



# Air Quality Related Values (AQRVs) for Northeast Coastal and Barrier Network (NCBN) Parks

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

Natural Resource Report NPS/NCBN/NRR—2016/1176



#### 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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Natural Resource Report NPS/NCBN/NRR—2016/1176

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

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

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## Summary

This section describes the Air Quality Related Values (AQRVs) of the Northeast Coastal and Barrier Network (NCBN). AQRVs are those resources sensitive to air quality and include streams, lakes, soils, vegetation, fish and wildlife, and visibility. This report also describes air pollutant emissions and air quality in NCBN, and their effects on AQRVs. The primary pollutants likely to affect AQRVs include nitrogen (N) and sulfur (S) compounds (nitrate [ $\text{NO}_3^-$ ], ammonium [ $\text{NH}_4^+$ ], and sulfate [ $\text{SO}_4^{2-}$ ]), ground-level ozone ( $\text{O}_3$ ), 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).

This report covers the eight parks in NCBN considered to be part of the NPS Inventory and Monitoring Program: Assateague Island National Seashore (ASIS), Cape Cod National Seashore (CACO), Colonial National Historical Park (COLO), Fire Island National Seashore (FIIS), Gateway National Recreation Area (GATE), George Washington Birthplace National Monument (GEWA), Sagamore Hill National Historic Site (SAHI), and Thomas Stone National Historic Site (THST). Most parks in NCBN are located in or adjacent to the heavily developed coastal corridor between southern Virginia and Boston. There is a very high density of large human population centers within this network. Emissions of S and N are high upwind from portions of the network, but low elsewhere. Although both S and N deposition within NCBN are quite high, values of S, and to a lesser extent N, deposition have decreased in recent years.

Ecosystem Sensitivity to acidification was judged to be low or very low for all for all of the parks in NCBN, except CACO, where sensitivity was judged to be high. CACO contains numerous small seepage lakes that have minimal watershed contributions of base cations with which to neutralize atmospheric inputs of acidity.

One of the regions of the eastern United States where acidic (acid neutralizing capacity  $[\text{ANC}] \leq 0$   $\mu\text{eq/L}$ ) streams are numerous is the coastal lowlands of the Mid-Atlantic region (estimated 2530 km of stream length). This includes the area around ASIS. Both mineral acids associated with acidic deposition and organic acids associated with naturally occurring dissolved organic carbon (DOC) play important roles in the acid-base status of streams in the Mid-Atlantic Coastal Plain. The majority of the potentially acid-sensitive streams in Maryland occur in the Southern Coastal Plain region surrounding the Chesapeake Bay and in the Appalachian Plateau ecoregion in western Maryland. Streams on the Southern Coastal Plain of Maryland generally had relatively low acid neutralizing capacity (ANC). The Maryland Critical Loads Study applied the PROFILE model to help to estimate the steady-state critical load of S and N deposition to protect stream acid-base chemistry throughout Maryland (Janicki et al. 1995). About one-fourth of the stream reaches in Maryland had estimated levels of S deposition in their watersheds that were higher than the simulated steady-state critical load of acidity and were expected to be at risk of episodic acidification.

Salt marsh vegetation, which is common along the coastal corridor of NCBN, is highly sensitive to potential nutrient enrichment effects from atmospheric N deposition, and is also influenced by

changing water levels that will likely accompany climate change. Estuaries throughout NCBN are threatened by adverse effects from nutrient enrichment. One of the principal adverse impacts of eutrophication on estuarine and coastal ecosystems is a decrease in the extent of eelgrass and other submerged aquatic vegetation. Intertidal wetlands are highly susceptible to N inputs. Effects can include enhanced spread of non-native invasive species, decreased abundance of N-sensitive plant species such as eelgrass (Latimer and Rego 2010), increased primary productivity (Darby and Turner 2008, Wigand et al. 2003), and changes in inter-species competition.

Atmospheric S and N air pollutants have had substantial effects on lichen communities in the coastal plain and have reduced lichen cover and richness (Gilliam et al. 2011). Of 70 species found in about the year 1900 on Plummer's Island (15 km south of Washington, DC), only 20 remained in the early 1990s (Lawrey 1993).

Ozone exposure is an important threat to vegetation in NCBN. The W126 index was ranked high in four parks, and the SUM06 index was ranked high in five parks. Kohut (2007a) ranked all parks within the network as high in O<sub>3</sub> risk. The estimated O<sub>3</sub> exposures were higher than levels considered necessary for causing visible symptoms, although damage to plant foliage from O<sub>3</sub> exposure has not been documented.

Natural haze has been estimated by the Interagency Monitoring of Protected Visual Environments (IMPROVE) Network for CACO. Compared to other Inventory and Monitoring (I&M) parks, haze levels are high at CACO.

The majority of the total particulate light extinction ( $b_{\text{ext}}$ ) in CACO is attributable to  $\text{SO}_4^{2-}$ ,  $\text{NO}_3^-$  and organics. On the 20% haziest days, the contribution of  $\text{SO}_4^{2-}$  accounted for an estimated 73% of  $b_{\text{ext}}$ . On the best 20% visibility days, the contribution of  $\text{SO}_4^{2-}$  decreased substantially to 43%. Although Mid-Atlantic/Northeast Visibility Union (MANE-VU) has focused primarily on fine particle  $\text{SO}_4^{2-}$  abatement in its efforts toward compliance with the Regional Haze Rule (RHR), controls on other haze-producing constituents, such as organic C and both urban and mobile sources of nitrogen oxides ( $\text{NO}_x$ ) during winter will also be important. (Northeast States for Coordinated Air Use Management [NESCAUM] 2012).

Airborne contaminants, including mercury (Hg) and other heavy metals and also semi-volatile organic compounds (SOCs) can accumulate in food webs in NCBN, reaching toxic levels in top predators. The Hg methylation potential, which contributes to biomagnification, is relatively high in this network (Myers et al. 2007).

## Background

There are eight parks in NCBN: Assateague Island National Seashore (ASIS), Cape Cod National Seashore (CACO), Colonial National Historical Park (COLO), Fire Island National Seashore (FIIS), Gateway National Recreation Area (GATE), George Washington Birthplace National Monument (GEWA), Sagamore Hill National Historic Site (SAHI), and Thomas Stone National Historic Site (THST). Most are located in or adjacent to the heavily developed coastal corridor between Washington, DC and Boston. There is a very high density of large human population centers near the network, including New York City, Baltimore, Philadelphia, Washington, DC and Boston. Map 1 shows a map of the network boundary along with locations of each park and population centers with greater than 10,000 people around the network.

## Atmospheric Emissions and Deposition

Annual county-level sulfur (S) emissions were quite variable throughout NCBN, ranging from less than 1 ton of sulfur dioxide ( $\text{SO}_2$ ) per square mile ( $\text{ton}/\text{mi}^2/\text{yr}$ ) to over 100  $\text{tons}/\text{mi}^2/\text{yr}$ . Although a large portion of the network region had emissions less than 20  $\text{tons}/\text{mi}^2/\text{yr}$ , there were substantial areas with higher emissions, including the New York City area, most of Long Island, the Boston and Cape Cod area, and the area near Washington, DC. County-level nitrogen (N) emissions around the network were also highly variable, ranging from less than 1  $\text{ton}/\text{mi}^2/\text{yr}$  to greater than 100  $\text{tons}/\text{mi}^2/\text{yr}$ . At most locations, annual county N emissions were between 5 and 20  $\text{tons}/\text{mi}^2/\text{yr}$ , but were higher than 20  $\text{tons}/\text{mi}^2/\text{yr}$  in many areas, including the New York City area, all of Long Island, and portions of the network region near Washington, DC.

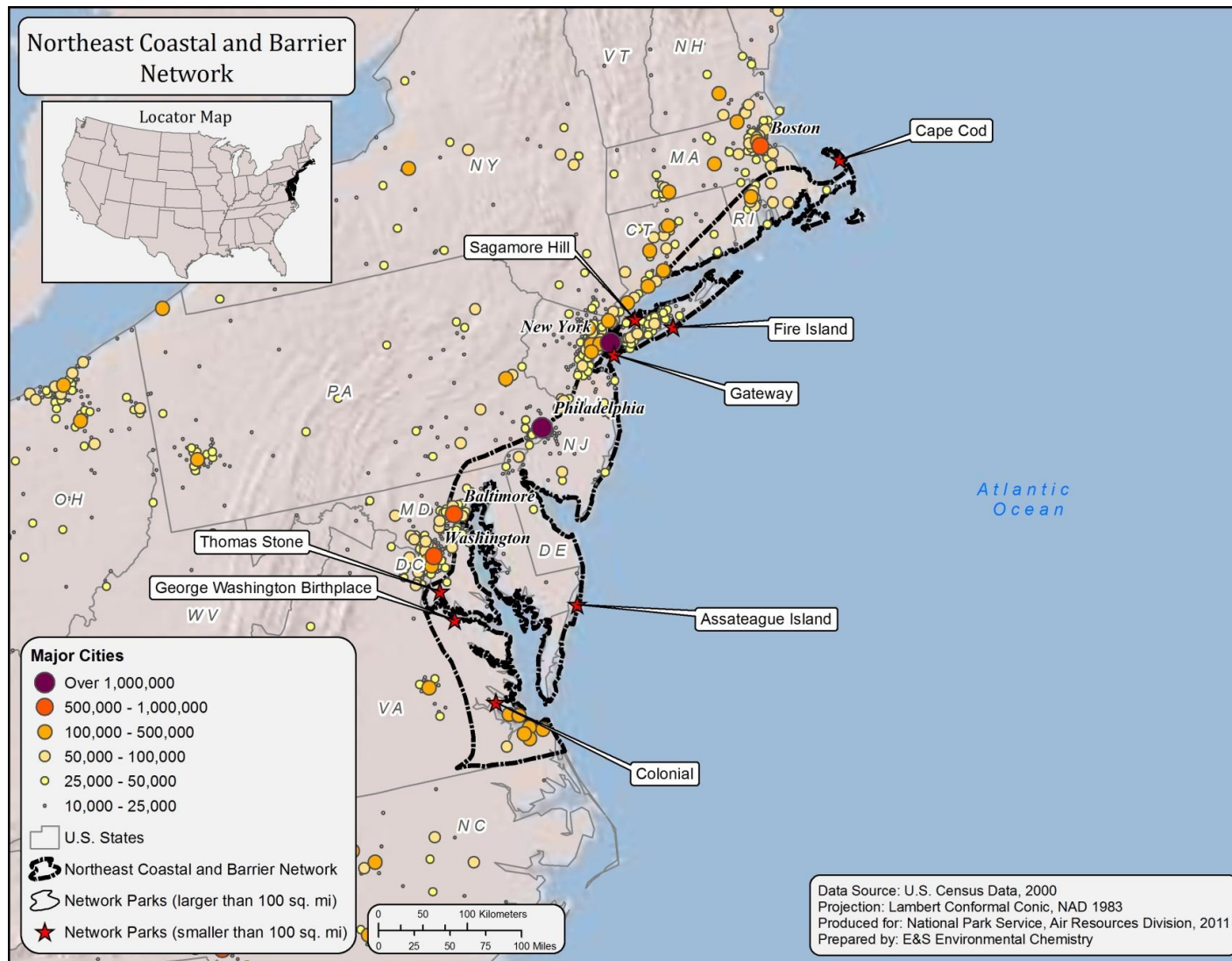
There were many  $\text{SO}_2$  point sources around the network; most of them emitted less than 5,000 tons of S per year, and were located in the vicinity of New York City and Boston. There were two near the Washington DC/Baltimore area that emitted larger quantities of  $\text{SO}_2$ , between 20,000 and 40,000 tons per year. There were several relatively large (larger than 2,000  $\text{tons}/\text{yr}$ ) point sources of oxidized N, but no large sources of reduced N, within the network region. Most of the largest N point sources in the network region were in Maryland.

Total S deposition was relatively high, over 10 kg S/ha/yr, throughout NCBN, with large areas receiving more than 15 kg S/ha/yr. There were scattered areas that received more than that, up to 30 kg S/ha/yr or more. Total N deposition throughout most of the network region ranged from 10 to 20 kg N/ha/yr. Although both S and N deposition within NCBN were quite high, values of S deposition, in particular, have decreased in recent years. Based on wet deposition collected at 29 national park locations, and reported by NPS (2010), concentrations of nitrate ( $\text{NO}_3^-$ ) in wet deposition during the period 1989 to 2008 decreased by statistically significant ( $p \leq 0.05$ ) amounts at four monitored locations, including CACO within NCBN ( $-0.34 \mu\text{eq}/\text{L}/\text{yr}$ ).

