Evaluation of the Sensitivity of Inventory and Monitoring National Parks to Acidification Effects from Atmospheric Sulfur and Nitrogen Deposition

Pacific Island Network (PACN)

Natural Resource Report NPS/NRPC/ARD/NRR—2011/370
ON THE COVER

Some ecosystems and vegetation types, such as remote high-elevation lakes, sugar maple trees, headwater streams, and red spruce trees, are sensitive to the effects of acidification from atmospheric nitrogen and sulfur deposition.

Photograph by: National Park Service
Evaluation of the Sensitivity of Inventory and Monitoring National Parks to Acidification Effects from Atmospheric Sulfur and Nitrogen Deposition

Pacific Island Network (PACN)

Natural Resource Report NPS/NRPC/ARD/NRR—2011/370

T. J. Sullivan
T. C. McDonnell
G. T. McPherson
S. D. Mackey
D. Moore

E&S Environmental Chemistry, Inc.
P.O. Box 609
Corvallis, OR 97339

April 2011

U.S. Department of the Interior
National Park Service
Natural Resource Program Center
Denver, Colorado
The National Park Service, Natural Resource Program Center publishes a range of reports that address natural resource topics of interest and applicability to a broad audience in the National Park Service and others in natural resource management, including scientists, conservation and environmental constituencies, and the public.

The Natural Resource Report Series is used to disseminate high-priority, current natural resource management information with managerial application. The series targets a general, diverse audience, and may contain NPS policy considerations or address sensitive issues of management applicability.

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

This report received peer review by subject-matter experts who were not directly involved in the collection, analysis, or reporting of the data. Data in this report were collected and analyzed using methods based on established, peer-reviewed protocols and were analyzed and interpreted within the guidelines of the protocols.

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

This report is available from Air Resources Division of the NPS (http://www.nature.nps.gov/air/Permits/ARIS/networks/acidification-eval.cfm) and the Natural Resource Publications Management website (http://www.nature.nps.gov/publications/nrpm/).

Please cite this publication as:

Pacific Island Network (PACN)

The Pacific Island Network includes islands at diverse locations in the Pacific Ocean (Map PACN-1). It includes the Hawaiian Islands, northern Mariana Islands, Guam, and American Samoa. There are nine parks in the Pacific Island Network. Only one is larger than 100 square miles: Hawaii Volcanoes (HAVO), which is located on the island of Hawaii. Data reflecting sensitivity to, and effects from, acidic deposition are sparse for the American Affiliated Islands.

National maps of atmospheric S and N emissions and deposition are provided in Maps A through D as context for subsequent network data presentations. Maps A and B show county-level emissions of total S and N, respectively, for the year 2002. Maps C and D show total S and N deposition, respectively, again for the year 2002. Deposition data are not available for the Pacific Islands Network, but deposition would be expected to be relatively high on some of the Hawaiian Islands, especially Oahu, and lower elsewhere.

Total annual S and N emissions, by county, are shown in Maps E and F, respectively, for lands in and surrounding the Hawaii portion of the Pacific Island Network. County-level S emissions within the network ranged from less than 1 ton per square mile on the big island of Hawaii and Kauai up to the range of 5 to 20 tons per square mile on Oahu. Other islands in the Hawaiian archipelago have S emissions in the range of 1 to 5 tons per square mile per year. County-level N emissions within the network ranged from less than 1 ton per square mile on the big island of Hawaii to between 20 and 50 tons per square mile on Oahu. Annual emissions of N on the other Hawaiian Islands were intermediate, between 1 and 5 tons per square mile. Emissions data are not available for the American Affiliated Islands. Individual point sources of S are shown on Map G. There are very few S point sources on any of the Hawaiian Islands and none of any magnitude. All emitted less than 5,000 tons S per year. Point source emissions of oxidized (nitrogen oxides, NOx) and reduced (ammonia, NH3) N are shown in Map H. There are relatively few N point sources in Hawaii. Most are located on Oahu and emit oxidized N.

