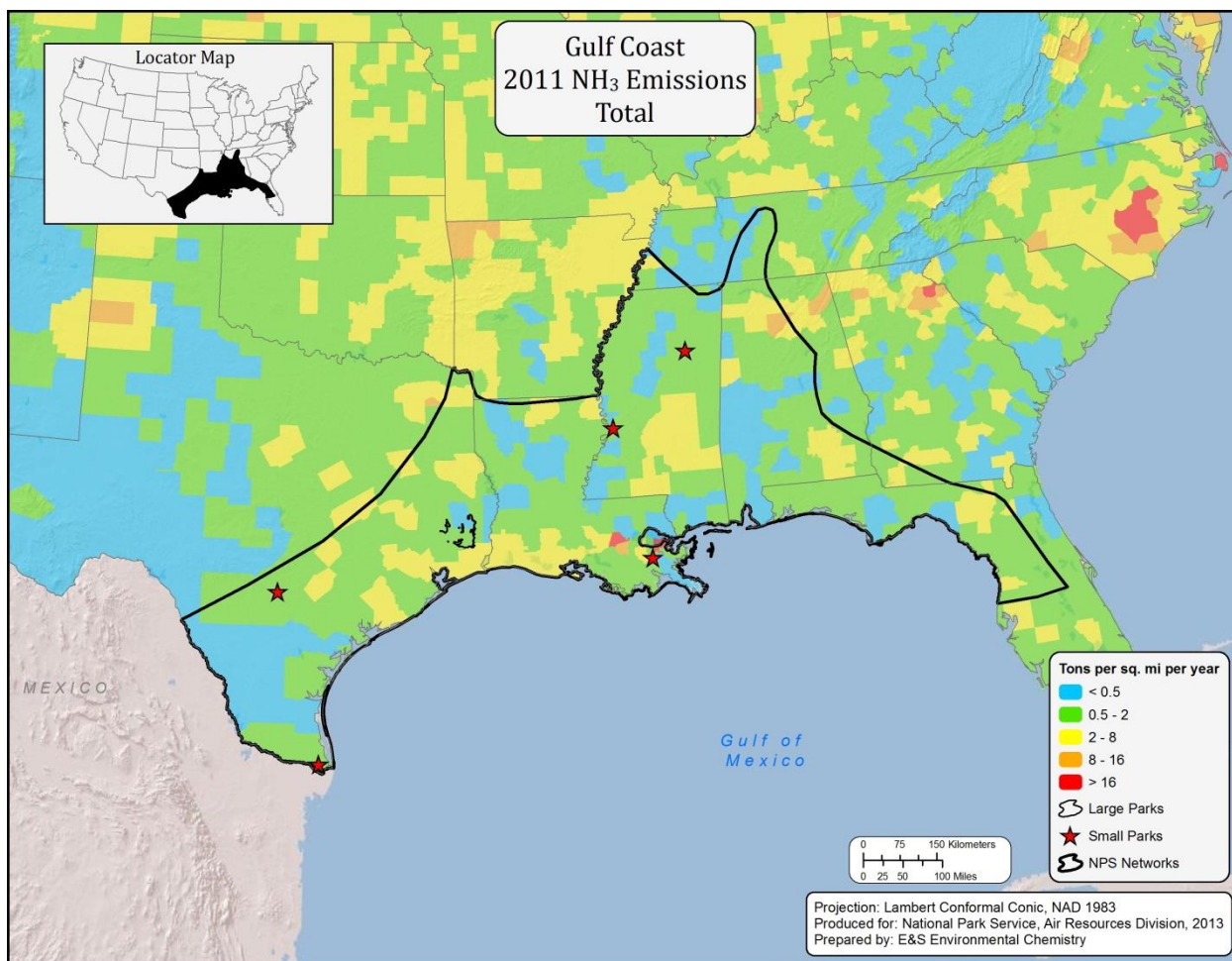
Map 1. Network boundary and locations of parks and population centers greater than 10,000 people. Note that a new unit (Beaumont) has recently been added to BITH, to the south of the previous park units. Also, note that the boundaries for NATR extend for 470 miles (756 km).



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



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



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

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 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. TDEP data reported here were developed in late 2013 and are designated version 2013.02.

Atmospheric S, and to a lesser extent N, deposition levels have declined in most parks in GULN since 2001, based on TDEP estimates (Table 1). Decreases in total S deposition over the previous decade for the parks in this network have been as large as -34.6% in VICK. The exceptions (those showing increased S deposition) are PAIS (+20.5%), PAAL (+1.4%), and JELA (+0.7%). Estimated total N deposition decreased over that same time period at all network parks, in many cases by more

than 30%. In most parks, oxidized N deposition decreased and reduced N increased over that time period.

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

Acidification

Two of the three I&M parks in the GULN that are larger than 100 square miles (BITH and GUIS) ranked High among I&M parks in acid Pollutant Exposure; PAIS was ranked Moderate (Table 2; Sullivan et al. 2011b). For the smaller parks, two were ranked High and three were ranked Moderate. NATR was ranked High for Ecosystem Sensitivity to acidification, based on topography and other broad screening criteria, but there are no site-specific data to confirm acid sensitivity at this park. In the absence of further data, it should be assumed that none of the parks in the GULN are especially sensitive to acidification. Portions of the region circumscribed by the GULN are known to be highly acid-sensitive, but they lie far to the southeast of NATR, in areas that do not contain any national park units. Other parks in this network were ranked Low (BITH, SAAN, and VICK) or Very Low (GUIS, JELA, PAIS, and PAAL) for this theme (Table 2; Sullivan et al. 2011b).

Nutrient Nitrogen Enrichment

The network rankings developed by Sullivan et al. (2011a) in a coarse screening analysis of nutrient N Pollutant Exposure, Ecosystem Sensitivity to nutrient N enrichment, and Park Protection yielded an overall network nutrient N enrichment Summary Risk ranking for the GULN that was near the bottom among all networks. However, some individual parks were estimated to be at higher risk (Table 3).