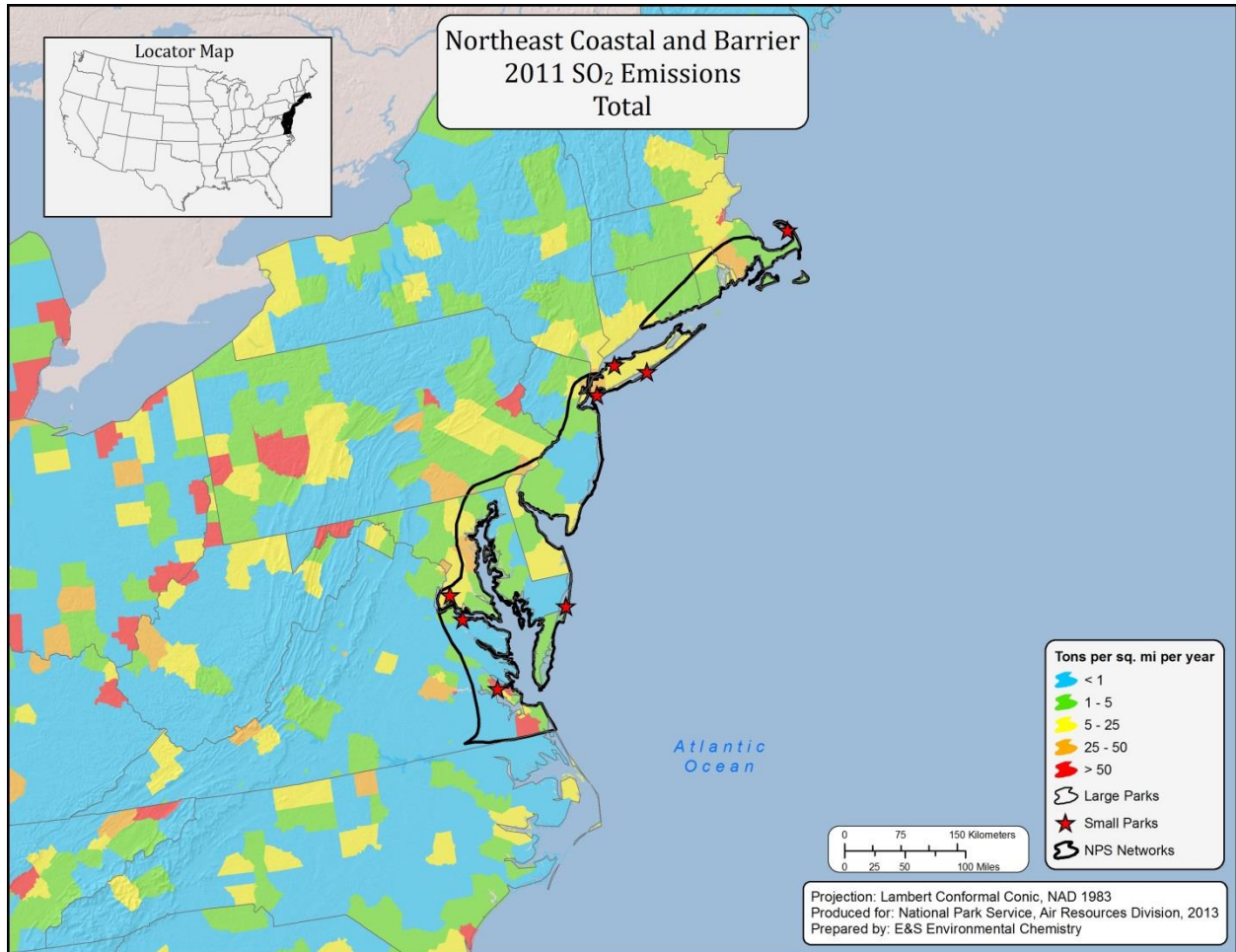
County-level emissions near NCBN, based on data from the EPA's National Emissions Inventory (NEI) during a recent time period (2011), are depicted in Maps 2 through 4 for  $\text{SO}_2$ , oxidized N ( $\text{NO}_x$ ), and reduced N ( $\text{NH}_3$ ), respectively. Many counties to the north and west of NCBN parks had

relatively high SO<sub>2</sub> emissions (> 50 tons/mi<sup>2</sup>/yr; Map 2). Spatial patterns in NO<sub>x</sub> emissions were generally similar, with highest values to the northwest of NCBN parks (Map 3). Emissions of NH<sub>3</sub> near NCBN parks were somewhat lower, with most counties showing emissions levels below 8 tons/mi<sup>2</sup>/yr (Map 4).

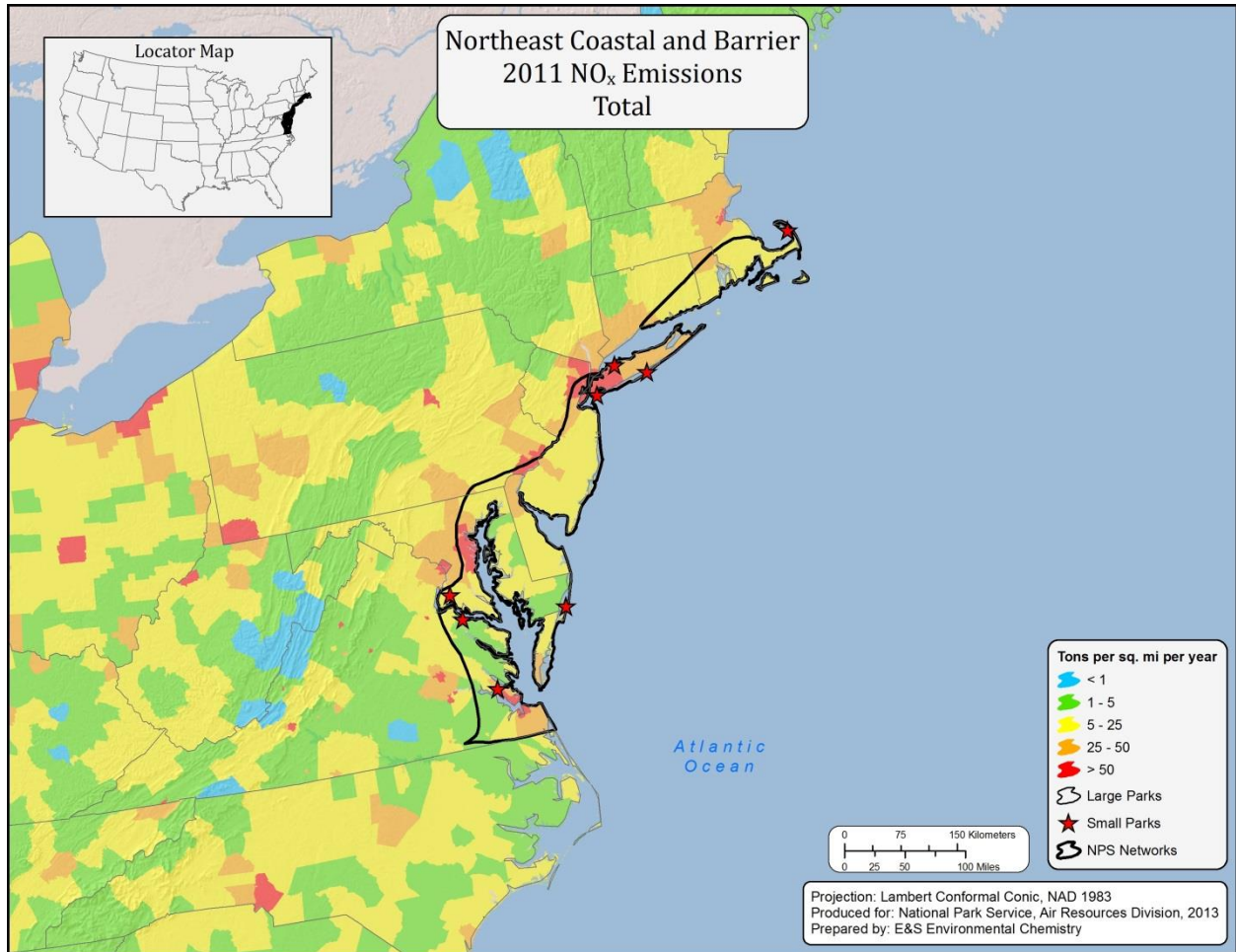
Recently, Schwede and Lear (2014) documented a hybrid approach developed by the National Atmospheric Deposition Program (NADP) Total Deposition (TDEP) Science Committee for estimating total N and S deposition. This approach combined monitoring and modeling data.



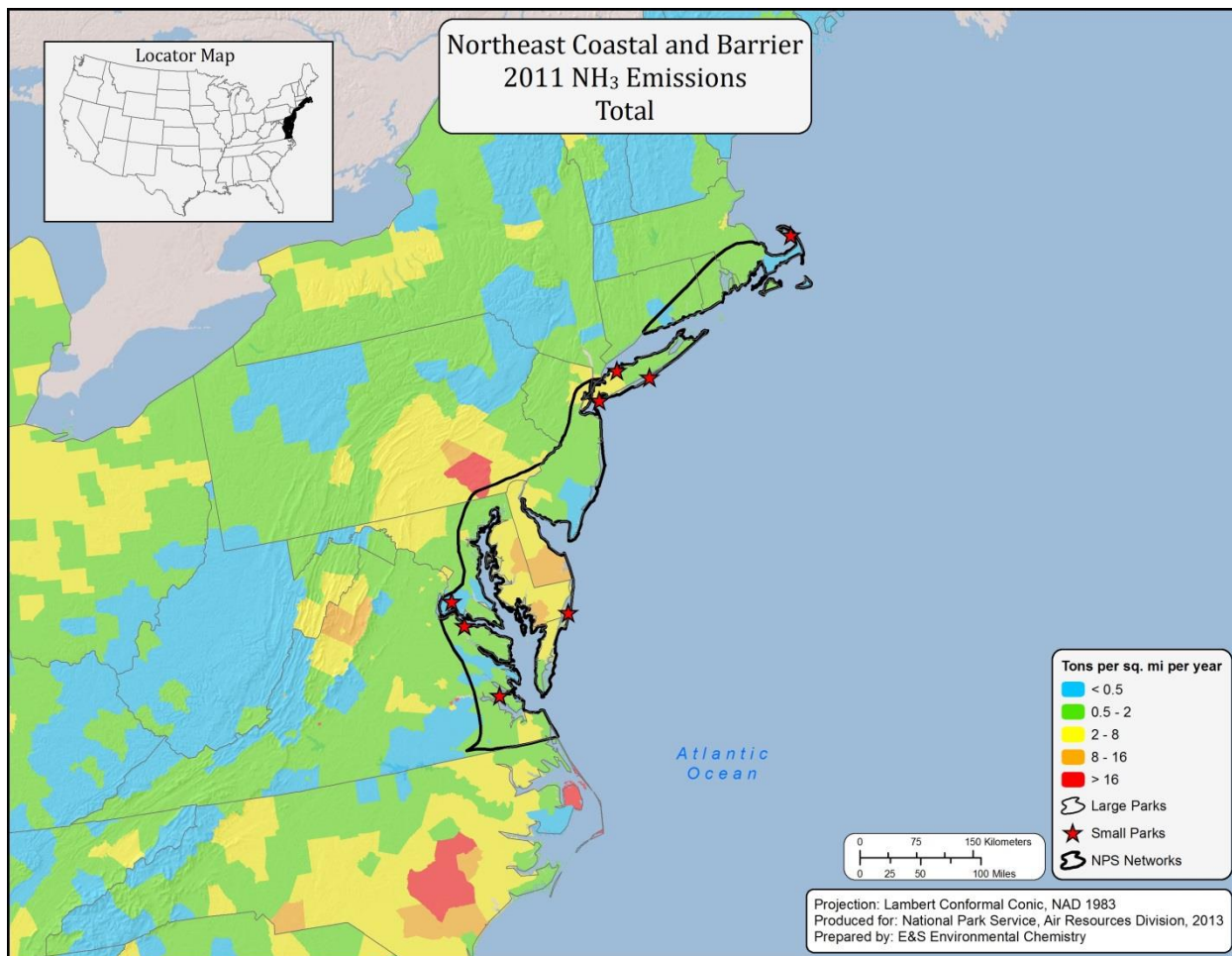
**Map 1.** Map showing network boundary and locations of parks and population centers with more than 10,000 people around NCBN.



**Map 2.** Total SO<sub>2</sub> emissions, by county, near NCBN for the year 2011. Data from EPA's National Emissions Inventory.



**Map 3.** Total NO<sub>x</sub> emissions, by county, near NCBN for the year 2011. Data from EPA's National Emissions Inventory.



**Map 4.** Total NH<sub>3</sub> emissions, by county, near NCBN for the year 2011. Data from EPA's National Emissions Inventory.

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 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, N<sub>2</sub>O<sub>5</sub>, NO, NO<sub>2</sub>, HONO, and organic NO<sub>3</sub>. 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 at most NCBN parks since 2001, based on TDEP estimates (Table NBCN-1). Decreases in total S deposition over the previous decade for the parks in this network have in many cases been larger than 30%. Estimated total N deposition over that same time period increased at some parks and decreased at others. Oxidized N deposition decreased at all but one park (GATE) in the network. Reduced N deposition showed variable changes since the monitoring period 2000-2002.