Urban centers within the network and within a 300-mile buffer around the network are shown on Maps I-1 and I-2. Map I-1 shows the Hawaiian Islands, while Map I-2 shows the American Affiliated Islands, including Guam, American Samoa, and the Northern Mariana Islands. The only population center of any magnitude (more than 100,000 people) is Honolulu on Oahu. There are no large population centers in the American Affiliated Islands (Map I-2).

Maps J and K (total S and N deposition) are not shown for the Pacific Island Network because there are no data available. Deposition of S and N are expected to be low on the American Affiliated Islands, but not necessarily on all of the Hawaiian islands, especially Oahu.

Land cover in and around the network is shown in Maps L-1 and L-2. The predominant cover types within this network are mixed and include substantial forest, row crop, shrubland, and grassland/herbaceous cover types. Pasture/hay is common on Guam.

Park slope is shown in Map M. An elevation dataset was not available for the American Affiliated Islands and therefore a slope map is not shown for this part of the network. Park slopes on the Hawaiian Islands tend to be low, generally less than 10°. One park, Haleakala (HALE) on Maui, has average slope in the range of 10° to 20° (Map M).
Park lands in Hawaii requiring special protection against potential adverse impacts associated with acidic deposition are shown on Map N. Also shown on Map N are all federal lands designated as wilderness, both lands managed by NPS and lands managed by other federal agencies. The land designations used to identify this heightened protection included Class I designation under the Clean Air Act Amendments and wilderness designation. There are some wilderness and Class I areas in the Hawaiian Islands, mostly limited to HAVO in the southern portion of the island of Hawaii. There are none on the American Affiliated Islands.

Network rankings are given in Figures A through C as the average ranking of the Pollutant Exposure, Ecosystem Sensitivity, and Park Protection metrics, respectively. Figure D shows the overall network Summary Risk ranking. In each figure, the rank for this particular network is highlighted to show its relative position compared with the ranks of the other 31 networks.

The Pacific Island Network ranked at the top of the middle quintile among networks in Pollutant Exposure (Figure A). Sulfur and N emissions and S and N deposition within the network were moderate. However, the network Ecosystem Sensitivity ranking was very low, within the lowest quintile among networks (Figure B). This network ranked in the second highest quintile in Park Protection, having moderately high amounts of protected lands (Figure C).

In combination, the network rankings for Pollutant Exposure, Ecosystem Sensitivity, and Park Protection yielded an overall Network Risk ranking that is below the middle of the distribution among networks (Figure D). The overall level of concern for acidification effects on I&M parks within this network is considered Moderate.

Similarly, park rankings are given in Figures E through H for the same metrics. In the case of the park rankings, we only show in the figures the parks that are larger than 100 square miles. Relative ranks for all parks, including the smaller parks, are given in Table A and Appendix A. As for the network ranking figures, the park ranking figures highlight those parks that occur in this network to show their relative position compared with parks in the other 31 networks. Note that the rankings shown in Figures E through H reflect the rank of a given park compared with all other parks, irrespective of size.

The one I&M park (HAVO) in the Pacific Island Network that is larger than 100 square miles ranked in the second lowest quintile in Pollutant Exposure (Figure E). This may be because HAVO is located on the southern side of the Island of Hawaii, some distance from the areas of concentrated pollution emissions sources on the islands of Oahu and Maui. Most of the smaller parks in the network also ranked Low, in the second lowest quintile, in Pollutant Exposure, except for Kalaupapa (KALA), which ranks Very High and HALE, which ranked Moderate. HAVO was in the second highest quintile in Ecosystem Sensitivity (Figure F) and in the highest quintile in Park Protection (Figure G). The smaller parks in the network varied in ranking for Ecosystem Sensitivity. One park (HALE) was ranked Very High; four parks were ranked Moderate, two are ranked Low, and one is ranked Very Low for this theme (Table A). Like HAVO, HALE was ranked in the highest quintile in Park Protection, whereas other parks in the network were ranked in the middle quintile.
The overall risk from acidic deposition to parks in this network varied. HALE was ranked Very High for park Summary Risk, and HAVO and KALA were ranked High (Figure H, Table A). The other parks in the network were ranked Moderate (three parks) or Low (three parks).

