National Park Service
U.S. Department of the Interior

Natural Resource Program Center

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

Appalachian Highlands Network (APHN)

Natural Resource Report NPS/NRPC/ARD/NRR—2011/350

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

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April 2011

U.S. Department of the Interior
National Park Service
Natural Resource Program Center
Denver, Colorado

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.

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:

Sullivan, T. J., G. T. McPherson, T. C. McDonnell, S. D. Mackey, and D. Moore. 2011. Evaluation of the sensitivity of inventory and monitoring national parks to acidification effects from atmospheric sulfur and nitrogen deposition: Appalachian Highlands Network (APHN). Natural Resource Report NPS/NRPC/ARD/NRR—2011/350. National Park Service, Denver, Colorado.

NPS 910/107384, April 2011

Appalachian Highlands Network (APHN)

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 total N for the year 2002. Maps C and D show total S and total N deposition, again for the year 2002.

The Appalachian Highlands Network contains three parks that are larger than 100 square miles: Great Smoky Mountains (GRSM), Big South Fork (BISO), and Blue Ridge (BLRI). It also contains one smaller park: Obed (OBRI).

Total annual S and N emissions, by county, are shown in Maps E and F, respectively, for lands in and surrounding the Appalachian Highlands Network. County-level S emissions within the network were mostly less than 1 ton per square mile, although some counties within the network, and to the north and west of the network, had much higher S emissions levels. Several counties inside, or partially inside, the network had annual S emissions higher than 20 tons per square mile, and one county had emissions higher than 100 tons per square mile (Map E). County-level annual N emissions within the network ranged from less than 1 ton per square mile to greater than 100 tons per square mile. In general, annual N emissions from most counties were between 1 and 20 tons per square mile. Individual point source emissions of S are shown in Map G. There were only two S point sources within the network that were larger than 20,000 tons per year, and none were larger than 40,000 tons per year. However, there were many such large point sources of S surrounding the network. Point source emissions of oxidized (nitrogen oxides, NO_x) and reduced (ammonia, NH_3) N are shown in Map H. All relatively large (larger than 1,000 tons per year) N point sources within the network, and most large point sources near the network, were oxidized N sources. Only one large point source of reduced N was located in proximity to the network; it was in Virginia, to the northeast of the network. There were two large point sources of NO_x within the network in Tennessee, situated between GRSM and BISO; each emitted more than 4,000 tons per year of oxidized N. Many other relatively large point sources of oxidized N occurred in the vicinity of the network boundary.

Urban centers within the network and within a 300-mile buffer around the network are shown in Map I. Few population centers of any magnitude are found in this network. However, there are several cities with populations over 500,000 within the 300-mile buffer.

Total S and N deposition levels in and around the network are shown in Maps J and K, respectively. Included in this analysis were both wet and dry forms of deposition, and both the oxidized and reduced N species. Total S deposition throughout much of the network, including in and around GRSM, ranged from about 10 to 15 kg/ha/yr (Map J). Some locations within the network had estimated S deposition higher than that. Total N deposition within the network ranged from as low as 2 to 5 kg N/ha/yr per year to as high as 10 to 15 kg N/ha/yr (Map K). In addition, it is known that cloud deposition, which is not represented in the total deposition values depicted on the maps, can be quite high at high-elevation sites (especially higher than 1,500 m) in and around GRSM. At the highest elevation locations, the total S and N deposition, including cloud inputs, might be as much as double the wet plus dry deposition values that are mapped from NADP interpolations and CMAQ simulations in Maps J and K.

Land cover in and around the network is shown in Map L. The predominant cover types within this network are generally forest and pasture/hay. Land cover within the major parks that occur in this network is primarily forested.

GRSM contains vegetation types that likely include red spruce and sugar maple, the two tree species thought to be most sensitive to acidification and accompanying soil base cation depletion. The vegetation types most likely to contain these two tree species are not found in BISO. Sensitive vegetation in GRSM is mapped at the park rather than the network scale.

Land slope tends to be fairly steep in GRSM, with most of the park having terrain steeper than 30^o (Map M). In addition, some land along the Blue Ridge Parkway is steeper than 30^o. Other park lands within the network generally have land slope less than 20^o.

Park lands 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. GRSM is designated as a Class I area. There are also substantial areas scattered throughout the network that are designated as wilderness.

Maps P-1 through P-3 are park-specific maps for GRSM, which show sensitive vegetation (Map P-1), high-elevation lakes and streams (Map P-2) and low-order streams (Map P-3). Nearly the entire park is covered by vegetation types likely to contain sugar maple, with the exception of lands around parts of the park boundary. Red spruce is confined to the higher elevations, generally higher than about 1,300 m. Much of this higher elevation land is distributed along the Appalachian Mountain ridgeline.

High-elevation lakes might be more prone than lakes at lower elevation to acidification, and therefore are considered potentially more susceptible to atmospheric S and N input. As shown in Map P-2, there are some lakes along the boundary of GRSM. In addition, elevations in GRSM are among the highest in the eastern United States, with the majority of the park land being higher than 1,000 m elevation. Nevertheless, the few lakes that are found within GRSM are generally not located at high elevation, and are therefore not considered likely to be especially sensitive to acidification impacts. Most streams in the park are located at relatively high elevation (greater than 1,000 m; Map P-2) and are first through third order (Map P-3). These low-order, high-elevation streams on steep terrain are often particularly sensitive to acidification impacts from both S and N deposition.

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 Appalachian Highlands Network ranked High in Pollutant Exposure, near the median of the second highest quintile (coded orange), among networks (Figure A). Sulfur emissions in and surrounding the network, and S deposition within the network, were both relatively high. The network is also surrounded by many relatively large urban areas and point sources of both S and N. Nitrogen emissions within and upwind of the network and N deposition within the network were both high. The data available for estimating deposition at the national scale of this assessment did not include cloud deposition, which is known to be important at the high elevations of GRSM. As a consequence, the Pollutant Exposure rankings for GRSM, and for the network as a whole, were likely biased low.

The Ecosystem Sensitivity ranking of this network was Very High, the highest among all networks (Figure B). This is because vegetation is primarily forest expected to contain sugar maple, one of the tree species thought to be especially sensitive to acidification effects from S and N deposition. In addition, there are many high-elevation and low-order streams on relatively steep terrain. This network ranked in the third quintile in Park Protection (Figure C), having moderate amounts of protected lands.

In combination, the network rankings for Pollutant Exposure, Ecosystem Sensitivity, and Park Protection yielded an overall network Summary Risk ranking that was High among all networks. The overall level of concern for acidification effects on I&M parks within this network can be considered High. Because the Pollution Exposure ranking is likely underestimated for this network, the network Summary Risk ranking was probably also biased low, and perhaps might more properly be considered Very High.

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 rankings, the park rankings 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.

All four parks in this network were ranked High in park-specific Pollutant Exposure (Table A, Figure E), indicating high levels of atmospheric S and N deposition. The Ecosystem Sensitivity ranking for each of these parks was Very High (Figure F, Table A), mainly because the vegetation in these parks is predominately types that contain sugar maple or red spruce, and there are abundant acid-sensitive streams. The Park Protection ranking was High for BLRI and Very High for GRSM (Figure G), but only moderate for BISO and OBRI. The overall park Summary Risk ranking (Table A, Figure H) for the parks in this network was Very High for BLRI and GRSM and High for the other two 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.

I&M Parks[2] in Network	Relative Ranking of Individual Parks[1]			
	Pollutant Exposure	**Ecosystem Sensitivity**	**Park Protection**	**Summary Risk**
Big South Fork	High	Very High	Moderate	High
Blue Ridge	High	Very High	High	Very High
Great Smoky Mountains	High	Very High	Very High	Very High
Obed	High	Very High	Moderate	High

[1] Relative park rankings are designated according to quintile ranking, among all I&M Parks, from the lowest quintile (very low risk) to the highest quintile (very high risk).

[2] Park name is printed in bold italic for parks larger than 100 square miles.

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)

Map B. National map of total N emissions by county for the year 2002. Both oxidized (nitrogen oxides, NO_x) and reduced (ammonia, NH_3) 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)

Map C. Total S deposition for the conterminous United States for the year 2002, expressed in units of kilograms of S deposited from the atmosphere to the Earth surface per hectare per year. 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. Total N deposition for the conterminous United States 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, NO_x) and reduced (ammonia, NH_3) 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, NO_x) and reduced (ammonia, NH_3) N. (Source of data: EPA National Emissions Inventory, http://www.epa.gov/ttn/chief/net/2002inventory.html)

Map G. Major point source emissions of SO_2 for lands surrounding the network. (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, NO_x) and reduced (ammonia, NH_3) 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. Urban centers having more than 10,000 people within the network and within a 300-mile buffer around the perimeter of the network. (Source of data: U.S. Census 2000)

Map J. Total S deposition in and around the network. Values are expressed as kilograms of S deposited per hectare per year. (Source of data: Interpolated NADP wet and CMAQ Model dry deposition data for 2002; see information for Map C above for details)

Map K. Total N deposition in and around the network. Included in the total are wet plus dry forms of both oxidized (nitrogen oxides, NO_x) and reduced (ammonia, NH_3) N. Values are expressed as kilograms of N deposited per hectare per year. (Source of data: Interpolated NADP wet and CMAQ Model dry deposition data for 2002; see information for Map D above for details)

Map L. Land cover types in and around 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)

Map P-1. Park-specific map: sensitive vegetation types in GRSM. (Source of data: Landfire [http://www.landfire.gov/] and NPS Vegetation Survey)

Map P-2. Park-specific map: high-elevation lakes and streams in GRSM. (Source of data: U.S. EPA National Elevation Dataset [http://ned.usgs.gov/] and U.S. EPA/USGS National Hydrography Dataset Plus [http://www.horizon-systems.com/nhdplus/])

Map P-3. Park-specific map: low-order streams in GRSM. (Source of data: U.S. EPA/USGS National Hydrography Dataset Plus [http://www.horizon-systems.com/nhdplus/])

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.

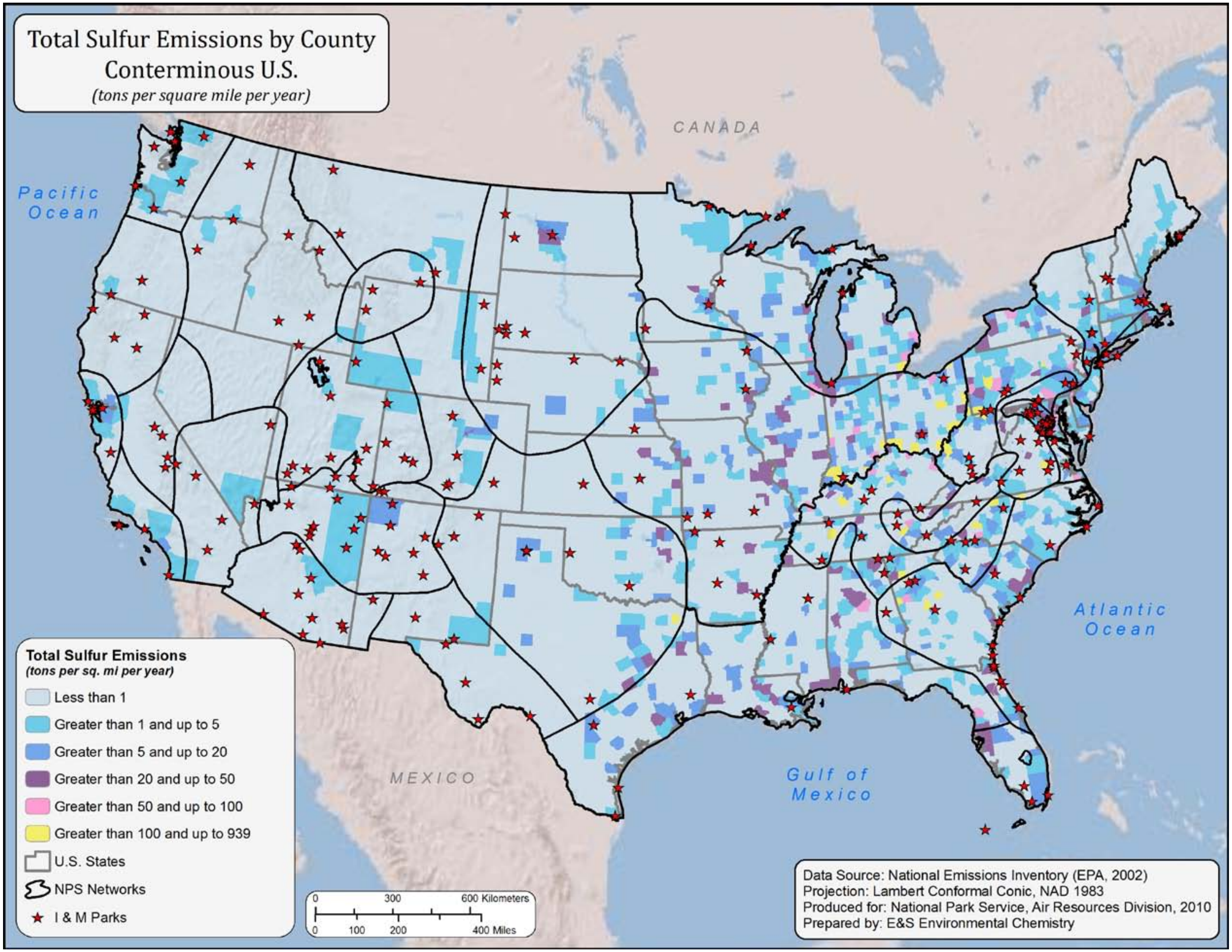
Figure E. Park rankings for Pollutant Exposure for all parks larger than 100 square miles. Ranks for each park were calculated relative to all parks, regardless of size, as the average of scores for all Pollutant Exposure variables.

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.