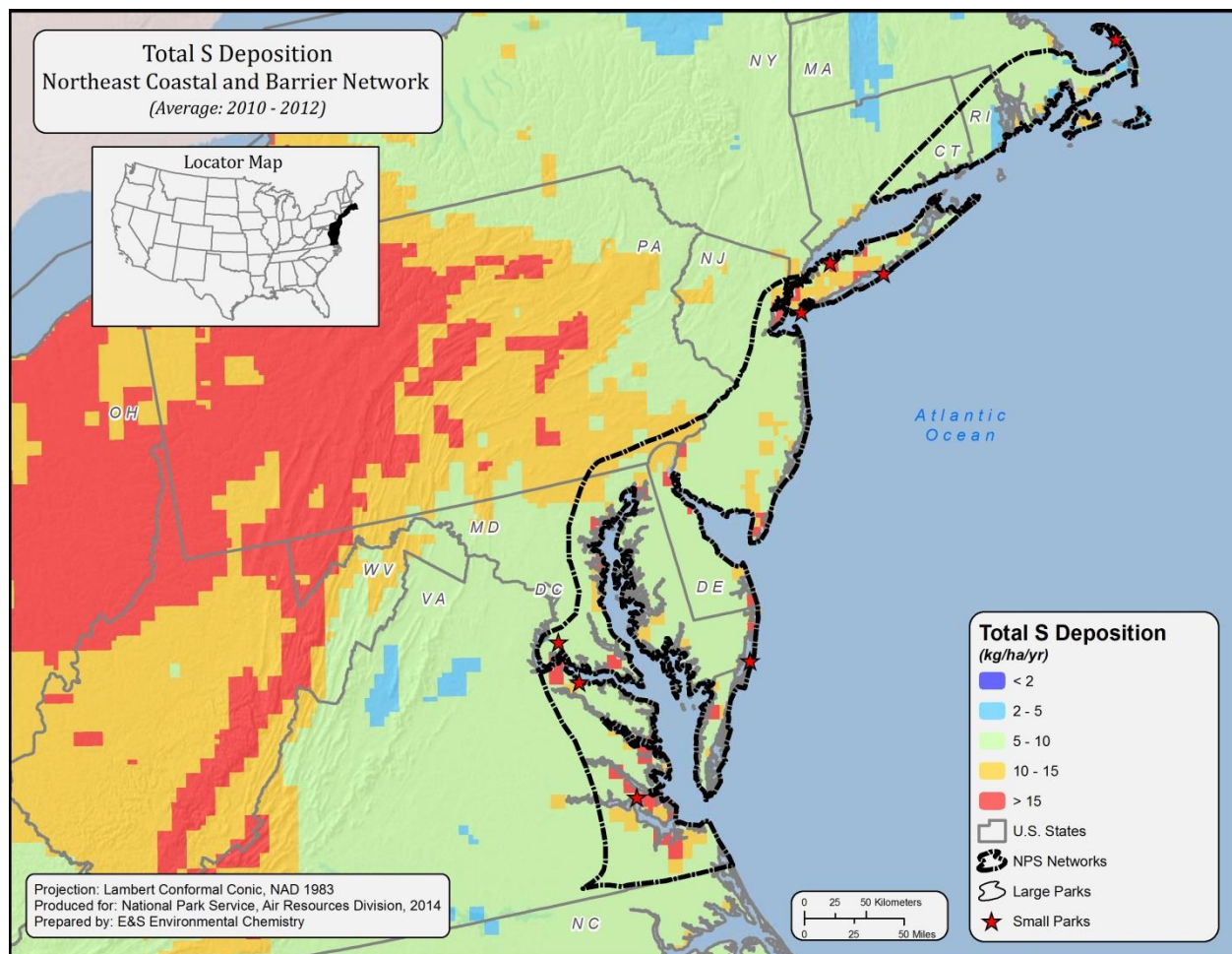
**Table 1.** Average changes in S and N deposition between 2001 and 2011 across park grid cells at NCBN parks. Deposition estimates were determined by the Total Deposition Project, TDEP, based on three-year averages centered on 2001 and 2011 for all ~4 km grid cells in each park. The minimum, maximum, 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) |
|-----------|------------------------------|------------|-------------------------|-------------------------|----------------------------|----------------|-------------------------|-------------------------|-----------------------|
| ASIS      | Assateague Island            | Total S    | 13.48                   | 8.74                    | -4.74                      | -35.1%         | 6.65                    | 15.54                   | 8.89                  |
|           |                              | Total N    | 7.02                    | 7.83                    | 0.81                       | 11.8%          | 5.94                    | 13.95                   | 8.01                  |
|           |                              | Oxidized N | 4.59                    | 3.65                    | -0.94                      | -20.4%         | 2.97                    | 5.84                    | 2.88                  |
|           |                              | Reduced N  | 2.43                    | 4.18                    | 1.76                       | 72.9%          | 2.97                    | 8.49                    | 5.52                  |
| CACO      | Cape Cod                     | Total S    | 9.93                    | 5.02                    | -4.91                      | -49.4%         | 4.83                    | 5.10                    | 0.27                  |
|           |                              | Total N    | 5.87                    | 4.15                    | -1.72                      | -29.3%         | 4.01                    | 4.24                    | 0.23                  |
|           |                              | Oxidized N | 4.22                    | 2.49                    | -1.73                      | -41.0%         | 2.43                    | 2.54                    | 0.11                  |
|           |                              | Reduced N  | 1.65                    | 1.66                    | 0.01                       | 0.7%           | 1.58                    | 1.70                    | 0.12                  |
| COLO      | Colonial                     | Total S    | 13.54                   | 15.50                   | 1.98                       | 15.2%          | 8.40                    | 18.38                   | 9.98                  |
|           |                              | Total N    | 12.19                   | 10.67                   | -1.52                      | -11.7%         | 9.13                    | 11.21                   | 2.08                  |
|           |                              | Oxidized N | 8.71                    | 5.97                    | -2.74                      | -30.4%         | 5.59                    | 6.29                    | 0.70                  |
|           |                              | Reduced N  | 3.48                    | 4.70                    | 1.22                       | 34.9%          | 3.50                    | 5.12                    | 1.62                  |
| FIIS      | Fire Island                  | Total S    | 12.69                   | 6.00                    | -6.66                      | -52.5%         | 5.88                    | 10.49                   | 4.61                  |
|           |                              | Total N    | 7.80                    | 5.32                    | -2.45                      | -31.4%         | 5.18                    | 10.65                   | 5.48                  |
|           |                              | Oxidized N | 5.51                    | 3.30                    | -2.19                      | -39.6%         | 3.19                    | 7.22                    | 4.03                  |
|           |                              | Reduced N  | 2.29                    | 2.01                    | -0.26                      | -11.6%         | 1.98                    | 3.43                    | 1.45                  |
| GATE      | Gateway                      | Total S    | 15.31                   | 14.61                   | -0.71                      | -5.5%          | 6.90                    | 24.53                   | 17.64                 |
|           |                              | Total N    | 8.08                    | 13.63                   | 5.55                       | 68.6%          | 6.54                    | 16.63                   | 10.09                 |
|           |                              | Oxidized N | 5.35                    | 8.17                    | 2.82                       | 53.0%          | 3.71                    | 9.11                    | 5.40                  |
|           |                              | Reduced N  | 2.73                    | 5.45                    | 2.73                       | 98.8%          | 2.83                    | 8.08                    | 5.25                  |
| GEWA      | George Washington Birthplace | Total S    | 15.92                   | 7.08                    | -8.84                      | -55.6%         | 7.08                    | 7.08                    | 0.00                  |
|           |                              | Total N    | 13.33                   | 5.30                    | -8.03                      | -60.3%         | 5.30                    | 5.30                    | 0.00                  |
|           |                              | Oxidized N | 9.90                    | 2.91                    | -6.99                      | -70.6%         | 2.91                    | 2.91                    | 0.00                  |
|           |                              | Reduced N  | 3.43                    | 2.39                    | -1.04                      | -30.4%         | 2.39                    | 2.39                    | 0.00                  |

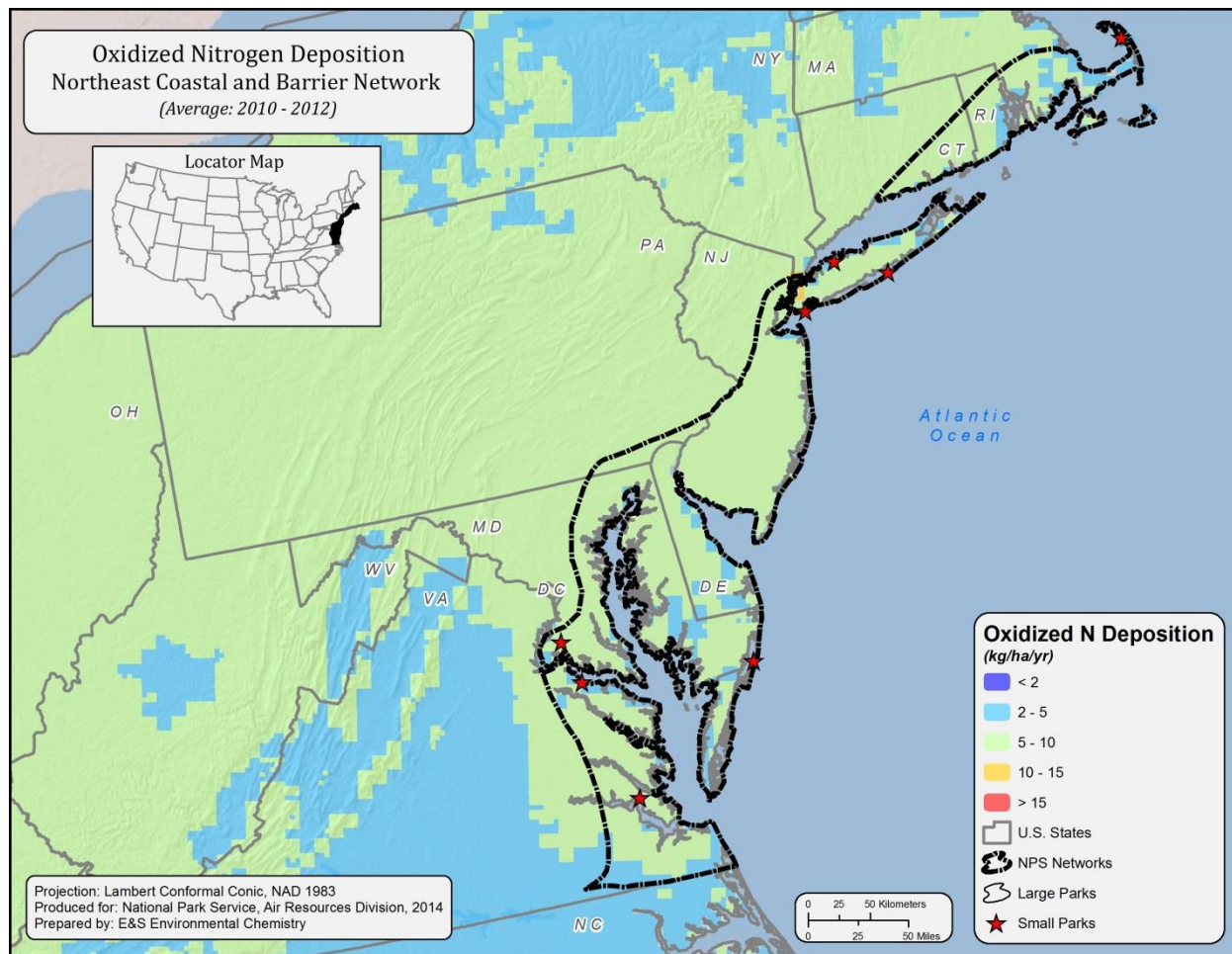
**Table 1 (continued).** Average changes in S and N deposition between 2001 and 2011 across park grid cells at NCBN parks. Deposition estimates were determined by the Total Deposition Project, TDEP, based on three-year averages centered on 2001 and 2011 for all ~4 km grid cells in each park. The minimum, 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) |
|-----------|---------------|------------|-------------------------|-------------------------|----------------------------|----------------|-------------------------|-------------------------|-----------------------|
| SAHI      | Sagamore Hill | Total S    | 16.17                   | 18.13                   | 1.96                       | 12.1%          | 6.26                    | 6.26                    | 0.00                  |
|           |               | Total N    | 18.40                   | 11.41                   | -6.99                      | -38.0%         | 5.81                    | 5.81                    | 0.00                  |
|           |               | Oxidized N | 14.14                   | 7.53                    | -6.61                      | -46.8%         | 3.48                    | 3.48                    | 0.00                  |
|           |               | Reduced N  | 4.26                    | 3.88                    | -0.38                      | -9.0%          | 2.34                    | 2.34                    | 0.00                  |
| THST      | Thomas Stone  | Total S    | 17.23                   | 7.76                    | -9.47                      | -55.0%         | 7.57                    | 8.16                    | 0.60                  |
|           |               | Total N    | 13.21                   | 9.37                    | -3.84                      | -29.1%         | 9.02                    | 10.15                   | 1.13                  |
|           |               | Oxidized N | 10.04                   | 5.76                    | -4.28                      | -42.6%         | 5.57                    | 6.17                    | 0.59                  |
|           |               | Reduced N  | 3.17                    | 3.61                    | 0.44                       | 13.9%          | 3.45                    | 3.99                    | 0.54                  |

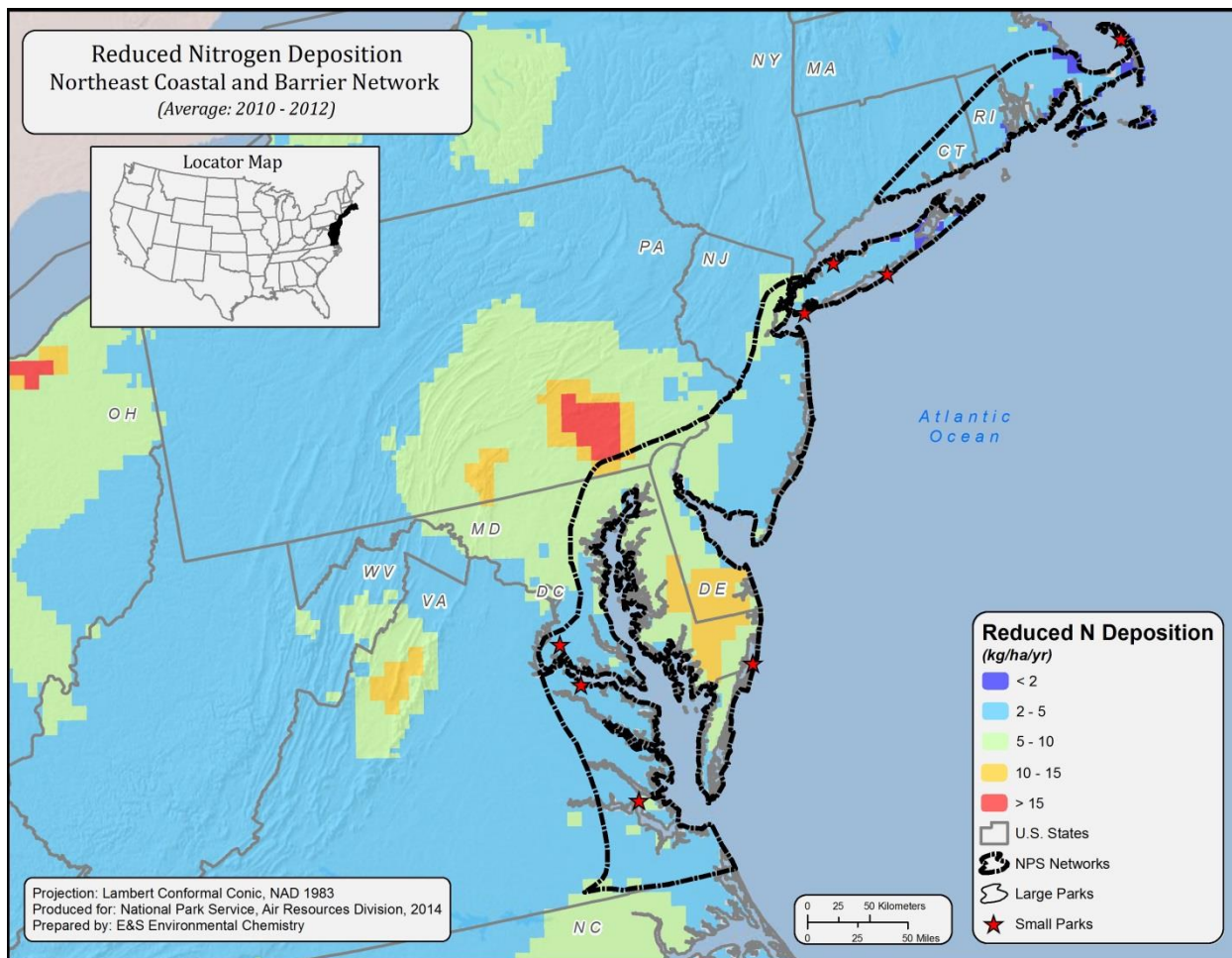
Total S deposition in and around NCBN for the period 2010-2012 was generally highest ( $> 10$  kg S/ha/yr) to the northwest (Map 5). Oxidized inorganic N deposition for the period 2010-2012 was less than 10 kg N/ha/yr throughout the park land within NCBN (Map 6). Most areas received less than 5 kg N/ha/yr of reduced inorganic N from atmospheric deposition during this same period (Map 7); a few areas received higher amounts. Total N deposition was more than 10 kg N/ha/yr at most park locations (Map 8).