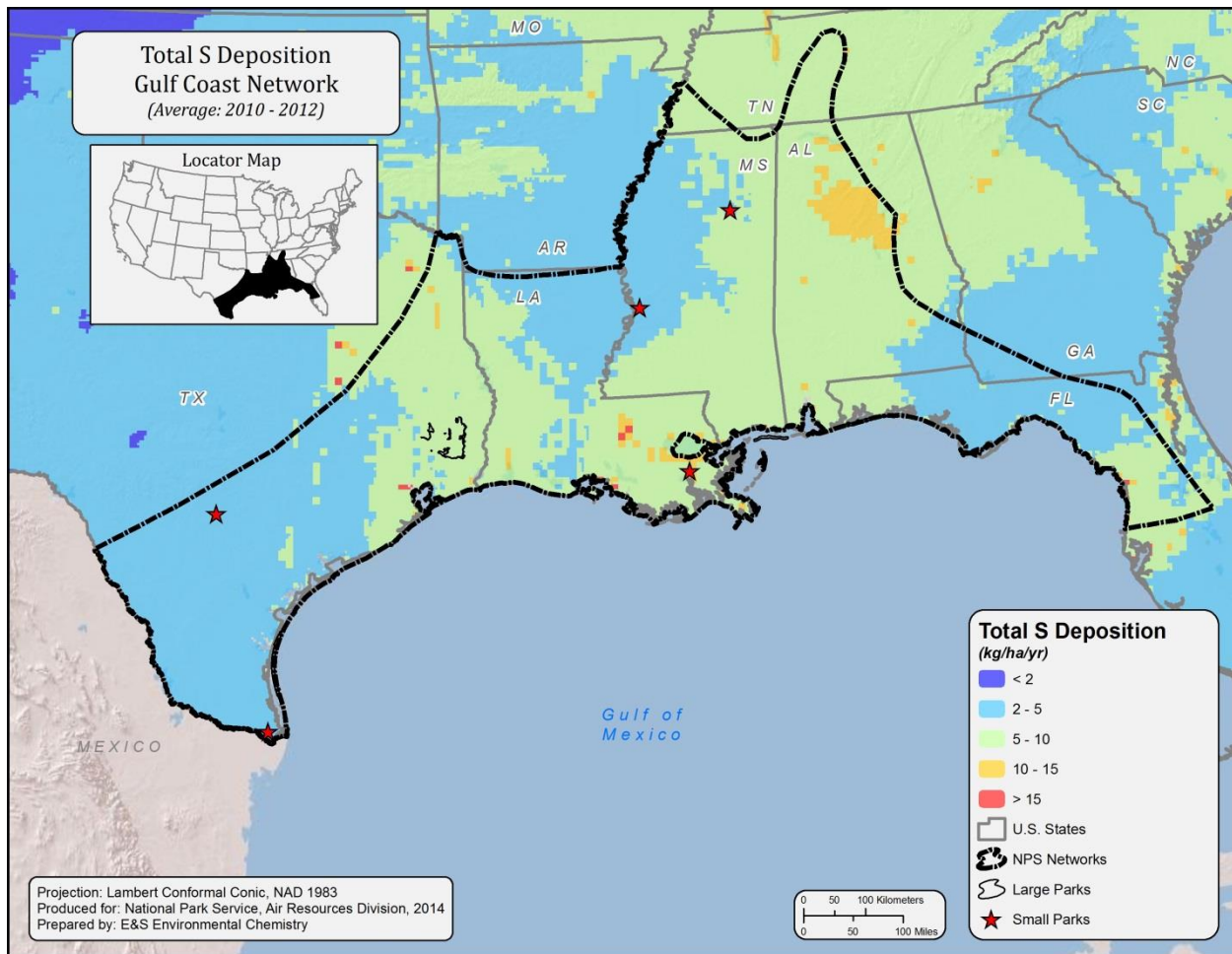
Two of the three I&M parks in the GULN that are larger than 100 square miles (BITH and GUIS) ranked High among parks in nutrient N Pollutant Exposure; PAIS was ranked Moderate. Two of the smaller parks (JELA and SAAN) were ranked High in Ecosystem Sensitivity to nutrient N enrichment (Table 3; Sullivan et al. 2011a). Nitrogen deposition can cause changes in plant community composition and diversity, and has been linked to increases in invasive species in grasslands and arid lands. In wetlands, rare species may be lost as N-loving species increase. Other parks in this network were ranked Moderate (BITH, PAIS, and PAAL), Low, or Very Low for this theme (Table 3). 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. Pardo et al. (2011) compiled data on empirical CL for protecting sensitive resources in EPA Level I ecoregions across the conterminous United States against nutrient enrichment effects caused by atmospheric N deposition. Available data on empirical CL of nutrient N suggested that the lower end of the estimated range of empirical CL is near 4-5 kg N/ha/yr for many sensitive receptors at many of the parks in GULN (Table 4). Ambient N deposition reported by Pardo et al. (2011) was higher than these lower CL estimates at all of the parks in GULN, suggesting the possibility of widespread exceedance of the empirical CL.

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

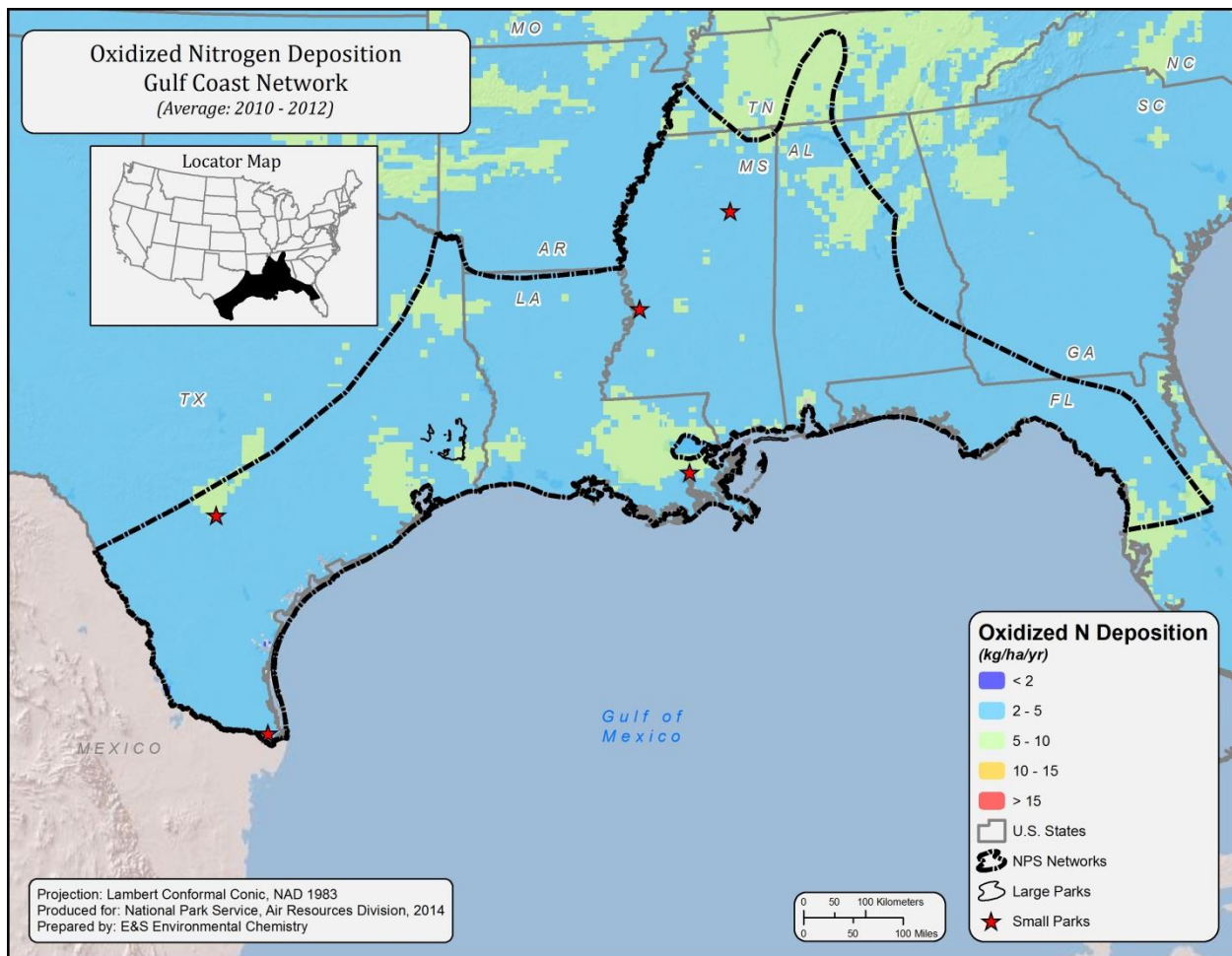
Park Code	Park Name	Parameter	2001 Average (kg/ha/yr)	2011 Average (kg/ha/yr)	Absolute Change (kg/ha/yr)	Percent Change	2011 Minimum (kg/ha/yr)	2011 Maximum (kg/ha/yr)	2011 Range (kg/ha/yr)
BITH	Big Thicket	Total S	7.84	5.98	-1.87	-23.6%	5.06	7.26	2.20
		Total N	11.24	7.79	-3.45	-30.4%	7.05	8.97	1.91
		Oxidized N	7.80	4.82	-2.98	-38.1%	4.13	5.87	1.74
		Reduced N	3.44	2.97	-0.47	-10.7%	2.81	3.34	0.53
GUIS	Gulf Islands	Total S	9.60	9.32	-0.29	-9.1%	5.05	15.66	10.62
		Total N	8.60	6.13	-2.47	-31.1%	4.10	9.15	5.05
		Oxidized N	6.67	3.75	-2.92	-45.8%	2.49	5.61	3.12
		Reduced N	1.94	2.39	0.45	20.1%	1.61	3.54	1.93
JELA	Jean Lafitte	Total S	10.62	10.70	0.08	0.7%	5.17	11.63	6.46
		Total N	12.63	7.29	-5.34	-42.0%	7.02	10.57	3.55
		Oxidized N	10.05	4.68	-5.36	-53.0%	4.37	7.74	3.37
		Reduced N	2.58	2.61	0.03	1.1%	2.12	3.06	0.94
NATR	Natchez Trace Pky and National Scenic Tr	Total S	8.50	5.92	-2.58	-30.4%	4.17	8.46	4.29
		Total N	10.42	8.89	-1.53	-14.7%	6.88	13.01	6.13
		Oxidized N	7.00	4.84	-2.16	-30.8%	3.81	7.22	3.41
		Reduced N	3.41	4.05	0.64	18.0%	2.59	8.60	6.02
PAAL	Palo Alto Battlefield	Total S	3.55	3.60	0.05	1.4%	3.58	4.27	0.69
		Total N	6.33	5.43	-0.91	-14.3%	5.40	5.78	0.38
		Oxidized N	4.58	3.40	-1.19	-25.9%	3.39	3.69	0.30
		Reduced N	1.75	2.03	0.28	16.0%	2.01	2.09	0.08