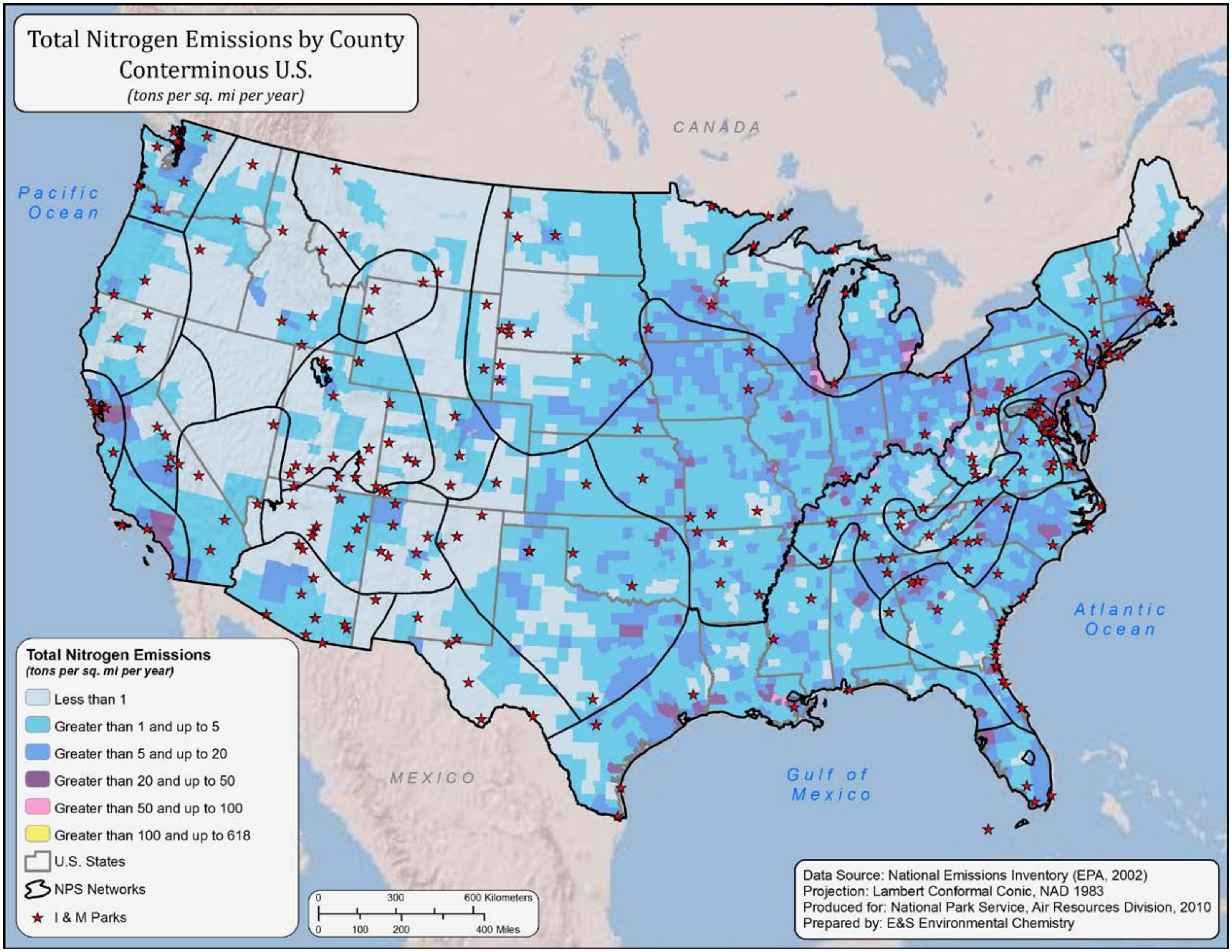
Figure H. Park rankings for Summary Risk for all parks larger than 100 square miles. Ranks for each park were calculated relative to all parks, regardless of size, as the average of the quintile ranks for the Pollutant Exposure, Ecosystem Sensitivity, and Park Protection themes.

APHN-7

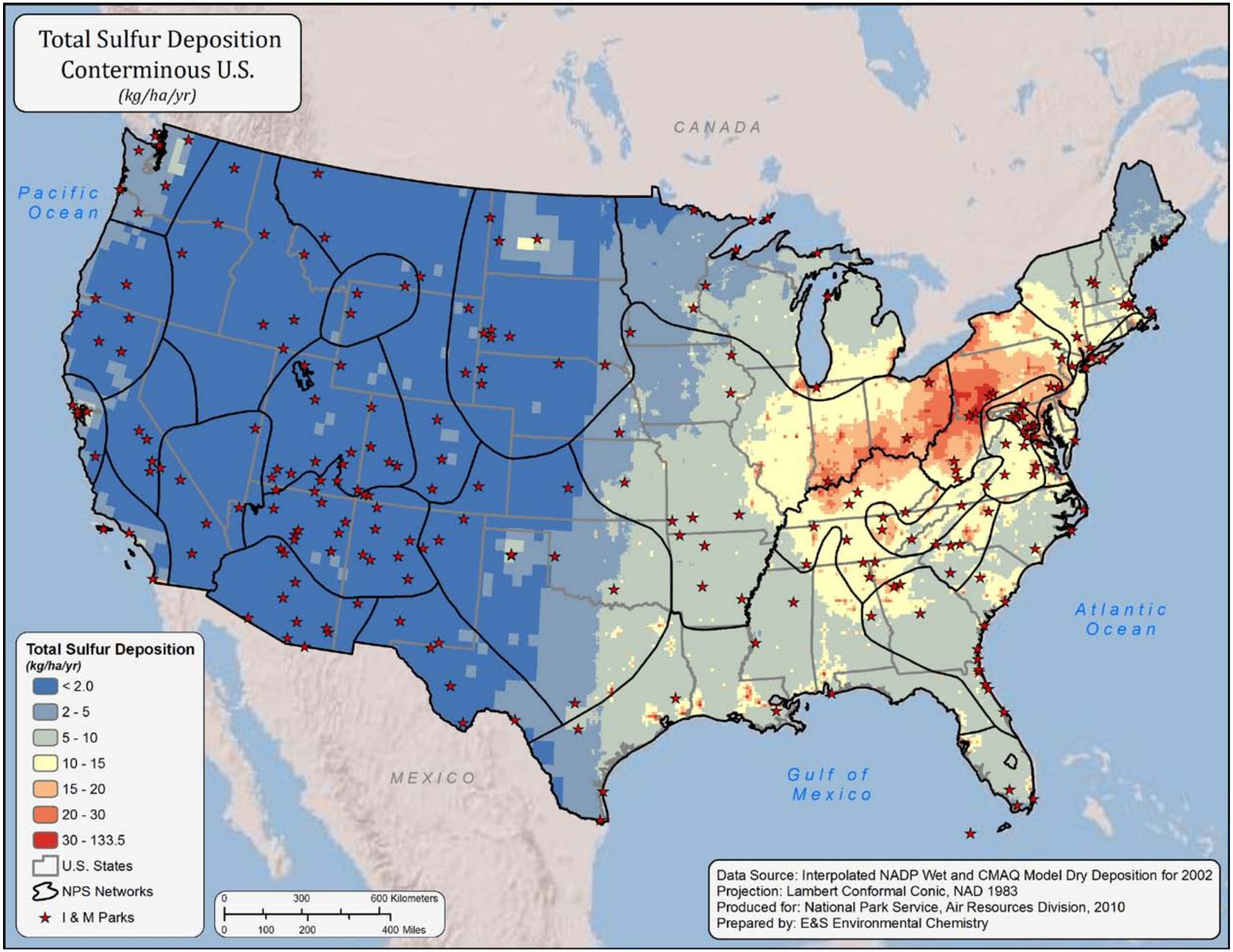


Total Sulfur Emissions by County
Conterminous U.S.
(tons per square mile per year)
CANADA
Pacific Ocean
Atlantic Ocean
Gulf of Mexico
MEXICO
Total Sulfur Emissions
(tons per sq. mi per year)
Less than 1
Greater than 1 and up to 5
Greater than 5 and up to 20
Greater than 20 and up to 50
Greater than 50 and up to 100
Greater than 100 and up to 939
U.S. States
NPS Networks
I & M Parks
0 300 600 Kilometers
0 100 200 400 Miles
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&S Environmental Chemistry

Map A

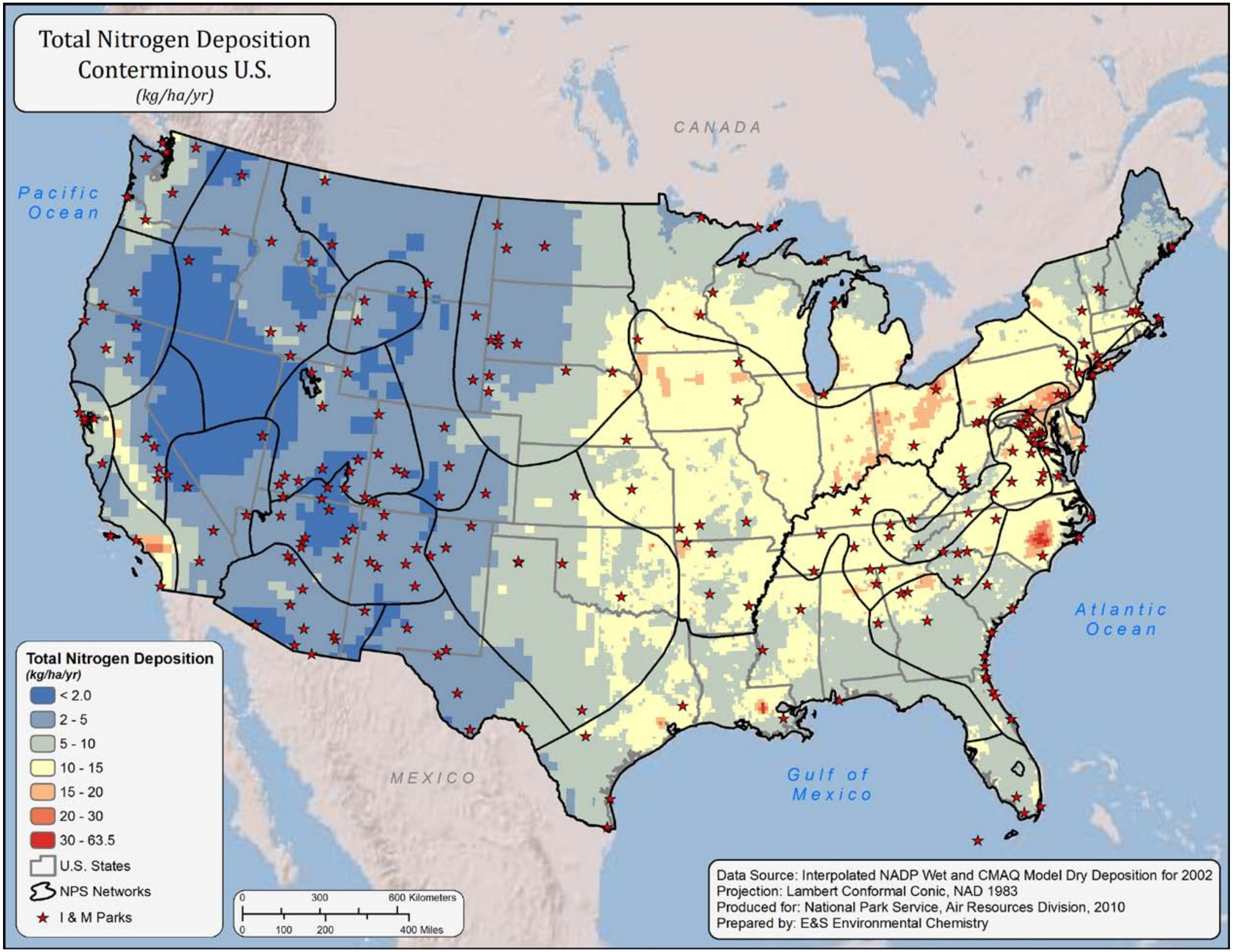

Total Nitrogen Emissions by County
Conterminous U.S.
(tons per sq. mi per year)
CANADA
Pacific Ocean
Atlantic Ocean
Gulf of Mexico
MEXICO
Total Nitrogen Emissions
(tons per sq. mi per year)
Less than 1
Greater than 1 and up to 5
Greater than 5 and up to 20
Greater than 20 and up to 50
Greater than 50 and up to 100
Greater than 100 and up to 618
U.S. States
NPS Networks
I & M Parks
0
300
600 Kilometers
0
100
200
400 Miles
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&S Environmental Chemistry

Map B

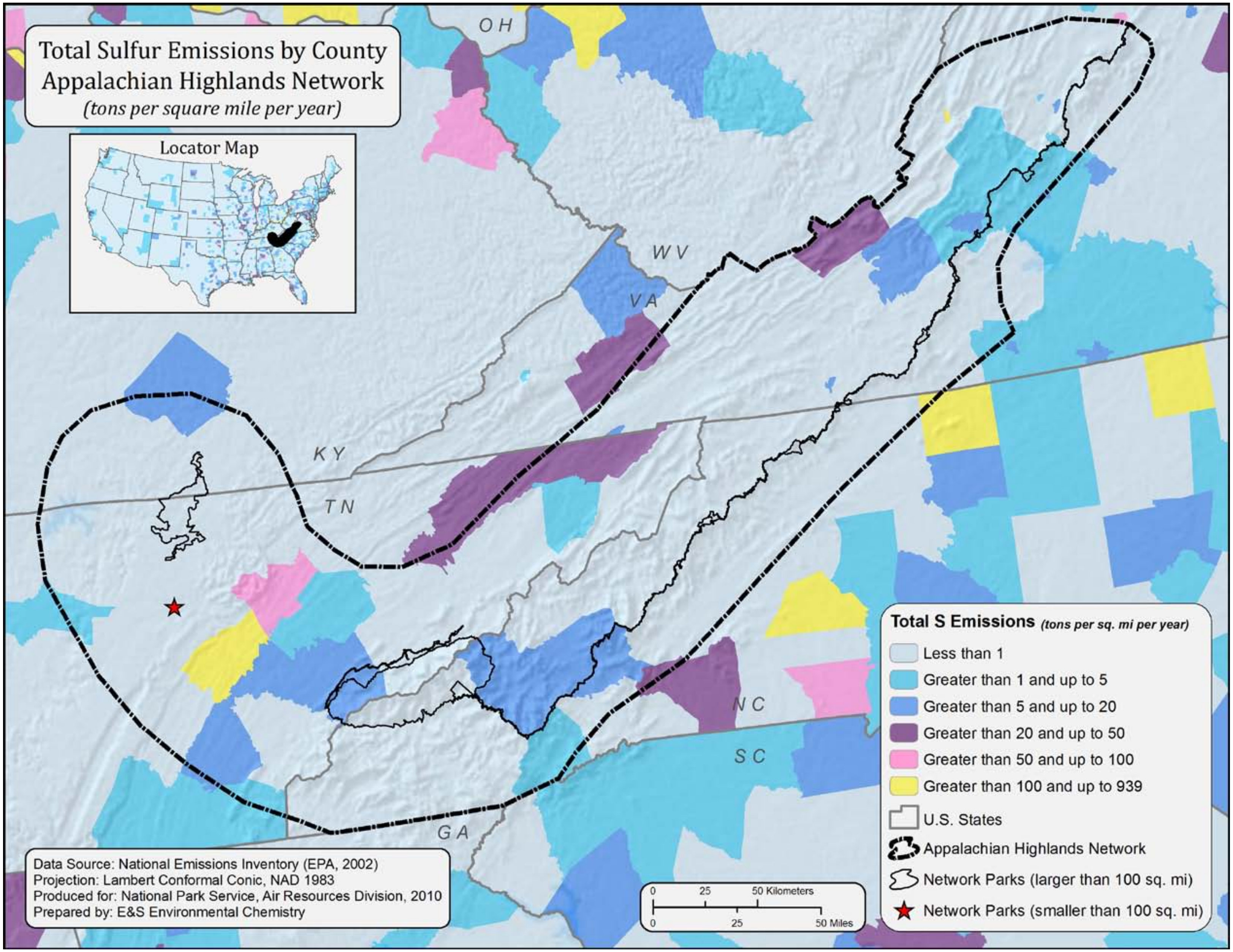


Total Sulfur Deposition
Conterminous U.S.
(kg/ha/yr)
CANADA
Pacific Ocean
Atlantic Ocean
Gulf of Mexico
MEXICO
Total Sulfur Deposition
(kg/ha/yr)
< 2.0
2 - 5
5 - 10
10 - 15
15 - 20
20 - 30
30 - 133.5
U.S. States
NPS Networks
I & M Parks
0 300 600 Kilometers
0 100 200 400 Miles
Data Source: Interpolated NADP Wet and CMAQ Model Dry Deposition for 2002
Projection: Lambert Conformal Conic, NAD 1983
Produced for: National Park Service, Air Resources Division, 2010
Prepared by: E&S Environmental Chemistry

