National Park Service
U.S. Department of the Interior

Natural Resource Stewardship and Science

Harpers Ferry National Historical Park
Natural Resource Condition Assessment

National Capital Region

Natural Resource Report NPS/HAFE/NRR—2013/746

ON THE COVER

John Brown's Fort was the building built in 1848 that was originally constructed for use as a guard and fire engine house for the federal Harpers Ferry Armory.
Photo by Joy Schoenberger.

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This report received informal 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 the National Capital Region Network website (*http://science.nature.nps.gov/im/units/ncrn/index.cfm*) and the Natural Resource Publications Management website (*http://www.nature.nps.gov/publications/NRPM*) . To receive this report in a format optimized for screen readers, please email *irma@nps.gov*.

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Executive Summary

Natural resoures in Harpers Ferry National Historical Park are in degraded condition overall and are under threat from surrounding land use, regionally poor air quality, and overpopulation of deer. Climate change is predicted to negatively affect many of the natural resources of the park.

BACKGROUND

Harpers Ferry National Historical Park was established in 1944 to "be a public national memorial commemorating historical events at or near Harpers Ferry." At the confluence of the Shenandoah and Potomac Rivers, the park contains riparian habitats, floodplains, agricultural fields, geologic exposures, rare limestone glades, developed areas, and upland forests.

Harpers Ferry National Historical Park's natural resources are challenged by multiple regional and local stressors. Air pollution from power plants, industry, and vehicle emissions result in reduced air quality through large regions of the central eastern seaboard of North America. The park is therefore subjected to high ozone and atmospheric deposition, potentially impacting flora, fauna, and park visitors. Watershed-wide urbanization and development result in challenges to water quality. Increased nutrients, pollutants, and flashiness of river flow can result in impacts to wetland flora and fauna as well as streambank erosion. Other threats to the park include exotic species, deer overpopulation, and gypsy moths.

NATURAL RESOURCE CONDITION ASSESSMENT

Assessment of natural resource condition within Harpers Ferry National Historical Park (HAFE) was carried out using the Inventory and Monitoring Program Vital Signs ecological monitoring framework. Twenty-five metrics were synthesized in four categories: Air Quality, Water Resources, Biological Integrity, and Landscape Dynamics. The assessment of condition was based on the comparison of available data collected between 2000 and 2011 to justified ecological threshold values.

Overall, the natural resources of Harpers Ferry National Historical Park were in *degraded condition*.

ECOLOGICAL MONITORING FRAMEWORK

The Vital Signs framework showed that air quality condition was generally very degraded, water resources condition was moderate, biological integrity condition was variable but degraded overall, and landscape dynamics condition was generally moderate.

All air quality metrics were evaluted to be in conditions of significant concern, except particulate matter which was in moderate condition. HAFE scored as very good for pH, water temperature, acid neutralizing capacity, and dissolved oxygen while nitrate, specific conductance, and total phosphorus scored as very degraded. Specific conductance also showed a significant degrading trend. HAFE had variable results for biological integrity. The park scored as very good condition for area of exotic trees and saplings and good condition for forest pests, while birds scored as medium integrity. The remaining metrics scored as degraded/poor or very degraded. HAFE scored as very good for forest cover within the park, and for impervious surface at both scales. Forest interior area within the park was good, and was moderate at the 5x park area scale. Forest cover at the 5x park area scale and road density at both scales were very degraded.

RECOMMENDATIONS AND DATA GAPS

Air quality was in a very degraded condition. Degraded air quality is a problem throughout the eastern United States and while the causes of degraded air quality are out of the park's control, the specific implications to the habitats and species in the park are less well known. Gaining a better understanding of how reduced air quality is impacting sensitive habitats and species within the park would help prioritize management efforts.

Despite mercury wet deposition data being available, there is no published reference condition for wet deposition. The only available reference condition for mercury is for fish tissue concentration—a human health threshold. As fish tissue concentrations are not regularly monitored, establishment of a wet deposition reference condition would give a better picture of the effect of mercury in the ecosystem.

Water resources were in a moderate condition overall. Nutrients (nitrogen and phosphorus), specific conductance, and the Benthic Index of Biotic Integrity (BIBI) were in poor to very degraded condition while pH, dissolved oxygen, water temperature and acid neutralizing capacity were in very good condition, similar to results found in parks throughout the region. Specific conductance showed a general degrading trend which is also in keeping with trends throughout the region. Water quality is only measured at one site within the park, so it is recommended to expand monitoring to include sites in Elk Run and Piney Run. These streams do not originate in the park and only run through the park for a short distance but it would be informative to monitor what is coming through the park from upstream. Data gaps and research recommendations revolve around maintaining good water quality by identification of nutrient sources and sensitive organisms.

Biological integrity was in a degraded condition overall. Deer density and the seedling stocking index were both in very degraded condition. Studies show a relationship between high deer density and poor forest regeneration and as such, deer management should continue to be a top priority. Other monitoring recommendations include exotic species education, and continuing to monitor exotic species, pests, and diseases. Data gaps and research needs include developing a bird index for non-forest species and modeling the effects of climate change and other stressors on the region's forests.

Landscape dynamics were in a moderate condition overall. Impervious surface at both spatial scales was in very good condition, as was forest cover within the park. Forest interior area within the park was in good condition, and was in moderate condition at the 5x park area scale. Road density was in very degraded condition at both spatial scales. The amount of forest cover and interior area within the park are influenced by the leased agricultural lands and developed areas within the park boundary. At the larger spatial scale, the proximity of the towns of Harpers Ferry and Bolivar, as well as developments to the south-west of the park, affects all of the landscape dynamics metrics.

CONCLUSIONS

Natural resoures in Harpers Ferry National Historical Park are in degraded condition overall and are under threat from surrounding land use, regionally poor air quality, and overpopulation of deer. Climate change is predicted to negatively affect many of the natural resources of the park, including increasing ozone levels and particle pollution, raising the water temperature of cold-water, trout-supporting streams, changing forest composition, and affecting exotic species and forest pests and diseases.

Acknowledgements

Geoff Sanders, John Paul Schmit, Jim Pieper, Marian Norris, and NPS National Capital Region Inventory & Monitoring, who provided data support. Rebecca Harriett, Superintendent at Harpers Ferry National Historical Park. Holly Salazer, Air Resources Coordinator, Northeast Region and Ellen Porter, Drew Bingham, and John Ray, NPS Air Resources Division, for advice on air quality metrics. Katie Foreman, Chesapeake Bay Program for assistance with benthic metrics. Staff at the Center for Urban Ecology who assisted with data sourcing, scoping, and proofing. Tim Carruthers, Joanna Woerner, and Melissa Andreychek at the Integration and Application Network for assistance with project scoping and initiation.

Chapter 1: NRCA background information

1.1 NRCA BACKGROUND INFORMATION

Natural Resource Condition Assessments (NRCAs) evaluate current conditions for a subset of natural resources and resource indicators in national park units, hereafter "parks". For these condition analyses they also report on trends (as possible), critical data gaps, and general level of confidence for study findings. The resources and indicators emphasized in the project work depend on a park's resource setting, status of resource stewardship planning and science in identifying high-priority indicators for that park, and availability of data and expertise to assess current conditions for the things identified on a list of potential study resources and indicators.

NRCAs represent a relatively new approach to assessing and reporting on park resource conditions. They are meant to complement, not replace, traditional issue and threat-based resource assessments. As distinguishing characteristics, all NRCAs:

- are multi-disciplinary in scope;[1]
- employ hierarchical indicator frameworks;[2]
- identify or develop logical reference conditions/values to compare current condition data against;[3,4]
- emphasize spatial evaluation of conditions and GIS (map) products;[5]
- summarize key findings by park areas;[6] and
- follow national NRCA guidelines and standards for study design and reporting products.

Although current condition reporting relative to logical forms of reference conditions and values is the primary objective, NRCAs also report on trends for any study indicators where the underlying data and methods support it. Resource condition influences are also addressed. This can include past activities or conditions that provide a helpful context for understanding current park resource conditions. It also includes present-day condition influences (threats and stressors) that are best interpreted at park, watershed, or landscape scales, though NRCAs do not judge or report on condition status per se for land areas and natural resources beyond the park's boundaries. Intensive cause and effect analyses of threats and stressors or development of detailed treatment options is outside the project scope.

Credibility for study findings derives from the data, methods, and reference values used in the project work—are they appropriate for the stated purpose and adequately documented? For each study indicator where current condition or trend is reported it is important to identify critical data gaps and describe level of confidence in at least qualitative terms. Involvement of park staff and National Park Service (NPS) subject matter experts at critical points during the project timeline is also important: 1) to assist selection of study indicators; 2) to recommend study data sets, methods, and reference conditions and values to use; and 3) to help provide a multi-disciplinary review of draft study findings and products.

NRCAs provide a useful complement to more rigorous NPS science support programs such as the NPS Inventory and Monitoring Program. For example, NRCAs can provide current condition estimates and help establish reference conditions or baseline values for some of a park's "vital signs" monitoring indicators. They can also

NRCAs strive to provide *credible condition reporting for a subset of important park natural resources and indicators*

Important NRCA success factors

Obtaining good input from park and other NPS subjective matter experts at critical points in the project timeline.

Using study frameworks that accommodate meaningful condition reporting at multiple levels (measures → indicators → broader resource topics and park areas).

Building credibility by clearly documenting the data and methods used, critical data gaps, and level of confidence for indicator-level condition findings.

1. However, the breadth of natural resources and number/type of indicators evaluated will vary by park.
2. Frameworks help guide a multi-disciplinary selection of indicators and subsequent 'roll up' and reporting of data for measures → conditions for indicators → condition summaries by broader topics and park areas.
3. NRCAs must consider ecologically based reference conditions, must also consider applicable legal and regulatory standards, and can consider other management-specified condition objectives or targets; each study indicator can be evaluated against one or more types of logical reference conditions.
4. Reference values can be expressed in qualitative to quantitative terms, as a single value or range of values; they represent desirable resource conditions or, alternatively, condition states that we wish to avoid or that require a follow-on response (e.g., ecological thresholds or management 'triggers').
5. As possible and appropriate, NRCAs describe condition gradients or differences across the park for important natural resources and study indicators through a set of GIS coverages and map products.
6. In: addition to reporting on indicator-level conditions, investigators are asked to take a bigger picture (more holistic) view and summarize overall findings and provide suggestions to managers on an area-by-area basis: 1) by park ecosystem/habitat types or watersheds and 2) for other park areas as requested.

bring in relevant non-NPS data to help evaluate current conditions for those same vital signs. In some cases, NPS inventory data sets are also incorporated into NRCA analyses and reporting products.

In-depth analysis of climate change effects on park natural resources is outside the project scope. However, existing condition analyses and data sets developed by a NRCA will be useful for subsequent park-level climate change studies and planning efforts.

NRCAs do not establish management targets for study indicators. Decisions about management targets must be made through sanctioned park planning and management processes. NRCAs do provide science-based information that will help park managers with an ongoing, longer term effort to describe and quantify their park's desired resource conditions and management targets. In the near term, NRCA findings assist strategic park resource planning[7] and help parks report to government accountability measures.[8]

Due to their modest funding, relatively quick timeframe for completion and reliance on existing data and information, NRCAs are not intended to be exhaustive. Study methods typically involve an informal synthesis of scientific data and information from multiple and diverse sources. Level of rigor and statistical repeatability will vary by resource or indicator, reflecting differences in our present data and knowledge bases across these varied study components.

NRCAs can yield new insights about current park resource conditions but in many cases their greatest value may be the development of useful documentation regarding known or suspected resource conditions within parks. Reporting products can help park managers as they think about near-term workload priorities, frame data and study needs for important park resources, and communicate messages about current park resource conditions to various audiences. A successful NRCA delivers science-based information that is credible and has practical uses for a variety of park decision making, planning, and partnership activities.

Over the next several years, the NPS plans to fund a NRCA project for each of the ~270 parks served by the NPS Inventory and Monitoring Program. Additional NRCA[9] Program information is posted at: *http://nature.nps.gov/water/nrca/index.cfm*

NRCA reporting products *provide a credible snapshot-in-time evaluation for a subset of important park natural resources and indicators, to help park managers:*

- *Direct limited staff and funding resources to park areas and natural resources that represent high need and/or high opportunity situations (near-term operational planning and management)*
- *Improve understanding and quantification for desired conditions for the park's "fundamental" and "other important" natural resources and values*

7. NRCAs are an especially useful lead-in to working on a park Resource Stewardship Strategy (RSS) but study scope can be tailored to also work well as a post-RSS project.
8. While accountability reporting measures are subject to change, the spatial and reference-based condition data provided by NRCAs will be useful for most forms of 'resource condition status' reporting as may be required by the NPS, the Department of the Interior, or the Office of Management and Budget.
9. Acronyms are defined in Table B-3 in Appendix B.

Chapter 2: Introduction and resource setting

2.1 INTRODUCTION

On June 30, 1944, the U.S. Congress designated Harpers Ferry National Monument to "be a public national memorial commemorating historical events at or near Harpers Ferry." Renamed in 1963 as a National Historical Park, Harpers Ferry is situated along a deep gap in the northern section of the Blue Ridge Mountains where the Shenandoah and Potomac Rivers converge. It lies principally in the state of- West Virginia, with additional areas in Virginia and Maryland.

The park commemorates many historic events and eras including the failed 1859 raid by abolitionist John Brown on the federal arsenal at Harpers Ferry, the development of modern industrial production using machine manufacture and interchangeable parts, and the Civil War period during which the town changed hands eight times (Harpers Ferry along with 12,693 defending Union soldiers was captured most famously by Jonathan 'Stonewall' Jackson in 1862). The park also commemorates African American history including the 1867 founding of Storer College, the nation's first integrated school designed primarily to educate former slaves but open to students of all races and both genders.

The 1,475-ha (3,645-acre) park contains riparian habitats, floodplains, agricultural fields, geologic exposures, rare limestone glades, developed areas, and upland forests (Moyer, et al. 2004). The lower areas of the park are subject to periodic flooding. In addition to the Potomac and Shenandoah Rivers, there are three perennial streams and several canals within the national historical park boundaries. The streams are Elks Run and Flowing Springs in West Virginia and Piney Run in Virginia.

These natural resources help constitute the park's historic viewshed down the Potomac River, landscapes associated with the national historical park's Civil War significance, the former Storer College campus, and other even more developed portions of the park including the Lower Town. The majority of the park's lands are forested.

Cannon at the Murphy Farm. Photo: Marsha B. Wassel/NPS.

Bridge piers of the original Baltimore & Ohio Railroad and the Shenandoah Bridge remain visible in the Potomac and Shenandoah respectively where the two rivers meet. The modern CSX railroad line crosses the Potomac River and proceeds through Harpers Ferry to the southwest, roughly paralleling the Shenandoah River (NPS 2008a). U.S. Route 340 that once passed through the town, now bypasses it to the south.

In the 1780s, Thomas Jefferson visited Harpers Ferry and from the shoreline cliffs of the Shenandoah he wrote in his book *Notes of the State of Virginia* that the view was "one of the most stupendous scenes in nature" and was "worth a voyage across the Atlantic."

Besides its natural beauty, Harpers Ferry attracted settlement for several reasons: it was situated at a natural gap in the Blue Ridge, it had an excellent supply of water power, and it had natural supplies of iron ore, a coal area, and forests to supply timber. One of the earliest businesses established in the area in 1733 was the ferry run by Robert Harper that served regional travelers. Iron ore mining began around the same time.

Little is known about the area before European arrival, although archeological excavations in the late 1980s and early 1990s

John Brown Fort on the Storer campus in 1915. Photo: NPS.

in lower town (at the tip of the Peninsula between the Shenandoah and Potomac Rivers) indicate that American Indians inhabited the region on a seasonal basis for at least several centuries before European contact (Moyer et al. 2004).

President George Washington established the Federal Armory at Harpers Ferry on June 15, 1796. By the mid-1830s, the town was well on its way to becoming strategically significant, with two railroads and the completion of the Chesapeake and Ohio Canal up to Harpers Ferry.

By 1859 (prior to the start of the Civil War), the town of Harpers Ferry was generally cleared of vegetation. According to the park's 1986 Statement for Management, "present vegetation in unflooded portions of the historic town, adjoining slopes and the surrounding Heights is secondary or tertiary growth. Upland areas were at various times completely cleared for farming or urban uses. These areas were once covered with a superior stand of hardwoods and a chestnut–oak climax forest. Areas of secondary or tertiary forest series are now composed mostly of inferior hardwoods. The original chestnut–oak forests have been succeeded by oak–hickory climax, the American chestnut being eliminated by the 1930s by a fatal blight."

Harpers Ferry was designated as a national monument in 1944 and initial NPS efforts restored the town to the 1859–1865 time period. Park visitors come not only to visit historic sites, but also for the area's natural and scenic beauty. Harpers Ferry is a major destination along the Appalachian Trail, is traversed by the Chesapeake and Ohio Canal (also a National Historical Park), and is included in the Potomac Heritage National Scenic Trail and the Lewis and Clark National Historic Trail.

2.1.1 Enabling legislation

Several laws and documents guide natural resource management for HAFE—the National Park Service Organic Act of 1916 ("Organic Act," Ch. 1, 39 Stat 535) and the federal legislation passed June 30, 1944 to establish the park. Other guidance documents include the NPS Management Policies (U.S. Dept of Interior 2006) and the park's General Management Plan finalized in 2010.

The Organic Act that established the National Park Service (NPS) on August 25, 1916 provides the primary mandate NPS has for natural resource protection within all national parks. It states,

> *"the Service thus established shall promote and regulate the use of Federal areas known as national parks, monuments and reservations . . . by such means and measures as conform to the fundamental purpose of the said parks, monuments and reservations, which purpose is to conserve the scenery and the natural and historic objects and the wild life therein and to provide for the enjoyment of the same in such manner and by such means as will leave them unimpaired for the enjoyment of future generations."*

Consequently, like all parks in the National Park system, one of HAFE's chief mandates is to preserve the scenery and the natural and cultural resources of the park. Any visitor activities associated with enjoyment can occur only to the extent that they do not impair the scenery and the natural resources for future generations.

The 1944 founding legislation for Harpers Ferry states that the park should "be a public national memorial commemorating historical events at or near Harpers Ferry."

In 1980, Public Law 96-199 was passed, which mandated preservation of the down river view described by Thomas Jefferson in the 1780s.

As a national historical park, natural resource management at Harpers Ferry is set within a cultural and historic context. The Cultural Landscapes section (5.3.5.2) of NPS Management Policies (U.S. Dept. of Interior 2006) clarifies the boundary between management for cultural and natural resources, stating that,

> *"The treatment of a cultural landscape will preserve significant attributes, biotic systems, and uses when those uses contribute to historical significance. Treatment decisions will be based on a cultural landscape's historical significance over time, existing conditions, and use. Treatment decisions will consider both the natural and built characteristics and features of a landscape, the dynamics inherent in natural processes and continued use, and the concerns of traditionally associated peoples."*

Harpers Ferry is therefore a park established to preserve historic landscapes and resources that is managed as much as possible to preserve physical attributes and biotic systems wherever historic considerations do not indicate otherwise.

The park's 2010 General Management Plan (GMP) indicated several specific actions related to natural resources including the removal of a non-historic campground on Schoolhouse Ridge and the restoration of Harpers Ferry Caverns to a more natural appearance (NPS 2008a). The GMP also states that on Loudoun Heights, the Sherwood House will be removed and the site developed as a Civil War overlook. Civil War camps and earthworks will be stabilized as needed and the majority of the site will be maintained for its natural resources. Short Hill is to be managed similarly.

2.1.2 Geographic setting

Park description

Harpers Ferry National Historical Park is situated in the Blue Ridge physiographic province at the confluence of the Potomac and Shenandoah Rivers. Located approximately 20 miles southwest of Frederick, MD and 50 miles northwest of Washington, D.C., most of the park lies in the northeast corner of West Virginia, while the Short Hill section of the national historical park is in Virginia, and Maryland Heights is across the Potomac River in Maryland (Figure 2.1).

Old Town. Photo: Robert Baker/NPS.

The 1,475-ha (3,645-acre) park, on the foothills of the Blue Ridge Mountains, is comprised of multiple land units including: Lower Town, Federal Armory, Potomac River Frontage, Virginius Island, Halls Island, Camp Hill, Loudoun Heights, Maryland Heights, Short Hill, Cavalier Heights, Bolivar Heights, Union Skirmish Line, Schoolhouse Ridge, Murphy Farm, Nash Farm, Potomac Terrace, Shenandoah City, Potomac Wayside, and Bull Falls Area. Many of the lower land units are subject to periodic/seasonal flooding.

The park has steep terrain ranging in elevation from approximately 60 m (200 ft) to 440 m (1,450 ft) above sea level (Figure 2.2) and contains riparian habitats, floodplains, agricultural fields, geologic exposures, rare limestone glades, developed areas, and upland forests (Moyer et al. 2004).

Land use

Land use in a 30-km radius around HAFE consists of a mixture of developed (urban, industrial and farm land), forested, shrub and grasslands, plantations, and wetlands (Figure 2.3). Natural and protected areas are predominantly located along the ridgelines of the Appalachian Mountains (Figure 2.4).

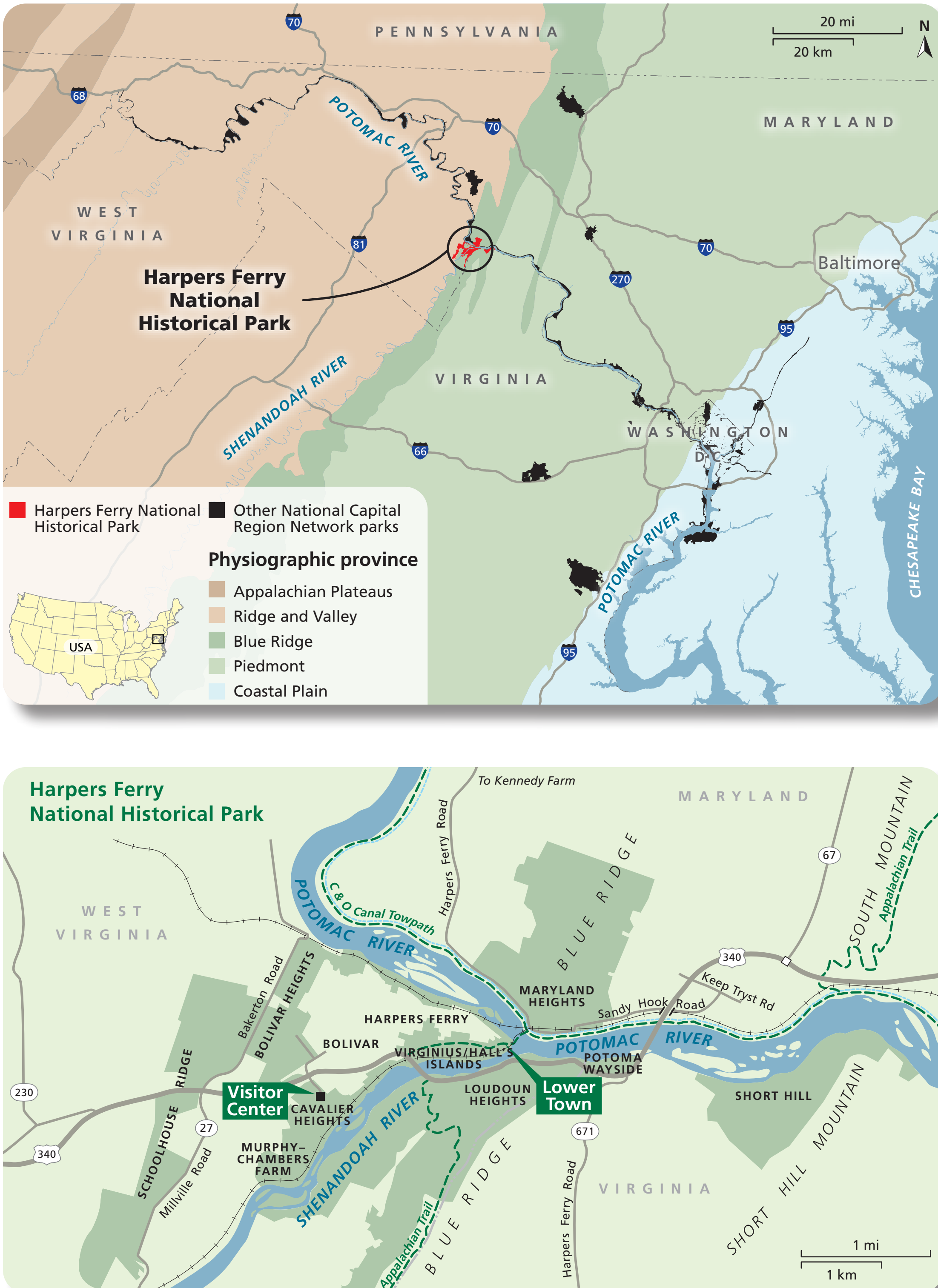


Figure 2.1. Location of HAFE at the confluence of the Potomac and Shenandoah Rivers.

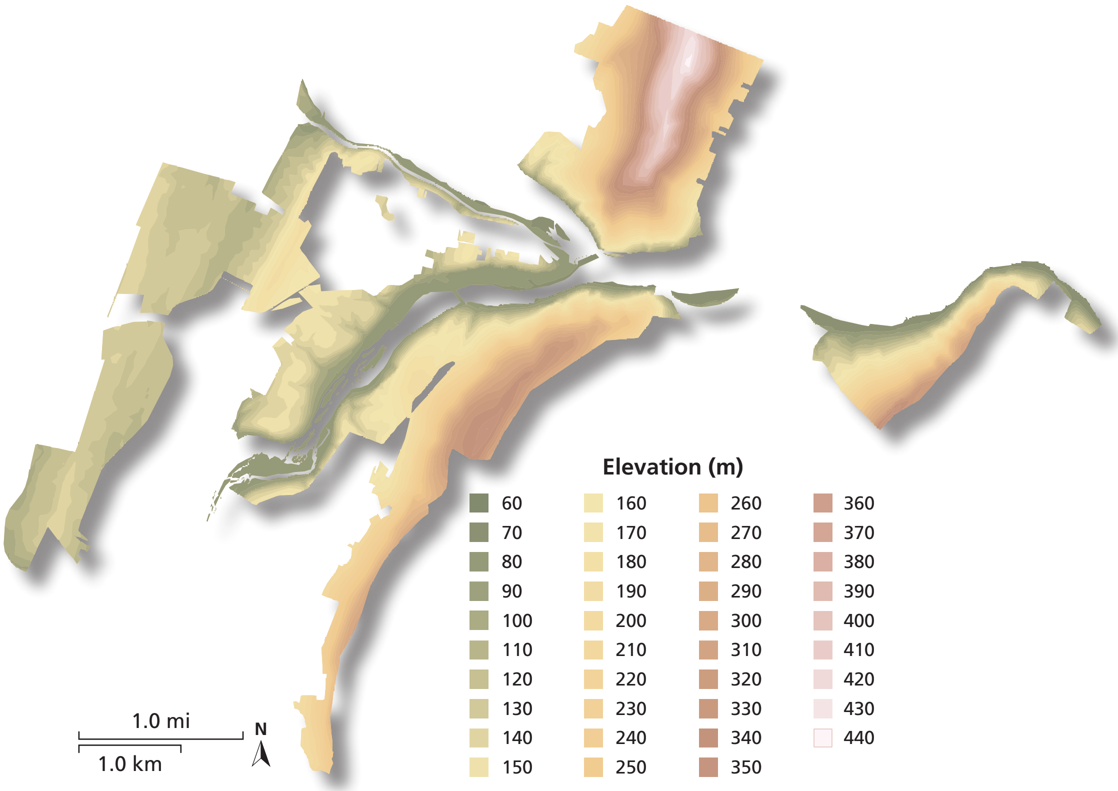


Figure 2.2. Topographic elevation of HAFE (Gesch 2007).

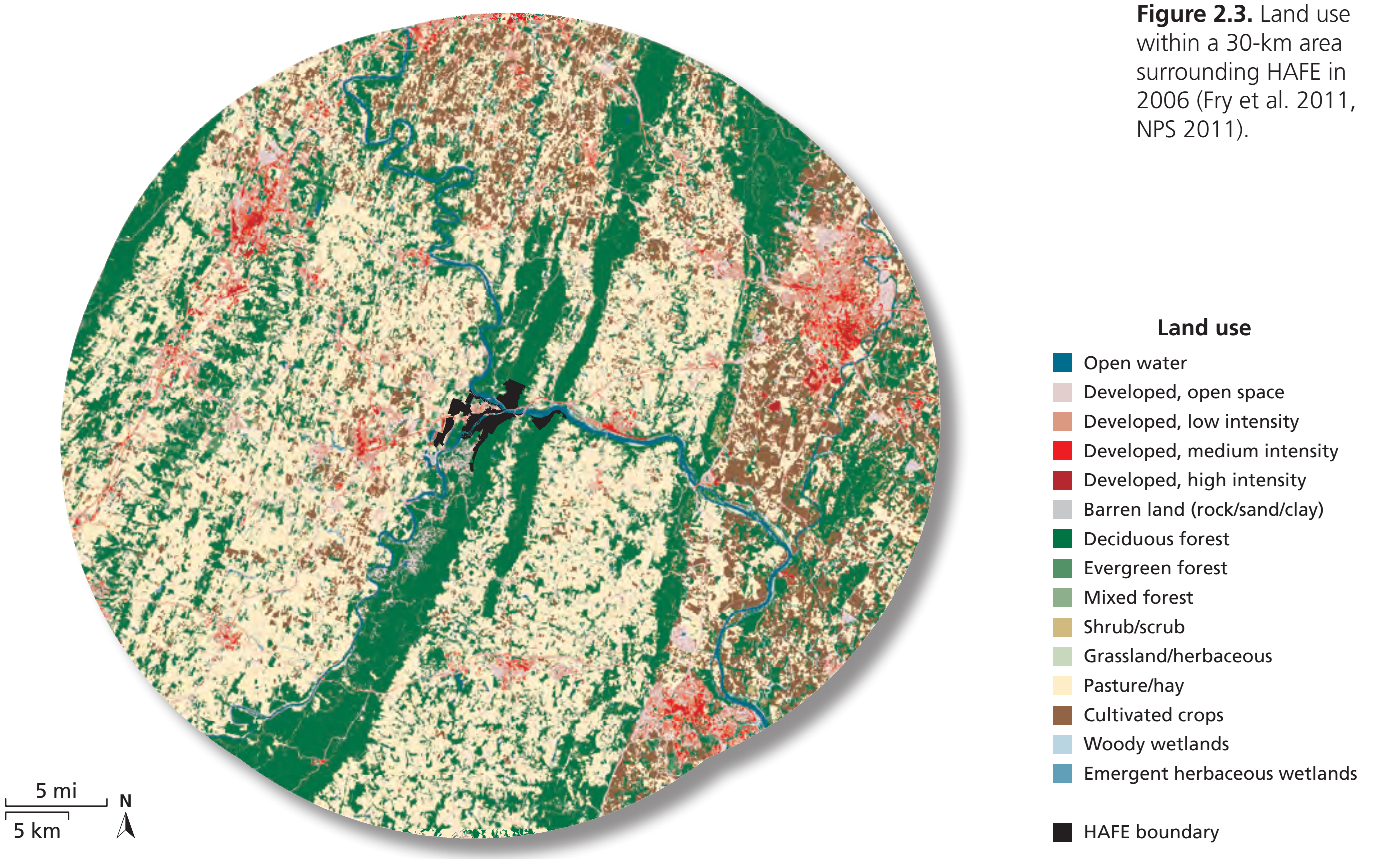


Figure 2.3. Land use within a 30-km area surrounding HAFE in 2006 (Fry et al. 2011, NPS 2011).

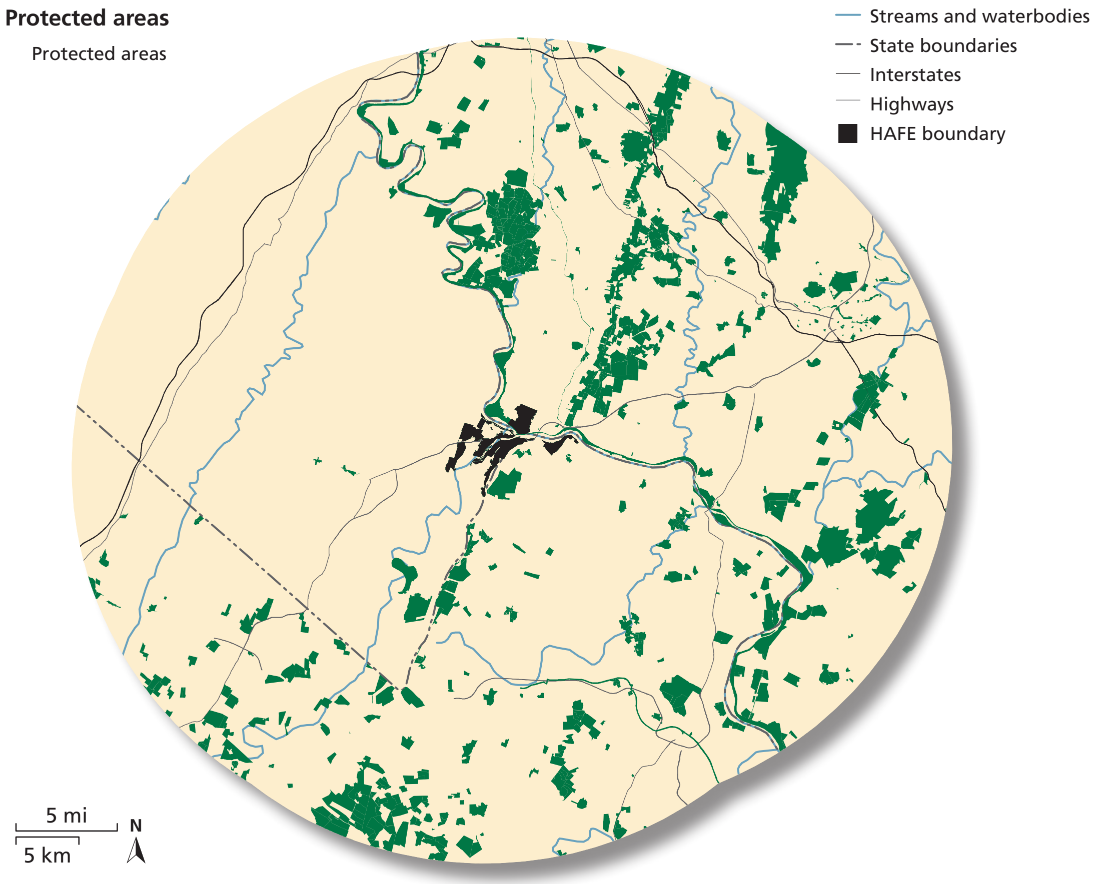


Figure 2.4. Protected areas within a 30-km area surrounding HAFE in 2011 (NPS 2011, USGS 2011).

Population

The tri-state region, long important for agricultural production, is now growing steadily influenced by development along the I-81 and I-70 transportation corridors. These transportation conduits have become convenient locations for a variety of light manufacturing and service industries, and as a 'bedroom community' for major metropolitan areas (NPS 2008a).

Since 2000, the eastern panhandle of West Virginia, which is comprised of Jefferson, Berkeley, and Morgan Counties, had an annual population growth rate of 3.2%. The growth far exceeds the rates for West Virginia (0.1%) and United States (1.0%) (NPS 2008a). Once dependent on the rural life, the populations of these three counties now have a portion of their economic roots in the major urban centers, including those as far away as Washington, D.C., Arlington, VA, and Baltimore, MD. The trend for this region is continued growth as more of the urban population moves into the eastern panhandle (Figures 2.5, 2.6). This migration will result in additional local jobs as well as residents looking to commute to employment in the major urban centers. Improved highways and commuter rail service are increasing the opportunities for residents to live locally and work regionally. Given the lowest inflation rates in West Virginia and Jefferson County's proximity to metropolitan Washington, D.C. and Baltimore, more than 50% of Jefferson County's workforce commutes out of the county to their workplace (NPS 2008a).

Because the eastern panhandle region is near many of the fastest growing counties in the United States, it has also become one of the fastest growing regions in West Virginia. Harpers Ferry National Historical Park is mostly located in Jefferson County—the fastest growing county in West Virginia, with 9.6% annual growth (NPS 2008a). Portions of the park are in Loudoun County, VA, which the U.S. Census Bureau has ranked as the second fastest growing county in the United States. From 2001 to 2003, Loudoun County had a population growth of 30.7% (NPS 2008a).

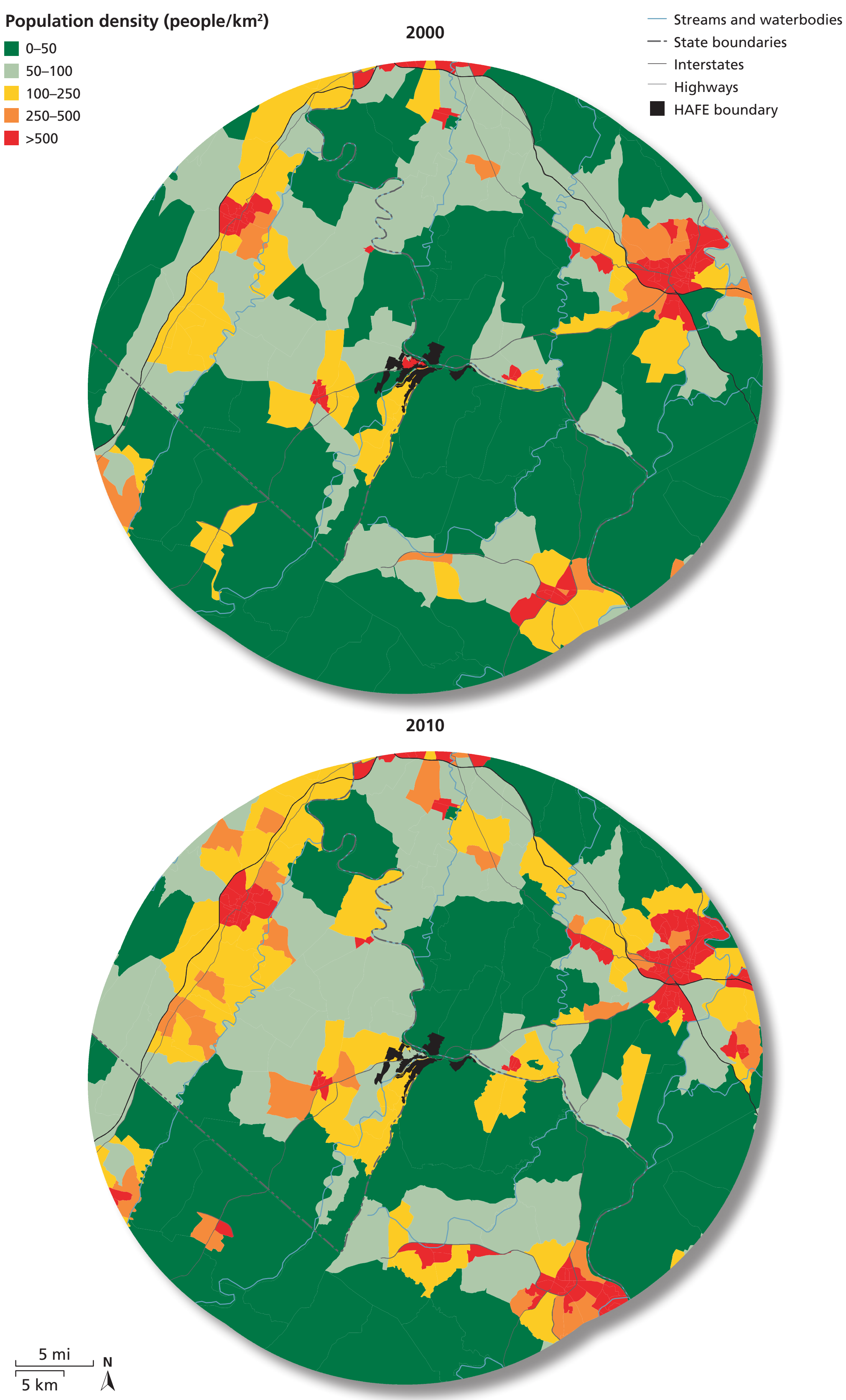


Figure 2.5. Population density within a 30-km area surrounding HAFE in 2000 and 2010, presented by U.S. Census units (NPS 2010a, 2011).

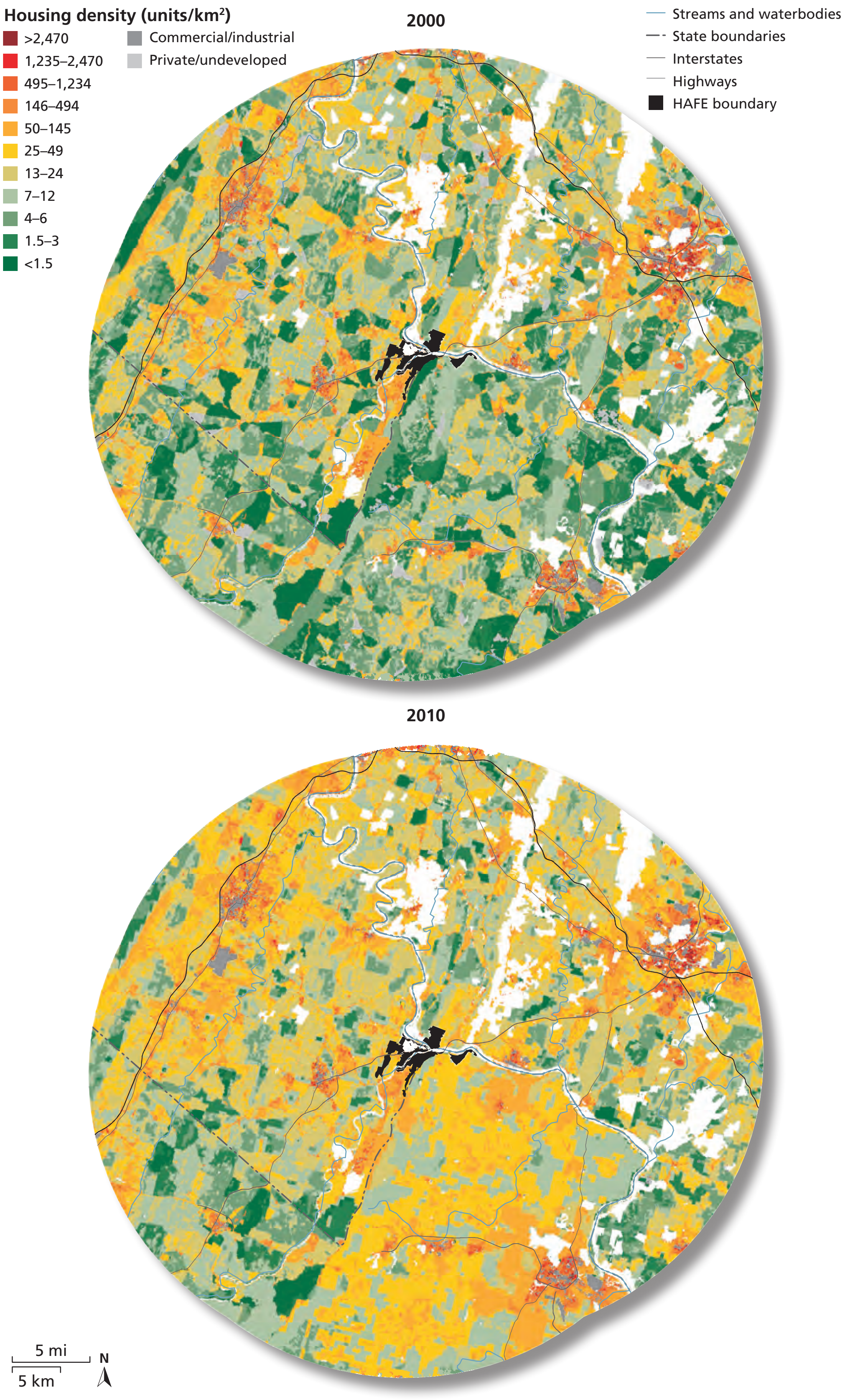


Figure 2.6. Housing density within a 30-km area surrounding HAFE in 2000 and 2010 (NPS 2010b, 2011).