Table 1 (continued). Average changes in S and N deposition between 2001 and 2011 across park grid cells at GULN 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.

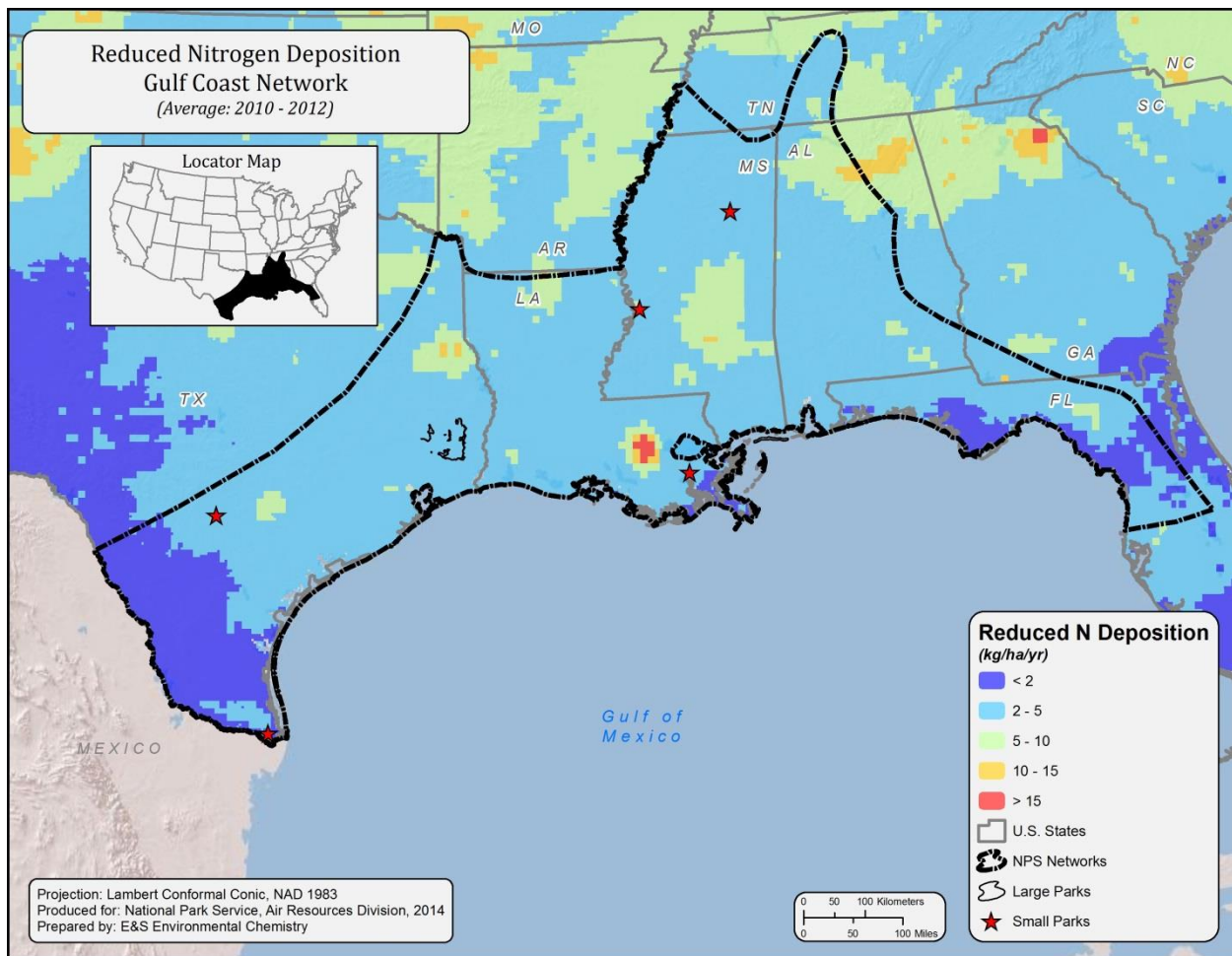
Park Code	Park Name	Parameter	2001 Average (kg/ha/yr)	2011 Average (kg/ha/yr)	Absolute Change (kg/ha/yr)	Percent Change	2011 Minimum (kg/ha/yr)	2011 Maximum (kg/ha/yr)	2011 Range (kg/ha/yr)
PAIS	Padre Island	Total S	3.97	4.74	0.77	20.6%	3.58	5.64	2.06
		Total N	5.25	4.99	-0.26	-3.1%	3.79	6.17	2.37
		Oxidized N	3.63	3.25	-0.38	-7.0%	2.16	4.02	1.86
		Reduced N	1.62	1.75	0.12	7.3%	1.43	2.14	0.71
SAAN	San Antonio Missions	Total S	4.71	3.71	-0.99	-21.2%	3.05	3.88	0.83
		Total N	9.10	8.99	-0.11	-1.4%	6.54	10.32	3.78
		Oxidized N	5.75	5.79	0.04	0.5%	3.61	6.86	3.25
		Reduced N	3.35	3.20	-0.15	-4.1%	2.92	3.46	0.53
VICK	Vicksburg	Total S	6.72	4.40	-2.33	-34.6%	4.15	4.46	0.31
		Total N	9.62	8.78	-0.81	-8.1%	7.86	12.81	4.95
		Oxidized N	6.40	4.69	-1.70	-26.6%	4.67	4.94	0.27
		Reduced N	3.23	4.08	0.89	27.9%	3.19	8.11	4.93