**Table A.** Relative rankings of individual I&M parks within the network for Pollutant Exposure, Ecosystem Sensitivity, Park Protection, and overall Summary Risk from acidic deposition.

<table>
<thead>
<tr>
<th>I&amp;M Parks² in Network</th>
<th>Relative Ranking of Individual Parks¹</th>
<th>Pollutant Exposure</th>
<th>Ecosystem Sensitivity</th>
<th>Park Protection</th>
<th>Summary Risk</th>
</tr>
</thead>
<tbody>
<tr>
<td>American Memorial Park</td>
<td>ND³</td>
<td>Moderate</td>
<td>Moderate</td>
<td>Moderate</td>
<td>Moderate</td>
</tr>
<tr>
<td>Haleakala</td>
<td>Moderate</td>
<td>Very High</td>
<td>Very High</td>
<td>Very High</td>
<td>Very High</td>
</tr>
<tr>
<td>Hawaii Volcanoes</td>
<td>Low</td>
<td>High</td>
<td>Very High</td>
<td>High</td>
<td></td>
</tr>
<tr>
<td>Kalalapapa</td>
<td>Very High</td>
<td>Moderate</td>
<td>Moderate</td>
<td>High</td>
<td></td>
</tr>
<tr>
<td>Kalokoko-Honokohau</td>
<td>Low</td>
<td>Very Low</td>
<td>Moderate</td>
<td>Low</td>
<td></td>
</tr>
<tr>
<td>National Park of American Samoa</td>
<td>ND ³</td>
<td>Moderate</td>
<td>Moderate</td>
<td>Moderate</td>
<td>Moderate</td>
</tr>
<tr>
<td>Pu‘uhonua o Honaunau</td>
<td>Low</td>
<td>Low</td>
<td>Moderate</td>
<td>Low</td>
<td></td>
</tr>
<tr>
<td>Puukohola Heiau</td>
<td>Low</td>
<td>Low</td>
<td>Moderate</td>
<td>Low</td>
<td></td>
</tr>
<tr>
<td>War in the Pacific</td>
<td>ND</td>
<td>Moderate</td>
<td>Moderate</td>
<td>Moderate</td>
<td></td>
</tr>
</tbody>
</table>

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 name is printed in bold italic for parks larger than 100 square miles.

³ ND indicates no data.

Map PACN-1. Location of the islands that comprise the Pacific Island Network.

Map A. National map of total S emissions by county for the year 2002, in units of tons of S per square mile per year. (Source of data: EPA National Emissions Inventory, [http://www.epa.gov/ttn/chief/net/2002inventory.html](http://www.epa.gov/ttn/chief/net/2002inventory.html))

Map B. National map of total N emissions by county for the year 2002. Both oxidized (nitrogen oxides, NOₓ) and reduced (ammonia, NH₃) forms of N are included. The total is expressed in tons per square mile per year. (Source of data: EPA National Emissions Inventory, [http://www.epa.gov/ttn/chief/net/2002inventory.html](http://www.epa.gov/ttn/chief/net/2002inventory.html))

Map C. Regional S deposition data are not available for the Pacific Island Network. Total S deposition throughout most areas is expected to be low, below about 1 to 2 kilograms of S per hectare per year. Total S deposition for the continental United States is presented for context here for the year 2002, expressed in units of kilograms of S deposited from the atmosphere to the earth surface per hectare per year. Wet and dry forms of deposition are included. For the eastern half of the country, wet deposition values were derived from interpolated measured values from NADP (three-year average centered on 2002) and dry deposition values were derived from 12-km CMAQ model projections for 2002. For the western half of the country, both wet and dry deposition values were derived...
from 36-km CMAQ model projections for 2002. NADP interpolations were performed using the approach of Grimm and Lynch (1997). CMAQ model projections were provided by Robin Dennis, U.S. EPA.