Climate

The national historical park is in the transitional zone between the more maritime climate of the Atlantic Slope and the drier areas of the Allegheny Mountains. The climate experienced here is characterized by large seasonal temperature differences but is somewhat tempered by the nearby marine influence. High temperatures reach over 90°F (32°C) in July and August, whereas lows can fall below 15°F (–9°C) in January (NPS 2008a). On average, annual high and low temperatures here are 63°F (17°C) and 40°F (4°C), respectively. The average annual precipitation from rain, Atlantic coastal storms, and snow combine to equal 38 in (97 cm) in the national historical park. Most precipitation is from rain in the summer (NPS 2008a).

2.1.3 Visitation statistics

Visitation at the park has averaged about 270,000 over the last 10 years (NPS 2010c), with 80% of visitation occurring between May and October, 53% occurring on weekends, and 28% occurring during holidays and special events (NPS 2008a) (Figure 2.7). The lightest visitation occurs during the winter months of December to February.

Visitors typically enter the national historical park at the Cavalier Heights entrance that has an information center and provides access to a shuttle bus that lets visitors off at the bus pavilion in Lower Town. Visitors are also able to drive straight to Lower Town and begin their visit there. No public transportation to the outlying Civil War locations is provided and visitors are required to use their own means of transport to access these areas. Interpretation and resource education is received primarily through self-guided walks among the historic structures and settings (NPS 2008a).

Visitors interact primarily with NPS personnel at three staffed stations—the NPS entrance station, Cavalier Heights visitor information/contact station, and the information center in Lower Town (NPS 2008a).

Tourists encounter a variety of opportunities in the three-state region centered on the confluence of the Shenandoah and Potomac Rivers. Some of the choices include visiting Civil War battlefields and other historic sites, going to the races in Charles Town, river rafting, taking short walks, and long-distance hiking (NPS 2008a).

2.2 NATURAL RESOURCES

2.2.1 Resource descriptions

The majority of the park is located in the Blue Ridge physiographic province. The Schoolhouse Ridge area in the west of the park is located in the Valley and Ridge province, and the Short Hill area in the east of the park is located in the Piedmont province. Ecological types include riparian zones, agricultural fields, upland forests, developed areas, wetlands, important geologic exposures and caves, rockslide sites, and rare limestone glades (NPS, 2010). The wide range of riparian and terrestrial environments found at HAFE creates a mosaic of habitats that support a diverse flora and fauna. Natural resources in the park, and threats to those resources, are depicted in Figure 2.8.

Geology

The national historical park is in the Blue Ridge Mountain section of the extensive Appalachian Mountain Range that rose 360 million years ago when collisions between continental plates caused massive folding of

A park ranger presents an educational program. Photo: Marsha B. Wassel/NPS.

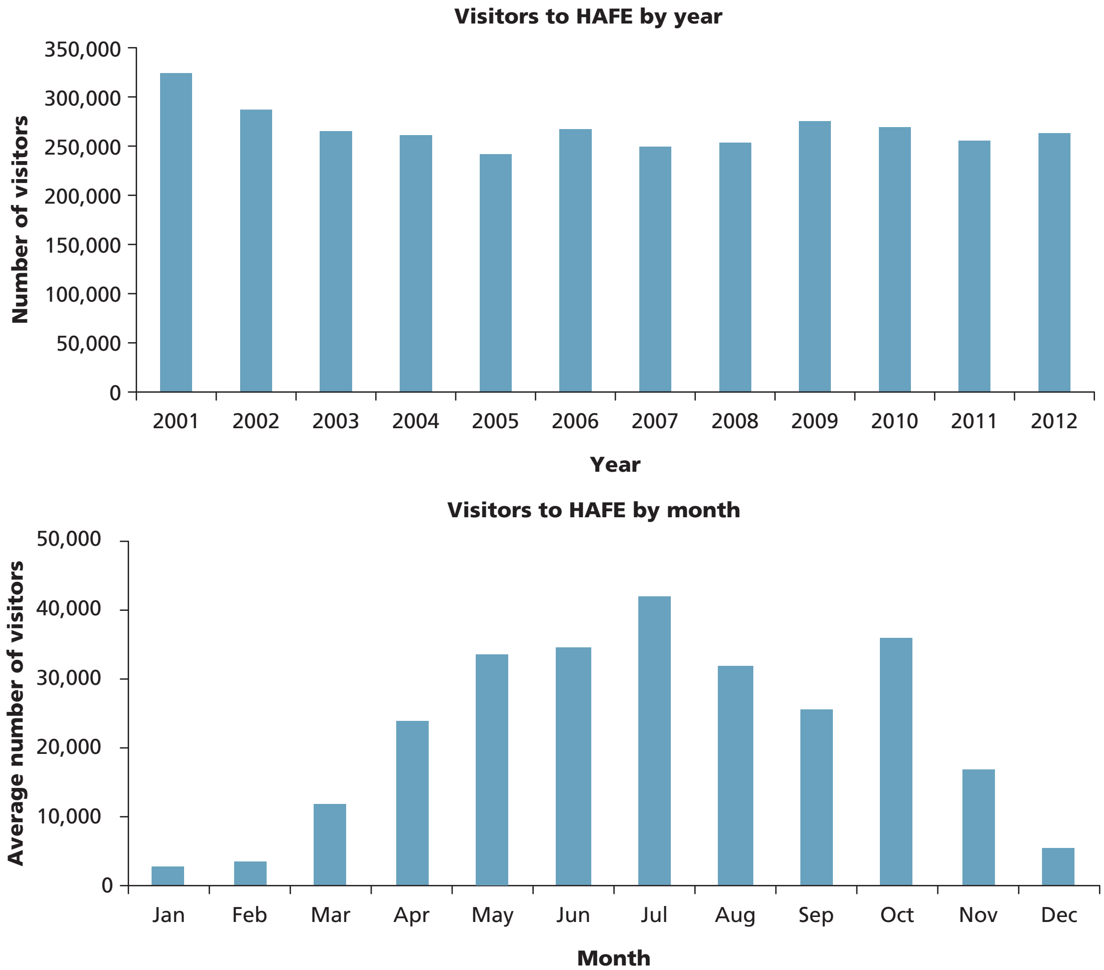
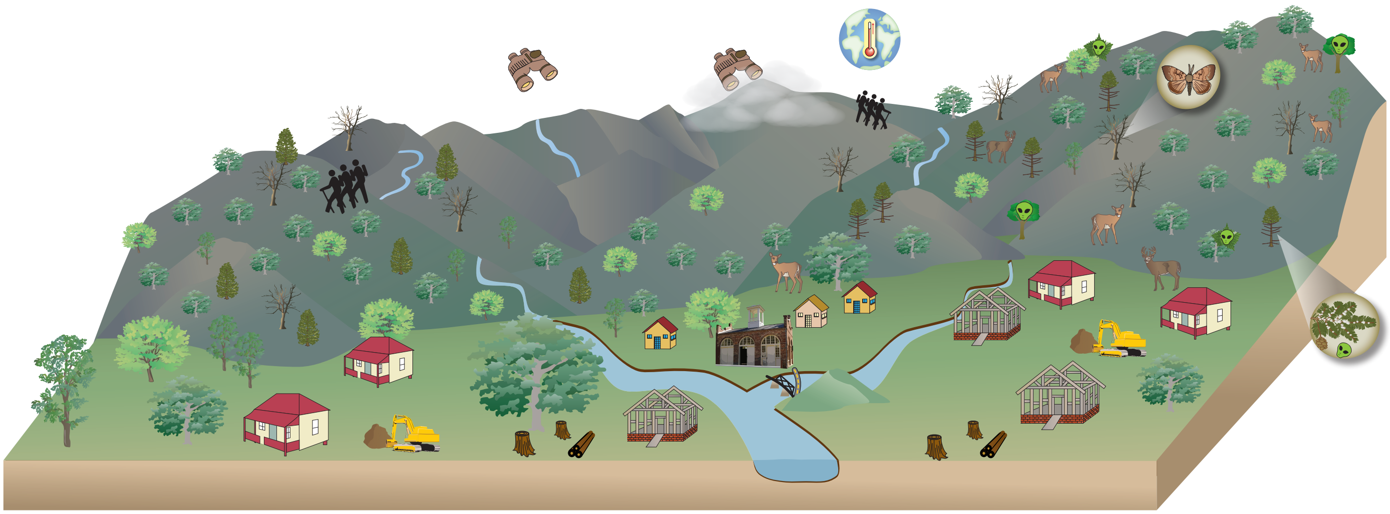


Figure 2.7. Visitors to HAFE over the past decade by year and by month (NPS 2010c).



Natural resources

- Scenic views (good air quality)
- Native plant communities
- Historic places and events
- Sustainable visitor use

Threats to park natural resources

- Obstructed scenic views (poor air quality)
- Invasive exotic species (including gypsy moth, hemlock woolly adelgid, and plant species)
- Deer overpopulation
- Exotic diseases and tree death
- Adjacent land use
- Global climate change

Figure 2.8. Features of and threats to the natural resources of Harpers Ferry National Historical Park.

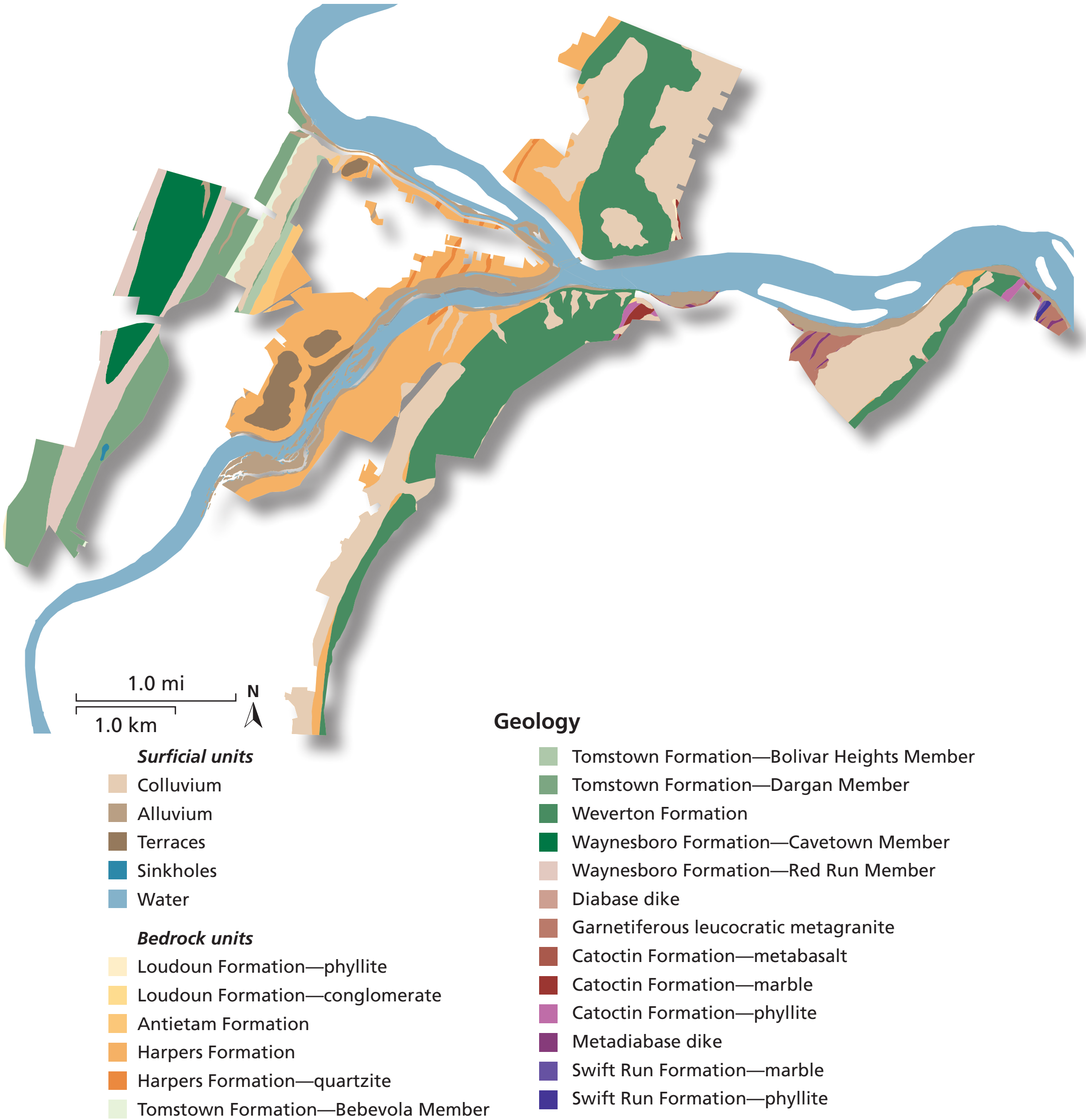


Figure 2.9. Geology of HAFE (Thorneberry–Ehrlich 2005).

the earth's crust. Once taller than the Rocky Mountains are today, these mountains have been worn down by wind, rain, and ice (NPS 2008a). The Central Appalachian area contains rocks varying in age from Quaternary sediments to Precambrian metamorphic gneisses (sedimentary rock that has recrystalized). The metasediments were deposited in an ancient sea basin skirting the eastern edge of the newly formed margin of the continent with the Iapetus Ocean. The Precambrian rocks form the basement upon which all other Appalachian rocks were deposited or intruded. Because of the intense regional erosion by the Shenandoah, Potomac, and other large rivers and tributaries, these rocks are on striking display, indicative of the history of the area.

The oldest rocks of the area are Proterozoic gneisses, metagranites, marbles, schists, and metarhyolites of the Catoctin, Swift Run and Loudon Formations (Thornberry–Ehrlich 2005) (Figure 2.9). Early Cambrian Period sediments include the sands, silts, limes, and muds of the Weverton, Harpers, Antietam, Tomstown and Waynesboro Formations. Jurassic diabase dikes and sills intrude overlying rocks locally (Thornberry–Ehrlich 2005). These rocks were uplifted, faulted, and folded during several orogenies, ultimately culminating in the Appalachian Mountains. Following each uplift, rapid erosion by the area's major rivers and tributaries resulted in thick deposits of sediments stretching the coastline further east in the Atlantic Coastal Plain physiographic province. Quaternary alluvium, colluvium, and terrace deposits manifest this erosion–sedimentation process (Thornberry–Ehrlich 2005). Soils of the park are shown in Figure 2.10.

Caves

Caves and numerous rock shelters have formed in or near the boundaries of Harpers Ferry. Subterranean ecosystems are typically in an extremely delicate balance and easily disrupted by human and natural events (NPS 2008a). There are three known caves on or near the national historical park. John Brown's Cave and John Brown's Annex Cave are in a bluff near the banks of the Potomac east of Elks Run. John Brown's Cave is rumored to have been used by John Brown to store weapons when preparing for his famous raid on the Federal Armory. However, due to the relatively small entrance and dampness of the cave, this is unlikely (NPS 2008a). The cave entrance is in the CSX railroad right-of-way and has been gated. Beyond the entrance, the cave is under NPS land. The cave is well known in the region and the front portion has been heavily vandalized. The back portions of the cave are beyond a sump (where the water meets the ceiling) that is passable only during dry periods. John Brown's Annex is a small cave above John Brown's Cave in the same cliff (information provided by Bob Bennett of the Tri-State Grotto of the National Speleological Society, Gerrardstown, West Virginia). Harpers Ferry Caverns are on land that was once private and was preserved by the Civil War Preservation Trust (NPS 2008a), who later transferred it to the National Park Service. Harpers Ferry Caverns is relatively small but was developed with trails, stairs, and lights and opened for tours when it was privately owned. The federally endangered Indiana bat (*Myotis sodalis*) uses caves as roost sites and may be in the area (NPS 2008a). A federal species of concern, the Allegheny woodrat (*Neotoma magister*), may use caves for its home. John Brown's Cave is known to contain three types of salamanders and the Eastern pipistrelle bat (*Pipistrellus subflavus*) (NPS 2008a).

Waterways

The Shenandoah and Potomac Rivers converge at Harpers Ferry and flow eastward as the Potomac River towards Chesapeake Bay and ultimately the Atlantic Ocean. The rivers are not within the national historical park's authorized boundary but do constitute approximately 24 km (15 mi) of shoreline within the park. In addition to the two major rivers, there are three perennial streams and several canals within the national historical park boundaries. The streams are Elks Run and Flowing Springs in West Virginia and Piney Run in Virginia (Figure 2.11). There is also a small ephemeral (unnamed) stream fed by springs on the west side of Maryland Heights. Additionally, parts of the watershed for Israel Creek in Maryland, is within park boundaries (Figure 2.11). The hydrology and topography of the area is such that surface and subsurface springs are numerous (NPS 2008a).

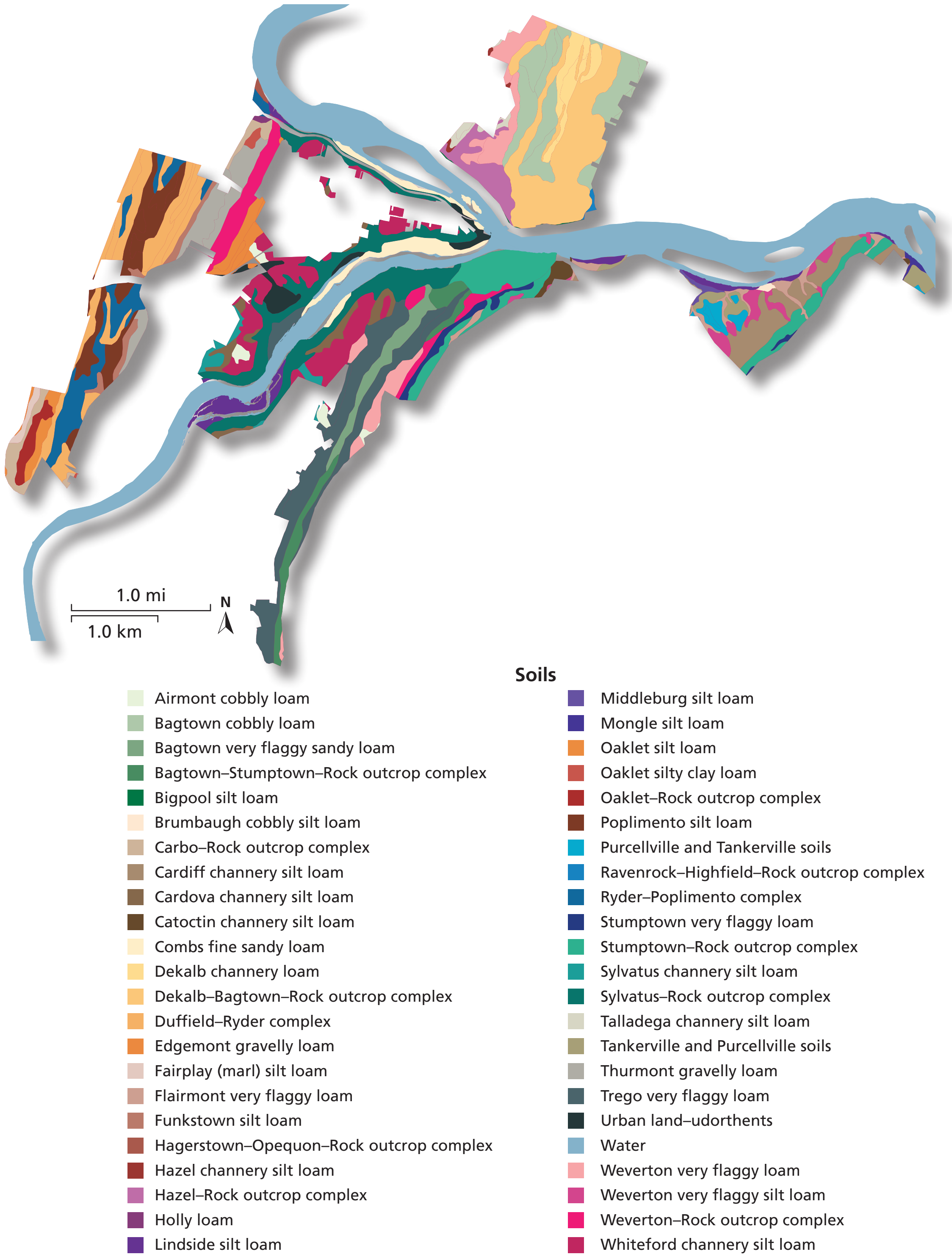
With the exception of Flowing Springs Run and Elk Run, which flow through flatter valleys, the small streams in Harpers Ferry National Park flow down very steep channels that are characterized by bedrock and boulders (Slawson 2010). The valley walls are also steep and floodplains are either very narrow or non-existent. The flow regimes are either torrent or step-pool. The flow is flashy during storm events and base flow may be minimal or non-existent during dry weather. Large and small woody debris is prevalent and often causes debris jams. Riparian areas are forested, but browsing by deer has removed most of the understory (Slawson 2010).

Canals within the park include the Chesapeake and Ohio (C&O) Canal on the east side of the Potomac River, the Federal Armory canal on the Potomac frontage, the Shenandoah Canal adjacent to the Shenandoah River, and the historic Potomack Canal in the Lower Town area.

Wetlands

Wetlands within the national historical park (identified by the presence of hydrophytic plants, hydric soils, and frequency of flooding) are mainly along the floodplains of the Potomac and Shenandoah rivers (NPS 2008a). Additional wetlands include

Figure 2.10. Soils of HAFE (NPS 2008b).



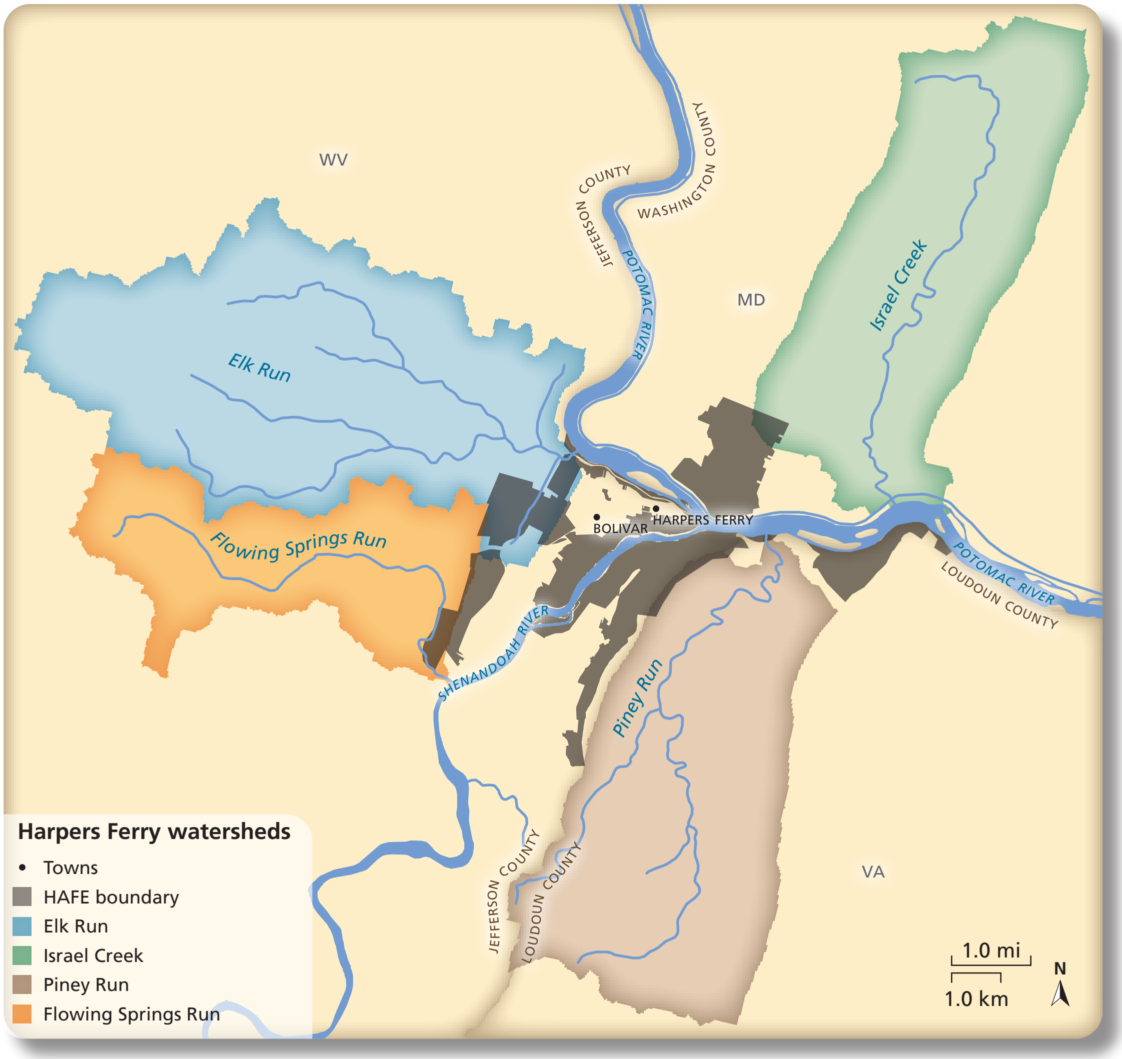


Figure 2.11. Watersheds of the major streams within HAFE (USGS EDNA watersheds, ESRI).

a wetland created by beavers in Jackson's Right Flank of Flowing Springs Run and human induced wetlands from no longer used canals and headraces for historical water-powered industry. According to the National Wetland Inventory (accessed at *www.nwi.fws.gov*), the national historical park contains more than 40 ha (100 acres) of wetlands. Most of these are classified as palustrine, forested (deciduous), and temporarily flooded (U.S. Fish and Wildlife Service 2003). Other areas classified as wetlands are within the rivers' banks and not on NPS land. The most prominent wetland in the national historical park is the 2.8-ha (7-acre) area adjacent to Shoreline Drive that is the former Lake Quigley, a man-made lake that was part of the Shenandoah Canal. In this wetland, a few inches of standing water lie above the substrate, with greater duckweed (*Spirodela polyrrhiza*) frequently covering the surface (NPS 2008a). This type of habitat supports many species of both terrestrial and aquatic invertebrates, small mammals, waterfowl, marsh birds, reptiles, and amphibians (NPS 2008a).

Floodplains

Floodplains are along the shores of the Potomac and Shenandoah Rivers, sometimes reaching inland along stream banks that drain into these rivers. Many of the structures in Lower Town are within the floodplains of these two rivers and subject to inundation during high river flows. Flooding of these structures is of a particular concern when they house expensive interpretive exhibits or irreplaceable museum collections. According to the historic record, Harpers Ferry may experience a flood over 6 m (20 ft.) every five to 10 years. The level of the 1936 flood, which reached a record height of 11 m (36.5 ft.), is estimated to only occur every 125 years (NPS 2008a). Floods in the national historical park tend to be fairly deep, since there is not much room for river water to spread out once it overflows its banks. Heavy precipitation that produces rapid runoff is a major flood-causing factor (NPS 2008a).

Flora

Native plants

Numerous ferns, grasses, sedges, and rushes play a valuable role in the national historical park's plant communities. Trees such as chestnut oak and tulip poplar often dominate the forest canopy; whereas red maple and hackberry and common shrub species make up the understory. A variety of wildflowers color the hillsides every spring (NPS 2008a).

Many fern species have been found occupying a wide variety of habitats. On the rock ledges and crevices, woolly lip fern (*Cheilanthes tomentosa*), the locally rare lobed spleenwort (*Asplenium pinnatifidum*), and the common polypody (*Polypodium virginianum*) are likely to be found. But on the steep, rocky, and partially shaded slopes of Short Hill, Maryland Heights, and Loudoun Heights, marginal shield fern (*Dryopteris mariginalis*) and Christmas fern (*Polystichum acrostichoides*) are more common. The floodplains and moist, shaded, low slopes surrounding the Potomac and Shenandoah Rivers support even more fern species, including intermediate shield fern (*Dryopteris intermedia*), New York fern (*Thelypteris noveboracensis*), and fragile fern (*Cystopteris protrusa*) (NPS 2008a).

Grasses and grass-like plants, including sedges and rushes, are a diverse and important part of plant communities. On the dry, rocky ridge tops of Maryland Heights, Loudoun Heights, and Short Hill, poverty grass (*Danthonia spicata*) and greenish sedge (*Carex virescens*) are the most frequent species encountered. At lower elevations on these ridges, cliff muhly (*Muhlenbergia sobolifera*), tall brome-grass (*Bromus pubescens*), and Bosc's panicgrass (*Dicanthelium boscii*) are commonly found. In floodplain forests, there are species such as nodding fescue (*Festuca subverticillata*) and deertongue grass (*Dichanthelium clandestinum*). Prairie grasses such as big bluestem (*Andropogon gerardii*), the locally uncommon prairie cordgrass (*Spartina pectinata*), and the bank-stabilizing Emory's sedge (*Carex emoryi*) are more likely to be seen along the riverbanks of the Potomac and Shenandoah (NPS 2008a).

Colorful wildflower species such as woodland sunflowers (*Helianthus strumosus*), birdfoot violets (*Viola pedata*), and Virginia bluebells (*Mertensia virginica*) grow in the forest. Along the banks of the Potomac and Shenandoah Rivers, a different group of wildflowers can be seen, including monkeyflower (*Mimulus ringens*), wide-leaved joe-pye weed (*Eupatorium purpureum*), and the New England aster (*Aster novae-angliae*) (NPS 2008a).

A wide variety of tree and shrub species occur in the 70% of the national historical park that is forested. Chestnut oak (*Quercus prinus*) is usually the dominant tree in the forest canopy on rocky soils of higher ridges such as Maryland Heights. Black oak (*Quercus velutina*) is also important on south-, west-, and east-facing slopes. Northern red oak (*Quercus rubra*) is found with chestnut oak on rocky, north-facing slopes, where eastern hemlock (*Tsuga canadensis*) was formerly prominent. Red maple (*Acer rubrum*), black gum (*Nyssa sylvatica*), and flowering dogwood (*Cornus florida*) are frequent understory trees, while mountain laurel (*Kalmia latifolia*), black huckleberry (*Gaylussacia baccata*), Blue Ridge blueberries (*Vaccinium pallidum*), deerberry (*V. stamineum*), and maple leaf viburnum (*Viburnum acerifolium*) are common shrubs (NPS 2008a).

Lower-elevation, north-facing slopes with base-rich soils support a mixed mesophytic forest of northern red oak, white ash (*Fraxinus americana*), sugar maple (*Acer saccharum*), basswood (*Tilia americana*), hackberry (*Celtis occidentalis*), bitternut hickory (*Carya cordiformis*), slippery elm (*Ulmus rubra*), tulip poplar (*Liriodendron tulipifera*), hop hornbeam (*Ostrya virginiana*), and pawpaw (*Asimina triloba*). Woody understorey plants of the mesophytic forests include spicebush (*Lindera benzoin*) and American bladdernut (*Staphylea trifolia*) (NPS 2008a).

There are two extensive types of floodplain riparian forests along the Potomac and Shenandoah Rivers—lower areas that flood on average every one to three years have silver maple (*Acer saccharinum*) as a prominent component with associated species such as sycamore (*Platanus occidentalis*), green ash (*Fraxinus pennsylvanica*), and cottonwood (*Populus deltoides*); and higher parts of floodplains have a diverse forest of sycamore, white and green ash, tulip poplar, bitternut hickory, hackberry, sugar maple, black walnut (*Juglans nigra*), and the locally rare Shumard oak (*Quercus shumardii*) (NPS 2008a).

Flood waters at John Brown's Fort. Photo: NPS.

The town of Harpers Ferry was generally cleared of vegetation in 1859, except for a few trees retained to provide shade. Most of the remaining ground was covered with grass or ornamental vegetation. Upland areas were completely cleared for fuel, building material, and artillery firing lines at various times. Present vegetation is secondary or tertiary growth. The original chestnut–oak forests have been succeeded by oak–hickory climax forests. The once-predominant American chestnut was eliminated from the area by the 1930s (NPS

Great blue heron. Photo: Marsha B. Wassel/NPS.

1986). This extirpation was partly a result of the chestnut blight that affected the eastern U.S. in the first half of the 20th century (NPS 2008a).

Fauna

Harpers Ferry is home to a highly diverse animal community of insects, fish, reptiles, amphibians, birds, and mammals. Habitat types include riparian zones, agricultural fields, upland forests, developed areas, wetlands and waterways, geologic exposures, rock slide sites, and rare limestone glades (NPS 2008a).

Mammals

Harpers Ferry is home to more than 30 mammal species (NPS 2008a). Some of these, however, such as the American mink (*Mustela vison*) and the short-tailed shrew (*Blarina brevicauda*) are not frequently observed. On Loudoun Heights, gray and fox squirrels (*Sciurus carolinensis* and *S. niger*), and eastern chipmunks (*Tamias striatus*) are commonly seen. The southern flying squirrel (*Glaucomys volans*) was found in the national historical park in a 2001 mammal survey. Groundhogs (*Marmota monax*), Virginia opossums (*Didelphis virginiana*), raccoons (*Procyon lotor*) and several bat species are common. White-tailed deer (*Odocoileus virginianus*) move and feed throughout undeveloped districts of the park. Park resource specialists are concerned that deer have overpopulated the Maryland Heights district and are causing impacts on other resources (NPS 2008a). Coyotes (*Canis latrans*) have also made a recent return to the park (D. Nisbet, pers. comm.).

Birds

Over 170 bird species have been identified in the national historical park (NPS 2008a). The specific species depends on the habitat encountered. Great blue herons (*Ardea herodias*) and Canada geese (*Branta canadensis*) are found along the rivers. On Maryland and Loudoun Heights, species such as the pileated woodpecker (*Dryocopus pileatus*) and Baltimore oriole (*Icterus galbula*) are likely to be seen. Bald eagles (*Haliaeetus leucocephalus*) may be seen over the national historical park between late winter and early summer. Along with bird species that reside here year round, many other species use the national historical park during their spring and fall migrations.

Herpetofauna

Two frog species and eight species of salamanders have been documented in the park, including the northern green frog (*Rana clamitans*), the wood frog (*Rana sylvatica*), the spotted salamander (*Ambystoma maculatum*), and the seal salamander (*Desmognathus monticola*) (NPS 2008a). Eastern box turtles (*Terrapene carolina*) and Eastern milksnakes (*Lampropeltis triangulum*) are often encountered in the park. These reptiles are found in the mountains and within the lower historical district. Northern red-bellied turtles (*Pseudemys rubriventris*) also live in the national historical park. Other snakes found here include the common water snake (*Nerodia sipedon*) and northern copperhead (*Agkistrodon contortrix*). Lizards frequently spotted within the national historical park's forests include the broadheaded skink (*Eumeces laticep*) and the fence lizard (*Sceloporus undulatus*).

Fishes

Historically, 43 species of fish have been encountered in the national historical park, including the Potomac and Shenandoah Rivers and their tributaries (NPS 2008a). Freshwater game fish include largemouth and smallmouth bass (*Micropterus salmoides* and *M. dolomieu*), channel catfish (*Ictalurus punctatus*), and bluegill sunfish (*Lepomis macrochirus*) (NPS 2008a). Other fish indigenous to the river waters include dace, chub, shiner, darter, minnows, bullhead, and carp. Eels may also be present here. In an inventory study conducted by Raesly (2004), fishes were collected from Elks Run, Flowing Springs Run, and Piney Run. A total of 632 fishes representing 32 species from six families were captured and identified. All species have been previously reported from the Potomac River. This represents a reasonably high diversity of fishes given the limited amount of stream habitats within the national historical park (NPS 2008a).

Invertebrates

Approximately 140 insect species, including spiders, butterflies, ticks, mites, millipedes, and centipedes, have been identified in the park. Butterfly species that have been observed include eastern tiger swallowtails (*Papilio glaucus*), zebra swallowtails (*Eurytides marcellus marcellus*), meadow fritillaries (*Boloria bellona bellona*), silverspotted skippers (*Epargyreus clarus*), and monarchs (*Danaus plexippus*).

Rare, threatened, and endangered animals

HAFE contains, or has habitat suitable for, a number of federally threatened species and species of concern including the Indiana bat (*Myotis sodalis*) and the Allegheny woodrat (*Neotoma magister*) (Table 2.1) (NPS 2008a). Additionally HAFE hosts state-listed species including the American peregrine falcon (*Falco peregrinus*) (Table 2.2) (NPS 2008a).

Soundscapes

Natural soundscapes exist in the absence of human-caused sound (NPS 2008a). The natural soundscape in Harpers Ferry is a result of the biological and physical resources of the national historical park such as:

- sounds produced by animal life such as birds, frogs, and insects to define territories or attract mates.
- sounds produced by physical processes such as wind in the trees, flowing water, or claps of thunder. Natural sounds predominate throughout most of the undeveloped outlying portions of the national historical park (Maryland Heights, Loudoun Heights, and Short Hill).

Current impacts on the natural soundscape in these areas are primarily from trains using the two tracks and traffic noise from U.S. Highway 340. At the Schoolhouse Ridge (North and South) portions of the national historical park, noise from agricultural operations could disturb the natural quiet at certain times of the year. Also at Schoolhouse Ridge South, noise from operation of the adjacent U.S. Customs and Border Patrol Firearms Training Facility could periodically affect the natural sounds cape in that area (NPS 2008a). Human-caused sounds are prevalent in the developed portions of the national historical park within the town limits of Harpers Ferry and Bolivar. In certain places near the rivers, the natural sound level may be great enough to overcome some human sounds. Levels of human-caused sound will also fluctuate with variations in weather conditions (including temperature, wind and humidity) and the general topography of these areas (NPS 2008a).

Park personnel preparing to put peregrine falcon chick into hack box—Maryland Heights. Photo: NPS.

Table 2.1. Federally listed species in HAFE (NPS 2008a).

State	Listed species	Species of Concern
West Virginia	Indiana bat (*Myotis sodalis*). Endangered, possible summer resident	Butternut (*Juglans cinerea*)
		Allegheny woodrat (*Neotoma magister*)
		Cerulean warbler (*Dendroica cerulea*)
		Migrant loggerhead shrike (*Lanius ludovicianus migrans*)
		Dotted skipper (*Hesperia attalus slossonae*)
		Bigger's amphipod (*Stygobromus biggersi*). Found in Ditmer Cave
Maryland	(none known in park)	(none known in park)
Virginia	(none known in park)	(none known in park)

Table 2.2. State-listed species in HAFE (NPS 2008a).

State	Listed species	Species of Concern
West Virginia	Short's rock-cress	Osprey
	Wild blue indigo	Broad-headed skink
	Glomerate sedge	Wood turtle
	Chestnut lipfern	
	Woolly lipfern	
	Awned cyperus	
	Hairy swamp loosestrife	
	Halberd-leaved mallow	
	Winged loosestrife	
	Starflower	
	False Solomon's seal	
	Yellow nail-wort	
	Arrow-arum	
	Torrey's mountain-mint	
	Shumard oak	
	Rock skullcap	
	Snowy campion	
	Four-flowered loosestrife	
	Three-flower melic grass	
	Flat-stemmed spikerush	
Maryland	Lobed spleenwort	Pepper and salt skipper
	Crested iris	Giant swallowtail
		Allegheny woodrat
		Peregrine falcon (reintroduced)
Virginia	Short's rock-cress	Peregrine falcon (reintroduced)
	White trout-lily	
	Sweet-scented Indian Plantain	
	Winged loosestrife	

Lightscapes

The clarity of night skies is important to the visitor experience as well as being ecologically important. Artificial light sources both within and outside the national historical park have diminished the clarity of night skies by creating a 'haze' of light that obscures views of stars and distant topographic features. The primary culprit is any type of outdoor lighting that allows light to shine up into the sky. Outdoor lighting is common throughout the region, including inside national historical park boundaries. While such lighting may be necessary for safety or security reasons, there are outdoor lighting fixtures available that direct light downward and do not allow stray light to scatter into the sky (NPS 2008a).

2.2.2 Resource issues overview

Internal park threats

Exotic plants

Non-native species—also known as exotic, alien, or introduced species—are defined as species that occur in a certain place due to deliberate, accidental, direct, or indirect human actions. Harpers Ferry's long history of human habitation is responsible for the introduction of many non-native plant species. These were brought into the area as ornamental landscape plantings, livestock feed, or for other purposes. Others, such as noxious weeds, are undesirable but continue to spread, especially in disturbed areas (NPS 2008a). Native, old-growth communities remain only on steep slopes or otherwise inaccessible land. Many decades of agricultural operations have eliminated native communities on portions of the Murphy Farm, the Nash Farm, Bolivar Heights, and Schoolhouse Ridge.

Small social trails occur in almost all areas of the national historical park. These are unplanned and unmaintained trails created by visitors that damage vegetation, disrupt animal habitats, and cause soil erosion. Seeds carried by wind and humans have created infestations of noxious weeds and other invasive plant species. These species cause long-term adverse impacts on native vegetation by competing for available resources such as water and nutrients. These actions have resulted in long-term moderate adverse impacts on native vegetation. The establishment of Harpers Ferry National Historical Park has resulted in moderate beneficial impacts to vegetation through protection of native vegetation in outlying areas and non-native species eradication efforts (NPS 2008a).