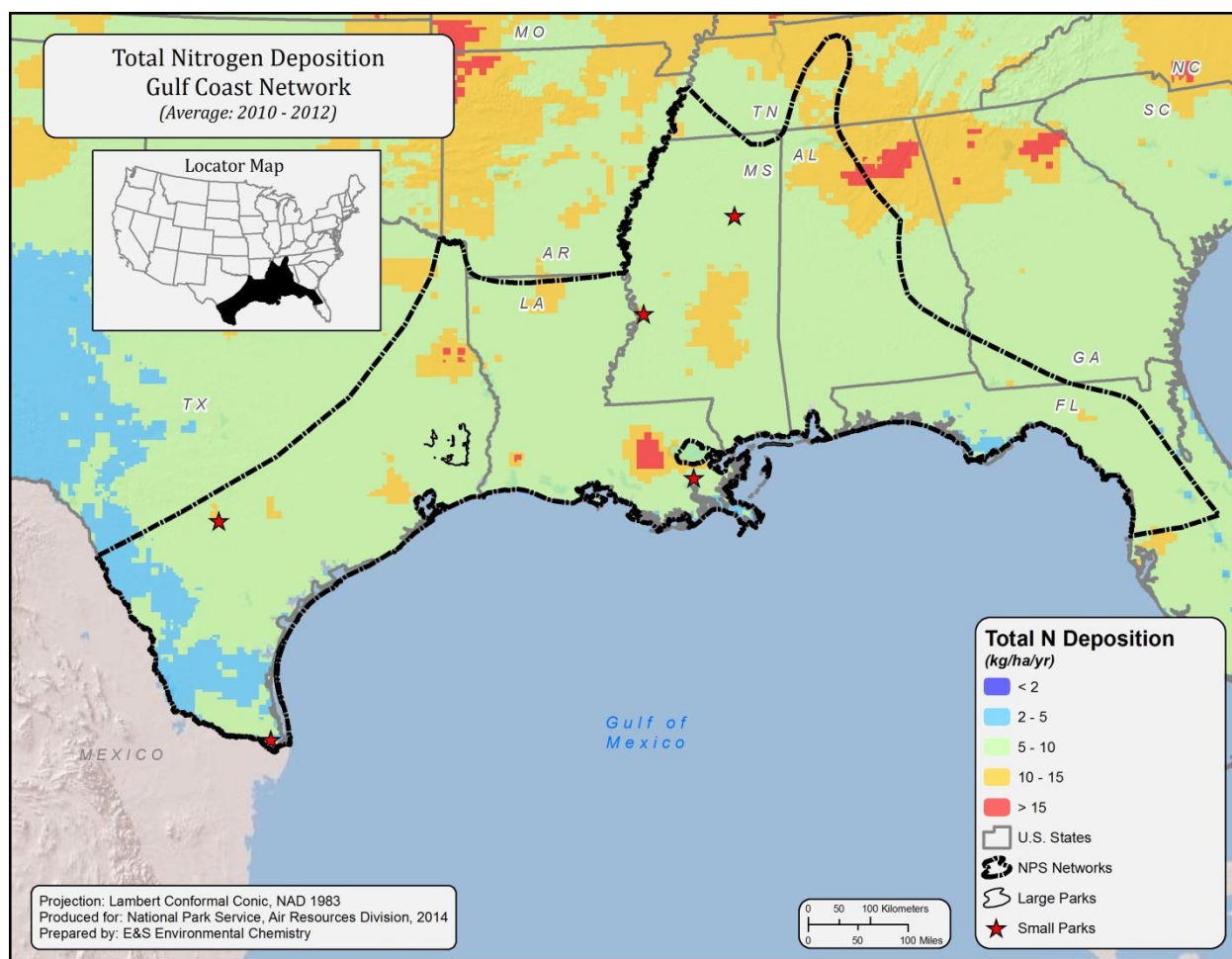
Map 5. Total S deposition for the three-year period centered on 2011 in and around the GULN. (Source: Schwede and Lear 2014)



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



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



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

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

Park Name ²	Park Code	Estimated Acid Pollutant Exposure	Estimated Ecosystem Sensitivity to Acidification
Big Thicket	BITH	High	Low
Gulf Islands	GUIS	High	Very Low
Jean Lafitte	JELA	High	Very Low
Natchez Trace Parkway	NATR	High	High
Padre Island	PAIS	Moderate	Very Low
Palo Alto Battlefield	PAAL	Moderate	Very Low
San Antonio Missions	SAAN	Moderate	Low
Vicksburg	VICK	Moderate	Low

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

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

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>Big Thicket</i>	BITH	High	Moderate
<i>Gulf Islands</i>	GUIS	High	Low
Jean Lafitte	JELA	High	High
Natchez Trace Parkway	NATR	High	Low
<i>Padre Island</i>	PAIS	Moderate	Moderate
Palo Alto Battlefield	PAAL	Moderate	Moderate
San Antonio Missions	SAAN	Moderate	High
Vicksburg	VICK	Moderate	Very Low

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

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

To date, many of the N effects studies in the U.S. have either relied on N gradients, which cannot identify the lowest deposition level at which there is no effect on biotic diversity, or on N addition experiments, which are usually conducted over a relatively short time period (less than 10 years) and also have limited ability to identify impacts at low levels of N. In an analysis of European study results, Payne et al. (2013) found that, because of limitations with gradient or addition studies, they could not identify the lowest level of N deposition at which individual species declined. They concluded that, for certain grassland types, the only way to have no harm over time is to have no pollution (Payne et al. 2013). Although plant community types expected to be N-sensitive (i.e., grasslands) are common in the GULN, data are not available to confirm the sensitivity of park resources in this network to potential nutrient enrichment caused by atmospheric N deposition. Additional field studies could be helpful.

Table 4. Empirical critical loads for nitrogen in GULN, 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	N Deposition (kg N/ha/yr)	Critical Load (kg N/ha/yr)				
			Mycorrhizal Fungi	Lichen	Herbaceous Plant	Forest	Nitrate Leaching
Big Thicket NPRES	Eastern Temperate Forests	13.5	5 - 12	4 - 8	17.5	3 - 8	8
Gulf Islands NS	Eastern Temperate Forests	11.2	5 - 12	4 - 8	17.5	3 - 8	8
Jean Lafitte NPRES	Eastern Temperate Forests	18.7	5 - 12	4 - 8	17.5	3 - 8	8
Jean Lafitte NPRES	Great Plains	18.7	12	NA	5 - 25	NA	10 - 25
Natchez Trace Parkway	Eastern Temperate Forests	12.7	5 - 12	4 - 8	17.5	3 - 8	8
Palo Alto Battlefield NHS	Great Plains	5.0	12	NA	5 - 25	NA	10 - 25
Padre Island NS	Great Plains	5.0	12	NA	5 - 25	NA	10 - 25
San Antonio Missions NHP	Eastern Temperate Forests	11.6	5 - 12	4 - 8	17.5	3 - 8	8
San Antonio Missions NHP	Great Plains	11.6	12	NA	5 - 25	NA	10 - 25
Vicksburg NC	Eastern Temperate Forests	10.0	5 - 12	4 - 8	17.5	3 - 8	8

Ozone Injury to Vegetation

The O₃-sensitive plant species that are known or expected to occur within the I&M parks found in the GULN are listed in Table 5. Those considered to be bioindicators, that display visible and easily recognizable O₃ injury symptoms. They are designated in the table by an asterisk. One park within the network (PAAL) did not contain any O₃-sensitive and/or bioindicator species. Each of the other parks in this network contains a number of O₃ sensitive and bioindicator species (NPSpecies 2013; <https://irma.nps.gov/App/Portal/Home>). Ozone can cause visible plant injury as well as reduced photosynthesis and growth. Effects are usually induced by cumulative exposures over time; these are commonly expressed as the W126 (a measure of cumulative O₃ exposure that preferentially weights higher concentrations) or the SUM06 (a measure of cumulative exposure that includes only hourly concentrations over 60 ppb O₃), which are calculated by summing up hourly O₃ concentrations over a period of time, usually 3 months, during the growing season.