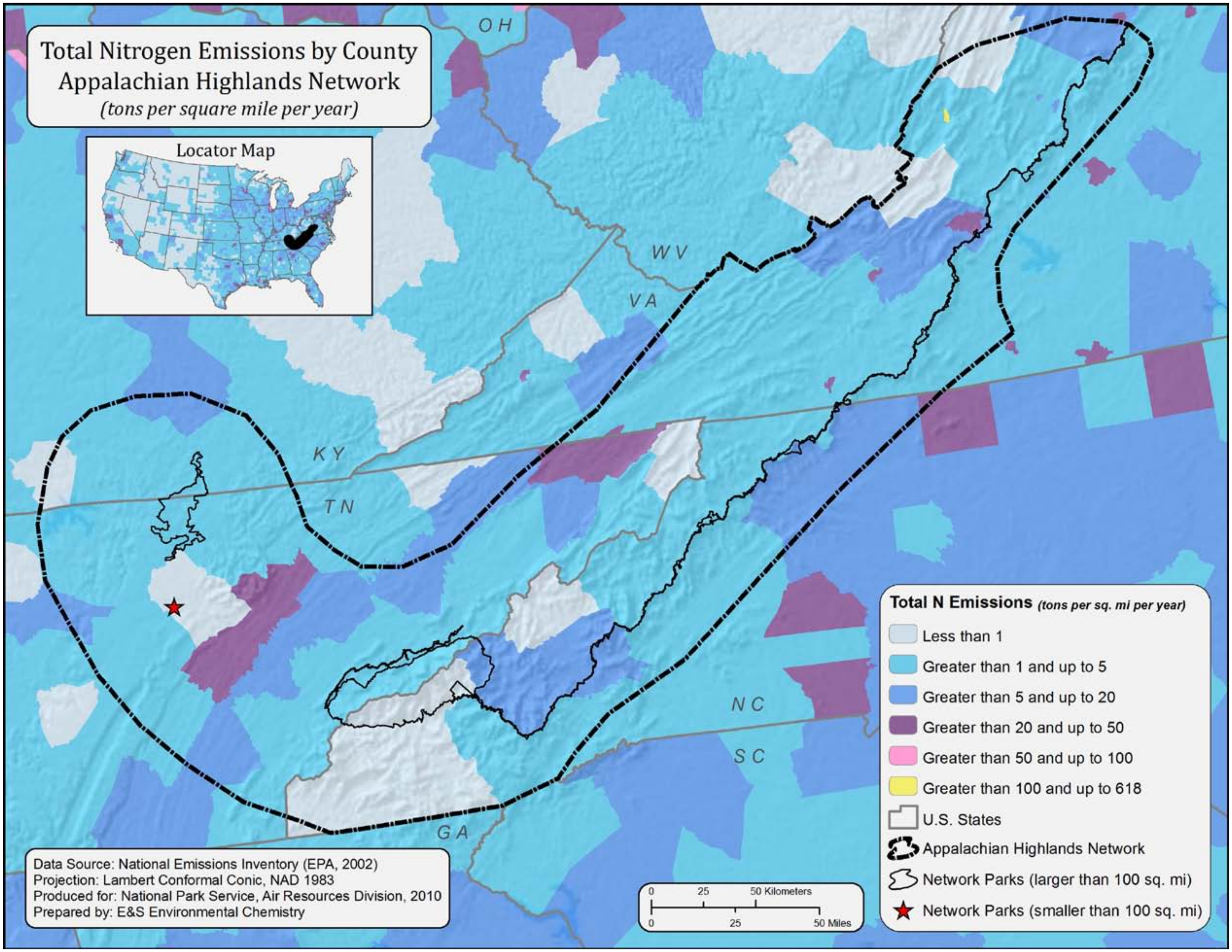
Map C


Total Nitrogen Deposition
Conterminous U.S.
(kg/ha/yr)
CANADA
Pacific Ocean
Atlantic Ocean
Gulf of Mexico
MEXICO
Total Nitrogen Deposition
(kg/ha/yr)
< 2.0
2 - 5
5 - 10
10 - 15
15 - 20
20 - 30
30 - 63.5
U.S. States
NPS Networks
I & M Parks
0 300 600 Kilometers
0 100 200 400 Miles
Data Source: Interpolated NADP Wet and CMAQ Model Dry Deposition for 2002
Projection: Lambert Conformal Conic, NAD 1983
Produced for: National Park Service, Air Resources Division, 2010
Prepared by: E&S Environmental Chemistry

Map D

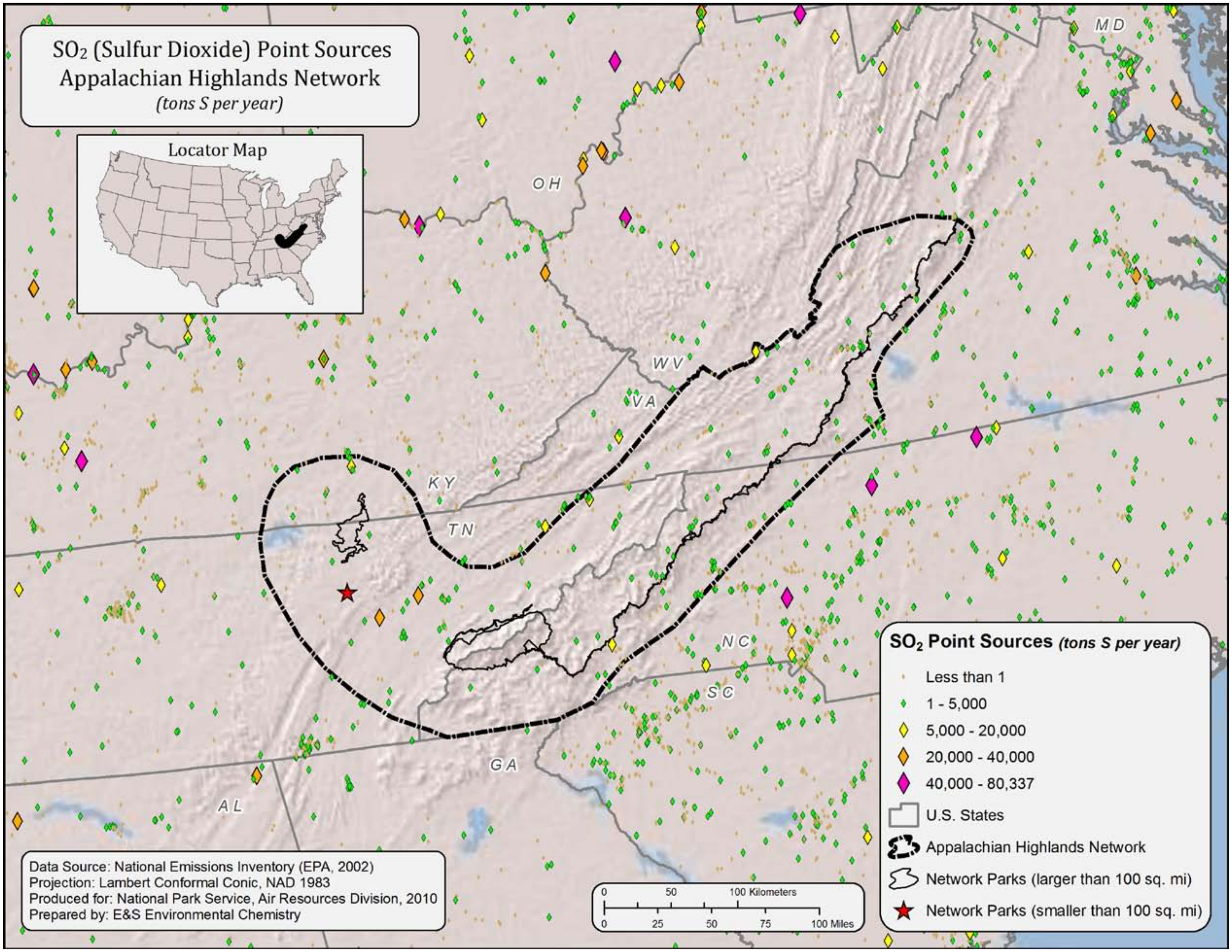

Total Sulfur Emissions by County
Appalachian Highlands Network
(tons per square mile per year)
Locator Map
OH
WV
VA
KY
TN
NC
SC
GA
Total S Emissions (tons per sq. mi per year)
Less than 1
Greater than 1 and up to 5
Greater than 5 and up to 20
Greater than 20 and up to 50
Greater than 50 and up to 100
Greater than 100 and up to 939
U.S. States
Appalachian Highlands Network
Network Parks (larger than 100 sq. mi)
Network Parks (smaller than 100 sq. mi)
0 25 50 Kilometers
0 25 50 Miles
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&S Environmental Chemistry

Map E

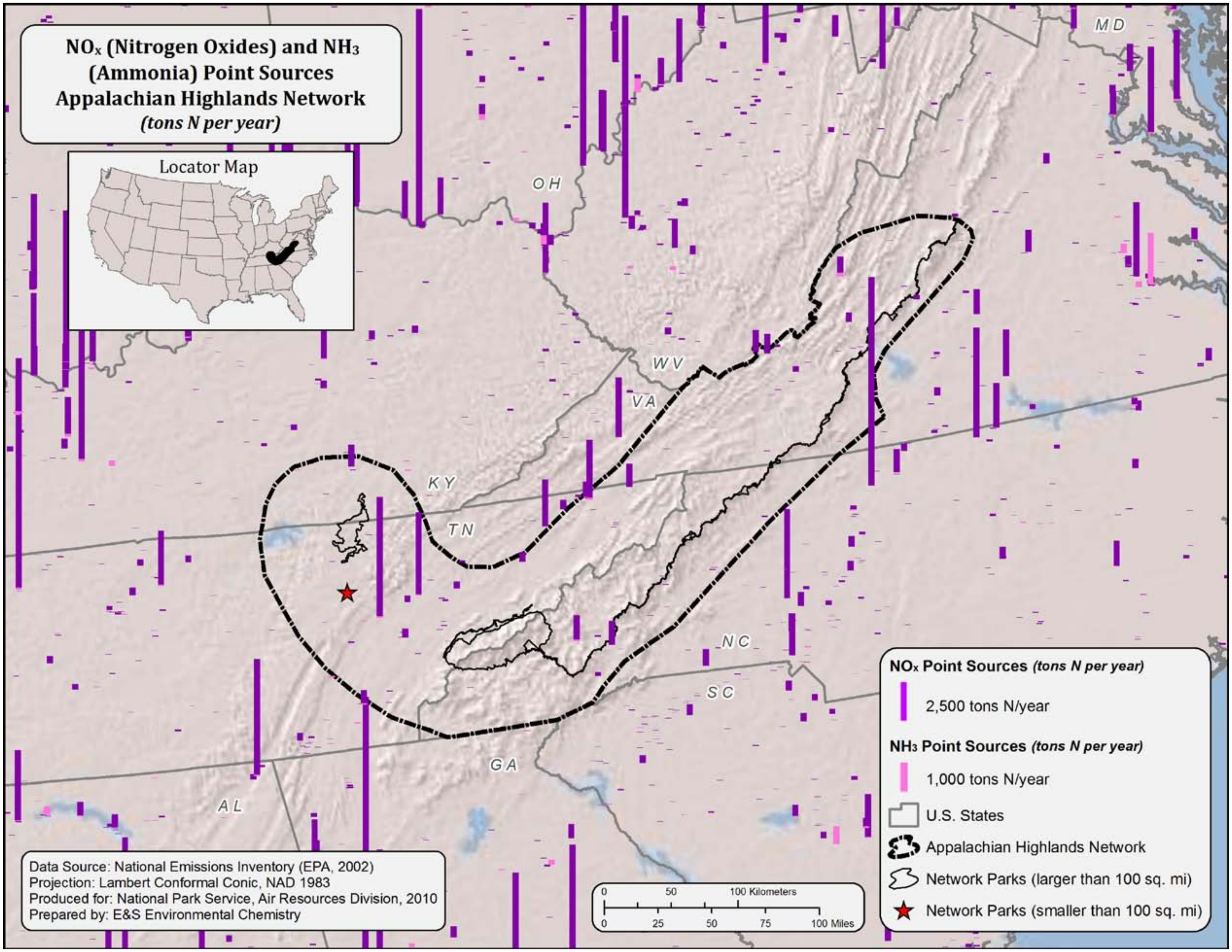


Total Nitrogen Emissions by County
Appalachian Highlands Network
(tons per square mile per year)
Locator Map
OH
WV
VA
KY
TN
NC
SC
GA
Total N Emissions (tons per sq. mi per year)
Less than 1
Greater than 1 and up to 5
Greater than 5 and up to 20
Greater than 20 and up to 50
Greater than 50 and up to 100
Greater than 100 and up to 618
U.S. States
Appalachian Highlands Network
Network Parks (larger than 100 sq. mi)
Network Parks (smaller than 100 sq. mi)
0 25 50 Kilometers
0 25 50 Miles
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&S Environmental Chemistry

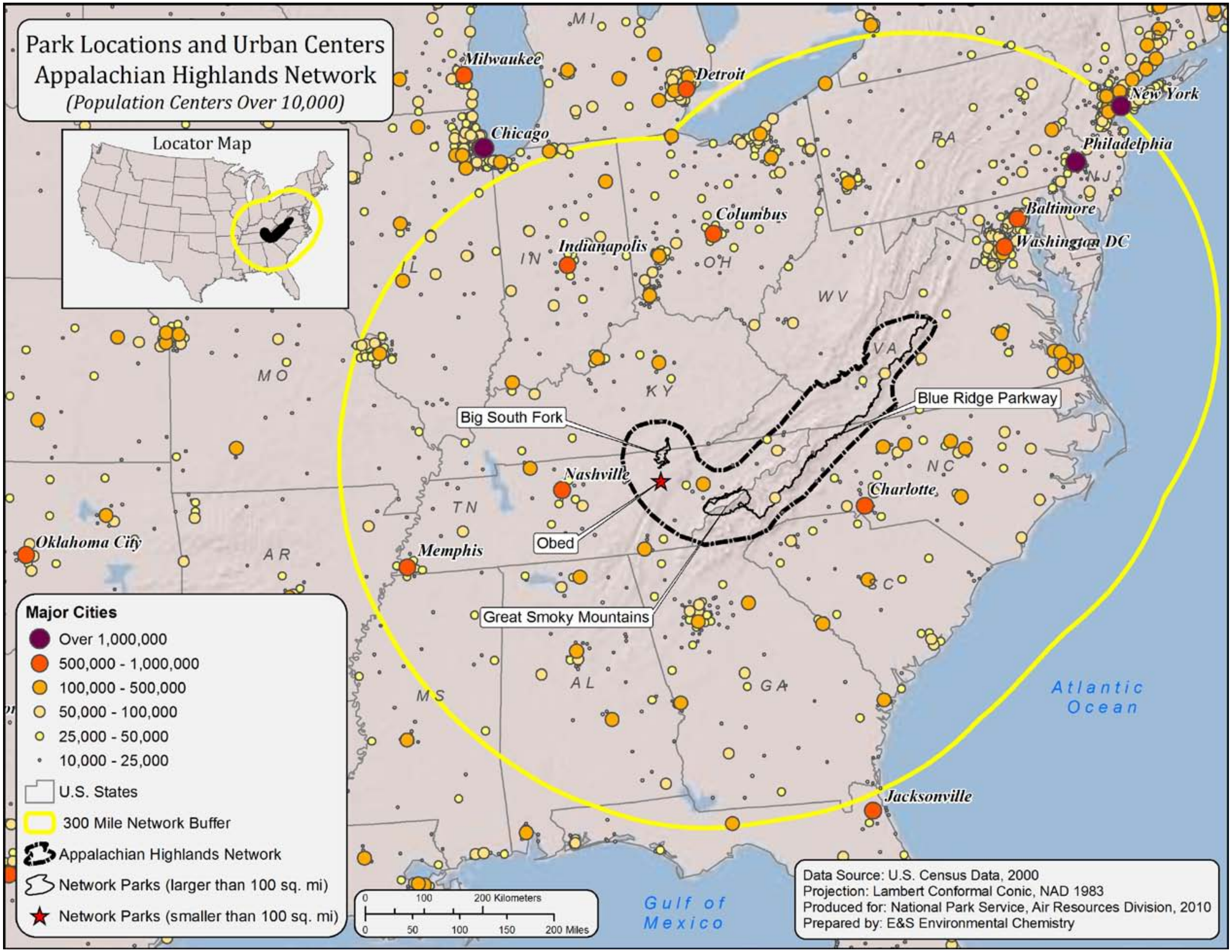
Map F


SO2 (Sulfur Dioxide) Point Sources
Appalachian Highlands Network
(tons S per year)
Locator Map
OH
WV
VA
KY
TN
NC
SC
GA
AL
MD
SO2 Point Sources (tons S per year)
Less than 1
1 - 5,000
5,000 - 20,000
20,000 - 40,000
40,000 - 80,337
U.S. States
Appalachian Highlands Network
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&S Environmental Chemistry
0 50 100 Kilometers
0 25 50 75 100 Miles