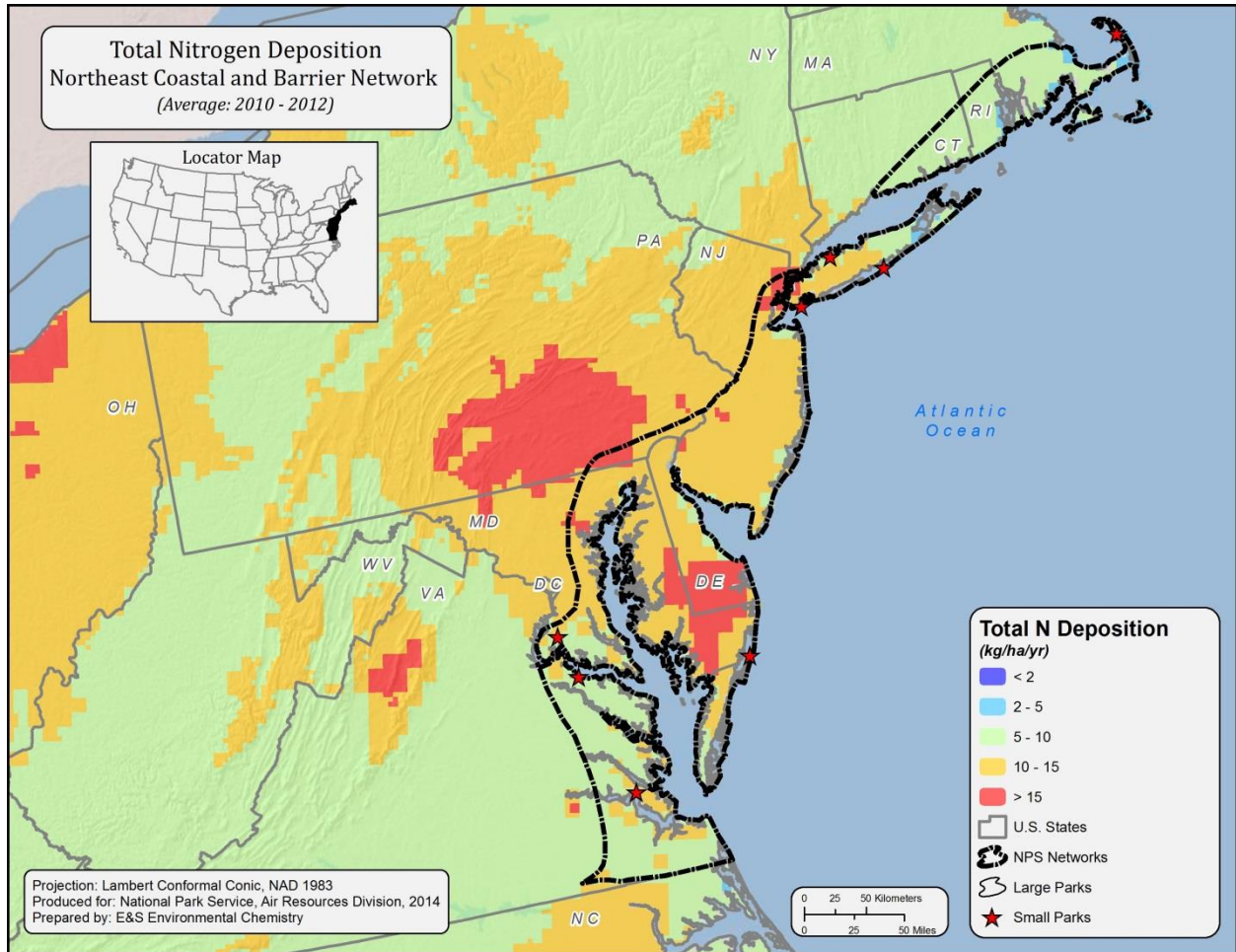
**Map 5.** Total S deposition for the three-year period centered on 2011 in and around NCBN. (Source: Schwede and Lear 2014)



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



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



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

## Acidification

Based on a coarse screening assessment, the network rankings for acid Pollutant Exposure, Ecosystem Sensitivity to acidification, and Park Protection yielded an overall network acidification Summary Risk ranking (Sullivan et al. 2011b) that was relatively low among 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 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. Relief in NCBN is low, with less than 10° average slope in all of the parks, suggesting a low potential for acid sensitivity of aquatic ecosystems. Nevertheless, some portions of NCBN, including Cape Cod, contain numerous precipitation-dominated perched seepage lakes, which are known to often be highly acid-sensitive.

The acid Pollutant Exposure ranking was Very High for all of the parks in this network except CACO, which was ranked High (Table 2). Ecosystem Sensitivity to acidification rankings were lower: Low or Very Low for all of the parks except CACO, which was ranked High (Sullivan et al. 2011b). While rankings are an indication of risk, park-specific data, particularly data on ecosystem sensitivity, are needed to fully evaluate risk from acidification.

**Table 2.** Estimated I&M park rankings<sup>1</sup> according to risk of acidification impacts on sensitive receptors (Source: Sullivan et al. 2011b).

| Park Name                    | Park Code | Estimated Acid Pollutant Exposure | Estimated Ecosystem Sensitivity to Acidification |
|------------------------------|-----------|-----------------------------------|--------------------------------------------------|
| Assateague Island            | ASIS      | Very High                         | Very Low                                         |
| Cape Cod                     | CACO      | High                              | High                                             |
| Colonial                     | COLO      | Very High                         | Low                                              |
| Fire Island                  | FIIS      | Very High                         | Very Low                                         |
| Gateway                      | GATE      | Very High                         | Low                                              |
| George Washington Birthplace | GEWA      | Very High                         | Very Low                                         |
| Sagamore Hill                | SAHI      | Very High                         | Low                                              |
| Thomas Stone                 | THST      | Very High                         | Low                                              |

<sup>1</sup> 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).

Comiskey et al. (2013) reported soil chemistry at forest vegetation monitoring locations in GEWA and THST. The median Ca:Al ratio in GEWA was low (0.41), suggesting high acid sensitivity and/or soil acidification impact. The Ca:Al ratio of THST was much higher (14.4), suggesting good acid-base chemistry condition.

The Maryland Synoptic Stream Chemistry Survey (MSSCS) was designed to estimate the number and extent of acidic and relatively acid-sensitive streams in Maryland, including in the vicinity of ASIS (Knapp et al. 1988). Based on this survey of 73 streams, the majority of potentially acid-sensitive streams in the state occur in the Southern Coastal Plain region surrounding the Chesapeake

Bay and in the Appalachian Plateau ecoregion in western Maryland. Streams on the Southern Coastal Plain of Maryland generally had relatively low ANC. Nearly three-fourths of the streams in this region included in the MSSCS had ANC less than 200  $\mu\text{eq/L}$  (Janicki et al. 1995). Stream chemistry may be detrimental to the health of fish in many of these streams (Klauda 1989, Morgan et al. 1990).

The Maryland Critical Loads Study applied the PROFILE model to simulate the chemical behavior of soils and stream water and to estimate the steady-state critical load of S and N deposition to protect stream acid-base chemistry throughout Maryland (Janicki et al. 1995). About one-fourth of the stream reaches in Maryland had estimated levels of S deposition in their watersheds that was higher than the simulated steady-state critical load of acidity and were expected to be at risk of episodic acidification. The Appalachian Plateau and Coastal Plain had steady-state critical loads estimated to generally be below 8 kg S/ha/yr. It is not clear whether this level of acid sensitivity extends to the park lands in NCBN.

## Nutrient Nitrogen Enrichment

The network rankings for nutrient N Pollutant Exposure, Ecosystem Sensitivity to nutrient N enrichment, and Park Protection yielded an overall nutrient Network Risk ranking for NCBN that was at the bottom of the third quintile, below the median among all networks. The overall level of concern for nutrient N enrichment effects on I&M parks within NCBN was judged by Sullivan et al. (2011a) to be below average among park networks.

Nutrient N Pollutant Exposure for each of the individual parks in NCBC was ranked in the highest or second highest quintile. Ecosystem Sensitivity to nutrient N enrichment rankings for the individual parks tended to be somewhat lower, in the middle and lower quintiles for all of the parks except GEWA, which was ranked High (Table 3; Sullivan et al. 2011a). 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.

**Table 3.** Estimated park rankings<sup>1</sup> according to risk of nutrient enrichment impacts on sensitive receptors (Source: Sullivan et al. 2011a)

| Park Name                    | Park Code | Estimated Nutrient N Pollutant Exposure | Estimated Ecosystem Sensitivity to Nutrient N Enrichment |
|------------------------------|-----------|-----------------------------------------|----------------------------------------------------------|
| Assateague Island            | ASIS      | High                                    | Moderate                                                 |
| Cape Cod                     | CACO      | High                                    | Moderate                                                 |
| Colonial                     | COLO      | High                                    | Moderate                                                 |
| Fire Island                  | FIIS      | Very High                               | Low                                                      |
| Gateway                      | GATE      | Very High                               | Moderate                                                 |
| George Washington Birthplace | GEWA      | Very High                               | High                                                     |
| Sagamore Hill                | SAHI      | Very High                               | Low                                                      |
| Thomas Stone                 | THST      | Very High                               | Very Low                                                 |

<sup>1</sup> 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).

The median soil C:N ratio reported by Comiskey et al. (2013) at THST was low (15.4), suggesting significant concern regarding N enrichment. The C:N ratio at GEWA was somewhat higher (20.4) and was rated by Comiskey et al. (2013) as reflective of the need for caution regarding nutrient addition.

Salt marsh vegetation is highly sensitive to potential nutrient enrichment effects from atmospheric N deposition, and is also influenced by changing water levels that will likely accompany climate change. Sea level rise will contribute to conversion of some vegetated marshlands to mudflat or open water. NPS and USGS have been jointly monitoring salt marsh elevation change at CACO, FIIS, and GATE for over a decade (Roman et al. 2011). Preliminary results suggest that changes in the coverage of some salt marshes are not keeping pace with sea level rise.

Estuaries throughout NCBN are severely threatened by adverse effects from nutrient enrichment (Neckles et al. 2011). Estuarine water samples have been collected since 2003 to track changes in nutrient concentrations. Park-specific data are planned to be examined in the regional context, by comparing results with regional sampling by the U.S. EPA.

One of the adverse impacts of eutrophication on estuarine and coastal ecosystems is a decrease in the extent of eelgrass and other submerged aquatic vegetation. Investigators in some parks are delineating the extent of submerged aquatic vegetation in park estuaries to provide data needed for more effective resource management. The Provincetown Center for Coastal Studies is conducting a study to develop benthic habitat maps in coastal waters of Massachusetts. High-resolution interferometric sidescan sonar together with swath bathymetry are being used to map shallow water vegetation in Cape Cod Bay (Brown et al. 2011). Similarly, USGS and the National Oceanic and Atmospheric Administration (NOAA) have partnered with NPS to map submerged resources in nine coastal parks in Alaska, California, Great Lakes, Gulf of Mexico, and the Caribbean (Cross and Curdts 2011).

Atmospheric S and N air pollutants have had substantial effects on lichen communities in the southeastern coastal plain (Gilliam et al. 2011), including reduced lichen cover and richness. Of 70 species found in about the year 1900 on Plummer's Island (15 km south of Washington, DC), only 20 remained in the early 1990s (Lawrey 1993). On the northern shoreline of Long Island, epiphytic lichen-richness had decreased to 14 species by 1966 (Brodo 1966).

The Coastal Plains ecoregions extend from Long Island to Florida. Tree cover is generally pine (*Pinus* spp.) with herbaceous understory of high diversity (Gilliam 2007, Platt et al. 2006). Responses of coastal plains ecosystems to N enrichment have not been well-studied (Gilliam et al. 2011). It is likely, however, that these forest ecosystems can tolerate relatively high atmospheric N loading because they have historically been maintained by periodic disturbance, mainly fire and storm damage. Fire is known to alter the N status of forest soils in this region (Boerner et al. 2004), as is the frequency and intensity of tropical storms (Gilliam et al. 2006).

Intertidal wetlands are highly susceptible to N inputs. Effects can include enhanced spread of non-native invasive species (Tyler et al. 2007), decreased abundance of N-sensitive plant species such as eelgrass (*Zostera* spp. Latimer and Rego 2010), increased primary productivity (Darby and Turner 2008, Wigand et al. 2003), and changes in competition.

Eelgrass provides important nursery habitat in estuaries for a variety of marine, estuarine, and anadromous species of fish and shellfish. Eelgrass also plays an important role in sediment accumulation and stabilization. The distribution of eelgrass has declined substantially in recent decades in both East and West Coast estuaries in the United States. Atmospheric and non-atmospheric N loading has contributed to this decline (Greaver et al. 2011). Total estuarine N loading higher than 50 kg N/ha/yr was shown to be associated with decline in eelgrass distribution in 62 shallow estuaries in coastal Massachusetts, Connecticut, and Rhode Island (Latimer and Rego 2010). At N input above 100 kg N/ha/yr, nearly all eelgrass was eliminated.

Few studies have been conducted on the relative sensitivity of different tree species to the nutrient enrichment effects of N deposition in NCBN. However, based on research at Harvard Forest (Magill et al. 2004), conifers seem more sensitive (as evidenced by growth declines) to the effects of N addition than hardwood species (which often exhibited increased production). Among hardwoods, red maple appeared to be particularly sensitive to N addition, indicated by high mortality, but the effects of this study were complicated by drought conditions.

Pardo et al. (2011) 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. Available data on empirical CL of nutrient-N suggested that the lower end of the estimated CL range for resource protection in parks in NCBN was generally about 3-8 kg N/ha/yr (Table 4). Pardo et al.'s (2011) estimates of ambient N deposition at these parks were higher than these levels in most cases. These data suggest the possibility of widespread exceedance of empirical nutrient-N CL at parks in NCBN. The sensitive receptors that are subjects of exceedance include mycorrhizal fungi, lichens, and forest vegetation, as well as prevention of  $\text{NO}_3^-$  leaching to drainage water. Pardo et al. (2011) also estimated that GATE, but not other parks in the network, may be in exceedance for protecting herbaceous plants.