The W126 and SUM06 exposure indices calculated by NPS staff are given in Table 6 for GULN parks, along with Kohut's (2007) O₃ risk ranking. The two ranking systems differ. The NPS ranking system (NPS 2010) simply ranks O₃ exposure levels according to injury thresholds from the literature (Heck and Cowling 1997). Kohut's rankings consider O₃ exposure, but also consider environmental conditions, especially soil moisture. 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 the peak O₃ season during summer, O₃ uptake and injury is limited by stomatal closure even when exposures are relatively high. So, for example, although O₃ exposures are relatively high at GUI, Kohut concluded that the risk to vegetation is Low in that park because of generally dry soil conditions during the summer. Portions of the park having locally moist soils might exhibit higher risk.

Kohut (2007) concluded that, in general, the low levels of O₃ exposure, and at some parks the frequent low soil moisture, limited the risk of foliage damage to Low (GUI, PAIS, PAAL, VICK) or Moderate (JELA, SAAN) at most network parks. Only at BITH was the risk of foliar injury classified as High. Ozone concentrations interpolated to BITH frequently exceeded 80 ppb, and exceeded 100 ppb for a significant number of hours during each of the five years analyzed. Such levels of O₃ exposure might be expected to cause foliar symptoms. In some years, however, dry soil conditions would constrain O₃ uptake into foliage and reduce the likelihood of foliar injury.

Atmospheric O₃ concentrations at 568 monitoring sites nationwide showed generally stable levels throughout the 1990s, but declined after 2000, due largely to NO_x emissions reductions (U.S. EPA 2008). Even though there have been widespread improvements in atmospheric O₃ levels, there are still over forty cities and counties classified as nonattainment areas because of failure to meet the O₃ National Ambient Air Quality Standard (U.S. EPA 2013). BITH is in an O₃ nonattainment area (<http://www.epa.gov/airquality/greenbook/hnc.html>).

Table 5. Ozone-sensitive and bioindicator plant species known or thought to occur in the I&M parks of the GULN. (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							
		<i>BITH</i>	<i>GUIS</i>	<i>JELA</i>	<i>NATR</i>	<i>PAAL</i>	<i>PAIS</i>	<i>SAAN</i>	<i>VICK</i>
No Species Present						x			
<i>Aesculus flava</i>	Yellow buckeye				x				
<i>Ageratina altissima</i> var. <i>altissima</i> *	White snakeroot			x					
<i>Ailanthus altissima</i> * (exotic)	Tree-of-heaven				x			x	x
<i>Apios americana</i> *	Groundnut	x			x				
<i>Apocynum cannabinum</i>	Dogbane, Indian hemp			x	x			x	
<i>Artemisia ludoviciana</i> *	Silver wormwood	x						x	
<i>Asclepias incarnata</i>	Swamp milkweed				x				
<i>Asclepias syriaca</i> *	Common milkweed				x				
<i>Cercis canadensis</i> *	Redbud	x			x				x
<i>Clematis virginiana</i>	Virgin's bower				x				x
<i>Corylus americana</i> *	American hazelnut				x				
<i>Eupatorium rugosum</i> *	White snakeroot				x				x
<i>Fraxinus americana</i> *	White ash	x			x				x
<i>Fraxinus pennsylvanica</i>	Green ash	x		x	x				
<i>Liquidambar styraciflua</i>	Sweetgum	x	x	x	x				x
<i>Liriodendron tulipifera</i> *	Yellow-poplar		x		x				x
<i>Lyonia ligustrina</i> var. <i>foliosiflora</i> *	Maleberry	x							
<i>Parthenocissus quinquefolia</i>	Virginia creeper	x	x	x	x			x	x
<i>Pinus taeda</i>	Loblolly pine	x	x	x	x				x
<i>Pinus virginiana</i>	Virginia pine				x				
<i>Platanus occidentalis</i> *	American sycamore	x	x	x	x			x	x
<i>Prunus serotina</i> *	Black cherry	x	x	x	x				x
<i>Rhus copallinum</i>	Winged sumac		x		x				
<i>Robinia pseudoacacia</i>	Black locust	x			x				
<i>Rubus allegheniensis</i> *	Allegheny blackberry				x				
<i>Rubus cuneifolius</i>	Sand blackberry				x				
<i>Rudbeckia laciniata</i> *	Cutleaf coneflower				x				
<i>Sambucus nigra</i> spp. <i>canadensis</i> *	American elder	x	x	x	x			x	x
<i>Sassafras albidum</i>	Sassafras	x	x		x				x
<i>Solidago altissima</i>	Goldenrod	x	x	x	x				
<i>Spartina alterniflora</i>	Smooth cordgrass		x				x		
<i>Triadica sebifera</i> * (exotic)	Chinese tallowtree	x	x	x				x	x
<i>Verbesina occidentalis</i> *	Crownbeard		x						
<i>Vitis labrusca</i> *	Northern fox grape				x				

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

* Bioindicator species

Table 6. NPS ozone conditions and risk to vegetation for I&M parks in the GULN. NPS condition 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 2007a)¹.

Park Name ²	Park Code	W126		SUM06		Kohut Risk to Vegetation
		Value (ppm-hr)	NPS Condition	Value (ppm-hr)	NPS Condition	
<i>Big Thicket</i>	BITH	8.40	Moderate	10.90	Moderate	High
<i>Gulf Islands</i>	GUIS	12.81	Moderate	17.07	High	Low
Jean Lafitte	JELA	10.25	Moderate	13.33	Moderate	Moderate
Natchez Trace Parkway and National Scenic Trail ³	NATR	10.89	Moderate	14.52	Moderate	No Rank
<i>Padre Island</i>	PAIS	5.03	Low	6.38	Low	Low
Palo Alto Battlefield	PAAL	4.24	Low	5.05	Low	Low
San Antonio Missions	SAAN	9.61	Moderate	12.34	Moderate	Moderate
Vicksburg	VICK	9.75	Moderate	13.06	Moderate	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

³ NATR exhibits a wide range of O₃ exposure because of its length.

Visibility Degradation

Natural Background and Ambient Visibility Conditions

Visibility refers to not only how far one can see, but also how well one can see landscape features, colors, and contrast. 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 visibility¹ in mandatory Class I federal areas which impairment results from manmade air pollution” (42 U.S.C. 7491). EPA set up the Regional Haze Program to meet this goal and, although the GULN does not include any Class I areas, emissions reductions required by the Program are likely to benefit all the parks. In addition, NPS Management Policies (2006) require protection of visibility in all parks from air pollution. Visibility is monitored by the Interagency Monitoring of Protected Visual Environments Network (IMPROVE) and typically reported using the haze index deciview² (dv). Visibility measurements at an area are analyzed with respect to both ambient and natural haze conditions. Natural haze is the amount of haze that would result from natural biogenic emissions and dust in the absence of anthropogenic pollution. Visibility conditions are typically grouped into the 20% clearest days, the 20% haziest days, and average ambient and natural condition days.