Based on vegetation inventories conducted in the 1990s, over 260 non-native plant species have been identified in the park, including garlic mustard (*Alliaria petiolata*), Japanese honeysuckle (*Lonicera japonica*), tree-of-heaven (*Ailanthus altissima*), Japanese stiltgrass (*Microstegium vimineum*), and wine berry (*Rubus phoenicolasius*). In 2002–2003, the NPS National Capital Region's Exotic Plant Management Team inventoried 51 of the most invasive species and mapped their ranges. The inventory indicates that these plants inhabit over 17,000 ha (43,000 acres) (cumulative acreage for all the non-native species). Garlic mustard alone inhabits over 800 ha (2,000 acres) of the national historical park (NPS 2008a).

Deer overpopulation

White-tailed deer are considered an important stressor on forests of the National Capital Region, having increased in density from between 3.1 and 4.2 deer/km^2 (8.0–10.9 deer/mi^2) since pre-European times to 20 deer/km^2 (52 deer/mi^2) today in the eastern deciduous forest zone (Bates 2009). Factors such as fire suppression, the rapid spread of invasive, exotic plants, and overabundant deer populations are working in concert to alter the regeneration, and hence, the natural successional pathways of the forests in the region (Bates 2009).

Garlic mustard. Photo: Chris Evans.

Deer can alter forest composition and succession by inhibiting the regeneration of preferred species likes oaks (*Quercus* spp.) and hickories (*Carya* spp.). This, in turn, allows less palatable herbaceous plants to spread and further inhibit regeneration of woody and herbaceous species. Deer reduce or eliminate populations of many forest herbs by stifling growth and reproduction and they have been shown to reduce understory diversity. Subsequent declines in populations of forest nesting birds, small mammals and changes to insect communities have been reported (as summarized in Bates 2009). Deer can also cause significant damage to private property, forests managed for wood, crop yields, nurseries and orchards (Bates 2009).

Deer and tick (*Ixodes dammini*) densities have been shown to move in tandem which may lead to increases in zoonotic diseases such as Lyme disease (Wilson et al. 1990, Deblinger et al. 1993), although other factors have also been implicated regardless of deer density (Amerasinghe et al. 1993, Ostfield et al. 2006). Deer are also carriers of diseases such as chronic wasting disease (Williams et al. 2002). They can alter availability of nutrients in the soil (Pastor and Naiman 1992, Hobbs 1996, Ritchie et al. 1998) and ultimately, over-browsing can lead to alternate stable states (Stromayer and Warren 1997, Augustine et al. 1998) whereby relative abundance of preferred species and successional direction is altered. These alternate stable states often are not reversible even when deer populations are lowered (Westoby et al. 1989, Scheffer et al. 2001).

Gypsy moths

The gypsy moth (*Lymantria dispar dispar*), a native of Europe, was introduced into North America around 1869 near Boston, Massachusetts. Since that time, the moth has become established and has spread throughout the northeastern United States, into Ohio and Michigan, and further south into Virginia. Gypsy moths have been in Jefferson County, WV since 1975 and have been monitored by the park since 1981. The first noticeable effects of gypsy moth defoliation occurred in 1983 with seven acres of light defoliation on Maryland Heights.

Gypsy moth larva.
Photo: Ferenc Lakatos.

Gypsy moth larvae are voracious defoliators. They prefer oaks, but will also consume dozens of other tree and shrub species to varying degrees. These include species found in HAFE, such as box elder, sweet gum, willow, maple, hickory, beech, and dogwood. In the park, the larval or caterpillar life stage of the gypsy moth emerges from egg masses in late April to early May. By late June, defoliation damage is most apparent. Adult moths begin to emerge in numbers by late June through early August. After mating, each female lays one egg mass containing 100–1,000 eggs that remain where they are deposited through the winter (NPS 2008c).

Defoliation directly affects trees by decreasing their health and vigor. This can result in an increased susceptibility to disease and parasites, leading to increased tree mortality (NPS 2008c). Defoliation and the loss of mature trees can change forest and under story composition, water quality in streams and lakes, and food and habitat quality and availability for both terrestrial and aquatic wildlife (NPS 2008c). This can result in changes in the abundance and distribution of wildlife.

Gypsy moths also present aesthetic, safety, and health concerns to employees and the public. Large stands of defoliated or dead trees can impact scenic values and present hazardous tree conditions along roadsides and trails (NPS 2008c). Large numbers of caterpillars and their frass (droppings) can be a nuisance, affecting outdoor recreational experiences. Forest fire hazard levels can be increased with defoliation and tree mortality. Dead trees themselves are safety hazards for park visitors. Some individuals that are exposed to the hairs on gypsy moth larvae may develop skin rashes or irritations and allergies.

Non-native animals

Invasive, non-native species are capable of displacing native species and therefore threaten the diversity and integrity of native ecosystems. As well as gypsy moth, non-native animal species found in the park include hemlock woolly adelgid (*Aldeges tsugae*), European starlings (*Sturnus vulgaris*), and house sparrows (*Passer domesticus*) (NPS 2008a).

Regional threats

Surrounding land use

Actions affecting wildlife are occurring in the region around Harpers Ferry as a result of agriculture and urban development (NPS 2008a). Certain actions occurring on private, state, and federal land can disrupt or fragment habitat, displace individuals, or otherwise cause stress to animals. Incremental development of the region has affected the abundance and diversity of wildlife by changing the capacity of habitats to provide necessary food, shelter, and reproduction sites. Wildlife is slowly becoming more restricted by current land uses, increasing development, and human activity, causing individuals and populations to either adapt or move. This has resulted in minor to moderate adverse impacts. The presence of human visitors in the backcountry areas can disturb wildlife, resulting in long-term negligible to minor adverse impacts. Establishment of the national historical park has resulted in long-term benefits for fish and wildlife populations. Acquisition of the natural areas has curtailed development and allowed more natural environmental processes to continue. These protected areas in the national historical park are highly important because of the quality fish and wildlife habitat they provide. Hunting is prohibited in the national historical park and the white-tailed deer population on Maryland Heights has increased to the point where it could be causing some ecological damage. Continued population growth in Maryland and West Virginia would reduce habitat available to wildlife species, resulting in long term minor to moderate adverse impacts (NPS 2008a).

Air quality

The Clean Air Act and NPS Management Policies state that managers have a responsibility to protect national historical park air quality-related values from adverse air pollution impacts. Sources of pollution that affect air quality in HAFE are primarily outside the national historical park's boundaries.

Stationary and mobile emissions in the region are the major source of air pollution. Sources of emissions in the region around Harpers Ferry include the following:

- motorized vehicles and trains
- residential woodstoves and fireplaces
- lumber and paper mills
- sand and gravel or limestone quarries
- other industries

Air pollution is somewhat mitigated locally by the filtering effect of trees and other vegetation in the undeveloped areas of the national historical park during leaf-on season. Conversely, natural resource specialists are concerned that atmospheric pollutants are adversely affecting the health of trees and plants.

Comprehensive air quality data have been collected by the NPS Air Resources Division (ARD). According to the division's data, Loudoun County, VA, had nonattainment of the National Ambient Air Quality Standard for ozone, which is 75 ppb for an 8-hour period (U.S. EPA 2007, 2011, NPS ARD 2011d). ARD also identifies Jefferson County, WV, and Washington County, MD, as Early Action counties (U.S. EPA 2011). Early Action means that an agreement has been entered into with EPA for more time to allow the county to achieve compliance with air quality standards.

2.3 RESOURCE STEWARDSHIP

2.3.1 Management directives and planning guidance

General Management Plan (GMP) directives

The General Management Plan for Harpers Ferry National Historical Park is comprised of the Draft General Management Plan/Environmental Impact Statement (NPS 2008a) and abbreviated Final General Management Plan/Environmental Impact Statement for Harpers Ferry National Historical Park (NPS 2009a). The plan prescribes the resource conditions and visitor experiences that are to be achieved and maintained in the park over time, based on review of the park's purpose, significance, and special mandates. This followed the assessment (both internally and externally) of three alternatives for managing Harpers Ferry National Historical Park for the next 20 years. The selected (preferred) alternative (Alternative 2) provided greater visitor enjoyment, increased access to park locales, more varied interpretation, and new life and excitement to Harpers Ferry National Historical Park. It also analyzes the impacts of implementing each of the alternatives.

Alternative 2 recommends the following (see Figure 2.1 for for major locations within the park):

- *Visitation*—visitors would enter Harpers Ferry National Historical Park at Cavalier Heights where a visitor contact station would be enlarged to function as a visitor center. This facility would provide orientation for park visitors and information on the park's many resources. It would be the starting point for an expanded transportation system that would allow visitors to reach areas of the park such as the Murphy Farm, Schoolhouse Ridge, and Camp Hill that were previously difficult to access without a car. It would also be a stop on the new around-the-park trail that would allow visitors to hike to all areas of the park. Leaving their personal vehicles at Cavalier Heights, visitors could ride the transportation system to Lower Town where visitors would be immersed in a 19th century environment. Preserved historic buildings, period shops, exhibits, and outdoor furnishings would complement the interpretation provided by rangers and possible period artisans/demonstrators that would bring life to this area. Traveling exhibits would be sought to supplement10/ interpretation provided within the park. A smaller information center and bookstore would remain but possibly in new locations. Park artifact storage would be removed from the historic structures and the space converted to office use or other types of storage.
- *The Federal Armory*—would retain its current access. A study of the feasibility of returning John Brown's Fort to its original location would be undertaken. The train station would become a secondary portal to the site with proposed excursion trains arriving from Washington several days of the week.
- *The Armory Canal*—would be restored and rewatered with the turbine also restored for interpretive purposes. The power plant would be rehabilitated for exhibits.
- *Virginius and Halls Islands*—would be preserved as an archeological preserve with ruins stabilized and outlined and wayside exhibits explaining the history and industrial development that was here. Camp Hill would be managed with a campus atmosphere reminiscent of the Storer College era. Additional signs and waysides would allow visitors to get the feel of the site. Museum exhibits now in Lower Town would be moved to one or more of the Storer College structures to better explain the importance of Harpers Ferry to the story of the civil rights movement in America. Several historic buildings from the military occupation of Camp Hill would be restored and adaptively used for park headquarters. The historic Shipley School on Camp Hill would be made available for rehabilitation by a proposed public/private partnership to allow its preservation and use.
- *The historic Grandview School*—would be rehabilitated and enlarged for use by the park's protection division.
- *The Nash Farm*—would be preserved as a dairy farm of the 1940s with its structures adapted for use as an environmental education center and outdoor laboratory managed by the National Park Service or an affiliated organization.
- *Bolivar Heights*—would be actively managed to maintain a battlefield landscape appearance. Occasional programs would be supplemented by new signs and wayside exhibits. Restrooms, an enlarged parking area, and drinking water would be provided.
- *Murphy Farm*—the civil war earthworks and the foundations of John Brown's fort would be stabilized, and the Chambers/Murphy house studied to determine the best use for it. A bus

stop and trail to the earthworks and foundations would be developed. Restrooms and drinking water would also be developed at the site.

- ***Schoolhouse Ridge***—would also be managed as a battlefield landscape with agricultural leases helping to maintain the 1862 appearance. The non-historic campground would be removed and the Harpers Ferry Caverns restored to a more natural appearance. Non-historic structures would be removed. On-site interpretation and occasional demonstrations with a military focus would be provided. Bus parking and trails would be developed. A possible tunnel under route 340 would be developed in consultation with the State to facilitate the round-the-park trail. Schoolhouse Ridge would also be a likely location for a satellite maintenance facility easing pressure to enlarge the existing facility on Camp Hill.
- ***Potoma Wayside***—upgraded take-out facilities would be developed to facilitate river use. The takeout would be hardened and restroom facilities provided. To the extent possible, parking would also be upgraded. Interpretation would be provided by the concessioner.
- ***Loudoun Heights***—the Sherwood House would be removed and the site developed as a Civil War overlook. All Civil War camps and earthworks would be stabilized as necessary. The majority of the site would be maintained for its natural resources. Short Hill would be managed similarly.
- ***Maryland Heights***—would undergo stabilization of earthworks and fortifications as necessary and restoration of line of fire vistas. Historic roads would continue to be used and maintained. A higher level of interpretation would be achieved through wayside exhibits, site brochures and occasional ranger-guided hikes.

2.3.2 Status of supporting science

Inventory and Monitoring Program

The Inventory and Monitoring (I&M) Program was formed in response to the Natural Resource Challenge of 1999, which led to the formation of the I&M Program. The goals of the Program are to (NPS 2013):

1. Inventory the natural resources under National Park Service stewardship to determine their nature and status.
2. Monitor park ecosystems to better understand their dynamic nature and condition and to provide reference points for comparisons with other altered environments.
3. Establish natural resource inventory and monitoring as a standard practice throughout the National Park system that transcends traditional program, activity, and funding boundaries.
4. Integrate natural resource inventory and monitoring information into National Park Service planning, management, and decision making.
5. Share National Park Service accomplishments and information with other natural resource organizations and form partnerships for attaining common goals and objectives.

In addition to conducting baseline inventories, I&M monitors Vital Signs that are indicators of ecosystem health. Vital Signs include:

1. physical, chemical, and biological elements and processes of park ecosystems;
2. known or hypothesized effects of stressors; and/or
3. elements that have important human values (Fancy et al. 2009).

HAFE is one of 11 parks served by the National Capital Region I&M Network (NCRN I&M). Numerous baseline inventories have been conducted at Harpers Ferry (Table 2.3) and NRCN Vital Signs monitoring makes up a large portion of the natural resource data described in this report. The long-term monitoring of these vital signs is meant to serve as an 'early warning system' to detect declines in ecosystem integrity and species viability before irreversible loss has occurred (Fancy et al. 2009).

Research at the park

The National Park Service has performed its own research and collaborated with a

Table 2.3. Status of NRCN I&M inventories at Harpers Ferry National Historical Park.

Inventory	Description	Status
Natural Resource Bibliography	The Natural Resource Bibliography, one of the 12 core NPS natural resource inventories, was developed to catalog and manage natural resource-related information sources pertaining to national parks. The bibliography has been managed in several different systems in the past, including NPBib and NatureBib. In 2010 all records were migrated to the NPS Data Store, part of the IRMA data system.	Completed 2008
Base Cartography Data	The Base Cartography inventory is one of 12 core inventories identified by the National Park Service as essential to effectively manage park natural resources. Base cartographic information from this inventory provides geographic information systems (GIS) data layers to National Park resource management staff, researchers, and research partners.	In progress?
Air Quality Data	One of the 12 core natural resource inventories, the Air Quality Inventory objective is to provide actual-measured or estimated concentrations of indicator air pollutants such as ozone, wet deposition species (NO3, SO4, NH4, etc.), dry deposition species (NO3, SO4, HNO3, NH4, SO2), and visibility (extinction for 20% cleanest days and 20% worst days for visibility).	Completed 2006
Air Quality Related Values		?
Climate Inventory	The primary objective of climate and weather monitoring for the NCRN is to provide monthly and annual summaries of climate data, including precipitation and temperature, and determine long-term trends in seasonal and annual patterns of climate parameters and soil moisture.	Completed 2006
Geologic Resources Inventory	The Geologic Resources Inventory aims to raise awareness of geology and the role it plays in the environment, and to provide natural resource managers and staff, park planners, interpreters, and researchers with information that can help them make informed management decisions. A part of the program's mission is to provide more than 270 parks with digital geologic-GIS data and a geology report.	In progress
Soil Resources Inventory	The Soil Resources Inventory (SRI) includes maps of the locations and extent of soils in a park; data about the physical, chemical, and biological properties of those soils; and information regarding the potential use and management of each soil. The SRI adheres to mapping and database standards of the National Cooperative Soil Survey (NCSS) and meets the geospatial requirements of the Soil Survey Geographic (SSURGO) database. SRI data are intended to serve as the as the official database for all agency applications regarding soil resources.	Completed 2008
Water Body Location and Classification	This document provides: (1) a complete inventory of all retrieved water quality parameter data, water quality stations, and the entities responsible for data collection; (2) descriptive statistics and appropriate graphical plots of water quality data characterizing period of record, annual, seasonal central tendencies and trends; (3) a comparison of the park's water quality data to relevant EPA and WRD water quality screening criteria; and (4) an Inventory Data Evaluation and Analysis (IDEA) to determine what Servicewide Inventory and Monitoring Program "Level I" water quality parameters have been measured within the study area. Accompanying the report are disks containing digital copies of all data used in the report, as well as all components of the report (tables, figures, etc.).	Completed 1997
Baseline Water Quality Data	This inventory documents and summarizes existing, readily-available digital water quality data collected in the vicinity of national parks.	Completed 1997
Vegetation Inventory	The Vegetation Inventory Program (VIP) is an effort by the National Park Service (NPS) to classify, describe, and map detailed vegetation communities in more than 270 national park units across the United States. Stringent quality control procedures ensure the reliability of the vegetation data and encourage the use of resulting maps, reports, and databases at multiple scales.	In progress

variety of outside researchers and to fill gaps in knowledge and have a better understanding of baseline conditions of park resources. Collaborators have included various state and federal government agencies, The University of Maryland, The University of Arkansas, and non-government organizations. A partial bibliography of research that has been completed at Harpers Ferry can be seen in Table 2.4.

Table 2.4. A partial bibliography of research that has been completed at Harpers Ferry National Historical Park.

Study topic	Reference
Mammals	McShea and O'Brien 2003, Gates and Johnson 2005, Rattner and Ackeron 2006, Bates 2009.
Birds	Sinclair et al. 2004, Rattner and Ackerson 2006, Ladin and Shriver 2013*.
Herpetofauna	Pauley et al. 2005, Rattner and Ackerson 2006.
Fish	Raesly et al. 2004.
Insects	Richardson 1994, Hebb 1984, 1987, 1993, 1994, 2001, 2002, Durkin 2003, Orr 2005, Nisbet 2009.
Plants	Bartgis and Ludwig 1996, Rouse 1998, 1999, Fleming 1999, Tracy et al. 1999, Vanderhorst 2000, Engelhardt et al. 2008, NPS 2008, 2009b.
Geology	Craig 1990, Thorneberry–Ehrlich 2005.
Hydrology	Craig 1990, Fuertsch 1992, NPS 1997, Slawson 2010.
Water Quality	NPS 1997, Norris and Pieper 2010*.
Habitat	Perles 2007, UMCES 2007, Schmit and Campbell 2007*, 2008*, Schmit et al. 2009*, 2010*.
Fungi	Stephenson 2008.
Rare and Endangered Species	Bartgis and Ludwig 1996, Rohrer 1997, Fleming 1999.

*Publications describing results of ongoing monitoring by the NCRN I&M program.

2.4 LEGISLATION

U.S. Congress. Act to provide for the establishment of the Harpers Ferry National Monument. June 30, 1944. 58 Statute 645 – Public Law 386, Chapter 328-2d Session, H.R. 3524.

U.S. Congress. Act to authorize the acquisition of certain lands for addition to Harpers Ferry National Monument, and for other purposes. July 14, 1960. 74 Statute 520 – Public Law 86-655, 86th Congress, S. 2674.

U.S. Congress. Act to change the name of Harper Ferry National Monument to HAFE. May 29, 1963. 77 Statute 52 – Public Law 88-33, 88th Congress, S. 18.

U.S. Congress. Act to amend the Act of June 30, 1944, and Act "To provide for the establishment of the Harpers Ferry National Monument:, and for other purposes." October 24, 1974. 88 Statute 1420 – Public Law 93-466, 93rd Congress, S. 605.

U.S. Congress. Act to establish the Channel Islands National Park, and for other purposes. January 3, 1980. Public Law 96-199. Sec. 108.

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Chapter 3: Study scoping and design

3.1 PRELIMINARY SCOPING

3.1.1 Park involvement

Scoping for the assessment of Harpers Ferry National Historical Park (HAFE) began in December 2010 with a meeting at HAFE to start the Natural Resource Condition Assessment (NRCA) process for Harpers Ferry National Historical Park, Catoctin Mountain Park, and Chesapeake and Ohio Canal National Historical Park. In attendance were staff from the three parks, the NPS National Capital Region Network (NCRN) Inventory and Monitoring (I&M) Program, and the University of Maryland Center for Environmental Science Integration and Application Network (UMCES-IAN) (Table 3.1). Data for park resources from HAFE and NCRN I&M were organized into an electronic library comprised of management reports, hard data files, and geospatial data, which provided the primary sources for the assessment. Additional datasets were obtained from the NPS Air Resources Division (ARD) and the Interagency Monitoring of Protected Visual Environments (IMPROVE).

Several follow-up meetings with staff from HAFE, NCRN I&M, and UMCES-IAN were used to identify and locate key resources for completing the assessment, to present work and calculations already completed, and to outline and brainstorm content conclusions and recommendations.

Strong collaboration with park natural resource staff was essential to the success of this assessment, and key park staff invested significant time to assist in the development of reference conditions, calculation of metrics, and interpretation of calculated results.

3.2 STUDY DESIGN

3.2.1 Reporting areas

The focus of the reporting area for the NRCA was the Harpers Ferry National Historical Park administrative boundary. An area five times the total area of the park (evenly distributed around the entire park boundary) was examined for landscape dynamic metric analysis. Lands within 30 km (19 mi) of the park boundary were examined for context (Budde et al. 2009) but not included in the formal assessment.

3.2.2 Indicator framework

The framework utilized for presenting assessment data in Chapter 4 was the Vital Signs categorization developed by NPS I&M (Fancy et al., 2008). Metrics included in this assessment were sorted into their respective Vital Signs categories so that they could be utilized in future studies (Figure 3.1). Fancy *et al.* (2008) identified the key challenge to large scale monitoring programs is the development of information products which integrate and translate large amounts of complex scientific data into highly aggregated metrics for communication to policy-makers and non-scientists. Aggregated indices were developed and presented within the current natural resource assessment for Harpers Ferry National Historical Park.

3.2.3 General approach and methods

The approach taken to assess natural resource condition was to determine indicators of current status within each habitat, establish a reference condition for each indicator, and then assess the percentage attainment of reference condition. Details of approach, background, and justification are provided on a metric-by-metric basis in Chapter 4. Once attainment was calculated for each indicator, the median was calculated to determine the condition for each Vital Sign category and then similarly to combine Vital Sign categories to calculate an overall park assessment.

3.2.4 Condition assessment calculations

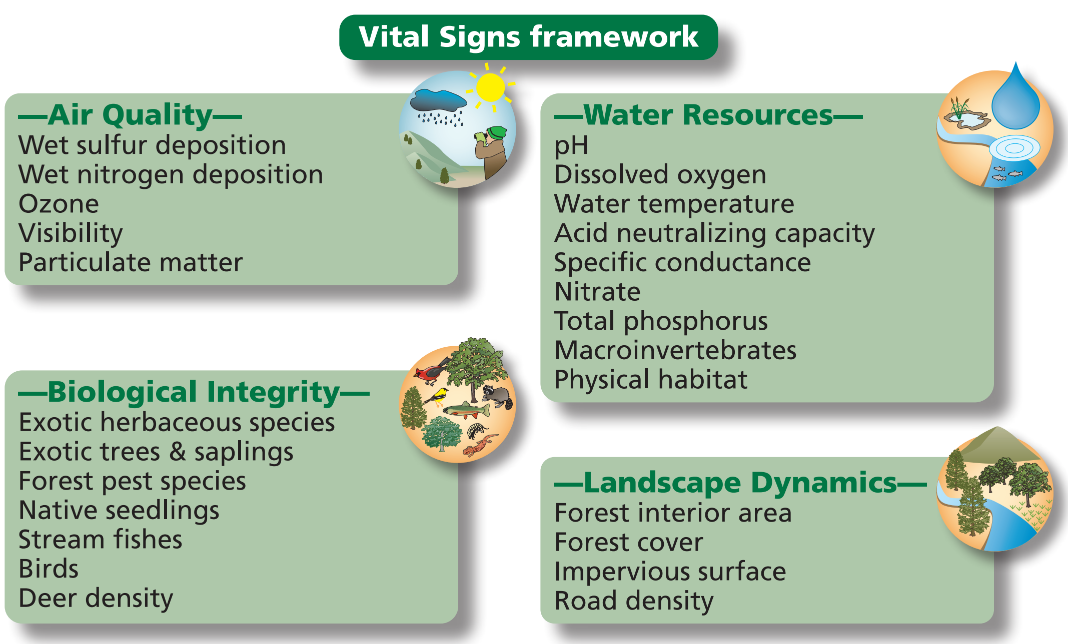
A total of 25 metrics were used to determine the natural resource condition of

Table 3.1. Ecological monitoring framework data provided by agencies and specific sources included in the assessment of Harpers Ferry National Historical Park.

Date	Meeting type	Topics discussed	Attendees
12/10/2010	Phone call	Overall project timeline	NCRN I&M: Patrick Campbell, Megan Nortrup. UMCES-IAN: Tim Carruthers, Jane Thomas.
12/17/2010	In person	Introduce NRCA project and timeline.	CATO: Scott Bell, Becky Loncosky. CHOH: Brian Carlstrom, Chris Stubbs, John Hitchcock, Michelle Carter. HAFE: Mia Parsons, Rebecca Harriet, Dale Nisbet, Andrew Lee. NCRN I&M: Pat Campbell, Mark Lehman, Megan Nortrup. UMCES-IAN: Tim Carruthers, Jane Thomas.
3/3/2011	In person	Compile resources for Chapter 2, compile a list of potential metrics for the NRCA, and to achieve a consensus on which park boundary to use for the NRCA.	HAFE: Mia Parsons, Dale Nisbet. NCRN I&M: Pat Campbell, Mark Lehman, Megan Nortrup. UMCES-IAN: Heath Kelsey, Jane Thomas, Kate Bentsen.
7/5/2011	Phone call	Progress on the NRCA and next steps.	NCRN I&M: Patrick Campbell, John Paul Schmit, Mark Lehman, Megan Nortrup. UMCES-IAN: Heath Kelsey, Jane Thomas.
9/2/2011	Phone call	Landscape Dynamics metrics analyses.	University of Richmond: Todd Lookingbill. NCRN I&M: John Paul Schmit, Mark Lehman, Megan Nortrup. UMCES-IAN: Heath Kelsey, Jane Thomas.
11/1/2011	Phone call	Progress on the NRCA and next steps.	NCRN I&M: Patrick Campbell, John Paul Schmit, Mark Lehman, Megan Nortrup. UMCES-IAN: Heath Kelsey, Jane Thomas.
12/5/2011	In person	Present NRCA drafts to park staff and discuss progress and next steps.	CATO: Scott Bell, Becky Loncosky, Lindsey Donaldson. CHOH: Brian Carlstrom, John Hitchcock, Michelle Carter. HAFE: Mia Parsons, Dale Nisbet. NCRN I&M: Pat Campbell, Mark Lehman, Megan Nortrup. UMCES-IAN: Bill Dennison, Simon Costanzo, Jane Thomas.
10/22/2012	In person	Draft conclusions and recommendations for Chapter 5.	HAFE: Mia Parsons, Dale Nisbet. NCRN I&M: Pat Campbell, Mark Lehman, Megan Nortrup. UMCES-IAN: Bill Dennison, Simon Costanzo, Jane Thomas.

CATO—Catoctin Mountain Park; CHOH—Chesapeake & Ohio Canal National Historical Park; HAFE—Harpers Ferry National Historical Park; NCRN I&M—National Capital Region Network Inventory and Monitoring; NRCA—Natural Resource Condition Assessment; UMCES-IAN—University of Maryland Center for Environmental Science Integration & Application Network.

Figure 3.1. Vital Signs framework used in this assessment.



Harpers Ferry National Historical Park. The approach for assessing resource condition within HAFE required establishment of a reference condition (i.e., threshold) for each metric. Thresholds ideally were ecologically based and derived from the scientific literature. However, when data were not available to support peer-reviewed ecological thresholds, regulatory and management-based thresholds were used.

Due to the wide range of data values for some of the metrics, medians were presented as the overall result instead of the mean.

Threshold attainment of metrics was calculated based on the percentage of sites or samples that met or exceeded threshold values set for each metric. A metric attainment score of 100% reflected that the metric at all sites and at all times met the threshold identified to maintain natural resources. Conversely, a score of 0% indicated that no sites at any sampling time met the threshold value. Once attainment was calculated for each metric, an unweighted mean was calculated to determine the condition of each Vital Sign. Attainment scores were categorized on a scale from very good to very degraded. Attainment scores for each metric are presented in Chapter 4.

The four Vital Signs scores were then averaged to produce a single assessment score for the entire park. Key findings, conclusions, and recommendations were also given for each Vital Sign and for the park as a whole in Chapter 5.

3.3 LITERATURE CITED

Budde P.J., B.J. Frakes, L. Nelson, and U. Glick. 2009. Technical guide for NPScape data and processing. Inventory & Monitoring Division, National Park Service, Fort Collins, CO.

Fancy, S.G., J.E. Gross, and S.L. Carter. 2008. Monitoring the condition of natural resources in US national parks. Environmental Monitoring and Assessment: Electronically published May 29, 2008.

Chapter 4: Natural resource conditions

4.1 AIR QUALITY

4.1.1 Air quality summary

Five metrics were used to assess air quality in Harpers Ferry National Historical Park (HAFE)—wet sulfur (S) deposition, wet nitrogen (N) deposition, ozone (ppb and W126), visibility, and particulate matter. A sixth metric (ozone [W126]) was analyzed but not included in the overall assessment due to an ozone metric (ppb) already being included in the assessment. A seventh metric (mercury deposition) was included for informational purposes but not included in the overall assessment. Data used for the assessment of current condition of wet sulfur and nitrogen deposition, ozone, and visibility were obtained from the NPS Air Resources Division (ARD) Air Quality Estimates (NPS ARD 2011a, b, c) (Table 4.1). These data were calculated by the ARD on a national scale between 2005 and 2009 using an interpolation model based on monitoring data. The values for individual parks were taken from the interpolation at the park centroid, which is a location near the center of the park and within the park

Table 4.1. Ecological monitoring framework data for Air Quality provided by agencies and specific sources included in the assessment of HAFE.

Metric	Agency	Reference/source
Wet sulfur deposition	NPS ARD	NPS ARD 2011a, *http://nadp.sws.uiuc.edu/sites/ntnmap.asp*
Wet nitrogen deposition	NPS ARD	NPS ARD 2011a, *http://nadp.sws.uiuc.edu/sites/ntnmap.asp*
Ozone (ppb and W126)	NPS ARD	NPS ARD 2011b
Visibility	NPS ARD	NPS ARD 2011c
Particulate matter (PM 2.5)	IMPROVE	*http://www.epa.gov/airdata/*
Mercury deposition	MDN-NADP	*http://nadp.sws.uiuc.edu/mdn/*

Table 4.2. Air Quality reference conditions for HAFE.

Metric	Reference conditions	Sites	Samples	Period
Wet sulfur deposition (kg/ha/yr)	< 1; 1–3; > 3	Whole park	N/A*	2005–2009
Wet nitrogen deposition (kg/ha/yr)	< 1; 1–3; > 3	Whole park	N/A*	2005–2009
Ozone (ppb)	≤ 60; 60.1–75; > 75	Whole park	N/A*	2005–2009
Ozone (W126; ppm-hrs)	< 7; 7–13; > 13	Whole park	N/A*	2005–2009
Visibility (dv)	< 2; 2–8; > 8	Whole park	N/A*	2005–2009
Particulate matter (PM2.5; µg/m³)	≤ 12; 12.1–15; > 15	2	3,170	2001–2010
Mercury deposition (ng/L)	N/A	2	701	2001–2011

* One interpolated value represents a five-year average of weekly measurements at multiple sites.

Table 4.3. Categorical ranking of the reference condition attainment categories for Air Quality metrics.

Metric reference conditions					Attainment of reference condition	Natural resource condition
S & N deposition (kg/ha/yr)	Ozone (ppb)	Ozone (W126)	Visibility (dv)	Particulate matter (µg/m³)		
< 1	≤ 60	< 7	< 2	≤ 12	100%	Good
1–3	60.1–75	7–13	2–8	12.1–15	0–100% (scaled)	Moderate
> 3	> 75	> 13	> 8	> 15	0%	Significant concern

boundary (Figure 4.1). Data for the other two metrics (particulate matter and mercury deposition) were obtained from national monitoring network sites (Table 4.1).

Reference conditions were established for each of the five metrics (Table 4.2) and the data were compared to these reference conditions to obtain the percent attainment and converted to the condition assessment for that metric (Table 4.3). Multiple reference condition categories were used in accordance with the NPS ARD documentation (NPS ARD 2011a) (Table 4.2).

To assess trends, data from the NPS ARD report were used where possible (NPS ARD 2010). Otherwise, monitoring sites used were those closest to HAFE from the National Atmospheric Deposition Program (NADP) and Interagency Monitoring of Protected Visual Environments (IMPROVE) program (Figure 4.1).

HAFE scored 0% attainment (or conditions of significant concern) for all air quality metrics except particulate matter (33% attainment) which scored as moderate (Table 4.4). This resulted in an overall air quality condition attainment of 6.6%, or very degraded condition.

Literature cited

NPS ARD (National Park Service, Air Resources Division). 2010. Air quality in National Parks: 2009 annual performance and progress report. Natural Resource Report NPS/NRPC/ARD/NRR—2010/266. National Park Service, Denver, CO.

Table 4.4. Summary of resource condition assessment of Air Quality in HAFE.

Metric	Result	Reference conditions	% attainment	Condition	Air quality condition
Wet sulfur deposition (kg/ha/yr)	5.12	< 1; 1–3; > 3	0	Significant concern	**6.6%** **Very degraded**
Wet nitrogen deposition (kg/ha/yr)	4.38	< 1; 1–3; > 3	0	Significant concern	
Ozone (ppb)	75.8	≤ 60; 60.1–75; > 75	0	Significant concern	
Ozone (W126; ppm-hrs)	12.5	< 7; 7–13; > 13	8.3	Moderate	
Visibility (dv)	12.8	< 2; 2–8; > 8	0	Significant concern	
Particulate matter (PM2.5; μg/m^3)	14.0	≤ 12; 12.1–15; > 15	33	Moderate	
Mercury deposition (ng/L)	9.1	N/A	N/A	N/A	

Figure 4.1. Regional air quality monitoring sites for wet deposition of sulfur and nitrogen, ozone, visibility, particulate matter, and mercury deposition. Wet deposition, ozone, and visibility condition data for 2005–2009 were interpolated by NPS ARD to estimate mean concentrations for HAFE.

NPS ARD (National Park Service, Air Resources Division). 2011a. 2005–2009 5-year average wet deposition estimates. NPS Air Quality Estimates. Accessed April 9, 2013. *http://www.nature.nps.gov/air/Maps/AirAtlas/IM_materials.cfm*

NPS ARD (National Park Service, Air Resources Division). 2011b. 2005–2009 5-year average ozone estimates. NPS Air Quality Estimates. National Park Service. Denver, CO. Accessed April 9, 2013. *http://www.nature.nps.gov/air/Maps/AirAtlas/IM_materials.cfm*

NPS ARD (National Park Service, Air Resources Division). 2011c. 2005–2009 5-year average visibility estimates. NPS Air Quality Estimates. National Park Service. Denver, CO. Accessed April 9, 2013. *http://www.nature.nps.gov/air/Maps/AirAtlas/IM_materials.cfm*

NPS ARD (National Park Service, Air Resources Division). 2011d. Rating air quality conditions. National Park Service, Denver, CO. Accessed April 9, 2013. *http://www.nature.nps.gov/air/planning/docs/20111122_Rating-AQ-Conditions.pdf*

4.1.2 Wet sulfur deposition

Description

Emissions of sulfur dioxide (SO_2) in the U.S. increased from nine million metric tons in 1900 up to 28.8 million metric tons by 1973, with 60% of these emissions coming from electric utilities. Geographically, 41% came from the seven Midwest states centered on the Ohio Valley (Driscoll et al. 2001). Largely as a result of the Clean Air Act, emissions of SO_2 had reduced to 17.8 million metric tons by 1996 and while large areas of the eastern U.S. had annual sulfur wet deposition loads > 30 kg/ha/yr over the period 1983–1985, these areas were mostly < 25 kg/ha/yr by the period 1995–1997 (Driscoll et al. 2001). Once in the atmosphere, SO_2 is highly mobile and can be transported distances greater than 500 km (311 miles) (Driscoll et al. 2001).Wet sulfate (SO_4^{2-}) deposition is significant in the eastern parts of the United States (Figure 4.2).

Data and methods

The reference condition for total sulfur wet deposition is ecological. Natural background total sulfur deposition in the east of the U.S. is 0.5 kg/ha/yr which equates to a wet deposition of approximately 0.25 kg/ha/yr (Porter and Morris 2007, NPS ARD 2011b).

The wet sulfur deposition data used for the assessment of current condition were taken from the NPS Air Resources Division (ARD) Air Quality Estimates (NPS ARD 2011a) (Table 4.1). These estimates were calculated on a national scale between 2005 and 2009 using an interpolation model based on monitoring data. The value for HAFE was taken from the interpolation at the park centroid, which is a location near the center of the park (Figure 4.1).

NPS ARD has established wet sulfur deposition guidelines as < 1 kg/ha/yr indicating good condition (or 100% attainment of reference condition) and > 3 kg/ha/yr indicating significant concern (or 0% attainment). Concentrations of 1–3 kg/ha/yr were considered in moderate condition, and attainment scores were scaled linearly from 0 to 100% between these two reference points (Figure 4.3, Table 4.5). For the current assessment, the reported wet deposition value was assessed against these guidelines (NPS ARD 2011a, b) (Tables 4.2. 4.3).

This analysis meant that there was only one value reported for wet sulfur deposition for HAFE, so this value was assessed against

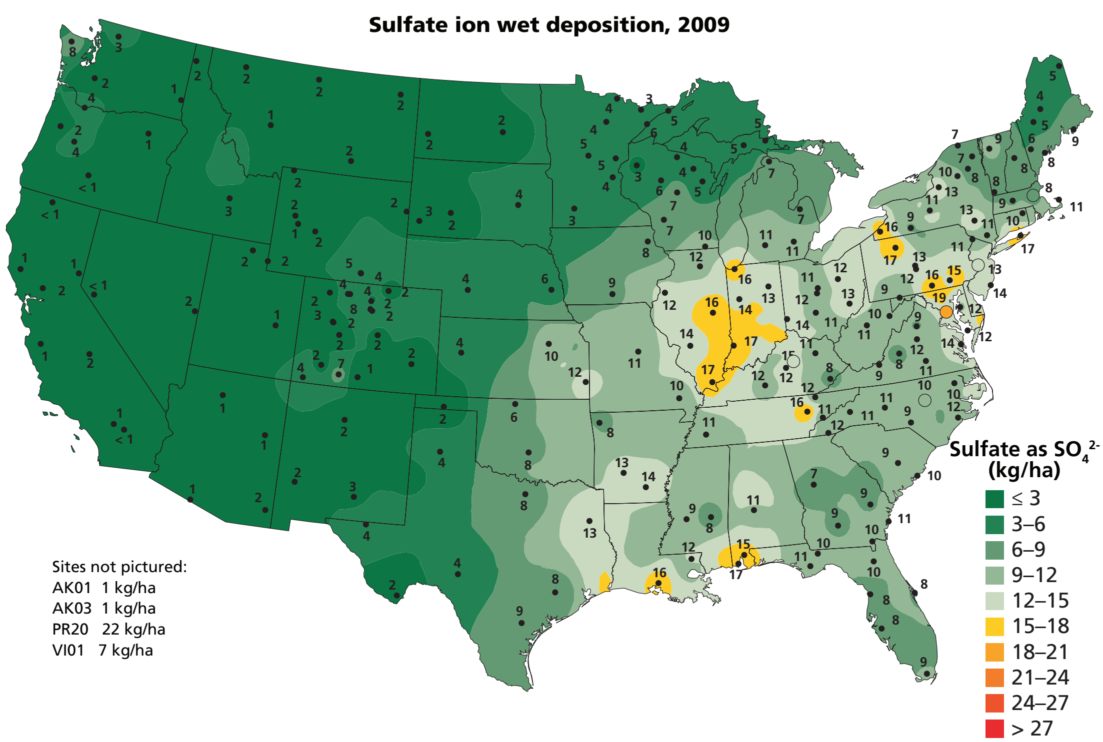


Figure 4.2. Total wet deposition of sulfate (SO_4^{3-}) for the continental United States in 2009 (NADP/NTN 2010).

the three reference condition ranges described above.

Additionally, National Atmospheric Deposition Program (NADP) data from the three monitoring sites closest to HAFE were used—sites MD07, PA00, and MD99 (Table 4.1, Figure 4.1).

Condition and trend

Interpolated wet sulfur deposition between 2005 and 2009 for HAFE was 5.12 kg/ha/yr which resulted in 0% attainment of reference condition, or a condition of significant concern (NPS ARD 2011a) (Table 4.4). In a national assessment that ranked parks according to relative risk from sulfur (and nitrogen) acidification effects, HAFE was ranked at very high risk (Sullivan et al. 2011a, b), suggesting that streams and soils in the park are very vulnerable to acidification. At this time, however, park streams are not showing signs of acidification (see section *4.2—Water Resources*).

HAFE is included in the national assessment of current air quality conditions by NPS ARD but has not yet been included in the country-wide trends analyses. However, when deposition data were analyzed from the three sites closest to the park, site MD07 (within the park) showed a significant improvement of wet deposition over the past decade (p-value < 0.01) (Figure 4.4). The other two sites nearest the park (PA00 and MD99) did not show such a trend.

Sources of expertise

Air Resources Division, National Park Service. *http://www.nature.nps.gov/air/*

National Atmospheric Deposition Program. *http://nadp.sws.uiuc.edu/*

Drew Bingham, Geographer, NPS Air Resources Division.

Ellen Porter, NPS Air Resources Division.

Holly Salazer, NPS Air Resources Coordinator for the Northeast Region.

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Driscoll, C.T., G.B. Lawrence, A.J. Bulger, T.J. Butler, C.S. Cronan, C. Eagar, K.F. Lambert, G.E. Likens, J.L. Stoddard, and K.C. Weathers. 2001. Acidic deposition in the northeastern

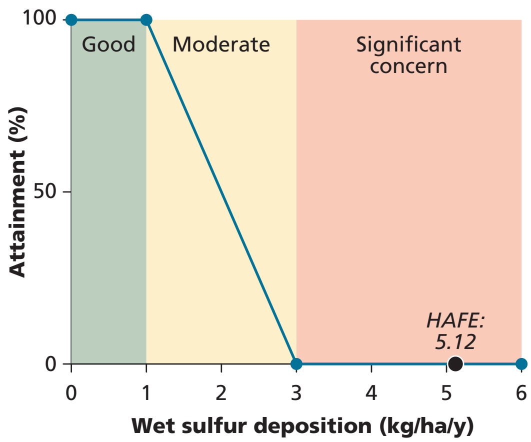

Figure 4.3. Application of the percent attainment categories to the wet sulfur deposition value categories. Wet sulfur deposition at HAFE was 5.12 kg/ha/y which equated to 0% attainment of the reference condition.