Map D. Deposition data are not available for the Pacific Island Network. Total N deposition throughout most areas is expected to be low, below about 2 kilograms of N per hectare per year. Total N deposition for the continental United States is presented for context here for the year 2002, expressed in units of kilograms of N deposited from the atmosphere to the earth surface per hectare per year. Wet and dry forms of both oxidized (nitrogen oxides, NOx) and reduced (ammonia, NH3) N are included. For the eastern half of the country, wet deposition values were derived from interpolated measured values from NADP (three-year average centered on 2002) and dry deposition values were derived from 12-km CMAQ model projections for 2002. For the western half of the country, both wet and dry deposition values were derived from 36-km CMAQ model projections for 2002. NADP interpolations were performed using the approach of Grimm and Lynch (1997). CMAQ model projections were provided by Robin Dennis, U.S. EPA.

Map E. Total S emissions by county for lands surrounding the network, expressed as tons of S emitted into the atmosphere per square mile per year. (Source of data: EPA National Emissions Inventory, http://www.epa.gov/ttn/chief/net/2002inventory.html)

Map F. Total N emissions by county for lands surrounding the network, expressed as tons of N emitted into the atmosphere per square mile per year. The total includes both oxidized (nitrogen oxides, NOx) and reduced (ammonia, NH3) N. (Source of data: EPA National Emissions Inventory, http://www.epa.gov/ttn/chief/net/2002inventory.html)


Map H. Major point source emissions of oxidized (nitrogen oxides, NOx) and reduced (ammonia, NH3) N in and around the network. The base of each vertical bar is positioned in the map at the approximate location of the source. The height of the bar is proportional to the magnitude of the source. (Source of data: EPA National Emissions Inventory, http://www.epa.gov/ttn/chief/net/2002inventory.html)

Map I-1. Urban centers having more than 10,000 people within the Hawaiian portion of the network and within a 300-mile buffer around the perimeter of the network. (Source of data: U.S. Census 2000)
Map I-2. Urban centers having more than 10,000 people within the American Affiliated Islands portion of the network and within a 300-mile buffer around the perimeter of the network. (Source of data: U.S. Census 2000)

Map L-1. Land cover types in and around the Hawaiian portion of the network, based on the National Land Cover dataset. (Source of data: National Land Cover Dataset, http://www.mrlc.gov/nlcd_multizone_map.php)


Map M. Average land slope within park units that occur within the network, by 10-digit HUC. (Source of data: U.S. EPA National Elevation Dataset [http://ned.usgs.gov/])

Map N. Lands within the network that are classified as Class I or wilderness area. (Source of data: USGS 2005 [National Atlas; http://nationalatlas.gov] and NPS)

Figure A. Network rankings for Pollutant Exposure, calculated as the average of scores for all Pollutant Exposure variables.

Figure B. Network rankings for Ecosystem Sensitivity, calculated as the average of scores for all Ecosystem Sensitivity variables.

Figure C. Network rankings for Park Protection, calculated as the average of scores for all Park Protection variables.

Figure D. Network Summary Risk rankings, calculated as the average of the quintile ranks for the Pollutant Exposure, Ecosystem Sensitivity, and Park Protection themes.

Figure E. Park rankings for Pollutant Exposure for all parks larger than 100 square miles. Ranks for each park were calculated relative to all parks, regardless of size, as the average of scores for all Pollutant Exposure variables.

Figure F. Park rankings for Ecosystem Sensitivity for all parks larger than 100 square miles. Ranks for each park were calculated relative to all parks, regardless of size, as the average of scores for all Ecosystem Sensitivity variables.
Figure G. Park rankings for Park Protection for all parks larger than 100 square miles. Ranks for each park were calculated relative to all parks, regardless of size, as the average of scores for all Park Protection variables.