**Table 4.** Empirical critical loads for nitrogen in NCBN, 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<br>(kg N/ha/yr) | Critical Load (kg N/ha/yr) |        |                     |        |                     |
|------------------------------------|---------------------------------|------------------------------|----------------------------|--------|---------------------|--------|---------------------|
|                                    |                                 |                              | Mycorrhizal<br>Fungi       | Lichen | Herbaceous<br>Plant | Forest | Nitrate<br>Leaching |
| Assateague Island NS               | Eastern<br>Temperate<br>Forests | 8.1                          | 5-12                       | 4-8    | 17.5                | 3-8    | 8                   |
| Cape Cod NS                        | Eastern<br>Temperate<br>Forests | 6.5                          | 5-12                       | 4-8    | 17.5                | 3-8    | 8                   |
| Colonial NHP                       | Eastern<br>Temperate<br>Forests | 12.8                         | 5-12                       | 4-8    | 17.5                | 3-8    | 8                   |
| Fire Island NS                     | NA                              | NA                           | -                          | -      | -                   | -      | -                   |
| Gateway NRA                        | Eastern<br>Temperate<br>Forests | 19.5                         | 5-12                       | 4-8    | 17.5                | 3-8    | 8                   |
| George Washington<br>Birthplace NM | Eastern<br>Temperate<br>Forests | 12.7                         | 5-12                       | 4-8    | 17.5                | 3-8    | 8                   |
| Sagamore Hill NHS                  | NA                              | NA                           | NA                         | NA     | NA                  | NA     | NA                  |
| Thomas Stone NHS                   | Eastern<br>Temperate<br>Forests | 14.3                         | 5-12                       | 4-8    | 17.5                | 3-8    | 8                   |

## Ozone Injury to Vegetation

The O<sub>3</sub> sensitive plant species that are known or thought to occur within the I&M parks found in NCBN are listed in Table 5. Those considered to be bioindicators, because they exhibit distinctive symptoms when injured by O<sub>3</sub> (e.g., dark stipple), are designated by an asterisk. Each park within the network contained at least 15 O<sub>3</sub>-sensitive and/or bioindicator species.

**Table 5.** Ozone-sensitive and bioindicator plant species known or thought to occur in the I&M parks of NCBN. (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 |      |      |      |      |      |      |      |
|------------------------------------------------|----------------------|------|------|------|------|------|------|------|------|
|                                                |                      | ASIS | CACO | COLO | FIIS | GATE | GEWA | SAHI | THST |
| <i>Ailanthus altissima</i> *                   | Tree-of-heaven       | x    | x    | x    | x    | x    | x    | x    | x    |
| <i>Alnus incana</i> spp. <i>rugosa</i> *       | Speckled alder       |      | x    |      |      |      |      |      |      |
| <i>Apios americana</i> *                       | Groundnut            | x    | x    | x    | x    | x    | x    |      |      |
| <i>Apocynum androsaemifolium</i> *             | Spreading dogbane    |      | x    |      |      |      |      |      |      |
| <i>Apocynum cannabinum</i>                     | Dogbane, Indian hemp | x    | x    | x    | x    | x    | x    |      | x    |
| <i>Artemisia ludoviciana</i> *                 | Silver wormwood      | x    |      |      |      |      |      |      |      |
| <i>Asclepias incarnata</i>                     | Swamp milkweed       |      |      | x    |      | x    | x    |      |      |
| <i>Asclepias incarnata</i> spp. <i>pulchra</i> | Swamp milkweed       | x    |      |      |      |      |      |      |      |
| <i>Asclepias syriaca</i> *                     | Common milkweed      | x    | x    | x    | x    | x    | x    | x    | x    |
| <i>Cercis canadensis</i> *                     | Redbud               |      |      | x    |      | x    | x    |      | x    |
| <i>Clematis virginiana</i>                     | Virgin's bower       |      |      |      |      |      |      |      | x    |
| <i>Corylus americana</i> *                     | American hazelnut    |      | x    |      |      |      |      | x    | x    |
| <i>Eupatorium rugosum</i> *                    | White snakeroot      |      |      | x    |      | x    |      | x    |      |
| <i>Eupatorium serotinum</i> *                  | White snakeroot      | x    |      |      |      |      |      |      |      |
| <i>Fraxinus americana</i> *                    | White ash            |      |      | x    | x    | x    |      |      | x    |
| <i>Fraxinus pennsylvanica</i>                  | Green ash            |      |      | x    |      | x    |      |      |      |
| <i>Gaylussacia baccata</i> *                   | Black huckleberry    | x    | x    | x    | x    | x    |      | x    | x    |
| <i>Liquidambar styraciflua</i>                 | Sweetgum             | x    |      | x    |      | x    | x    | x    | x    |
| <i>Liriodendron tulipifera</i> *               | Yellow-poplar        | x    |      | x    |      | x    | x    | x    | x    |
| <i>Lyonia ligustrina</i> *                     | Maleberry            |      | x    | x    | x    |      |      |      |      |
| <i>Parthenocissus quinquefolia</i>             | Virginia creeper     | x    | x    | x    | x    | x    | x    | x    | x    |
| <i>Pinus banksiana</i>                         | Jack pine            |      | x    |      |      |      |      |      |      |
| <i>Pinus rigida</i>                            | Pitch pine           | x    | x    |      | x    | x    |      |      |      |
| <i>Pinus taeda</i>                             | Loblolly pine        | x    |      | x    |      |      | x    |      |      |
| <i>Pinus virginiana</i>                        | Virginia pine        | x    |      | x    |      | x    | x    |      | x    |
| <i>Platanus occidentalis</i> *                 | American sycamore    | x    |      | x    |      | x    | x    |      | x    |
| <i>Populus tremuloides</i> *                   | Quaking aspen        |      | x    | x    |      | x    |      |      |      |
| <i>Prunus serotina</i> *                       | Black cherry         | x    | x    | x    | x    | x    | x    | x    | x    |
| <i>Prunus virginiana</i>                       | Choke cherry         |      | x    |      |      | x    |      |      |      |
| <i>Rhus copallina</i>                          | Winged sumac         | x    |      |      |      | x    | x    | x    |      |
| <i>Rhus copallinum</i>                         | Winged sumac         |      | x    | x    | x    |      |      |      |      |
| <i>Robinia pseudoacacia</i>                    | Black locust         | x    | x    | x    | x    | x    | x    | x    | x    |

\* Bioindicator species

**Table 5 (continued).** Ozone-sensitive and bioindicator plant species known or thought to occur in the I&M parks of NCBN. (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 |      |      |      |      |      |      |      |
|-----------------------------------------------|----------------------|------|------|------|------|------|------|------|------|
|                                               |                      | ASIS | CACO | COLO | FIIS | GATE | GEWA | SAHI | THST |
| <i>Rubus allegheniensis</i> *                 | Allegheny blackberry | x    | x    | x    | x    | x    |      | x    |      |
| <i>Rubus cuneifolius</i>                      | Sand blackberry      | x    |      | x    |      |      |      |      |      |
| <i>Rudbeckia laciniata</i> *                  | Cutleaf coneflower   |      |      | x    |      | x    |      |      |      |
| <i>Sambucus canadensis</i> *                  | American elder       | x    | x    | x    | x    | x    | x    | x    | x    |
| <i>Sassafras albidum</i>                      | Sassafras            | x    | x    | x    | x    | x    | x    | x    | x    |
| <i>Solidago altissima</i>                     | Goldenrod            |      |      | x    |      |      |      |      |      |
| <i>Solidago canadensis</i> var. <i>scabra</i> | Goldenrod            |      |      |      | x    |      |      |      |      |
| <i>Spartina alterniflora</i>                  | Smooth cordgrass     | x    | x    | x    | x    | x    | x    | x    |      |
| <i>Symphoricarpos albus</i> *                 | Common snowberry     |      |      |      |      | x    |      |      |      |
| <i>Verbesina occidentalis</i> *               | Crownbeard           | x    |      | x    |      |      | x    |      | x    |
| <i>Vitis labrusca</i> *                       | Northern fox grape   |      | x    | x    | x    | x    | x    |      | x    |

\* Bioindicator species

The W126 and SUM06 O<sub>3</sub> exposure indices calculated by NPS staff are given in Table 6, along with Kohut's (2007a) O<sub>3</sub> risk ranking. The NPS and Kohut ranking systems differ. The NPS ranking system (NPS 2010) is a quick assessment of O<sub>3</sub> condition that ranks O<sub>3</sub> exposure levels according to injury thresholds from the literature (Heck and Cowling 1997), using a 5-year average of either the W126 or SUM06 index. The former is a measure of cumulative O<sub>3</sub> exposure that preferentially weights higher concentrations; the latter is a measure of cumulative O<sub>3</sub> exposure that includes only hourly concentrations over 60 ppb. Both metrics are calculated over a 3-month period. The W126 was classified as Moderate exposure at values between 7 and 13 ppm-hr, as defined by NPS (2010). Values higher than 13 ppm-hr were classified as High exposure, and values lower than 7 ppm-hr were classified as Low exposure. 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, as defined by NPS (2010). Using these criteria, ozone levels at the NCBN parks are rated Moderate to High.

Kohut's approach constitutes a rigorous assessment of potential risk to plants. It considers both O<sub>3</sub> exposure and environmental conditions (soil moisture). Kohut also used injury thresholds from the literature, but evaluated a different O<sub>3</sub> metric (after Lefohn et al. 1997), the W126 over a 5-month period in conjunction with the N100 (number of hours over 100 ppb O<sub>3</sub>). The rationale for the N100 statistic is that higher O<sub>3</sub> concentrations are most likely to cause plant injury. Kohut examined five individual years of O<sub>3</sub> exposure and soil moisture data and considered the effects of low soil moisture on O<sub>3</sub> uptake each year when assigning risk. Soil moisture is important because dry conditions induce stomatal closure in plants, which has the effect of limiting O<sub>3</sub> uptake and injury. In areas where low soil moisture levels correspond with high O<sub>3</sub> exposure, uptake and injury are limited by stomatal closure even when exposures are relatively high. Kohut's (2007a) ranking was High across all parks in this network.

**Table 6.** Ozone assessment results for I&M parks in NCBN 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 1995-1999<sup>1</sup>.

| Park Name                    | Park Code | W126           |          | Sum06          |          | Kohut O <sub>3</sub> Risk Ranking |
|------------------------------|-----------|----------------|----------|----------------|----------|-----------------------------------|
|                              |           | Value (ppm-hr) | Ranking  | Value (ppm-hr) | Ranking  |                                   |
| Assateague Island            | ASIS      | 15.00          | High     | 17.31          | High     | High                              |
| Cape Cod                     | CACO      | 9.72           | Moderate | 12.04          | Moderate | High                              |
| Colonial                     | COLO      | 13.64          | High     | 18.02          | High     | High                              |
| Fire Island                  | FIIS      | 12.23          | Moderate | 15.28          | High     | High                              |
| Gateway                      | GATE      | 12.00          | Moderate | 14.91          | Moderate | High                              |
| George Washington Birthplace | GEWA      | 14.52          | High     | 19.22          | High     | High                              |
| Sagamore Hill                | SAHI      | 11.68          | Moderate | 14.36          | Moderate | High                              |
| Thomas Stone                 | THST      | 14.48          | High     | 19.16          | High     | High                              |

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

The results of both ranking systems should be considered when evaluating the potential for O<sub>3</sub> injury to park vegetation. The Kohut approach considered environmental conditions that affect plant response to O<sub>3</sub>, but exposures have likely changed since the time of the assessment. The NPS approach considers more recent O<sub>3</sub> conditions, but not environmental conditions.

Davis and Orendovici (2006) calculated the percentage of plant species showing O<sub>3</sub>-induced foliar symptoms in the Edwin B. Forsythe National Wildlife Refuge along the coastline of New Jersey. Symptom incidence varied among species and years. The bioindicators most sensitive to O<sub>3</sub> appeared to be common milkweed (*Asclepias syriaca*) and wild grape (*Vitis* spp.). The researchers developed a model to illustrate the linkage between symptom incidence and various measured environmental parameters. Symptom incidence was significantly correlated with species exposed, Palmer Drought Severity Index, and the interaction of the W126 and N100 measures of O<sub>3</sub> exposure (Davis and Orendovici 2006).

Soil moisture levels appeared to be inversely related to O<sub>3</sub> exposure in each of the parks in NCBN, although these results were inconsistent in CACO and GEWA. In general, when O<sub>3</sub> exposure was high, soil moisture was low. This would be expected to limit O<sub>3</sub> uptake into foliage and reduce the likelihood of foliar injury. Nevertheless, given the high levels of exposure, Kohut (2007b) classified the risk of foliar injury due to O<sub>3</sub> exposure as High in each of the parks in NCBN.

Ollinger et al. (1997) modeled O<sub>3</sub> impacts to forest productivity from 1987 to 1992 in the northeastern U.S., predicting declines in net primary productivity of 3-16% due to O<sub>3</sub>. EPA modeled seedling biomass losses due to O<sub>3</sub> levels in 2001, predicting losses exceeding 10% for several tree species in the Northeast, including black cherry and aspen (Lehrer et al. 2007).

Atmospheric O<sub>3</sub> concentrations at 568 monitoring sites nationwide showed generally stable levels throughout the 1990s, but concentrations declined between 2002 and 2007, due largely to NO<sub>x</sub> emissions reductions (U.S. EPA 2008). Even though there have been widespread improvements in atmospheric O<sub>3</sub> levels, there were still 51 sites classified as nonattainment areas in 2007 because of failure to meet the O<sub>3</sub> NAAQ standard (U.S. EPA 2008). Some of the highest O<sub>3</sub> concentrations in the United States in 2007 were located in Connecticut, Massachusetts, and Pennsylvania (U.S. EPA 2008), in or near NCBN. There were 18 sites that showed O<sub>3</sub> levels that were above the new O<sub>3</sub> standard (fourth highest daily maximum 8-hour concentration equal to 0.075 ppm) in 2007, and also showed an increase of more than 0.005 ppm. One of these sites was New York, NY.

