National Park Service
U.S. Department of the Interior

Natural Resource Stewardship and Science

Shenandoah National Park Natural Resource Condition Assessment

April 2017 Revision

Natural Resource Report NPS/SHEN/NRR—2017/1429

ON THE COVER
View of Shenandoah National Park
Photograph courtesy of Kevin Kelley

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Executive Summary

Background

Shenandoah National Park comprises 79,900 hectares (ha) of land in Virginia. The park is famous for its 167 kilometer (km) recreational highway, Skyline Drive, which runs the entire length of the park along the crest of the Blue Ridge Mountains and parallel to a portion of the Appalachian Trail.

The park's biota and natural features include: well-exposed strata of the Appalachians, one of the oldest mountain ranges in the world; diverse animal and plant populations and habitats; migratory bird breeding habitat and stopover points; and forested watersheds that perpetuate numerous streams flowing from uplands to lowlands. Many of these park features and resources are threatened by poor air quality (which decreases visibility of vistas), acid precipitation (which degrades water quality), and invasive plants and pests (which threaten forest health). Due to its linear shape, visibility and air quality in Shenandoah National Park is threatened by encroachment of animals, plants, and in some cases, people, as a result of surrounding land use changes.

The National Park Service has implemented numerous monitoring programs within the park that are aimed at informing park managers of changes in habitat quality and/or species populations. These monitoring programs create numerous long-term datasets, which allow park managers to assess variability over time, and also formed the basis of this Natural Resource Condition Assessment.

Natural Resource Condition Assessment

Assessment of natural resource condition within SHEN was carried out using the National Park Service Inventory and Monitoring Program Vital Signs ecological monitoring framework. The park was categorized into six reporting areas (Figure E-1) based on two altitudes and three major geology types underlying Shenandoah National Park:

- Low-moderate / Siliciclastic (<915 m elevation)
- Low-moderate / Metabasaltic (<915 m elevation)
- Low-moderate / Granitic (<915 m elevation)
- High / Siliciclastic (>915 m elevation)
- High / Metabasaltic (>915 m elevation)
- High / Granitic (>915 m elevation)

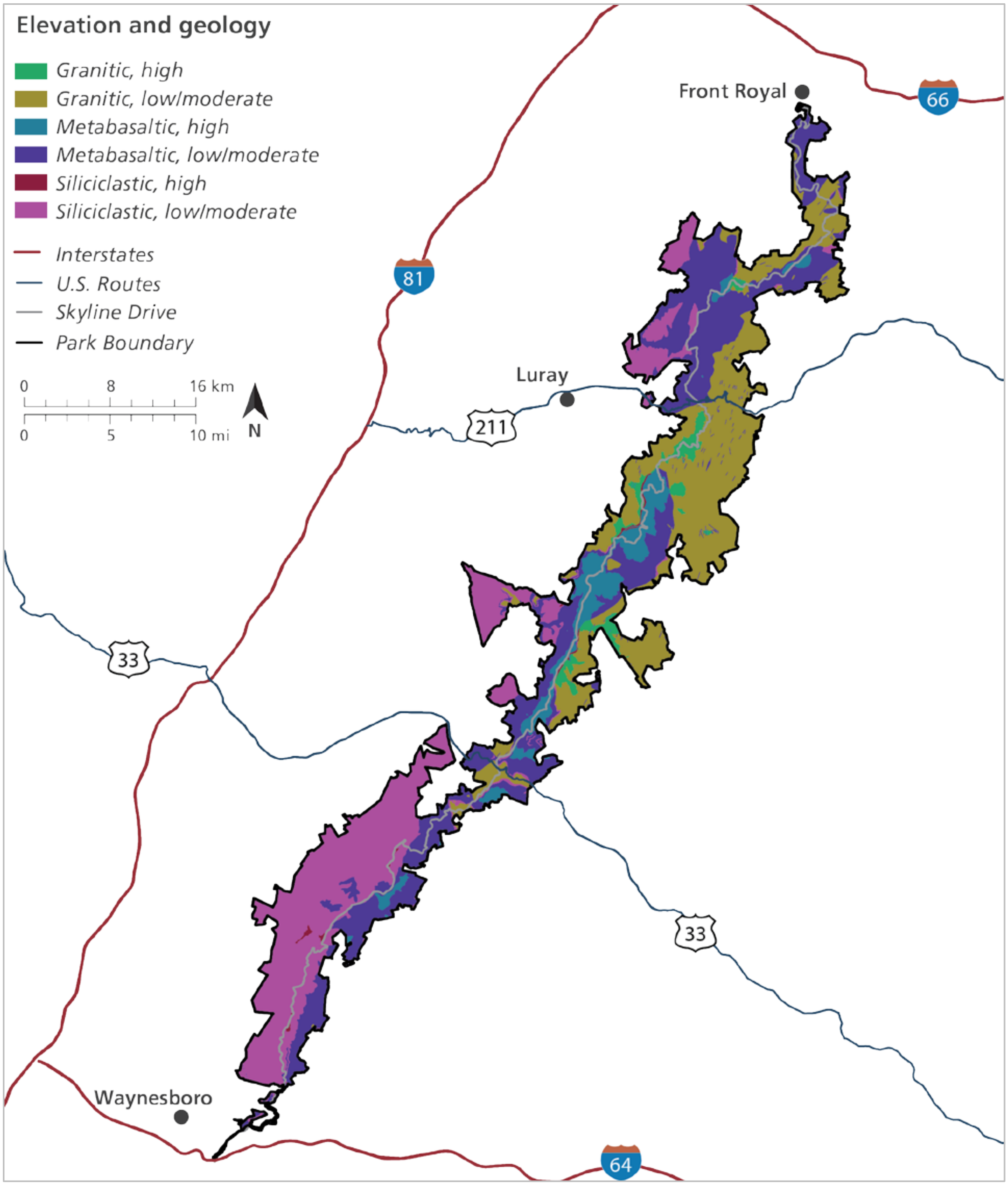


Figure E-1. Park delineation by geology and elevation. Derived from Young *et al.* (2009).

Thirty-one metrics were analyzed for 14 indicators grouped into four categories: Air Resources, Terrestrial Resources, Aquatic Resources, and Landscape Dynamics. The assessment of condition was based on the comparison of recent available data collected over the past five years (typically 2009-2013) to ecological threshold values derived from the scientific literature. When information was not available on peer-reviewed ecological thresholds, regulatory and management-based thresholds were used (Figure E-2).

Reference condition attainment of metrics was calculated based on the percentage of sites or samples that met or exceeded threshold values set for each metric. An attainment score of 100% reflected that the metric at all sites and at all times met the reference condition identified to maintain natural resources. Conversely, a score of 0% indicated that no sites at any sampling time met the reference condition value. Metric attainment scores were calculated for each geo-elevation reporting area where possible. The park condition was calculated as an unweighted mean of the six geo-elevation class scores. Indicator scores were calculated as an unweighted mean of all metrics relevant to the indicator.

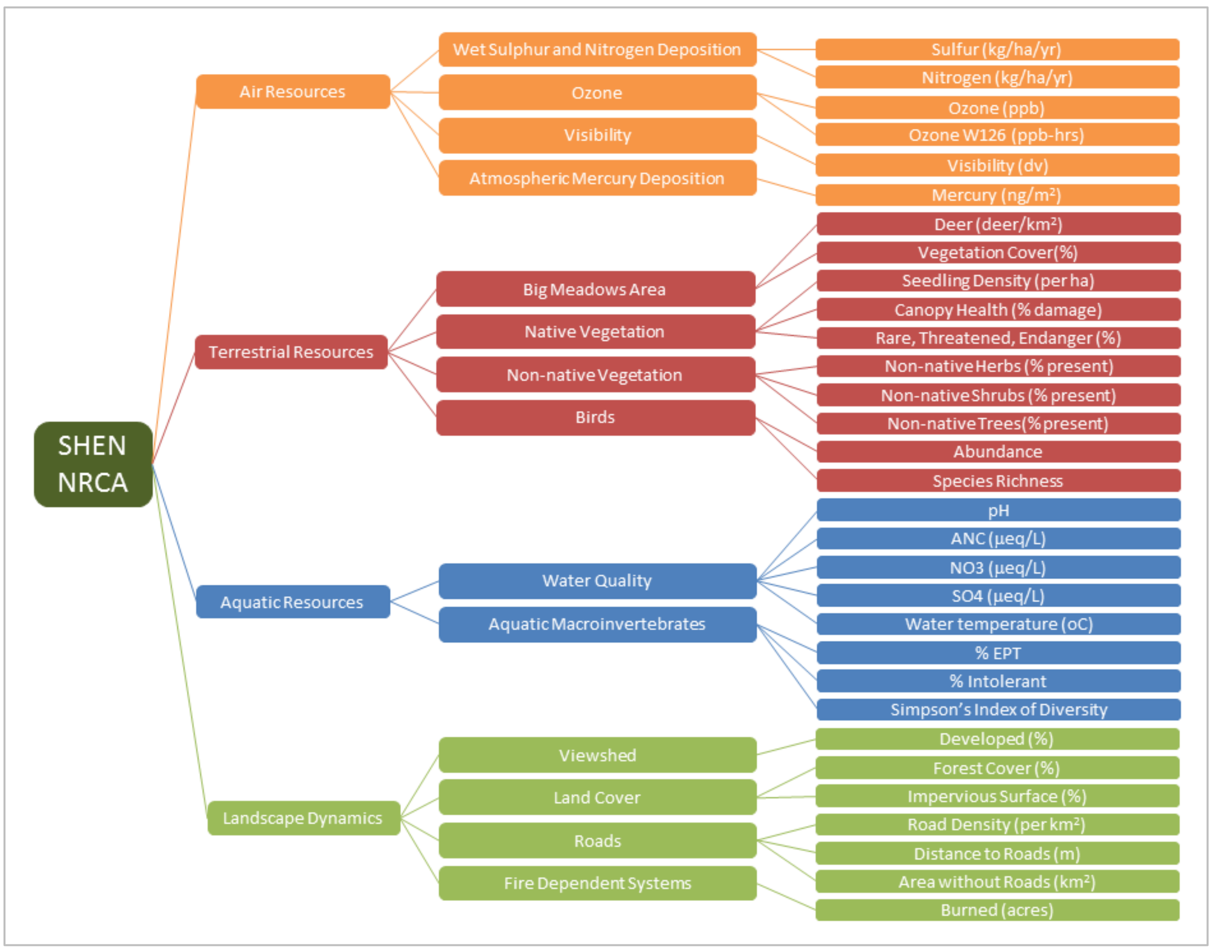


Figure E-2. Vital sign indicators and associated metrics chosen for this Natural Resource Condition Assessment of Shenandoah National Park.

Indicators and reporting areas were assigned a qualitative rating (Figure E-3) corresponding to the quantitative score:

- Significant concern (0-25% reference condition attainment),
- Moderate condition (26-75% reference condition attainment), and
- Good condition (76-100% reference condition attainment).

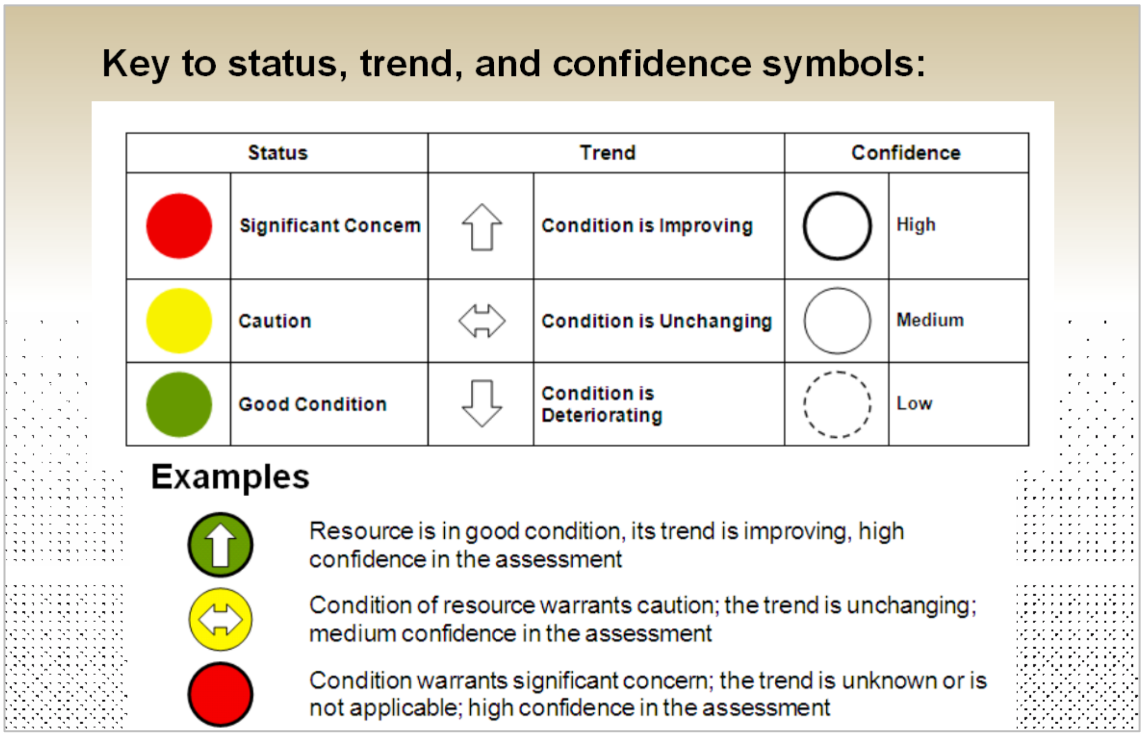


Figure E-3. Status, trend, and confidence symbols for indicators corresponding to quantitative scores.

Strong collaboration with park natural resource staff was essential to the success of this assessment. Project collaboration and exchange of data occurred throughout the project by way of scoping meetings, site visits, and follow-up phone calls with park staff. Outcomes of these discussions helped identify natural resources to be included in the assessment, identify key metrics to assess the condition of these resources, assign geo-elevation reporting areas, and develop desired or target thresholds for the metrics. Park staff also provided the majority of the data used in the report and provided important context and background information not necessarily available in published form.

Overall, the natural resources of Shenandoah National Park were in **moderate condition –** based on significant concern for air resources, and moderate concern for terrestrial and aquatic resources and landscape dynamics.

Table E-1. Summary condition table for natural resources at Shenandoah National Park.

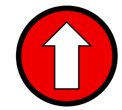
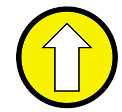
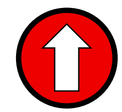
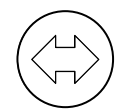
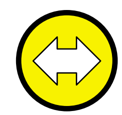
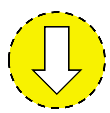
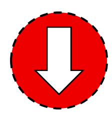
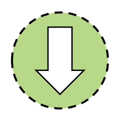
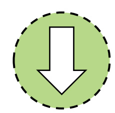
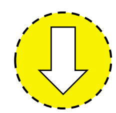
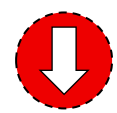
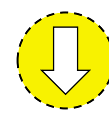
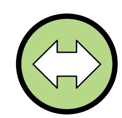
Resource Type	Metric	Geo-elevation Condition < 915 m			Geo-elevation Condition > 915 m			Park Status	Resource Status
		Granitic	*Metabasaltic*	*Siliciclastic*	*Granitic*	*Metabasaltic*	*Siliciclastic*		
Air Resources	Wet sulphur and nitrogen deposition	Insufficient data	Insufficient data	Insufficient data	Insufficient data	Insufficient data	Insufficient data		24%
	Ozone	Insufficient data	Insufficient data	Insufficient data	Insufficient data	Insufficient data	Insufficient data		
	Visibility	Insufficient data	Insufficient data	Insufficient data	Insufficient data	Insufficient data	Insufficient data		
	Atmospheric mercury deposition	No threshold available	No threshold available	No threshold available	No threshold available	No threshold available	No threshold available		
Terrestrial Resources	Big Meadows Area	Not applicable	Not applicable	Not applicable	Not applicable	Not applicable	Not applicable		58%
	Non-native vegetation								
	Birds	Insufficient data	Insufficient data	Insufficient data	Insufficient data	Insufficient data	Insufficient data		

Table E-1 (continued). Summary condition table for natural resources at Shenandoah National Park.

		Geo-elevation Condition < 915 m			Geo-elevation Condition > 915 m				
Resource Type	**Metric**	***Granitic***	***Metabasaltic***	***Siliciclastic***	***Granitic***	***Metabasaltic***	***Siliciclastic***	**Park Status**	**Resource Status**
Aquatic Resources	**Water quality**						**Insufficient data**		**73%**
	Aquatic macro-invertebrates				**Insufficient data**		**Insufficient data**		
Landscape Dynamics	**Viewshed**								59%
	Land cover								
	Roads								
	Fire dependent systems								

Air resources

Air resources in Shenandoah National Park were of ***significant concern***, with wet sulfur and nitrogen deposition, ozone, and visibility all individually displaying levels of significant concern. Despite current poor air quality scores, air quality indicators are showing an overall improvement over recent decades, which will have positive implications for the parks natural ecosystems, particularly those with underlying siliciclastic geology (Table E-2).

Table E-2. Key findings, management implications, and recommended next steps for air resources in Shenandoah National Park.

Key findings	**Management implications**	**Recommended next steps**
Air quality is of significant concern and is a regional problem	Ecological impacts from acidic deposition (i.e. acid rain).	Support regional air quality initiatives such as Climate Friendly Parks. (www.nps.gob/climatefriendlyparks) Develop park-specific management actions. Stay engaged with the wider community in terms of air quality education and activities. Monitor recovery of ecosystems as/if air quality continues to improve.
Minimal soundscape information	Traffic noise from roadways potentially affects wildlife distribution and recreational experience. Effect is greater in fall and winter when foliage not able to dampen noise.	Conduct a noise/soundscape study to determine if management is required.

Terrestrial resources

Terrestrial resources in Shenandoah National Park were of ***moderate concern***. Birds, forest vegetation, and rare, threatened, endangered plants were generally in stable, good condition (Table E-3).Vegetation conditions in Big Meadows have improved with the implementation of mowing and burning management since 2000, but those gains are in danger of being lost as shrub cover has increased in the upland region of the meadow since 2004. Deer overpopulation is a significant problem throughout the Mid-Atlantic and the population levels observed in the Big Meadows Area fall within the general range of concern observed within other parks of the region. Non-native plant invasions represent an increasing threat throughout the park.

Table E-3. Key findings, management implications, and recommended next steps for terrestrial resource in Shenandoah National Park.

Key findings	Management implications	Recommended next steps
Overabundant deer populations and continuing problems with shrub encroachment in the Big Meadows Area (BMA)	Open landscapes have both natural and cultural resource benefits. Impaired meadow would reduce visitor experience.	Continue mowing/prescribed burning management with photopoint and vegetation monitoring of the main meadow with consideration of fall burns. Extend deer surveys beyond BMA and monitor for chronic wasting disease. Study deer effects on vegetation and interactions with non-native species.
Park is host to at least 58 rare plant species and a biodiverse forest vegetation with stable regeneration of native species but possibly declining canopy condition	Diversity and health of native vegetation acts as early warning of environmental stress. Provides habitat for diverse fauna. Interacts with stream water quality and quantity.	Continue forest vegetation monitoring and rare plant monitoring protocols that provide vital data on park trends. Expand monitoring for early detection of non-native species and expand treatment efforts for invasive plants. Educate public to reduce impacts of harmful introductions such as the emerald ash borer.
Bird populations remain diverse though abundance appears to be declining	Healthy bird populations are vital to visitor experience. Potential proxy/indicator for changes in habitat suitability within park or along flight-path. Provide seed dispersal within the park.	Investigate causes of declining bird populations. Investigate impacts of ongoing declines in bird populations to park ecology.

Aquatic resources

Aquatic resources in Shenandoah National Park were in ***moderate condition***, based on water quality and macroinvertebrates assessments (Table E-4). Lowest scores for all aquatic resource indicators belonged to the Siliciclastic geology, reflecting the susceptibility of this geology type to acidification. The assessment of aquatic resources was limited by insufficient data at high elevations and particularly in High (>915 m) Siliciclastic geologies, making overall comparisons between elevations not possible.

Table E-4. Key findings, management implications, and recommended next steps for aquatic resource in Shenandoah National Park.