Figure H. Park rankings for Summary Risk for all parks larger than 100 square miles. Ranks for each park were calculated relative to all parks, regardless of size, as the average of the quintile ranks for the Pollutant Exposure, Ecosystem Sensitivity, and Park Protection themes.
Total Sulfur Emissions by County
United States
(tons per square mile per year)

Data Source: National Emissions Inventory (EPA, 2002)
Projection: World Mercator, WGS 1984
Produced for: National Park Service, Air Resources Division, 2010
Prepared by: E&S Environmental Chemistry

Map A
Total Nitrogen Emissions by County
United States
(tons per square mile per year)

Data Source: National Emissions Inventory (EPA, 2002)
Projection: World Mercator, WGS 1984
Produced for: National Park Service, Air Resources Division, 2010
Prepared by: E&S Environmental Chemistry

Map B
Total Nitrogen Emissions by County
Pacific Island Network - Hawaii
(tons per square mile per year)

 Locator Map

Kauai
Oahu
Molokai
Lanai
Maui
Hawaii

Pacific Ocean

Total N Emissions (tons per sq. mi per year)
- Less than 1
- Greater than 1 and up to 5
- Greater than 5 and up to 20
- Greater than 20 and up to 50
- Greater than 50 and up to 100
- Greater than 100 and up to 618
- U.S. States
- Pacific Island Network - Hawaii
- Network Parks (larger than 100 sq. mi)
- Network Parks (smaller than 100 sq. mi)

Data Source: National Emissions Inventory (EPA, 2002)
Projection: Lambert Conformal Conic, NAD 1983
Produced for: National Park Service, Air Resources Division, 2010
Prepared by: E&F Environmental Chemistry

Map F
Map L-2

2001 Land Cover
Pacific Island Network
American Affiliated Islands
(National Land Cover Data)

Data Source: National Land Cover Data (NLCD, 2001), Liu, Z., and Fischer, L. (USGS 2008a, 2008b, 2007)
Projection: Lambert Conformal Conic, NAD-1983
Produced for: National Park Service, Air Resources Division, 2010
Prepared by: E&G Environmental Chemistry

Legend:
- Open Water
- Perennial Ice/Snow
- Developed
- Barren Land
- Forest
- Shrub/Scrub
- Grassland/Herbaceous
- Pasture/Hay
- Row Crops
- Wetland
- Unclassified
- U.S. States
- Pacific Island Network - American Affiliated Islands
- Network Parks (larger than 100 sq. mi)
- Network Parks (smaller than 100 sq. mi)
Figure A

Acidification Risk Assessment
Pollutant Exposure Ranking

Average of Network Ranking

Network
Northeast Coastal and Barrier Region
Mid Atlantic
National Capital Region
Heartland
Eastern Rivers and Mountains
South Florida / Caribbean
Cumberland Piedmont
Northeast Temperate
Great Lakes
Pacific Basin
Gulf Coast
Southern Plains
Northern Great Plains
North Coast and Cascades
Sierra Nevada
Klamath
Rocky Mountain
Mojave Desert
Sonoran Desert
Chihuahuan Desert
Northern Colorado Plateau
Upper Columbia Basin
Greater Yellowstone
Southern Colorado Plateau
Central Alaska
Southwest Alaska
Southeast Alaska
Arctic
Figure B

Acidification Risk Assessment
Ecosystem Sensitivity Ranking

Network

Average of Network Ranking

Appalachian Highlands
Sierra Nevada
Rocky Mountain
North Coast and Cascades
Greater Yellowstone
Mid Atlantic
Cumberland Piedmont
Klamath
Southern Colorado Plateau
Great Lakes
Heartland
Northern Colorado Plateau
Mojave Desert
Central Alaska
Northern Great Plains
Southwest Alaska
Northeastern Terrestrial
Arctic
Sonoran Desert
National Capital Region
Chihuahua Basin
San Francisco Bay Area
Mediterranean Coast
Gulf Coast
Northeast Coastal and Barrier
Pacific Island
Southeast Alaska
South Florida / Caribbean
Upper Columbia Basin
Figure C
Figure D
Acidification Risk Assessment
Pacific Island Network - Pollutant Exposure Ranking