# Visibility Degradation

## Natural Background and Ambient Visibility Conditions

The Clean Air Act set a specific goal for visibility protection in Class I areas: “the prevention of any future, and the remedying of any existing, impairment of visibility in mandatory Class I federal areas which impairment results from manmade air pollution” (42 U.S.C. 7491). In 1999, EPA passed the 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 in 2064. Natural background visibility, or natural haze, assumes no human-caused pollution, but varies with natural processes such as windblown dust, fire, volcanic activity and biogenic emissions. Although none of the NCBN parks are designated Class I areas under the Clean Air Act (they are designated as Class II), the RHR is expected to indirectly benefit many areas by requiring emissions reductions from large sources. Haze is monitored by the Interagency Monitoring of Protected Visual Environments (IMPROVE) Network and typically reported using the haze index deciview (dv)<sup>1</sup>.

Haze is monitored by IMPROVE in CACO in NCBN. Data are also available that are considered to be representative of visibility conditions in two of the other parks, GEWA and THST. 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.

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 IMPROVE monitors or representative monitors were used in generating the baseline visibility ranking. Table 7 gives estimated natural visibility and current visibility conditions for IMPROVE sites at CACO (CACO1) and Washington DC (WASH1), the site representative of GEWA and THST.

Measured current haze values on average days for the period 2004 through 2008 were substantially (approximately 8 to 15 dv) higher than the estimated natural conditions. Average visibility from 2005-2009 was moderate at the CACO1 monitor and of significant concern at the WASH1 monitor (NPS-ARD 2013).

IMPROVE data allow estimation of visual range (VR). Data indicate that air pollution in CACO has reduced average VR from 95 to 40 miles (153 to 64 km). On the haziest days, VR has been reduced from 60 to 20 miles (97 to 32 km). Severe haze episodes occasionally reduce visibility to 6 miles (10 km). At the WASH1 site (representative of GEWA and THST), air pollution has reduced average VR

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<sup>1</sup> 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.

from 100 to 20 miles (161 to 32 km). On the haziest days, VR has been reduced from 75 to 10 miles (121 to 16 km). Severe haze episodes occasionally reduce visibility to 6 miles (10 km).

### Composition of Haze

Various pollutants make up the haze that causes visibility impairment<sup>2</sup>. IMPROVE measures these pollutants and reports them as ammonium sulfate, ammonium nitrate, elemental carbon, coarse mass, organic mass, sea salt, and soil. Sulfates form in the atmosphere from SO<sub>2</sub> emissions from coal-burning power plants, smelters, and other industrial facilities. Nitrates form in the atmosphere from NO<sub>x</sub> emissions from combustion sources including vehicles, power plants, industry, and fires.

**Table 7.** Estimated natural haze and measured ambient haze in I&M parks averaged over the period 2004 through 2008.

| Park Name                                 | Park Code | Site ID | Estimated Natural Haze (dv)                             |                  |              |
|-------------------------------------------|-----------|---------|---------------------------------------------------------|------------------|--------------|
|                                           |           |         | 20% Clearest Days                                       | 20% Haziest Days | Average Days |
| Assateague Island                         | ASIS      | No Site |                                                         |                  |              |
| Cape Cod                                  | CACO      | CACO1   | 5.95                                                    | 13.20            | 9.08         |
| Colonial                                  | COLO      | No Site |                                                         |                  |              |
| Fire Island                               | FIIS      | No Site |                                                         |                  |              |
| Gateway                                   | GATE      | No Site |                                                         |                  |              |
| George Washington Birthplace <sup>1</sup> | GEWA      | WASH1   | 5.51                                                    | 11.86            | 8.26         |
| Sagamore Hill                             | SAHI      | No Site |                                                         |                  |              |
| Thomas Stone <sup>1</sup>                 | THST      | WASH1   | 5.51                                                    | 11.86            | 8.26         |
| Park Name                                 | Park Code | Site ID | Measured Ambient Haze (for Years 2004 through 2008; dv) |                  |              |
|                                           |           |         | 20% Clearest Days                                       | 20% Haziest Days | Average Days |
| Assateague Island                         | ASIS      | No Site |                                                         |                  |              |
| Cape Cod                                  | CACO      | CACO1   | 11.18                                                   | 24.27            | 16.64        |
| Colonial                                  | COLO      | No Site |                                                         |                  |              |
| Fire Island                               | FIIS      | No Site |                                                         |                  |              |
| Gateway                                   | GATE      | No Site |                                                         |                  |              |
| George Washington Birthplace <sup>1</sup> | GEWA      | WASH1   | 16.86                                                   | 29.70            | 23.11        |
| Sagamore Hill                             | SAHI      | No Site |                                                         |                  |              |
| Thomas Stone <sup>1</sup>                 | THST      | WASH1   | 16.86                                                   | 29.70            | 23.11        |

<sup>1</sup> Data are borrowed from nearby IMPROVE sites. 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.

<sup>2</sup> *Visibility impairment* means any humanly perceptible change in visibility (light extinction, visual range, contrast, coloration) from that which would have existed under natural conditions.

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.

Within the northeastern United States, visibility improvement in recent years has been most pronounced in the western and southern portions of the MANE-VU region, in and near NCBN. The area of greatest visibility improvement has been in proximity to large power plant sources of SO<sub>2</sub> emissions in the Ohio River and Tennessee Valleys to the west of NCBN (NESCAUM 2006).

Regional sulfate (SO<sub>4</sub><sup>2-</sup>) emissions generally control visibility in the MANE-VU region during summer. During winter, visibility depends more on both regional and local S sources and also on local meteorological conditions (including temperature inversions). Organic C is, after SO<sub>4</sub><sup>2-</sup>, the next most important contributor to regional haze within MANE-VU (NESCAUM 2006).

A variety of model estimates suggested that emissions from the MANE-VU states account for about 25 to 30% of the fine particulate SO<sub>4</sub><sup>2-</sup> observed in Class I sites within the MANE-VU region. The Midwest Regional Planning Organization (MWRPO) and Visibility Improvement State and Tribal Association of the Southeast (VISTAS) states each accounted for another approximately 25% of total fine particulate SO<sub>4</sub><sup>2-</sup> at most Class I areas within the MANE-VU region (NESCAUM 2006).

Although MANE-VU has focused primarily on fine particle SO<sub>4</sub><sup>2-</sup> abatement in its efforts toward compliance with the RHR (NESCAUM 2006), controls on other haze-producing constituents, such as organic C and both urban and mobile sources of NO<sub>x</sub> during winter will also be important.

MANE-VU is using a weight of evidence approach to meeting the requirements of the RHR. Multiple independent methods are used to assess the relative contribution of different emissions sources and source regions to regional haze in the Class I areas within and near the MANE-VU region (NESCAUM 2006). These approaches include application of Eulerian grid-based source models, Lagrangian (air parcel-based) source dispersion models, back trajectory calculations, and analysis of monitoring data.

Sulfate is the most important cause of fine particle pollution and visibility impairment across the MANE-VU states. At the Class I sites in this region, SO<sub>4</sub><sup>2-</sup> accounts for about one-half to two-thirds of total fine particle mass on the 20% haziest days (NESCAUM 2006). On the 20% clearest days, SO<sub>4</sub><sup>2-</sup> typically accounts for 40% or more of total fine particle mass.

Extinction charts are shown for CACO, GEWA, and THST in Figure 1. The majority of the  $b_{ext}$  in all of the monitored parks for all groups (20% clearest, 20% haziest, and annual average days) was attributable to SO<sub>4</sub><sup>2-</sup>, NO<sub>3</sub><sup>-</sup>, and organics (Figure 2). In CACO, on average, SO<sub>4</sub><sup>2-</sup> contributed 55.6% of  $b_{ext}$ , NO<sub>3</sub><sup>-</sup> 9.8% and organics 12.5%. On the 20% haziest days, the contribution of SO<sub>4</sub><sup>2-</sup> increased to 67.5% of  $b_{ext}$ , while NO<sub>3</sub><sup>-</sup> was 8.3%, and organics were 11.8%. On the best 20% visibility days, the contribution of SO<sub>4</sub><sup>2-</sup> decreased substantially to 41.9%, while NO<sub>3</sub><sup>-</sup> accounted for 9.6% and organics for 15.4% of  $b_{ext}$ ; sea salt extinction was proportionally more important on the clearer days,

contributing 16.2% of  $b_{\text{ext}}$ . In GEWA and THST,  $\text{SO}_4^{2-}$  was the largest contributor to  $b_{\text{ext}}$  for all groups. Organics,  $\text{NO}_3^-$ , and carbon also contributed to the haze at these parks.

Annual mean dv levels on the haziest days at 47 monitored park locations during the period 2006-2008 ranged from 1.5 to 21 dv higher than the estimated natural condition (NPS 2010). The average difference between measured dv and estimated natural condition was 8.3 dv. Monitoring sites showing the largest differences during the period 2006-2008 between measured visibility on the clearest days and estimated natural conditions included Washington, DC, within the NCBN region (NPS 2010). Similarly, results for a slightly different time period (2004-2008) shown in Table 6 indicate a large difference (14.8 dv) between natural and ambient haze on the average days at GEWA and THST.

### **Trends in Visibility**

NPS (2010) reported long-term trends in annual dv on the clearest and haziest 20% of days at monitoring sites in 29 national parks. All 27 parks that showed statistically significant ( $p \leq 0.05$ ) dv trends on the clearest days for the 11-20 year monitoring periods through 2008 exhibited decreases in dv over time. None of the sites showed increasing trends on the clearest days. Some of the steepest declines (-0.2 dv/yr) on the clearest days were reported for Washington DC, with 18 years of monitoring data. Ten parks showed statistically significant decreases in dv on the haziest days, with the steepest declines reported for four parks, including Washington DC (-0.25 dv/yr).

Trends in haze on the 20% clearest, average, and 20% haziest days are shown in Figure 2 for CACO, GEWA, and THST. The most substantial improvements in haze occurred on the 20% haziest days, especially between 2005 and 2010.

## CACO

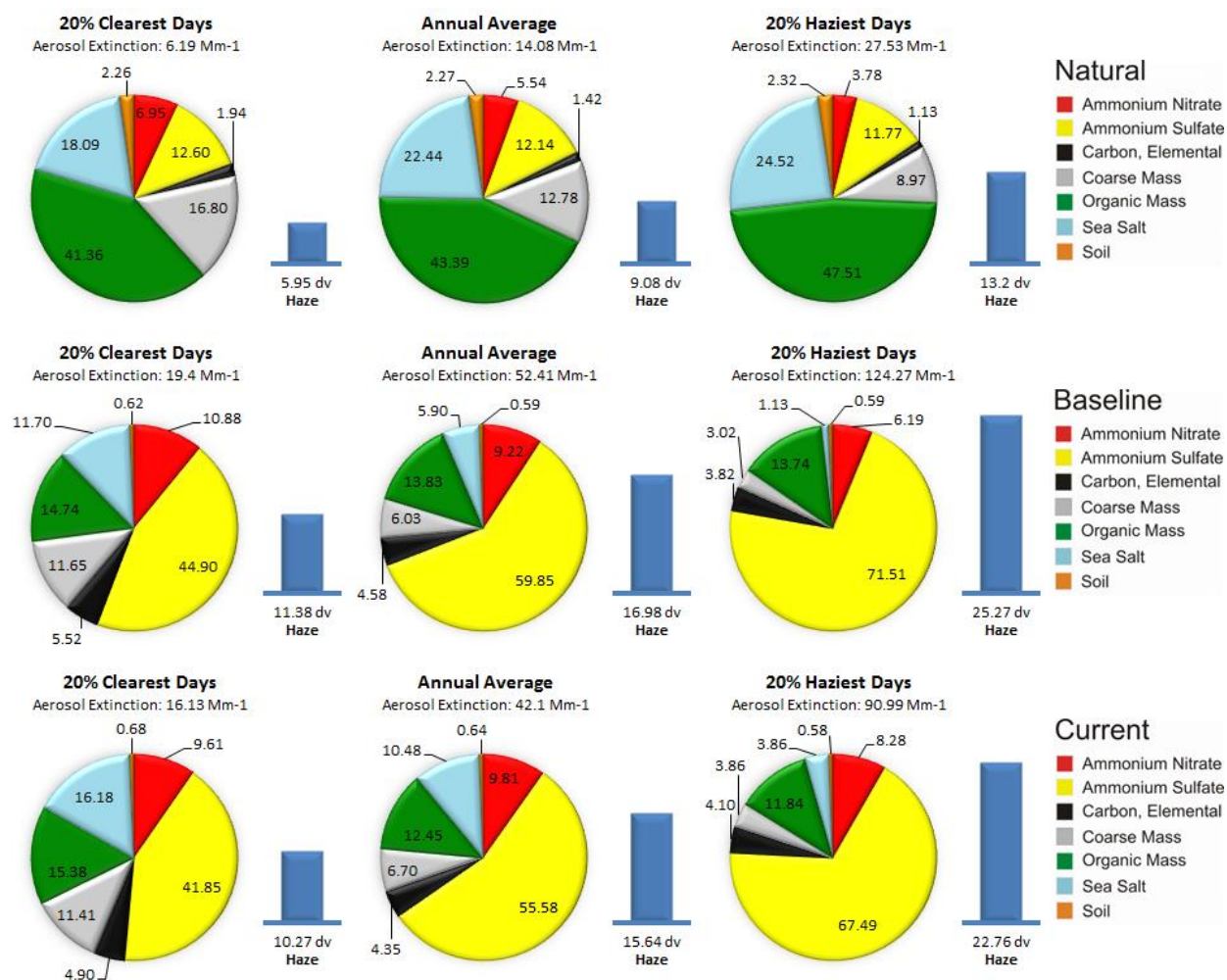


**Figure 1a.** Estimated natural (pre-industrial), baseline (2000-2004), and current (2006-2010) levels of haze (blue columns) and its composition (pie charts) on the 20% clearest, annual average, and 20% hazeiest visibility days for CACO. Data for GEWA and THST were taken from a nearby site (WASH1). CACO has no data for the years 2000 and 2001; GEWA and THST have no data for the year 2010. Data Source: NPS-ARD.