Key findings	Management implications	Recommended next steps
Significant concern for pH and ANC in streams with underlying siliciclastic geology classes	Acidic conditions affect stream flora and fauna. Reduces biodiversity and quality of visitor experience.	Gather additional data for water quality in high elevations. Investigate liming options for increasing stream pH
Moderate – significant concern for temperature across all geo-elevation classes	Affects stream flora and fauna. Reduces biodiversity and quality of visitor experience.	Implement stream restoration and shading via restored riparian vegetation in disturbed areas.
Lack of reference condition for native fish size and abundance	Unable to adequately assess condition of fish in this report. No clear long-term vision for fish restoration.	Develop goal for native fish restoration.

Landscape dynamics

Landscape dynamics in Shenandoah National Park were in ***moderate condition*** (Table E-5). The viewshed and largely intact forest cover are distinctive attributes of the park, although land cover changes outside of the park are a concern. Paved and unpaved roads bisect the park, especially Skyline Drive at high elevations, but are generally less abundant in the park than in the surrounding landscape. A legacy of fire suppression is a primary concern, and the park has begun conducting prescribed fires in dry oak and pine ecosystems in an effort to restore the ecological resilience and integrity of these forested communities. Prescribed fires will be implemented during dormant and growing seasons with a targeted rotation of every 5-7 years. The park is authorized in the 2006 Fire Management Plan to manage wildfire for multiple objectives, which may include natural resource benefit.

Table E-5. Key findings, management implications, and recommended next steps for landscape dynamics in Shenandoah National Park.

Key findings	Management implications	Recommended next steps
Viewsheds comprised of nearly 10% developed land	Worsening trend has potential to impair visitor experience.	Maintain dialogue with George Washington & Jefferson National Forest and other neighbors about future land use/ land cover trajectories, especially for locations viewable from multiple park vantage points. Monitor how improving air quality affects range of visibility. Gather additional data on sensitivity of visitors to development in the viewshed.
Intact forest land cover of diverse community associations is a primary natural resource asset	Forest core habitat contributes to park biodiversity. Large forest patches are central to wilderness experience.	Track any significant changes in forest extent potentially triggered by emergent forest pests and pathogens. Consider periodically updating the park-level detailed mapping of forest vegetation associations.
Paved roads concentrated in the upper elevations of the park	Fragmentation and pollution effects are possible from paved and unpaved roads.	New road development within the park could consider the spatial balance of existing roads and avoid regions of highest density. Continue studies of possible runoff effects adjacent and downslope of roads.
Legacy of fire suppression has negatively impacted fire-tolerant forest communities	Fuel build-ups lead to forest fire danger and potentially hotter fires. Altered fire regime may affect forest assemblage and habitat quality.	Manage ignitions for natural resource benefit in identified fire dependent vegetation associations. Continue monitoring of fire effects and link observations to fire prescriptions. Consider interactions of fire with other disturbance vectors on the landscape.

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Chapter 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." NRCAs also report on trends in resource condition (when possible), identify critical data gaps, and characterize a general level of confidence for study findings. The resources and indicators emphasized in a given project depend on the park's resource setting, status of resource stewardship planning and science in identifying high-priority indicators, and availability of data and expertise to assess current conditions for a variety of potential study resources and indicators.

> ***NRCAs Strive to Provide…***
>
> - *Credible condition reporting for a subset of important park natural resources and indicators*
> - *Useful condition summaries by broader resource categories or topics, and by park areas*

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 reference conditions/values for comparison against current conditions;[3]
- Emphasize spatial evaluation of conditions and GIS (map) products; [4]
- Summarize key findings by park areas; and [5]
- Follow national NRCA guidelines and standards for study design and reporting products.

Although the primary objective of NRCAs is to report on current conditions relative to logical forms of reference conditions and values, NRCAs also report on trends, when appropriate (i.e., when the underlying data and methods support such reporting), as well as influences on resource conditions. These influences may include past activities or conditions that provide a helpful context for

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[1] 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. 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-up response (e.g., ecological thresholds or management "triggers").

[4] As possible and appropriate, NRCAs describe condition gradients or differences across a park for important natural resources and study indicators through a set of GIS coverages and map products.

[5] 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.

understanding current conditions, and/or present-day threats and stressors that are best interpreted at park, watershed, or landscape scales (though NRCAs do not report on condition status for land areas and natural resources beyond park boundaries). Intensive cause-and-effect analyses of threats and stressors, and development of detailed treatment options, are outside the scope of NRCAs.
Due to their modest funding, relatively quick timeframe for completion, and reliance on existing data and information, NRCAs are not intended to be exhaustive. Their methodology typically involves 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 existing data and knowledge bases across the varied study components.

The credibility of NRCA results is derived from the data, methods, and reference values used in the project work, which are designed to be appropriate for the stated purpose of the project, as well as adequately documented. For each study indicator for which current condition or trend is reported, we will identify critical data gaps and describe the 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. These staff will be asked to assist with the selection of study indicators; recommend data sets, methods, and reference conditions and values; and help provide a multi-disciplinary review of draft study findings and products.

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 both credible and has practical uses for a variety of park decision making, planning, and partnership activities.

Important NRCA Success Factors

- *Obtaining good input from park staff and other NPS subject-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*

However, it is important to note that NRCAs do not establish management targets for study indicators. That process must occur through park planning and management activities. What an NRCA can do is deliver science-based information that will assist park managers in their ongoing, long-term efforts to describe and quantify a park’s desired resource conditions and management targets. In the near term, NRCA findings assist strategic park resource planning[6] and help parks to report on government accountability measures.[7] In addition, although in-depth analysis of the effects of climate change on park natural resources is outside the scope of NRCAs, the condition analyses and data sets developed for NRCAs will be useful for park-level climate-change studies and planning efforts.

NRCAs also provide a useful complement to rigorous NPS science support programs, such as the NPS Natural Resources Inventory & Monitoring (I&M) Program.[8] 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 draw upon non-NPS data to help evaluate current conditions for those same vital signs. In some cases, I&M data sets are incorporated into NRCA analyses and reporting products.

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* ***(longer-term strategic planning)***
- *Communicate succinct messages regarding current resource conditions to government program managers, to Congress, and to the general public* ***("resource condition status" reporting)***

Over the next several years, the NPS plans to fund an NRCA project for each of the approximately 270 parks served by the NPS I&M Program. For more information visit the NRCA Program website.

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[6]An NRCA can be useful during the development of a park's Resource Stewardship Strategy (RSS) and can also be tailored to act as a post-RSS project.

[7] 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.

[8] The I&M program consists of 32 networks nationwide that are implementing "vital signs" monitoring in order to assess the condition of park ecosystems and develop a stronger scientific basis for stewardship and management of natural resources across the National Park System. "Vital signs" are a subset of physical, chemical, and biological elements and processes of park ecosystems that are selected to represent the overall health or condition of park resources, known or hypothesized effects of stressors, or elements that have important human values.

Chapter 2. Introduction and Resource Setting

The park comprises 79,900 hectares (ha) of land, including 32,204 ha of designated wilderness, all bounded by eight counties in Virginia: Albemarle, Augusta, Greene, Madison, Page, Rappahannock, Rockingham, and Warren. The park is famous for its 167 kilometer (km), recreational highway, Skyline Drive, which runs the entire length of the park along the crest of the Blue Ridge Mountains and parallel to a portion of the Appalachian Trail.

The park's biota and natural features include: well-exposed strata of the Appalachians, one of the oldest mountain ranges in the world; diverse animal and plant populations and habitats; migratory bird breeding habitat and stopover points; and forested watersheds that perpetuate numerous streams flowing from uplands to lowlands. Today, many of these park features and resources are threatened by poor air quality (which decreases visibility of vistas), acid precipitation (which degrades water quality), and invasive plants and pests (which threaten forest health). Shenandoah National Park is threatened by encroachment of animals, plants, and in some cases, people, as a result of surrounding land use changes.

The I&M program implemented numerous monitoring programs within the park aimed at informing park managers of changes in habitat quality and/or species populations. These monitoring programs create numerous long-term datasets for park managers to assess variability over time and form the basis of this Natural Condition Resource Assessment.

2.1 History and enabling legislation

The Southern Appalachian National Park Commission (S.A.N.P.C.) was authorized by Congress in 1924 to investigate potential sites in the eastern United States for a large national park. In its final report to Congress, the Commission recommended two sites: the Great Smoky Mountains and the Blue Ridge of Virginia which was later to become Shenandoah National Park (Department of the Interior, 1931).

Shenandoah National Park was authorized by an Act of Congress on May 22, 1926 (44 Stat. 616) and established on December 26, 1935. President Franklin Delano Roosevelt delivered the keynote speech during the original dedication at Big Meadows in Shenandoah National Park on July 3, 1936 (Figure 2-1, Figure 2-2). As per the 1916 Act to establish a National Park Service (Organic Act) (39 Stat. 535), the National Park Service was now responsible for administration, protection, and development of Shenandoah National Park. A series of private land donations and expenditures by the Commonwealth of Virginia lead to the official establishment of the park by 1935 (Conners 1988; Lambert 1989; Moore 2003). In 1976, 32,204.48 ha (79,579 ac) of the 79,900.63 ha (197,438.76 ac) park area were designated as wilderness under the Wilderness Act (Public Law [PL] 04-567) requiring special provisions in the management of these lands.

Figure 2-1. President Franklin Delano Roosevelt delivers the keynote speech during the original dedication at Big Meadows in Shenandoah National Park on July 3, 1936. Photo credit: National Park Service.

Figure 2-2. President Franklin Delano Roosevelt arrives at Big Meadows in Shenandoah National Park during the original July 3, 1936 dedication ceremony. Photo credit: National Park Service.

Part of Shenandoah National Park's purpose is to maintain the 167 km recreational highway, Skyline Drive, which was the first of its type in the United States when it was opened to the public in 1934 (Conners 1988). Camp Hoover, the Rapidan Camp (summer retreat) of President Herbert Clark Hoover, is a National Historic Landmark and adds a significant cultural element to the landscape (Mahan 2006). President Hoover donated the 66 ha (164 ac) complex to Shenandoah when he left office. Additionally, the Civilian Conservation Corps aided in the construction of overlooks and comfort stations along Skyline Drive, and had six camps within the park boundary. These camps became the foundation of visitor facilities within the park (Mahan 2006).

Shenandoah National Park is also host to a portion of the 3500+ km Appalachian Trail. The National Park Service Park must administer this section of the trail as a National Scenic Trail (PL 90-543).

Figure 2-3. Construction of Neighbor Mt. Spur Trail East of Pulpit Rock. Photo credit: National Park Service.

2.2 Geographic setting

2.2.1 Park description

Shenandoah National Park is located in northwestern Virginia and lies closer to more people than any other park in the country (Figure 2-4) (Conners 1988). Shenandoah National Park lies along the Blue Ridge Mountains, which are the eastern-most remnant of the ancient Appalachian mountain chain (Mahan 2006). The park is divided into three management districts: North, Central, and South. Elevations vary from 171 m (561 ft) near the north end of the park to 1,234 m at Hawksbill Summit.

2.2.2 Land use

Approximately 95% of Shenandoah National Park is dominated by forested land cover, 2% is covered by wetland communities, and about 3% of the area is occupied by other natural communities such as barrens (Mahan 2006)(Figure 2-6). Roughly 2% of Shenandoah National Park is developed or disturbed by humans and includes drivable roads, parking lots, power line right of ways, and buildings (Mahan 2006; Young et al. 2006a). U.S. Routes 211 and 33 run east and west of the park. Shenandoah National Park has an extensive network of unpaved roads that is used for management activities, fire control, and rescue operations (Vana-Miller and Weeks 2004). Due to its linear shape, visibility and air quality in Shenandoah National Park is threatened by encroachment of animals, plants, and in some cases, people, as a result of surrounding land use changes.

2.2.3 Population

Shenandoah National Park is located in parts of eight counties in Virginia: Albemarle, Augusta, Greene, Madison, Page, Rappahannock, Rockingham, and Warren. Albemarle County’s population has grown considerably in recent years (Figure 2-7), increasing 17.21% between 2000 (population 84,622) and 2010 (population 99,186). Adjacent Green County has also undergone considerable growth, increasing 20.06% between 2000 (population 15,360) and 2010 (population 18,441). To the north of the park, Warren County has grown 18.91% during the period 2000-2010, compared to 12.93% statewide in Virginia (United States Census Bureau).

Figure 2-4. Location of Shenandoah National Park in northwestern Virginia. Source: U.S. Geological Survey, National Geospatial Technical Operations Center, 2014 (Watershed Boundary Dataset).

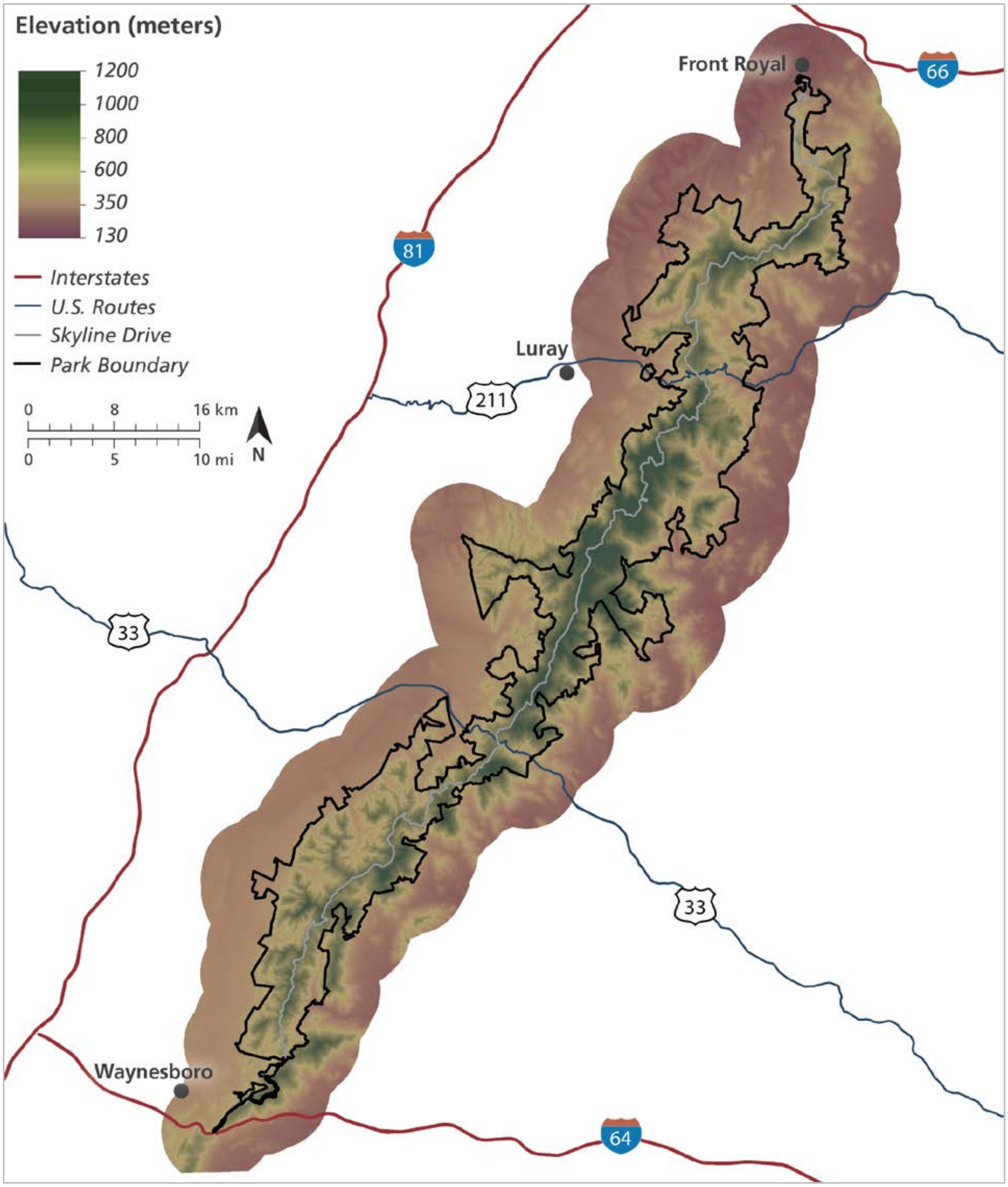

Figure 2-5. Elevation map of Shenandoah National Park. Source: U.S. Geological Survey National Elevation Data (NED)

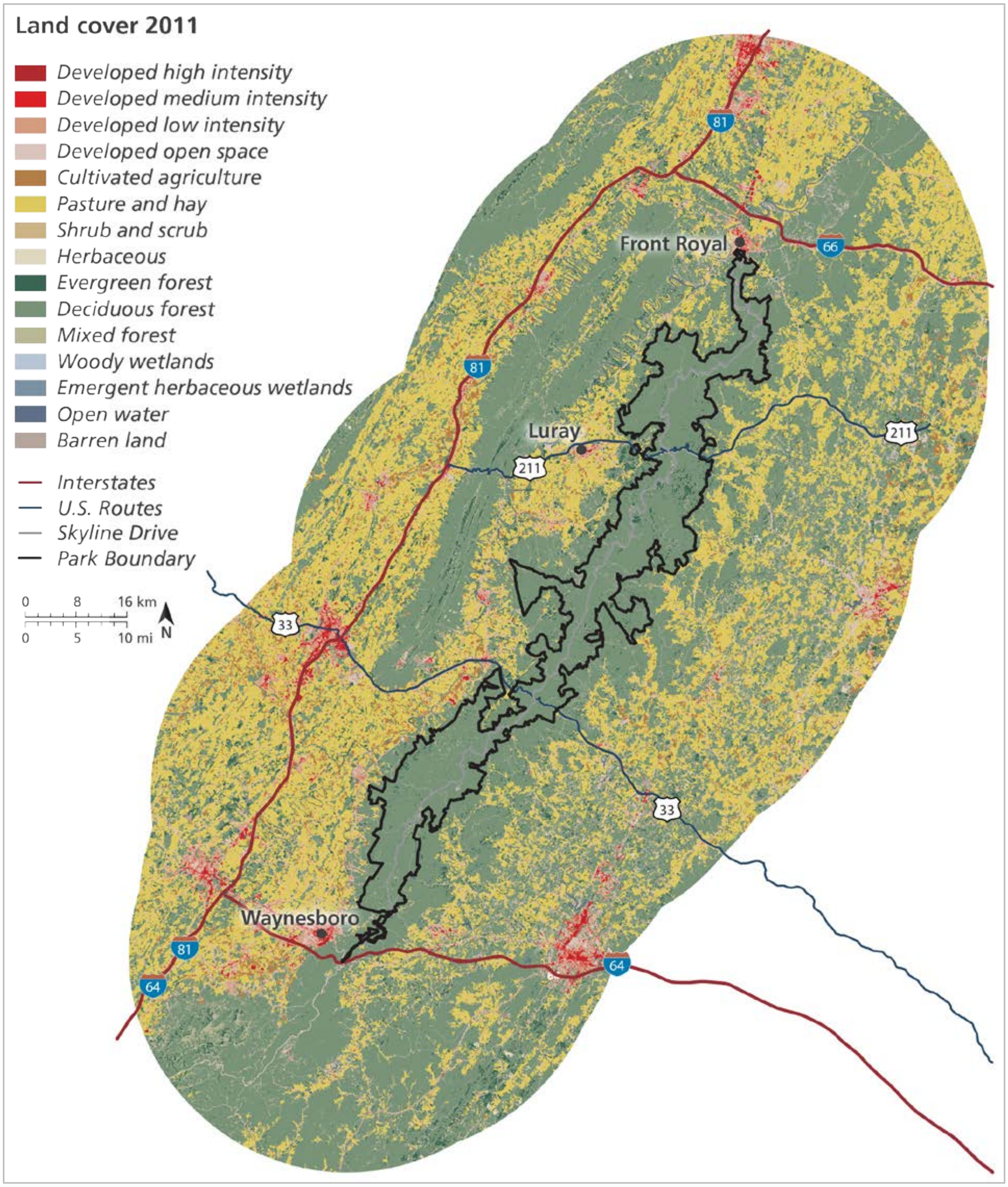

Figure 2-6. Land cover surrounding and within 30 km of the Park boundary. Source: 2011 National Land Cover Dataset (NLCD).