Table 4.5. Wet sulfur deposition categories, percent attainment, and condition assessment.

S deposition (kg/ha/yr)	% attainment	Condition
< 1	100%	Good
1–3	0–100% (scaled)	Moderate
> 3	0%	Significant concern

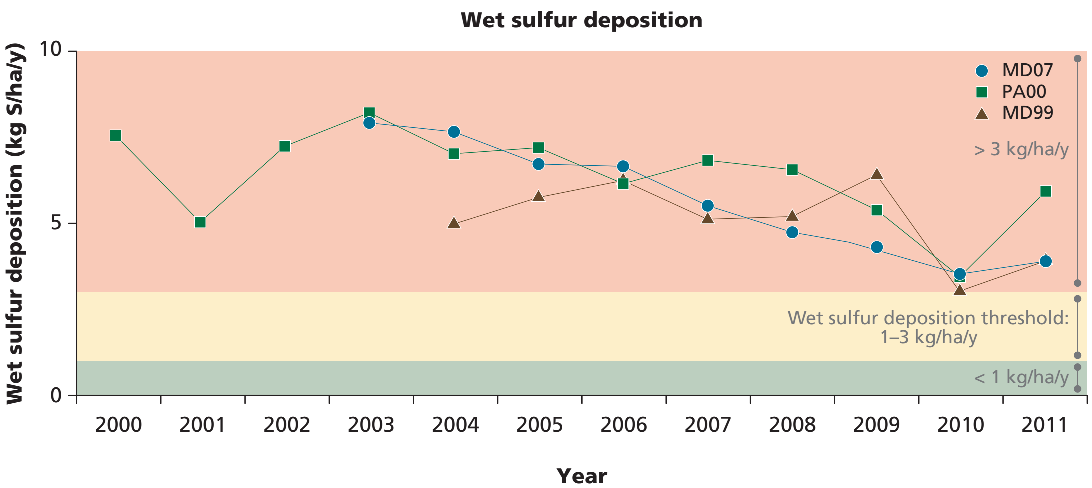

Figure 4.4. Annual wet deposition of sulfate (kg SO_4/ha/yr) at the three sites closest to HAFE. Data were reported as SO_4 deposition; these data were converted to total S deposition using atomic weights (multiplying by 0.333). Reference conditions are shown in gray.

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NADP/NTN. 2010. *http://nadp.sws.uiuc.edu*

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NPS ARD (National Park Service, Air Resources Division). 2011b. Rating air quality conditions. National Park Service, Denver, CO. Accessed April 9, 2013. *http://www.nature.nps.gov/air/planning/docs/20111122_Rating-AQ-Conditions.pdf*

Porter, E., K. Morris. 2007. Wet Deposition Monitoring Protocol: Monitoring Atmospheric Pollutants in Wet Deposition. Natural Resource Technical Report NPS/NRPC/ARD/NRTR—2007/004. National Park Service, Fort Collins, CO.

Sullivan, T.J., G.T. McPherson, T.C. McDonnell, S.D. Mackey, and D. Moore. 2011a. Evaluation of the sensitivity of Inventory and Monitoring National Parks to acidification effects from atmospheric sulfur and nitrogen deposition: main report. Natural Resource Report NPS/NRPC/ARD/NRR—2011/349. National Park Service, Denver, CO.

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: National Capital Region Network (NCRN). Natural Resource Report NPS/NRPC/ARD/NRR—2011/367. National Park Service, Denver, CO.

4.1.3 Wet nitrogen deposition

Description

During the 1940s and 1950s, it was recognized in the United States and Great Britain that emissions from coal burning and large-scale industry such as power plants and steel mills were causing severely degraded air quality in major cities. This resulted in severe human health impacts and by the early 1970s, the U.S. Environmental Protection Agency had established the National Ambient Air Quality Standards (NAAQS) (Porter and Johnson 2007). Since 1970, in addition to human health effects, it was increasingly recognized that there were significant ecosystem impacts of atmospheric nitrogen deposition, including acidification and nutrient fertilization of waters and soils (NPS ARD 2011a). These impacts included such measurable effects as the disruption of nutrient cycling, changes to vegetation structure, loss of stream biodiversity, and the eutrophication of streams and coastal waters (Driscoll et al. 2001, Porter and Johnson 2007). Wet nitrogen deposition is significant in the eastern parts of the United States (Figure 4.5).

Data and methods

The reference condition for total nitrogen wet deposition is ecological. Natural background total nitrogen deposition in the east of the U.S. is 0.5 kg/ha/yr which equates to a wet deposition of approximately 0.25 kg/ha/yr (Porter and Morris 2007, NPS ARD 2011a). Some sensitive ecosystems, such as coastal and estuarine waters and upland areas, show responses to wet nitrogen deposition rates of 1.5 kg/ha/yr, while there is no evidence of ecosystem harm at deposition rates less than 1 kg/ha/yr (Fenn et al. 2003).

The wet nitrogen deposition data used for the assessment of current condition were taken from the NPS Air Resources Division (ARD) Air Quality Estimates (NPS ARD 2011b) (Table 4.1). These estimates were calculated on a national scale between 2005 and 2009 using an interpolation model based on monitoring data. The value for HAFE was taken from the interpolation at the park centroid, which is a location near the center of the park (Figure 4.1).

NPS ARD has established wet nitrogen deposition guidelines as < 1 kg/ha/yr indicating good condition (or 100% attainment of reference condition) and > 3 kg/ha/yr indicating significant concern (or 0% attainment). Concentrations of 1–3 kg/ha/yr were considered in moderate condition, and attainment scores were scaled linearly from 0 to 100% between these two reference points (Figure 4.6, Table 4.6). For the current assessment, the reported

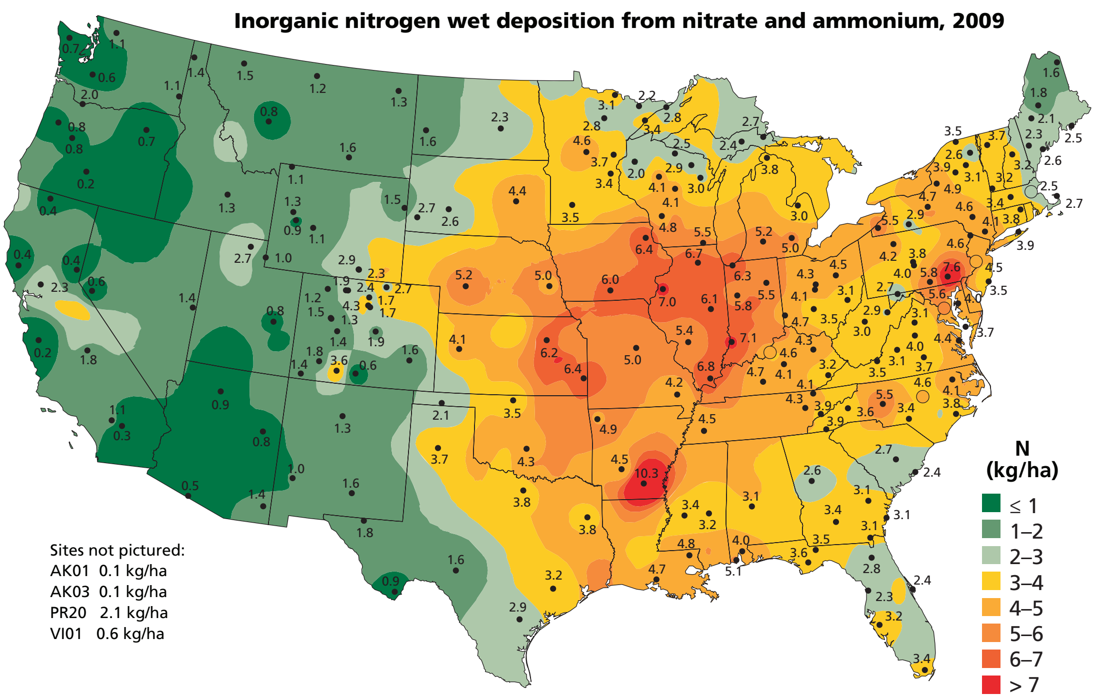

Figure 4.5. Total wet deposition of nitrate (NO_3^-) and ammonium (NH_4^+) (kg/ha) for the continental United States in 2009 (NADP/NTN 2010).

wet deposition value was assessed against these guidelines (NPS ARD 2011a, b) (Tables 4.2, 4.3).

This analysis meant that there was only one value reported for wet nitrogen deposition for HAFE, so this value was assessed against the three reference condition ranges described above.

Additionally, National Atmospheric Deposition Program (NADP) data from the three monitoring sites closest to HAFE were used—sites MD07, PA00, and MD99 (Table 4.1, Figure 4.1).

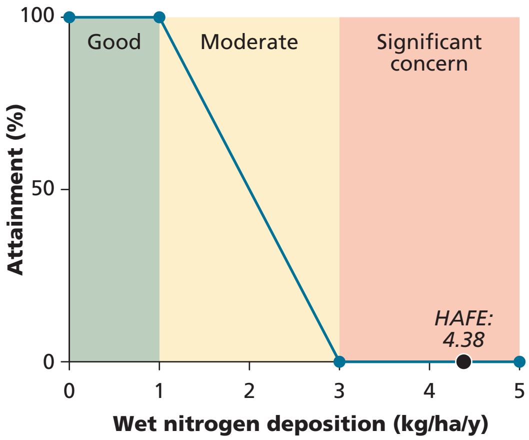

Figure 4.6. Application of the percent attainment categories to the wet nitrogen deposition value categories. Wet nitrogen deposition at HAFE was 4.38 kg/ha/y which equated to 0% attainment of the reference condition.

Table 4.6. Wet nitrogen deposition categories, percent attainment, and condition assessment.

N deposition (kg/ha/yr)	% attainment	Condition
< 1	100%	Good
1–3	0–100% (scaled)	Moderate
> 3	0%	Significant concern

Condition and trend

Interpolated wet nitrogen deposition between 2005 and 2009 for HAFE was 4.38 kg/ha/yr which resulted in 0% attainment of reference condition, or a condition of significant concern (NPS ARD 2011b) (Table 4.4). In a national assessment that ranked parks according to relative risk from nutrient nitrogen effects, HAFE was ranked at moderate risk (Sullivan et al. 2011a, b).

HAFE is included in the national assessment of current air quality conditions by NPS ARD but has not yet been included in the country-wide trends analyses. However, when deposition data were analyzed from the three sites closest to the park, none of the sites showed a significant improvement of wet deposition over the past decade (p-value > 0.01) (Figure 4.7).

Sources of expertise

Air Resources Division, National Park Service. *http://www.nature.nps.gov/air/*

National Atmospheric Deposition Program. *http://nadp.sws.uiuc.edu/*

Drew Bingham, Geographer, NPS Air Resources Division.

Ellen Porter, NPS Air Resources Division.

Holly Salazer, NPS Air Resources Coordinator for the Northeast Region.

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Driscoll, C.T., G.B. Lawrence, A.J. Bulger, T.J. Butler, C.S. Cronan, C. Eagar, K.F. Lambert, G.E. Likens, J.L. Stoddard, and K.C. Weathers. 2001. Acidic deposition in the northeastern United States: sources and inputs, ecosystem effects, and management strategies. Bioscience 51: 180–198.

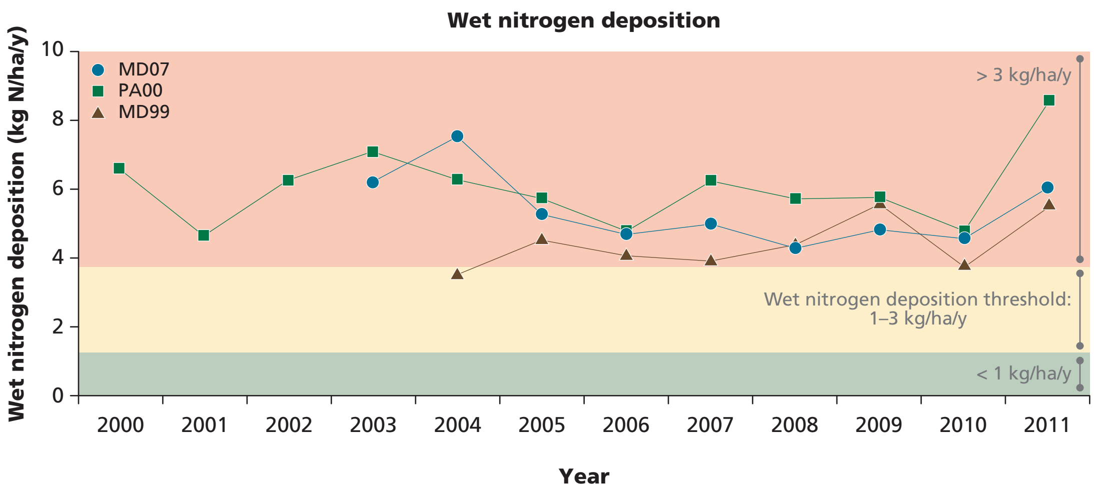

Figure 4.7. Annual wet deposition of total nitrogen (kg N/ha/yr) at the three sites closest to HAFE. Reference conditions are shown in gray.

Fenn, M.E., R. Haeuber, G.S. Tonnesen, J.S. Baron, S. Grossman–Clarke, D. Hope, D.A. Jaffe, S. Copeland, L. Geiser, H.M. Rueth, and J.O. Sickman. 2003. Nitrogen emissions, deposition, and monitoring in the Western United States. BioScience 53: 391–403.

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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: main report. Natural Resource Report NPS/NRPC/ARD/NRR—2011/313. National Park Service, Denver, CO.

Sullivan, T.J., T.C. McDonnell, G.T. McPherson, S.D. Mackey, and D. Moore. 2011b. Evaluation of the sensitivity of inventory and monitoring national parks to nutrient enrichment effects from atmospheric nitrogen deposition: National Capital Region Network (NCRN). Natural Resource Report NPS/NRPC/ARD/NRR—2011/317. National Park Service, Denver, CO.

4.1.4 Ozone

Description

Ozone is a secondary atmospheric pollutant, meaning it is not directly emitted but rather is formed by a sunlight-driven chemical reaction on nitrogen oxides and volatile organic compounds emitted largely from burning fossil fuels (Haagen–Smit and Fox 1956). In humans, ozone can cause a number of health-related issues such as lung inflammation and reduced lung function, which can result in hospitalization. Although adverse health effects can occur in very sensitive groups at levels below 60 ppb, the U.S. EPA's 2007 review of the standard concluded that levels between 60 and 70 ppb would likely be protective of most of the population (U.S. EPA 2007). In 2010, the U.S. EPA proposed establishing a separate secondary standard to protect vegetation, based on an ecologically relevant metric, the W126, which is explained in more detail in the following section. Some plant species are more sensitive to ozone than humans. These sensitive plants can develop foliar injury from elevated ozone exposure levels especially when soil moisture levels are moderate to high. Under these conditions, plants have their stomata open, allowing gas exchange for photosynthesis, but also allowing ozone to enter.

Data and methods

Ground-level ozone is regulated under the Clean Air Act and the U.S. EPA is required to set standard concentrations for ozone (U.S. EPA 2004). The current National Ambient Air Quality Standards (NAAQS) standard is 75 ppb, based on the three-year average annual fourth-highest daily maximum eight-hour ozone concentration at a monitor (NAAQS 2008). Both the three-year average annual fourth-highest daily maximum eight-hour concentration (averaged over five years) and the plant-exposure metric, the W126, are incorporated into the benchmarks to assess ozone condition within National Park units by the National Park Service Air Resources Division (NPS ARD 2011a).

The ozone concentration data used for the assessment of current condition were taken from the NPS ARD Air Quality Estimates (NPS ARD 2011b) (Table 4.1). These estimates were calculated on a national scale between 2005 and 2009 using an interpolation model based on monitoring data. The value for HAFE was taken from the interpolation at the park centroid, which is a location near the center of the park (Figure 4.1).

NPS ARD has established ozone concentration (three-year average fourth-highest daily maximum eight-hour ozone concentration, averaged over five years) guidelines as ≤ 60.0 ppb (set as 80% of the current standard of 75 ppb) indicating good condition (or 100% attainment of reference condition) and > 75 ppb indicating significant concern (or 0% attainment) (U.S. EPA 2007, NPS ARD 2011a). Concentrations of 60.1–75.0 ppb were considered in moderate condition, and attainment scores were scaled linearly from 0 to 100% between these two reference points (Figure 4.8, Table 4.7). For the current assessment, the reported ozone value was assessed against these guidelines (NPS ARD 2011a, b) (Tables 4.2, 4.3).

NPS ARD also looks at the W126 standard to assess the risk for ozone-induced foliar damage to sensitive plants. W126 provides an index of the cumulative ozone exposure to plants during daylight hours. The W126 weights higher ozone concentration more heavily because they are more likely to cause injury. Values less than 7 parts per million-hour (ppm-hrs) are considered safe for sensitive plants (or 100% attainment of reference condition) and > 13 ppm-hrs is

Table 4.7. Ozone deposition categories, percent attainment, and condition assessment.

Ozone (ppb)	Ozone (W126)	% attainment	Condition
≤ 60	< 7	100%	Good
60.1–75	7–13	0–100% (scaled)	Moderate
> 75	> 13	0%	Significant concern

considered a significant concern for very sensitive plant species (or 0% attainment). Values of 7–13 ppm-hrs represents a moderate condition, and attainment scores were scaled linearly from 0 to 100% between these two reference points (NPS ARD 2010, 2011c) (Figure 4.9, Table 4.7). Although the W126 metric was analyzed and the attainment was calculated, the score was omitted from the overall assessment due to the ozone (ppb) metric already being included in the assessment.

This analysis meant that there was only one value reported for ozone concentration for HAFE, so this value was assessed against the three reference condition ranges described above.

Condition and trend

Interpolated fourth-highest daily maximum eight-hour ozone concentration between 2005 and 2009 for HAFE was 75.8 ppb which resulted in 0% attainment of reference condition, or a condition of significant concern (NPS ARD 2011a) (Table 4.4). In addition, the U.S. EPA has announced its

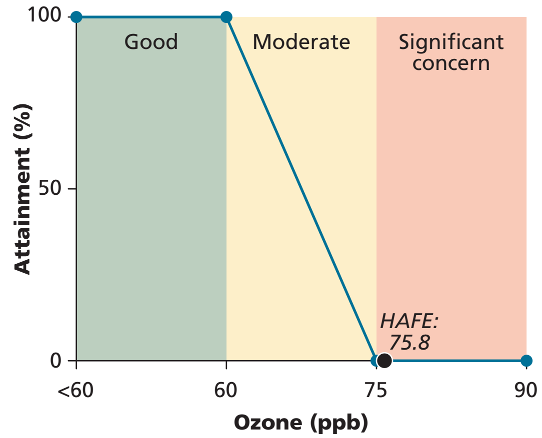

Figure 4.8. Application of the percent attainment categories to the ozone (ppb) value categories. Ozone at HAFE was 75.8 ppb which equated to 0% attainment of the reference condition.

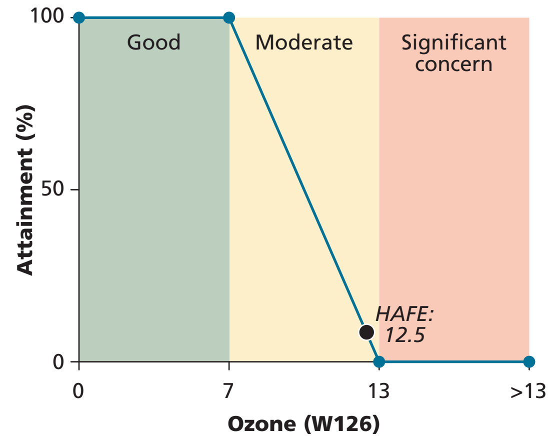

Figure 4.9. Application of the percent attainment categories to the ozone (W126) value categories. W126 at HAFE was 12.5 which equated to 8.3% attainment of the reference condition.

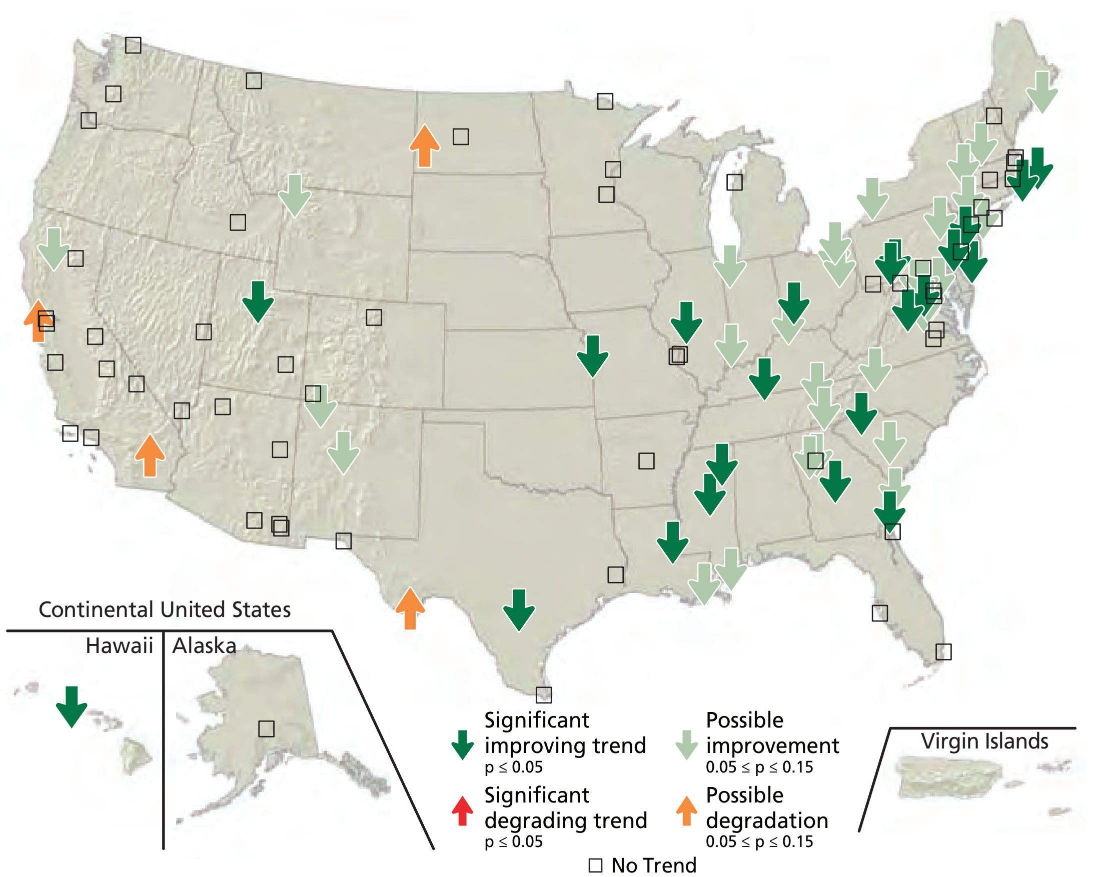

Figure 4.10. Trends in annual fourth-highest eight-hour ozone concentration (ppb), 1999–2008 (NPS ARD 2010).

intention to designate Loudoun County, VA, which encompasses part of HAFE, as nonattainment for ozone (U.S. EPA 2011) because of violations of the 75 ppb standard, recognizing that air quality is unhealthy at times in the area.

Interpolated W126 value between 2005 and 2009 for HAFE was 12.5 ppm-hrs which resulted in 8.3% attainment of reference condition, or moderate conditions (NPS ARD 2011a) (Table 4.4). A national assessment concluded that vegetation at HAFE was at high risk of injury from ozone, which can cause visible foliar injury and reduced growth and reproduction (Kohut 2007).

Although the trend in HAFE was not individually assessed, a country-wide assessment of ozone trends within 159 park units found that in the eastern U.S., ozone trends are generally improving over the past 10 years, largely influenced by the implementation of the NO_X State Implementation Plan (SIP) Call rule (EPA 2010, NPS ARD 2010) (Figure 4.10).

The overall ozone condition at HAFE is of significant concern, as the interpolated estimate of the eight-hour ozone average exceeds the human health standard of 75 ppb. Additionally, the park is partially located in Loudoun County, VA, which is considered nonattainment for the standard.

Sources of expertise

Air Resources Division, National Park Service. *http://www.nature.nps.gov/air/*

Drew Bingham, Geographer, NPS Air Resources Division.

Ellen Porter, NPS Air Resources Division.

Holly Salazer, NPS Air Resources Coordinator for the Northeast Region.

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4.1.5 Visibility

Description

The presence of sulfates, organic matter, soot, nitrates, and soil dust can impair visibility. In the eastern U.S., the major cause of reduced visibility is sulfate particles formed from SO_2 emitted from coal combustion (National Research Council 1993). The Clean Air Act includes visibility as one of its national goals as it is an indicator of emissions (U.S. EPA 2004).

Data and methods

Air pollution causes haze and reduces visibility. Visibility is measured using the Haze Index in deciviews (dv). As the Haze Index increases, the visibility worsens. Conditions for visibility are based on five-year average visibility minus estimated average natural visibility, where average visibility is the mean of visibility between 40th and 60th percentiles (U.S. EPA 2003, NPS ARD 2011a). Interpolated five-year averages are used within the contiguous U.S. The visibility condition is expressed as:

Visibility Condition = average current visibility – estimated average natural visibility

The reference condition for visibility is based on the national goal of restoring natural visibility. The Regional Haze Rule requires remedying existing and preventing any future visibility impairment in the nation's largest parks and wilderness areas, known as the 'Class I' areas (NPS ARD 2010). NPS has adopted this goal for all parks, including HAFE and all others designated as Class II under the Clean Air Act.

The haze index data used for the assessment of current condition were taken from the NPS Air Resources Division (ARD) Air Quality Estimates (NPS ARD 2011b) (Table 4.1). These estimates were calculated on a national scale between 2005 and 2009 using an interpolation model based on monitoring data. The value for HAFE was taken from the interpolation at the park centroid, which is a location near the center of the park (Figure 4.1).

NPS ARD has established visibility guidelines as ≤ 2 dv above natural conditions

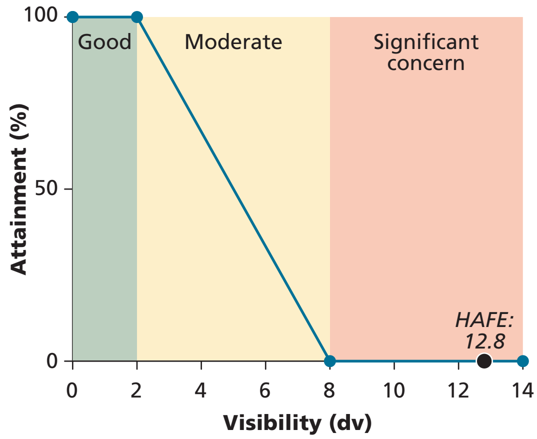


Figure 4.11. Application of the percent attainment categories to the visibility value categories. Visibility at HAFE was 12.8 dv which equated to 0% attainment of the reference condition.

Table 4.8. Visibility categories, percent attainment, and condition assessment.

Visibility (dv)	% attainment	Condition
< 2	100%	Good
2–8	0–100% (scaled)	Moderate
> 8	0%	Significant concern

indicating good condition (or 100% attainment of reference condition) and ≥ 8 dv above natural conditions indicating significant concern (or 0% attainment). Concentrations of 2–8 dv above natural conditions were considered in moderate condition, and attainment scores were scaled linearly from 0 to 100% between these two reference points (Figure 4.11, Table 4.8). For the current assessment, the reported visibility value was assessed against these guidelines (NPS ARD 2011a, b) (Tables 4.2, 4.3).

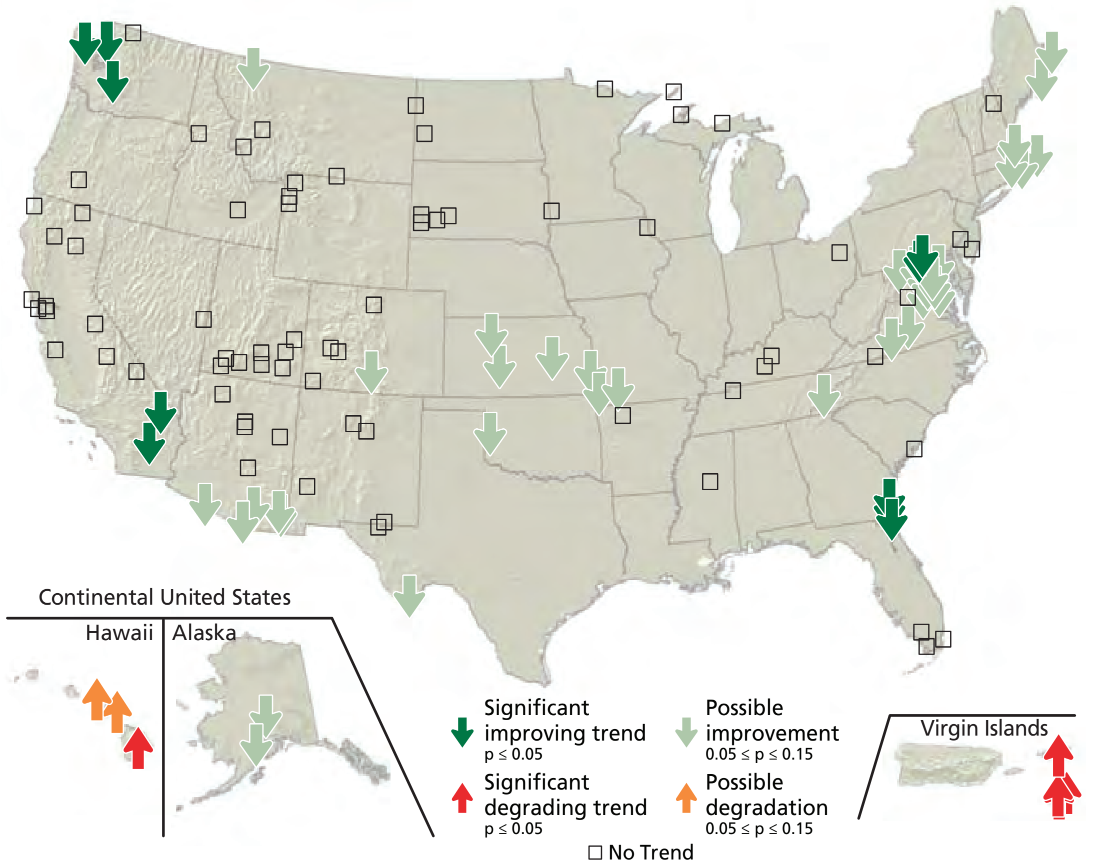
This analysis meant that there was only one value reported for the haze index for HAFE, so this value was assessed against the three reference condition ranges described above.

Condition and trend

Interpolated haze index between 2005 and 2009 for HAFE was 12.8 dv, which resulted in 0% attainment of reference condition, or a condition of significant concern (NPS ARD 2011a) (Table 4.4).

A country-wide assessment of visibility trends between 1999 and 2008 within 157 parks found that there was no significant trend in visibility at HAFE, although general trends in the region seem to be improving (NPS ARD 2010) (Figure 4.12).

Figure 4.12. Visibility trends measured by the haze index (deciview) on haziest days, 1999–2008 (NPS ARD 2010).



Sources of expertise

Air Resources Division, National Park Service. *http://www.nature.nps.gov/air/*

Drew Bingham, Geographer, NPS Air Resources Division.

Ellen Porter, NPS Air Resources Division.

Holly Salazer, NPS Air Resources Coordinator for the Northeast Region.

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4.1.6 Particulate matter

Description

Fine particles less than 2.5 µm diameter (PM 2.5) are emitted as smoke from power plants, gasoline and diesel engines, wood combustion, steel mills, forest fires, and chemical reactions such as the release of sulfur dioxide or nitrogen dioxide. These fine particles—airborne soot—have multiple human health impacts and can aggravate lung disease and cause non-fatal heart and asthma attacks, acute bronchitis, respiratory infection, coughing, wheezing, shortness of breath, and changes in lung function (U.S. EPA 2006). In recognition of these significant health impacts, ground-level particulate matter is regulated under the Clean Air Act and the U.S. EPA is required to set standard concentrations for airborne particulates (U.S. EPA 2004a).

Data and methods

Data was obtained from the Interagency Monitoring of Protected Visual Environments (IMPROVE) database through the U.S. EPA's AirData interface (Table 4.1) for the two sampling locations closest to HAFE: sites 240430009 near St. James in Washington County, MD and 540030003 near Martinsburg in Berkeley County, WV (Figure 4.1, Table A-1).

The current National Ambient Air Quality Standards (NAAQS) particulate matter regulatory threshold is a concentration of 35 µg/m³ (NAAQS 2008). There are two primary standards for PM 2.5. The annual standard is met (air condition is considered acceptable) when the three-year average of the annual mean concentration is ≤ 15.0 µg/m³, and the 24-hour or 'daily' standard is met when the three-year average of the annual 98th percentile is ≤ 65.0 µg/m³ (NAAQS 2008). The annual standard (≤ 15.0 µg/m³) was used as the reference condition in the current assessment (Tables 4.2, 4.3).

In keeping with the NPS ARD calculation of multiple thresholds for ozone (NPS ARD 2011), good condition (or 100% attainment) for particulate matter represents 80% or less (or ≤12.0 µg/m³) of the cur-

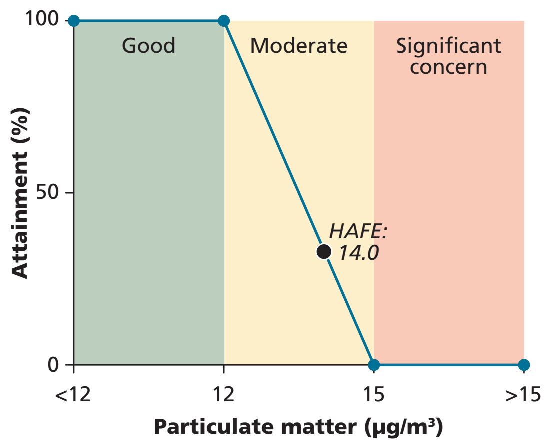

Figure 4.13. Application of the percent attainment categories to the particulate matter value categories. Particulate matter at HAFE was 14.0 µg/m³ which equated to 33% attainment of the reference condition.

Table 4.9. Particulate matter categories, percent attainment, and condition assessment.

Particulate matter (µg/m³)	% attainment	Condition
≤ 12	100%	Good
12.1–15	0–100% (scaled)	Moderate
> 15	0%	Significant concern

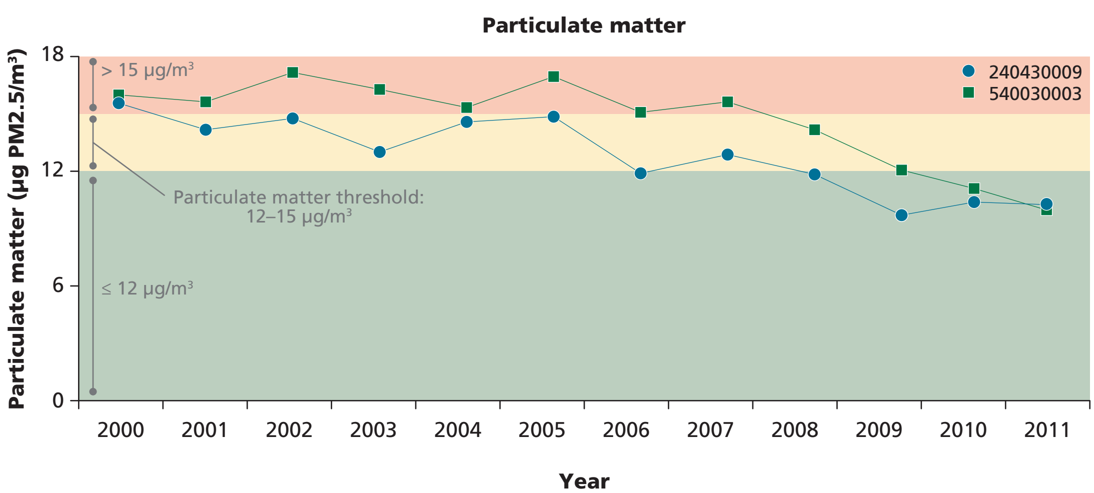

Figure 4.14. Particulate matter (µg PM2.5/m³) at the two sites closest to HAFE. Reference conditions are shown in gray. Data show the annual mean concentrations.

rent standard. Values > 15 µg/m^3 indicated significant concern (or 0% attainment). Values of 12.0–15.0 µg/m^3 indicated moderate condition, and attainment scores were scaled linearly from 0 to 100% between these two reference points (Figure 4.13, Tables 4.2, 4.3, 4.9).

Data were 24-hour averages; three-year averages of the annual mean concentrations were calculated. The median of all these values was taken and assessed against the three reference condition ranges described above.

Condition and trend

The two sites closest to HAFE had a median of 14.0 µg/m^3 between 2001 and 2010, with 33% attainment of the reference condition, or moderate condition (Figure 4.14, Table 4.4). Both sites showed a significant improving trend of particulate matter over the past decade (p-value < 0.01) (Figure 4.14).

Sources of expertise

Interagency Monitoring of Protected Visual Environments (IMPROVE). *http://vista.cira.colostate.edu/improve/Data/IMPROVE/improve_data.htm*

U.S. EPA PM Standards. *http://epa.gov/ttn/naaqs/standards/pm/s_pm_index.html*

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U.S. EPA. 2006. Provisional assessment of recent studies on health effects of particulate matter exposure. EPA/600/R-06/063.

4.1.7 Mercury deposition

Description

Atmospheric mercury (Hg) comes from natural sources, including volcanic and geothermal activity, geological weathering, anthropogenic sources such as burning of fossil fuels, processing of mineral ores, and incineration of certain waste products (UNEP 2008). At a global scale, annual anthropogenic emissions of mercury approximately equal all natural marine and terrestrial emissions, with anthropogenic emissions in North America being 153 metric tons in 2005 (UNEP 2008). Exposure of humans and other mammals to mercury *in utero* can result in developmental disabilities, cerebral palsy, deafness, blindness, and dysarthria (speech disorder), and exposure as adults can lead to motor dysfunction and other neurological and mental impacts (U.S. EPA 2001). Avian species' reproductive potential is negatively impacted by mercury, and measured trends in mercury deposition, from west to east across North America, can also be measured in the common loon (*Gavia immer*), and throughout North America in mosquitoes (Evers et al. 1998, Hammerschmidt and Fitzgerald 2006). Mercury is also recorded to have a toxic effect on soil microflora, although no ecological depositional threshold is currently established (Meili et al. 2003).

Data and methods

Data was obtained from the National Atmospheric Deposition Program, Mercury Deposition Network (Table 4.1) for two sites: Arendtsville (PA00) in Adams County, PA, and Beltsville (MD99) in Prince Georges County, MD (Figure 4.1). Samples are collected weekly and within 24 hours of a precipitation event and analyzed for mercury concentration, measured in nanograms (ng) of Hg/L. Annual mean mercury concentrations were calculated for each sampling site.

There are no published thresholds for wet deposition of mercury, so this metric was not included in the overall assessment of HAFE, but was included for informational purposes only.

Condition and trend

Annual median mercury concentrations in precipitation from two sites in the region of HAFE over the past decade range from ~7–13 ng/L (Figure 4.15, Table 4.4) and the Mid-Atlantic region in general has relatively low levels of mercury deposition (Figure 4.16). If it is assumed that precipitation constitutes much of the flow in streams in the parks, then it can be assumed that mercury concentrations in streams would be comparable to the range observed in precipitation. The U.S. EPA does provide National Recommended Water Quality Criteria for the protection of aquatic life. Criteria for total dissolved mercury are 1,400 ng/L (acute criteria) and 770 ng/L (chronic criteria) (U.S. EPA 2012). These criteria values are 1–2 orders of magnitude greater than what has been recorded in rainfall in the region, suggesting a low risk to aquatic life. However, mercury concentrations in streams within the region are not

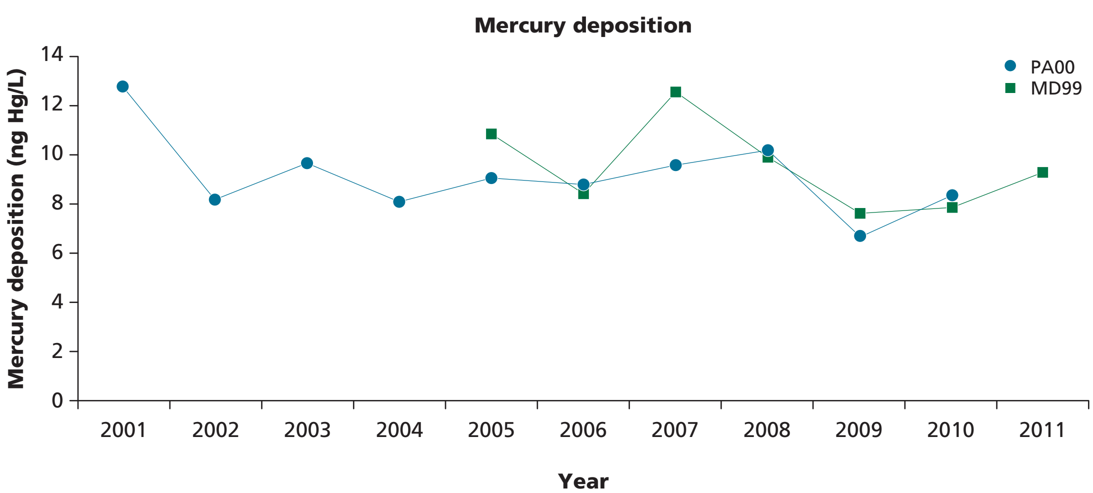

Figure 4.15. Median annual mercury concentrations (ng Hg/L) in precipitation from two sites in the region of HAFE.