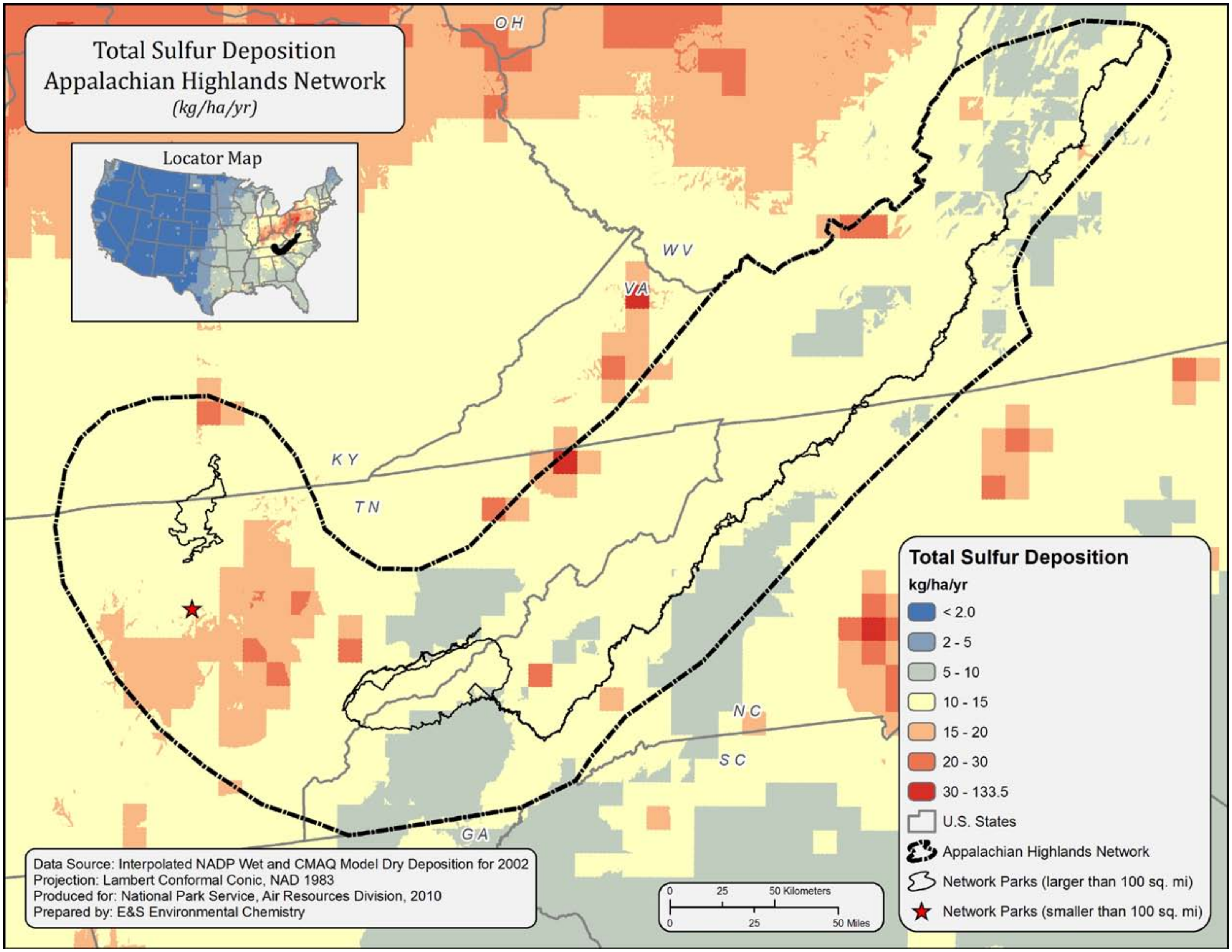
Map G


NOx (Nitrogen Oxides) and NH3 (Ammonia) Point Sources Appalachian Highlands Network
(tons N per year)
Locator Map
OH
WV
VA
KY
TN
NC
SC
GA
AL
MD
NOx Point Sources (tons N per year)
2,500 tons N/year
NH3 Point Sources (tons N per year)
1,000 tons N/year
U.S. States
Appalachian Highlands Network
Network Parks (larger than 100 sq. mi)
Network Parks (smaller than 100 sq. mi)
0 50 100 Kilometers
0 25 50 75 100 Miles
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&S Environmental Chemistry

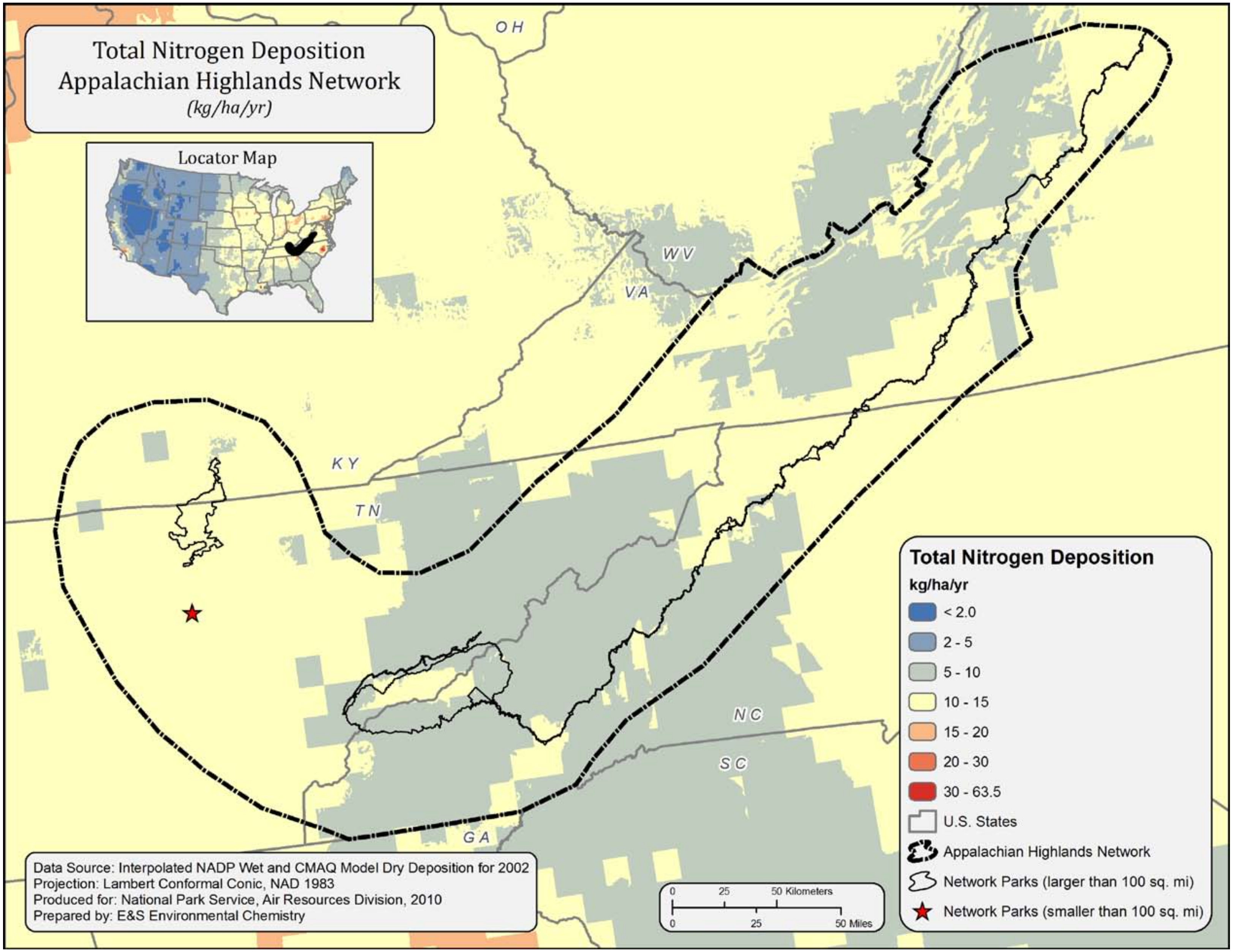
Map H


Park Locations and Urban Centers
Appalachian Highlands Network
(Population Centers Over 10,000)
Locator Map
Milwaukee
Detroit
Chicago
New York
Philadelphia
Baltimore
Washington DC
Columbus
Indianapolis
Nashville
Charlotte
Memphis
Oklahoma City
Jacksonville
Big South Fork
Blue Ridge Parkway
Obed
Great Smoky Mountains
MI
PA
NJ
IN
OH
WV
VA
IL
MO
KY
TN
NC
AR
SC
AL
GA
MS
Atlantic Ocean
Gulf of Mexico
Major Cities
Over 1,000,000
500,000 - 1,000,000
100,000 - 500,000
50,000 - 100,000
25,000 - 50,000
10,000 - 25,000
U.S. States
300 Mile Network Buffer
Appalachian Highlands Network
Network Parks (larger than 100 sq. mi)
Network Parks (smaller than 100 sq. mi)
0 100 200 Kilometers
0 50 100 150 200 Miles
Data Source: U.S. Census Data, 2000
Projection: Lambert Conformal Conic, NAD 1983
Produced for: National Park Service, Air Resources Division, 2010
Prepared by: E&S Environmental Chemistry

Map I

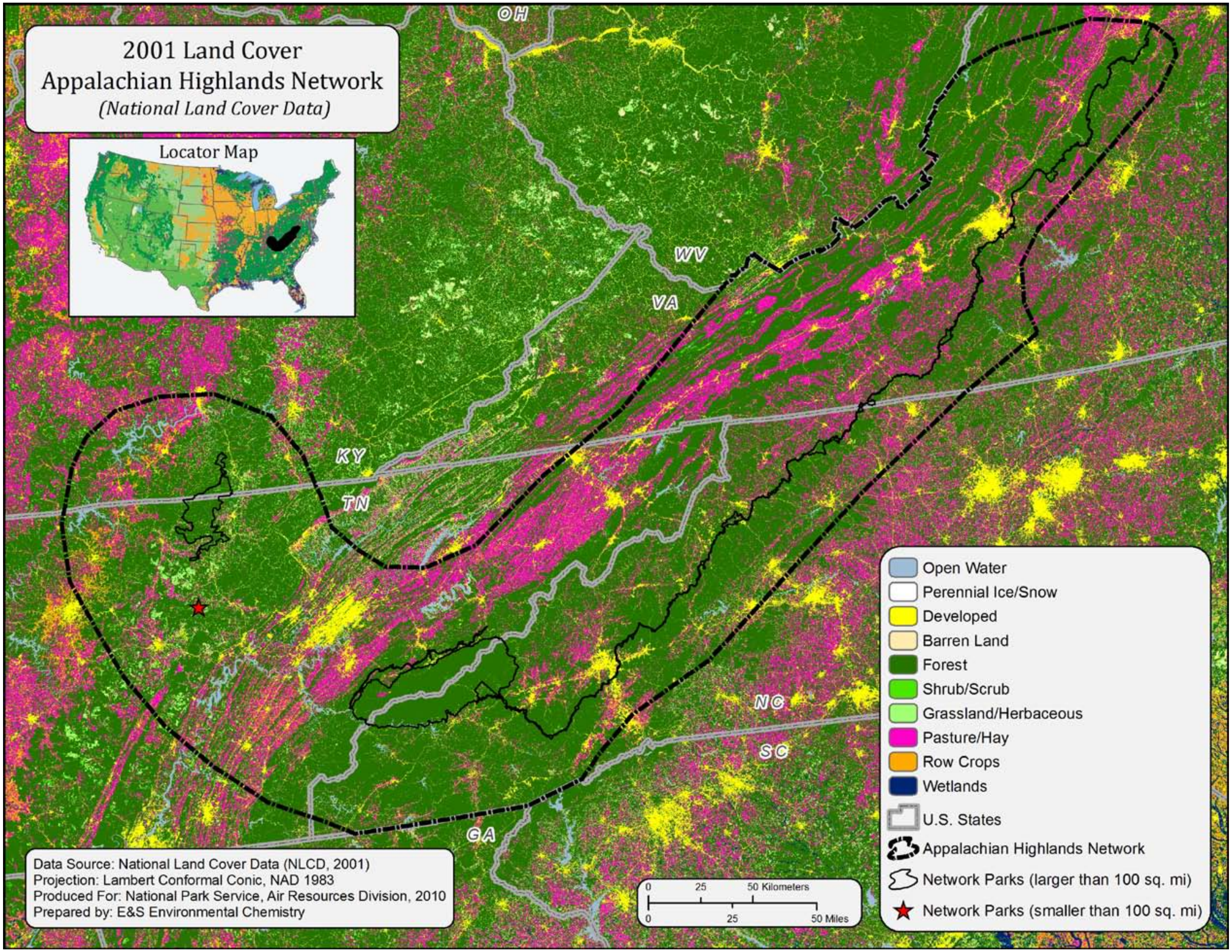

Total Sulfur Deposition
Appalachian Highlands Network
(kg/ha/yr)
Locator Map
OH
WV
VA
KY
TN
NC
SC
GA
Total Sulfur Deposition
kg/ha/yr
< 2.0
2 - 5
5 - 10
10 - 15
15 - 20
20 - 30
30 - 133.5
U.S. States
Appalachian Highlands Network
Network Parks (larger than 100 sq. mi)
Network Parks (smaller than 100 sq. mi)
0 25 50 Kilometers
0 25 50 Miles
Data Source: Interpolated NADP Wet and CMAQ Model Dry Deposition for 2002
Projection: Lambert Conformal Conic, NAD 1983
Produced for: National Park Service, Air Resources Division, 2010
Prepared by: E&S Environmental Chemistry