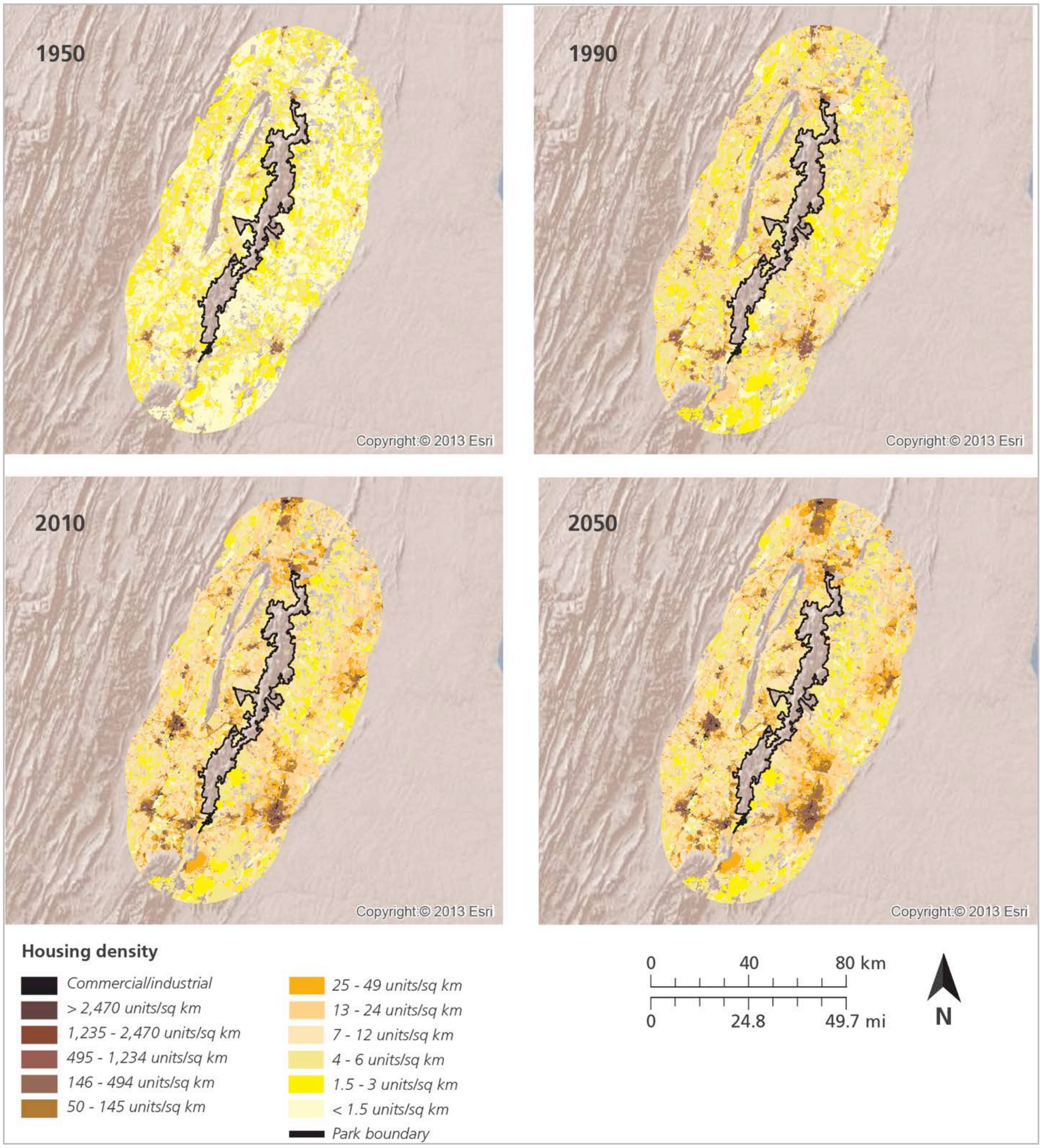

Figure 2-7. Housing density changes over time within 30 km of the Park boundary. Source: National Park Service Office of Inventory, Monitoring, and Evaluation, published 2009.

2.2.4 Climate

Temperatures in Shenandoah National Park are quite variable across its high relief. Temperatures in January range from about -7°C–4°C and in July from about 14–24°C. Higher elevation areas of the park experience winters that are moderately cold and summers that are relatively cool. Mean maximum daily temperatures in July average about 3.3°C cooler at Big Meadows than in the lowland areas of the park.

West-northwest winds predominate in all months, with secondary maximum frequency from the northwest (Gawtry and Stenger 2007). Snow and ice are common in the winter and storms can cause considerable damage to trees within the park. When sufficiently cold air comes into Virginia from the west and the northwest, frontal storms can bring heavy snowfall. Thunderstorms occur in all months of the year, but are most common during the summer. Precipitation is well distributed through the year, with maximum in September and minimum in February (Davey *et al.* 2006). Most locations receive 100–150 cm of precipitation per year. The average annual precipitation at Big Meadows is 132 cm, which includes about 94 cm of snow, whereas at the lowland area of Luray, the average annual precipitation is 91 cm, with about 43 cm of snow (Figure 2-8).

Figure 2-8. Snow and ice are common in winter in Shenandoah National Park. Photo credit: National Park Service.

2.2.5 Visitation statistics

According to the National Park Service Public Use Statistics Office, over one million visitors travel to Shenandoah National Park each year. Visitors to Shenandoah National Park primarily use the park for recreation, which includes hiking, camping, birdwatching, wildlife viewing, picnicking, photography, bicycling, fishing, and horseback riding. In 2014, 22% of visitors overnight stayed in the park, and the park ranked 13th in the National Park Service system for overnight backcountry camping in 2014 (National Park Service Visitor Use Statistics - https://irma.nps.gov/Stats/).

Skyline Drive traverses north to south along the crest of the Blue Ridge Mountains in Shenandoah National Park and is the only public road through the park (Figure 2-9). The Drive has 75 overlooks of the Shenandoah Valley to the west and rolling piedmont to the east.

Figure 2-9. Skyline Drive in Shenandoah National Park. Photo credit: Adam Fagen.

While visitation has dropped significantly since the peak of nearly 2.8 million in 1978, it has been fairly steady for the last four years (Figure 2-10).

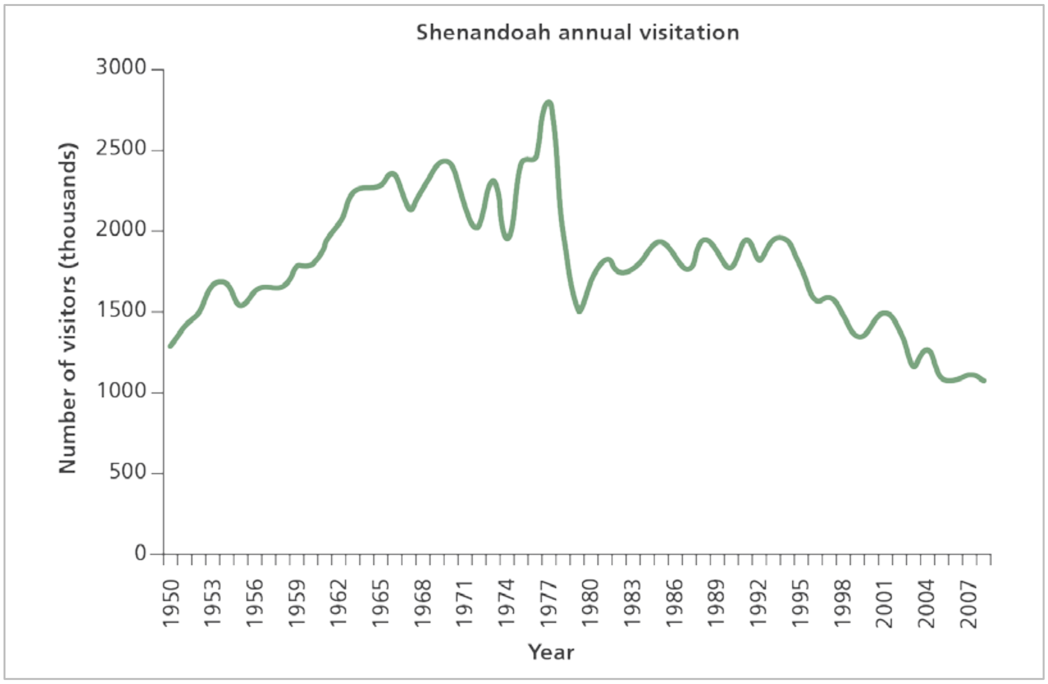

Figure 2-10. Annual visitation to Shenandoah National Park. Source: National Park Service Public Use Statistics Office.

Monthly visitation peaks in October when scenic fall foliage draws many visitors to the park, and is lowest in winter (approximately 10-fold lower) (Figure 2-11).

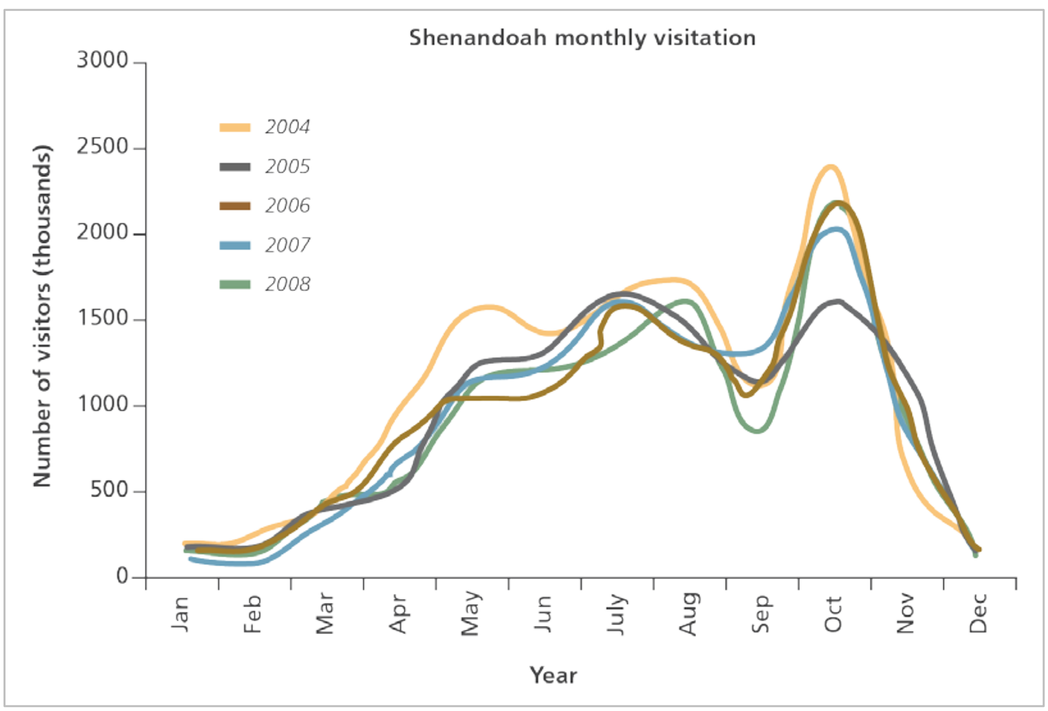

Figure 2-11. Monthly visitation to Shenandoah National Park. Source: National Park Service Public Use Statistics Office.

Vehicles entering the park pass through one of the four entrance stations to pay an entrance fee for admission to the park. Front Royal, VA, the northernmost entrance and the most convenient entrance point for travelers arriving from Washington DC, accounts for approximately one-third of all vehicles that arrive at the park. The Thornton Gap Entrance Station is about 40 km south of the Front Royal entrance and accounts for approximately 25% of vehicles entering the park. The Swift Run Entrance Station is located about 55 km south of the Thornton Gap entrance, and accounts for approximately 20% of park traffic. Rockfish Gap is the southernmost entrance to Shenandoah National Park and is located about 64 km south of the Swift Run Entrance Station, and accounts for approximately 15% of vehicles that arrive at the park. Approximately 5% of park entries are via hiking trailheads located at the park boundary.

2.3 Natural resources

The range of elevation, slopes and aspects of mountain and hillsides, rock and soil types, precipitation conditions, and latitude interact to create a variety of habitats within Shenandoah National Park. However, prior to park establishment, people had harvested and used the resources of these mountains for almost 200 years. Timbering, grazing, hunting, and cultivation ceased when these lands became a national park.

2.3.1 Geology

Shenandoah National Park lies within 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 the Earth’s crust. Once taller than the Rocky Mountains are today, these mountains have been worn down by wind, rain, and ice (Thornberry-Ehrlich 2014).

The park is underlain by three major rock types (Figure 2-12, Figure 2-13):

- Granitic “Basement”,
- Siliciclastic “Chilowee”, and
- Metabasaltic “Greenstone”.

Figure 2-12. Rock types in Shenandoah National Park. Photo credit: Adam Fagen.

The oldest rocks in Shenandoah National Park, Basement Rocks, date back a billion years and are a complex set of igneous and metamorphic rocks that occur mostly along the base of the Blue Ridge Mountains, forming the "foundation" upon which all other rocks in the park lie. Basement rock crops out in the eastern Blue Ridge Mountains and the adjoining foothills, but also underlies peaks such as Old Rag Mountain, Mary's Rock, and Roundtop.

The youngest rocks within Shenandoah National Park, Chilhowee metasedimentary rocks, date back to the Cambrian period over 500 million years ago when a vast ocean spread across what is now eastern North America depositing thick layers of sediments as it rose and fell. In Shenandoah, a few thousand meters of these sediments records the early history of this ocean, called Iapetus (after the mythical father of Atlantis). Long after their deposition, and subsequent hardening into rock, these units were deformed by the heat and pressure associated with the formation of the Appalachian Mountains. The originally flat layers were folded, faulted, and otherwise deformed, and under these conditions underwent subtle changes that affect their composition and appearance. The Chilhowee Group is best exposed in the South District of the Park. It rarely appears in the Central, but is exposed in a few places in the North, especially around Knob and Neighbor Mountains.

Perhaps the most unique rocks in Shenandoah National Park are the greenstones, old lava flows that now cap many of the highest peaks in the park. These rocks formed around 570 million years ago, when two tectonic plates began to spread apart along a system of rifts releasing molten rock onto the surface as lava eventually covering over 6,400 km2. Together, the related lava flows in Virginia, Maryland, and southern Pennsylvania are called the Catoctin Formation. The Catoctin formation is upwards of 700 m thick in the park, and thins towards the west and southwest (Southworth et al. 2009). It forms an extensive unit in the park, and is characterized by metabasaltic greenstone with thin layers of meta-arkose, phylitte, and epiclastic breccia (Southworth et al. 2009). Excellent exposures of greenstone can be found at the summits of Mount Marshall, Stony Man Mountain, Little Stony Man, Hawksbill, Blackrock Central (at Big Meadows Lodge), Bearfence Mountain, Pass Mountain, Loft Mountain, and Hightop Mountain.

The local topography and geology of Shenandoah National Park greatly influences soil profile thickness and properties within the park (Figure 2-14). In general, soils derived from the quartzites and sandstones (siliciclastic rock) tend to produce sandy, low-fertility soils. Profiles are typically thin, and distinct floras concentrate in these conditions, including chestnut oaks and huckleberries. When disturbed by fire or clear cutting, sandy soils have a moderate susceptibility to erosion.

In contrast, the Catoctin greenstones weather to soils that have clay content and thick B horizon. Due to the high cohesion of these soils, their susceptibility to erosion is minimal. Flora requiring high fertility, including some globally rare plant communities, prefer the greenstone soils due to the calcium and magnesium released during the weathering processes.

Finally, the granites and gneisses initially weather to sandy soils and are comprised primarily of quartz and feldspar. With time, the feldspars (initially sand-sized) weather to clay minerals, thereby decreasing the amount of sand while increasing the percentage of clay.

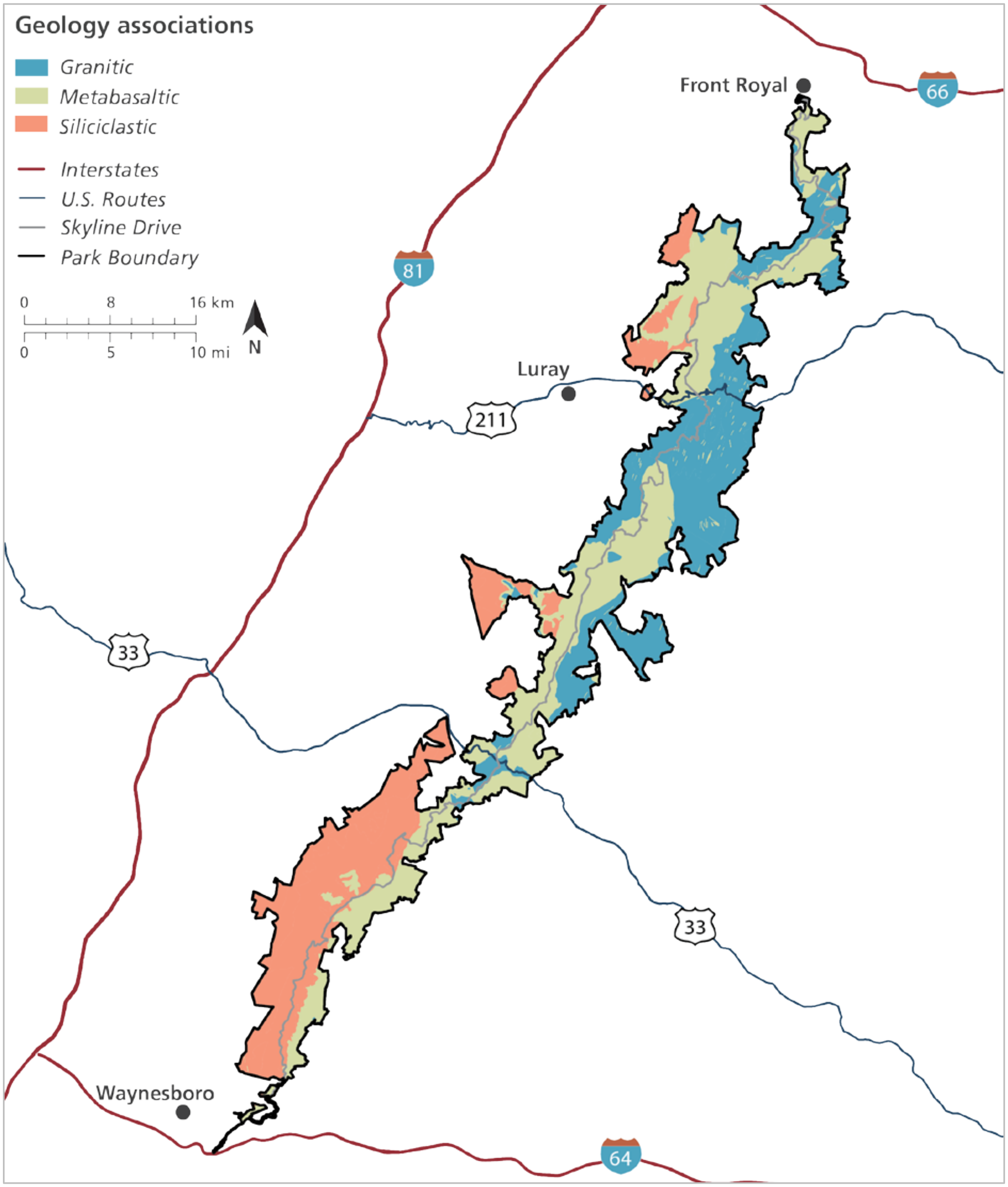

Figure 2-13. Geology associations with the dominant metabasaltic, granitic, and siliciclastic rock types. Source: U.S. Geological Survey Geologic Map of the Shenandoah National Park Region, Virginia.