There are no IMPROVE monitoring sites at any of the parks within the GULN for estimating natural and ambient visibility. However, data are available that are considered to be representative of visibility conditions in one Class II area (NATR). A monitoring site is considered by IMPROVE to be representative of an area if it is within 60 mi (100 km) and 425 ft (130 m) in elevation of that area. Data from this representative IMPROVE site (Sipsey Wilderness - SIPS1) indicate that NATR likely experienced high levels of natural haze, that is, the haze that would occur in the absence of human-caused pollution, in comparison with all I&M parks for the 20% clearest days, for the average days, and for the 20% haziest days (Table 7). Note, however, that levels of atmospheric N, which contributes to haze, might be substantially higher at Sipsey Wilderness, as compared with GULN parks, based on estimates of N deposition (Map 8).

Current visibility estimates reflect current pollution levels and were used to rank conditions at parks in order to provide park managers with information on spatial differences in visibility and air pollution. Rankings range from very low haze (very good visibility) to very high haze (very poor visibility). Only parks with on-site or representative IMPROVE monitors were used in generating the visibility ranking. Table 7 gives the relative park haze rankings on the 20% clearest, 20% haziest, and average days.

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

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

Table 7. Estimated natural background visibility (top panel) and ambient visibility conditions in GULN parks averaged over the period 2004 through 2008 (bottom panel)¹.

Park Name ²	Park Code	Site ID	Estimated Natural Background Visibility (dv)		
			20% Clearest Days	20% Haziest Days	Average Days
<i>Big Thicket</i>	BITH	No Site			
<i>Gulf Islands</i>	GUIS	No Site			
Jean Lafitte	JELA	No Site			
Natchez Trace Parkway	NATR	SIPS1	5.02	10.99	7.79
<i>Padre Island</i>	PAIS	No Site			
Palo Alto Battlefield	PAAL	No Site			
San Antonio Missions	SAAN	No Site			
Vicksburg	VICK	No Site			

Park Name	Park Code	Site ID	Ambient Visibility Conditions (For Years 2004 through 2008)					
			20% Clearest Days		20% Haziest Days		Average Days	
			dv	Ranking	dv	Ranking	dv	Ranking
<i>Big Thicket</i>	BITH	No Site						
<i>Gulf Islands</i>	GUIS	No Site						
Jean Lafitte	JELA	No Site						
Natchez Trace Parkway	NATR	SIPS1	14.73	Very High	29.37	Very High	21.65	Very High
<i>Padre Island</i>	PAIS	No Site						
Palo Alto Battlefield	PAAL	No Site						
San Antonio Missions	SAAN	No Site						
Vicksburg	VICK	No Site						

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 borrowed from a nearby site for NATR. A monitoring site is considered by IMPROVE to be representative of an area if it is within 60 mi (100 km) and 425 ft (130 m) in elevation of that area. Note that the designated representative site (Sipsey Wilderness) may have higher levels of atmospheric S and N, based on deposition maps (Maps 5 and 8)

Measurements of visibility for the periods 2004-2008 and 2006-2010 indicate that haze is very high on the 20% clearest, average, and 20% haziest days at the Sipsey Wilderness monitor, the representative monitor for NATR (Table 7). Data from the monitor show that pollution has reduced average natural visual range from 110 miles to 25 miles (177 km to 40 km). On the haziest days, visual range is reduced from 80 to 15 miles (129 km to 24 km). Severe haze episodes occasionally reduce visibility to 5 miles (8 km). Visibility is slightly better in coastal areas of the GULN, but is still relatively degraded (<http://vista.cira.colostate.edu/improve/>).

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 C, coarse mass, organic mass, sea salt, and soil. Sulfates form in the atmosphere from SO₂ emissions from coal-burning power plants, smelters, and other industrial facilities. Nitrates form in the atmosphere from NO_x emissions from combustion sources including vehicles, 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 1 shows estimated natural (pre-industrial), baseline (2000-2004), and current (2006-2010) levels of haze and its composition at the Sipsey Wilderness monitor (SIPS1), considered representative for NATR. The figure illustrates that sulfates are the primary components of haze in the region on the 20% clearest, average, and 20% haziest visibility days. Organics also contribute significantly to haze in the region.

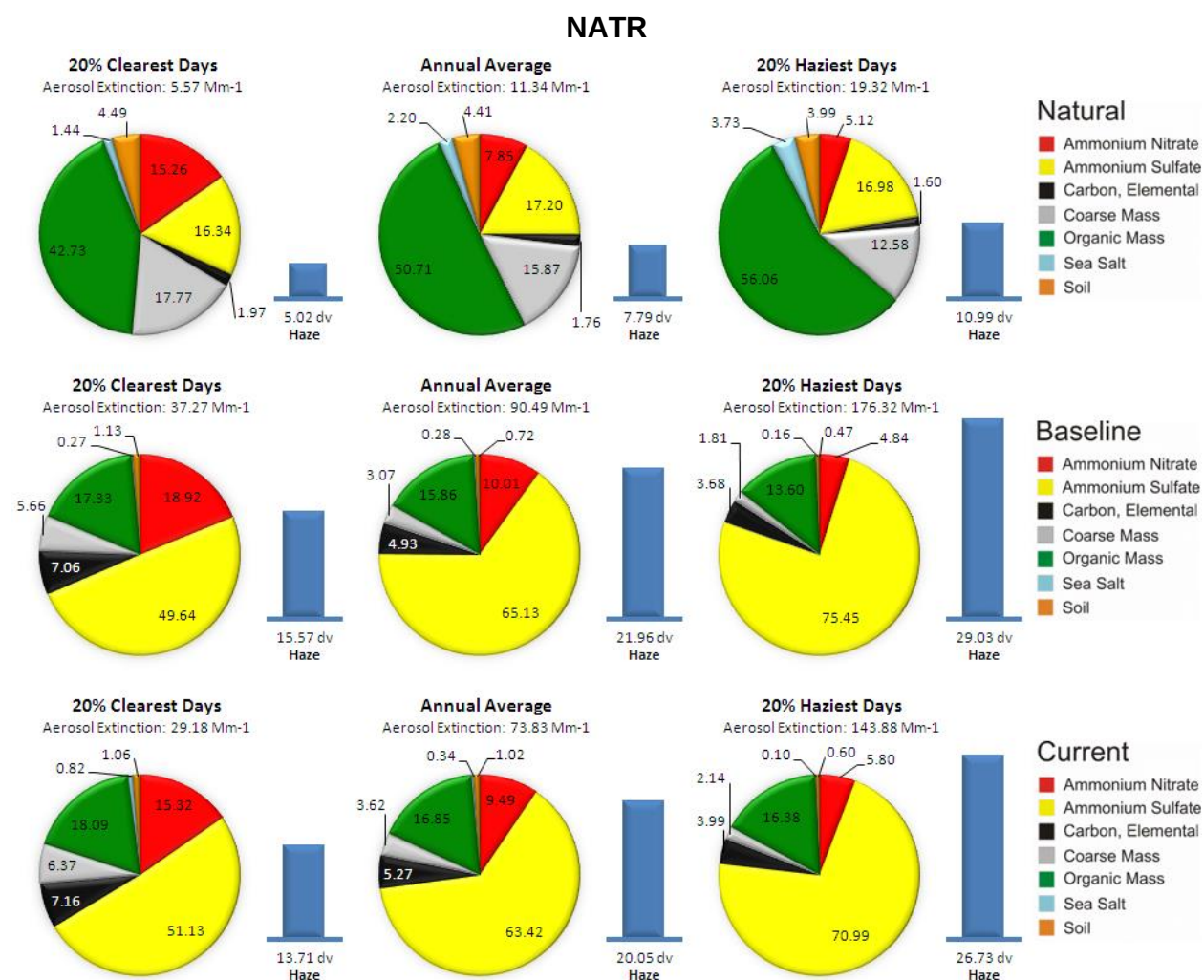


Figure 1. Estimated natural (pre-industrial), baseline (2000-2004), and current (2006-2010) levels of haze (blue columns) and its composition (pie charts) on the 20% clearest, annual average, and 20% haziest visibility days for NATR. Data for NATR were taken from a nearby site (SIPS1). NATR has no data for the year 2000. Data Source: NPS-ARD.