Map J

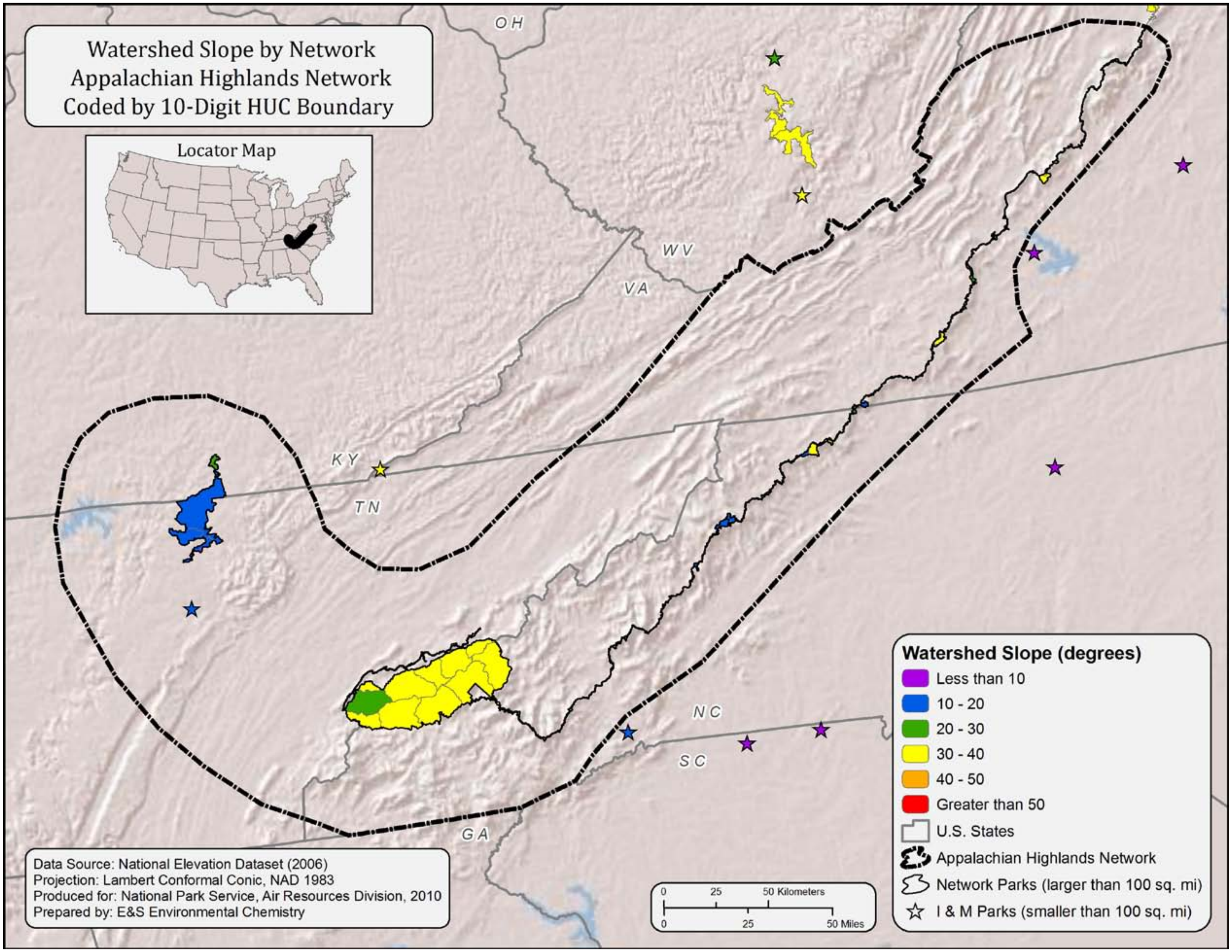


Total Nitrogen Deposition
Appalachian Highlands Network
(kg/ha/yr)
Locator Map
OH
WV
VA
KY
TN
NC
SC
GA
Total Nitrogen Deposition
kg/ha/yr
< 2.0
2 - 5
5 - 10
10 - 15
15 - 20
20 - 30
30 - 63.5
U.S. States
Appalachian Highlands Network
Network Parks (larger than 100 sq. mi)
Network Parks (smaller than 100 sq. mi)
0 25 50 Kilometers
0 25 50 Miles
Data Source: Interpolated NADP Wet and CMAQ Model Dry Deposition for 2002
Projection: Lambert Conformal Conic, NAD 1983
Produced for: National Park Service, Air Resources Division, 2010
Prepared by: E&S Environmental Chemistry

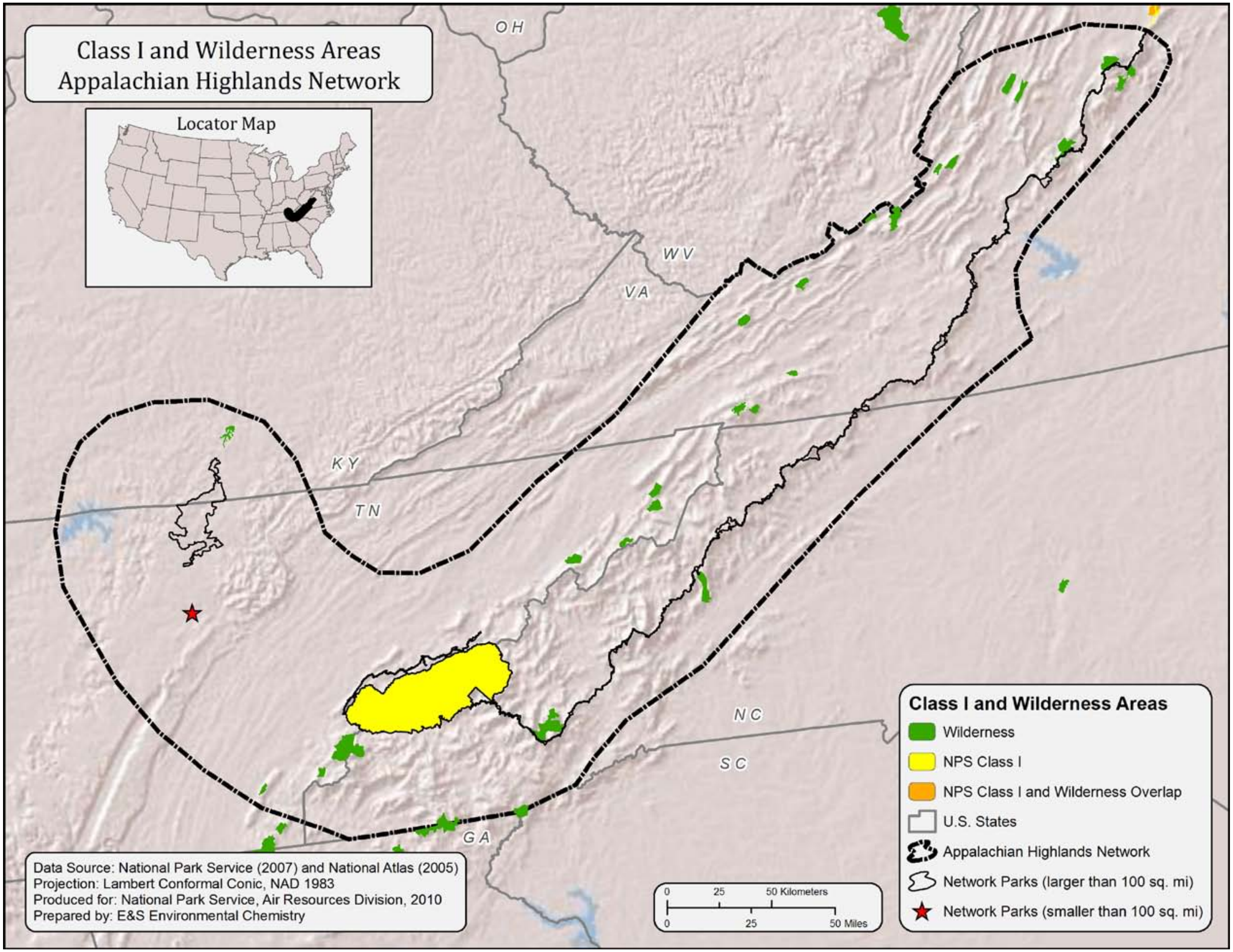
Map K


2001 Land Cover
Appalachian Highlands Network
(National Land Cover Data)
Locator Map
OH
WV
VA
KY
TN
NC
SC
GA
Open Water
Perennial Ice/Snow
Developed
Barren Land
Forest
Shrub/Scrub
Grassland/Herbaceous
Pasture/Hay
Row Crops
Wetlands
U.S. States
Appalachian Highlands Network
Network Parks (larger than 100 sq. mi)
Network Parks (smaller than 100 sq. mi)
0 25 50 Kilometers
0 25 50 Miles
Data Source: National Land Cover Data (NLCD, 2001)
Projection: Lambert Conformal Conic, NAD 1983
Produced For: National Park Service, Air Resources Division, 2010
Prepared by: E&S Environmental Chemistry

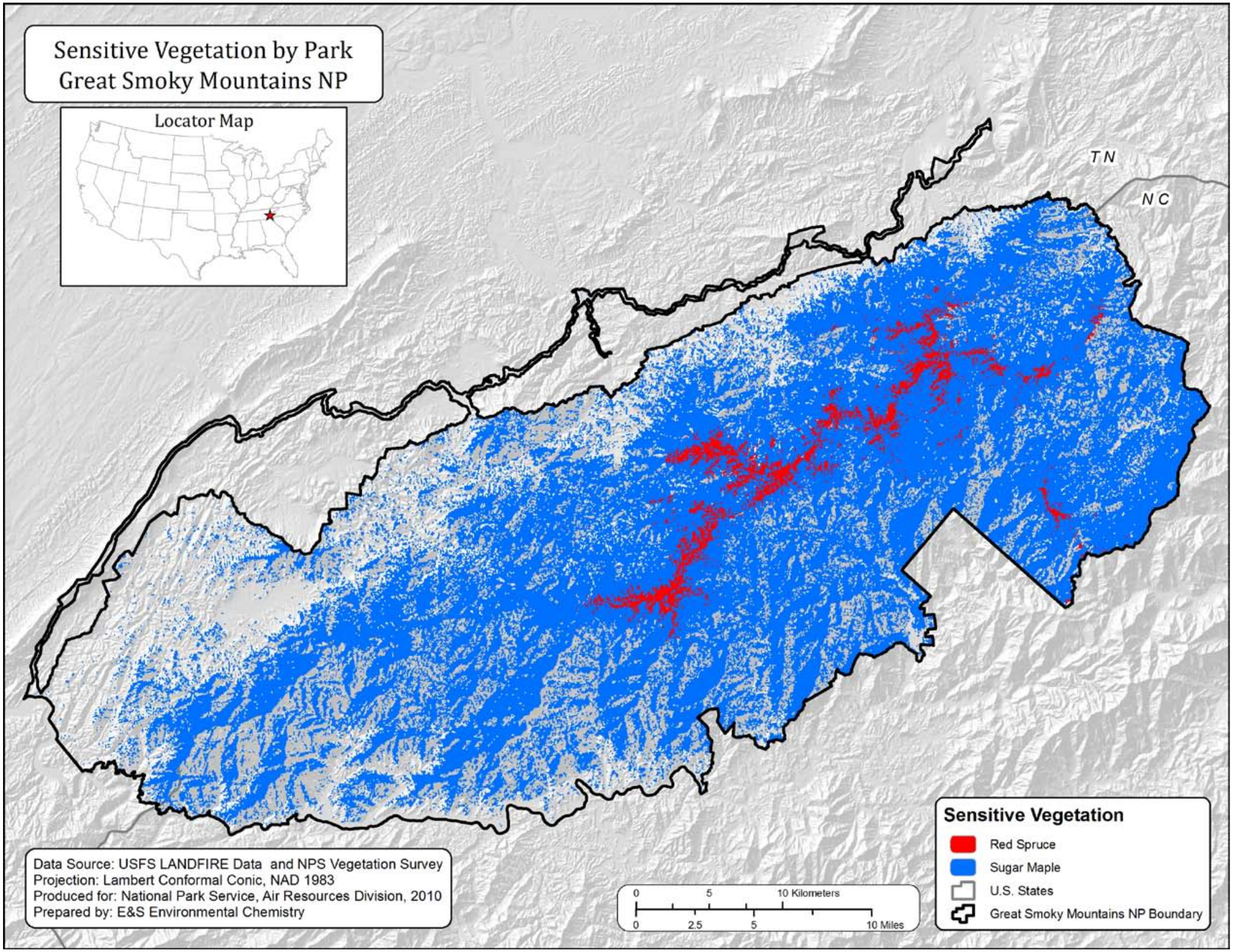
Map L


Watershed Slope by Network
Appalachian Highlands Network
Coded by 10-Digit HUC Boundary
Locator Map
OH
WV
VA
KY
TN
NC
SC
GA
Watershed Slope (degrees)
Less than 10
10 - 20
20 - 30
30 - 40
40 - 50
Greater than 50
U.S. States
Appalachian Highlands Network
Network Parks (larger than 100 sq. mi)
I & M Parks (smaller than 100 sq. mi)
0 25 50 Kilometers
0 25 50 Miles
Data Source: National Elevation Dataset (2006)
Projection: Lambert Conformal Conic, NAD 1983
Produced for: National Park Service, Air Resources Division, 2010
Prepared by: E&S Environmental Chemistry

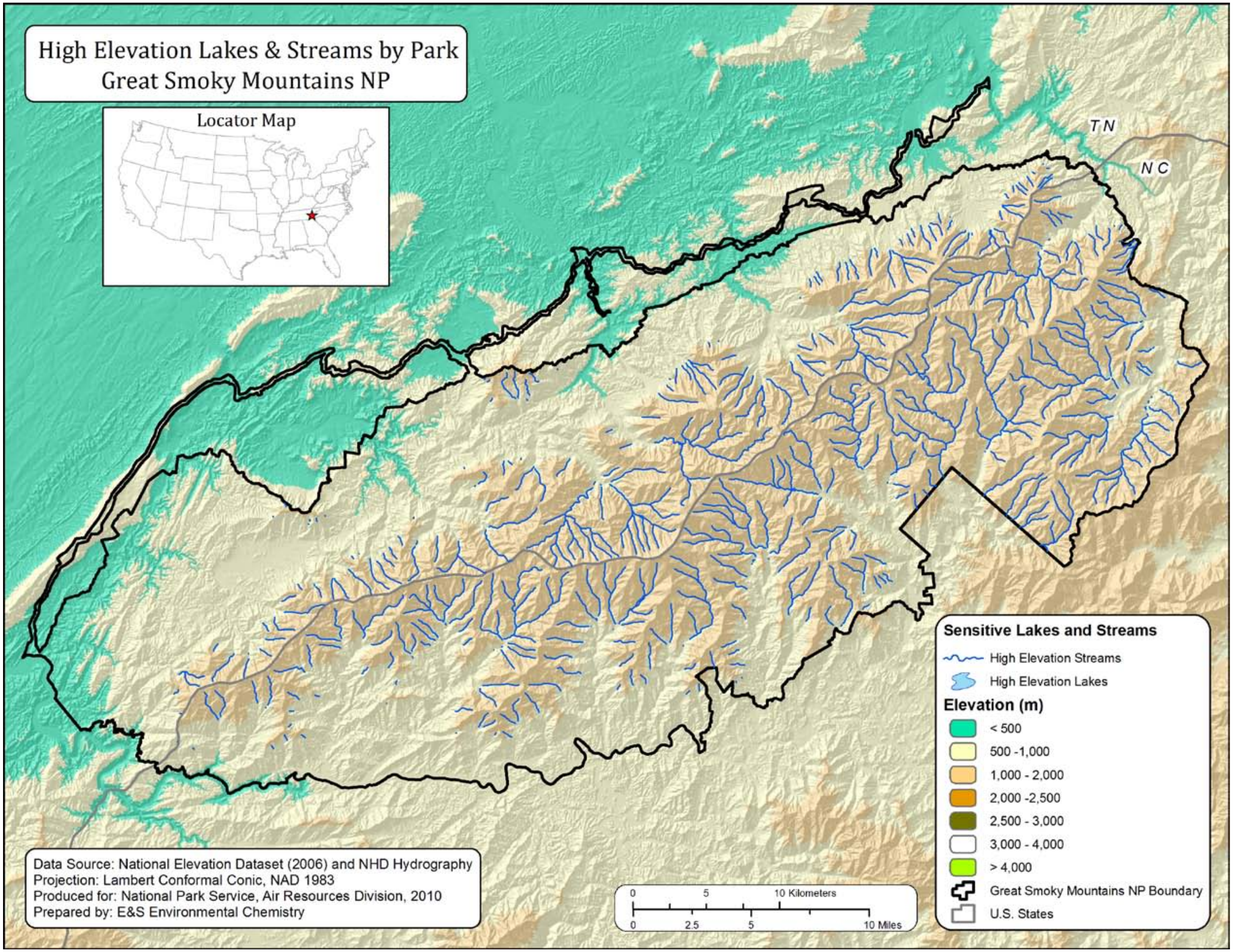
Map M


Class I and Wilderness Areas
Appalachian Highlands Network
Locator Map
O H
W V
V A
K Y
T N
N C
S C
G A
Class I and Wilderness Areas
Wilderness
NPS Class I
NPS Class I and Wilderness Overlap
U.S. States
Appalachian Highlands Network
Network Parks (larger than 100 sq. mi)
Network Parks (smaller than 100 sq. mi)
0 25 50 Kilometers
0 25 50 Miles
Data Source: National Park Service (2007) and National Atlas (2005)
Projection: Lambert Conformal Conic, NAD 1983
Produced for: National Park Service, Air Resources Division, 2010
Prepared by: E&S Environmental Chemistry