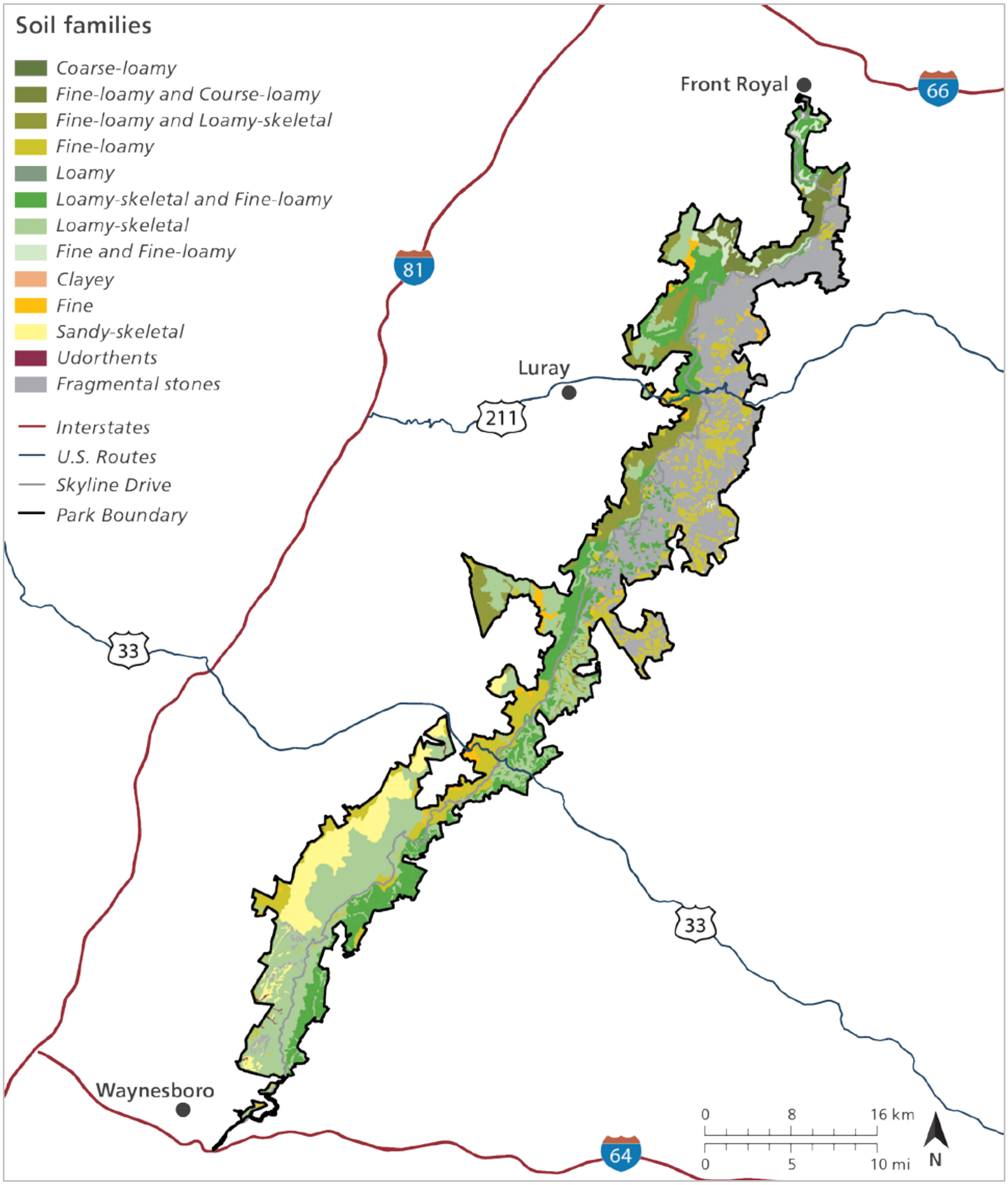

Figure 2-14. Soil families found within Shenandoah National Park. Source: USDA Natural Resources Conservation Service (NRCS) Soil Survey Geographic Database (SSURGO).

2.3.2 Groundwater

Groundwater in Shenandoah National Park resides in, and is transported via, bedrock fractures. Fracture density decreases with depth, and few wells yield water from depths greater than 90 m (Plummer *et al.* 2001). In part because the groundwater is mostly shallow and flow along open fractures can be rapid, the water is relatively young, meaning it has not been stored for great lengths of time in underlying aquifers or had the opportunity to chemically react much with adjacent bedrock. For this reason, surface disturbances such as the introduction of contaminants are reflected quickly in groundwater. Plummer *et al.* (1999, 2001) determined residence times of spring water in the range of 0–3 years and well water in the range of 0–25 years. The park also serves as a large recharge area for adjacent watersheds and the aquifers of neighboring valleys (Thornberry-Ehrlich 2005).

The potential for groundwater contamination and contaminant transportation is high (Plummer *et al.* 2000) particularly from roads such as Skyline Drive and at lower elevations from increasing surrounding development. Water discharged from shallow, unconfined springs is easily compromised by surficial contaminants. Contaminant introduction and transportation in deeper groundwater is difficult to predict due to the unknown interconnectivity of the fractures that serve as flow paths. Groundwater pumping can exacerbate these properties by causing rapid transport of contaminants over large distances within the system (Plummer *et al.* 2000). Hydrogeologic models would help manage the groundwater resource in the park and predict the response of the system to contamination, drought, and excess precipitation. The latter two are expected to increase as climate continues to change. Wells in the park could serve useful in park-wide monitoring efforts and hydrogeologic studies (Thornberry-Ehrlich 2014)

2.3.3 Rivers and streams

Shenandoah National Park is the origin of the headwaters of three river drainages: the Shenandoah River to the west and the Rappahannock and James Rivers to the east (Vana-Miller and Weeks 2004) (Figure 2-15).

There are 42 watershed basins on the west side of Shenandoah and 28 watershed basins on the east, combining for a total of about 90 small streams (Figure 2-16). A chief feature of these high elevation streams is high gradient, with pools interspersed with riffles, rapids, cascades and falls, and bottoms chiefly of large gravel, rubble, boulder, and bedrock. In many places, streams drop over ledges, creating waterfalls up to 28 m high (Figure 2-17). Most streams are heavily shaded and cool or even cold in the summer, and are typically clear with rain-caused turbidity quickly disappearing.

Within Shenandoah National Park, flow rates in streams are largely influenced by precipitation, with peak stream flow occurring in spring months when soils are saturated (Lynch 1987, sourced from Mahan 2006). Headwaters, which are closest to the summit of the Blue Ridge, may experience greater or more frequent precipitation, snow accumulation, canopy coverage, discharge volume variation, and debris flow than downslope streams (Mahan 2006).

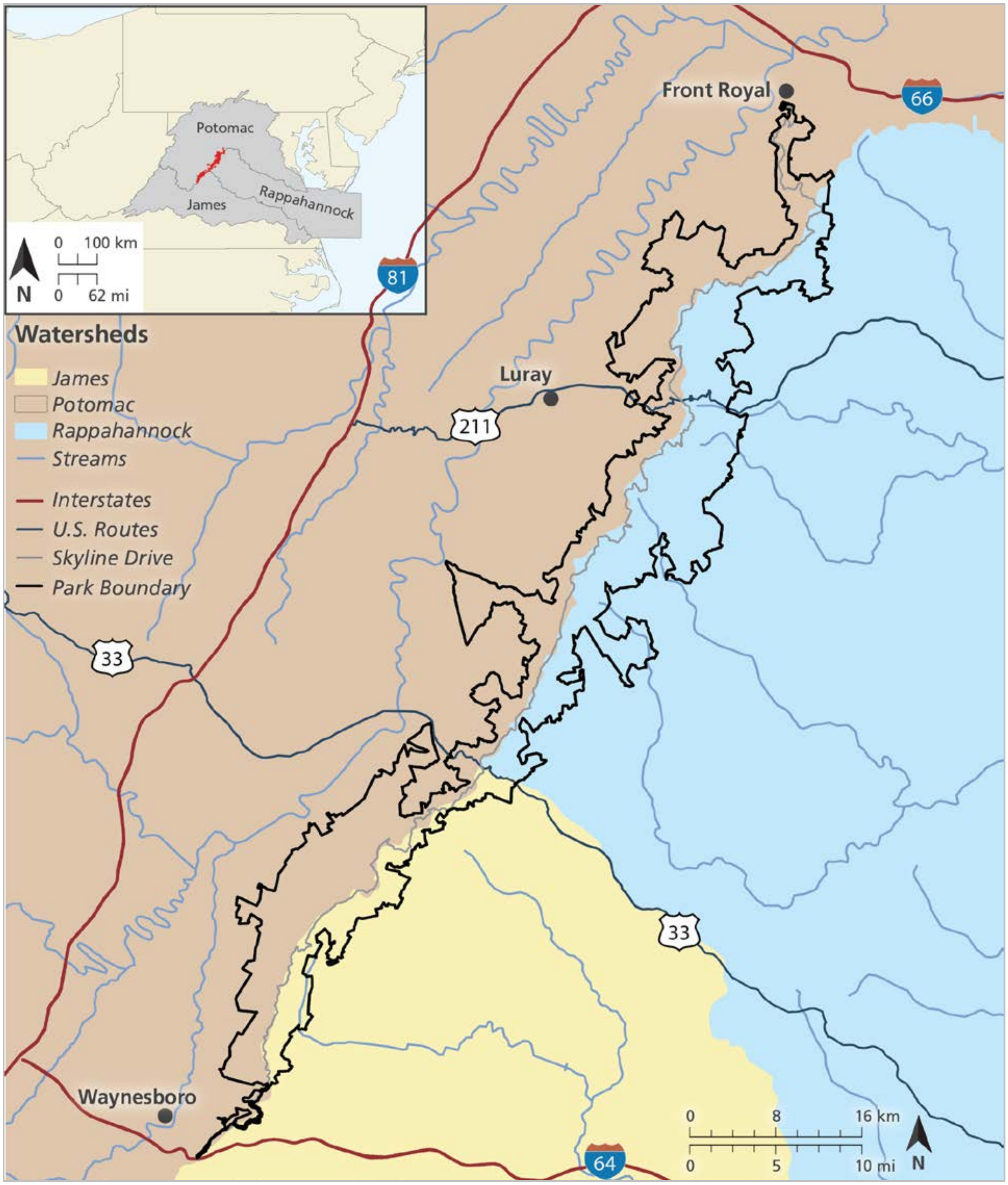

Figure 2-15. Watersheds of Shenandoah National Park. Source: Streams map by U.S. National Atlas Water Feature Lines; Watershed boundaries by U.S. Geological Survey.

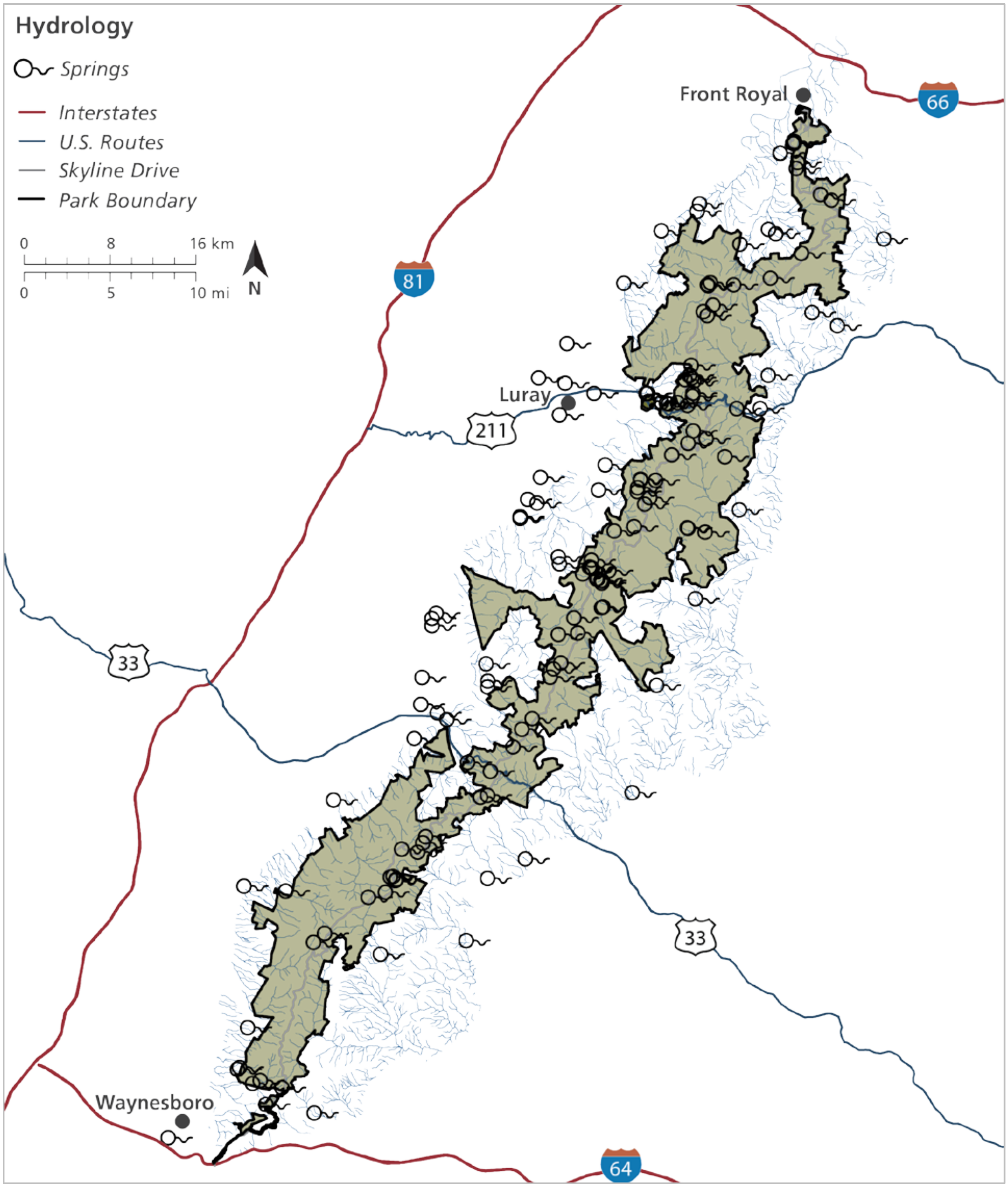

Figure 2-16. Shenandoah National Park hydrology map. Source: Shenandoah National Park, Administration Division-Information Management Branch, 2004; Publisher, Dan Hurlbert.

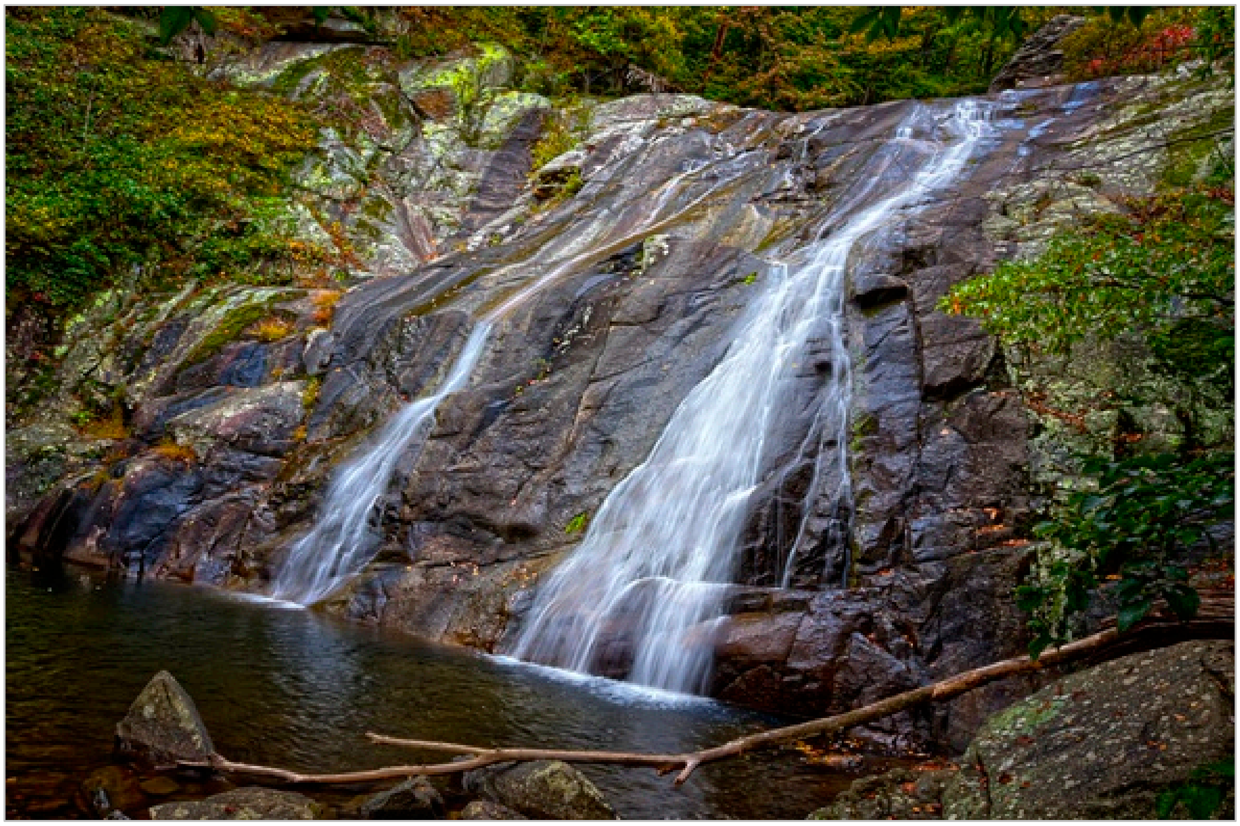

Figure 2-17. Whiteoak Falls within Shenandoah National Park. Photo credit: Eric B. Walker.

2.3.4 Springs and seeps

The park obtains most of its potable water from groundwater springs and wells. Approximately 850 springs and seeps occur throughout the park, primarily in bedrock where fractures funnel the water to discrete outlets (Plummer *et al.* 2000). Springs and seeps also occur at the tops of slope wash deposits because their high clay content restricts groundwater flow as an "aquitard" below perched water tables (Morgan *et al.* 2003). Siting of facilities during the development of the park in the 1930s focused on areas near springs and in higher-altitude areas, for example, Skyline Drive passes near approximately 70 springs identified as "suitable for development". Thus, the park's water supplies are also near the most populated areas increasing potential for surface contamination (Thornberry-Ehrlich 2014). Other infrastructure is far from productive water sources (Plummer *et al.* 2000). Most information about springs in the park has focused on the 70 springs that are located near Skyline Drive or along the Appalachian Trail, which are considered suitable for development as water sources (Figure 2-16).

2.3.5 Wetlands, marshes, and swamps

Little is known about the number or extent of wetlands in Shenandoah National Park. The park currently identifies wetlands using the National Wetland Inventory maps, but several studies are underway to help better refine these maps. In 2009, Young *et al.* classified seven wetland types throughout the park, which were included in the key to vegetation community types of the Park; however only two of these wetland types had sufficiently large occurrences to be included in the map. In addition, according to agency policy, areas along stream banks are considered wetlands, thus greatly increasing the number of wetland areas in the park. The park has several known wetland areas beyond stream banks, with Big Meadows being the most visible and studied wetland.

The Northern Blueridge Mafic Fen is a type of globally rare wetland plant community, which is found at two locations in Big Meadows (Ludwig *et al.* 1993). These wetland communities are endemic to the park and support eight state rare plant species (Figure 2-18). Big Meadows also supports an abundance of mammals, birds, amphibians, reptiles, and insects, some of which are not found elsewhere in the park (Ludwig *et al.* 1993). A State-listed snake, a rare insect, and several salamander and bird species are among the animals that occupy the Big Meadows wetland areas. Although currently little is known about the other wetlands in the park, it can be expected that at least a portion of them contain flora and fauna unique to wetland habitats.

Other known non-alluvial wetlands known to exist in the park include: Central Appalachian Basic Seepage Swamp, Central Appalachian Acidic Seepage Swamp, High-Elevation Hemlock – Tellow Birch Seepage Swamp, Central Appalachian Woodland Seep, and Shenandoah Valley Sinkhole Swamp (Young *et al*. 2009).

Figure 2-18. Mafic fen at Big Meadows. Photo credit: National Park Service.

2.3.6 Flora

Forests make up the dominant ecosystems in the eastern United States and form a key ecosystem component in Shenandoah National Park (Cass *et al.* 2012). Shenandoah National Park covers 79,900 ha (197,437 ac) of forested terrain on the crest of the Blue Ridge Mountains (Cass *et al.* 2011a). When the park was first established, only 2% of Shenandoah's original forests remained (Fievet *et al.* 2003). The establishment of Shenandoah as a national park has since allowed these forests to regenerate and forests occupy 95% the park's landscape (Young *et al.* 2009) (Figure 2-19).

Most forest plant communities in Shenandoah National Park are less than 100 years old, partly due to the land use history, as well as natural and anthropogenic disturbances (Cass *et al.* 2012). Today, the majority of Shenandoah National Park's vegetation can be found in its natural state; however, vegetation around developed areas, scenic overlooks and along roadsides is managed by the park's maintenance division (Mahan 2006). According to Young *et al.* (2009), 40 vegetation community types (35 natural, three successional, and two disturbed types) have been recorded and mapped in the park. Forest vegetation is one of the vital signs selected by the Shenandoah National Park I&M program for long-term study, and forest condition is considered fundamental to knowing the status of park resources (Cass *et al.* 2012).