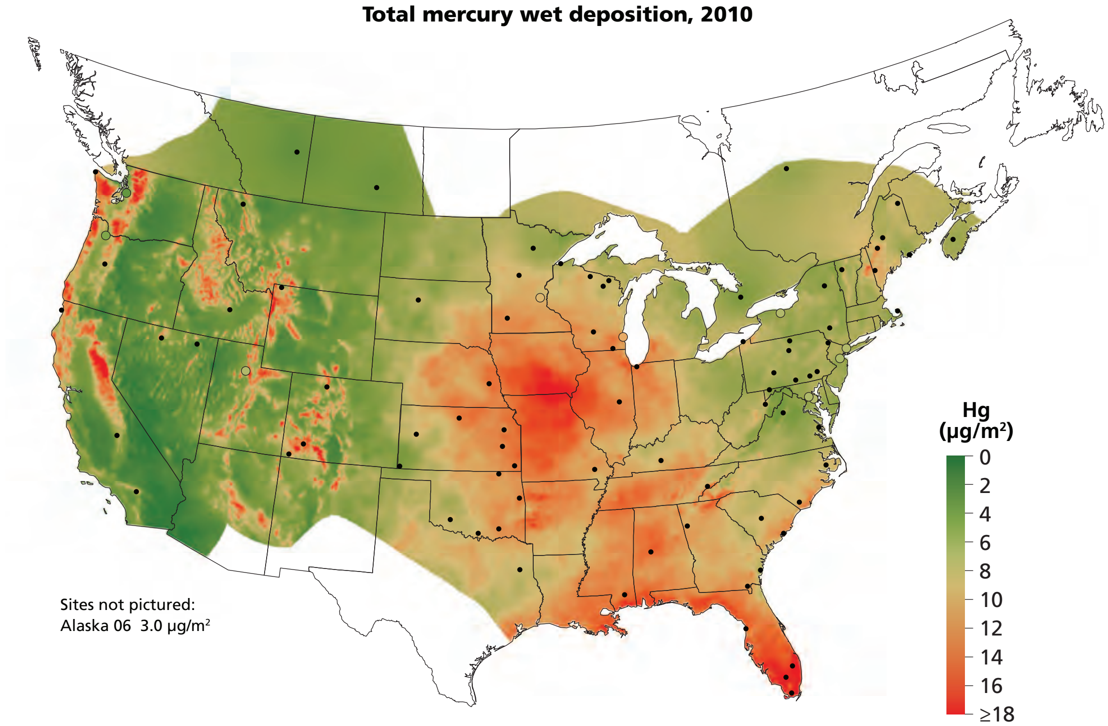

Figure 4.16. Total mercury wet deposition across the United States in 2010 (NADP/MDN 2012).

available. Experimental research in boreal lakes in Canada has shown a linear relationship between mercury deposition and accumulation in biota, using similar deposition values as seen in the National Capital Region (Orihel et al. 2007). However, due to the lack of research in the region linking mercury deposition to accumulation in fish, mercury was not included in the overall assessment.

Over the data range available, no significant trend was present (p-value > 0.01) (Figure 4.15).

Sources of expertise

National Atmospheric Deposition Program, Mercury Deposition Network. *http://nadp.sws.uiuc.edu/MDN/*

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4.2 WATER RESOURCES

4.2.1 Water resources summary

Nine metrics were used to assess water resources in HAFE—pH, dissolved oxygen (DO), water temperature, acid neutralizing capacity (ANC), salinity/specific conductance, nitrate, total phosphorus, Benthic Index of Biotic Integrity (BIBI), and Physical Habitat Index (PHI) (Table 4.10). Data were collected by National Capital Region Network (NCRN) Inventory & Monitoring (I&M) staff. Monitoring sites are shown in Figure 4.17.

Reference conditions were established for each metric (Table 4.11) and the data were compared to these reference conditions to obtain the percent attainment and converted to the condition assessment for that metric (Table 4.12). Single reference conditions were used for pH, dissolved oxygen, temperature, acid neutralizing capacity, specific conductance, nitrate, and total phosphorus, while multiple reference conditions were used for BIBI and PHI (Tables 4.11, 4.12a, 4.12b).

HAFE scored as very good for pH, water temperature, ANC (all 100% attainment), and DO (96% attainment). BIBI scored as degraded (45% attainment), PHI scored as partially degraded (67% attainment), and nitrate, specific conductance, and total phosphorus scored as very degraded (7.2%, 2.9%, and 0% attainment, respectively) (Table 4.13). This resulted in an overall water resources condition attainment of 58%, or moderate condition.

Literature cited

Norris M.E. & G. Sanders. 2009. National Capital Region Network biological stream survey protocol: physical habitat, fish, and aquatic

Table 4.10. Ecological monitoring framework data for Water Resources provided by agencies and specific sources included in the assessment of HAFE.

Metric	Agency	Reference/source
pH	NCRN I&M	Pieper et al. 2012, Norris et al. 2011
Dissolved oxygen	NCRN I&M	Pieper et al. 2012, Norris et al. 2011
Water temperature	NCRN I&M	Pieper et al. 2012, Norris et al. 2011
Acid neutralizing capacity	NCRN I&M	Pieper et al. 2012, Norris et al. 2011
Specific conductance	NCRN I&M	Pieper et al. 2012, Norris et al. 2011
Nitrate	NCRN I&M	Pieper et al. 2012, Norris et al. 2011
Total phosphorus	NCRN I&M	Pieper et al. 2012, Norris et al. 2011
Benthic Index of Biotic Integrity	NCRN I&M, MBSS	Norris and Sanders 2009, MBSS
Physical Habitat Index	NCRN I&M, MBSS	Norris and Sanders 2009, MBSS

Table 4.11. Water Resources reference conditions for HAFE.

Metric	Reference condition/s	Sites	Samples	Period
pH	6.0 ≤ pH ≤ 9.0	1	68	2005–2011
Dissolved oxygen (mg/L)	≥ 5.0	1	67	2005–2011
Water temperature (°C)	≤ 30.56 May–Nov; ≤ 22.78 Dec–Apr	1	68	2005–2011
Acid neutralizing capacity (μeq/L)	≥ 200	1	69	2005–2011
Specific conductance (μS/cm)	≤ 500	1	68	2005–2011
Nitrate (mg/L)	≤ 2	1	69	2005–2011
Total phosphorus (mg/L)	≤ 0.01	1	52	2007–2011
Benthic Index of Biotic Integrity	1.0–1.9; 2.0–2.9; 3.0–3.9; 4.0–5.0	4	4	2004
Physical Habitat Index	0–50; 51–65; 66–80; 81–100	4	4	2004

macroinvertebrate vital signs. Natural Resource Report. NPS/NCRN/NRR—2009/116. National Park Service, Fort Collins, CO.

Norris, M.E., J.M. Pieper, T.M. Watts, and A. Cattani. 2011. National Capital Region Network Inventory and Monitoring Program water chemistry and quantity monitoring protocol version 2.0: Water chemistry, nutrient dynamics, and surface water dynamics vital signs. Natural Resource Report NPS/NCRN/NRR—2011/423. National Park Service, Fort Collins, CO.

Pieper, J., M. Norris, and T. Watts. 2012. National Capital Region Network FY 2010 water resources monitoring data report. Natural Resources Data Series NPS/NCRN/NRDS—2012/381. Natural Resources Program Center, Fort Collins, CO.

Table 4.12a. Categorical ranking of reference condition attainment categories for pH, dissolved oxygen, temperature, acid neutralizing capacity, specific conductance, nitrate, and total phosphorus.

Attainment of reference condition	Natural resource condition
80–100%	Very good
60–<80%	Good
40–<60%	Moderate
20–<40%	Degraded
0–<20%	Very degraded

Table 4.12b. Categorical ranking of the reference condition attainment categories for the Benthic Index of Biotic Integrity and the Physical Habitat Index.

Reference conditions	Attainment of reference condition	Natural resource condition
Benthic Index of Biotic Integrity (BIBI)		
4.0–5.0	100%	Good
3.0–3.9	↑ scaled	Fair
2.0–2.9	linearly ↓	Poor
1.0–1.9	0%	Very poor

Reference conditions	Attainment of reference condition	Natural resource condition
Physical Habitat Index (PHI)		
81–100	75–100% (scaled)	Minimally degraded
66–80	50–75% (scaled)	Partially degraded
51–65	25–50% (scaled)	Degraded
0–50	0–25% (scaled)	Severely degraded

Table 4.13. Summary of resource condition assessment of Water Resources in HAFE.

Metric	Result	Reference condition	% attainment	Condition	Water resources condition
pH	8.2	6.0–9.0	100	Very good	**58%** **Moderate**
Dissolved oxygen (mg/L)	8.4	≥ 5.0	96	Very good	
Water temperature (°C)	19.1 May–Nov; 7.4 Dec–Apr	≤ 30.56 May–Nov; ≤ 22.78 Dec–Apr	100	Very good	
Acid neutralizing capacity (μeq/L)	4,820	≥ 200	100	Very good	
Specific conductance (μS/cm)	660	≤ 500	2.9	Very degraded	
Nitrate (mg/L)	4.1	≤ 2	7.2	Very degraded	
Total phosphorus (mg/L)	0.14	≤ 0.01	0	Very degraded	
Benthic Index of Biotic Integrity	2.8	1.0–1.9; 2.0–2.9; 3.0–3.9; 4.0–5.0	45	Poor	
Physical Habitat Index	75	0–50; 51–65; 66–80; 81–100	67	Partially degraded	

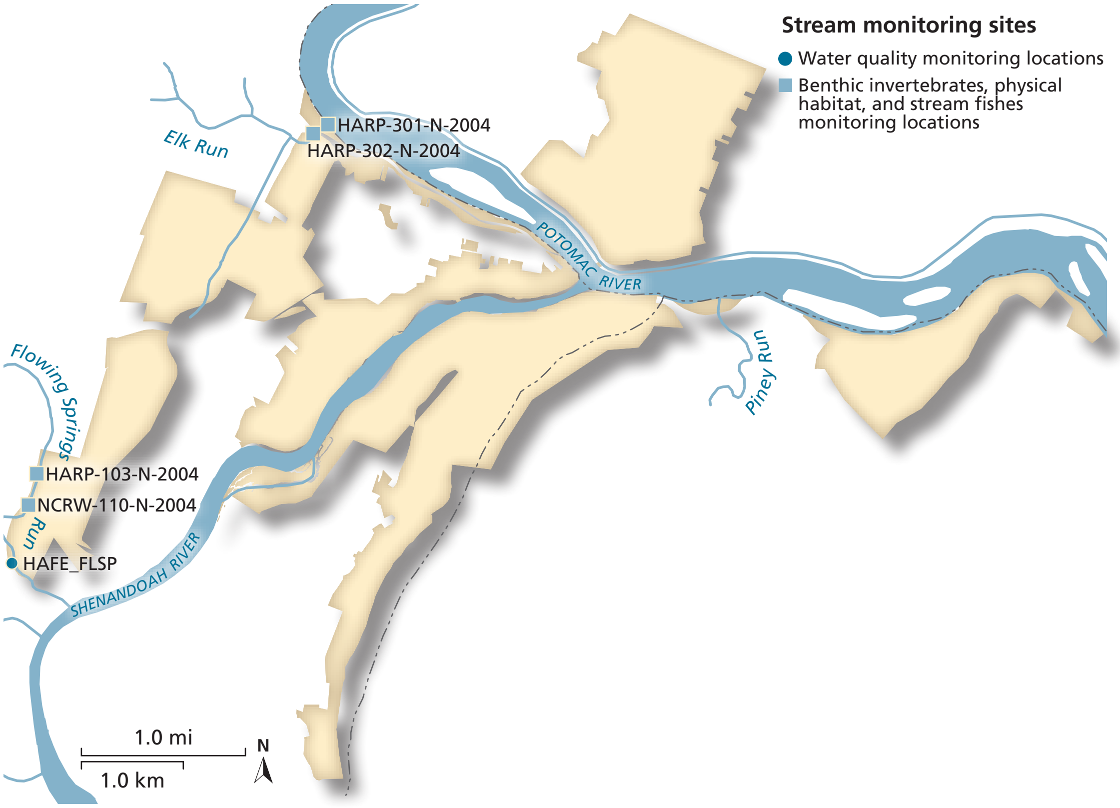

Figure 4.17. Stream sampling location in HAFE used for long-term water quality monitoring (Norris et al. 2007).

4.2.2 Water pH

Description

The streams in and adjacent to HAFE are an important and unique habitat for plants, invertebrates, fish, and amphibians, as well as an important water source for mammals and birds. Deposition of atmospheric sulfate and nitrogen are a significant regional concern, and freshwater habitats may be impacted by acidification (Sardinski and Dunson 1992, NPS ARD 2010). Salamanders and fish are susceptible to extreme pH values and can be limited by food availability even at less extreme acidification by, for example, reduced zooplankton and periphyton communities (Sadinski and Dunson 1992, Barr and Babbitt 2002). Reduced pH can result in reduced salamander hatching success, suppression of larval newt survival, and impacts upon frog metamorphosis (Sadinski and Dunson 1992).

Data and methods

The data analyzed were collected monthly at one site between 2005 and 2011 by Inventory & Monitoring staff (Pieper et al. 2012) (Figure 4.17, Table 4.10, Table A-2). NCRN followed the sampling protocol specified in Norris et al. 2011.

A reference condition pH range of 6.0–9.0 was used for this assessment, which is the West Virginia criteria for Designated Use Category C: Water Contact Recreation (State of West Virginia 2008) (Table 4.11). Each data point was compared against the reference condition and assigned a pass or fail result. The percentage of passing results was used as the percent attainment and translated to a condition assessment (Table 4.12a).

Condition and trend

Condition of pH in HAFE was very good, with a median pH of 8.2 and 100% of data points attaining the reference condition of 6.0–9.0 between 2005 and 2011 (Figure 4.18, Table 4.13). Over the data range available, no significant trend was present (p-value > 0.01) (Figure 4.18).

Sources of expertise

James Pieper, Hydrologic Technician, National Capital Region Network Inventory & Monitoring Program, National Park Service.

Literature cited

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Norris, M.E., J.M. Pieper, T.M. Watts, and A. Cattani. 2011. National Capital Region Network Inventory and Monitoring Program water chemistry and quantity monitoring protocol version 2.0: Water chemistry, nutrient dynamics, and surface water dynamics vital signs. Natural Resource Report NPS/NCRN/NRR—2011/423. National Park Service, Fort Collins, CO.

Pieper, J., M. Norris, and T. Watts. 2012. National Capital Region Network FY 2010 water resources monitoring data report. Natural Resources Data Series NPS/NCRN/NRDS—2012/381. Natural Resources Program Center, Fort Collins, CO.

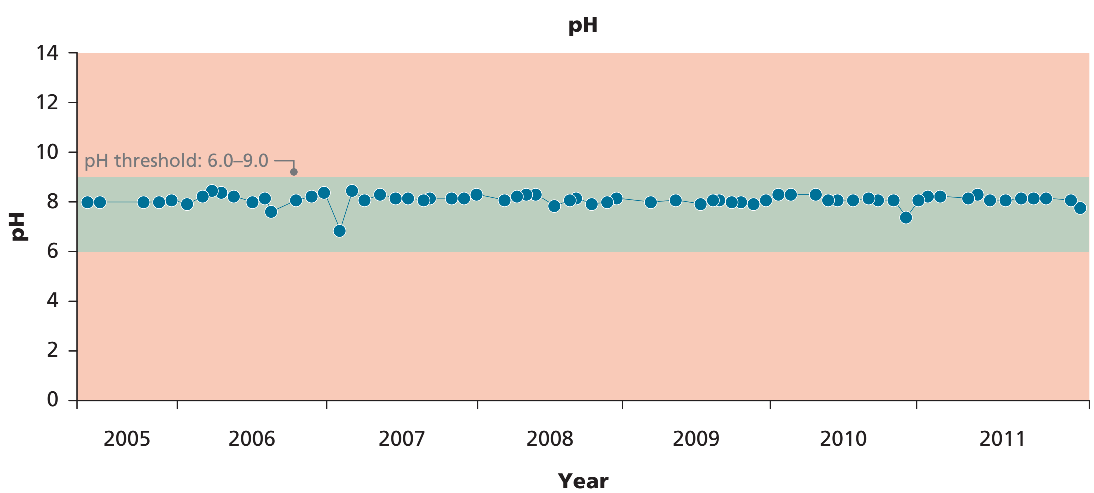


Figure 4.18. pH from 2005 to 2011 for one stream sampling location in HAFE. Reference condition (6.0 ≤ pH ≤ 9.0) is shown in gray.

Sadinski, W.J. and W.A. Dunson. 1992. A multi-level study of effects of low pH on amphibians of temporary ponds. Journal of Herpetology 26: 413–422.

State of West Virginia. 2008. 47CRS2 – Requirements governing water quality standards. Accessed April 9, 2013. *http://www.dep.wv.gov/WWE/Programs/wqs/Documents/47-02.pdf*

4.2.3 Dissolved oxygen

Description

Dissolved oxygen (DO) concentration in water is often used as an indicator to gauge the overall health of the aquatic environment. It is needed to maintain suitable habitat for the survival and growth of fish and many other aquatic organisms (USGS 2013). Low DO is of great concern due to detrimental effects on aquatic life. Conditions that generally contribute to low DO levels include warm temperatures, low flows, water stagnation and shallow stream gradients, organic matter inputs, and high respiration rates. Decay of excessive organic debris in the water column from aquatic plants, municipal or industrial discharges, or storm runoff can also cause DO concentrations to be undersaturated or depleted. Insufficient DO can lead to unsuitable conditions for aquatic life and its absence can result in the unpleasant odors associated with anaerobic decomposition. Minimum required DO concentration to support fish varies because the oxygen requirements of fish vary with a number of factors, including the species and age of the fish, prior acclimatization, temperature, and concentration of other substances in the water.

Data and methods

The data analyzed were collected monthly at one site between 2005 and 2011 by Inventory & Monitoring staff (Pieper et al. 2012) (Figure 4.17, Table 4.10, Table A-2). NCRN followed the sampling protocol specified in Norris et al. 2011.

A reference condition of ≤ 5.0 mg DO/L was used for this assessment, which is the West Virginia criteria for Designated Use Category C: Water Contact Recreation (State of West Virginia 2008) (Table 4.11). Each data point was compared against the reference condition and assigned a pass or fail result. The percentage of passing results was used as the percent attainment and translated to a condition assessment (Table 4.12a).

Condition and trend

Condition of dissolved oxygen in HAFE was very good, with a median DO of 8.4 mg/L and 96% of data points attaining the reference condition of ≥ 5.0 mg/L between 2005 and 2011 (Figure 4.19, Table 4.13). There have been no instances of dissolved oxygen failing the reference condition since 2006. Over the data range available, no significant trend was present (p-value > 0.01) (Figure 4.19).

Sources of expertise

James Pieper, Hydrologic Technician, National Capital Region Network Inventory & Monitoring Program, National Park Service.

Literature cited

Norris, M.E., J.M. Pieper, T.M. Watts, and A. Cattani. 2011. National Capital Region Network Inventory and Monitoring Program water chemistry and quantity monitoring protocol version 2.0: Water chemistry, nutrient dynamics, and surface water dynamics vital signs. Natural Resource Report NPS/NCRN/NRR—2011/423. National Park Service, Fort Collins, CO.

Pieper, J., M. Norris, and T. Watts. 2012. National Capital Region Network FY 2010 water

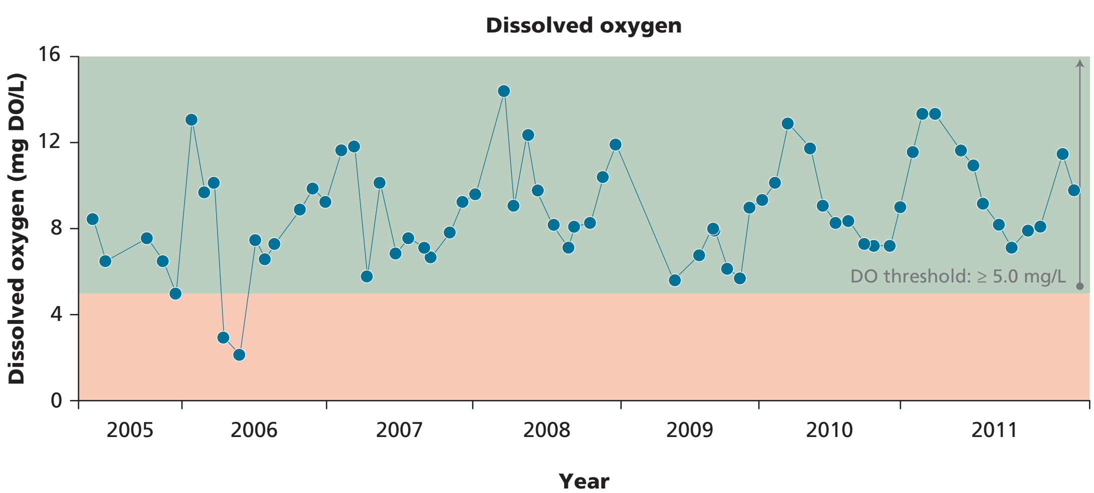


Figure 4.19. Dissolved oxygen concentrations (mg/L) from 2005 to 2011 for one stream sampling location in HAFE. Reference condition (DO ≥ 5.0 mg/L) is shown in gray.

resources monitoring data report. Natural Resources Data Series NPS/NCRN/NRDS—2012/381. Natural Resources Program Center, Fort Collins, CO.

State of West Virginia. 2008. 47CRS2 – Requirements governing water quality standards. Accessed April 9, 2013. *http://www.dep.wv.gov/WWE/Programs/wqs/Documents/47-02.pdf*

USGS (United States Geological Survey). 2013. Dissolved oxygen, from USGS Water Science for Schools: All about water. Accessed April 23, 2013. *http://ga.water.usgs.gov/edu/dissolvedoxygen.html*

4.2.4 Water temperature

Description

Aquatic organisms are dependent on certain temperature ranges for optimal health. Temperature affects many other parameters in water, including the amount of dissolved oxygen available, the types of plants and animals present, and the susceptibility of organisms to parasites, pollution, and disease (USGS 2013). Causes of temperature changes in the water include weather conditions, shade, and discharges into the water from urban sources or groundwater inflows.

Data and methods

The data analyzed were collected monthly at one site between 2005 and 2011 by Inventory & Monitoring staff (Pieper et al. 2012) (Figure 4.17, Table 4.10, Table A-2). NCRN followed the sampling protocol specified in Norris et al. 2011.

A reference condition of ≤ 87°F/30.56°C for May–November and ≤ 73°F/22.78°C for December–April was used for this assessment, which is the West Virginia criteria for Designated Use Category C: Water Contact Recreation (State of West Virginia 2008) (Table 4.11). Each data point was compared against the reference condition and assigned a pass or fail result. The percentage of passing results was used as the percent attainment and translated to a condition assessment (Table 4.12a).

Condition and trend

Condition of water temperature in HAFE was very good, with median temperatures of 19.1°C (May–November) and 7.4°C (December–April), and 100% of data points attaining the reference condition between 2005 and 2011 (Figure 4.20, Table 4.13). Over the data range available, no significant trend was present (p-value > 0.01) (Figure 4.20).

Sources of expertise

James Pieper, Hydrologic Technician, National Capital Region Network Inventory & Monitoring Program, National Park Service.

Literature cited

Norris, M., J.P. Schmit, and J. Pieper. 2007. National Capital Region Network 2005–2006 water resources monitoring report. Natural Resources Technical Report NPS/NCRN/NRTR—2007/066. Natural Resource Program Center, Fort Collins, CO.

Norris, M.E., J.M. Pieper, T.M. Watts, and A. Cattani. 2011. National Capital Region Network Inventory and Monitoring Program water chemistry and quantity monitoring protocol version 2.0: Water chemistry, nutrient dynamics, and surface water dynamics vital signs. Natural Resource Report NPS/NCRN/NRR—2011/423. National Park Service, Fort Collins, CO.

Pieper, J., M. Norris, and T. Watts. 2012. National Capital Region Network FY 2010 water resources monitoring data report. Natural Resources Data Series NPS/NCRN/NRDS—2012/381. Natural Resources Program Center, Fort Collins, CO.

State of West Virginia. 2008. 47CRS2 – Requirements governing water quality standards. Accessed April 9, 2013. *http://www.dep.wv.gov/WWE/Programs/wqs/Documents/47-02.pdf*

USGS (United States Geological Survey). 2013. Temperature – water properties. USGS Water Science School. Accessed April 23, 2013. *http://ga.water.usgs.gov/edu/temperature.html*

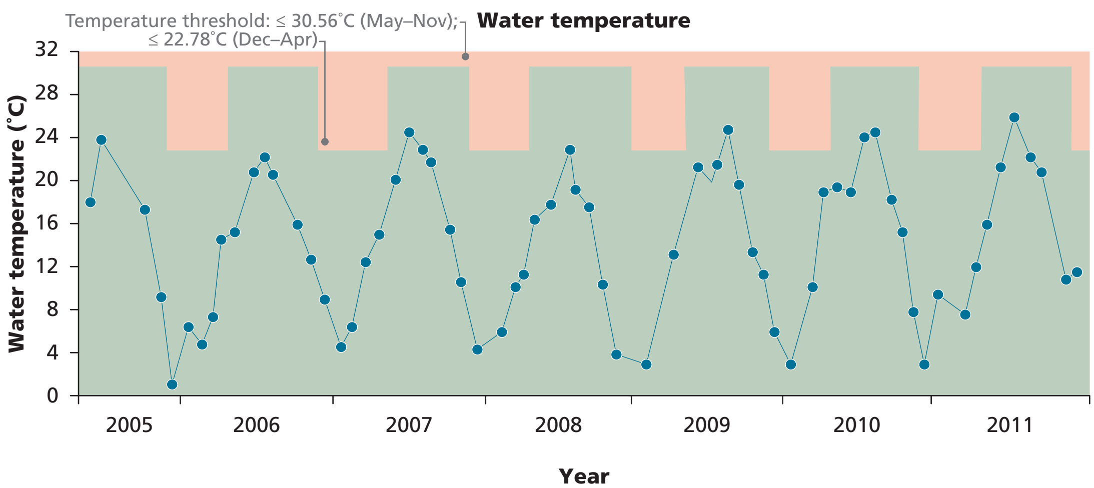


Figure 4.20. Water temperature (°C) from 2005 to 2011 for one stream sampling location in HAFE. Reference condition (temperature ≤ 30.56°C May–Nov and ≤ 22.78°C Dec–Apr) is shown in gray.

4.2.5 Acid neutralizing capacity

Description

Acid neutralizing capacity (ANC) is the prime indicator of a waterbody's susceptibility to acid inputs. ANC is a measure of the amount of carbonate and other compounds in the water that neutralize low (acidic) pH. Streams with higher ANC levels (better buffering capacity) are affected less by acid rain and other acid inputs than streams with lower ANC values (Welch et al. 1998).

Data and methods

The data analyzed were collected monthly at one site between 2005 and 2011 by Inventory & Monitoring staff (Pieper et al. 2012) (Figure 4.17, Table 4.10, Table A-2). NCRN followed the sampling protocol specified in Norris et al. 2011.

The acid neutralizing capacity (ANC) threshold was developed by the Maryland Biological Stream Survey (MBSS) program after their first round of sampling (1995–1997). The MBSS data were used to detect stream degradation so as to identify streams in need of restoration and to identify 'impaired waters' candidates (Southerland et al. 2007). A total of 539 streams that received a fish or benthic index of biotic integrity (FIBI or BIBI) rating of poor (2) or very poor (1) were pooled and field observations and site-specific water chemistry data were used to determine stressors likely causing degradation.

The resulting ANC threshold linked to degraded streams was values less than 200 μeq/L, which was used as the threshold in this assessment (where 1 mg/L [1 ppm] $CaCO_3$ = 20 μeq/L) (Southerland et al. 2007, Norris and Sanders 2009) (Table 4.11). A less conservative threshold of 50 μeq/L has also been suggested by some authors (Hendricks and Little 2003, Schindler 1988). Each data point was compared against the reference condition and assigned a pass or fail result. The percentage of passing results was used as the percent attainment and translated to a condition assessment (Table 4.12a).

Condition and trend

Condition of ANC in HAFE was very good, with a median ANC of 4,820 μeq/L and 100% of data points attaining the reference condition of ≥ 200 μeq/L between 2005 and 2011 (Figure 4.21, Table 4.13). Over the data range available, no significant trend was present (p-value > 0.01) (Figure 4.21).

Sources of expertise

James Pieper, Hydrologic Technician, National Capital Region Network Inventory & Monitoring Program, National Park Service.

Literature cited

Hendricks, J. and J. Little 2003. Thresholds for regional vulnerability analysis. Regional vulnerability assessment program. National exposure research laboratory. U.S. EPA (E243-05). Accessed April 9, 2013. *http://www.epa.gov/reva/docs/final_stressor_threshold_table.pdf*

Norris M.E. & G. Sanders. 2009. National Capital Region Network biological stream survey protocol: physical habitat, fish, and aquatic macroinvertebrate vital signs. Natural Resources Report NPS/NCRN/NRR—2009/116. National Park Service, Fort Collins, CO.

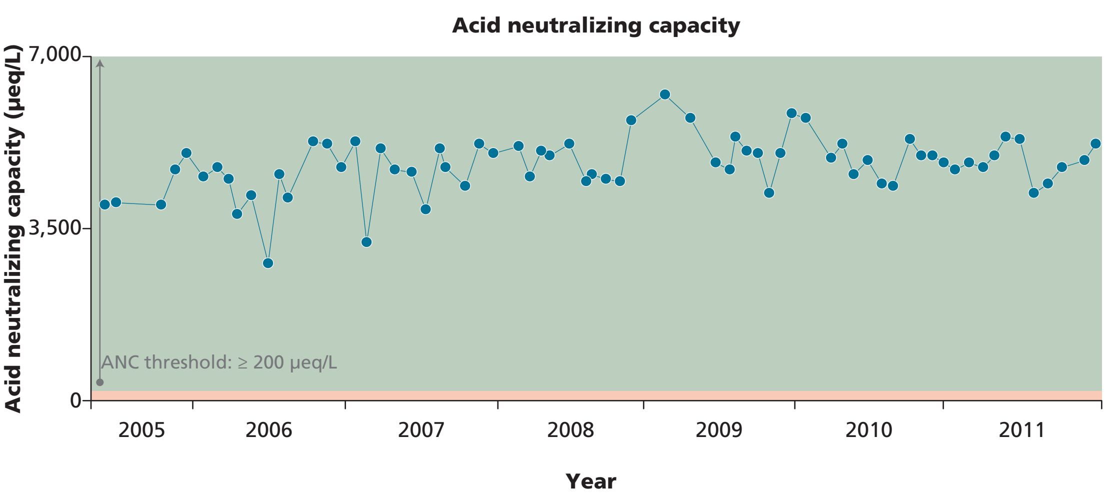


Figure 4.21. Acid neutralizing capacity (μeq/L) from 2005 to 2011 for one stream sampling location in HAFE. Reference condition (ANC ≥ 200 μeq/L) is shown in gray.

Norris, M.E., J.M. Pieper, T.M. Watts, and A. Cattani. 2011. National Capital Region Network Inventory and Monitoring Program water chemistry and quantity monitoring protocol version 2.0: Water chemistry, nutrient dynamics, and surface water dynamics vital signs. Natural Resource Report NPS/NCRN/NRR—2011/423. National Park Service, Fort Collins, CO.

Pieper, J., M. Norris, and T. Watts. 2012. National Capital Region Network FY 2010 water resources monitoring data report. Natural Resources Data Series NPS/NCRN/NRDS—2012/381. Natural Resources Program Center, Fort Collins, CO.

Schindler, D.W. 1988. Effects of acid rain on fresh water ecosystems. Science 239: 149–157.

Southerland, M.T., G.M. Rogers, M.J. Kline, R.P. Morgan, D.M. Boward, P.F. Kazyak, R.J. Klauda, and S.A. Stranko. 2007. Improving biological indicators to better assess the condition of streams. Ecological Indicators 7: 751–767.

Welch, E.B., J.M. Jacoby, and C.W. May. 1998. Stream quality. In: Naiman R.J. and R.E. Bilby (eds). River ecology and management: lessons from the Pacific coastal ecoregion. Springer-Verlag, New York, NY.

4.2.6 Specific conductance

Description

Salinity is a measurement of the mass of dissolved salt in a given body of water. Salinity is an important property of industrial and natural waters. Collectively, all substances in solution exert osmotic pressure on the organisms living in it, which in turn adapt to the condition imposed upon the water by its dissolved constituents. With excessive salts in solution, osmotic pressure becomes so high that water may be drawn from gills and other delicate external organs resulting in cell damage or death of the organism (USGS 1980, Stednick and Gilbert 1998, NPS 2002).

Electrical conductivity is related to salinity and is a measure of water's ability to conduct electricity, and therefore a measure of the water's ionic activity and content. The higher the concentration of ionic (dissolved) constituents, the higher the conductivity (Radtke et al. 1998). As conductivity changes with temperature, conductivity can be normalized to a temperature of 25° C and reported as specific conductance to enable comparisons.

Common sources of pollution that can affect specific conductance are deicing salts, dust-reducing compounds, agriculture (primarily from the liming of fields), and acid mine drainage associated with mining operations (USGS 1980, Stednick and Gilbert 1998, NPS 2002). Deicing compounds alone are significantly elevating the specific conductance of some streams in the northeast during winter periods (Kaushal et al. 2005, Allan and Castillo 2007).

Data and methods

The data analyzed were collected monthly between 2005 and 2011 at one site by National Capital Region Network (NCRN) Inventory & Monitoring (I&M) staff (Pieper et al. 2012) (Figure 4.17, Table 4.10, Table A-2). NCRN followed the sampling protocol specified in Norris et al. 2011.

The reference condition for specific conductance was ≤ 500 µS/cm, above which conditions are said to be degraded (Buchanan et al. 2011) (Table 4.11). Each data point was compared against the reference condition and assigned a pass or fail result. The percentage of passing results was used as the percent attainment and translated to a condition assessment (Table 4.12a).

Condition and trends

Condition of specific conductance in HAFE was very degraded, with a median conductance of 660 µS/cm and 2.9% of data points attaining the reference condition of ≤ 500 µS/cm between 2005 and 2011 (Figure 4.22, Table 4.13). Over the data range available, no significant trend was present (p-value > 0.01) (Figure 4.22).

Sources of expertise

James Pieper, Hydrologic Technician, National Capital Region Network Inventory & Monitoring Program, National Park Service.

Literature cited

Allan, J.D. and M.M. Castillo. 2007. Stream ecology: structure and function of running waters. Springer, Dordrecht, The Netherlands.

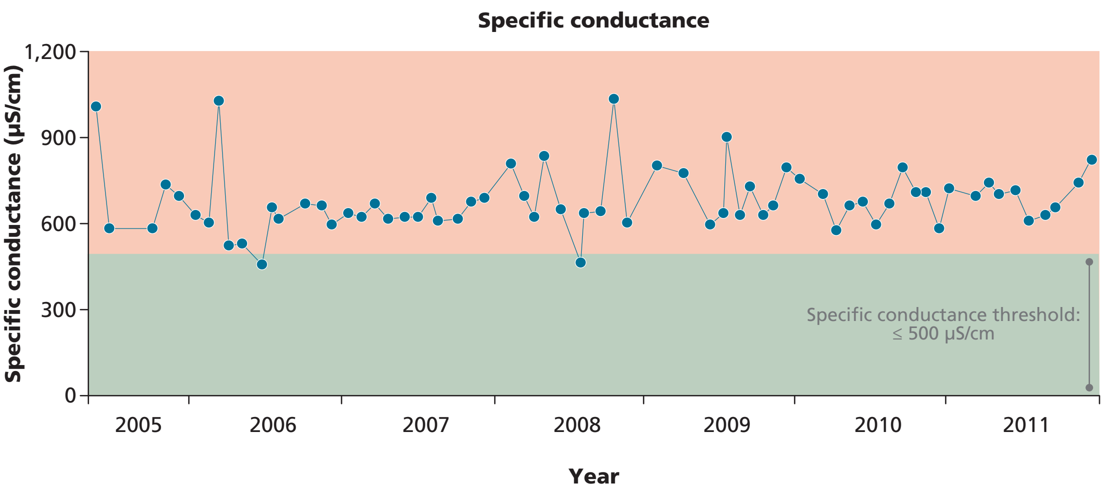


Figure 4.22. Specific conductance (µS/cm) from 2005 to 2011 for one stream sampling location in HAFE. Reference condition (specific conductance ≤ 500 µS/cm) is shown in gray.

Buchanan, C., K. Foreman, J. Johnson, and A. Griggs. 2011. Development of a basin-wide Benthic Index of Biotic Integrity for non-tidal streams and wadeable rivers in the Chesapeake Bay watershed: Final report to the Chesapeake Bay Program Non-Tidal Water Quality Workgroup. ICPRB Report 11-1. Report prepared for the U.S. Environmental Protection Agency, Chesapeake Bay Program.

Kaushal, S.S., P.M. Groffman, G.E. Likens, K.T. Belt, W.P. Stack, V.R. Kelly, L.E. Band, and G.T. Fisher. 2005. Increased salinization of fresh water in the northeastern United States. Proceedings of the National Academy of Sciences of the United States of America 102: 13517.

Norris, M.E., J.M. Pieper, T.M. Watts, and A. Cattani. 2011. National Capital Region Network Inventory and Monitoring Program water chemistry and quantity monitoring protocol version 2.0: Water chemistry, nutrient dynamics, and surface water dynamics vital signs. Natural Resource Report NPS/NCRN/NRR—2011/423. National Park Service, Fort Collins, CO.

Pieper, J., M. Norris, and T. Watts. 2012. National Capital Region Network FY 2010 water resources monitoring data report. Natural Resources Data Series NPS/NCRN/NRDS—2012/381. Natural Resources Program Center, Fort Collins, CO.

NPS 2002. Draft recommendations for core water quality monitoring parameters and other key elements of the NPS Vital Signs Program water quality monitoring component, Freshwater Workgroup Subcommittee, June 14, 2002. National Park Service, Water Resources Division, Fort Collins, CO.

Radtke, D.B., Davis, J.V., and Wilde, F.D, 1998, Specific electrical conductivity. In: Wilde, F.D., and D.B. Radtke (eds.). 1998. Field measurements, in national field manual for the collection of water-quality data: U.S. Geological Survey Techniques of Water-Resources Investigations, book 9, chap. A6.3, 22 p.

Stednick, J.D. and D.M. Gilbert. 1998. Water quality inventory protocol: riverine environments. NPS/NRWRD/NRTR—98/177, National Park Service, Servicewide Inventory and Monitoring Program, Fort Collins, CO.

USGS (United States Geological Survey). 1980. Surfacewater. National handbook of recommended methods for water-data acquisition. U.S. Geological Survey.

4.2.7 Nitrate

Description

Nitrate (NO_3) is a form of nitrogen which aquatic plants can absorb and incorporate into proteins, amino acids, nucleic acids, and other essential molecules. Nitrate is highly mobile in surface and groundwater and may seep into streams, lakes, and estuaries from groundwater enriched by animal or human wastes, commercial fertilizers, and air pollution. High concentrations of nitrate can enhance the growth of algae and aquatic plants in a manner similar to enrichment in phosphorus and thus cause eutrophication of a water body. Nitrate is typically indicative of agricultural pollution. Nitrate in surface water may occur in dissolved or particulate form resulting from inorganic sources. The dissolved, inorganic forms of nitrogen are most available for biological uptake and chemical transformation. Nitrate also travels freely through soil and therefore may pollute groundwater (USGS 2013).

Data and methods

The data analyzed were collected monthly between 2005 and 2011 at one site by National Capital Region Network (NCRN) Inventory & Monitoring (I&M) staff (Pieper et al. 2012) (Figure 4.17, Table 4.10, Table A-2). NCRN followed the sampling protocol specified in Norris et al. 2011.

It should be noted that the current methodology for measuring nitrate has been in use since July 2007. During the month of July 2007, a different method was used after an equipment malfunction. A third method was utilized prior to July 2007 (Norris and Pieper 2010).

The nitrate concentration threshold was developed by the Maryland Biological Stream Survey (MBSS) program after their first round of sampling as described for the ANC threshold. The MBSS determined that a nitrate concentration of 2 mg NO_3/L (2 ppm) and above indicated stream degradation (Southerland et al. 2007, Norris and Sanders 2009), so this was used as the reference condition in this assessment (Table 4.11). Each data point was compared against the reference condition and assigned a pass or fail result. The percentage of passing results was used as the percent attainment and translated to a condition assessment (Table 4.12a).

Condition and trend

Condition of nitrate in HAFE was very degraded, with a median nitrate concentration of 4.1 mg/L and 7.2% of data points attaining the reference condition of 2 mg/L between 2005 and 2011 (Figure 4.23, Table 4.13). Over the data range available, no significant trend was present (p-value > 0.01) (Figure 4.23).

Sources of expertise

James Pieper, Hydrologic Technician, National Capital Region Network Inventory & Monitoring Program, National Park Service.

Literature cited

Norris, M.E. and J. Pieper. 2010. National Capital Region Network 2007–2008 water resources monitoring data report. Natu-

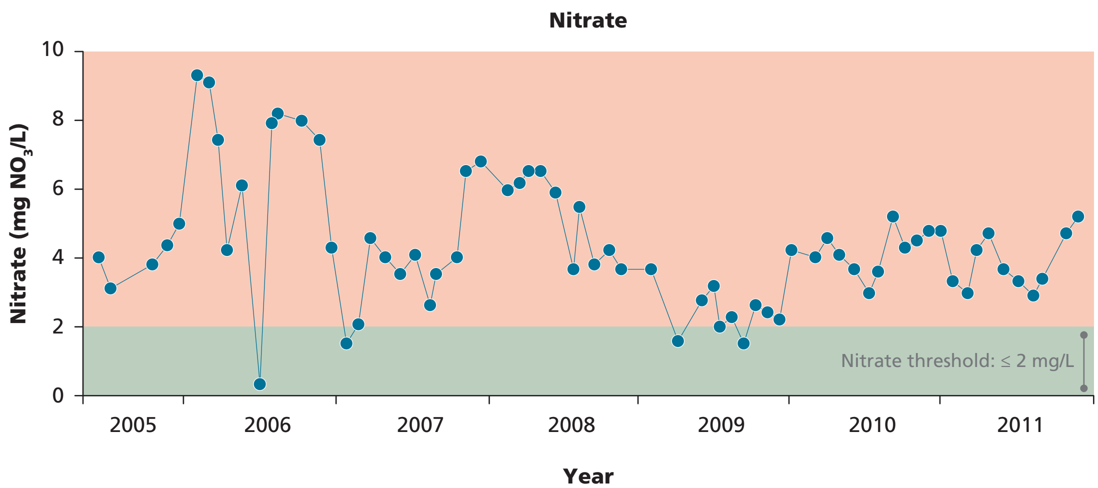


Figure 4.23. Nitrate concentrations (mg NO_3/L) from 2005 to 2011 for one stream sampling location in HAFE. Reference condition ($NO_3 \leq 2.0$ mg/L) is shown in gray.

ral Resource Data Series NPS/NCR/NCRN/NRDS—2010/105.