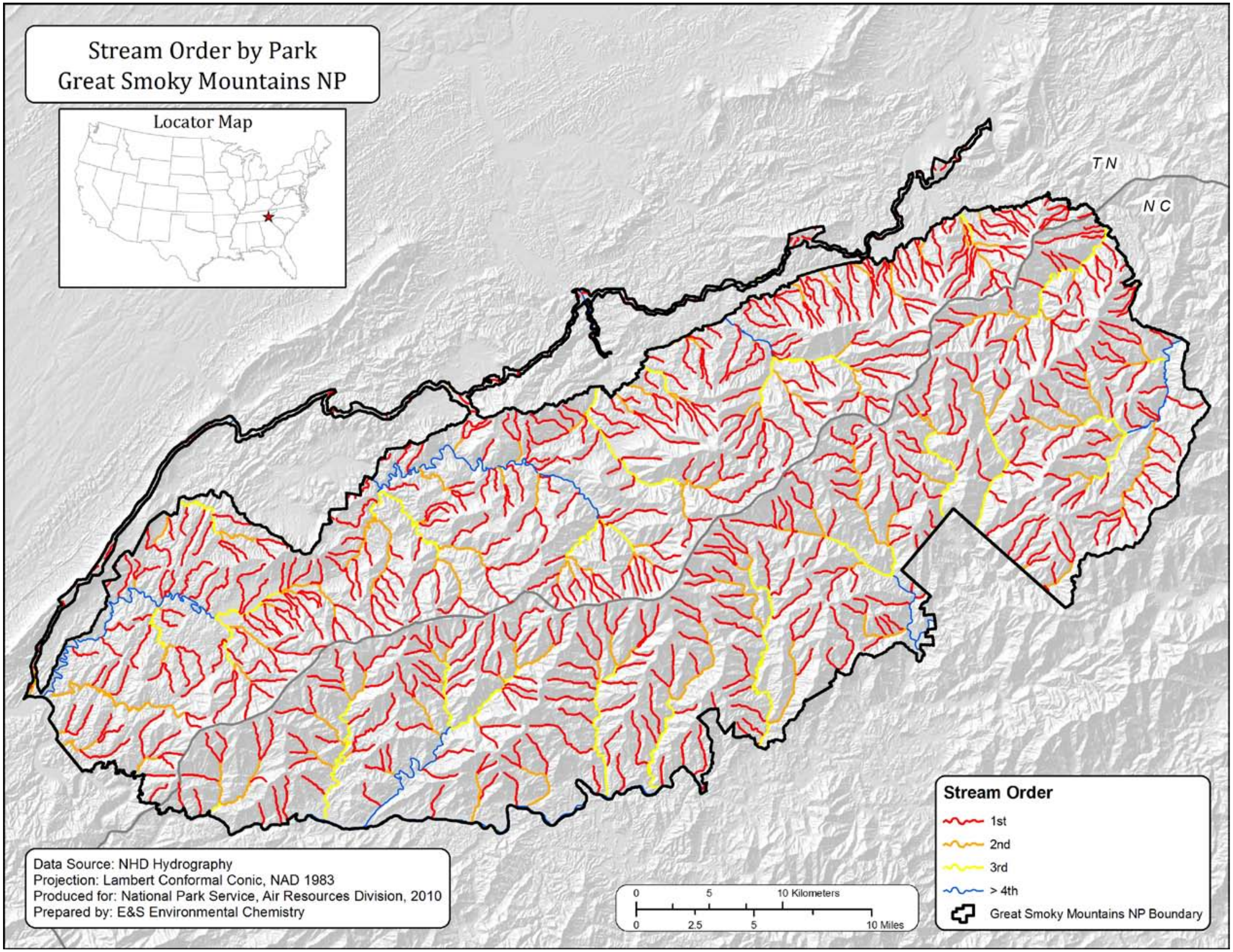
Map N


Sensitive Vegetation by Park
Great Smoky Mountains NP
Locator Map
TN
NC
Sensitive Vegetation
Red Spruce
Sugar Maple
U.S. States
Great Smoky Mountains NP Boundary
0 5 10 Kilometers
0 2.5 5 10 Miles
Data Source: USFS LANDFIRE Data and NPS Vegetation Survey
Projection: Lambert Conformal Conic, NAD 1983
Produced for: National Park Service, Air Resources Division, 2010
Prepared by: E&S Environmental Chemistry

Map P-I


High Elevation Lakes & Streams by Park
Great Smoky Mountains NP
Locator Map
TN
NC
Sensitive Lakes and Streams
High Elevation Streams
High Elevation Lakes
Elevation (m)
< 500
500 -1,000
1,000 - 2,000
2,000 -2,500
2,500 - 3,000
3,000 - 4,000
> 4,000
Great Smoky Mountains NP Boundary
U.S. States
0 5 10 Kilometers
0 2.5 5 10 Miles
Data Source: National Elevation Dataset (2006) and NHD Hydrography
Projection: Lambert Conformal Conic, NAD 1983
Produced for: National Park Service, Air Resources Division, 2010
Prepared by: E&S Environmental Chemistry

Map P-2



Stream Order by Park
Great Smoky Mountains NP
Locator Map
TN
NC
Stream Order
1st
2nd
3rd
> 4th
Great Smoky Mountains NP Boundary
0
5
10 Kilometers
0
2.5
5
10 Miles
Data Source: NHD Hydrography
Projection: Lambert Conformal Conic, NAD 1983
Produced for: National Park Service, Air Resources Division, 2010
Prepared by: E&S Environmental Chemistry

Map P-3

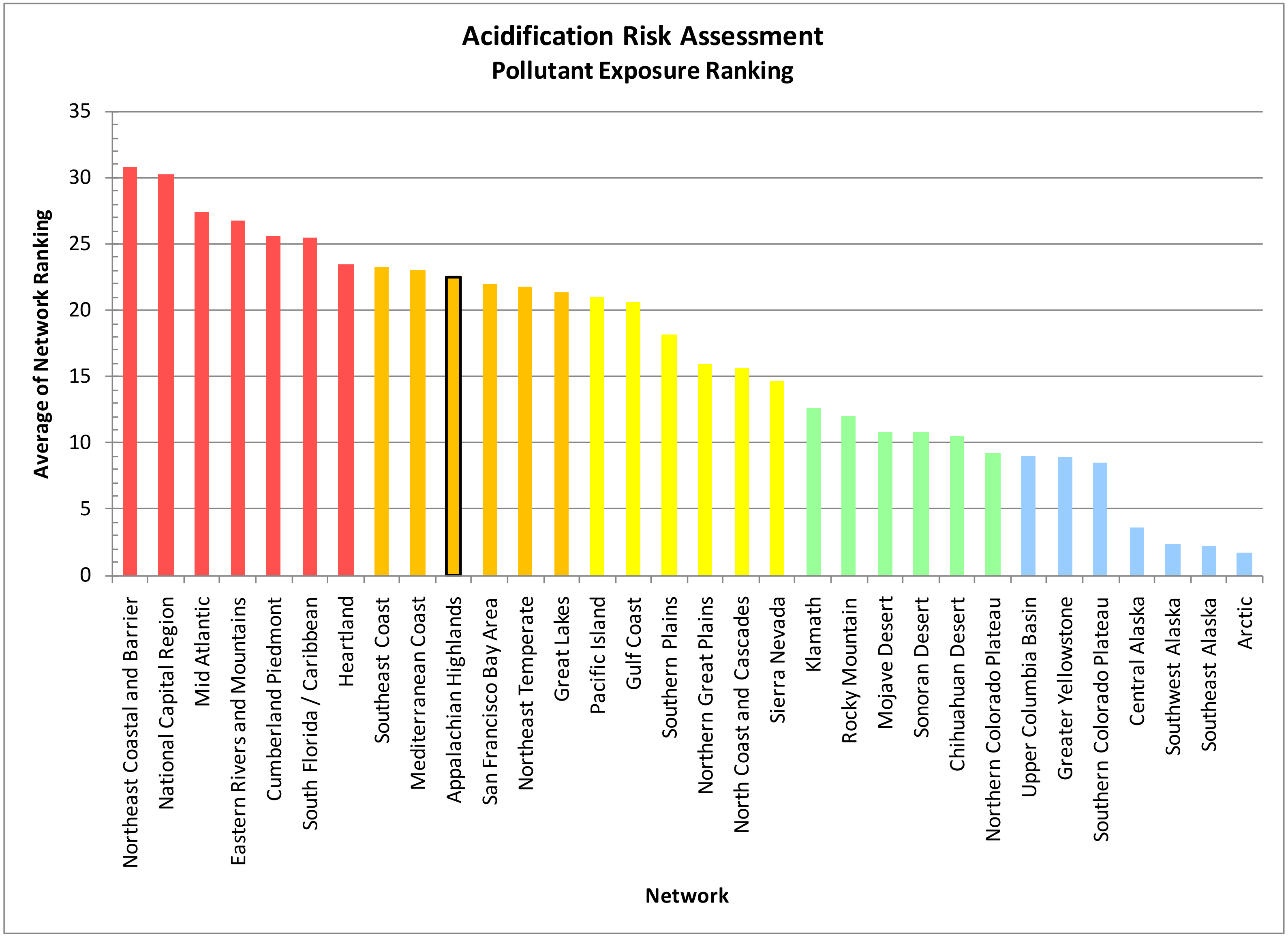

Acidification Risk Assessment
Pollutant Exposure Ranking
Average of Network Ranking
0
5
10
15
20
25
30
35
Northeast Coastal and Barrier
National Capital Region
Mid Atlantic
Eastern Rivers and Mountains
Cumberland Piedmont
South Florida / Caribbean
Heartland
Southeast Coast
Mediterranean Coast
Appalachian Highlands
San Francisco Bay Area
Northeast Temperate
Great Lakes
Pacific Island
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
Network

Figure A

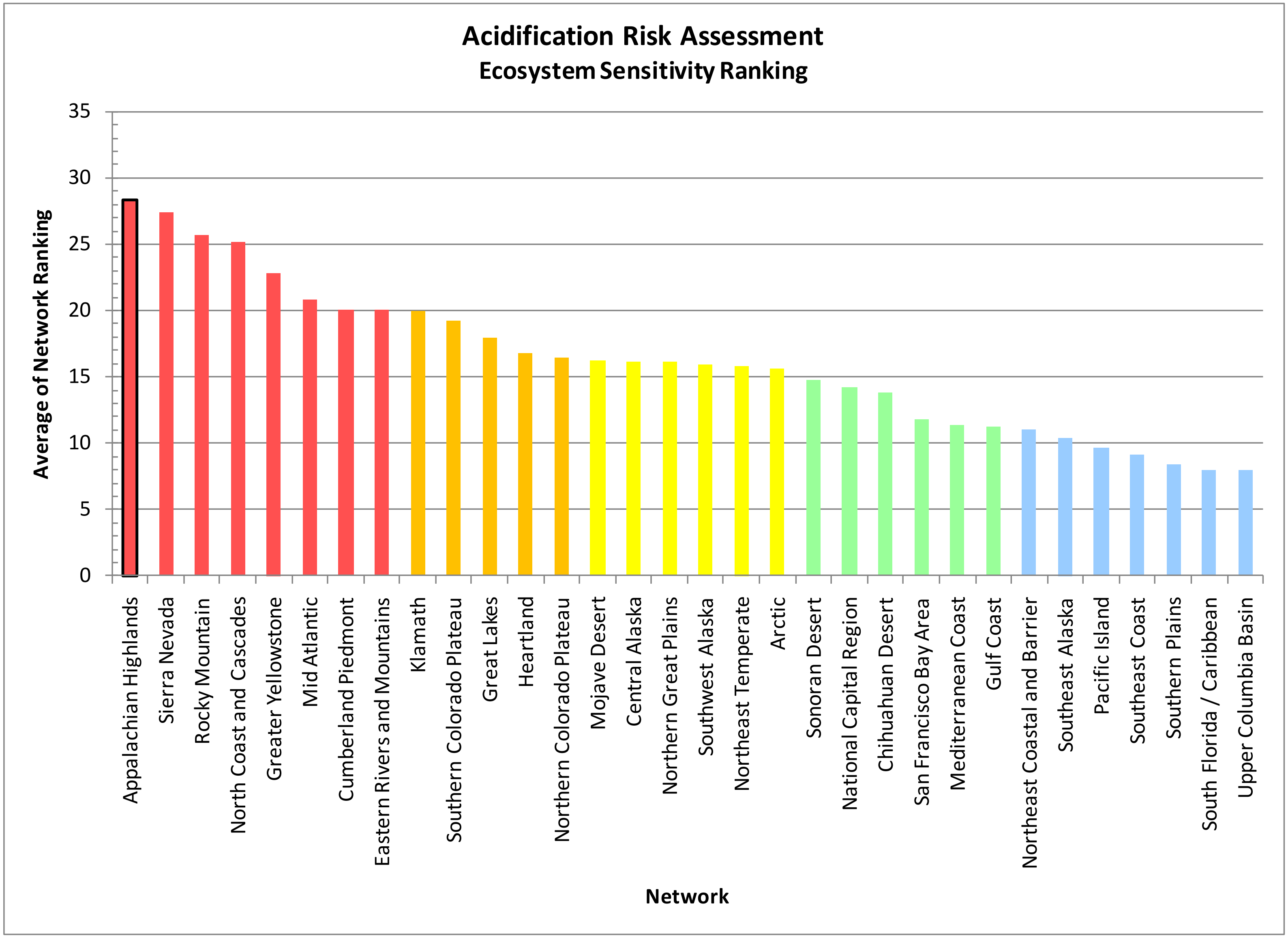

Acidification Risk Assessment
Ecosystem Sensitivity Ranking
Average of Network Ranking
35
30
25
20
15
10
5
0
Appalachian Highlands
Sierra Nevada
Rocky Mountain
North Coast and Cascades
Greater Yellowstone
Mid Atlantic
Cumberland Piedmont
Eastern Rivers and Mountains
Klamath
Southern Colorado Plateau
Great Lakes
Heartland
Northern Colorado Plateau
Mojave Desert
Central Alaska
Northern Great Plains
Southwest Alaska
Northeast Temperate
Arctic
Sonoran Desert
National Capital Region
Chihuahuan Desert
San Francisco Bay Area
Mediterranean Coast
Gulf Coast
Northeast Coastal and Barrier
Southeast Alaska
Pacific Island
Southeast Coast
Southern Plains
South Florida / Caribbean
Upper Columbia Basin
Network