<u>Native flora</u>

The three major bedrock formations (Basement, Catoctin, Chilhowee) found in the park have distinct chemical and physical properties that directly influence vegetation communities (Cass *et al.* 2011a). A number of factors such as slope, aspect, elevation, geology, and moisture, as well as human disturbance also influence plant communities within the park. The occurrence of vascular plant species has been documented in Shenandoah National Park (Cass *et al.* 2011b) (https://irma.nps.gov/NPSpecies/Search/SpeciesList/SHEN). Approximately 20% or 267 of the vascular plant species documented in the park are trees or shrubs.

The forest composition of this region changed in the early 1900s due to the loss of American chestnut (*Castanea dentata*) trees (Stephenson *et al.* 1991) (Figure 2-20). Also in the 1900's, there was tremendous damage done by gypsy moths, predominantly from 1989-1994. The majority of the park is forested with large, unfragmented Eastern Deciduous Forest stands of oak-hickory, cove hardwood, and tulip trees (Olson *et al.* 2010).

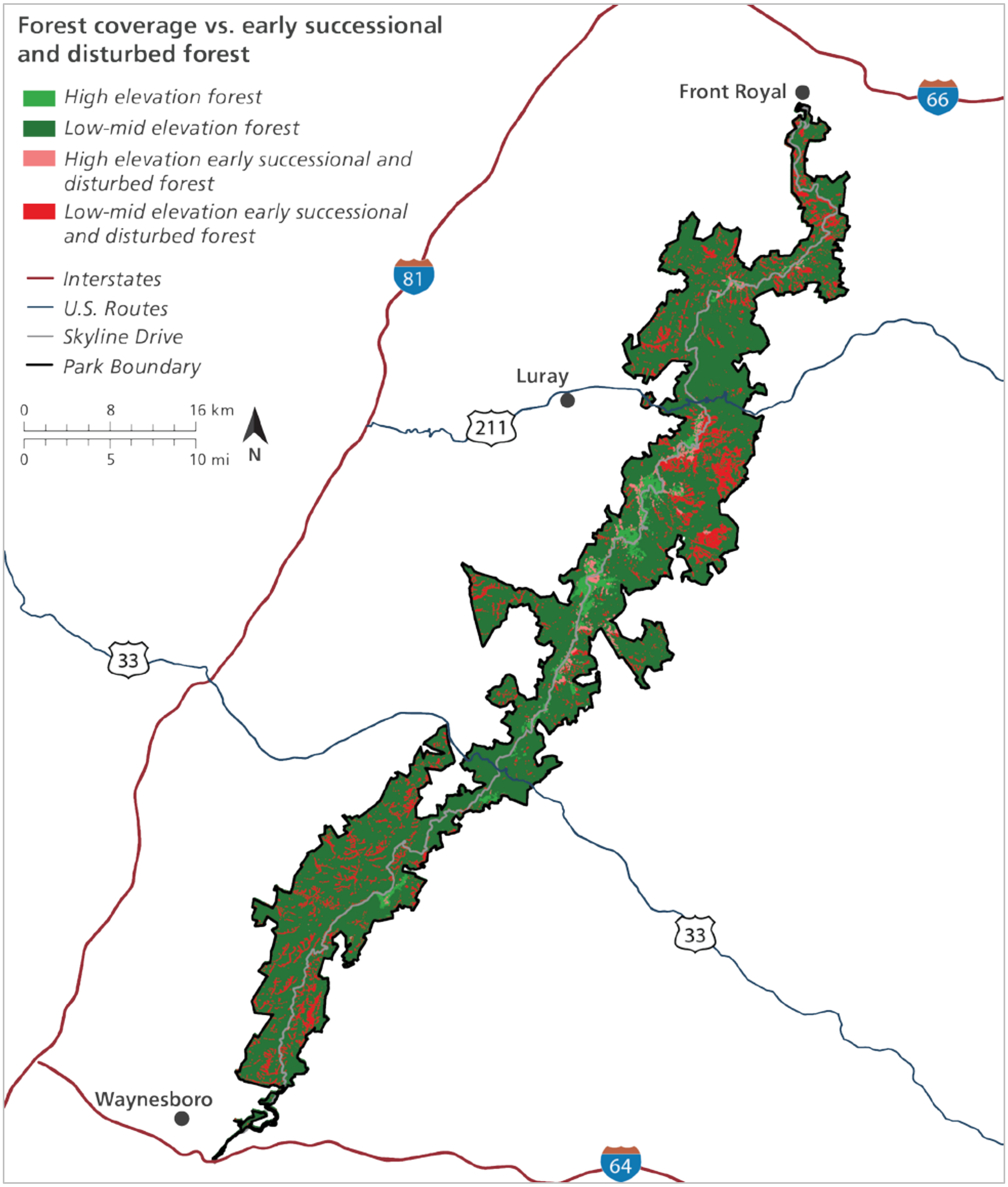

Figure 2-19. Dominant forest types within Shenandoah National Park. Derived from Young et al. 2009.

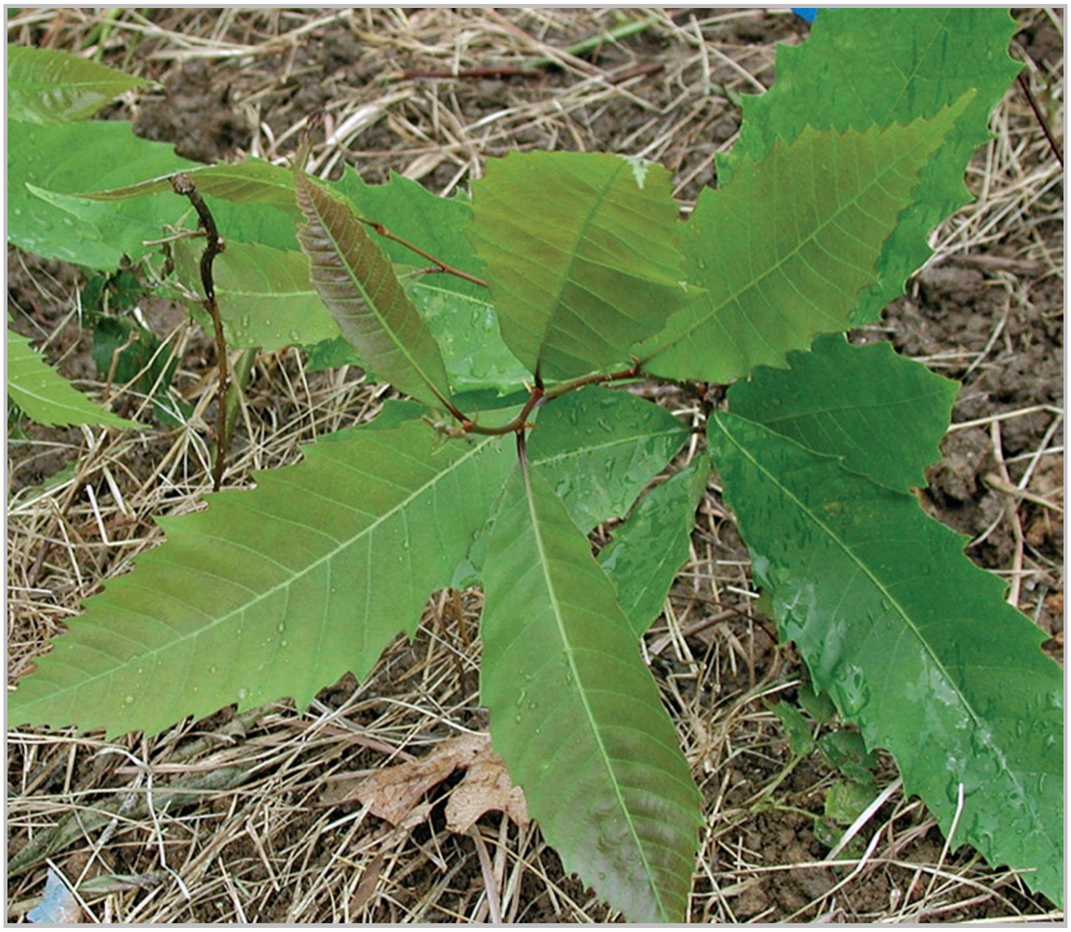

Figure 2-20. American chestnut seedling (*Castanea dentata*). Photo credit: American Chestnut Foundation.

Forest communities dominated by oak (*Quercus* spp.), hickory (*Carya* spp.), and pine (*Pinus* spp.) are situated on the ridge tops and upper slopes of the park, and compose 74% of park vegetation (Cass *et al.* 2012). Rich mixed hardwood forests of maple (*Acer* spp.), birch (*Betula* spp.), tulip tree (*Liriodendron tulipifera*), basswood (*Tilia americana*), and ash (*Fraxinus* spp.) compose 25% of park vegetation and are predominately located in mid-slope positions (Cass *et al.* 2012). Tulip tree (*Liriodendron tulipifera*) forests are found on the lower slopes and along streams. The remaining 1% of park vegetation is composed of wetland and rock outcrop communities (Young *et al.* 2009).

The eastern hemlock (*Tsuga canadensis*) is a shade-tolerant, late-successional conifer that provides unique habitat in the deciduous forest landscape, as some plants and animals may have evolved in association with hemlock stands (Mahan *et al.* 2004). Remaining hemlock are largely second growth, and many trees are treated with insecticides to ward off infestation by the hemlock wooly adelgid. However, areas once dominated by old growth hemlock still support State rare plants such as the speckled alder (*Alnus rugosa)*, American fly-honeysuckle (*Lonicera canadensis*), alderleaf buckthorn (*Rhamnus alnifolia*), and finely-nerved sedge (*Carex leptonervia*). Hemlock habitats in the park also cater to particular bird species such as blackburnian warbler (*Dendroica fusca*), and the Federally endangered Shenandoah salamander (*Plethodon shenandoah*) occurs in dense hemlock stands

(Mahan *et al.* 2004; Mahan 2006). However, stands of this community have largely disappeared as they are undergoing physiognomic and compositional changes due to extensive, adelgid-related mortality of *Tsuga canadensis* (Young *et al.* 2009).

Wetland communities, although only a small percent of the land cover found in the park, represent ecologically significant species and provide important habitat for rare flora and fauna (Mahan 2006). For example, the Northern Blue Ridge Mafic Fen is endemic to Shenandoah National Park, confined to groundwater-saturated, high-elevation stream-head wetlands (Young *et al.* 2009). This community is made up of a patch-mosaic of shrub thickets and herbaceous openings. Commonly found plant species include white meadowsweet (*Spiraea alba var. latifolia*), gray dogwood (*Cornus racemosa*), gray birch (*Betula populifolia*), bluejoint (*Calamagrostis canadensis*), Canadian burnet (*Sanguisorba canadensis*), and broom sedge (*Carex scoparia*). The Northern Blue Ridge Mafic Fen can be found in Big Meadows **–** a ridge-top meadow located along the Skyline Drive (Mahan 2006). The meadow is the only large non-forested area in the park and supports populations of 18% of the State-listed rare plant species in the park (Mahan 2006). This fact is even more compelling when you take into consideration that the Big Meadows Area is less than 1/10 of 1% of the Park's area as a whole.

Big Meadows supports a variety of grasses and commonly viewed species include red top (*Agrostis perennans*) and tall oat grass (*Arrhenatherum elatius*). Grass and grass-like species (sedges and rushes) account for 13% of the vascular plants found within Shenandoah National Park (http://www.nps.gov/shen/learn/nature/grasses.htm). Seasonal wildflowers grow throughout the park and comprise 862 species, where almost 20% of these species are in the aster (*Asteraceae*) family (http://www.nps.gov/shen/learn/nature/wildflowers.htm). The next most abundantly represented wildflower plant families are the pea (*Fabaceae*), lily (*Lilaceae*), mint (*Lamiaceae*) and mustard (*Brassicaceae*) families. Some commonly viewed species in the park include hepatica (*Anemone amencana*), bloodroot (*Sanguinaria canadensis*), violet (*Viola* spp.), large-flowered trillium (*Trillium grandiflorum*), pink lady's slippers (*Cypripedium acaule*), wild geraniums (*Geranium maculatum*), Quaker ladies (*Houstonia caerulea*), pink azaleas (*Rhododendron* spp.), mountain laurel (*Kalmia latifolia*) columbine (*Aquilegia canadensis*), milkweed (*Asclepias* spp.), nodding onion (*Allium cernuum*), ox eye daisy (*Leucanthemum vulgare*), turk's cap lily (*Lilium superbum*) touch-me-nots (*Impatiens* spp.), black cohosh (*Actaea racemosa*), goldenrods (*Solidago* spp.), asters (S*ymphyotrichum* spp.), and wild sunflowers (*Helianthus* spp.) (http://www.nps.gov/shen/learn/nature/wildflowers.htm).

Rock barrens and outcrops occur in low to high elevation areas of the park, and are made predominately of wooded herbaceous vegetation (Fleming *et a.l* 2007, Young *et al.* 2009; VDCR 2013). The Central Appalachian Circumneutral Barren is a globally rare community type of low-elevation outcrop barrens on Catoctin metabasalt (Young *et al.* 2009). The most constant and abundant herbaceous species are little bluestem (*Schizachyrium scoparium*), Pennsylvania sedge (*Carex pensylvanica*), poverty oatgrass (*Danthonia spicata*), and hairy lipfern (*Cheilanthes lanosa*) (Young *et al.* 2009). The globally rare and State-vulnerable mountain pimpernel (*Taenidia montana*) also occurs in this vegetation community. The High Elevation Greenstone Outcrop Barren plant community is endemic to the park and globally rare.

Lichen boulderfield communities also occur in low to middle elevation sections of the park and are dominated by non-vascular vegetation (Young *et al.* 2009). An example of a rare boulderfield community is the Central Appalachian Mafic Boulderfield, which is endemic to Shenandoah National Park. This community is characterized by a distinctive assemblage of umbilicate, foliose, and crustose lichens – commonly found species include snow lichen (*Stereocaulon glaucescens*), dust lichen (*Chrysothrix chlorina*), shield lichen (*Parmelia omphaloides*), and sulphur dust lichen (*Psilolechia lucida*) (Young *et al.* 2009). After completing lichen survey work on roadsides and rock outcrops, there were 359 species of lichen recorded in Shenandoah National Park, and green foliose boulder lichen (*Parmelia* spp.) is the most commonly seen (National Park Service 2013a). Other non-vascular plants found in the park include bryophytes, of which approximately 818 species of moss and liverwort species have been documented; and 476 species of fungi (Wendy Cass, pers.comm 2015). Examples of bryophytes recorded in Shenandoah National Park include white cushion moss (*Leucobryum glaucum*) on nutrient poor acidic soil, haircap moss (*Polytrichum commune*) on moist ground, and sphagnum moss (*Sphagnum* spp.) in the Big Meadows swamp (http://www.nps.gov/shen/learn/nature/mossesandliverworts.htm).

<u>Rare, threatened, and endangered plants</u>

Shenandoah National Park is home to many locally and globally rare plant species, and there are 12 globally rare plant communities within the park (Young *et al.* 2009). Some 93 plant species that are considered rare or species of special concern have been documented in the park (Mahan 2006). The Virginia Natural Heritage Program considers 80 of these plant species to be rare (Cass *et al.* 2011b). Rare plants are located throughout the park, but are commonly found in wetland and rock outcrop habitats (Young *et al.* 2009). Some communities, such as wetland plant communities at Big Meadows or rock outcrop plant communities at Hawksbill Mount, are both endemic to Shenandoah National Park and globally rare (Young *et al.* 2009).

Plant species that are listed as threatened in Virginia include variable sedge (*Carex polymorpha*) and American ginseng (*Panax quinquefolius*). Small whorled pogonia (*Isotria medeoloides*) is listed as an endangered species in Virginia (Mahan 2006). Globally rare species found in the park include glade spurge (*Euphorbia purpurea*), Appalachian oak fern (*Gymnocarpium appalachianum*), shale-barren blazing star (*Liatris turgida*), sweet pinesap (*Monotropsis odorata*), Canby’s mountain-lover (*Paxistima canbyi*), sword-leaved phlox (*Phlox buckleyi*), bog bluegrass (*Poa paludigena*), Torrey's mountain-mint (*Pycnanthemum torrei*), and mountain pimpernel (*Taenidia montana*) (Ludwig *et al.* 1993, Mahan 2006). For non-vascular plants, map lichen (*Rhizocarpon geographicum*) and black crust (*Melinelia stigia*) are extremely rare in Virginia and found only on rock outcrops in the central district of the park (http://www.nps.gov/shen/learn/nature/lichens.htm).

2.3.7 Fauna

<u>Mammals</u>

European settlement in the Shenandoah Valley and Blue Ridge Mountains from the 1700s resulted in the disappearance of many native animals due to land development, agriculture, and hunting activities (National Park Service 2013b). Mammal populations that were either extirpated or drastically diminished in this region included American bison (*Bison bison*), elk (*Cervus* *canadensis*), eastern timber wolf (*Canis lupus lycaon*), black bear (*Ursus americanus*), bobcat (*Lynx rufus*), white-tailed deer (*Odocoileus virginianus*), beaver (*Castor canadensis*), and northern river otter (*Lontra canadensis*) (National Park Service 2013b).

Shenandoah National Park provides an important refuge for many species of animals and, through re-introduction and natural recovery, many animal species have returned to the park. Despite nearly being eliminated from the Shenandoah Valley and surrounding areas by the 1900s, the black bear population is an example of an animal species that has successfully re-established in the park (Figure 2-21) (National Park Service 2006a). In the late 1930s, two black bears were observed in Shenandoah and today the population ranges up to several hundred (National Park Service 2006a).

Figure 2-21. Black bear (*Ursus americanus*). Photo credit: National Park Service.

Presently, there are reportedly over 50 species of mammals present in the park (Olson *et al.* 2010). Mammals commonly found in the park include black bear (*Ursus americanus*), white-tailed deer (*Odocoileus virginianus*), Virginia opossum (*Didelphis virginiana*), eastern cottontail (*Sylvilagus floridanus*), raccoon (*Procyon lotor*), groundhog (*Marmota monax*), and several species of bat (National Park Service 2005a). Other commonly sighted animals include gray squirrels (*Sciurus carolinensis*) and eastern chipmunks (*Tamias striatus*). Less commonly observed mammals found in Shenandoah include beaver (*Castor canadensis*), northern river otter (*Lontra canadensis*), bobcat (*Lynx rufus*), as well as spotted skunk (*Spilogale putorius*) (National Park Service 2005a).

Birds

It is estimated that over 200 species of resident and transient birds occur in the park, where half of these species breed in the park (Olson *et al.* 2010) (https://irma.nps.gov/NPSpecies/Search/SpeciesList/SHEN). Due to the park's location along the Blue Ridge and its forested habitat, Shenandoah National Park provides important breeding and migration corridor habitat for neotropical migratory birds (National Park Service 2008a). The 2003 annual report of the Monitoring Avian Productivity and Survivorship (MAPS) program found that there was a slight but steady decrease in the overall bird population from 1993 to 2003, indicating a negative impact on adult population sizes of species breeding in the park (DeSante *et al.* 2004).

Approximately 30 of the bird species in the park are year-round residents, such as red-tailed hawk (*Buteo jamaicensis*), barred owl (*Strix varia*), wild turkey (*Meleagris gallopavo*), ruffed grouse (*Bonasa umbellus*), slate-colored juncos (*Junco hyemalis*), and Carolina chickadee (*Parus carolinensis*) (National Park Service 2008a). The park is also home to over 18 species of warblers and a wide variety of sparrows, woodpeckers, and flycatchers (National Park Service 2008a, National Park Service 2005b). Abundant bird species include indigo bunting (*Passerina cyanea*), eastern towhee (*Pipilo erythrophthalmus*) (Figure 2-22), ovenbird (*Seiurus aurocapillus*), American redstart (*Setophaga ruticilla*), veery (*Catharus fuscescens*), wood thrush (*Hylocichla mustelina*), and red-eyed vireo (*Vireo olivaceus*) (National Park Service 2005b).

Figure 2-22. Eastern towhee (*Pipilo erythrophhalmus*). Photo credit: Ken Thomas.