Norris M.E. & G. Sanders. 2009. National Capital Region Network biological stream survey protocol: physical habitat, fish, and aquatic macroinvertebrate vital signs. Natural Resources Report NPS/NCRN/NRR—2009/116. National Park Service, Fort Collins, CO.

Norris, M.E., J.M. Pieper, T.M. Watts, and A. Cattani. 2011. National Capital Region Network Inventory and Monitoring Program water chemistry and quantity monitoring protocol version 2.0: Water chemistry, nutrient dynamics, and surface water dynamics vital signs. Natural Resource Report NPS/NCRN/NRR—2011/423. National Park Service, Fort Collins, CO.

Pieper, J., M. Norris, and T. Watts. 2012. National Capital Region Network FY 2010 water resources monitoring data report. Natural Resources Data Series NPS/NCRN/NRDS—2012/381. Natural Resources Program Center, Fort Collins, CO.

Southerland, M.T., G.M. Rogers, M.J. Kline, R.P. Morgan, D.M. Boward, P.F. Kazyak, R.J. Klauda, and S.A. Stranko. 2007. Improving biological indicators to better assess the condition of streams. Ecological Indicators 7: 751–767.

USGS (United States Geological Survey). 2013. Urbanization/water quality: Nitrogen. Accessed April 24, 2013. *http://ga.water.usgs.gov/edu/nitrogen.html*

4.2.8 Total phosphorus

Description

Phosphorus is an essential nutrient for plants to live and is frequently the limiting nutrient for plant growth in aquatic systems. Consequently, a minor increase in phosphorus concentration can significantly affect water quality by stimulating algal growth, leading to eutrophication (Allan 1995). The most common form of phosphorus pollution is in the form of phosphate (PO_4). Sources of phosphate pollution include sewage, septic tank leachate, fertilizer runoff, soil erosion, animal waste, and industrial discharge.

Data and methods

The data analyzed were collected monthly between 2007 and 2011 at one site by National Capital Region Network (NCRN) Inventory & Monitoring (I&M) staff (Pieper et al. 2012 (Figure 4.17, Table 4.10, Table A-2). NCRN followed the sampling protocol specified in Norris et al. 2011.

The total phosphorus threshold is based on the U.S. EPA Ecoregional Nutrient Criteria. These criteria were developed to prevent eutrophication nationwide and are not regulatory (U.S. EPA 2000). The criteria were developed as baselines for specific geographic regions known as Ecoregions, which are classified based on multiple geographic characteristics such as soils, climate, vegetation, geology, and land use—all of which affect the natural concentrations of nutrients found in streams. Reference sites in each Ecoregion were identified to calculate nutrient criteria. HAFE is located in Ecoregion XI or the Central and Eastern Forested Uplands region (U.S. EPA 2000). The ecoregional reference condition value for total phosphorus is 0.010 mg P/L (10 ppb) (U.S. EPA 2000) (Table 4.11). Each data point was compared against the reference condition and assigned a pass or fail result. The percentage of passing results was used as the percent attainment and translated to a condition assessment (Table 4.12).

Condition and trend

Condition of total phosphorus at HAFE was very poor, with a median total phosphorus concentration of 0.14 mg/L and 0% of data points attaining the reference condition of 0.01 mg/L between 2007 and 2011 (Figure 4.24, Table 4.13).Over the data range available, no significant trend was present (*p*-value > 0.01) (Figure 4.24).

Sources of expertise

James Pieper, Hydrologic Technician, National Capital Region Network Inventory & Monitoring Program, National Park Service.

Literature cited

Allan, J. D. 1995. Stream ecology: structure and function of running waters. Chapman and Hall, New York, NY.

Norris, M.E., J.M. Pieper, T.M. Watts, and A. Cattani. 2011. National Capital Region Network Inventory and Monitoring Program water chemistry and quantity monitoring protocol version 2.0: Water chemistry, nutrient dynamics, and surface water dynamics vital signs. Natural Resource Report NPS/NCRN/NRR—2011/423. National Park Service, Fort Collins, CO.

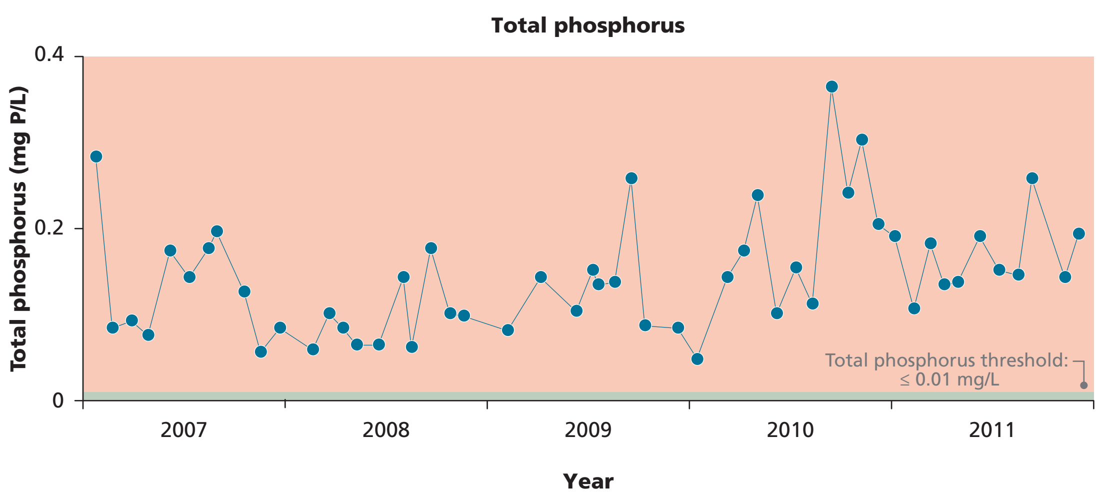


Figure 4.24. Phosphorus concentrations (mg P/L) from 2007 to 2011 for one stream sampling location in HAFE. Reference condition (TP ≤ 0.031 mg/L) is shown in gray.

Pieper, J., M. Norris, and T. Watts. 2012. National Capital Region Network FY 2010 water resources monitoring data report. Natural Resources Data Series NPS/NCRN/NRDS—2012/381. Natural Resources Program Center, Fort Collins, CO.

U.S. EPA. 2000. Ambient water quality criteria recommendations—rivers and streams in Nutrient Ecoregion XI. EPA 822-B-00-020. United States Environmental Protection Agency, Washington DC.

4.2.9 Stream macroinvertebrates

Description

The State of Maryland uses biological indicators of stream condition to assess status and trends in biological integrity for all 9,400 non-tidal stream miles in Maryland (Southerland et al. 2007). The Benthic Index of Biotic Integrity (BIBI) is one multimetric index monitored by the Maryland Department of Natural Resources' Maryland Biological Stream Survey (MBSS). BIBI is an indicator of the health of the benthic macroinvertebrate communities in a stream.

Data and methods

Data were collected at four sites in 2004 (Figure 4.17, Table 4.10). These sites were sampled as part of the effort to develop the National Capital Region Biological Stream Survey protocol (Norris and Sanders 2009). The protocol is based on the MBSS. Twenty-three standard operating procedures (SOPs) document the methods used to collected the relevant data. Reported data are for one BIBI assessment per site.

The reference conditions are based on the MBSS interpretation of the BIBI. The BIBI scores range from 1 to 5 and are calculated by comparing the site's benthic assemblage to the assemblage found at minimally impacted sites (Norris and Sanders 2009). A score of 3 indicates that a site is considered to be comparable to (i.e., not significantly different from) reference sites. A score greater than 3 indicates that a site is in better condition than the reference sites. Any sites with BIBIs less than 3 are in worse condition than reference sites (Southerland et al. 2007, Norris and Sanders 2009). BIBI values were ranked as follows: 1.0–1.9 (very poor), 2.0–2.9 (poor), 3.0–3.9 (fair), 4.0–5.0 (good), and these were the scale and categories used in this assessment (Southerland et al. 2007).

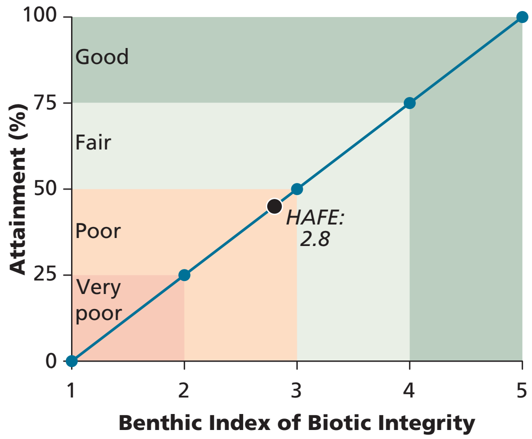


Figure 4.25. Application of the percent attainment categories to the Benthic Index of Biotic Integrity (BIBI) categories. BIBI at HAFE was 2.8 which equated to 45% attainment of the reference condition.

Table 4.14. Benthic Index of Biotic Integrity (BIBI) categories, percent attainment, and condition assessment.

BIBI range	% attainment	Condition
4.0–5.0	100%	Good
3.0–3.9	↑ scaled linearly ↓	Fair
2.0–2.9		Poor
1.0–1.9	0%	Very poor

Table 4.15. Benthic Index of Biotic Integrity (BIBI) in HAFE. Monitoring sites are shown in Figure 4.17.

Year	Site	Location	BIBI
2004	HARP-103-N-2004	Flowing Springs Run	2.56†
2004	HARP-301-N-2004	Elks Run	3.00†
2004	HARP-302-N-2004	Elks Run	2.56†
2004	NCRW-110-N-2004	Flowing Springs Run	3.00†

† Values calculated using old formula and may be different from scores on file with the State of Maryland.

The range of BIBI scores from 1 to 5 were scaled linearly from 0 to 100% attainment (Figure 4.25, Table 4.14). The median of all the data points was compared to these reference conditions and given a percent attainment and converted to a condition assessment (Tables 4.11, 4.12b).

Condition and trend

Current condition of benthic macroinvertebrates in HAFE was poor, with a median BIBI of 2.8 and 45% attainment of reference condition (Figure 4.26, Tables 4.13, 4.15).

In addition to the data collection and analysis done by MBSS, several other agencies collect macroinvertebrate data within the Chesapeake Bay watershed. These disparate data sources have been included in a new Chesapeake Bay basin-wide BIBI ('Chessie BIBI') analysis method (Buchanan et al. 2011). When this method was applied to the 2004 data collected

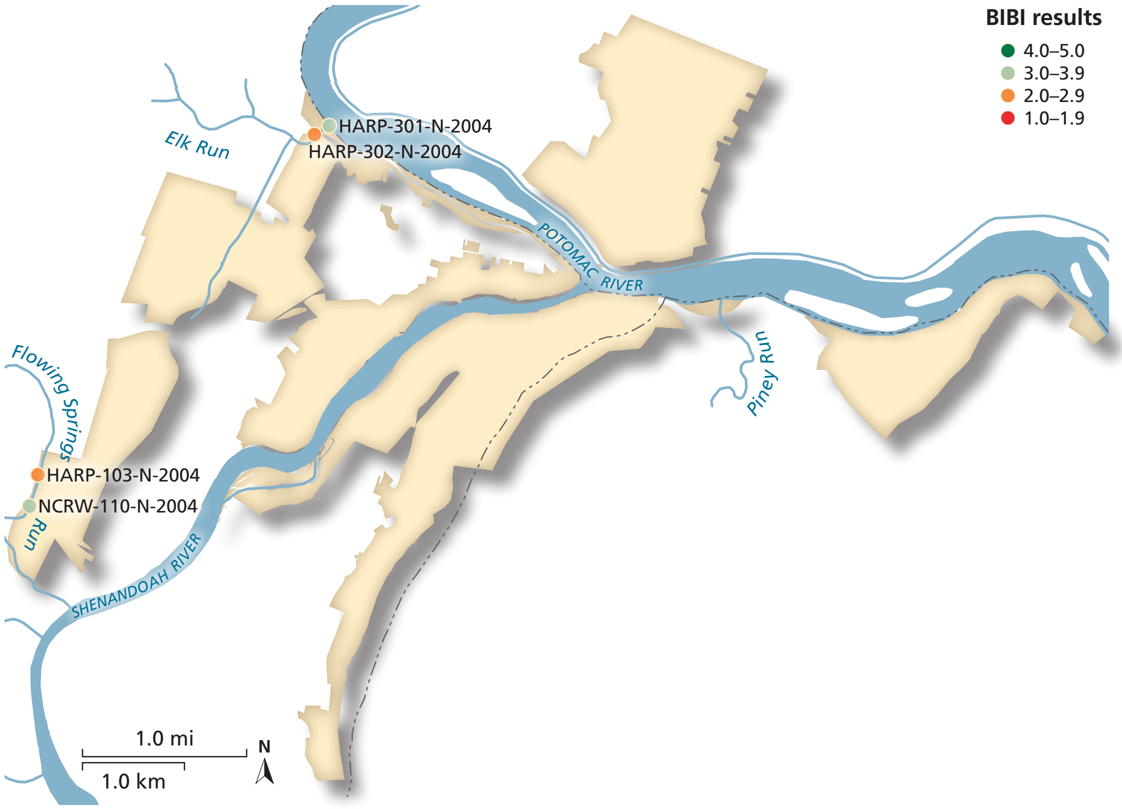


Figure 4.26. Benthic Index of Biotic Integrity (BIBI) results by site for HAFE.

at sites within HAFE, the overall attainment was 16% with a very poor condition assessment.

No trend analysis was possible with the current data set.

Sources of expertise

James Pieper, Hydrologic Technician, National Capital Region Network Inventory & Monitoring Program, National Park Service.

Literature cited

Norris, M.E. & G. Sanders. 2009. National Capital Region Network biological stream survey protocol: physical habitat, fish, and aquatic macroinvertebrate vital signs. Natural Resource Report. NPS/NCRN/NRR—2009/116. National Park Service, Fort Collins, CO.

Southerland, M.T., G.M. Rogers, M.J. Kline, R.P. Morgan, D.M. Boward, P.F. Kazyak, R.J. Klauda, and S.A. Stranko. 2007. Improving biological indicators to better assess the condition of streams. Ecological Indicators 7: 751–767.

4.2.10 Physical habitat

Description

Physical habitat is an integral part of overall stream condition. Components of physical habitat include the diversity of flow conditions, the diversity and stability of substrates, the degree and extent of erosion, the amount of woody debris, and many other factors. These physical factors affect the biological potential of streams by providing the physical template upon which stream biological community structure is built (Paul et al. 2002).

Data and methods

Data for the Physical Habitat Index (PHI) were collected at four sites between 2006 and 2010 (Figure 4.17, Table 4.10). NCRN followed the National Capital Region Biological Stream Survey protocol (Norris and Sanders 2009). Habitat assessments are determined based on data from numerous metrics such as riffle quality, stream bank stability, woody debris, quality of streambed substrates, shading, and many more. Sites are given scores for each of the applicable categories and then those scores are adjusted to a percentile scale (Norris and Sanders 2009). Reported data are for one PHI assessment per site.

The PHI threshold was developed by the Maryland Biological Stream Survey (MBSS) program after initial sampling as described for the ANC threshold. The MBSS determined the scale for PHI values to be 0–50 (severely degraded), 51–65 (degraded), 66–80 (partially degraded), and 81–100 (minimally degraded), and these were the scale and categories used in this assessment (Paul et al. 2002, Southerland et al. 2005). Each of the four PHI value categories were assigned a percent attainment range (Figure 4.27, Table 4.16). The median of all the data points was compared to these reference conditions and given a percent attainment and converted to a condition assessment (Tables 4.11, 4.12b).

Condition and trend

Current condition of PHI in HAFE was partially degraded, with a mean PHI of 75 which equated to 67% attainment of reference condition (Figure 4.28, Tables 4.13, 4.17). No trend analysis was possible with the current data set.

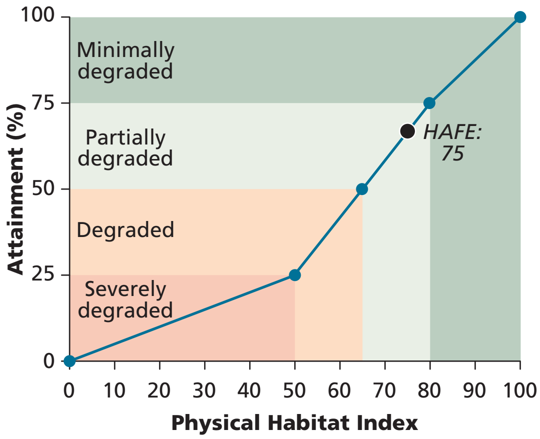


Figure 4.27. Application of the percent attainment categories to the Physical Habitat Index (PHI) value categories. PHI at HAFE was 75 which equated to 67% attainment of the reference condition.

Table 4.16. Physical Habitat Index (PHI) categories, percent attainment, and condition assessment.

PHI range	% attainment	Condition
81–100	75–100%	Minimally degraded
66–80	50–75%	Partially degraded
51–65	25–50%	Degraded
0–50	0–25%	Severely degraded

Table 4.17. Physical Habitat Index (PHI) in HAFE. Monitoring sites are shown in Figure 4.17.

Year	Site	Location	PHI
2004	HARP-103-N-2004	Flowing Springs Run	87.4
2004	HARP-301-N-2004	Elks Run	65.9
2004	HARP-302-N-2004	Elks Run	69.6
2004	NCRW-110-N-2004	Flowing Springs Run	81.3

Sources of expertise

James Pieper, Hydrologic Technician, National Capital Region Network Inventory & Monitoring Program, National Park Service.

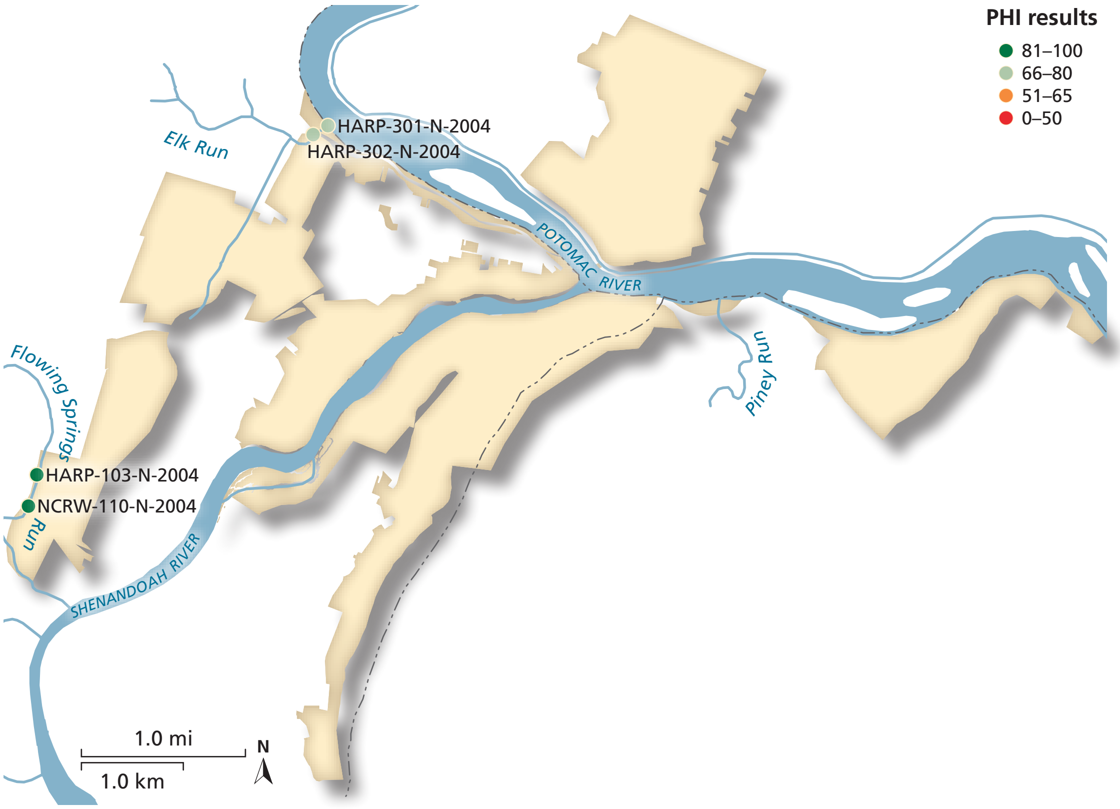
Literature cited

Norris, M.E. & G. Sanders. 2009. National Capital Region Network biological stream survey protocol: physical habitat, fish, and aquatic macroinvertebrate vital signs. Natural Resource Report. NPS/NCRN/NRR—2009/116. National Park Service, Fort Collins, CO.

Paul, M.J., J.B. Stribling, R. Klauda, P. Kazyak, M. Southerland, and N. Roth. 2003. A Physical Habitat Index for freshwater wadeable streams in Maryland. Report to the Maryland Department of Natural Resources, Annapolis, MD.

Southerland, M.T., L.A Erb, G.M. Rogers and P.F. Kazyak. 2005. Maryland Biological Stream Survey 2000–2004. Volume 7: Statewide and tributary basin results. Prepared for Maryland Department of Natural Resources.

Figure 4.28. Physical Habitat Index (PHI) results by site for HAFE.



4.3 BIOLOGICAL INTEGRITY

4.3.1 Biological integrity summary

Seven metrics were used to assess biological integrity in HAFE—exotic herbaceous species, exotic trees and saplings, forest pest species, native tree seedling regeneration, fish index of biotic integrity (FIBI), bird community index (BCI), and deer density (Table 4.18). All data were collected by National Capital Region Network (NCRN) Inventory & Monitoring (I&M) staff except deer density which was collected by park staff. FIBI monitoring sites are shown in Figure 4.17, forest monitoring sites are shown in Figure 4.29, bird community index sites are shown in Figure 4.30, and deer monitoring sites are shown in Figure 4.31.

Reference conditions were established for each metric (Table 4.19) and the data were compared to these reference conditions to obtain the percent attainment and converted to the condition assessment for that metric (Table 4.20). Single reference conditions were used for exotic plants, forest pests, native tree seedling regeneration, and deer density, while multiple reference conditions were used for FIBI and BCI (Tables 4.19, 4.20).

HAFE had variable results for biological integrity. The park scored as very good condition for area of exotic trees and saplings (90% attainment) and good condition for forest pests (62% attainment), while BCI scored as medium integrity (50% attainment). The remaining metrics scored as degraded/poor (FIBI with 36% attainment and absence of exotic herbaceous species with 29% attainment) or very degraded (seedling stocking index and deer density, both with 0% attainment) (Table 4.21). This resulted in an overall biological integrity condition attainment of 37%, or degraded condition.

Literature cited

Bates, S.E. 2009. National Capital Region Network 2008 deer monitoring report. Natu-

Table 4.18. Ecological monitoring framework data for Biological Integrity provided by agencies and specific sources included in the assessment of HAFE.

Metric	Agency	Reference/Source
Cover of exotic herbaceous species	NCRN I&M	Schmit et al. 2009, 2010
Area of exotic trees & saplings	NCRN I&M	Schmit et al. 2009, 2010
Presence of forest pest species	NCRN I&M	Schmit et al. 2009, 2010
Seedling stocking index	NCRN I&M	Schmit et al. 2009, 2010
Fish index of biotic integrity	NCRN I&M, MBSS	Norris and Sanders 2009, MBSS
Bird community index	NCRN I&M	O'Connell et al. 1998
Deer density	NCRN I&M	Bates 2009

Table 4.19. Biological Integrity reference conditions for HAFE.

Metric	Reference condition/s	Sites	Samples	Period
Presence of exotic herbaceous species (% of plots with exotic species)	0% (absence)	21	21	2006–2010
Area of exotic trees & saplings (% of basal area)	< 5%	21	40	2006–2010
Presence of forest pest species (% of trees infested)	< 1%	21	21	2006–2010
Seedling stocking index	> 115	20	20	2007–2010
Fish index of biotic integrity	1.0–1.9; 2.0–2.9; 3.0–3.9; 4.0–5.0	4	4	2004
Bird community index	< 40; 40.1–52; 52.1–60; > 60	20	20	2007–2011
Deer density (deer/km^2)	< 8	Park	7	2001–2008

ral Resource Technical Report NPS/NCRN/NRTR—2009/275. National Park Service, Fort Collins, CO.
Norris, M.E. & G. Sanders. 2009. National Capital Region Network biological stream survey protocol: physical habitat, fish, and aquatic macroinvertebrate vital signs. Natural Resource Report. NPS/NCRN/NRR—2009/116. National Park Service, Fort Collins, CO.
O'Connell, T.J., L.E. Jackson, and R.P. Brooks. 1998. A Bird Community Index of Biotic Integrity for the Mid-Atlantic Highlands. Environmental Monitoring and Assessment 51: 145–156.
Schmit, J.P., G. Sanders, M. Lehman, and T. Paradis. 2009. National Capital Region Network long-term forest monitoring protocol. Version 2.0. Natural Resource Report NPS/NCRN/NRR—2009/113. National Park Service, Fort Collins, CO.
Schmit, J.P., P. Campbell, and J. Parrish. 2010. National Capital Region Network 2009 forest vegetation monitoring report. Natural Resource Data Series NPS/NCRN/NRDS—2010/043. National Park Service, Fort Collins, CO.

Table 4.20a. Categorical ranking of reference condition attainment categories for exotic plants, forest pests, native tree seedling regeneration, and deer density.

Attainment of reference condition	Natural resource condition
80–100%	Very good
60–<80%	Good
40–<60%	Moderate
20–<40%	Degraded
0–<20%	Very degraded

Table 4.20b. Categorical ranking of the reference condition attainment categories for the Fish Index of Biotic Integrity and the Bird Community Index.

Reference conditions	Attainment of reference condition	Natural resource condition
Fish Index of Biotic Integrity (FIBI)		
4.0–5.0	100%	Good
3.0–3.9	↑ scaled	Fair
2.0–2.9	linearly ↓	Poor
1.0–1.9	0%	Very poor

Reference conditions	Attainment of reference condition	Natural resource condition
Bird Community Index (BCI)		
60.1–77	75–100% (scaled)	Highest integrity
52.1–60	50–75% (scaled)	High integrity
40.1–52	25–50% (scaled)	Medium integrity
20–40	0–25% (scaled)	Low integrity

Table 4.21. Summary of resource condition assessment of Biological Integrity in HAFE.

Metric	Result	Reference condition	% attainment	Condition	Biological integrity condition
Presence of exotic herbaceous species (% of plots with exotic species)	71%	0% (absence)	29	Degraded	**37%** **Degraded**
Area of exotic trees & saplings (% of basal area)	0%	< 5%	90	Very good	
Presence of forest pest species (% of trees infested)	0%	< 1%	62	Good	
Seedling stocking index	11	> 115	0	Very degraded	
Fish index of biotic integrity	2.4	1.0–1.9; 2.0–2.9; 3.0–3.9; 4.0–5.0	36	Poor	
Bird community index	48.5	< 40; 40.1–52; 52.1–60; > 60	43	Medium integrity	
Deer density (deer/km^2)	32	< 8	0	Very degraded	

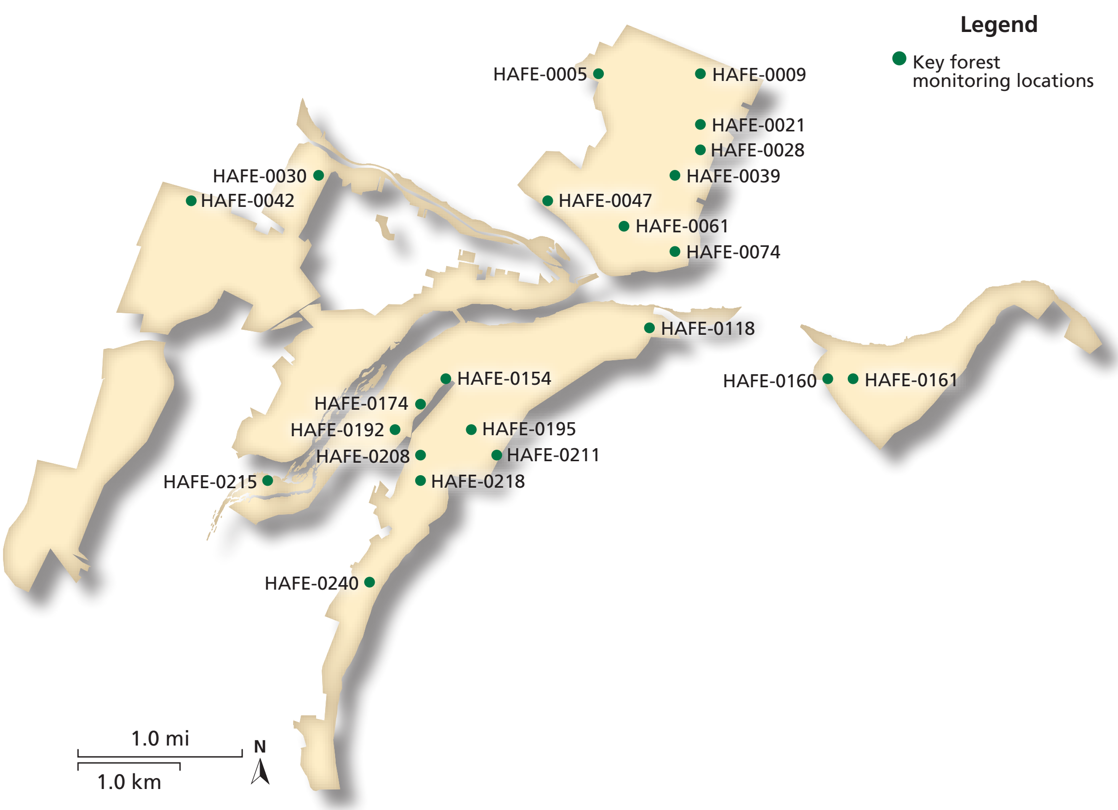


Figure 4.29. Forest monitoring sites in HAFE.

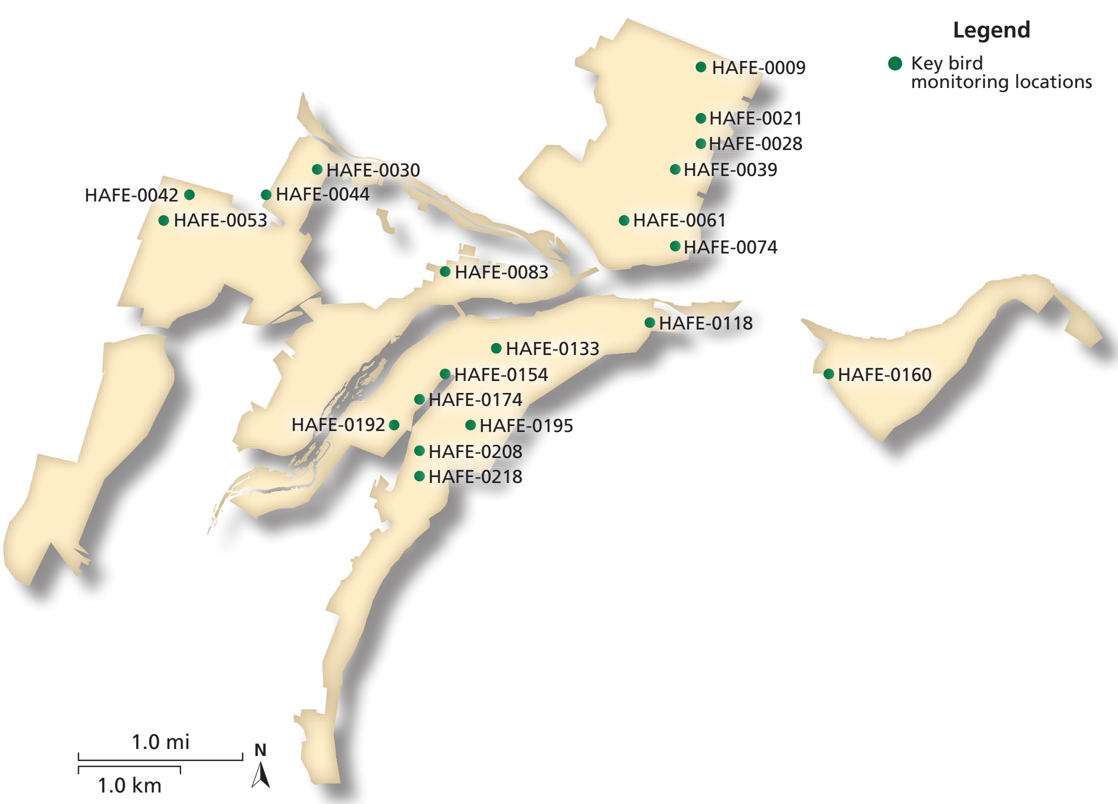


Figure 4.30. Bird monitoring sites in HAFE.

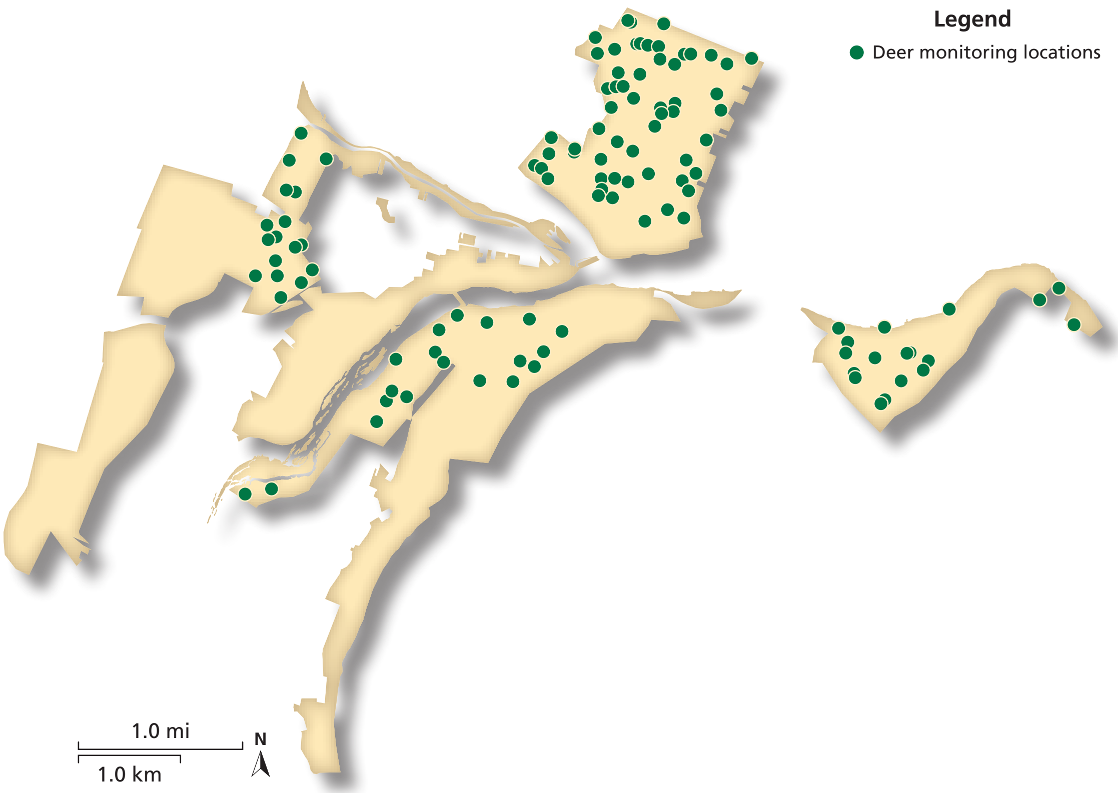


Figure 4.31. Deer pellet monitoring sites in HAFE.

4.3.2 Exotic herbaceous species

Description

Invasive exotic plants are non-native species that can reduce abundance and diversity of native plant communities (Vila et al. 2011). This can cause loss of forage and habitat for wildlife, reduced biodiversity, loss of forest productivity, changed groundwater levels, soil degradation, diminished recreational enjoyment, and economic harm (Mack et al. 2000). Although certain plant species were introduced in the United States for agriculture, erosion control (kudzu), or ornamental purposes (Japanese barberry, English ivy), many are now considered invasive threats. Exotic plant species, especially those that are invasive, are a widespread and growing threat in the National Capital Region.

Exotic herbaceous plants make up the majority of exotic plant species found in the forests of the National Capital Region, including HAFE, and so pose a serious problem to park management (Schmit et al. 2010). The most common exotic herbaceous species in HAFE forests are garlic mustard (*Alliaria petiolata*), Indian strawberry (*Duchesnea indica*), Japanese stiltgrass (*Microstegium vimineum*), Japanese honeysuckle (*Lonicera japonica*), Oriental ladysthumb (*Polygonum caespitosum*), and wineberry (*Rubus phoenicolasius*) (Schmit and Campbell 2007, 2008, Schmit et al. 2009a, 2010).

Data and methods

Forest monitoring took place annually but not all plots were measured every year (Schmit et al. 2009b) (Figure 4.29, Table 4.18). To minimize soil compaction and trampling of the understory, plots were sampled on a rotating panel design, with four panels. Each year one panel was sampled. Sampling took place from May through October, when foliage was fully developed.

Each plot was assigned as having exotic herbaceous plants either present or absent. Each plot was then given a rating of either pass (no exotic herbaceous plants present) or fail (any exotic herbaceous plants present). The percentage of passing results was used as the percent attainment.

The Organic Act that established the National Park Service in 1916 and the U.S. Department of Interior NPS Management Policies (U.S. Dept of Interior 2006) mandates the conservation of natural resources (see Section *2.1.1—Enabling legislation*). Because of the threat to the park posed by many exotic herbaceous plants, the threshold used for this assessment was that exotic herbaceous plants should be completely absent (Table 4.19). Each plot was compared against the reference condition to determine the percent attainment and condition (Table 4.20a).

Condition and trend

Current condition for cover of exotic herbaceous species in HAFE was degraded, with 71% of plots containing at least one exotic herbaceous plant. Therefore, only 29% of plots attained the reference condition of having no exotic herbaceous species present (Tables 4.21, 4.22).

No trend analysis was possible with the current data set.

Sources of expertise

John Paul Schmit, Quantitative Ecologist, Center for Urban Ecology, National Park Service.

Literature cited

Mack, R.N., D. Simberloff, W.M. Lonsdale, H. Evans, M. Clout, and F.A. Bazzaz. 2002. Biotic invasions: causes, epidemiology, global consequences, and control. Ecological Applications 10: 689–710.

Schmit, J.P. and P. Campbell. 2007. National Capital Region Network 2006 forest vegetation monitoring report. Natural Resource Report NPS/NCRN/NRTR—2007/046. National Park Service, Fort Collins, CO.

Schmit, J.P. and P. Campbell. 2008. National Capital Region Network 2007 forest vegetation monitoring report. Natural Resource Report NPS/NCRN/NRTR—2008/125. National Park Service, Fort Collins, CO.

Schmit, J.P., P. Campbell, and J. Parrish. 2009a. National Capital Region Network 2008 forest vegetation monitoring report. Natural Resource Report NPS/NCRN/NRTR—2009/181. National Park Service, Fort Collins, CO.

Schmit, J.P., G. Sanders, M. Lehman, and T. Paradis. 2009b. National Capital Region Network long-term forest monitoring protocol. Version 2.0. Natural Resource Report NPS/NCRN/NRR—2009/113. National Park Service, Fort Collins, CO.

Schmit, J.P., P. Campbell, and J. Parrish. 2010. National Capital Region Network 2009 forest

Table 4.22. Presence of exotic herbaceous plants. Site locations are shown in Figure 4.29.

Site	Year	Exotic plants
HAFE-0005	2009	Present*
HAFE-0009	2008	Present*
HAFE-0021	2008	Present*
HAFE-0028	2008	Present*
HAFE-0030	2010	Present*
HAFE-0039	2010	Absent
HAFE-0047	2009	Present*
HAFE-0061	2010	Present*
HAFE-0074	2010	Absent
HAFE-0118	2010	Present*
HAFE-0154	2010	Present*
HAFE-0160	2008	Present*
HAFE-0161	2009	Present*
HAFE-0174	2007	Present*
HAFE-0192	2007	Present*
HAFE-0195	2008	Absent
HAFE-0208	2008	Absent
HAFE-0211	2009	Present*
HAFE-0215	2010	Present*
HAFE-0218	2008	Absent
HAFE-0240	2009	Absent

* Values outside of reference condition of having no exotic herbaceous plants present.

vegetation monitoring report. Natural Resource Data Series NPS/NCRN/NRDS—2010/043. National Park Service, Fort Collins, CO.

U.S. Department of Interior. National Park Service. 2006. Management policies 2006.

Vila, M., J.L. Espinar, M. Hejda, P.E. Hulme, V. Jarosik, J.L. Maron, J. Pergl, U. Schaffner, Y. Sun, and P. Pysek. 2011. Ecological impacts of invasive alien plants: a meta-analysis of their effects on species, communities and ecosystems. Ecological Letters 14: 702–708.

4.3.3 Exotic trees & saplings

Description

Invasive exotic plants are non-native species that can reduce abundance and diversity of native plant communities (Vila et al. 2011). This can cause loss of forage and habitat for wildlife, reduced biodiversity, loss of forest productivity, changed groundwater levels, soil degradation, diminished recreational enjoyment, and economic harm (Mack et al. 2000). Exotic plant species, especially those that are invasive, are a ubiquitous and growing threat in the National Capital Region. The most common exotic tree and shrub species in HAFE forests are tree of heaven (*Ailanthus altissima*) and sweet cherry (*Prunus avium*) (Schmit and Campbell 2007, 2008, Schmit et al. 2009a, 2010).

Data and methods

Forest monitoring took place annually but not all plots were measured every year (Schmit et al. 2009b) (Figure 4.29, Table 4.18). To minimize soil compaction and trampling of the understory, plots were be sampled on a rotating panel design, with four panels. Each year one panel was sampled. Sampling took place from May through October, when foliage was fully developed.

The basal area of exotic trees and saplings in a plot was calculated as a percentage of total tree basal area. Results from each plot were assessed against the threshold and assigned a pass or fail result and the percentage of passing results was used as the percent attainment.

The threshold used for this assessment was that the abundance of these invasive exotic plants should not exceed 5% of total basal area of trees and saplings (Table 4.19). Because 100% eradication is not a realistic goal, the threshold is intended to suggest more than just simple presence of these exotic species but that the observed abundance has the potential to establish and spread, i.e., 5% basal area may be considered as the point where the exotic plants are becoming established rather than just present. The Organic Act that established the National Park Service in 1916 and the U.S. Department of Interior NPS Management Policies (U.S. Dept of Interior 2006) mandates the conservation of natural resources (see Section *2.1.1—Enabling legislation*). This threshold is a guide to consider active management of an area by removal of these species. Each data point was compared against the reference condition to determine the percent attainment and condition (Table 4.20a).