Trends in Visibility

Measured haze values at the IMPROVE site (SIPS1) considered representative of NATR between 1998 and 2010 suggest decreasing haze on the 20% clearest, average, and 20% haziest days (Figure 2). The largest improvements (about 10 dv) have occurred on the haziest days.

Development of State Implementation Plans

Although none of the GULN parks are Class I areas, plans to improve visibility under the Regional Haze Rule (RHR) are likely to result in air quality improvements that will benefit all areas, including parks in the GULN. 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

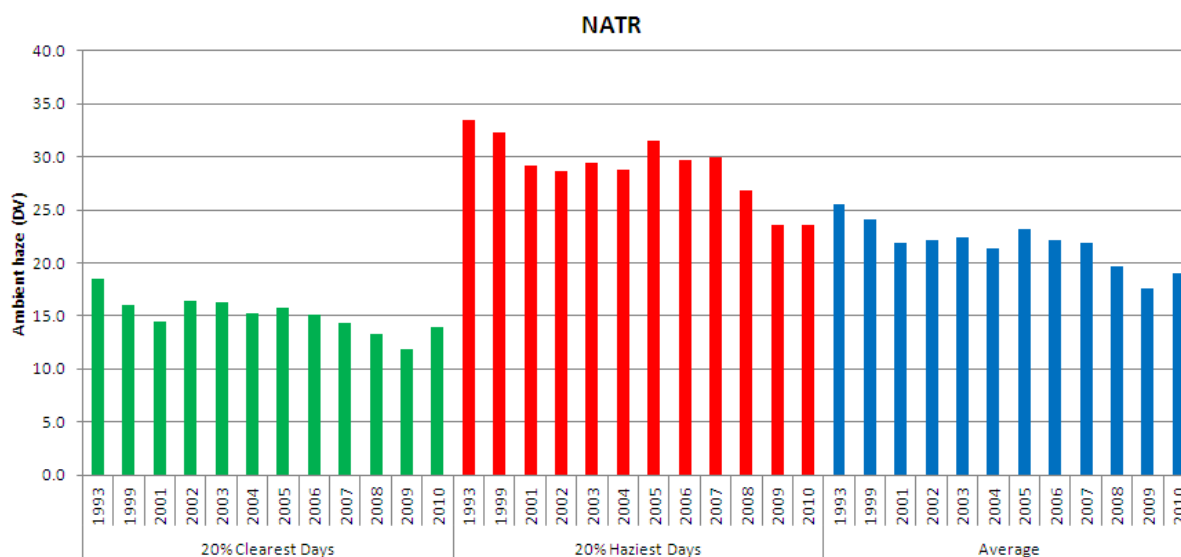


Figure 2. Trends in ambient haze levels at Sipsey Wilderness near NATR, based on IMPROVE measurements on the 20% clearest, 20% haziest, and annual average visibility days over the monitoring period of record. Data from Sipsey Wilderness ((SIPS1) are considered representative of NATR. Data Source: http://vista.cira.colostate.edu/improve/Data/IMPROVE/summary_data.htm

Class I areas to natural background levels in 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).

The Visibility Improvement State and Tribal Association of the Southeast (VISTAS) is a collaborative effort among state governments, tribal governments, and federal agencies involved in management of visibility and regional haze in the Southeast. Analyses conducted on behalf of VISTAS have included determination of baseline visibility conditions, calculation of the glideslope from the baseline necessary to achieve background conditions in 2064, and determination of air pollutant source areas.

The glideslope analysis shown in Figure 3 illustrates that recent improvements in visibility on the 20% haziest days in the Sipsey Wilderness may have been sufficient to demonstrate proportionate

progress to attain natural visibility conditions in 2064 (~ 11 dv). States will have to achieve further reductions in air pollution and reduce haze another 50% (12 dv) on the 20% haziest days in order to reach the targeted natural visibility conditions to comply with the RHR.

Toxic Airborne Contaminants

The Gulf coast has been impacted by relatively high levels of atmospheric Hg deposition, contaminating the soil, water, and biota of the region. Atmospheric deposition, primarily from coal-fired power plant emissions, is the largest source of Hg to freshwater and marine ecosystems in the GULN (Mason et al. 2012). As a consequence of atmospheric Hg deposition and other sources of Hg in and upwind of the GULN region, substantial Hg bioaccumulation has occurred. Katner et al. (2010) compared fish Hg concentrations measured in Louisiana with the U.S. EPA's methylmercury (MeHg) criterion of 0.3 µg/g, which was established to protect sensitive human populations (pregnant women and children). Nearly half of all edible finfish samples collected by Katner et al. (2010) between 1994 and 2008 had Hg concentrations higher than the EPA standard.

Myers et al. (2007) and USGS (Last modified February 20, 2015) prepared a national map showing the relative sensitivity of aquatic ecosystems to Hg contamination. Areas showing the highest estimated sensitivity were mainly confined to the East Coast, Gulf Coast (within the GULN), and Upper Midwest, with scattered small areas in other regions. Estimates of Hg methylation potential generated by USGS (Last modified February 20, 2015) for watershed boundaries (based on eight-digit hydrologic unit codes [HUCs]) containing national park lands in the GULN suggested high methylation potential at most parks considered in this analysis (Map 9). This result is likely driven mainly by relatively high concentrations of total organic C in aquatic ecosystems in this network. There are fish consumption advisories in BITH (Village Creek)