Other bird species commonly sighted include chimney swift (*Chaetura pelagica*), Carolina wren (*Thryothorus ludovicianus*), mourning dove (*Zenaida macroura*), American crow (*Corvus brachyrhynchos*), common raven (*Corvus corax*), American goldfinch (*Carduelis tristis*), blue jay (*Cyanocitta cristata*), northern cardinal (*Cardinalis cardinalis*), brown-headed cowbird (*Molothrus ater*), northern parula (*Parula americana*), rose-breasted grosbeak (*Pheucticus ludovicianus*), scarlet tanager (*Piranga olivacea*), eastern bluebird (*Sialia sialis*), American robin (*Turdus migratorius*), tufted titmouse (*Parus bicolor*), white-breasted nuthatch (*Sitta carolinensis*), gray catbird (*Dumetella carolinensis*), and ruby-throated hummingbird (*Archilochus colubris*) (National Park Service 2005b).

Birds of prey commonly found in Shenandoah National Park include broad-winged hawk (*Buteo platypterus*), turkey vulture (*Cathartes aura*), and black vulture (*Coragyps atratus*) (National Park Service 2005b). Programs, such as the Peregrine Falcon Restoration Program, have been able to successfully establish state-threatened species like the peregrine falcon (*Falco peregrinus*) (Figure 2-23) back in the mountainous regions of the park (National Park Service 2008b).

Figure 2-23. Peregrine falcon (*Falco peregrinus*). Photo credit: Dennis Jarvis.

Eastern United States peregrine falcon populations declined sharply between the 1940s and 1960s due to the widespread use of the pesticide DDT and several other factors. DDT was most damaging to peregrine reproduction due to eggshell thinning, egg breakage, and hatching failure. After DDT was banned (1972) and the peregrine was placed on the endangered species list in 1973, Cornell University (later the Peregrine Fund), U.S. Fish & Wildlife Service (USFWS), and various natural resource agencies began reintroducing peregrine falcons back into their native range. This program involved the release of captive-reared peregrines with the hope that these birds would re-colonize their historic breeding range. Between 1975 and 1993, over 1200 young falcons were released throughout the East by regional peregrine falcon recovery teams. From 1978 to 1993, approximately 250 of those falcons were released in Virginia. These birds were released into the wild using a management technique referred to as "hacking".

Shenandoah National Park has the longest hacking history of any site in Virginia. The first hacking phase took place between 1989 and 1993. These efforts were rewarded when the first peregrine pair documented in Virginia's mountains since recovery efforts began was confirmed at the park's Stony Man Mountain in the eraly 1990's. Despite the park's nesting success of the mid 90's, peregrine populations in the mountains of Virginia continued to lag. In 2000, the park re-entered a peregrine restoration agreement with the Center for Conservation Biology at the College of William & Mary, the Virginia Dept of Game & Inland Fisheries, and the VA Dept of Transportation. From 2000-2015 park staff and project partners successfully restored 127 peregrine falcons back into the park. The "foster" peregrine chicks used for this restoration program came from coastal bridge nests in Virginia where juvenile peregrine survival has been low due to premature fledging over open water. The goal of this project is to boost peregrine falcon numbers in the Central Appalachians where peregrine recovery has been slow. This restoration work directly supports the conservation and long-term recovery efforts of state-threatened peregrine falcons in the park and throughout the Central Appalachians. As a result of the park's ongoing restoration efforts, the park has supported a nesting pair from 1994-1997, 2005-2007, and 2009-2014 (comprised of three different pairs). During this time, these pairs have seen a 62% breeding success rate. Shenandoah represents one of the best places in the Mountains of Virginia to see these amazing birds of prey.

Extensive monitoring by National Park Service staff and volunteers has been a critical component in documenting the status of breeding falcons at Shenandoah National Park. It will continue to accompany efforts at the Park into the foreseeable future (http://www.dgif.virginia.gov/wildlife/birds/peregrine-falcon/shenandoah-national-park.asp; http://www.ccbbirds.org/2013/07/01/the-good-hackers/).

Herpetofauna

There are over 50 reported species of reptiles and amphibians that range throughout Shenandoah National Park in diverse habitats (Olson *et al.* 2010) (https://irma.nps.gov/NPSpecies/Search/SpeciesList/SHEN). Approximately 26 species of reptiles are recorded in the park, including snake species – of which the commonly found copperhead (*Agkistrodon contortrix*) and timber rattlesnake (*Crotalus horridus*) (Figure 2-24) are venomous (National Park Service 2005c). Other common species in the park are the ring-necked snake (*Diadophis punctatus*), rat snake (*Elaphe obsolete*), red-bellied snake (*Storeria occipitomaculata*), and common garter snake (*Thamnophis sirtalis*) (National Park Service 2005c).

Figure 2-24. Timber rattlesnake (*Crotalus horridus*). Photo credit: Alan Williams, National Park Service.

Of the turtle species found inside the park, the most widely distributed species is the eastern box turtle (*Terrapene carolina*) (National Park Service 2005c) (Figure 2-25). The more aquatic turtles, such as the common snapping turtle (*Chelydra serpentine*), spotted turtle (*Clemmys guttata*), and painted turtle (*Chrysemys picta*) are found near aquatic habitats like ponds and streams, but are uncommon in the park (National Park Service 2005c). The only lizard species commonly reported in the park is the eastern fence lizard (*Sceloporus undulatus*) (National Park Service 2005c). The five-lined skink (*Eumeces fasciatus*) and skink (*Scincella lateralis*) have been reported in the park (National Park Service 2005c).

Figure 2-25. Eastern box turtle (*Terrapene carolina*). Photo credit: National Park Service.

Among the amphibian species found in the park, 10 species of frogs and toads have been documented and 14 species of salamanders or newts (National Park Service 2005d). Commonly seen frog species include green frog (*Rana clamitans*) and pickerel frog (*Rana palustris*) (National Park Service 2005d). The American toad (Bufo americanus) is the common species of toad that occurs in the park (National Park Service 2005d). The Appalachian Mountains are a hotspot for salamander diversity and contain 15% of the world's species (National Park Service 2010). The Shenandoah salamander (*Plethodon shenandoah*) is a rare species and endemic to the park, making it the only federally endangered animal species found in the park (National Park Service 2010) (Figure 2-26). Salamander species commonly found in the park include dusky salamander (*Desmognathus fuscus*), seal salamander (*Desmognathus monticola*), northern two-lined salamander (*Eurycea bislineata*), eastern red-backed salamander (*Plethodon cinereus*), and white-spotted slimy salamander (*Plethodon cylindraceus*) (National Park Service 2005d).

Figure 2-26. Shenandoah salamander *(Plethodon shenandoah).* Photo credit: Andrew Kraemer.

Fish

Native eastern brook trout (*Salvelinus fontinalis*) (Figure 2-27) is the only trout species indigenous to most of the eastern United States and historically featured as an important dietary component to Native Americans and early European settlers (Atkinson 2005). Nationally, streams in the park are recognized for the quality and concentration of this native trout species (Atkinson 2005). Brook trout are abundant in most of the 90 small streams in the park; however, streams with less capability to buffer acid rain usually have poor brook trout reproduction and fewer adult fish (Wofford and Demarest 2012a). Non-native brown trout (*Salmo trutta*) and rainbow trout (*Oncorhynchus mykiss*) are uncommon; however, they have disrupted brook trout populations in streams shared by native and non-native trout species (Hudy *et al.* 2006).

Other commonly occurring fish species in park waters include mottled sculpin (*Cottus bairdii*), rosyside dace (*Clinostomus funduloides*), bluehead chub (*Nocomis leptocephalus*), river chub (*Nocomis micropogon*), blacknose dace (*Rhinichthys atratulus*), longnose dace (*Rhinichthys cataractae*), creek chub (*Semotilus atromaculatus*), and fantail darter (*Etheostoma flabellare*) (National Park Service 2005e).

The American eel (*Anguilla rostrata*) and torrent sucker (*Thoburnia rhothoeca*) are also commonly found in the park's waters (National Park Service 2005e). Despite being commonly sighted in the park, American eel populations have declined significantly over the last 50 years partly due to migration barriers (Hitt *et al.* 2012). The American eel is the only North American fish species that spawn in the open waters of the Sargasso Sea, and then migrates to freshwater streams and estuarine to mature. The removal of dams has resulted in an increase in the eel numbers over time in the park, and may yield long-term benefits for eel management and conservation at the landscape scale (Hitt *et al.* 2012).

Figure 2-27. Eastern brook trout (*Salvelinus fontinalis*). Photo credit: Chesapeake Bay Program.

Acidification is an ongoing concern, particularly if aquatic systems within the park increasingly acidify over time. The number of fish species present is largely influenced by the degree of acid neutralizing capacity (ANC), and to some extent by habitat quality and water temperature (Atkinson

2003). Streams with lowest ANC values are influenced by large sandstone or siliciclastic formations, mainly located along the southern half of the western slope. These streams have the fewest number of fish species (Atkinson 2002). Moderate ANC streams are influenced by granitic formations, are more evenly distributed park-wide, and have intermediate numbers of fish species present (Atkinson 2002). Streams with higher ANC, underlain by basaltic rock, are fairly well distributed through the park and have the highest number of fish species (Atkinson 2002). Currently, stable brook trout populations persist within the park's most acidified streams that have stable flow and suitable habitat. To their advantage in persisting in acidified waters, brook trout are the most acid tolerant fish of the park's current suite of species, capable of successfully reproducing in water with a pH as low as 4.5. Most park streams currently have pH ranges considerably higher than 4.5.

Shenandoah National Park has had a comprehensive fisheries monitoring program in place since 1982 and 40 species of fish, as well as one additional hybrid species, have been documented in park waters (National Park Service 2011a) (https://irma.nps.gov/NPSpecies/Search/SpeciesList/SHEN). Data collected in 2010 on fish species in the park suggests that fish populations and communities are negatively affected by acid deposition and climate variation (Wofford and Demarest 2012a).

Invertebrates

Terrestrial invertebrates are not well documented in Shenandoah National Park and it is unknown how many different types of invertebrates are present (Olson *et al.* 2010). During a study of terrestrial invertebrates in the park, the most abundant order was *Diptera*, followed by *Collembola*, *Lepidoptera*, and *Hymenoptera* (Mahan *et al.* 2004).

Figure 2-28. Monarch butterfly (*Danaus plexippus*). Photo credit: Virginia State Parks.

Aquatic invertebrates are better recorded in the park as they have been sampled since 1986, and aquatic insects have been used as indicators for stream health for many years (National Park Service 2011b). Approximately 240 species of aquatic macroinvertebrates (Figure 2-29) have been recorded in the park (National Park Service 2011b). The overall macroinvertebrate community health has not significantly declined since the start of the aquatic invertebrate monitoring program in the 1980s (Wofford and Demarest 2012b). However, macroinvertebrate data from 2009 indicates that aquatic ecosystems within the park are negatively affected by acid deposition, as portions of the macroinvertebrate assemblage continued to decline in abundance (Wofford and Demarest 2012b). Streams in the park that are more capable of buffering acid rain events have been found to support more functional macroinvertebrate assemblages than those more sensitive to acid deposition (Wofford and Demarest 2012b).

Figure 2-29. Appalachian brook crayfish (*Cambarus bartonii cavatus*). Photo credit: National Park Service.

2.3.8 Wilderness

In 1976, Congress designated and authorized a total of 32,205 ha (79,580 ac) of Shenandoah National Park as wilderness (Figure 2-30). Wilderness classification mandates that specific areas of the park be managed with special consideration for human impacts to the natural environment and visitor recreation opportunities (Bair 1998). Nearly all of the area now designated as wilderness was once cleared and inhabited, farmed, logged, and/or burned. The natural regeneration to the 'wilderness' conditions which followed formation of the park encouraged National Park Service officials to recommend and eventually designate 42% of the Park as wilderness (National Park Service 2008c).

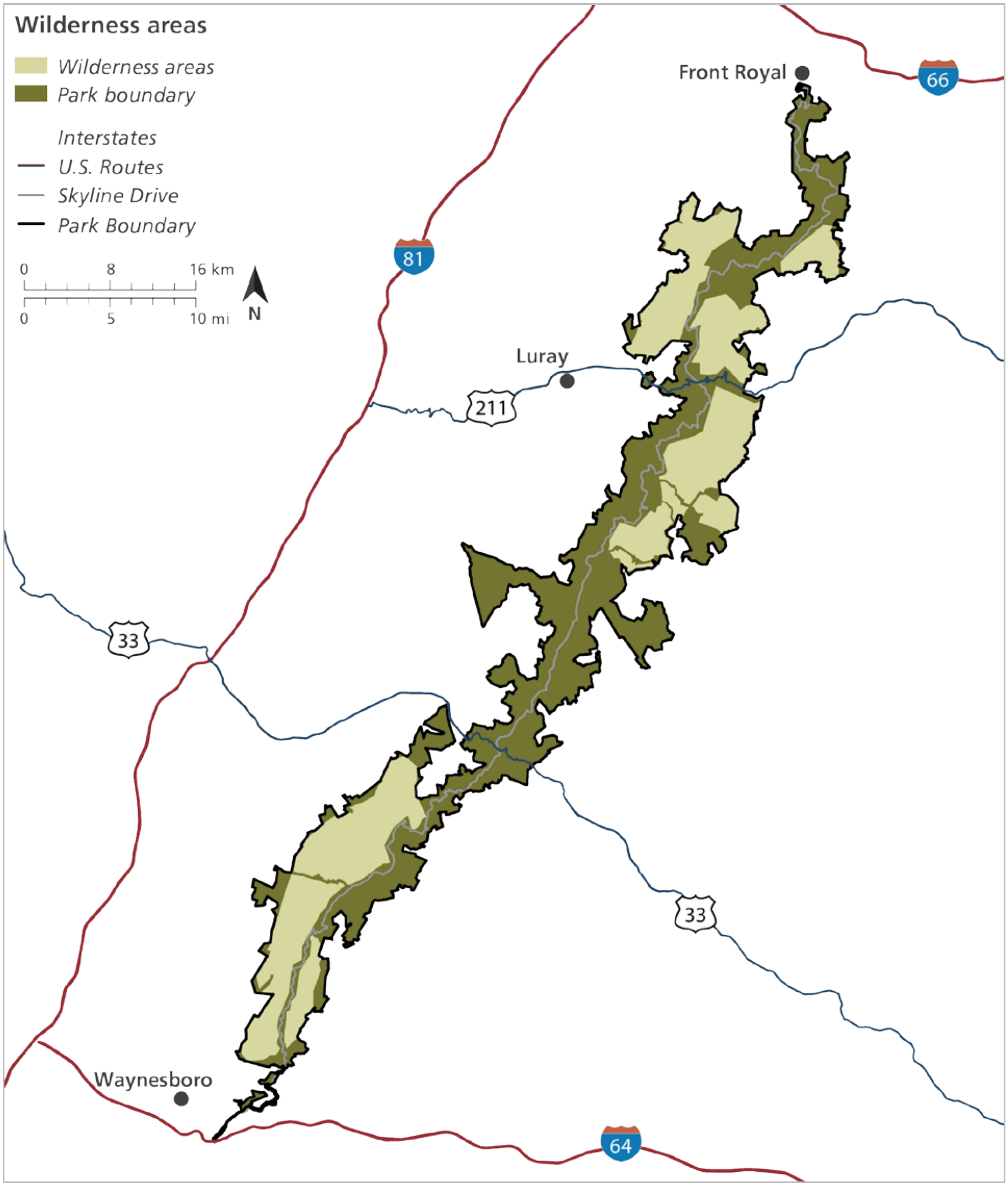

Figure 2-30. Wilderness Areas designated within Shenandoah National Park. Source: National Park Service.

The designation of the park as wilderness obligated Shenandoah National Park to administer these lands "in accordance with the applicable provisions of the Wilderness Act" (Public Law [PL] 04-567):

… in contrast with those areas where man and his own works dominate the landscape, [wilderness] is hereby recognized as an area where the earth and its community of life are untrammeled by man, where man himself is a visitor who does not remain. An area of wilderness is further defined to mean an area of undeveloped Federal land retaining its primeval character and influence, without permanent improvements or human habitation, which is protected and managed so as to preserve its natural conditions and which (1) generally appears to have been affected primarily by the forces of nature, with the imprint of man's work substantially unnoticeable; (2) has outstanding opportunities for solitude or a primitive and unconfined type of recreation; (3) has at least five thousand acres of land or is of sufficient size as to make practicable its preservation and use in an unimpaired condition; and (4) may also contain ecological, geological, or other features of scientific, educational, scenic, or historical value" (Public Law 88-577, 1964).

Protecting and preserving wilderness quality is a difficult challenge in Shenandoah National Park because of its popularity and proximity to major population centers. Wilderness is sensitive to a wide variety of human impacts, including impacts from adjacent non-wilderness lands in highly developed and conflicting land uses. Most of the park's wilderness experiences low visitor use. Some of the designated wilderness in Shenandoah National Park (Figure 2-31), however, receives high visitor use such as the Ridge Trail on Old Rag Mountain, which is one of the most frequently used trails within the park (Bair 1998). Day hiking and overnight camping are wilderness-dependent recreational activities that encompass nearly all use within Shenandoah National Park. Rock climbing occurs at some of the more accessible sites. Recreation using mechanized equipment, such as bicycles and mountain bikes, and use of aircraft such as hang gliders are prohibited in the Wilderness (Bair 1998). The only signs permitted in Wilderness Areas are for resource protection or trail direction (Bair 1998). Administrative roads or structures are not permitted in any Wilderness Area, and, only historic structures are permitted. Motorized vehicle or equipment use within Wilderness Areas also is not permitted, except under emergency conditions.

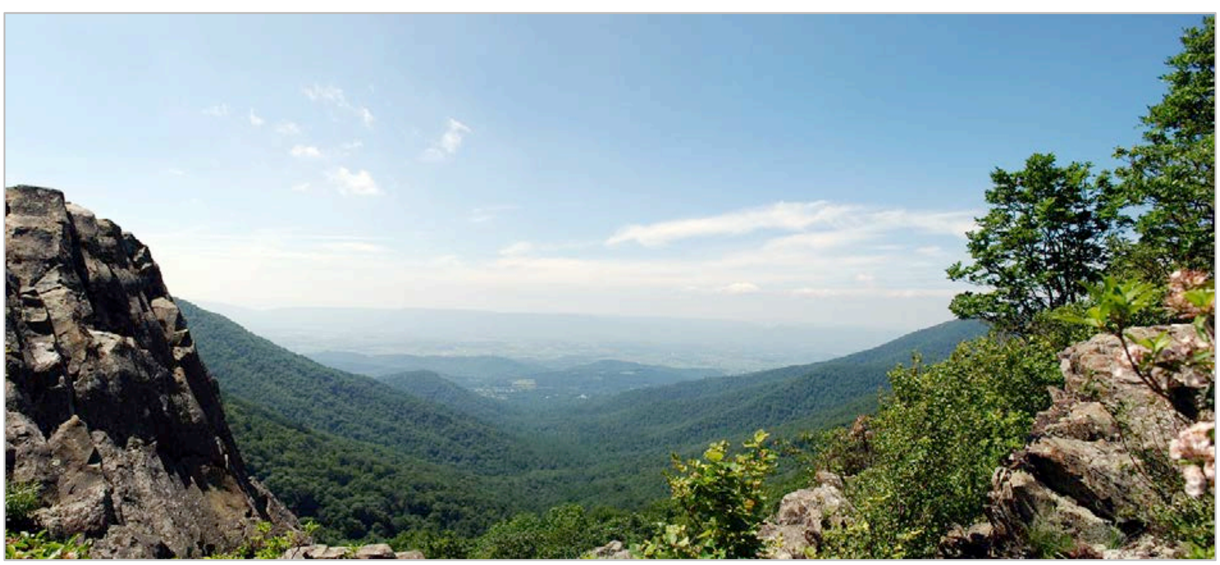

Figure 2-31. Hawksbill Gap. Photo credit: National Park Service.

Natural resources inventory and monitoring activities completed within Wilderness Areas use methods to minimize impact whenever possible. If mechanized means (e.g., backpack electrofishing devices to monitor fish populations) or destructive sampling procedures are the only means of data collection, they are reviewed and documented prior to being given clearance (Bair 1998).

2.3.9 Soundscape

The National Park Service is obligated to preserve, to the greatest extent possible, the natural soundscapes of parks. Natural soundscapes exist in the absence of human-caused sound and can include geophysical (e.g., wind, rain, running water) and biological sounds (e.g., insects, frogs, birds) (Pijanowski *et al*. 2011) (Figure 2-32). By agency policy and legal requirements of the Wilderness Act, specific measures are taken to eliminate, or greatly reduce, the opportunity for visitors to encounter the sounds of motorized equipment while in Wilderness Areas.