### WASH1 (for GEWA and THST)

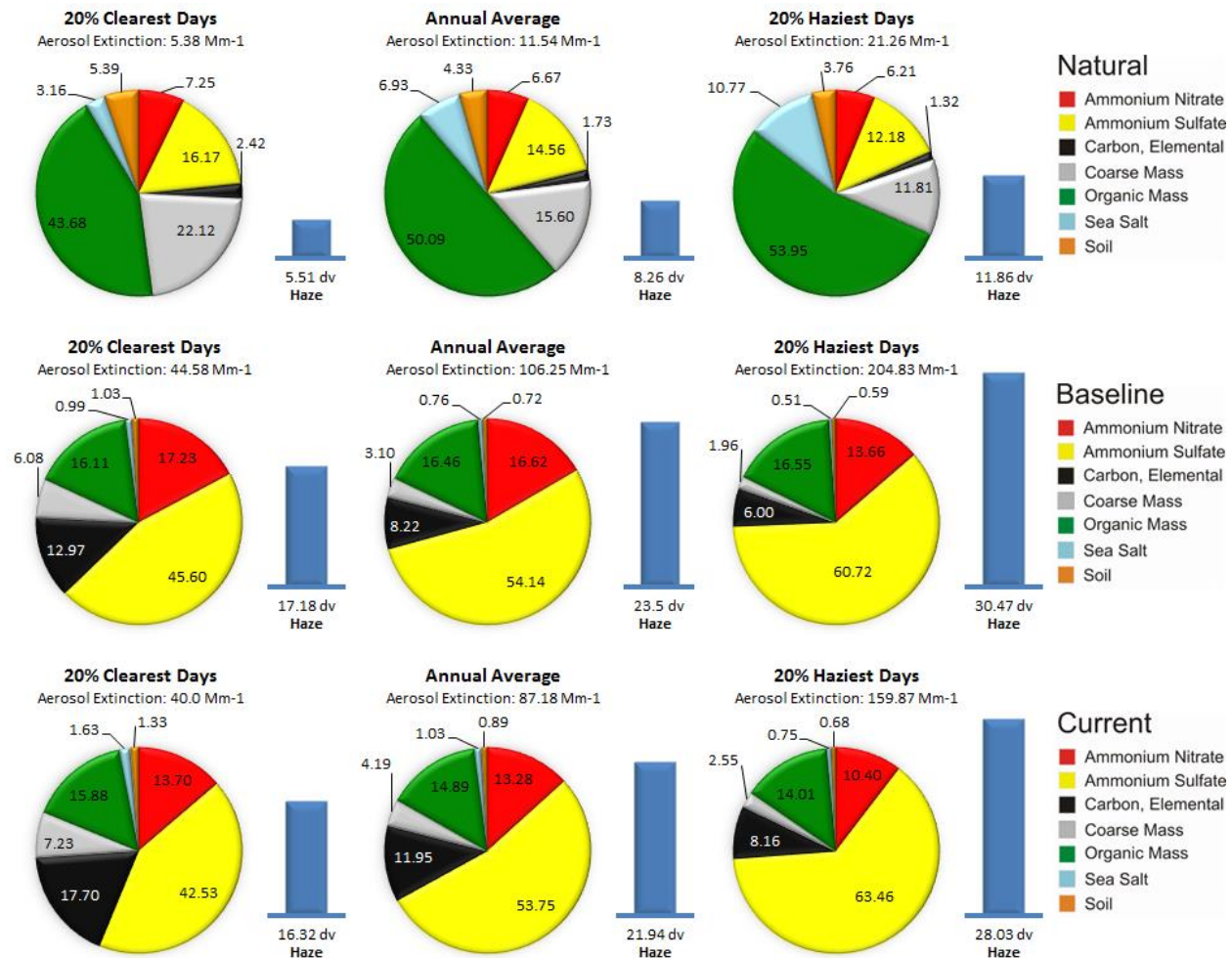


**Figure 1b.** Estimated natural (pre-industrial), baseline (2000-2004), and current (2006-2010) levels of haze (blue columns) and its composition (pie charts) on the 20% clearest, annual average, and 20% hazyest visibility days for GEWA and THST. Data for GEWA and THST were taken from a nearby site (WASH1). CACO has no data for the years 2000 and 2001; GEWA and THST have no data for the year 2010. Data Source: NPS-ARD.

### 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% hazyest 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 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).

Progress to date in NCBN in meeting the national visibility goal is illustrated in Figure 3 using a uniform rate of progress glideslope. Although clear progress has been made since the baseline period (2000-2004), substantial additional visibility improvement is needed to eliminate anthropogenic haze in 2064.

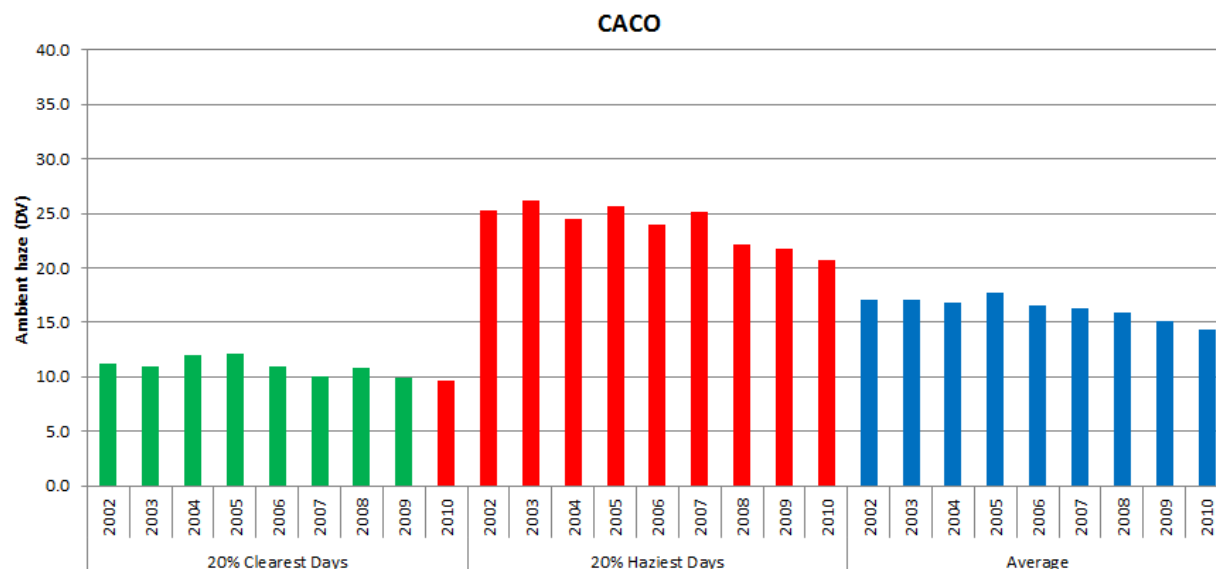


**Figure 2a.** Trends in ambient haze levels at CACO, based on IMPROVE measurements on the 20% clearest, 20% haziest, and annual average visibility days over the monitoring period of record. Data for GEWA and THST were taken from a nearby site (WASH1). Data Source: [http://vista.cira.colostate.edu/improve/Data/IMPROVE/summary\\_data.htm](http://vista.cira.colostate.edu/improve/Data/IMPROVE/summary_data.htm)

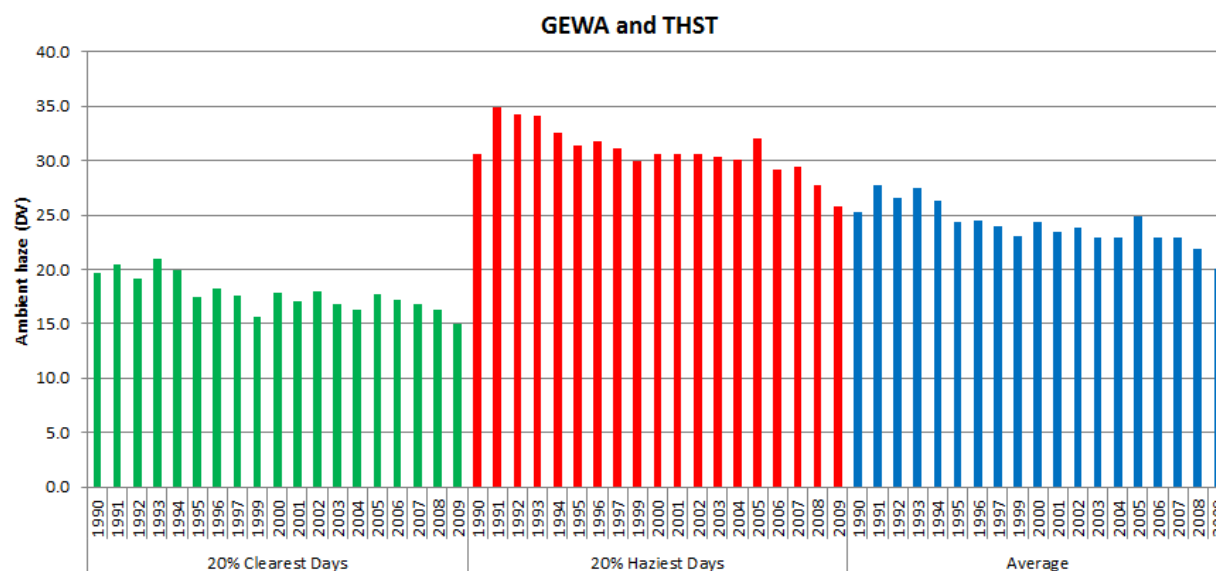


**Figure 2b.** Trends in ambient haze levels at GEWA and THST, based on IMPROVE measurements on the 20% clearest, 20% haziest, and annual average visibility days over the monitoring period of record. Data for GEWA and THST were taken from a nearby site (WASH1). Data Source: [http://vista.cira.colostate.edu/improve/Data/IMPROVE/summary\\_data.htm](http://vista.cira.colostate.edu/improve/Data/IMPROVE/summary_data.htm)

## Toxics

Myers et al. (2007) proposed a national map showing the relative sensitivity of aquatic ecosystems to mercury (Hg) contamination. Areas showing the highest estimated sensitivity were mainly confined to the East Coast (including within NCBN), Gulf Coast, and Upper Midwest, with scattered small areas in other regions.

Water contaminants are important management concerns in park lands in NCBN, including COLO (Cooper and Borjan 2010). However, the major contaminant sources at many locations are land-based point and nonpoint sources of nutrients, toxic materials, and household waste. The relative importance of atmospheric inputs of these contaminants to park lands in this network is not known, but is probably small in most cases.

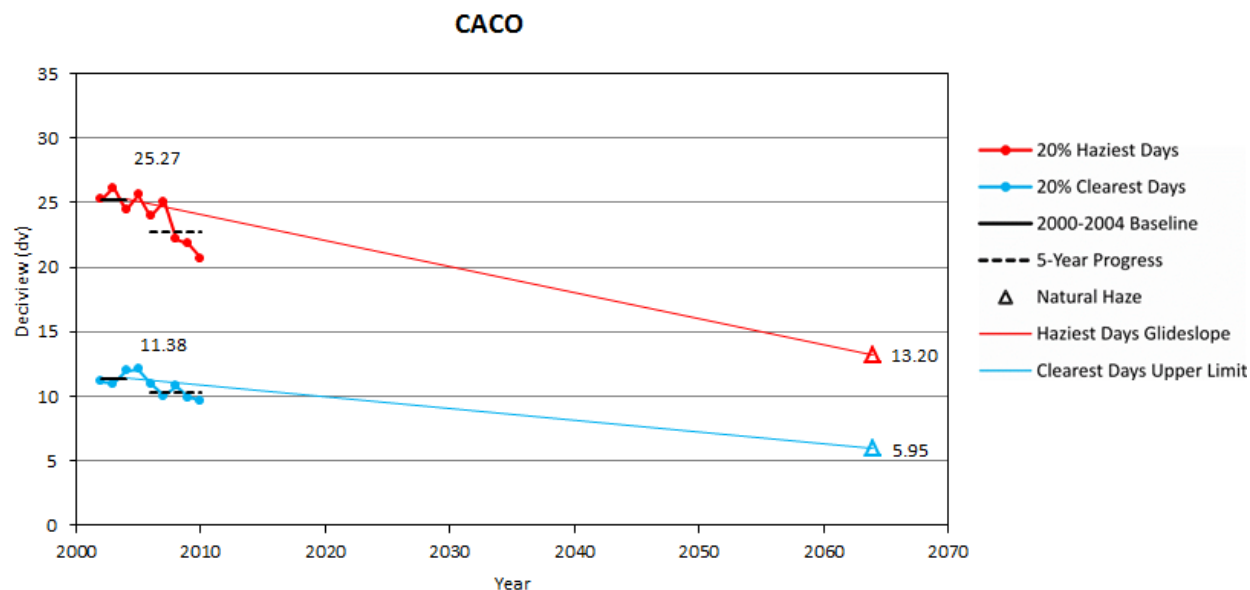


**Figure 3a.** Glideslopes to achieving natural visibility conditions in 2064 for the 20% haziest (red line) and the 20% clearest (blue line) days in CACO. In the regional haze rule, the clearest days do not have a uniform rate of progress glideslope; the rule only requires that the clearest days do not get any worse than the baseline period. Also shown are measured values during the period 2000 to 2010. Data for GEWA and THST were taken from a nearby site (WASH1). CACO has no data for the years 2000 and 2001; GEWA and THST have no data for the year 2010. Data Source:

[http://vista.cira.colostate.edu/improve/Data/IMPROVE/summary\\_data.htm](http://vista.cira.colostate.edu/improve/Data/IMPROVE/summary_data.htm)