Figure E
Figure F

Acidification Risk Assessment
Pacific Island Network - Ecosystem Sensitivity Ranking

Average of Park Ranking

Parks

Blue Ridge
Great Smoky Mountains
Kings Canyon
North Cascades
Sequoia
Mount Rainier
Rocky Mountain
Shenandoah
Glacier
Yellowstone
New River Gorge
Saint Croix
Lassen Volcanic
Delaware Water Gap
Big South Fork
Olympic
Grand Canyon
Grand Teton
Pictured Rocks
Great Sand Dunes
Buffalo
Crater Lake
Lake Clark
Voyageurs
Gates of the Arctic
Wrangell-St. Elias
Apostle Islands
Death Valley
Great Basin
Denali
Katmai
Saguaro
Yukon-Charley Rivers
Lake Mead
Dinosaur
Kenai Fjords
Noatak
Kobuk Valley
Guadalupe Mountains
Big Bend
Glacier Bay
Hawaii Volcanoes
Capitol Reef
Golden Gate
Mojave
Ainliakhak
Zion
Santa Monica Mountains
Canyonlands
Redwood
Isle Royale
Glen Canyon
Joshua Tree
Sleeping Bear Dunes
Channel Islands
Canyon de Chelly
Bighorn Canyon
Point Reyes
Ozark
Bering Land Bridge
Arches
Organ Pipe Cactus
Theodore Roosevelt
Badlands
Lake Roosevelt
Missouri
Petrified Forest
Big Thicket
Everglades
Cape Krusenstern
White Sands
El Malpais
Big Cypress
Craters of the Moon
Gulf Islands
Biscayne
Dry Tortugas
Padre Island

Acidification Risk Assessment
Pacific Island Network - Ecosystem Sensitivity Ranking

Average of Park Ranking

Parks

Blue Ridge
Great Smoky Mountains
Kings Canyon
North Cascades
Sequoia
Mount Rainier
Rocky Mountain
Shenandoah
Glacier
Yellowstone
New River Gorge
Saint Croix
Lassen Volcanic
Delaware Water Gap
Big South Fork
Olympic
Grand Canyon
Grand Teton
Pictured Rocks
Great Sand Dunes
Buffalo
Crater Lake
Lake Clark
Voyageurs
Gates of the Arctic
Wrangell-St. Elias
Apostle Islands
Death Valley
Great Basin
Denali
Katmai
Saguaro
Yukon-Charley Rivers
Lake Mead
Dinosaur
Kenai Fjords
Noatak
Kobuk Valley
Guadalupe Mountains
Big Bend
Glacier Bay
Hawaii Volcanoes
Capitol Reef
Golden Gate
Mojave
Ainliakhak
Zion
Santa Monica Mountains
Canyonlands
Redwood
Isle Royale
Glen Canyon
Joshua Tree
Sleeping Bear Dunes
Channel Islands
Canyon de Chelly
Bighorn Canyon
Point Reyes
Ozark
Bering Land Bridge
Arches
Organ Pipe Cactus
Theodore Roosevelt
Badlands
Lake Roosevelt
Missouri
Petrified Forest
Big Thicket
Everglades
Cape Krusenstern
White Sands
El Malpais
Big Cypress
Craters of the Moon
Gulf Islands
Biscayne
Dry Tortugas
Padre Island
Acidification Risk Assessment
Pacific Island Network - Park Protection Ranking

Figure G
Acidification Risk Assessment
Pacific Island Network - Summary Risk Ranking

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

NPS 988/107406, April 2011