The presence of Skyline Drive along the length of Shenandoah National Park results in substantial traffic-induced sounds permeating many aspects of the park. A 2012 study by Manni *et al.* in the park reported that 25% of visitor groups in the summer and 23% of visitor groups in the fall indicated that sounds of motorcycles detracted from their park experience.

Figure 2-32. Woodpeckers are one of the natural sounds heard within Shenandoah National Park. Red-bellied woodpecker (*Melanerpes carolinus*). Photo credit: Ken Thomas.

2.3.10 Night skies

The natural darkness associated with the night sky is an important natural, scientific, and cultural resource valued by the National Park Service (National Park Service nd-a). Natural darkness is important ecologically for wildlife mating, migration, sleep, foraging, orientation, and other aspects of their life cycle, as well as astronomically for stargazing (Longcore and Rich 2004). It is anticipated that night sky viewing within the Shenandoah National Park will become increasingly more important as visitors seek out locations where better views of the night sky are available away from urban influences (Figure 2-33, Figure 2-34).

Figure 2-33. Night sky viewing within Shenandoah National Park is becoming more popular. Photo credit: ForestWander Nature Photography.

Figure 2-34. Satellite image of night light observed in the U.S. with brightest regions in proximity to Shenandoah National Park. Source: NASA Earth Observatory/NOAA NGDC.

The high elevation of Shenandoah National Park combined with its relative remoteness from urban areas make the park an ideal place to engage in night sky viewing on moonless and cloud-free nights. Little about the night sky at Shenandoah has been formally documented and public interest, while known to exist, has not been tracked or recorded.

Ecological light pollution includes direct glare, sky glow, and temporary, unexpected fluctuations in lighting. Behavioral and population-level ecology is affected based on individual and species differences in orientation or disorientation to increased light availability, attraction or repulsion to light sources, lowered reproductive capacity, and hindered visual and audio intraspecies communication. These factors culminate in changes in community ecology, influencing competition, including resource partitioning, and predation, ultimately favoring species that are most light tolerant (Longcore and Rich 2004). Studies indicate that light pollution may adversely affect water quality, salamander foraging, bird migration, and turtle breeding (Duriscoe 2001; Harder 2004).

2.3.11 Vistas

Some of the most visited and well-loved features in Shenandoah National Park include overlooks along Skyline Drive, and vistas from the Appalachian Trail, rock outcrops, and mountain peaks such as Old Rag. The scenic vistas of the Shenandoah Valley and the Virginia Piedmont provided justification of park establishment and are, therefore, nationally significant (Mahan 2006). Central to the significance of the park are the rural agricultural landscapes that surround it. They are the additional components of the ecosystem that supports park wildlife and other values that are significant to Shenandoah National Park's original establishment (Sullivan *et al.* 2003a). Skyline Drive was constructed in the 1930s to provide scenic views within the park and into the Piedmont plateau to the east and the Shenandoah Valley to the west. Seventy-six overlooks and many drive-by vistas were constructed along the drive so motorists could enjoy the views as they toured the park. Visibility has degraded in the park, potentially detracting from visitor enjoyment of vistas accessible from Skyline Drive, the Appalachian National Scenic Trail, and other trails and points in the park (Sullivan *et al.* 2003a). Air quality, vegetative cover and condition, landform, and land use all influence the characteristics of a scenic vista. Hot hazy summer days may afford only indistinct views of nearby mountains and the valley floor, while clear winter days may afford spectacular views of multiple adjacent ridgelines and many details of valley homesteads. Furthermore, vegetation management in vista clearing areas is expensive and time-consuming for the park, but has large impacts on the availability of natural resources and viewability of surrounding landscapes.

2.4 Resource issues overview

2.4.1 Air quality

A significant driver of the condition of natural resources within Shenandoah National Park is caused either directly or indirectly by air pollution (Sullivan *et al.* 2003a). Shenandoah National Park has one of the most comprehensive air quality monitoring and research programs of all national parks and wilderness areas that are afforded special protection under the Clean Air Act. Under the Clean Air Act (as amended), the Assistant Secretary for Fish, Wildlife and Parks (acting through the Park Superintendent) has an “affirmative responsibility” to protect air quality-related values from the adverse effects of human-made air pollution.

Over 30 years of monitoring and research in the park has identified degraded air quality as affecting:

- aquatic chemistry – chronic and episodic acidification of stream waters, most importantly those occurring in watersheds underlain by siliciclastic, and to a lesser degree, granitic bedrock;
- aquatic biota – loss of sensitive species, changes in condition of sensitive species, reduction in species richness of fish and benthic insects;
- forest health – ozone damage to foliage, reduced biomass growth for several tree species and reduced occurrence of white ash and other species; and,
- visibility – significant degradation of visual range and scenic quality relative to estimated natural conditions (Sullivan *et al.* 2003a)

<u>Sources of air pollution</u>
Sources of air pollution that affect Shenandoah National Park are largely located outside of the park. These include electric power plants, industrial facilities, and highway vehicles. Source contributions are influenced by weather patterns that transport pollutants to Shenandoah. The geographic areas most likely to contribute to sulfate air concentrations (haze) and sulfur and nitrogen deposition in Shenandoah are similar: the Ohio River Valley, Virginia, and the neighboring states of West Virginia, Pennsylvania, Kentucky, and North Carolina (Figure 2-35).

For five air pollutants (sulfur dioxide, nitrogen oxides, volatile organic compounds, carbon monoxide, coarse particulate matter), in-park emissions comprise less than 1% of total human-made emissions from the eight counties encompassing the park. In-park emission sources are limited, but do include motor vehicles, maintenance equipment, small boilers, and diesel generators (Sullivan *et al.* 2003a).

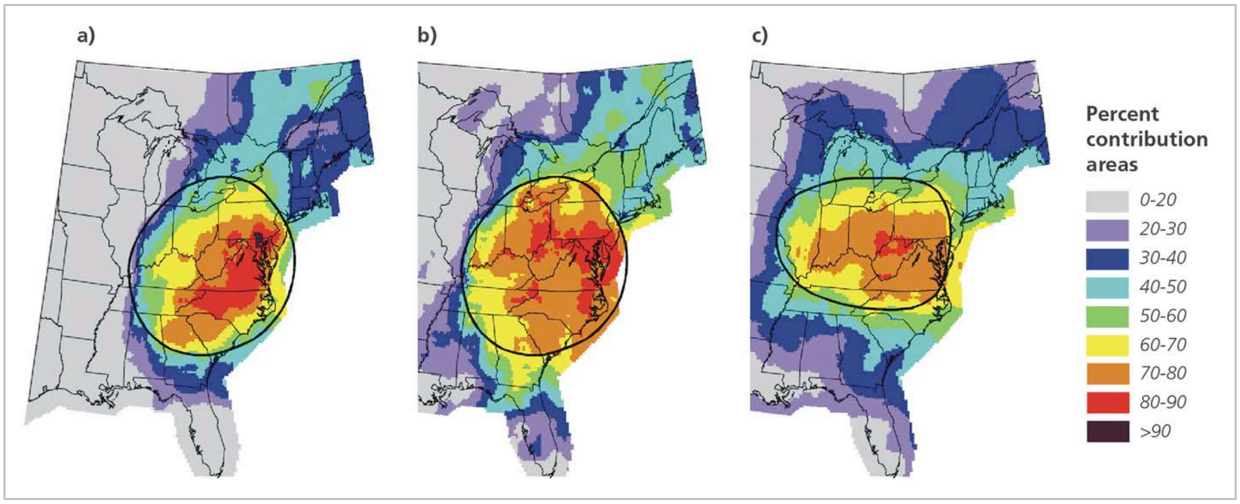

Figure 2-35. Major airsheds for Shenandoah National Park for a) oxidized nitrogen deposition, b) sulfur deposition, and c) sulfate air concentrations. Contours show the percent contribution. Source: Sullivan *et al.* 2003a.

Acid Deposition

Acidification effects caused by atmospheric sulfur (S) and nitrogen (N) deposition result from a reduced capacity of soil, soil water, and surface water to buffer acidity (Sullivan *et al.* 2003b). The addition of acidity from S and N sources of air pollution to national park ecosystems can alter plant, animal, and algal communities and influence the mix of species that thrive in those ecosystems. Atmospheric deposition of N can also contribute to nutrient enrichment effects; these nutrient N enrichment topics are addressed in a companion report (Sullivan *et al.* 2011a).

Sulfur emissions in the United States derive primarily from electricity generating power plants (Figure 2-36), and secondarily from industrial and mobile sources (Sullivan *et al.* 2011a). Sulfur is commonly emitted into the atmosphere as sulfur dioxide (SO_2), released when S-containing coal or other fuel is burned. There are two major kinds of human-caused emissions of N into the atmosphere in the United States: NO_x and NH_x. The oxidized forms (primarily nitrogen dioxide) derive mainly from motor vehicles, power plants, and industrial facilities. The reduced forms (primarily ammonia) derive mainly from agriculture, via volatilization of N contained in animal manures and fertilizers.

Figure 2-36. Sulfur emissions in the United States derive primarily from electricity generating power plants. Photo credit: Alan Williams, National Park Service.

In order for atmospheric S or N emitted from human-caused sources to cause environmental impacts (e.g., to soil, plants, lichens, or aquatic organisms), it must first be deposited from the air to the ground surface (Rice *et al.* 2006). Although this transfer is commonly called "acid rain", rain only accounts for part of the transfer. Atmospheric pollutants move to the ground also in snow, clouds, and as dry particles and gases. The overall transfer process is called "acid deposition" which can be broken down into wet and dry components.

Acid deposition levels occurring within Shenandoah National Park are amongst the highest when compared to other national parks that collect deposition information (Rice *et al.* 2006). Although the acidity of rain is uniform across the entire park, differences result from underlying geology and topography. The majority of streams in Shenandoah start at higher elevations, and these 'headwater streams' begin with little water. The addition of acid rain makes these streams more acidic than larger streams at lower elevations (Rice *et al.* 2006). Roughly 60% of the watersheds within the park include bedrock types that have a low acid buffering capacity. This allows chemical interactions between soil, bedrock, and surface waters with acid depositions to proceed without neutralization or buffering. These three main bedrock types are basaltic, granitic, and siliciclastic. These three types yield streams with higher, medium, and lower acid neutralizing capacity (ANC), respectively. ANC is the capacity of natural waters to neutralize acid inputs, and is highly influenced by underlying bedrock. For example, a small stream near the crest of a mountain on a steep slope underlain by siliciclastic bedrock is likely to have some of the most acidic water in the park, and therefore will not support high biodiversity. In contrast, a large stream with a gentle slope underlain by basaltic bedrock will have near neutral water, and support a more diverse community.

Streams in Shenandoah (and elsewhere in the Southeast U.S.) have been slower to recover from the effects of long-term acidic deposition than streams in the Northeast, because soils in the Southeast are better at retaining sulfate pollutants over time. Computer simulation models predict that with the recent reductions in sulfur air pollution in the US, sensitive streams in Shenandoah should be expected to begin recovering sometime in the next two decades. Park staff and researchers monitoring stream chemistry hope to see declines in surface water sulfate levels by this time, which will indicate streams are becoming healthier and will be able to support more types of fish and other plants and animals in the future (Rice *et al.* 2014).

When combined with other stressors (such as tree defoliation by the gypsy moth), significant problems can develop from acid rain. Streams within the park provide important habitat for fish and other aquatic organisms that are particularly sensitive to the acidic condition of the water in which they live. Acid levels have risen so high in some streams that even the native brook trout, an acid-tolerant species, is threatened (Rice *et al.* 2006).

Forested areas within the park are subject to various forms of stress including drought, disease, and insect damage. In some cases, the diseases and insects are not native to the park. Acid deposition builds on these conditions causing direct and indirect damage to forest vegetation. Among the vascular plants, sugar maple trees (*Acer saccharum*) and red spruce (*Picea rubens*), are known to be particularly sensitive, and are found in the park (Sullivan *et al.* 2011a; Sullivan *et al.* 2011b). Some lichens are also sensitive to acidification, with documented effects occurring in the deposition range of only a few kilograms of sulfur or nitrogen per hectare per year (Sullivan *et al.* 2011a). Additionally, increased soil acidity causes the release of more soluble forms of aluminum, which can kill a tree's fine root system, reducing its nutrient uptake ability (Webb *et al.* 1995; Welsch *et al.* 2001; Sullivan *et al.* 2003a).

Mercury deposition

Human activities have greatly increased the amount of mercury (Hg) currently cycling in the atmosphere, soils, lakes, and streams through processes such as burning coal for electricity and burning municipal, hazardous, and medical waste (National Park Service 2006b). Mercury is emitted to the air in the elemental or inorganic form and deposited to ecosystems by precipitation or dry deposition. In the environment, particularly certain types of wetlands, biological processes convert these bio-unavailable forms into methyl-mercury, which is toxic and accumulates up the food chain (National Park Service 2006b). The National Atmospheric Deposition Program has been operating a monitoring site within Shenandoah National Park at Big Meadows (VA28) since 2002. Snyder *et al.* (2006) indicated that Hg does not pose a significant human health threat in Shenandoah National Park based on brook trout Hg concentrations relative to EPA recommended consumption limits, though uncertainty remained for other fish species. Minimal other information on the effects of mercury on park flora and fauna is currently available, though a nationwide study including Shenandoah National Park has recently begun to assess mercury accumulation in dragonfly larvae from sampling sites within the park (Nelson *et al.* 2015, National Park Service 2014).

Ozone

Ozone in the lower atmosphere is an air pollutant, forming when nitrogen oxides from vehicles, power plants, and other sources combine with volatile organic compounds from gasoline, solvents, and vegetation in the presence of sunlight. In addition to inducing respiratory problems in people, elevated ozone exposures can injure plants.

Ground-level ozone concentrations at the park have been among the highest recorded at all national parks and has in the past exceeded the National Ambient Air Quality Standards set by the U.S. Environmental Protection Agency to protect public health. Park managers have instituted an ozone advisory program aimed at educating employees and park visitors about the risks of exposure to ozone and precautions that can be taken.

Visibility and haze

Fine particles in the air are the main contributor to human-caused visibility impairment. Visibility degradation results from scattering and absorption of visible light by these fine mass particles in the atmosphere. These particulates create haze and, not only decrease the distance one can see, but also reduce the colors and clarity of scenic vistas (Figure 2-37). Moisture in the air enhances the impact, so areas in the eastern U.S. with higher relative humidity have worse visibility than areas in the arid west. The chemical composition of fine mass particulates also influences their effect on visibility.

Reports prepared in 1924 and 1925 regarding creation of National Parks in the Appalachian Mountains specifically cite interest in protecting views to the west over the Shenandoah Valley and east over the Piedmont of Virginia (Source:

http://www.nps.gov/shen/naturescience/visibility_and_haze.htm) . These reports were the basis for the May 22, 1926 legislation establishing Shenandoah National Park Visibility or lack thereof, which is a significant issue at Shenandoah National Park related directly to the fundamental purposes of the park. Many visitors to the park spend time on Skyline Drive moving from overlook to overlook, taking in the scenery. Other visitors hike to the tops of various peaks in the park to take in spectacular views. Unfortunately, these experiences are often marred by poor air quality. Visibility unimpaired by manmade emissions should be in the range of 241 km. Haziest days usually occur in the summer when humidity is high and winds are low. Summertime visibility on clear days should be in the range of 121 km. In the 1990s, summertime visibility dropped to the range of 16 km due primarily to regional emissions of sulfur dioxide from coal fired power plants and industrial boilers. In the past decade, regional emissions of sulfur dioxide have been reduced 50-70%. Summertime visibility is now in the range of 48 km or better. Park staff members monitor visibility conditions and work with State and Federal regulatory agencies in an effort to limit emissions of pollutants that degrade visibility. Park staff members monitor visibility conditions and work with State and Federal regulatory agencies in an effort to limit emissions of pollutants that degrade visibility.

Figure 2-37. Visibility can be significantly reduced in Shenandoah National Park due to air pollution. Photo credit: Alan Williams, National Park Service.

2.4.2 Diseases

Examples of native diseases that occur in wildlife at Shenandoah include rabies in skunks, fox, and raccoons, and bacterial kidney disease in fish. A native disease of plants in Shenandoah is leaf spot. Non-native plant diseases that have been documented in Shenandoah include dogwood anthracnose, sycamore anthracnose, chestnut blight, and beech bark disease. Below sections are sourced from the National Park Service website: www.nps.gov/shen/naturescience/diseases.htm, amongst other sources as identified.

Dogwood Anthracnose

Dogwood anthracnose is a disease caused by the fungus *Discula destructiva* that attacks native and ornamental flowering dogwood trees (Anderson *et al.* 1994). This disease was first identified in New York in the late 1970s. The origin of the dogwood anthracnose is unknown. It may have been introduced or was an existing pathogen that altered its host due to a change in environmental conditions.

Dogwood trees can be affected at any time throughout the growing season, but are most susceptible to the fungus in the cool, wet seasons of spring and fall (USDA-FS. 1994). Trees weakened by drought or winter injury are especially vulnerable to infection. Spotting on leaves and flower bracts are the first signs that a tree has been infected (Figure 2-38). These spots are tan with dark purple borders and normally appear in mid- to late May. During cool, wet weather, blighted gray and drooping leaves are also noticeable. The fungus then spreads into the twigs and limbs, eventually killing them. As a result of twig and limb death, the tree will produce succulent shoots on the lower trunk and main branches. These new branches are very prone to infections, which can then transport the disease into the trunk. Thousands of native dogwood trees have died as a result of dogwood anthracnose within the Park.

Figure 2-38. Diseased dogwood anthracnose. Photo credit: Robert L Anderson, USDA Forest Service.

American chestnut blight

The American chestnut tree (*Castanea dentata*) once dominated eastern forests from Maine to Alabama, and comprised 50% of the mountain forests of this country. It is estimated that if all the chestnut trees alive at that time had been in one pure stand, there would have been a forest of more than 3.6 million km^2. In size they were the "redwoods of the east", growing to a height of over 30 m and a diameter of nearly 3 m. Renowned for their weather resistant wood and dependable crop of nuts, the chestnut tree was of great value to man and wildlife.

These giants are now absent from the landscape – a tragic loss that has been said to be one of the worst natural calamities ever experienced by this nation. In the early 1900s, a fungus (*Cryphonectria parasitica*) was accidentally introduced into New York City from trees imported from Asia (Sinclair *et al.* 1987). The blight quickly spread on its new host, the American chestnut, destroying it throughout its range. Today, chestnut trees can only be found in the understory, as shoots from blight resistant roots. By the time they reach 6 m in height the blight attacks and kills them (Figure 2-39).

Figure 2-39. Chestnut blight still affects the few stunted American chestnut tree survivors. Photo credit: Claudette Hoffman.

Chronic wasting disease

There are currently no cases of chronic wasting disease (CWD) in Shenandoah National Park.. Because of the contagious nature of this serious nonnative disease, Shenandoah scientists must plan for CWD detection and management of the deer herd should infection occur (Figure 2-40).

Figure 2-40. White-tailed deer suffering from chronic wasting disease. Photo credit: Wisconsin DNR.

2.4.3 Disturbed lands

Human occupation of the Blue Ridge Mountains is well documented and has resulted in many disturbances to the landscape (Sisk 1998). Lands were cleared of trees and rocks for establishment of homesteads and for the purpose of growing crops or grazing livestock. Trees were cut for firewood and construction of fences and buildings. Rocks were gathered or quarried to build foundations and walls. Small mining operations were started. Plants and animals were harvested for various reasons. In a few situations, stream channels were dammed and water diversion structures were installed. While most of these land uses were short-lived, some were long-lasting. More recent development, particularly in association with the park, has become permanent. Skyline Drive, State highways, utility right of ways, campgrounds, lodges, picnic areas, and other visitor facilities have endured (Figure 2-41).

Figure 2-41. Power line corridor bisects Shenandoah National Park. Photo credit: Simon Costanzo.

The accumulation of these uses constitutes the history of the park and the remnants (walls, foundations, and other features) make up the cultural resources protected by the park. Each of these uses, while of value culturally, resulted in disturbances including either outright loss of natural resources or alteration of those resources. Under limited circumstances, restoration activities are undertaken to re-establish lost or damaged natural resources.

Today, most human activities that disturb the environment are forbidden within the park. Some activities are allowed to continue to facilitate park use and enjoyment. Construction and rehabilitation of buildings, roads, and utility corridors in the park are always carefully planned to minimize damage to park resources. New projects generally are limited to the existing disturbed 'footprint'. Before a project gets underway, the area is assessed for sensitive habitats or populations of rare plants or animals. Consideration is also given to impacts on soils, air, and water resources.