Condition and trend

Condition for basal cover of exotic trees and saplings in HAFE was very good, with a median of 0% of total basal area and 90% of plots attaining the reference condition of ≤ 5% of total basal area (Tables 4.21, 4.23).

No trend analysis was possible with the current data set.

Sources of expertise

John Paul Schmit, Quantitative Ecologist, Center for Urban Ecology, National Park Service.

Literature cited

Mack, R.N., D. Simberloff, W.M. Lonsdale, H. Evans, M. Clout, and F.A. Bazzaz. 2002. Biotic invasions: causes, epidemiology, global consequences, and control. Ecological Applications 10: 689–710.

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Schmit, J.P. and P. Campbell. 2008. National Capital Region Network 2007 forest vegetation monitoring report. Natural Resource Report NPS/NCRN/NRTR—2008/125. National Park Service, Fort Collins, CO.

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U.S. Department of Interior. National Park Service. 2006. Management policies 2006.

Vila, M., J.L. Espinar, M. Hejda, P.E. Hulme, V.

Table 4.23. Percent basal area of exotic trees and saplings. Site locations are shown in Figure 4.29.

Site	Year	Exotic trees	Exotic saplings
HAFE-0005	2009	0	0
HAFE-0009	2008	0	0
HAFE-0021	2008	0	0
HAFE-0028	2008	0	
HAFE-0030	2010	6.6*	0
HAFE-0039	2010	0	0
HAFE-0047	2009	0.5	0
HAFE-0061	2010	0	
HAFE-0074	2010	1.9	
HAFE-0118	2010	4.6	0
HAFE-0154	2010	0	0
HAFE-0160	2008	0	0
HAFE-0161	2009	8.5*	0
HAFE-0174	2007	6.8*	0
HAFE-0192	2007	0.6	0
HAFE-0195	2008	0	0
HAFE-0208	2008	1	21.4*
HAFE-0211	2009	1.3	0
HAFE-0215	2010	0	0
HAFE-0218	2008	0.5	0.9
HAFE-0240	2009	0	0

* Values outside of reference condition of ≤ 5% cover. Blank cells indicate that there were no saplings present in the plot.

Jarosik, J.L. Maron, J. Pergl, U. Schaffner, Y. Sun, and P. Pysek. 2011. Ecological impacts of invasive alien plants: a meta-analysis of their effects on species, communities and ecosystems. Ecological Letters 14: 702–708.

4.3.4 Forest pests

Description

Forests in HAFE have historically been impacted by pests such as the gypsy moth (*Lymantria dispar*), and diseases such as the chestnut blight and dogwood anthracnose.

The gypsy moth was accidentally introduced to North America in the late 1860s and has spread widely, resulting in an estimated 160,000 km^2 (62,500 mi^2) of forest defoliation during the 1980s alone (Liebhold et al. 1994, Montgomery 1990). The gypsy moth larvae feed on the foliage of hundreds of species of plants in North America, but its most common hosts are oak (*Quercus* spp.) and aspen (*Populus* spp.) trees (USDA Forest Service 2009a). Hemlock woolly adelgid (*Adelges tsugae*) is another insect pest first reported in the eastern United States in 1951 near Richmond, Virginia (USDA Forest Service 2009b). This aphid-like insect is originally from Asia and feeds on Eastern hemlock trees (*Tsuga canadensis*), which are often damaged and killed within a few years of becoming infested.

Data and methods

Forest monitoring took place annually but not all plots were measured every year (Schmit et al. 2009a) (Figure 4.29, Table 4.18). To minimize soil compaction and trampling of the understory, plots were be sampled on a rotating panel design, with four panels. Each year one panel was sampled. Sampling took place from May through October, when foliage was fully developed.

The percentage of trees infested was calculated by dividing the number of trees afflicted by pests in each plot by the total number of trees in each plot. Results from each plot were assessed against the threshold and assigned a pass or fail result. The percentage of plots passing was used as the percent attainment.

Due to the destructive nature and potential for forest damage from these pests, the threshold used was established as any observation of these pests (i.e., > 0% of trees infested) being considered degraded (Table 4.19). Each data point was compared against the reference condition to determine the percent attainment and condition (Table 4.20a).

Condition and trend

Current condition for forest pests in HAFE was good, with a median of 0% of trees infested and 62% of data points attaining the reference condition of having no forest pest species present (Tables 4.21, 4.24).

Gypsy moth was the only forest pest species detected and was found on trees in HAFE in plots monitored in 2006, 2008, and 2009 (Schmit and Campbell 2007, 2008, Schmit et al. 2009b, 2010).

At the time of this report, emerald ash borer was not detected in any of the monitoring plots but it was detected in the park during the summer of 2013 and it is expected that it will eventually be found in the monitoring plots.

No trend analysis was possible with the current data set.

Sources of expertise

John Paul Schmit, Quantitative Ecologist, Center for Urban Ecology, National Park Service.

Literature cited

Liebhold, A., K. Thorpe, J. Ghent, and D.B. Lyons. 1994. Gypsy moth egg mass sampling for decision-making: a user's guide. NA-TP-04-94. USDA Forest Service. Accessed April 9, 2013. *http://www.sandyliebhold.com/pubs/Liebhold_etal_1994_guide_color.pdf*

Montgomery, M.E. 1990. Predicting defoliation by the gypsy moth using egg mass counts and a helper variable. Proceedings U.S. Department of Agriculture Interagency Gypsy Moth Research Review. General Technical Report NE-146. USDA Forest Service.

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Schmit, J.P. and P. Campbell. 2008. National Capital Region Network 2007 forest vegetation monitoring report. Natural Resource Report NPS/NCRN/NRTR—2008/125. National Park Service, Fort Collins, CO.

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Table 4.24. Percent of trees with evidence of forest pest species. Site locations are shown in Figure 4.29.

Site	Year	% trees with pests
HAFE-0005	2009	0.00
HAFE-0009	2008	4.00*
HAFE-0021	2008	27.03*
HAFE-0028	2008	20.00*
HAFE-0030	2010	0.00
HAFE-0039	2010	17.24*
HAFE-0047	2009	0.00
HAFE-0061	2010	5.71*
HAFE-0074	2010	25.00*
HAFE-0118	2010	0.00
HAFE-0154	2010	0.00
HAFE-0160	2008	0.00
HAFE-0161	2009	0.00
HAFE-0174	2007	0.00
HAFE-0192	2007	0.00
HAFE-0195	2008	50.00*
HAFE-0208	2008	3.23*
HAFE-0211	2009	27.27*
HAFE-0215	2010	0.00
HAFE-0218	2008	0.00
HAFE-0240	2009	5.56*

* Values outside of reference condition of having no evidence of forest pests.

sion 2.0. Natural Resource Report NPS/NCRN/NRR—2009/113. National Park Service, Fort Collins, CO.

Schmit, J.P., P. Campbell, and J. Parrish. 2009b. National Capital Region Network 2008 forest vegetation monitoring report. Natural Resource Report NPS/NCRN/NRTR—2009/181. National Park Service, Fort Collins, CO.

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USDA (United States Department of Agriculture) Forest Service. 2009a. Gypsy moth in North America. Accessed April 9, 2013. *http://www.fs.fed.us/ne/morgantown/4557/gmoth*

USDA (United States Department of Agriculture) Forest Service. 2009b. Hemlock woolly adelgid, Forest Health Protection, USDA Forest Service. Accessed April 9, 2013. *http://na.fs.fed.us/fhp/hwa*

4.3.5 Seedlings and forest regeneration

Description

Forests are the dominant natural vegetation in the parks of the National Capital Region Network. Many factors including dense white-tailed deer populations and fire suppression in forested regions can alter forest stand development and reduce wildlife habitat by reducing or eliminating young tree seedlings, shrubs, and herbaceous plants (Tierson et al. 1966, Jordan 1967, Marquis 1981, Tilghman 1989, Horsely et al. 2003, Côté et al. 2004, Nowacki and Abrams 2008). In response to regeneration concerns, scientists at the U.S. Forest Service developed a measure, called the 'stocking index,' to determine if regeneration is sufficient (Marquis and Bjorkbom 1982). The index takes into account three different aspects of forest regeneration: the number of seedlings recorded, the size of the seedlings, and the geographic distribution of the seedlings.

Data and methods

Forest monitoring took place annually but not all plots were measured every year (Schmit et al. 2009) (Figure 4.29, Table 4.18). To minimize soil compaction and trampling of the understory, plots were sampled on a rotating panel design, with four panels. Each year one panel was sampled. Sampling took place from May through October, when foliage was fully developed. At each plot, seedlings were counted and the height of each seedling was determined. Based on these measurements, each plot is given a score, with older/larger seedlings and saplings receiving a higher score than smaller plants. Seedlings were defined as trees less than 1 cm diameter at breast height and ≥ 15 cm height.

The seedling stocking index reference condition used in this assessment was 115, above which a plot is considered to be adequately stocked at high densities of white-tailed deer (Table 4.19). Each measurement was assessed against the reference condition and assigned a pass or fail result and the percentage of passing results was used as the percent attainment. (Table 4.20a).

Condition and trend

Current condition for native tree seedling regeneration in HAFE was very degraded, with a median index value of 11 and 0% of data points attaining the reference condition of > 115 (Tables 4.21, 4.25).

No trend analysis was possible with the current data set.

Sources of expertise

John Paul Schmit, Quantitative Ecologist, Center for Urban Ecology, National Park Service.

Literature cited

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Table 4.25. Seedling stocking index values. Site locations are shown in Figure 4.29.

Site	Year	Index
HAFE-0005	2009	47.5*
HAFE-0009	2008	8.5*
HAFE-0021	2008	11.25*
HAFE-0028	2008	0*
HAFE-0030	2010	66*
HAFE-0039	2010	8.5*
HAFE-0047	2009	8.5*
HAFE-0061	2010	4*
HAFE-0074	2010	0*
HAFE-0118	2010	104.5*
HAFE-0154	2010	2*
HAFE-0160	2008	9*
HAFE-0161	2009	12*
HAFE-0192	2007	103.75*
HAFE-0195	2008	55*
HAFE-0208	2008	11.5*
HAFE-0211	2009	22.25*
HAFE-0215	2010	34.5*
HAFE-0218	2008	50.5*
HAFE-0240	2009	8.25*

* Values outside of reference condition of > 115.

4.3.6 Stream fishes

Description

The Fish Index of Biotic Integrity (FIBI) was proposed as a way of providing a more informative measure of anthropogenic influence on fish communities and ecological integrity than measurements of physiochemical metrics alone (Karr 1981). The metric was then adapted and validated for streams of Maryland using a reference condition approach, based on 1994–1997 data from a total of 1,098 sites.

Data and methods

Data were collected at four sites in 2004 (Figure 4.17, Table 4.18). NCRN followed the National Capital Region Biological Stream Survey protocol (Norris and Sanders 2009). Sites were classified based on physical and chemical data and fish assemblages were compared to identified reference sites. Reported data are for one FIBI assessment per site.

FIBI values were ranked as follows: 1.0–1.9 (very poor), 2.0–2.9 (poor), 3.0–3.9 (fair), 4.0–5.0 (good), and these were the scale and categories used in this assessment (Southerland et al. 2007). The range of FIBI scores from 1 to 5 were scaled linearly from 0 to 100% attainment (Figure 4.32, Table 4.26). The median of all the data points was compared to these reference conditions and given a percent attainment and converted to a condition assessment (Tables 4.19, 4.20b).

Condition and trend

Current condition of FIBI in HAFE was very degraded, with a median FIBI of 2.4 and 36% attainment of reference condition (Figure 4.33, Tables 4.21, 4.27).

No trend analysis was possible with the current data set.

Sources of expertise

Marian Norris, Water Resources Specialist, Inventory and Monitoring Program, National Capital Region Network, National Park Service.

Literature cited

Karr, J.R. 1981. Assessment of biotic integrity using fish communities. Fisheries 6 :21–27.

Norris, M.E. & G. Sanders. 2009. National Capital Region Network biological stream survey protocol: physical habitat, fish, and aquatic macroinvertebrate vital signs. Natural Resource Report. NPS/NCRN/NRR—2009/116. National Park Service, Fort Collins, CO.

Southerland, M.T., G.M. Rogers, M.J. Kline, R.P. Morgan, D.M. Boward, P.F. Kazyak, R.J. Klauda, and S.A. Stranko. 2007. Improving biological indicators to better assess the condition of streams. Ecological Indicators 7: 751–767.

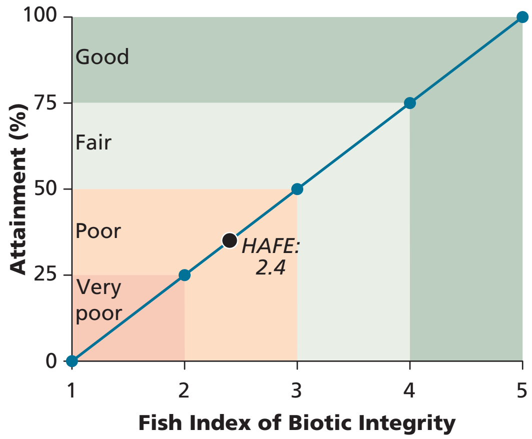

Figure 4.32. Application of the percent attainment categories to the Fish Index of Biotic Integrity (FIBI) value categories. FIBI at HAFE was 2.4 which equated to 36% attainment of the reference condition.

Table 4.26. Fish Index of Biotic Integrity (FIBI) categories, percent attainment, and condition assessment.

FIBI range	% attainment	Condition
4.0–5.0	100%	Good
3.0–3.9	scaled linearly	Fair
2.0–2.9		Poor
1.0–1.9	0%	Very poor

Table 4.27. Fish Index of Biotic Integrity (FIBI) in HAFE. Monitoring sites are shown in Figure 4.18.

Year	Site	Location	FIBI
2004	HARP-103-N-2004	Flowing Springs Run	2.43†
2004	HARP-301-N-2004	Elks Run	2.43†
2004	HARP-302-N-2004	Elks Run	2.71†
2004	NCRW-110-N-2004	Flowing Springs Run	1.29†

† Values calculated using old formula and may be different from scores on file with the State of Maryland.

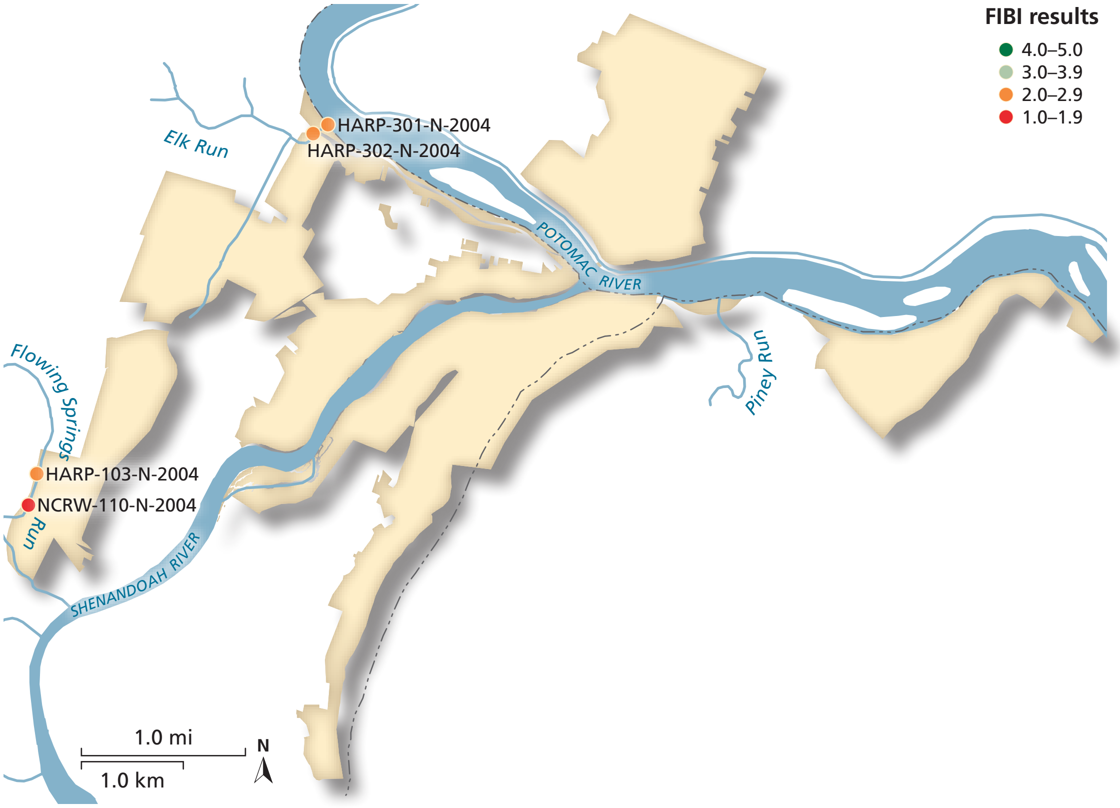

Figure 4.33. Fish Index of Biotic Integrity (FIBI) results by site for HAFE.

4.3.7 Birds

Description

Birds exhibit numerous characteristics that make them appropriate as ecological indicators. They are conspicuous components of terrestrial ecosystems in the National Capital Region, they can integrate conditions across major habitat types, and many require specific habitat conditions (O'Connell et al. 1998).

Modeled after previously developed Indices of Biotic Integrity (IBIs), the Bird Community Index (BCI) was developed as a multi-resource indicator of biotic integrity in the central Appalachians (O'Connell et al. 1998).

Data and methods

Data were collected at 20 forest sites between 2007 and 2011 (Figure 4.30, Table 4.18). Point count data from each plot were used to assess the BCI using the O'Connell et al. (1998) scoring and guild assignments for the Appalachian bird conservation region (BCR) (Ladin and Shriver 2013). BCI scores were ranked as follows: highest integrity (60.1– 77.0), high integrity (52.1–60.0), medium integrity (40.1–52.0), and low integrity (20.0–40.0), and these were the scale and categories used in this assessment (O'Connell et al. 1998).

Each of the four BCI value categories were assigned a percent attainment range (Figure 4.34, Table 4.28). The median of all the data points was compared to these reference conditions and given a percent attainment and converted to a condition assessment (Tables 4.19, 4.20b).

Condition and trend

The 2011 BCI of forest sites in CHOH showed medium integrity, with a median of 48.5 and 43% attainment of reference condition (Figure 4.35, Tables 4.21, 4.29).

Sources of expertise

John Paul Schmit, Quantitative Ecologist, Center for Urban Ecology, National Park Service.

Literature cited

Ladin Z.S. and W.G. Shriver. 2013. Avian monitoring in the National Capital Region Network: Summary report 2007–2011. Natural Resource Technical Report. NPS/NCRN/NRTR—2013/698. National Park Service. Fort Collins, CO. Published Report-2193341.

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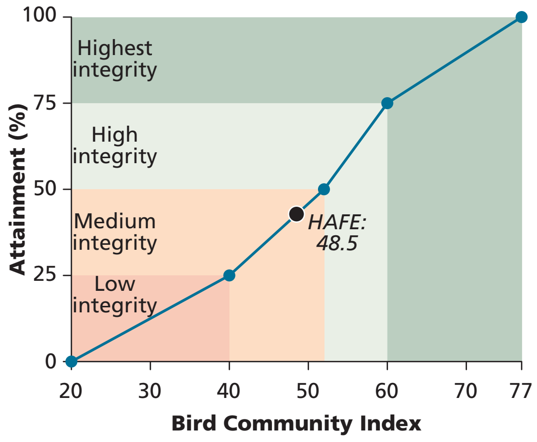

Figure 4.34. Application of the percent attainment categories to the BCI value categories. BCI at HAFE was 48.5 which equated to 43% attainment of the reference condition.

Table 4.28. Bird Community Index (BCI) categories, percent attainment, and condition assessment.

BCI range	% attainment	Condition
60.1–77	75–100%	Highest integrity
52.1–60	50–75%	High integrity
40.1–52	25–50%	Medium integrity
20.0–40	0–25%	Low integrity

Table 4.29. Median Bird Community Index (BCI) scores in HAFE. Monitoring sites are shown in Figure 4.30.

Site	Median	Site	Median
HAFE-0009	49.0	HAFE-0083	44.0
HAFE-0021	53.0	HAFE-0118	51.5
HAFE-0028	50.5	HAFE-0133	46.5
HAFE-0030	46.0	HAFE-0154	45.5
HAFE-0039	53.5	HAFE-0160	52.0
HAFE-0042	40.0	HAFE-0174	46.5
HAFE-0044	38.75	HAFE-0192	47.5
HAFE-0053	36.25	HAFE-0195	52.5
HAFE-0061	47.5	HAFE-0208	50.0
HAFE-0074	44.0	HAFE-0218	57.5

Figure 4.35. Bird Community Index (BCI) condition by site from 2007 to 2011 in 20 monitoring locations in HAFE. Site medians were used for this analysis.

4.3.9 Deer density

Description

White-tailed deer (*Odocoileus virginianus*) are considered a significant stressor on forests of the National Capital Region. White-tailed deer densities throughout the eastern deciduous forest zone increased rapidly during the latter half of the 20th century and may now be at historically high levels. McCabe and McCabe (1997) estimate that pre-European deer densities in the eastern United States ranged between 3.1 and 4.2 deer/km^2 (8.0 and 10.9 deer/mi^2) in optimal habitats. Today, examples of deer populations exceeding 20 deer/km^2 (52 deer/mi^2) are commonplace (e.g., Knox 1997, Russell et al. 2001, Augustine and deCalesta 2003, Rossel Jr. et al. 2005, Griggs et al. 2006, McDonald Jr. et al. 2007).

The currently high population numbers for white-tailed deer regionally have been recognized since the 1980s as being of concern due to potentially large impacts upon regeneration of woody tree species as well as the occurrence and abundance of herbaceous species and consequent alterations to trophic interactions (Decalesta 1997, Waller and Alverson 1997, Côté et al. 2004). Besides directly impacting vegetative communities, deer overbrowsing can contribute to declines in breeding bird abundances by decreasing the structural diversity and density in the forest understory (McShea and Rappole 1997).

Data and methods

Deer population density was estimated annually between 2001 and 2008 using the pellet-group count method (Bates 2006, 2009) (Figure 4.31, Table 4.18). Each measurement was assessed against the reference condition and assigned a pass or fail result and the percentage of passing results was used as the percent attainment.

The forest threshold for white-tailed deer density (8.0 deer/km^2 [21 deer/mi^2]) is a well-established ecological threshold (Horsley et al. 2003) (Table 4.19). Species richness and abundance of herbs and shrubs are consistently reduced as deer densities approach 8.0/km^2 (21 deer/mi^2), although shown in some studies to change at densities as low as 3.7 deer/km^2 (9.6 deer/mi^2) (Decalesta 1997). One large manipulation study in central Massachusetts found deer densities of 10–17/km^2 (26–44 deer/mi^2) inhibited the regeneration of understory species, while densities of 3–6 deer/km^2 (8–16 deer/mi^2) supported a diverse and abundant forest understory (Healy 1997). There are multiple sensitive species of songbirds that cannot be found in areas where deer grazing has removed the understory vegetation needed for nesting, foraging and protection. Even though songbird species vary in how sensitive they are to increases in deer populations, these changes generally occur at deer densities greater than 8 deer/km^2 (21 deer/mi^2) (Decalesta 1997). Annual densities were compared against the reference condition to determine the percent attainment and condition (Table 4.20a).

Condition and trend

Current condition of deer population density in HAFE was very degraded, with 0% of years attaining the reference condition of 8.0 deer/km^2 (Figure 4.36, Tables 4.21, A-3). Population estimates for deer population for 2001–2008 all exceed the reference condition of < 8 deer/km^2, with a median deer population of 32 deer/km^2 for all years. In all cases, the lower limit of the 95% confidence interval estimate was still an order of magnitude higher than the reference condition (Figure 4.36, Table A-3). As such, deer population density for 2001–2008 attains 0% of reference condition and indicates a very degraded condition.

There were no major changes in overall deer population size during the seven years of monitoring (Figure 4.36, Table A-3).

Sources of expertise

Scott Bates, Wildlife Biologist, National Park Service, Center for Urban Ecology.

Literature cited

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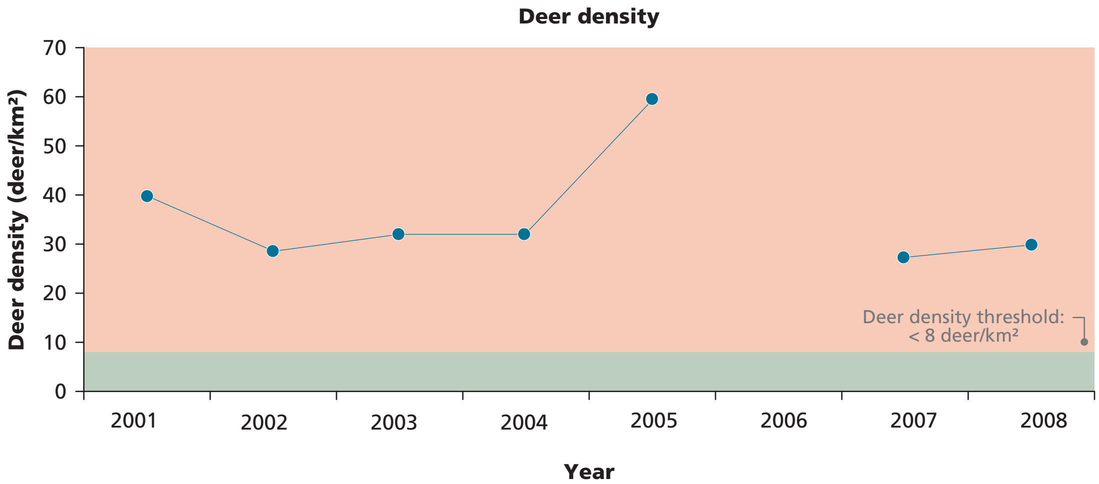
Figure 4.36. Annual mean deer density (deer/km²) from 2001 to 2011 in HAFE. Reference condition (< 8 deer/km²) is shown in gray. Deer density was not sampled in 2006.



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Tilghman, N.G. 1989. Impacts of white-tailed deer on forest regeneration in NW Pennsylvania. Journal of Wildlife Management 53: 524–532.

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4.4 LANDSCAPE DYNAMICS

4.4.1 Landscape dynamics summary

Four metrics were used to assess landscape dynamics in HAFE—forest interior area, forest cover, impervious surface, and road density (measured at two different scales) (Table 4.30). Data from the 2006 National Land Cover Database and the 2010 ESRI Streets layer were analyzed by National Capital Region Network (NCRN) Inventory & Monitoring (I&M) staff (ESRI 2010, Fry et al. 2011, NPS 2010a, b).

The two spatial scales used for the analyses were: 1) within the park boundary and 2) within the park boundary plus an area five times the total area of the park, evenly distributed as a 'buffer' around the entire park boundary. The purpose of this analysis was to assess the influence on ecosystem processes of land use immediately surrounding the park.

Reference conditions were established for each metric (Table 4.31) and the data were compared to these reference conditions to obtain the percent attainment and converted to the condition assessment for that metric (Table 4.32). This resulted in an overall landscape dynamics condition attainment of 54%, or moderate conditions.

HAFE scored as very good for forest cover within the park, and for impervious surface at both scales (all 100% attainment). Forest interior area within the park was good (72% attainment) and was moderate at the 5x park area scale (57% attainment). Forest cover at the 5x park area scale and road density at both scales were very degraded (all 0% attainment) (Table 4.33). This resulted in an overall landscape dynamics condition attainment of 54%, or moderate condition.

Literature cited

ESRI 2010. ESRI Data and Maps – U.S. and Canada Detailed Streets, TeleAtlas 2005.

Table 4.30. Ecological monitoring framework data for Landscape Dynamics provided by agencies and specific sources included in the assessment of HAFE.

Metric	Agency	Reference/Source
Forest interior area (within park)	NPS NPScape	NPS 2010a
Forest interior area (within park + 5x buffer)	NPS NPScape	NPS 2010a
Forest cover (within park)	NPS NPScape	NPS 2010a
Forest cover (within park + 5x buffer)	NPS NPScape	NPS 2010a
Impervious surface (within park)	NPS NPScape	NPS 2010a
Impervious surface (within park + 5x buffer)	NPS NPScape	NPS 2010a
Road density (within park)	NPS NPScape	NPS 2010b
Road density (within park + 5x buffer)	NPS NPScape	NPS 2010b

Table 4.31. Landscape Dynamics reference conditions for HAFE.

Metric	Reference condition	Sites	Samples	Period
Forest interior area (within park)	% of total potential forest area translates to % attainment	Park	1	2001
Forest interior area (within park + 5x buffer)	% of total potential forest area translates to % attainment	Park	1	2001
Forest cover (within park)	> 59%	Park	1	2006
Forest cover (within park + 5x buffer)	> 59%	Park	1	2006
Impervious surface (within park)	< 10%	Park	1	2006
Impervious surface (within park + 5x buffer)	< 10%	Park	1	2006
Road density (within park + 5x buffer)	< 1.5 km/km^2	Park	1	2006
Road density (within park + 5x buffer)	< 1.5 km/km^2	Park	1	2006

Fry, J., G. Xian, S. Jin, J. Dewitz, C. Homer, L. Yang, C. Barnes, N. Herold, and J. Wickham. 2011. Completion of the 2006 National Land Cover Database for the Conterminous United States, PE&RS, Vol. 77: 858–864.

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NPS 2010b. NPScape roads measure – Phase 2 road metrics processing SOP: Road density and distance from roads. National Park Service, Natural Resource Program Center. Fort Collins, CO.

Table 4.32. Categorical ranking of reference condition attainment categories for Landscape Dynamics metrics.

Attainment of reference condition	Natural resource condition
80–100%	Very good
60–<80%	Good
40–<60%	Moderate
20–<40%	Degraded
0–<20%	Very degraded

Table 4.33. Summary of resource condition assessment of Landscape Dynamics in HAFE.

Metric	Result	Reference condition	% attainment	Condition	Landscape dynamics condition
Forest interior area (within park)	72%	% of total potential forest area translates to % attainment	72%	Good	**54%** **Moderate**
Forest interior area (within park + 5x buffer)	57%	% of total potential forest area translates to % attainment	57%	Moderate	
Forest cover (within park)	67%	> 59%	100%	Very good	
Forest cover (within park + 5x buffer)	55%	> 59%	0%	Very degraded	
Impervious surface (within park)	1.5%	< 10%	100%	Very good	
Impervious surface (within park + 5x buffer)	3.4%	< 10%	100%	Very good	
Road density (within park + 5x buffer)	1.8 km/km^2	< 1.5 km/km^2	0%	Very degraded	
Road density (within park)	2.9 km/km^2	< 1.5 km/km^2	0%	Very degraded	

4.4.2 Forest interior area

Description

Forest interior habitat functions as the highest quality breeding habitat for forest interior dwelling species (FIDS) of birds. When a forest becomes fragmented, areas that once functioned as interior breeding habitat are converted to edge habitat and are often associated with a significant reduction in the number of young birds that are fledged in a year (Jones et al. 2000).

Higher rates of nest predation occur in forest edges. In addition, forest edges provide access to the interior for avian predators such as blue jays, crows, grackles and mammalian predators that include foxes, raccoons, squirrels, dogs and cats. These predators eat eggs and young birds still in the nest. They tend to be abundant near areas of human habitation and can be detrimental to nesting success (Jones et al. 2000).

Data and methods

Forest interior area as a percent of the park area (or buffered area) was calculated using the NPScape Phase 1 Landcover methods and script tools (NPS 2010) (Table 4.30) for forest morphology. The source data for this analysis was the 2006 National Land Cover Database (NLCD) (Fry et al. 2011) from which a Morphological Spatial Pattern Analysis (MSPA) dataset was generated using the GUIDOS software package (*http://forest.jrc.ec.europa.eu/download/software/guidos*) with the edge distance defined as 90 m (3 pixels). The number of acres of forest interior or 'core' area was extracted from the MSPA dataset for the park and the buffered areas.

The threshold attainment was expressed as the number of acres of interior forest in the park as a percentage of the total potential acres of interior forest within the park (if the total forest area was one large circular patch). The data used in this assessment represent a one-off calculation at two scales: 1) within the park boundary and 2) within the park boundary plus an area five times the total area of the park, evenly distributed as a 'buffer' around the entire park boundary (Figure 4.37, Table 4.31). The purpose of this analysis was to assess the influence on ecosystem processes of land use immediately surrounding the park. The percentage of potential forest interior area translated directly to the percent attainment and condition assessment (Table 4.32).

Table 4.34. Forest interior area (%) in HAFE.

Area	Interior area (%)
Park	72
Park + 5x area	57
Park + 30 km	36

Interior forest was defined as mature forested land cover ≥ 100 m (330 ft) from non-forest land cover or from primary, secondary, or county roads (i.e., roads considered large enough to break the canopy) (Temple 1986).

Condition and trend

Forest interior area in HAFE at the scale of the park and at the scale of the park plus the 5x buffer was 72% and 57%, respectively (Figure 4.37, Tables 4.33, 4.34). This indicated good condition at the scale of the park, and moderate condition at the 5x area scale. Note: forest interior area at an additional scale (park boundary plus a 30 km buffer is also shown in Table 4.34 for reference but was not included in the current assessment.

No trend analysis was possible with the current data set.

Sources of expertise

Mark Lehman, GIS specialist, Inventory and Monitoring Program, National Capital Region Network, National Park Service.

Literature cited

Fry, J., G. Xian, S. Jin, J. Dewitz, C. Homer, L. Yang, C. Barnes, N. Herold, and J. Wickham. 2011. Completion of the 2006 National Land Cover Database for the Conterminous United States, PE&RS, Vol. 77: 858–864.

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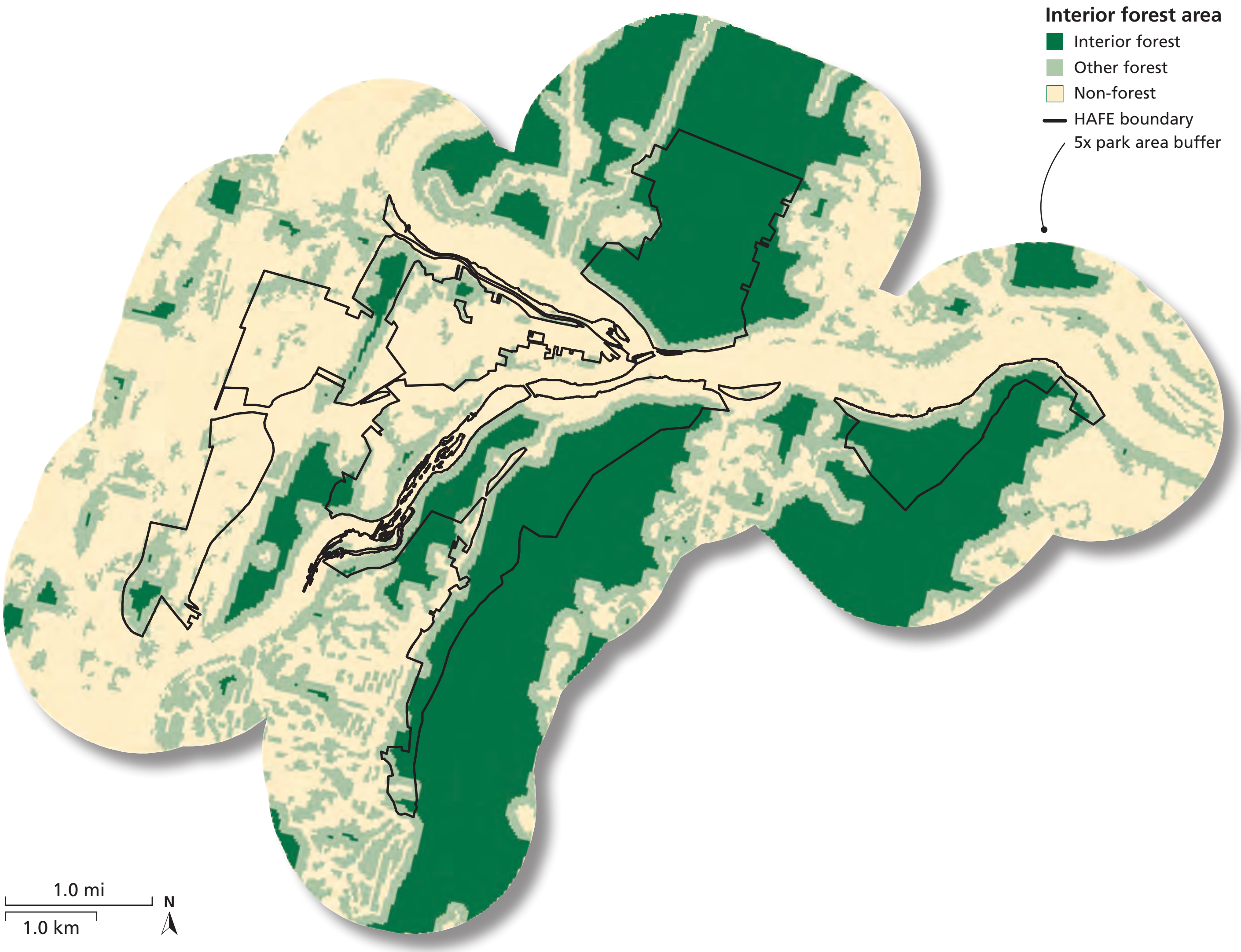

Figure 4.37. Extent of forest interior area within and around HAFE ivn 2006. The 5x area buffer is an area five times the total area of the park, evenly distributed as a 'buffer' around the entire park boundary.

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4.4.3 Forest cover

Description

Forest is the dominant historical land use in the region surrounding HAFE and is still the dominant land use within the park itself (Figure 2.3) (HAFE 2008, NPS 2011). As intact and connected forest provides habitat, wildlife corridors, and ecosystem services, forest cover was chosen as a Landscape Dynamics metric.

Data and methods

Forest cover as a percent of the park area (or buffered area) was calculated using the NPScape Phase 1 Landcover methods and script tools (NPS 2010) (Table 4.30). The source data for this analysis was the 2006 National Land Cover Database (NLCD) (Fry et al. 2011). Three of the NLCD classifications were considered to be forested areas for this analysis: Deciduous Forest, Evergreen Forest, and Mixed Forest.

Modeling studies have found that in ecological systems, there is a 'tipping point' of forest cover below which a system becomes so fragmented that it no longer functions as a single system (Hargis et al. 1998). USGS digital land use data were used for forest cover in areas of North Carolina, West Virginia, and Alabama to determine the critical value of 59.28% (Gardner et al. 1987). Forest was chosen as it is a dominant vegetation type within the region, providing major structure to faunal and floral communities.

A forest cover threshold of > 59% was used in this assessment and the data used represent a one-off calculation at two scales: 1) within the park boundary and 2) within the park boundary plus an area five times the total area of the park, evenly distributed as a 'buffer' around the entire park boundary (Figure 4.38, Table 4.31). The purpose of this analysis was to assess the influence on ecosystem processes of land use immediately surrounding the park. The park was given a rating of either 100% or 0% attainment based on the results of the one-off calculation.

Condition and trend

At the scale of the park, forest cover in HAFE was 67%, which exceeds the reference condition of 59%. This resulted in 100% attainment and very good condition (Figure 4.38, Tables 4.33, 4.35).

Table 4.35. Forest cover (%) in HAFE.

Area	Forest cover (%)
Park	67
Park + 5x area	55*
Park + 30 km	32*

* Values outside of reference condition of > 59%.

However, when a buffer of five times the park area was added, forest cover dropped to 55%. This did not meet the reference condition, resulting in 0% attainment of reference condition and indicating very degraded condition (Figure 4.38, Tables 4.33, 4.35). Note: forest cover at an additional scale (park boundary plus a 30 km buffer is also shown in Table 4.35 for reference but was not included in the current assessment.

No trend analysis was possible with the current data set.

Sources of expertise

Mark Lehman, GIS specialist, Inventory and Monitoring Program, National Capital Region Network, National Park Service.

Literature cited

Fry, J., G. Xian, S. Jin, J. Dewitz, C. Homer, L. Yang, C. Barnes, N. Herold, and J. Wickham. 2011. Completion of the 2006 National Land Cover Database for the Conterminous United States, PE&RS, Vol. 77: 858–864.

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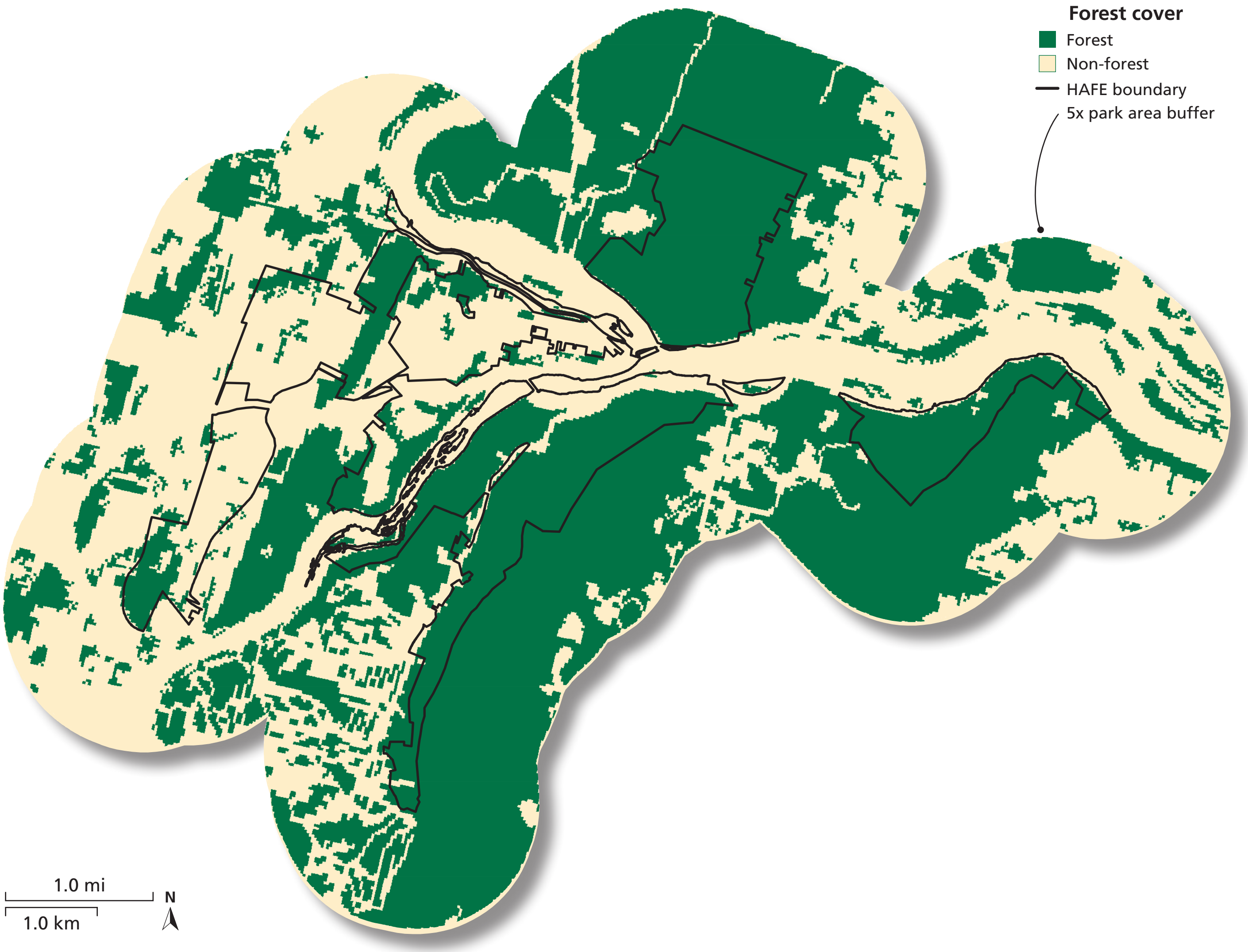
Hargis, C.D., J.A. Bissonette, and J.L. David. 1998. The behavior of landscape metrics commonly used in the study of habitat fragmentation. Landscape Ecology 13: 167–186.