Figure B

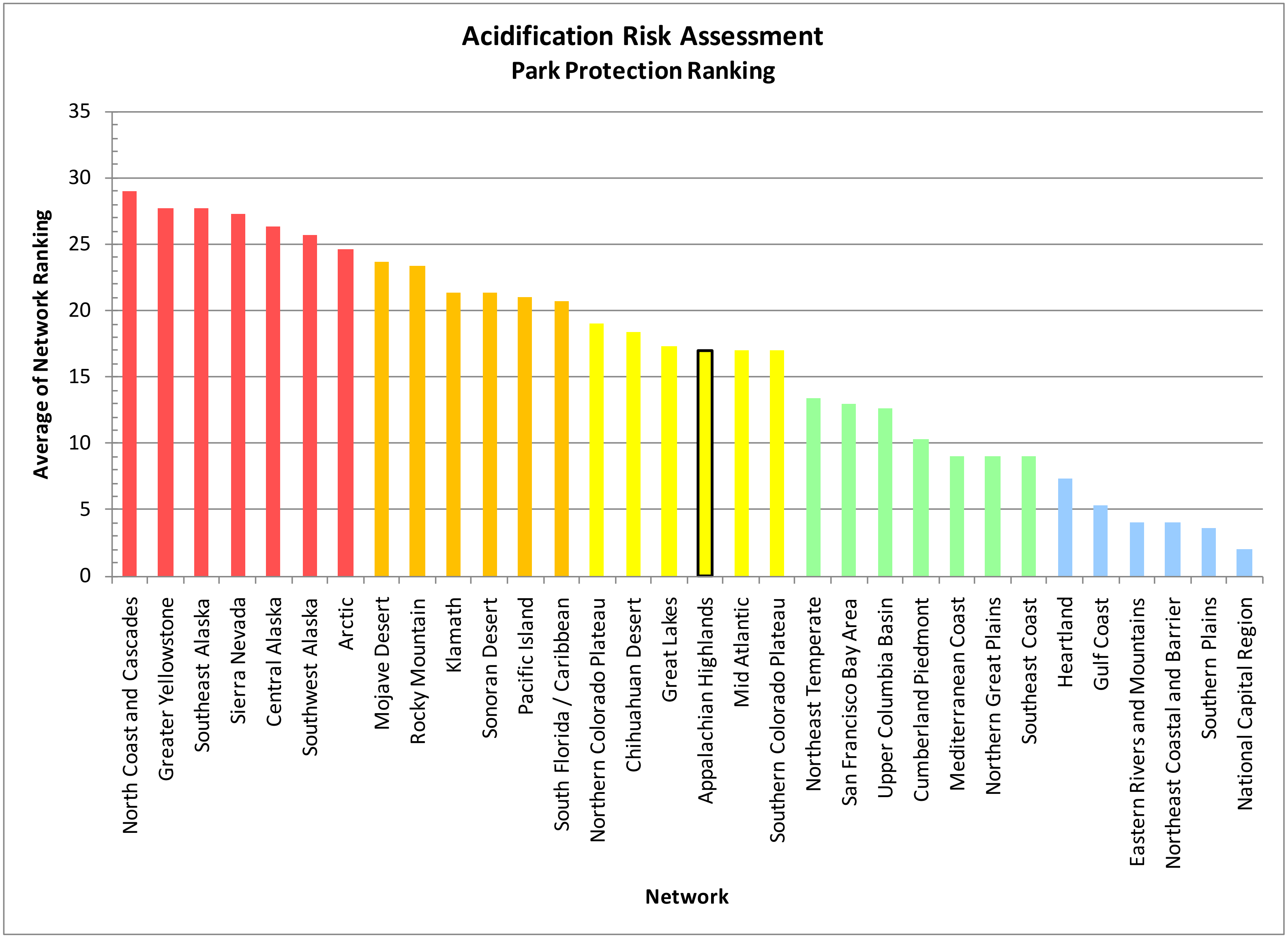

Acidification Risk Assessment
Park Protection Ranking
Average of Network Ranking
Network
0
5
10
15
20
25
30
35
North Coast and Cascades
Greater Yellowstone
Southeast Alaska
Sierra Nevada
Central Alaska
Southwest Alaska
Arctic
Mojave Desert
Rocky Mountain
Klamath
Sonoran Desert
Pacific Island
South Florida / Caribbean
Northern Colorado Plateau
Chihuahuan Desert
Great Lakes
Appalachian Highlands
Mid Atlantic
Southern Colorado Plateau
Northeast Temperate
San Francisco Bay Area
Upper Columbia Basin
Cumberland Piedmont
Mediterranean Coast
Northern Great Plains
Southeast Coast
Heartland
Gulf Coast
Eastern Rivers and Mountains
Northeast Coastal and Barrier
Southern Plains
National Capital Region

Figure C

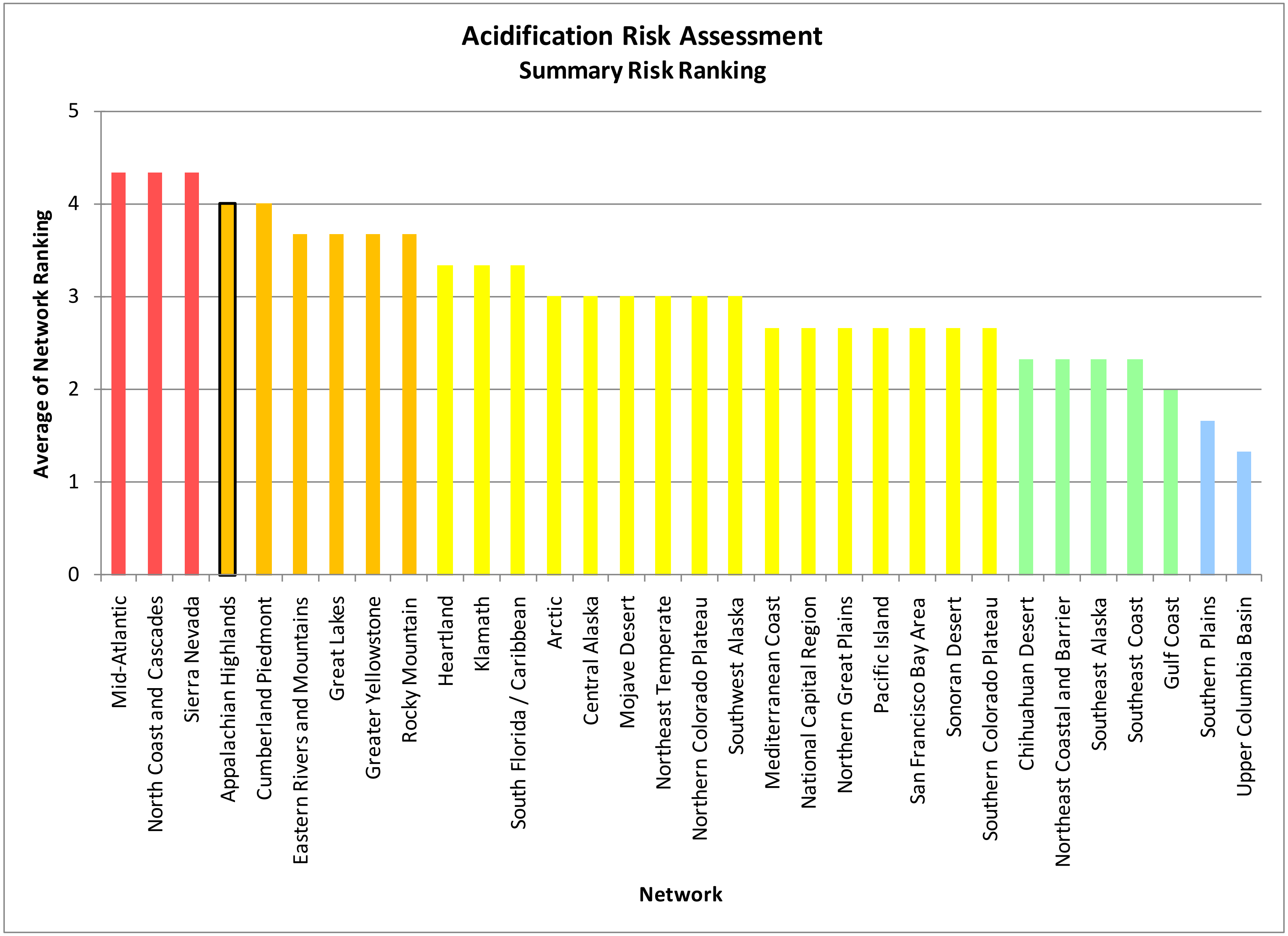

Acidification Risk Assessment
Summary Risk Ranking
Average of Network Ranking
0
1
2
3
4
5
Mid-Atlantic
North Coast and Cascades
Sierra Nevada
Appalachian Highlands
Cumberland Piedmont
Eastern Rivers and Mountains
Great Lakes
Greater Yellowstone
Rocky Mountain
Heartland
Klamath
South Florida / Caribbean
Arctic
Central Alaska
Mojave Desert
Northeast Temperate
Northern Colorado Plateau
Southwest Alaska
Mediterranean Coast
National Capital Region
Northern Great Plains
Pacific Island
San Francisco Bay Area
Sonoran Desert
Southern Colorado Plateau
Chihuahuan Desert
Northeast Coastal and Barrier
Southeast Alaska
Southeast Coast
Gulf Coast
Southern Plains
Upper Columbia Basin
Network

Figure D

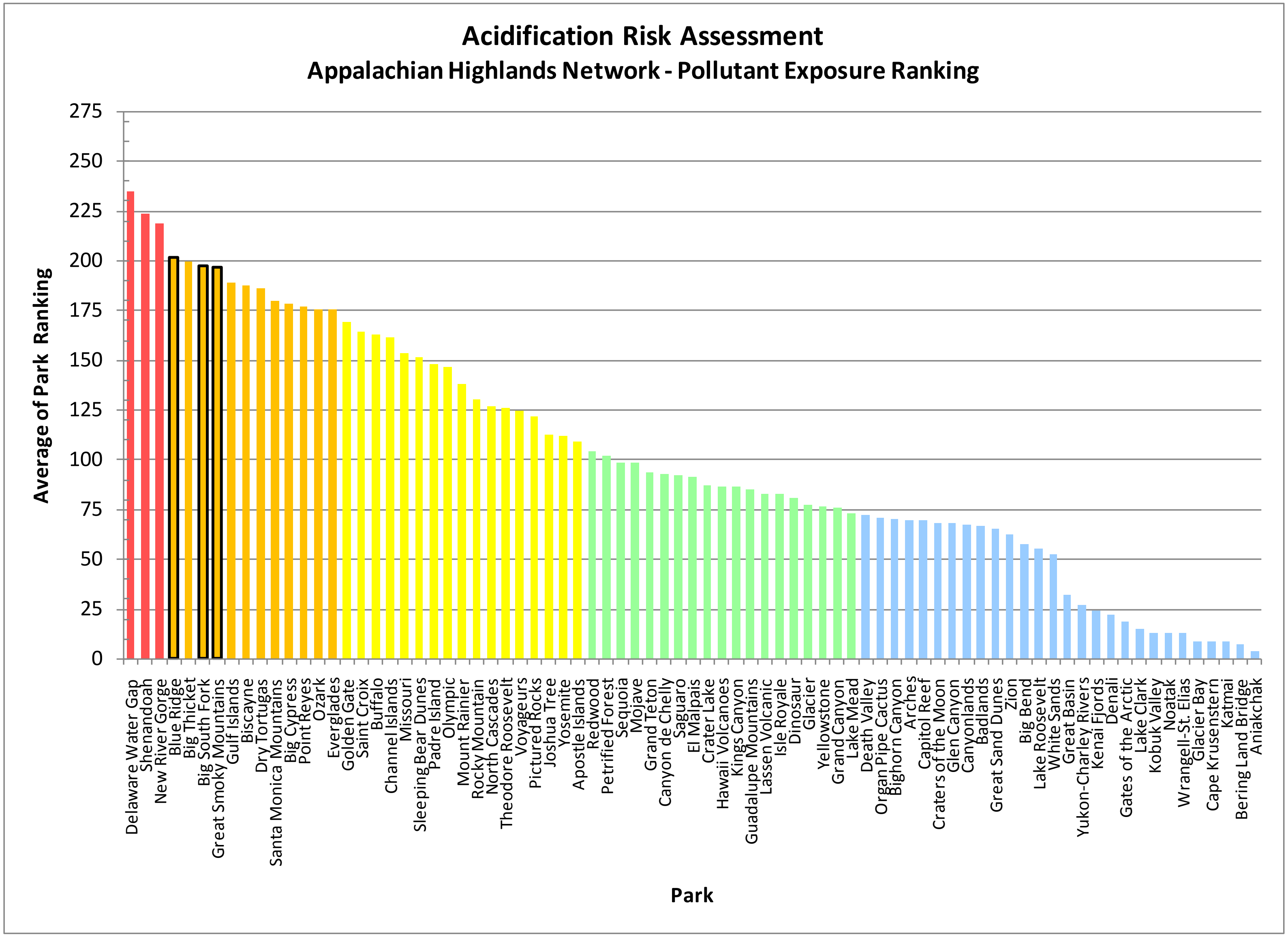

Acidification Risk Assessment
Appalachian Highlands Network - Pollutant Exposure Ranking
Average of Park Ranking
275
250
225
200
175
150
125
100
75
50
25
0
Delaware Water Gap
Shenandoah
New River Gorge
Blue Ridge
Big Thicket
Big South Fork
Great Smoky Mountains
Gulf Islands
Biscayne
Dry Tortugas
Santa Monica Mountains
Big Cypress
Point Reyes
Ozark
Everglades
Golden Gate
Saint Croix
Buffalo
Channel Islands
Missouri
Sleeping Bear Dunes
Padre Island
Olympic
Mount Rainier
Rocky Mountain
North Cascades
Theodore Roosevelt
Voyageurs
Pictured Rocks
Joshua Tree
Yosemite
Apostle Islands
Redwood
Petrified Forest
Sequoia
Mojave
Grand Teton
Canyon de Chelly
Saguaro
El Malpais
Crater Lake
Hawaii Volcanoes
Kings Canyon
Guadalupe Mountains
Lassen Volcanic
Isle Royale
Dinosaur
Glacier
Yellowstone
Grand Canyon
Lake Mead
Death Valley
Organ Pipe Cactus
Bighorn Canyon
Arches
Capitol Reef
Craters of the Moon
Glen Canyon
Canyonlands
Badlands
Great Sand Dunes
Zion
Big Bend
Lake Roosevelt
White Sands
Great Basin
Yukon-Charley Rivers
Kenai Fjords
Denali
Gates of the Arctic
Lake Clark
Kobuk Valley
Noatak
Wrangell-St. Elias
Glacier Bay
Cape Krusenstern
Katmai
Bering Land Bridge
Aniakchak
Park