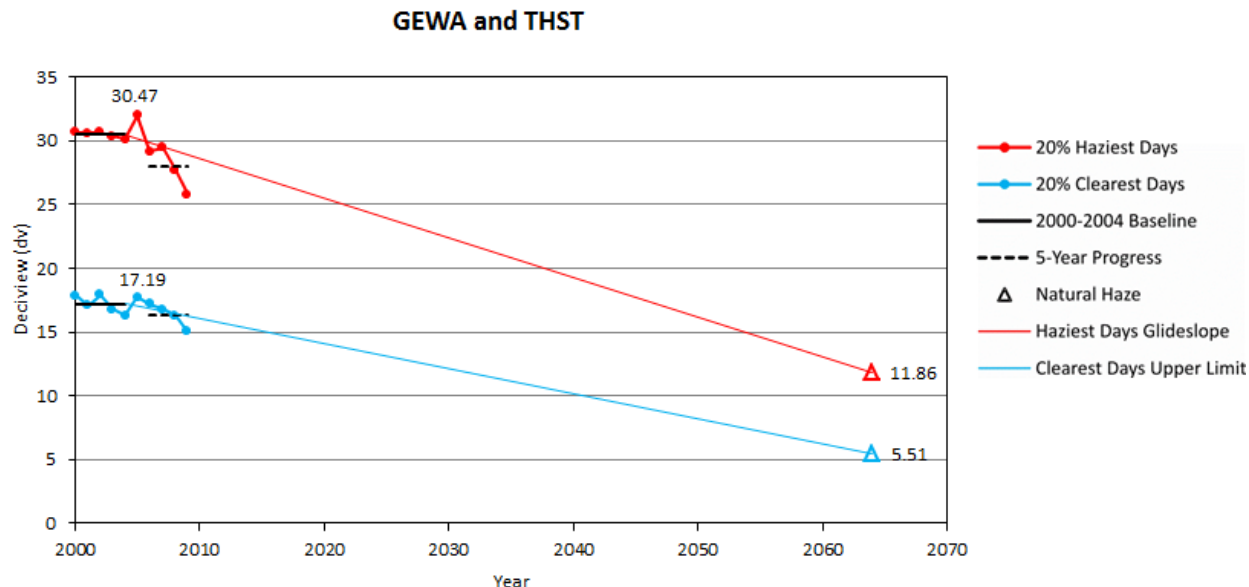


**Figure 3b.** Glideslopes to achieving natural visibility conditions in 2064 for the 20% haziest (red line) and the 20% clearest (blue line) days in GEWA and THST. In the regional haze rule, the clearest days do not have a uniform rate of progress glideslope; the rule only requires that the clearest days do not get any worse than the baseline period. Also shown are measured values during the period 2000 to 2010. Data for GEWA and THST were taken from a nearby site (WASH1). CACO has no data for the years 2000 and 2001; GEWA and THST have no data for the year 2010. Data Source:

[http://vista.cira.colostate.edu/improve/Data/IMPROVE/summary\\_data.htm](http://vista.cira.colostate.edu/improve/Data/IMPROVE/summary_data.htm)

## References Cited

- Air Resource Specialists. 2007. VISTAS Conceptual Description Support Document. Report prepared for Visibility Improvement State and Tribal Association of the Southeast. Fort Collins, CO.
- Boerner, R.E.J., J.A. Brinkman, and E.K. Sutherland. 2004. Effects of fire at two frequencies on nitrogen transformations and soil chemistry in a nitrogen enriched forest landscape. *Can. J. For. Res.* 34:609-618.
- Brodo, I.M. 1966. Lichen growth and cities: A study on Long Island, New York. *Bryologist* 69(4):427-449.
- Brown, T., A.R. Norton, M. Borrelli, and A. Gontz. 2011. Shallow water benthic habitat maps for resource managers: the technology and the science. Abstract. George Wright Society Conference on Parks, Protected Areas, & Cultural Sites. New Orleans, LA, May 14-18, 2011.
- Byun, D. and K.L. Schere. 2006. Review of the governing equations, computational algorithms, and other components of the Models-3 Community Multiscale Air Quality (CMAQ) modeling system. *Applied Mechanics Reviews* 59:51-77.
- Comiskey, J.A. 2013. Forest Vegetation Monitoring. Mid-Atlantic Network 2012 Summary Report. NPS/MIDN/NRDS-2013/555. National Park Service, Fort Collins, CO.
- Cooper, K.R. and M. Borjan. 2010. Northeast Coastal and Barrier Network Assessment of Contaminant Threats. Colonial National Historical Park. Natural Resource Report NPS/NCBN/NRTR-2010/355. U.S. Department of the Interior, National Park Service, Natural Resource Program Center, Fort Collins, CO.
- Cross, J. and T. Curdts. 2011. Mapping submerged resources in ocean, coastal, and great lakes parks. Abstract. George Wright Society Conference on Parks, Protected Areas, & Cultural Sites. New Orleans, LA, May 14-18, 2011.
- Darby, F.A. and R.E. Turner. 2008. Below- and aboveground *Spartina alterniflora* production in a Louisiana salt marsh. *Estuaries and Coasts* 31:223-231.
- Davis, D.D. and T. Orendovici. 2006. Incidence of ozone symptoms on vegetation within a National Wildlife Refuge in New Jersey, USA. *Environ. Pollut.* 143:555-564.
- Gilliam, F.S., W.J. Platt, and R.K. Peet. 2006. Natural disturbances and the physiognomy of pine savannas: a phenomenological model. *Appl. Veg. Sci.* 9:83-96.
- Gilliam, F.S. 2007. The ecological significance of the herbaceous layer in temperate forest ecosystems. *BioScience* 57(10):845-858.

- Gilliam, F.S., C.L. Goodale, L.H. Pardo, L.H. Geiser, and E.A. Lilleskov. 2011. Eastern Temperate Forests. *In* L.H. Pardo, M.J. Robin-Abbott and C.T. Driscoll (Eds.). *Assessment of Nitrogen Deposition Effects and Empirical Critical Loads of Nitrogen for Ecoregions of the United States*. General Technical Report NRS-80. U.S. Forest Service, Newtown Square, PA. pp. 99-116.
- Greaver, T., L. Liu, and R. Bobbink. 2011. Wetlands. *In* L.H. Pardo, M.J. Robin-Abbott and C.T. Driscoll (Eds.). *Assessment of Nitrogen Deposition Effects and Empirical Critical Loads of Nitrogen for Ecoregions of the United States*. General Technical Report NRS-80. U.S. Forest Service, Newtown Square, PA.
- Heck, W.W. and E.B. Cowling. 1997. The need for a long term cumulative secondary ozone standard - an ecological perspective. *Ecological Manager*:22-33.
- Janicki, A., D. Wade, H. Wilson, D. Heimbuch, H. Sverdrup, and P. Warfvinge. 1995. Maryland Critical Loads Study. Volume 1: Critical Loads Assessment for Maryland Streams. CBRM-AD-95-9. Prepared by Coastal Environmental Services, Inc., Linthicum, MD and Lund Institute of Technology, Lund, Sweden, for the Maryland Department of Natural Resources, Chesapeake Bay Research and Monitoring Division, Annapolis, MD.
- Klauda, R.J. 1989. Definitions of Critical Environmental Conditions for Selected Chesapeake Bay Finfishes Exposed to Acidic Episodes in Spawning and Nursery Habitats. AD-89-6. Report to Chesapeake Bay Research and Monitoring Division. Maryland Department of Natural Resources, Annapolis, MD.
- Knapp, C.M., W.P. Saunders, D.G. Heimbuch, H.S. Greening, and G.J. Filbin. 1988. Maryland synoptic stream chemistry survey: estimating the number and distribution of streams affected by or at risk from acidification. Maryland Department of Natural Resources, Annapolis, MD.
- Kohut, R. 2007a. Assessing the risk of foliar injury from ozone on vegetation in parks in the U.S. National Park Service's Vital Signs Network. *Environ. Pollut.* 149:348-357.
- Kohut, R.J. 2007b. Ozone Risk Assessment for Vital Signs Monitoring Networks, Appalachian National Scenic Trail, and Natchez Trace National Scenic Trail. Natural Resource Technical Report NPS/NRPC/ARD/NRTR—2007/001. National Park Service, Natural Resource Program Center, Fort Collins, CO.  
<http://www.nature.nps.gov/air/pubs/pdf/03Risk/OzoneRiskAssessmentsCoverRev20070227.pdf>.
- Latimer, J.S. and S.A. Rego. 2010. Empirical relationship between eelgrass extent and predicted watershed derived nitrogen loading for shallow New England estuaries. *Estuar. Coast. Shelf Sci.* 90:231-240.
- Lawrey, J.D. 1993. Lichens as monitors of pollutant elements at permanent sites in Maryland and Virginia. *Bryologist* 96(3):339-341.

- Lefohn, A.S., W. Jackson, D.S. Shadwick, and H.P. Knudson. 1997. Effect of surface ozone exposures on vegetation grown in the Southern Appalachian Mountains: Identification of possible areas of concern. *Atmos. Environ.* 31(11):1695-1708.
- Lehrer, J.A., M. Bacou, B. Blankespoor, D. McCubbin, J. Sacks, C.R. Taylor, and D.A. Weinstein. 2007. Technical Report on Ozone Exposure, Risk, and Impact Assessments for Vegetation. Report No. EPA 452/R-07-002. U.S. Environmental Protection Agency, Research Triangle Park, NC.
- Magill, A.H., J.D. Aber, W.S. Currie, K.J. Nadelhoffer, M.E. Martin, W.H. McDowell, J.M. Melillo, and P. Steudler. 2004. Ecosystem response to 15 years of chronic nitrogen additions at the Harvard Forest LTER, Massachusetts, USA. *For. Ecol. Manage.* 196:7-28.
- Morgan, R.P., II, A.J. Janicki, C.K. Murray, M.A. Pawlowski, and M.J. Pinder. 1990. Western Maryland Stream Survey. Relationships Between Fish Distributions, Acidification, and Watershed Characteristics. Final Report to Chesapeake Bay Research and Monitoring Program. Maryland Department of Natural Resources, Annapolis, MD.
- Myers, M.D., M.A. Ayers, J.S. Baron, P.R. Beauchemin, K.T. Gallagher, M.B. Goldhaber, D.R. Hutchinson, J.W. LaBaugh, R.G. Sayre, S.E. Schwarzbach, E.S. Schweig, J. Thormodsgard, C. van Riper, III, and W. Wilde. 2007. USGS goals for the coming decade. *Science* 318:200-201.
- National Park Service-Air Resources Division (NPS-ARD). 2013. Air quality in national parks: annual trends (2000–2009) and conditions (2005–2009) report. Natural Resource Report NPS/NRSS/ARD/NRR—2013/683. National Park Service, Denver, CO.
- National Park Service (NPS). 2010. Air Quality in National Parks: 2009 Annual Performance and Progress Report. Natural Resource Report NPS/NRPC/ARD/NRR-2010/266. National Park Service, Air Resources Division, Denver, CO.
- Neckles, H.A., J.M. Caldwell, P.S. Pooler, and D. Skidds. 2011. Integration of estuarine water-quality data in Northeast Coastal and Barrier Network parks at local and regional scales. Abstract. George Wright Society Conference on Parks, Protected Areas, & Cultural Sites. New Orleans, LA, May 14-18, 2011.
- Northeast States for Coordinated Air Use Management (NESCAUM). 2006. Contributions to Regional Haze in the Northeast and Mid-Atlantic United States. Mid-Atlantic/Northeast Visibility Union (MANE-VU) Contribution Assessment. Report prepared for the Mid-Atlantic/Northeast Visibility Union. Updated July, 2012.

- Northeast States for Coordinated Air Use Management (NESCAUM). 2012. The Nature of the Fine Particle and Regional Haze Air Quality Problems in the MANE-VU Region: A Conceptual Description. Second Update. Prepared by the Northeast States for Coordinated Air Use Management. Boston, MA. <http://www.nescaum.org/topics/regional-haze/regional-haze-documents>.
- Ollinger, S.V., J.D. Aber, and P.B. Reich. 1997. Simulating ozone effects on forest productivity: interactions among leaf-, canopy- and stand-level processes. *Ecol. Appl.* 7:1237-1251.
- Pardo, L.H., M.J. Robin-Abbott, and C.T. Driscoll (Eds.). 2011. Assessment of Nitrogen Deposition Effects and Empirical Critical Loads of Nitrogen for Ecoregions of the United States. General Technical Report NRS-80. U.S. Forest Service, Newtown Square, PA.
- Platt, W.J., S.M. Carr, M. Reilly, and J. Fahr. 2006. Pine savanna overstory influences on ground-cover biodiversity. *Appl. Veg. Sci.* 9:37-50.
- Roman, C., K. Medeiros, D. Cahoon, and J. Lynch. 2011. Monitoring salt marsh elevation change in the Northeast: Anticipating habitat responses to sea level rise. Abstract. George Wright Society Conference on Parks, Protected Areas, & Cultural Sites. New Orleans, LA, May 14-18, 2011.
- Schwede, D.B. and G.G. Lear. 2014. A novel hybrid approach for estimating total deposition in the United States. *Atmos. Environ.* 92:207-220. <http://dx.doi.org/10.1016/j.atmosenv.2014.04.008>.
- Sullivan, T.J., T.C. McDonnell, G.T. McPherson, S.D. Mackey, and D. Moore. 2011a. Evaluation of the Sensitivity of Inventory and Monitoring National Parks to Nutrient Enrichment Effects from Atmospheric Nitrogen Deposition. Natural Resource Report NPS/NRPC/ARD/NRR—2011/313. U.S. Department of the Interior, National Park Service, Denver. <http://www.nature.nps.gov/air/permits/aris/networks/n-sensitivity.cfm>.
- Sullivan, T.J., G.T. McPherson, T.C. McDonnell, S.D. Mackey, and D. Moore. 2011b. Evaluation of the Sensitivity of Inventory and Monitoring National Parks to Acidification Effects from Atmospheric Sulfur and Nitrogen Deposition. U.S. Department of the Interior, National Park Service, Denver. <http://nature.nps.gov/air/Permits/ARIS/networks/acidification-eval.cfm>.
- Sullivan, T.J. 2016. Air quality related values (AQRVs) in national parks: Effects from ozone; visibility reducing particles; and atmospheric deposition of acids, nutrients and toxics. Natural Resource Report NPS/NRSS/ARD/NRR—2016/1196. National Park Service, Fort Collins, CO.
- Tyler, A.C., J.G. Lambrinos, and E.D. Grosholz. 2007. Nitrogen inputs promote the spread of an invasive marsh grass. *Ecol. Appl.* 17(7):1886-1898.
- U.S. Environmental Protection Agency. 2008. Integrated Science Assessment for Oxides of Nitrogen and Sulfur -- Ecological Criteria. EPA/600/R-08/082F. National Center for Environmental Assessment, Office of Research and Development, Research Triangle Park, NC.

Wigand, C., R.A. McKinney, M.A. Charpentier, M.M. Chintala, and G.B. Thursby. 2003.  
Relationships of nitrogen loadings, residential development, and physical characteristics with  
plant structure in New England salt marshes. *Estuaries* 26:1494-1504.



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