NPS 2010. NPScape landcover measure – Phase 1 metrics processing SOP: Landcover area per category, natural vs. converted landcover, landcover change, and impervious surface metrics. Natural Resource Report. NPS/NRPC/IMD/NRR—2010/252. Published Report-2165449. National Park Service, Natural Resource Program Center. Fort Collins, CO.

NPS. 2011. NPScape: monitoring landscape dynamics of US National Parks. Natural



Resource Program Center, Inventory and Monitoring Division. Fort Collins, CO. Accessed April 9, 2013. *http://science.nature.nps.gov/im/monitor/npscape*

Figure 4.38. Extent of forest and non-forest landcover within and around HAFE in 2006. The 5x area buffer is an area five times the total area of the park, evenly distributed as a 'buffer' around the entire park boundary.

4.4.4 Impervious surface

Description

Impervious surface is a human impact on the landscape and directly correlates to land development (Conway 2007). It includes roads, parking lots, rooftops, and transport systems that decrease infiltration, water quality, and habitat while increasing runoff.

Data and methods

A single mean impervious surface percentage was calculated for the park (and buffered areas) using ESRI zonal statistics on the 2006 National Land Cover Database impervious surface layer (NPS 2010a, b, Fry et al. 2011) (Table 4.30).

Many ecosystem components such as wetlands, floral and faunal communities, and streambank structure show signs of impact and loss of biodiversity when impervious surface covers more than 10% of the land area (Arnold and Gibbons 1996, Lussier et al. 2008). A study of nine metropolitan areas in the United States demonstrated measurable effects of impervious surface on stream invertebrate assemblages at impervious surface cover of 5% (Cuffney et al. 2010). Percent urban land is correlated to impervious surface and can provide a good approximation of watershed degradation due to increases of impervious surface.

An impervious surface threshold of < 10% was used in this assessment and the data used represent a one-off calculation at two scales: 1) within the park boundary and 2) within the park boundary plus an area five times the total area of the park, evenly distributed as a 'buffer' around the entire park boundary (Figure 4.39, Table 4.31). The purpose of this analysis was to assess the influence on ecosystem processes of land use immediately surrounding the park. The park was given a rating of either 100% or 0% attainment based on the results of the one-off calculation.

Condition and trend

Impervious surface in HAFE at the scale of the park and at the scale of the park plus the 5x buffer was 1.5% and 3.4%, respectively. These were both below the reference condition of 10% impervious surface, resulting in 100% attainment and very good condition at both scales (Figure 4.39, Tables 4.33, 4.36). Note: impervious surface at an additional scale (park boundary plus a 30 km buffer) is also shown in Table 4.36 for reference but was not included in the current assessment.

Table 4.36. Impervious surface (%) in HAFE.

Area	Impervious surface (%)
Park	1.5
Park + 5x area	3.4
Park + 30 km	3.0

* Values outside of reference condition of < 10%.

No trend analysis was possible with the current data set.

Sources of expertise

Mark Lehman, GIS specialist, Inventory and Monitoring Program, National Capital Region Network, National Park Service.

Literature cited

Arnold Jr, C.L. and C.J. Gibbons. 1996. Impervious surface coverage. Journal of the American Planning Association 62: 243–269.

Conway, T.M. 2007. Impervious surface as an indicator of pH and specific conductance in the urbanizing coastal zone of New Jersey, USA. Journal of Environmental Management 85: 308–316.

Cuffney, T.F., R.A. Brightbill, J.T. May, and I.R. Waite. 2010. Responses of benthic macroinvertebraes to environmental changes associated with urbanization in nine metropolitan areas. Ecological Applications 20: 1384–1401.

Fry, J., G. Xian, S. Jin, J. Dewitz, C. Homer, L. Yang, C. Barnes, N. Herold, and J. Wickham. 2011. Completion of the 2006 National Land Cover Database for the Conterminous United States, PE&RS, Vol. 77: 858–864.

Lussier, S.M., S.N. da Silva, M. Charpentier, J.F. Heltshe, S.M. Cormier, D.J. Klemm, M. Chintala, and S. Jayaraman. 2008. The influence of suburban land use on habitat and biotic integrity of coastal Rhode Island streams. Environmental Monitoring and Assessment 139: 119–136.

NPS 2010. NPScape landcover measure – Phase 1 metrics processing SOP: Landcover area per category, natural vs. converted landcover, landcover change, and impervious surface metrics. Natural Resource Report. NPS/NRPC/IMD/NRR—2010/252. Published Report-2165449. National Park Service, Natural Resource Program Center. Fort Collins, CO.

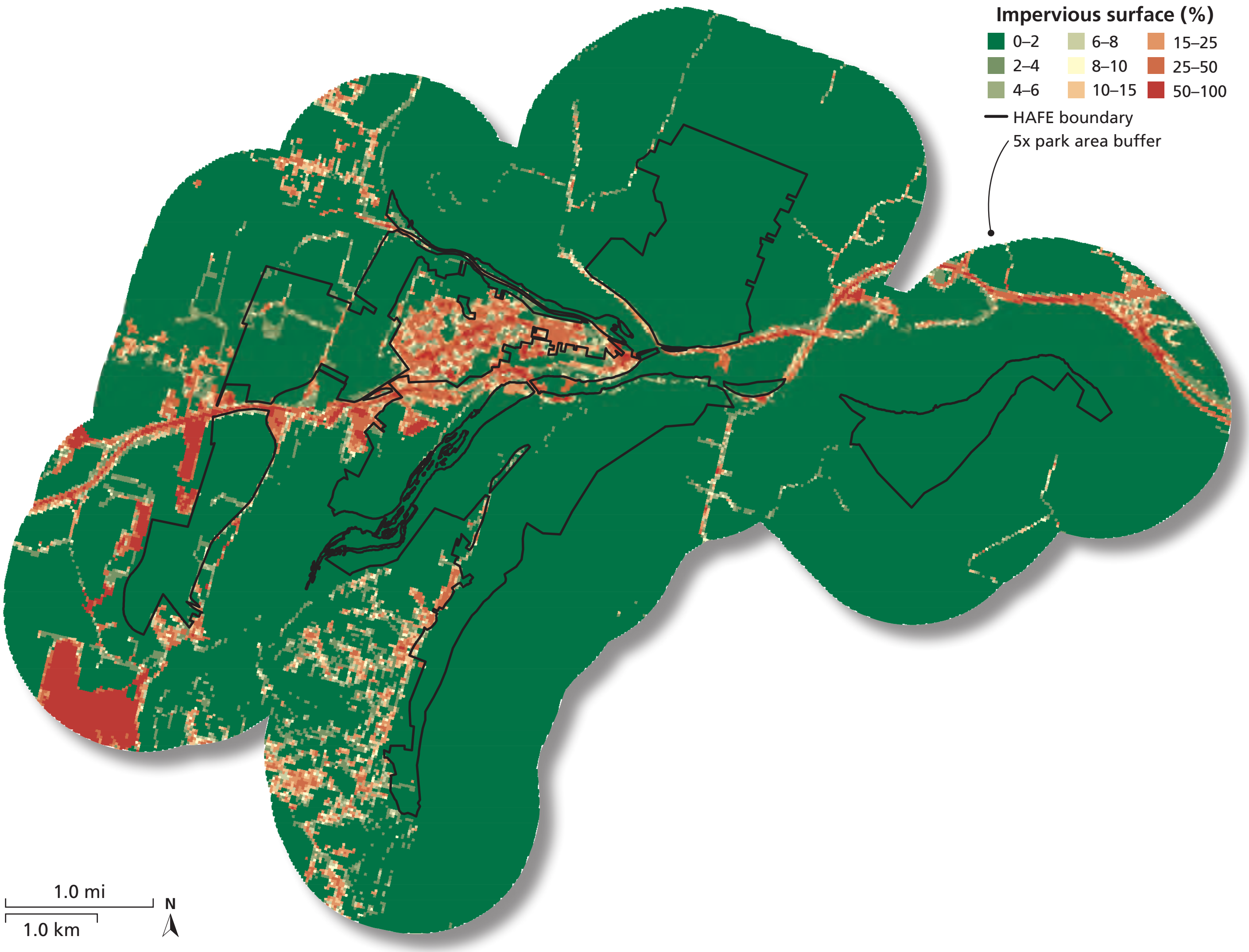


Figure 4.39. Percent impervious surface within and around HAFE in 2006. The 5x area buffer is an area five times the total area of the park, evenly distributed as a 'buffer' around the entire park boundary.

4.4.5 Road density

Description

Roads and other forest-dividing cuts such as utility corridors can act as barriers to wildlife movement and increase habitat fragmentation. High road density or the presence of a large roadway can decrease the quality of wildlife habitat by fragmenting it, and increases the risk of wildlife mortality by vehicle strike (Forman et al. 1995).

Data and methods

Road density (km of road per square km) and distance from roads were calculated using the NPScape Phase 2 Road Metrics Processing SOP (NPS 2010) for the park and buffered areas (Table 4.30). The 2010 ESRI Streets layer (ESRI 2010) was used as the source data. All of the features in this layer were included in this analysis with the exception of ferry routes.

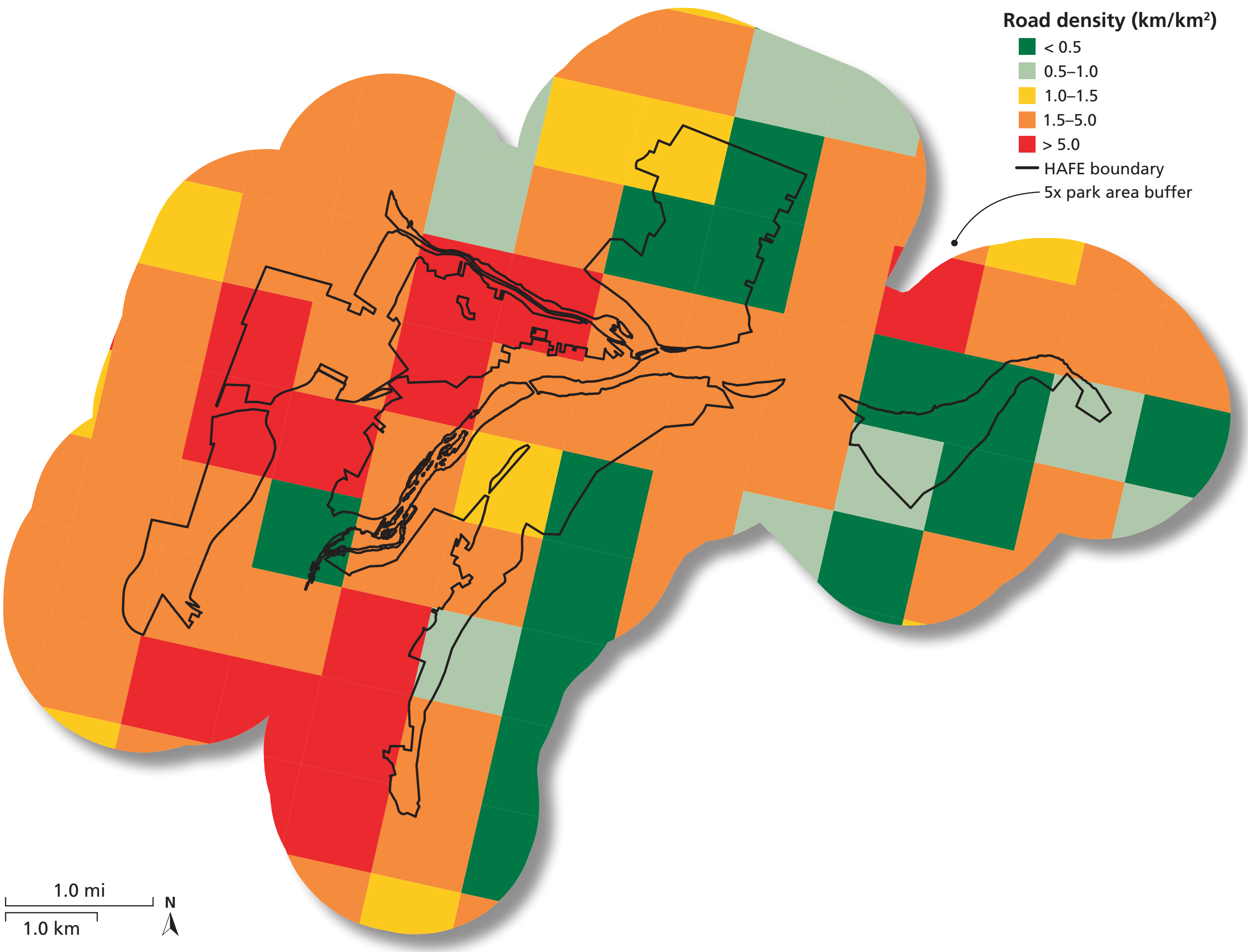
Table 4.37. Road density (km/km^2) in HAFE.

Area	Road density (km/km^2)
Park	1.8*
Park + 5x area	2.9*
Park + 30 km	2.4*

* Values outside of reference condition of < 1.5 km/km^2.

Road densities higher than 1.5 km/km^2 have been shown to impact turtle populations, while densities higher than 0.6 km/km^2 can impact natural populations of large vertebrates (Forman et al. 1995, Gibbs and Shriver 2002, Steen and Gibbs 2004). A road density threshold of < 1.5 km/km^2 was used in this assessment and data used in this assessment represent a one-off

Figure 4.40. Road density within and around HAFE in 2010. The 5x area buffer is an area five times the total area of the park, evenly distributed as a 'buffer' around the entire park boundary.



calculation at two scales: 1) within the park boundary and 2) within the park boundary plus an area five times the total area of the park, evenly distributed as a 'buffer' around the entire park boundary (Figures 4.40, 4.41, Table 4.31). The purpose of this analysis was to assess the influence on ecosystem processes of land use immediately surrounding the park. The park was given a rating of either 100% or 0% attainment based on the results of the one-off calculation.

Condition and trend

Road density in HAFE at the scale of the park and at the scale of the park plus the 5x buffer was 1.8 km/km^2 and 2.9 km/km^2, respectively. These both exceeded the reference condition of 1.5 km/km^2, resulting in 0% attainment and very degraded condition at both scales (Figure 4.40, Tables 4.33, 4.37). However, the Short Hill and Maryland Heights sections of the park had very low road densities. Note: road density at an additional scale (park boundary plus a 30 km buffer is also shown in Table 4.37 for reference but was not included in the current assessment.

No trend analysis was possible with the current data set.

Sources of expertise

Mark Lehman, GIS specialist, Inventory and Monitoring Program, National Capital Region Network, National Park Service.

Literature cited

ESRI 2010. ESRI Data and Maps – U.S. and Canada Detailed Streets, TeleAtlas 2005.

Forman, R.T.T., D.S. Friedman, D. Fitzhenry, J.D. Martin, A.S. Chen, and L.E. Alexander. 1995. Ecological effects of roads: Toward

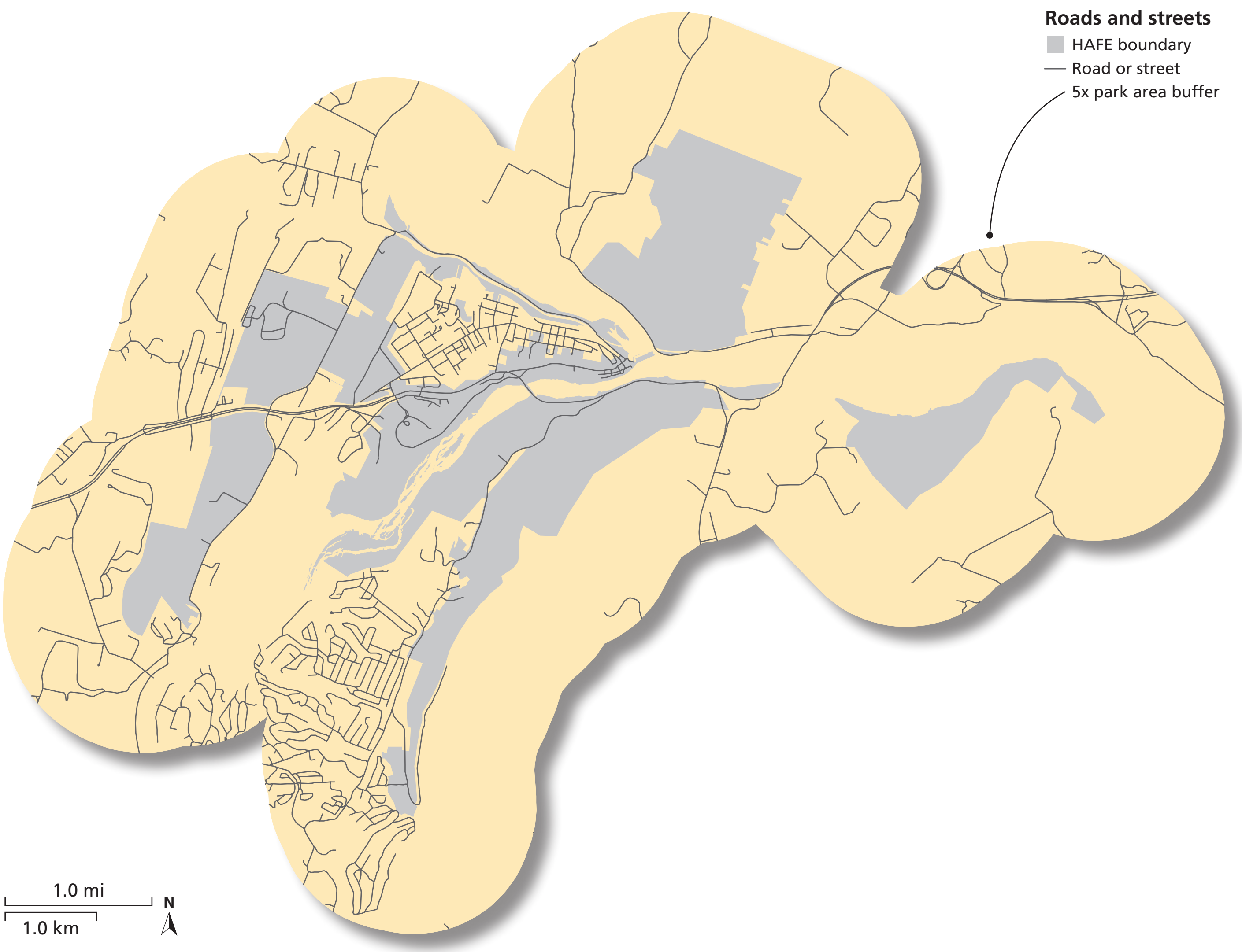


Figure 4.41. Map of roads and streets in and around HAFE in 2010. This is the base map from which the above map was generated.

three summary indices and an overview for North America. In: Canters, K (ed). Habitat fragmentation and infrastructure. Ministry of Transport, Public Works and Water Management: Maastricht and The Hague, Netherlands.

Gibbs, J.P. and W.G. Shriver. 2002. Estimating the effects of road mortality on turtle populations. Conservation Biology 16: 1647–1652.

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Steen, D.A. and J.P. Gibbs. 2004. Effects of roads on the structure of freshwater turtle populations. Conservation Biology 18: 1143–1148.

Chapter 5: Discussion

5.1 PARK NATURAL RESOURCE CONDITION

Overall, natural resources in Harpers Ferry National Historical Park were in a degraded condition, with 39% achievement of the reference conditions (Table 5.1).

Table 5.1. Natural resource condition assessment of HAFE.

Vital Sign	Reference condition attainment	Current condition
Air Quality	6.6%	Very degraded
Water Resources	58%	Moderate
Biological Integrity	37%	Degraded
Landscape Dynamics	54%	Moderate
Harpers Ferry National Historical Park	**39%**	**Degraded**

5.1.1 Air quality

Air quality was in a very degraded condition, with 7% attainment of the reference conditions (Tables 5.1, 5.2). Degraded air quality is a problem throughout the eastern United States, the causes of which are out of the park's control. The specific implications to the habitats and species in the park are less well known (Tables 5.3, 5.4). Gaining a better understanding of how reduced air quality is impacting sensitive habitats and species within the park would help prioritize management efforts.

Table 5.2. Summary of resource condition assessment of Air Quality in HAFE.

Metric	Condition
Wet sulfur deposition	Significant concern
Wet nitrogen deposition	Significant concern
Ozone (ppb)	Significant concern
Ozone (W126)	Moderate
Visibility	Significant concern
Particulate matter	Moderate
Air Quality	**Very degraded**

Despite mercury wet deposition data being available, there is no published reference condition for wet deposition. The only available reference condition for mercury is for fish tissue concentration—a human health threshold. As fish tissue concentrations are not regularly monitored, establishment of a wet deposition reference condition would give a better picture of the effect of mercury in the ecosystem.

Air quality is measured and interpolated on regional and national scales. Implementation of park-scale air quality monitoring would give better insights into park-level air quality condition and possible effects on park habitats and species.

Climate change

The close connection between climate and air quality is reflected in the impacts of climate change on air pollution levels. In particular, the U.S. EPA has concluded that climate change could have the following impacts on national air quality levels (U.S.

Table 5.3. Key findings, management implications, and recommended next steps for forest habitat in HAFE.

Key findings	Management implications	Recommended next steps
• Air quality is very degraded	• Habitats and species in the park may be affected	• Monitor for local effects
• Air quality is a regional problem	• Habitats and species in the park may be affected	• Support regional air quality initiatives

Table 5.4. Data gaps, justification, and research needs for air quality in HAFE.

Data gaps	Justification	Research needs
• Ecological thresholds for mercury wet deposition	• Wet deposition is monitored but the only available reference condition is for fish tissue concentration	• Relate fish tissue concentrations to wet deposition
• Park-scale air quality data	• Need to implement park-specific management actions	• Use transport and deposition models • Calibrate with roadside data within the park
• Effects of poor air quality on park habitats and species	• Need to implement park-specific management actions	• Investigate effects of poor air quality on sensitive habitats and species within the park

EPA 2009):

- produce 2–8 ppb increases in the summertime average ground-level ozone concentrations in many regions of the country;
- further exacerbate ozone concentrations on days when weather is already conducive to high ozone concentrations;
- lengthen the ozone season; and
- produce both increases and decreases in particle pollution over different regions of the U.S.

Literature cited

U.S. EPA. 2009. Assessment of the impacts of global change on regional U.S. air quality: a synthesis of climate change impacts on ground-level ozone. An Interim Report of the U.S. EPA Global Change Research Program. National Center for Environmental Assessment, Washington, DC; EPA/600/R-07/094F. Available from the National Technical Information Service, Springfield, VA, and online at *http://www.epa.gov/ncea*

5.1.2 Water resources

Water resources were in a moderate condition overall, with 58% attainment of reference conditions (Tables 5.1, 5.5). Nutrients (nitrogen and phosphorus), specific conductance, and the Benthic Index of Biotic Integrity (BIBI) were in poor to very degraded condition while pH, dissolved oxygen, water temperature and acid neutralizing capacity were in very good condition, similar to results found in parks throughout the region (Carruthers et al. 2009, Norris and Pieper 2010, Thomas et al. 2011a, b, c).

Table 5.5. Summary of resource condition assessment of Water Resources in HAFE.

Metric	Condition
pH	Very good
Dissolved oxygen	Very good
Water temperature	Very good
Acid neutralizing capacity	Very good
Specific conductance	Very degraded
Nitrate	Very degraded
Total phosphorus	Very degraded
Benthic Index of Biotic Integrity	Poor
Physical Habitat Index	Partially degraded
Water Resources	**Moderate**

Water quality is only measured at one site within the park, so it is recommended to expand monitoring to include sites in Elk Run and Piney Run. These streams do not originate in the park and only run through the park for a short distance but it would be informative to monitor what is coming through the park from upstream (Table 5.6). Data gaps and research recommendations revolve around maintaining good water quality by identification of nutrient sources and sensitive organisms (Table 5.7).

Climate change

Water temperature increase is one of the most immediate threats from climate change, and this would result in the loss of fish and other organisms that depend upon cooler water.

Table 5.6. Key findings, management implications, and recommended next steps for water resources in HAFE.

Key findings	Management implications	Recommended next steps
• Very degraded condition for nitrogen and phosphorus	• Affects stream flora and fauna • Reduces quality of visitor experience	• Reduce non-point source nutrient inputs from watershed (in partnership with agencies) • Continue riparian buffer establishment • Maintain implementation of best management practices on leased agricultural lands
• Water quality parameters are measured at only one site	• Only have data for one stream within the park	• Establish regular water quality monitoring in other streams within the park
• Water quantity	• Affects stream flora and fauna • Reduces quality of visitor experience	• Monitor water quantity as well as quality
• Benthic Index of Biotic Integrity (BIBI) and Physical Habitat Index (PHI) data have not been updated since 2004	• Current status of BIBI and PHI are poorly known	• Update and regularly repeat BIBI and PHI monitoring (scheduled to be repeated in 2013)

Table 5.7. Data gaps, justification, and research needs for water resources in HAFE.

Data gaps	Justification	Research needs
• Origins of nitrogen and phosphorus pollution are uncertain	• Affects stream flora and fauna • Reduces quality of visitor experience	• Identify sources of nutrients
• Karst features in and around the park are poorly understood	• Karst landscapes influence water flows into and through the park	• Locate, map, and monitor groundwater and springs • Monitor water quantity as well as quality

Literature cited

Carruthers, T., S. Carter, L.N. Florkowski, J. Runde, and W.C. Dennison. 2009. Rock Creek Park natural resource condition assessment. Natural Resource Report NPS/NCRN/NRR—2009/109. National Park Service, Natural Resource Program Center. Fort Collins, CO.

Norris, M. and J. Pieper. 2010. National Capital Region Network 2009 water resources monitoring report. Natural Resources Data Series. Natural Resources Program Center, Fort Collins, CO.

Thomas, J.E., T. Carruthers, W.C. Dennison, M. Lehman, M. Nortrup, P. Campbell, E. Wenschhof, J. Calzarette, D. Cohen, L. Donaldson, and A. Landsman. 2011a. Antietam National Battlefield natural resource condition assessment. Natural Resource Report NPS/NCRN/NRR—2011/413. National Park Service, Natural Resource Stewardship and Science. Fort Collins, CO.

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Thomas, J.E., T. Carruthers, W.C. Dennison, M. Lehman, M. Nortrup, P. Campbell, and A. Banasik. 2011c. Monocacy National Battlefield natural resource condition assessment. Natural Resource Report NPS/NCRN/NRR—2011/415. National Park Service, Natural Resource Stewardship and Science. Fort Collins, CO.

5.1.3 Biological integrity

Biological integrity was in a degraded condition overall, with 37% attainment of reference conditions (Tables 5.1, 5.8). Deer density and the seedling stocking index were both in very degraded condition. Studies show a relationship between high deer density and poor forest regeneration (Horsley et al. 2003, Côté et al. 2004) and as such, deer management should continue to be a top priority (Table 5.9). Other monitoring recommendations include exotic species monitoring and education, and continuing to monitor pests and diseases (Table 5.9).

Data gaps and research needs include developing a bird index for non-forest species and modeling the effects of climate change and other stressors on the region's forests (Table 5.10).

Table 5.8. Summary of resource condition assessment of Biological Integrity in HAFE.

Metric	Condition
Cover of exotic herbaceous species	Degraded
Area of exotic trees & saplings	Very good
Presence of forest pest species	Good
Seedling stocking index	Very degraded
Fish index of biotic integrity	Poor
Bird community index	Medium integrity
Deer density	Very degraded
Biological Integrity	Degraded

Table 5.9. Key findings, management implications, and recommended next steps for biological integrity in HAFE.

Key findings	Management implications	Recommended next steps
• Deer overpopulation may be impacting forest regeneration and agriculture	• Increased herbivory reducing desired plant and bird species, and lowering yields in agricultural areas • More road collisions • Potential for spread of chronic wasting disease	• Develop a deer management plan • Implement deer population control measures • Use exclosure studies to quantify effect of deer on forest regeneration
• Presence of exotic plants	• Displacement of native species, reducing biodiversity	• Prioritize species and locations/habitats for implementing control measures • Restore and maintain native species and communities
• Amphibians are not monitored	• Amphibians are an important ecosystem component	• Identify and map wetland and stream sites where monitoring could take place • Design and implement an amphibian monitoring program
• Small mammals are not monitored	• Small mammals, and bats in particular, are an important ecosystem component	• Design and implement an mammalian monitoring program, including monitoring bats in caves • Map cave systems and karst features
• Fish Index of Biotic Index (FIBI) is in poor condition	• Fish are an important ecosystem component	• Identify sensitive locations and unpack the Index to identify which measurements are showing degraded condition
• Emerald ash borer has been detected in the park	• Has the potential to spread throughout the park	• Continue to monitor for emerald ash borer in the park and implement management actions • Plan for the future forest with the absence of hemlock and ash trees • Establish a seed bank of hemlock and ash seeds

Table 5.10. Data gaps, justification, and research needs for biological integrity in HAFE.

Data gaps	Justification	Research needs
• Bird data is limited to forest species only	• Knowledge about usage of other habitats by birds is needed	• Development of indices related to bird use of other habitats (e.g., grasslands)
• Limited knowledge on how the return of larger predators (coyotes, black bears) to the region may impact ecosystems	• The return of these predators will impact populations of prey animals which in turn may impact deer tick populations and occurrence of Lyme disease	• Research and modeling into the effects of these predators on the ecosystem • Monitor occurrence and behavior of predators
• Limited knowledge on how forests might change in light of new and future stressors (climate change, pests, and diseases)	• These stressors are already present or will be present in the near future	• Research and modeling into the effects of these stressors on the region's forests

Climate change

How climate change may affect the park's resources and habitats should be an ongoing research focus, in particular how it might affect the introduction and spread of exotic species and forest pests and diseases.

Literature cited

Côté, S.D., T.P. Rooney, J.P. Tremblay, C. Dussault, and D.M. Waller. 2004. Ecological impacts of deer overabundance. Annual Review of Ecology, Evolution, and Systematics 35: 113–147.

Horsley, S.B., S.L. Stout, and D.S. deCalesta. 2003. White-tailed deer impact on the vegetation dynamics of a northern hardwood forest. Ecological Applications 31: 98–118.

5.1.4 Landscape dynamics

Landscape dynamics were in a moderate condition overall, with 54% attainment of reference conditions (Tables 5.1, 5.11). Impervious surface at both spatial scales was in very good condition, as was forest cover within the park (Table 5.12). Forest interior area within the park was in good condition, and was in moderate condition at the 5x park area scale. Road density was in very degraded condition at both spatial scales. The amount of forest cover and interior area within the park are influenced by the leased agricultural lands and developed areas within the park boundary. At the larger spatial scale, the proximity of the towns of Harpers Ferry and Bolivar, as well as developments to the south-west of the park, affects all of the landscape dynamics metrics.

Table 5.11. Summary of resource condition assessment of Landscape Dynamics in HAFE.

Metric	Condition
Forest interior area (within park)	Good
Forest interior area (within park + 5x buffer)	Moderate
Forest cover (within park)	Very good
Forest cover (within park + 5x buffer)	Very degraded
Impervious surface (within park)	Very good
Impervious surface (within park + 5x buffer)	Very good
Road density (within park + 5x buffer)	Very degraded
Road density (within park)	Very degraded
Landscape Dynamics	**Moderate**

Climate change

Research needs for the park mostly relate to its function as a habitat corridor in the region (Table 5.13). How climate change may affect the park's resources and habitats should be an ongoing research focus.

Table 5.12. Key findings, management implications, and recommended next steps for landscape dynamics in HAFE.

Key findings	Management implications	Recommended next steps
• Forest interior area and forest cover within the park are in good to very good condition, and impervious surface is in very good condition within and adjacent to the park	• Supports wildlife and slows the flow of stormwater entering park streams	• Maintain quality of existing forest habitat by managing for exotic species and forest pests
• Forest metrics were in moderate to very degraded condition adjacent to the park, and road density was very degraded at both spatial scales	• Road density may increase surface runoff/stormwater in the park, and may increase wildlife mortality • Poor forest habitat may impact wildlife habitat and movements	• Continue to maintain pervious surfaces within the park and consider installing stormwater retention basins in areas of high stormwater input • Maintain quality of existing forest habitat by managing for exotic species and forest pests

Table 5.13. Data gaps, justification, and research needs for landscape dynamics in HAFE.

Data gaps	Justification	Research needs
• Implications of external land use changes on park resources	• Connectivity of ecological processes from park to watershed	• Landscape analysis at multiple scales
• Impacts of climate change on habitat connectivity	• The park acts as a habitat corridor through the region	• Modeling of the potential effects of climate change on habitats within the park and surrounding region

Appendix A: Raw data

Table A-1. Particulate matter (μg PM2.5/m³). Site locations are shown in Figure 4.1 and thresholds are shown in Table 4.3.

Site	Years	3-year mean
240430009	2000–2002	14.8
	2001–2003	14.0
	2002–2004	14.1
	2003–2005	14.1
	2004–2006	13.8
	2005–2007	13.2
	2006–2008	12.2
	2007–2009	11.5
	2008–2010	11.0
	2009–2011	10.9
540030003	2000–2002	16.3
	2001–2003	16.4
	2002–2004	16.3
	2003–2005	16.2
	2004–2006	15.8
	2005–2007	15.9
	2006–2008	15.0
	2007–2009	14.0
	2008–2010	12.8
	2009–2011	11.8
Overall median		**14.0**

Table A-2. Water quality data. Site locations are shown in Figure 4.17 and reference conditions are shown in Table 4.11.

Site	Date	pH	DO	Temp	ANC	Cond.	NO_3	TP
HAFE_FLSP	6/2/05	8.08	8.42	17.85	4000	1005.00	4.0	
HAFE_FLSP	6/30/05	8.12	6.48	23.70	4040	581.00	3.1	
HAFE_FLSP	10/11/05	8.10	7.52	17.10	4000	583.00	3.8	
HAFE_FLSP	11/17/05	8.13	6.52	9.10	4700	737.00	4.4	
HAFE_FLSP	12/14/05	8.14	4.98	0.85	5040	698.00	5.0	
HAFE_FLSP	1/26/06	8.02	13.07	6.40	4540	628.33	9.3	
HAFE_FLSP	2/28/06	8.34	9.71	4.63	4740	600.50	9.1	
HAFE_FLSP	3/23/06	8.59	10.12	7.26	4480	1029.33	7.4	
HAFE_FLSP	4/12/06	8.50	2.97	14.30	3800	524.00	4.2	
HAFE_FLSP	5/18/06	8.33	2.10	15.00	4160	528.00	6.1	
HAFE_FLSP	6/28/06	8.10	7.45	20.60	2800	453.70	0.3	
HAFE_FLSP	7/26/06	8.24	6.61	22.00	4580	654.00	7.9	
HAFE_FLSP	8/14/06	7.67	7.28	20.50	4140	618.00	8.2	
HAFE_FLSP	10/12/06	8.19	8.86	15.75	5280	671.00	8.0	
HAFE_FLSP	11/18/06	8.35	9.83	12.47	5200	660.67	7.4	
HAFE_FLSP	12/18/06	8.51	9.22	8.80	4740	596.00	4.3	
HAFE_FLSP	1/25/07	6.97	11.68	4.40	5280	638.67	1.5	0.2838
HAFE_FLSP	2/22/07	8.59	11.83	6.30	3200	619.50	2.1	0.0848
HAFE_FLSP	3/27/07	8.19	5.82	12.40	5100	666.00	4.6	0.0914
HAFE_FLSP	4/27/07	8.41	10.13	14.90	4680	614.00	4.0	0.0750
HAFE_FLSP	6/5/07	8.26	6.89	20.00	4640	621.00	3.5	0.1729
HAFE_FLSP	7/9/07	8.23	7.53	24.50	3860	621.00	4.1	0.1436
HAFE_FLSP	8/13/07	8.19	7.07	22.70	5140	690.00	2.6	0.1762
HAFE_FLSP	8/30/07	8.25	6.69	21.50	4740	607.00	3.5	0.1958
HAFE_FLSP	10/17/07	8.22	7.83	15.40	4380	614.00	4.0	0.1272
HAFE_FLSP	11/14/07	8.29	9.26	10.40	5200	673.00	6.5	0.0555
HAFE_FLSP	12/19/07	8.39	9.60	4.12	5020	690.83	6.8	0.0848
HAFE_FLSP	1/22/08							
HAFE_FLSP	2/19/08	8.15	14.42	5.85	5180	811.50	6.0	0.0587
HAFE_FLSP	3/20/08	8.32	9.07	9.98	4540	694.25	6.2	0.1011
HAFE_FLSP	4/14/08	8.37	12.39	11.20	5080	621.50	6.5	0.0848
HAFE_FLSP	5/7/08	8.37	9.75	16.17	4960	837.33	6.5	0.0653
HAFE_FLSP	6/18/08	7.93	8.20	17.55	5200	648.67	5.9	0.0653
HAFE_FLSP	7/30/08	8.18	7.15	22.70	4448	461.58	3.7	0.1436
HAFE_FLSP	8/13/08	8.25	8.13	19.10	4600	639.00	5.5	0.0620
HAFE_FLSP	9/18/08	8.01	8.31	17.40	4520	642.50	3.8	0.1762
HAFE_FLSP	10/22/08	8.11	10.37	10.30	4460	1037.00	4.2	0.1011
HAFE_FLSP	11/19/08	8.28	11.90	3.75	5700	600.00	3.7	0.0979
HAFE_FLSP	2/4/09	8.13		2.70	6240	804.00	3.7	0.0816
HAFE_FLSP	4/6/09	8.18	5.61	13.10	5740	776.00	1.6	0.1436
HAFE_FLSP	6/9/09	8.02	6.80	21.05	4820	597.50	2.8	0.1044
HAFE_FLSP	7/8/09	8.19	7.97	19.70	4700	637.00	3.2	0.1501
HAFE_FLSP	7/21/09	8.19	7.87	21.27	5360	904.33	2.0	0.1338
HAFE_FLSP	8/17/09	8.11	6.10	24.70	5060	631.00	2.3	0.1370

Site	Date	pH	DO	Temp	ANC	Cond.	NO_3	TP
HAFE_FLSP	9/15/09	8.11	5.70	19.50	5020	727.00	1.5	0.2577
HAFE_FLSP	10/13/09	8.04	9.00	13.30	4200	629.70	2.6	0.0881
HAFE_FLSP	11/10/09	8.16	9.30	11.10	5040	659.70	2.4	
HAFE_FLSP	12/8/09	8.41	10.10	5.80	5860	796.00	2.2	0.0848
HAFE_FLSP	1/12/10	8.38	12.90	2.80	5760	756.00	4.2	0.0489
HAFE_FLSP	2/9/10							
HAFE_FLSP	3/9/10	8.42	11.70	9.95	4920	702.50	4.0	0.1436
HAFE_FLSP	4/6/10	8.20	9.05	18.90	5220	574.60	4.6	0.1729
HAFE_FLSP	5/4/10	8.21	8.25	19.30	4620	660.50	4.1	0.2382
HAFE_FLSP	6/8/10	8.18	8.40	18.80	4900	673.00	3.7	0.1011
HAFE_FLSP	7/13/10	8.22	7.30	23.90	4400	593.00	3.0	0.1533
HAFE_FLSP	8/9/10	8.19	7.20	24.50	4360	669.00	3.6	0.1109
HAFE_FLSP	9/15/10	8.17	7.20	18.10	5300	798.00	5.2	0.3654
HAFE_FLSP	10/13/10	7.46	8.95	15.05	5000	708.00	4.3	0.2414
HAFE_FLSP	11/8/10	8.20	11.60	7.60	5000	706.40	4.5	0.3034
HAFE_FLSP	12/6/10	8.30	13.30	2.90	4840	579.90	4.8	0.2055
HAFE_FLSP	1/5/11	8.31	13.30	9.30	4700	724.00	4.8	0.1892
HAFE_FLSP	2/7/11				4840		3.3	0.1077
HAFE_FLSP	3/9/11	8.22	11.65	7.40	4760	693.80	3.0	0.1827
HAFE_FLSP	4/4/11	8.38	10.90	11.85	5000	740.00	4.2	0.1338
HAFE_FLSP	5/2/11	8.19	9.20	15.70	5340	701.50	4.7	0.1370
HAFE_FLSP	6/6/11	8.20	8.15	21.05	5300	714.50	3.7	0.1892
HAFE_FLSP	7/11/11	8.23	7.15	25.80	4200	611.00	3.3	0.1501
HAFE_FLSP	8/16/11	8.23	7.90	22.10	4400	632.00	2.9	0.1468
HAFE_FLSP	9/13/11	8.25	8.05	20.60	4720	657.50	3.4	0.2577
HAFE_FLSP	11/8/11	8.16	11.50	10.60	4900	739.00	4.7	0.1436
HAFE_FLSP	12/6/11	7.88	9.75	11.50	5200	822.00	5.2	0.1925
Overall median		**8.2**	**8.4**	**15.03**	**4820**	**660.1**	**4.1**	**0.1403**

Table A-3. Deer density (deer/km^2) in HAFE. Deer monitoring sites are shown in Figure 4.29.

Year	Density
2001	39.86
2002	28.49
2003	32.04
2004	31.89
2005	59.43
2006	nd
2007	27.29
2008	29.85
Overall median	**31.89**

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