Figure E

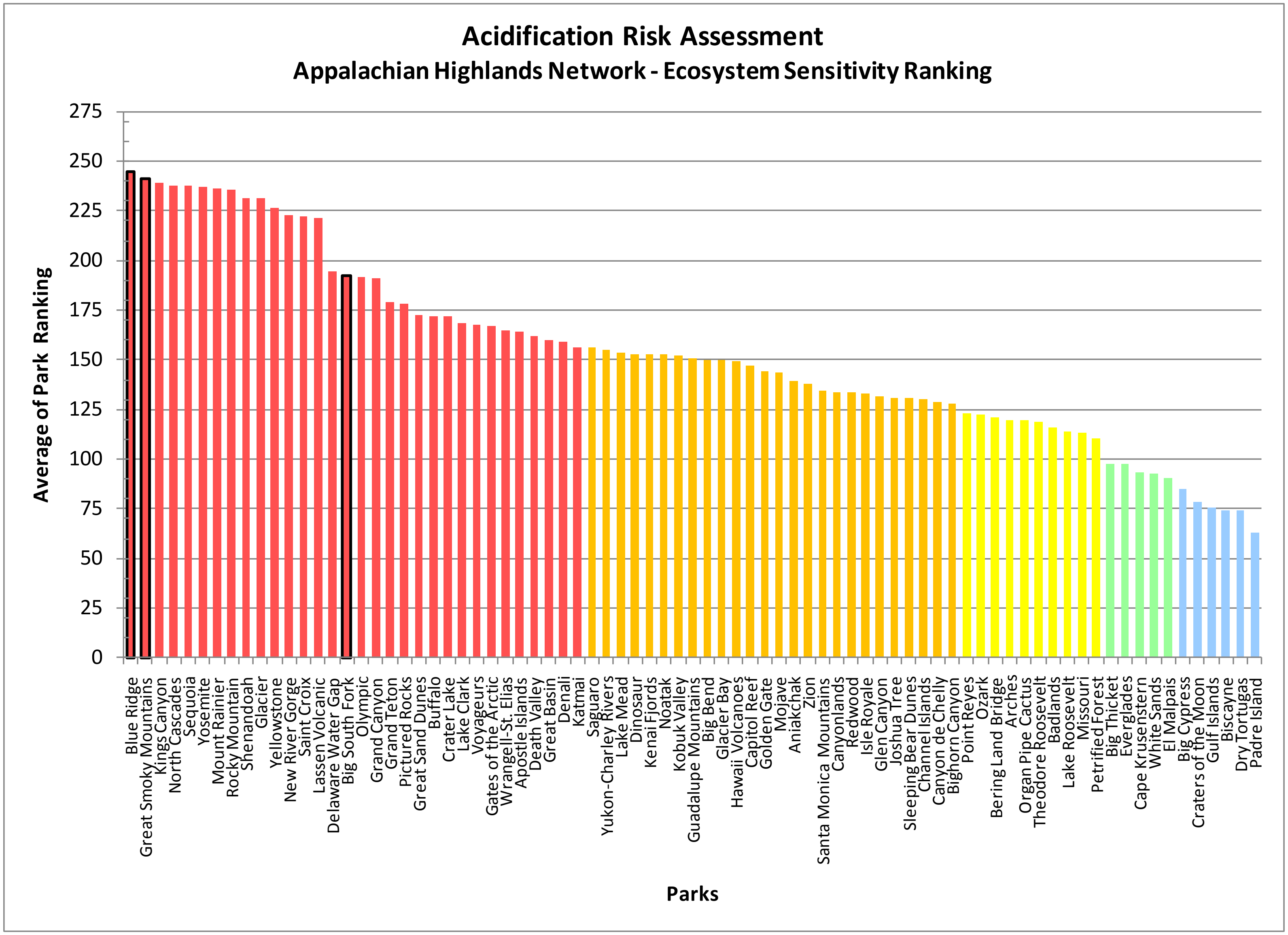
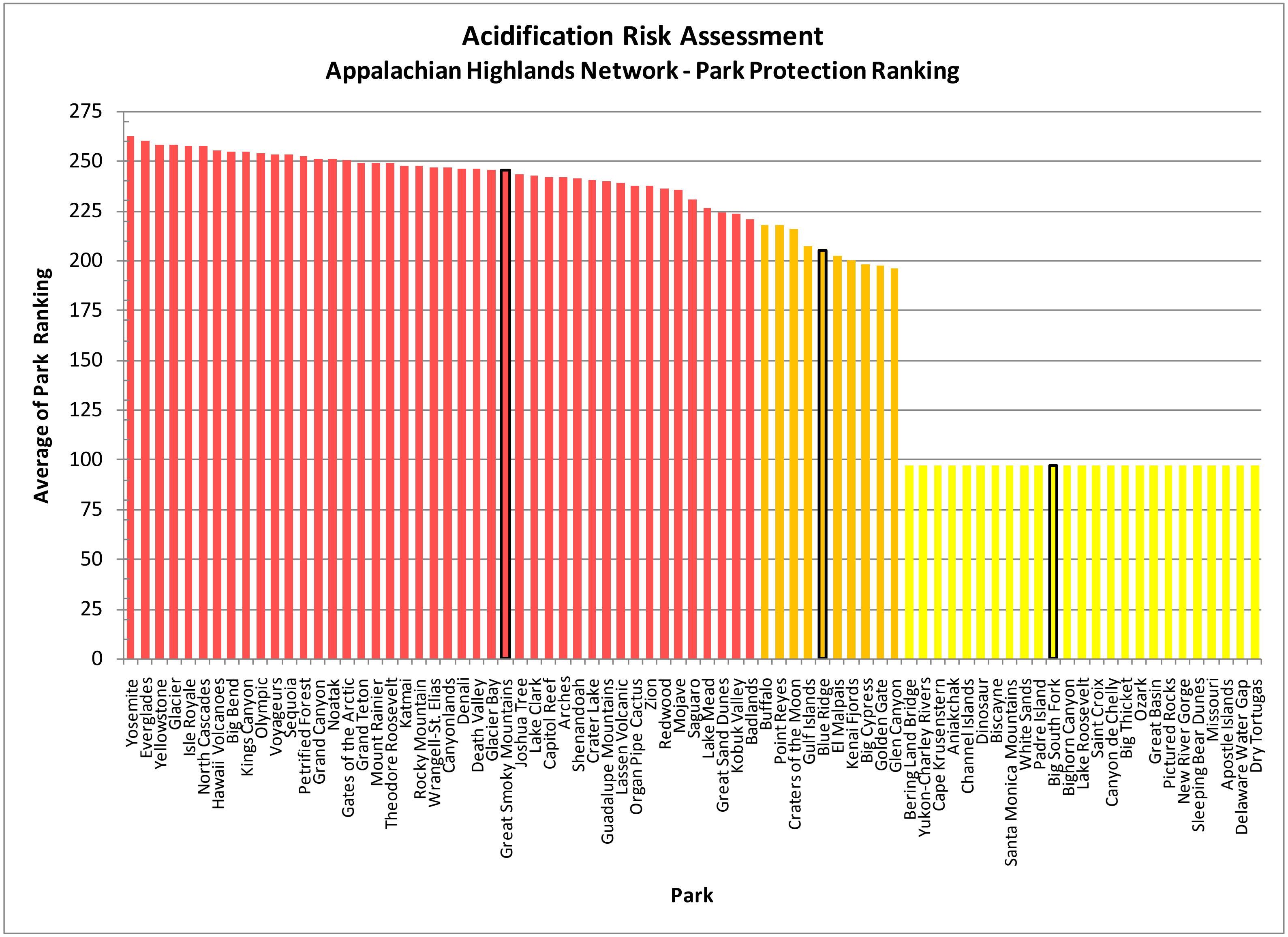

Acidification Risk Assessment
Appalachian Highlands Network - Ecosystem Sensitivity Ranking
Average of Park Ranking
275
250
225
200
175
150
125
100
75
50
25
0
Blue Ridge
Great Smoky Mountains
Kings Canyon
North Cascades
Sequoia
Yosemite
Mount Rainier
Rocky Mountain
Shenandoah
Glacier
Yellowstone
New 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
Aniakchak
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
Parks

Figure F



Acidification Risk Assessment
Appalachian Highlands Network - Park Protection Ranking
Average of Park Ranking
Park
275
250
225
200
175
150
125
100
75
50
25
0
Yosemite
Everglades
Yellowstone
Glacier
Isle Royale
North Cascades
Hawaii Volcanoes
Big Bend
Kings Canyon
Olympic
Voyageurs
Sequoia
Petrified Forest
Grand Canyon
Noatak
Gates of the Arctic
Grand Teton
Mount Rainier
Theodore Roosevelt
Katmai
Rocky Mountain
Wrangell-St. Elias
Canyonlands
Denali
Death Valley
Glacier Bay
Great Smoky Mountains
Joshua Tree
Lake Clark
Capitol Reef
Arches
Shenandoah
Crater Lake
Guadalupe Mountains
Lassen Volcanic
Organ Pipe Cactus
Zion
Redwood
Mojave
Saguaro
Lake Mead
Great Sand Dunes
Kobuk Valley
Badlands
Buffalo
Point Reyes
Craters of the Moon
Gulf Islands
Blue Ridge
El Malpais
Kenai Fjords
Big Cypress
Golden Gate
Glen Canyon
Bering Land Bridge
Yukon-Charley Rivers
Cape Krusenstern
Aniakchak
Channel Islands
Dinosaur
Biscayne
Santa Monica Mountains
White Sands
Padre Island
Big South Fork
Bighorn Canyon
Lake Roosevelt
Saint Croix
Canyon de Chelly
Big Thicket
Ozark
Great Basin
Pictured Rocks
New River Gorge
Sleeping Bear Dunes
Missouri
Apostle Islands
Delaware Water Gap
Dry Tortugas

Figure G

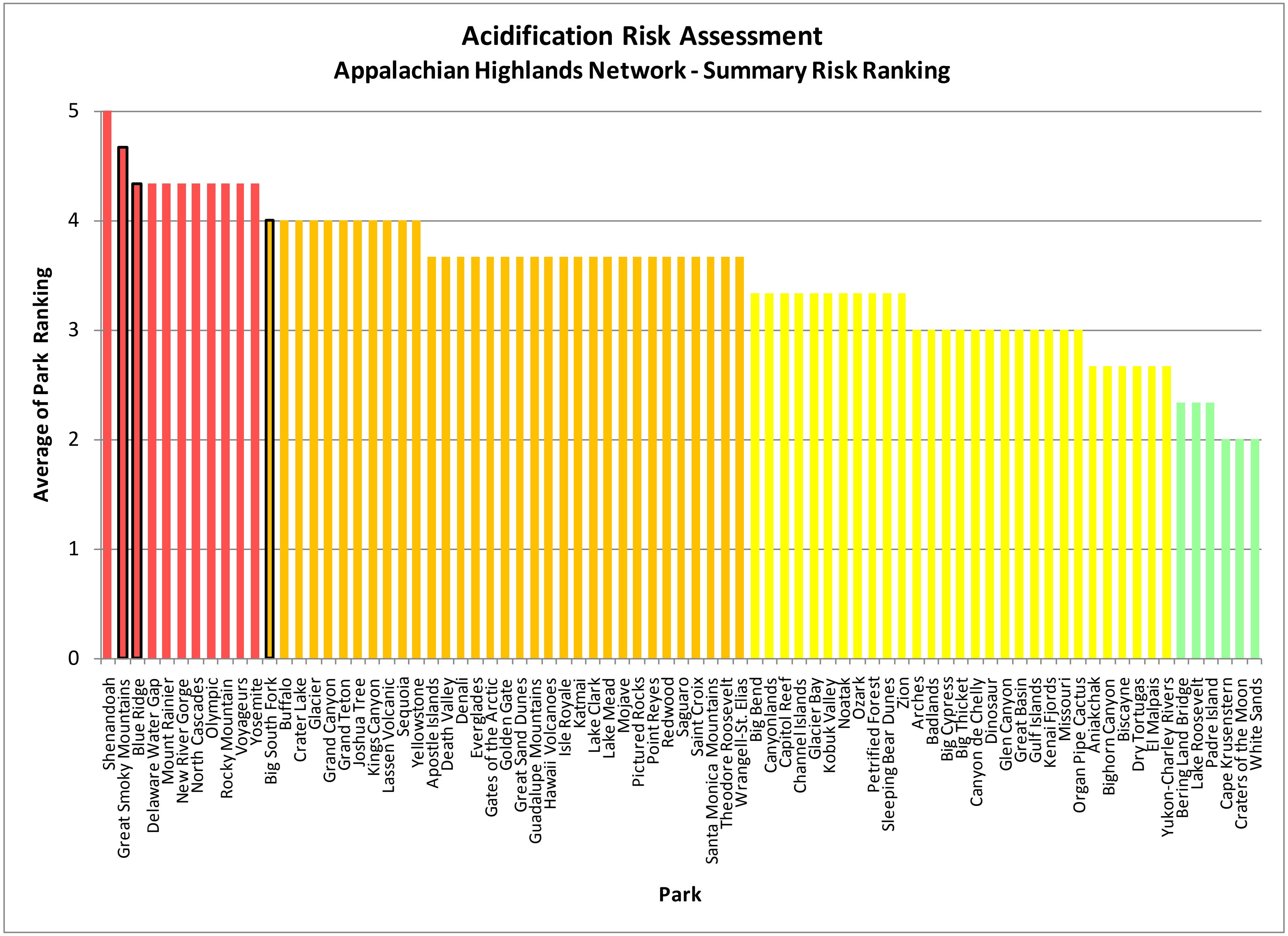

Acidification Risk Assessment
Appalachian Highlands Network - Summary Risk Ranking
Average of Park Ranking
Park
0
1
2
3
4
5
Shenandoah
Great Smoky Mountains
Blue Ridge
Delaware Water Gap
Mount Rainier
New River Gorge
North Cascades
Olympic
Rocky Mountain
Voyageurs
Yosemite
Big South Fork
Buffalo
Crater Lake
Glacier
Grand Canyon
Grand Teton
Joshua Tree
Kings Canyon
Lassen Volcanic
Sequoia
Yellowstone
Apostle Islands
Death Valley
Denali
Everglades
Gates of the Arctic
Golden Gate
Great Sand Dunes
Guadalupe Mountains
Hawaii Volcanoes
Isle Royale
Katmai
Lake Clark
Lake Mead
Mojave
Pictured Rocks
Point Reyes
Redwood
Saguaro
Saint Croix
Santa Monica Mountains
Theodore Roosevelt
Wrangell-St. Elias
Big Bend
Canyonlands
Capitol Reef
Channel Islands
Glacier Bay
Kobuk Valley
Noatak
Ozark
Petrified Forest
Sleeping Bear Dunes
Zion
Arches
Badlands
Big Cypress
Big Thicket
Canyon de Chelly
Dinosaur
Glen Canyon
Great Basin
Gulf Islands
Kenai Fjords
Missouri
Organ Pipe Cactus
Aniakchak
Bighorn Canyon
Biscayne
Dry Tortugas
El Malpais
Yukon-Charley Rivers
Bering Land Bridge
Lake Roosevelt
Padre Island
Cape Krusenstern
Craters of the Moon
White Sands

Figure H

NPS 910/107384, April 2011

National Park Service
U.S. Department of the Interior

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Air Resources Division
PO Box 25287
Denver, CO 80225

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