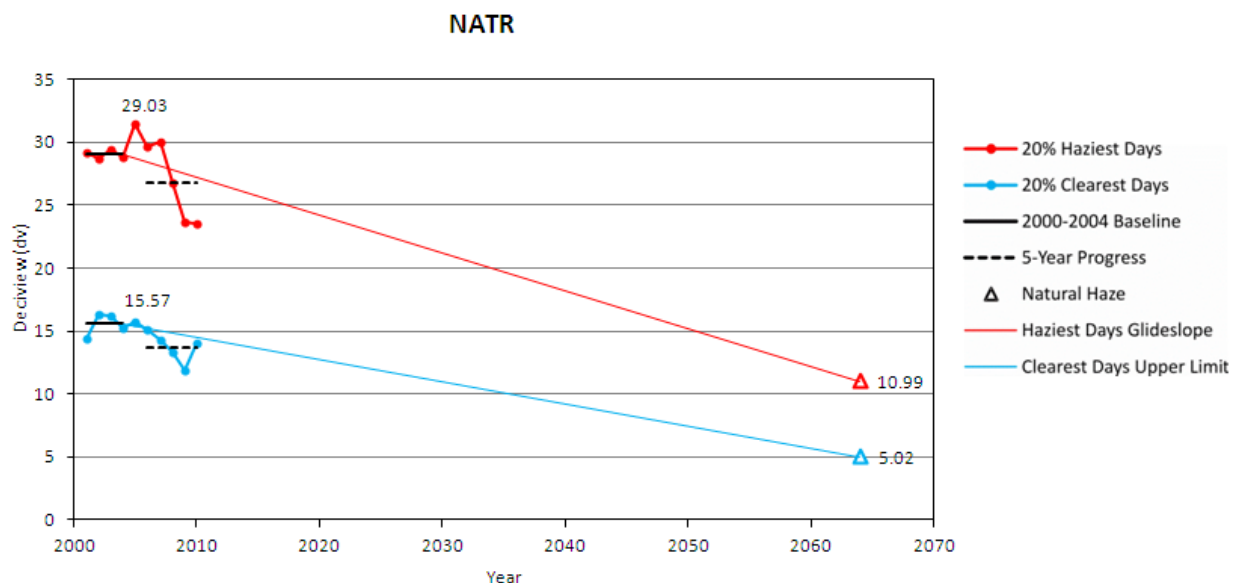


Figure 3. Glideslopes to achieving natural visibility conditions in 2064 for the 20% hazeiest (red line) and the 20% clearest (blue line) days in Sipsey Wilderness near NATR. In the regional haze rule, the clearest days do not have a uniform rate of progress glideslope; the rule only requires that the clearest days do not get any worse than the baseline period. Also shown are measured values during the period 2000 to 2010. Data from Sipsey Wilderness (SIPS1)) are considered representative of NATR. Data Source: http://vista.cira.colostate.edu/improve/Data/IMPROVE/summary_data.htm

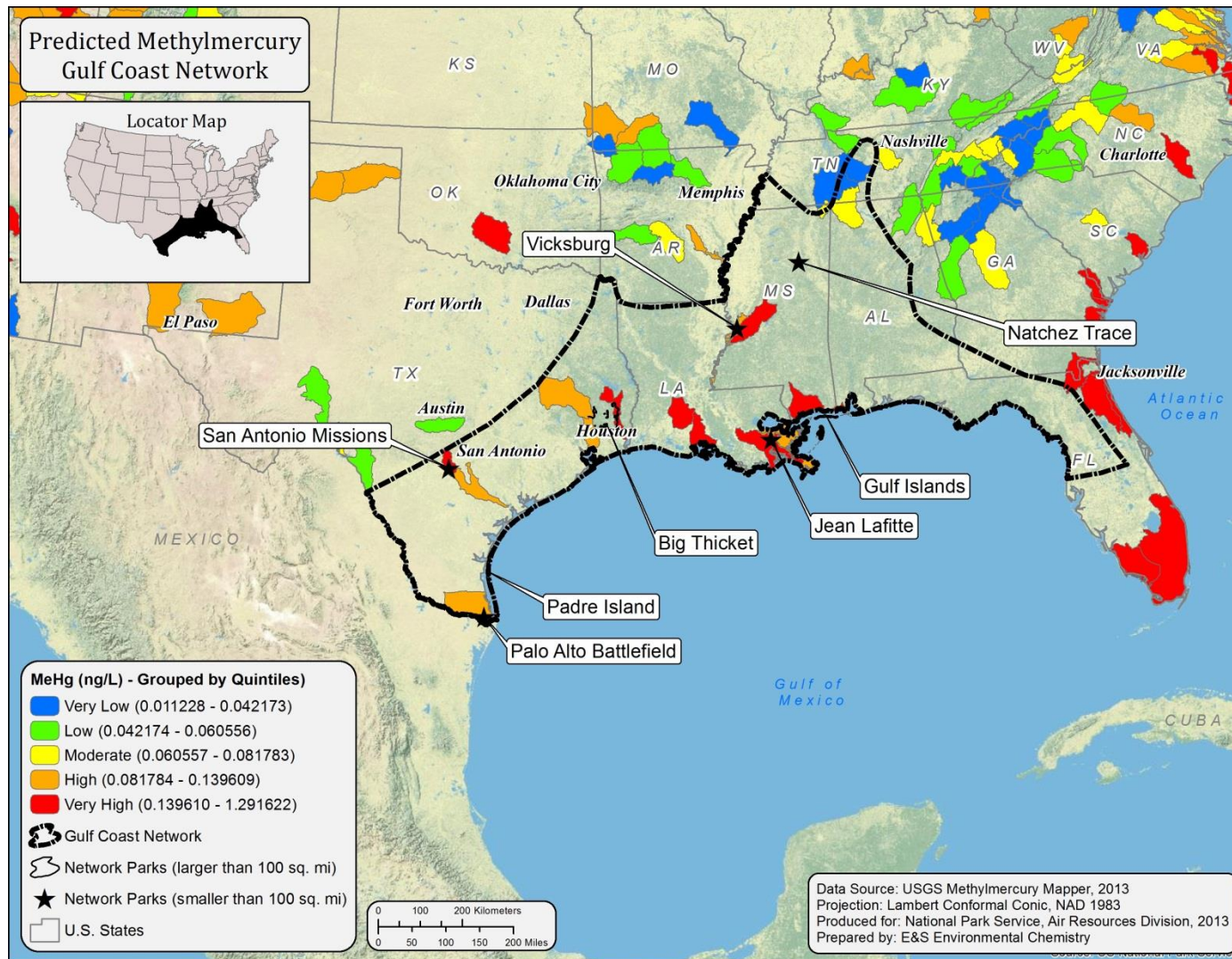
(<http://www.dshs.state.tx.us/seafood/PDF2/Risk%20Characterization/VillageCreekRC2007.pdf>) and in other water bodies throughout the GULN.

Information and data on persistent organic pollutants (POPs) and heavy metals in parks of the GULN were compiled in a 2005 report to the NPS (Gallaher et al. 2005). Legacy (i.e., historic use pesticides, now banned) POPs, especially pesticides, were detected in waters and sediments in and around JELA, although most of the concentrations were low. There was some indication of legacy pesticides in waters near BITH, but data were insufficient for assessment purposes. The possibility of impacts in this park is noteworthy, in part, because BITH is rich in biodiversity due to the convergence of three types of ecosystems: eastern hardwood forest, Gulf coastal plains, and Midwest prairie. BITH has been designated an International Biosphere Reserve by the United Nations Education Scientific and Cultural Organization (UNESCO) Man and the Biosphere Program and is a Globally Important Bird Area (<http://www.abcbirds.org/abcprograms/domestic/iba/alphalist.html>).

Available data suggest hydrocarbon contamination of PAIS and elsewhere in the Gulf of Mexico. This park is under pressure due to contamination from oil drilling, agriculture, and urbanization (Gallaher et al. 2005).

Because NATR forms a diagonal transect through an important agricultural region, past and present pesticide use represents an important threat to park resources. However, existing data on POPs are insufficient for evaluating current conditions in this park (Gallaher et al. 2005).

Marine and estuarine fish caught in Florida Bay often contain higher Hg concentration than fish in other parts of Florida (Adams and Onorato 2005, Evans and Crumley 2005). Some species of fish in the Gulf of Mexico also have higher concentrations of Hg than fish in the adjacent Atlantic Ocean, although the major factors governing Hg levels in fish in this region are not well understood (Adams and McMichael 2007, Glover et al. 2010, Katner et al. 2011). Potential Hg contamination is a particularly important issue in this region because Gulf of Mexico fisheries account for 41% of the marine recreational fish caught in the United States (NOAA 2011).



Map 9. Predicted MeHg concentrations in surface waters by HUCs that contain national parklands in the Gulf Coast Network. Estimates were generated by USGS (Last modified February 20, 2015). Rankings are based on quintile distributions across all I&M parks having estimates by USGS.

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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.

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