In many cases after construction, the surrounding area is revegetated using plant material previously gathered from the area. The park has begun to use its own small nursery so that local seed and seedlings can be grown into plants to restore disturbed areas. Some disturbances are long lasting and are difficult, if not impossible, to erase. Fortunately, the Blue Ridge is highly ecologically dynamic and resilient.

Disturbance of park resources is not solely the result of human activities. Many natural events also cause disturbance. Ice storms, high winds, and heavy snows bring down tree limbs and whole trees. Heavy rains cause flash flooding, and in rare cases debris flows in stream channels, and mudslides. Water penetration and freezing cause rock falls. Insect and pathogen infestations cause declined condition and death of biological resources. Drought and wet conditions stimulate or inhibit plant growth and mast production, alter habitat availability and conditions for aquatic organisms, and influence population sizes of aquatic insects and fish. Wildfires reduce vegetation biomass and create conditions that stimulate the recruitment and growth of some species while negatively impacting others.

2.4.4 Fire

Fire, intentionally used by Indians and early settlers for a variety of reasons, resulted in extensive modifications to the vegetation over most of North America, including the Appalachian Mountains, favoring the perpetuation of oak, pine, and chestnut (Brose et al. 2001). With the onset of capital-intensive forest harvesting in the Appalachians, the fire regime was altered to high-intensity, stand-replacing fires further increased the dominance of oak and chestnut over other species (Brose et al. 2001). The advent of wildfire control in the late 18th and early 19th centuries led to the establishment of extensive oak and chestnut stands (Banks 1960).

Fires also cause substantial changes to the physical environment by consuming vegetation, destroying leaf chlorophyll, exposing soil, charring stems, and altering aboveground and belowground moisture (Iverson and Hutchinson 2002, Epting *et al.* 2005, Groeschl *et al.*1990). These effects are highly sensitive to the intensity and seasonality of burning, especially in oak-dominated forests of the eastern U.S. (Groeschl *et al.*1990). Low intensity burns have been shown to kill the aboveground portions of most saplings and shrubs, but eventually stimulate understory growth (Cass 2002). Fires also alter competitive dynamics by allowing more sunlight to reach the forest floor. Native fire-tolerant species within the park are very likely to decline in the absence of fire management. Shenandoah National Park is currently employing controlled prescribed fire as an ecological restoration tool at Big Meadows and in xeric oak- and pine-dominated ecosystems (Figure 2-42).

Figure 2-42. A creeping fire in Shenandoah National Park. Photo credit: National Park Service.

2.4.5 Hydrologic activity

Hydrologic activity, or the action and influence of water on other natural resources are manifest in several forms at Shenandoah National Park. The primary activities include erosion, freezing and thawing, and the occurrence of catastrophic events.

Under normal precipitation and stream flow conditions, water and suspended sand and gravel material contribute to the gradual erosion or wearing away of streambeds and banks. Most stream segments, found in the park, are high gradient, or fall from a higher elevation to a lower one over a very short distance (Figure 2-43). This condition, common in mountainous terrain, leads to more erosion than sediment accumulation, although there are locations in the park where the stream gradient is lower and water velocity slows sufficiently to allow sediment to drop out of suspension and accumulate. Erosion is often regarded as an undesirable condition or process. In the park setting, assuming that it is not accelerated by human causes, erosion is accepted as a natural process.

Infiltration of waters into the ground and rock outcroppings sets the stage for an annual freeze and thaw cycle. As the water freezes, it expands, causing spalling of rocks from outcrop and cliff faces. Spring thawing of that ice creates below-surface rivulets and streams of water, which may further contribute to spalling.

Figure 2-43. Large-scale debris flow. Photo credit: Dave Steensen.

2.4.6 Non-native species

Shenandoah National Park contains a host of non-native animal and plant species. Indeed, for vegetation alone there are 352 non-native plants, about 25% of the total. "Exotic," "alien," "introduced," "non-indigenous," and "non-native" are all synonyms for species that humans intentionally or unintentionally introduce into an area outside of a species' natural range. Not all non-native species are invasive and it is well established that many non-native species are of little consequence in natural areas. In Shenandoah 41 of the identified non-native species are considered to be invasive and present one of the most serious threats that National Parks face today. Non-natives disrupt complex native ecological communities, jeopardize endangered native plants and animals, and degrade native habitats. Hybridization with non-natives alters the genetic integrity of native species. In some cases, non-natives are also regarded as pests because they cause human health and annoyance problems. If non-natives are not actively and aggressively managed, the National Park System is at risk of losing a significant portion of its biological resources.

Non-natives were introduced with the earliest European immigrants, but new introductions continue today. Among other reasons, purposeful introductions were for game management, wildlife habitat enhancement, industrial development, soil erosion protection, or just to remind settlers of their first homes far away. Accidental introductions have been through unintended releases and biological hitchhiking on vehicles, personal effects, or trade goods.

Examples of non-natives found at Shenandoah include:

- **Gypsy moth** (*Lymantria dispar*): brought to this country in 1869 for genetic crosses to create a more productive silkworm. It was accidentally released near Boston, MA. Millions of trees died in the park during the heavy infestations of 1986-95.
- **Hemlock woolly adelgid** (*Adelges tsugae*): accidentally introduced into this country on imported hemlock nursery stock (Figure 2-44). The insect has killed thousands of hemlocks

in the park, destroying valuable shaded riparian habitat along streams and springs, and causing the loss of hemlock-associated species.

- **Emerald Ash borer** (*Agrilus planipennis*)**:** has been confirmed in the park since 2013. If this species becomes well established in the park, it could lead to large-scale ash mortality and cause impacts similar to what was seen when the park's eastern hemlock trees were killed by hemlock woolly adelgid.
- **European starlings** (*Sturnus vulgaris*): introduced into the country in the late 1880s. They are known to compete with native cavity-nesting birds and have documented ill effects upon northern flickers and redheaded woodpeckers.
- **Japanese stilt grass** (*Microstegium vimineum*): introduced into the United States in Tennessee around 1919 and likely escaped as a result of its use as a packing material for porcelain. This species can be seen throughout the Elkwallow picnic area where it is has overrun virtually all other forest understory herbs.
- **Oriental Bittersweet** (*Celastrus orbiculatus*): introduced into the United States in the 1860s as an ornamental plant and it is still widely sold for landscaping despite its invasive qualities. Oriental bittersweet is a vigorous growing plant that threatens native vegetation from the ground to the canopy level.
- **Kudzu vine** (*Pueraria montana var. lobata*): originally brought to America in 1876 to decorate house arbors. It was later used in the U.S. to control erosion along highways. It now covers millions of hectares in the southern U.S. The park has a small infestation it controls along its eastern border.
- **Tree of heaven** (*Ailanthus altissima*): brought into this country in the 1780s for arboretum plantings. It escaped to dominate Mid-Atlantic forest edges and openings. The park has hundreds of infested hectares.

Figure 2-44. Hemlock woolly adelgids (*Adelges tsugae*). Photo credit: Alan Williams, National Park Service.

National Park Service policy on non-native species requires management in order to preserve native species and ecosystems, including full eradication efforts, if deemed feasible and if the species is suspected of causing harm. Executive Order #13112 on Invasive Species instructs all non-defense agencies to control non-native species and not permit new infestations. Though it is not humanly possible to eliminate all non-native species at this time, the park is engaged in a number of strategic actions including inventory, control, monitoring, and site restoration (Figure 2-45).

Figure 2-45. Mixture of invasive plant species Oriental bittersweet (*Celastrus orbiculatus*) and tree-of-heaven (*Ailanthus altissima*). Photo credit: National Park Service.

<u>Wavyleaf basketgrass</u>

Wavyleaf basketgrass is a perennial grass that is native to Europe and Asia. Highly shade tolerant, it grows vigorously in closed canopy forests. It appears to have the potential to crowd out native plants, including herbs and tree seedlings. Sticky seeds give this species the potential to spread rapidly over long distances. Wavyleaf basketgrass has only been found in a handful of locations in Maryland and Virginia, including seven sites in Shenandoah National Park (National Park Service 2008e).

Mile-a-minute

Mile-a-minute weed (*Persicaria perfoliata*) (Figure 2-46) has a wide range of suitable habitats and occurs at many sites in the Park, including Shop Run, Hull School Trail, Sams Ridge, and Hogwallow overlook. It is suspected to be present elsewhere in the park. It thrives in moist soils that are rich in nutrient and exposed to plenty of sunlight. It has been found on roadsides, and in moist thickets, clearings, and ditches.

Figure 2-46. Mile-a minute (*Persicaria perfoliata*). Photo credit: National Park Service.

Mile-a-minute is known to out-compete natives for resources. The plant grows very fast, and will absorb nutrients quicker than its competitors will. It will cover the native plants from available sunlight, which does not allow them to photosynthesize. This, in turn, puts stress on the sun-loving natives and eventually kills them.

There are a couple strategies taken by the National Park Service to prevent further growth. The most effective is to pull the plants by hand. This has been attempted at all known sites in the park. This is effective but very time consuming. Before 2006, the National Park Service sprayed the more overgrown sites in the park with an herbicidal soap solution, but this method proved to be ineffective at controlling the spread of mile-a-minute. Currently, the National Park Service relies on biological control using a weevil (*Rhinoncomimus latipes*) for all but the smallest sites.

Sweet cherry

The settlers that lived in the mountains of Shenandoah National Park often grew sweet cherry (*Prunus avium*) on their orchards. While sweet cherry is a non-native species, it is not considered invasive. Many of these same trees can be found on old homesites throughout the park today. Since the park was established in the 1930s, the orchards have become assimilated into the forest habitat that currently prevails in the park. Sweet cherry has survived and undoubtedly spread due to birds and mammals that browse its fruit (Figure 2-47).

Sweet cherry can grow in acid, neutral, and basic soils. It prefers average, medium wet, well-drained soils in full sun such as roadsides like Skyline Drive, to partial shade such as the more open canopied woodland settings of the park. Sweet cherries are also an important early summer food source for black bear and birds.

Figure 2-47. Sweet cherry (*Prunus avium*). Photo credit: National Park Service.

Tree of heaven

Within Shenandoah National Park, tree of heaven (*Ailanthus altissima*) is a non-native plant targeted because of its ability to rapidly grow and spread as well as produce a toxin in its leaves and bark that can inhibit the growth of other plants (Figure 2-48). It is important to the park to kill invasive non-native species such as tree of heaven because invasive non-native species are known to be a significant threat to biodiversity. Only habitat loss is a greater threat. As an invasive non-native plant, the National Park Service attempts to remove tree of heaven from its lands. Removal is a difficult task requiring extreme diligence. Current techniques for removal include treatment with herbicides and manual removal of small trees. (Hughes and Akerson 2006; National Park Service nd-b, VDCR nd).

Figure 2-48. Tree of heaven (*Ailanthus altissima*). Photo credit: National Park Service.

Brown trout

The presence and proliferation of non-native brown (*Salmo trutta)* trout (Figure 2-49) has the potential to impact brook trout and other native fish populations within several of the park's premier large streams. Due to a combination of size and diet, brown trout often displace native brook trout where the two species overlap. They tend to dominate the best available habitat by forcing brook trout from preferred habitat and, to an extent, by preying directly upon brook trout.

Within the park, brown trout have successfully colonized the lower gradient reaches of seven streams since initial stockings outside the park in the 1960s. Brown trout have been removed from four park streams since 1989. Only one incident of brown trout predation by a northern water snake has been recorded within the park, but they are likely also preyed upon by mink, kingfishers, herons and the occasional otter within the park, as are the other trout species.

Figure 2-49. Brown trout (*Salmo trutta)*. Photo credit: Michael Smith.

<u>Rainbow trout</u>

Rainbow trout (*Oncorhynchus mykiss)* were first introduced in stream habitats within and downstream of the park in 1943 (source: http://www.nps.gov/shen/naturescience/rainbow-trout.htm). The wild rainbows that inhabit Pass Run within the park are believed to have descended from hatchery stock introduced downstream during the 1950s. Rainbow trout (Figure 2-50) have also successfully reproduced intermittently in the North Fork Moorman's River since 1957 as the result of stocking programs downstream.

Figure 2-50. Rainbow trout (*Oncorhynchus mykiss)*. Photo credit: Matt Tillett.

Naturalized rainbow trout populations within the park likely have adapted to and assumed a similar ecosystem role to native brook trout populations. In smaller streams such as Pass Run, rainbow trout very likely compete with brook trout for available habitat and food resources. Competition factors are likely magnified during periodic surges within the rainbow trout population. Within the park, no incidents of rainbow trout predation have been recorded, but they are likely preyed upon by northern water snakes, mink, kingfishers, herons and the occasional otter within the park, as are the other trout species.

While not typically encountered in size classes beyond 30 cm in park streams, large rainbow trout of comparable size to large adult brook trout can be aggressive competitors for available habitat within the confines of a small stream. The Pass Run population is the only stable naturalized rainbow trout population currently persisting within the park. The limited and sporadic production within the lower reaches of the North Fork Moorman's River apparently results from very few, occasional redds (trout or salmon nest) as the result of rainbows stocked just downstream of the park boundary. The degree of displacement pressure on brook trout posed by these rainbow trout populations is currently unknown.

2.4.7 Scenic vistas

The quality of a scenic vista is influenced by landform and use, vegetative cover and condition, and air quality. Shenandoah National Park is known internationally for spectacular mountain scenes that can be viewed from the numerous vantage points along Skyline Drive. Skyline Drive was constructed in the 1930s to serve as a scenic drive along the crest of the Blue Ridge Mountains within Shenandoah National Park. The road was designed and constructed to provide scenic views within the park and into the Piedmont Plateau to the east and the Shenandoah Valley to the west. Seventy-six overlooks, or pullouts with parking, were constructed so motorists could stop at intervals along the Drive and enjoy the views (Figure 2-51).

When first constructed, the overlooks provided unobstructed views but gradually, forest succession has resulted in view closure by trees and shrubs. In the 1970s, park staff initiated a program to reopen these vistas. All overlooks in Shenandoah National Park are now maintained with periodic tree and shrub clearing to preserve the historic views. This clearing work is done within the original footprint of each overlook as it was created during the construction of Skyline Drive. Every overlook and drive-by vista exists because of a down-slope area of vegetation removal known as the 'vista clearing zone.' The park currently maintains vista clearing zones with broadcast herbicide application. In some cases, fire has been used to maintain the clearings. Prior to clearing, all vistas are surveyed for species of concern and non-native species (National Park Service 2008d).

Clear views from these locations are integral to visitor experiences, yet visibility (the distance at which a person can see an object clearly) is further impaired by particulate air. Despite improvements in air quality under the Clean Air Act, the park's visibility and sensitive aquatic systems are still adversely impacted relative to estimated natural or pre-industrial background conditions (Sullivan *et al.* 2003a). Visibility in the park has been severely degraded so that today, summertime visibility is in the range of 48 km or better, compared to a standard of 121 km on clear days.

Figure 2-51. A clear day view from Bearfence Mountain in Shenandoah National Park. Photo credit: Wendy Hochstedler, National Park Service.

2.4.8 Weather

Periodically catastrophic weather events strike the park such as severe thunderstorms and hurricanes. These storms often bring with them torrential amounts of rain. Park streams may flood and if sufficient ground saturation has occurred, major debris flows may occur. Additionally, periodic ice storms often damage overstory trees, especially at high elevations, causing canopy openings in the forest (Figure 2-52).

Figure 2-52. Ice storm brings down trees in Shenandoah National Park. Photo credit: National Park Service.

Although these events may result in undesirable flooding, erosion, and debris deposits downstream, they are regarded as natural events. The resulting disturbance of resources within park watersheds is visually alarming, but ecological recovery appears to be relatively rapid.

2.4.9 Depreciative visitor use

One of the missions of the National Park Service is to provide opportunities for visitor enjoyment and use of parks. Uses of parks vary widely and include activities like sightseeing, photography, hiking, camping, bird watching, skiing, rock climbing, natural and human history study, and picnicking.

Unfortunately, park visitors also engage in what are termed “depreciative behaviors” or actions that degrade park resources or experiences of other visitors. These inappropriate behaviors include such things as littering, feeding of wildlife, collection of green wood for use in campfires, disfiguring trees and rocks (Figure 2-53), and improper disposal of human waste in the backcountry. Other behaviors of concern include walking and hiking with pets that are not leashed, collection of specimens, construction of fire rings and ground fires in the backcountry, trampling of rare vegetation communities, illegal backcountry camping, and shortcutting on trail switchbacks. The list of inappropriate visitor activities could become quite extensive.

These behaviors are a concern because they may result in resource damage or destruction, alter behavior of wildlife, pose public health risks, or result in unsightly conditions. In many cases, park staff is called upon to intervene and restore resource conditions. In the most serious of circumstances, restoration may be impossible. A case in point may be a black bear that has become so habituated to people that it poses a threat and must be destroyed.

Figure 2-53. Graffiti on tree in Shenandoah National Park. Photo credit: Shenandoah Mountain Guides.

Recreational activities that currently occur within the park also have the potential to affect natural resources (Mahan 2006; Conners 1988). For example, rock climbing threatens the fragile plants associated with cliff communities; heavy use of hiking and horseback riding trails and backcountry campsites can contribute to soil erosion; and concession-supported activities like permanent campgrounds that require infrastructure such as wells, may alter hydrologic regimes and threaten water quality in the park (Bair 1988).

2.4.10 Unnatural light

The proliferation of development and associated installation of lights in the Shenandoah region results in light pollution at night in the park (Figure 2-54). Light pollution limits visibility of celestial systems and potentially interferes with the natural circadian rhythm of biota within the park. The Bortle scale is a nine-level numeric scale that measures the night sky's brightness of a particular location (Levels 1-9 with 9 reflecting an inner-city sky). It quantifies the astronomical observability of celestial objects and the interference caused by light pollution (John Bortle 2001 in Sky and Telescope Magazine February 2001).

Shenandoah National Park ranks as a 'Class 4' meaning light pollution domes are apparent over population centers in several directions (Figure 2-55). By comparison, close by cities of Harrisonburg, Staunton, Waynesboro, Charlottesville rank as "Class 5", meaning bright skies where you effectively see nothing but the brightest stars.

Figure 2-54. Night sky viewing of Milky Way affected by light pollution. Photo credit: William McIntosh.

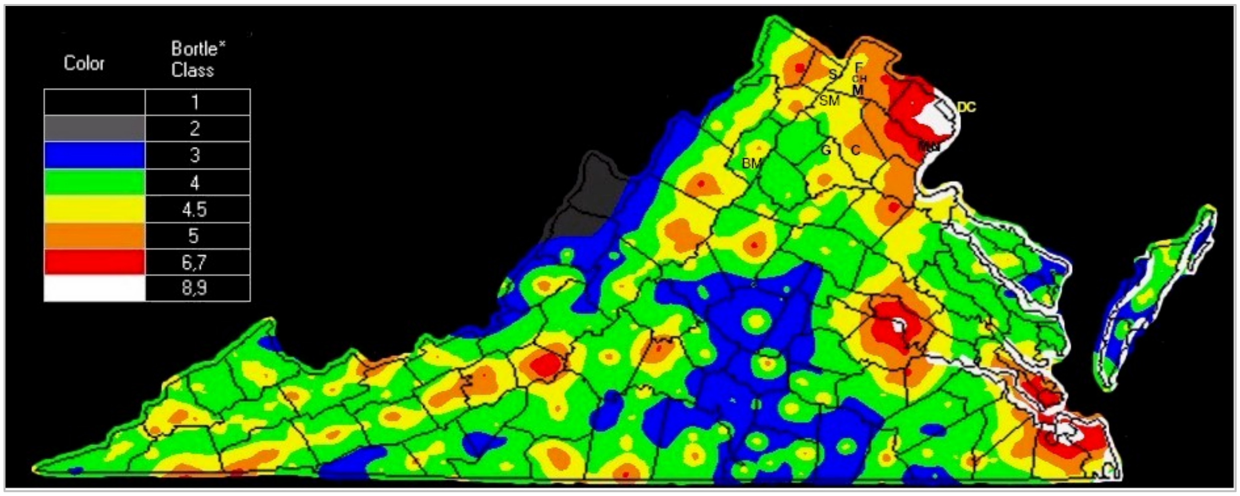

Figure 2-55. Light pollution map of Virginia as categorized by the Bortle Scale. Source: Forrest Hamilton of the Maryland section of the International Dark Sky Association (IDA) and The World Light Pollution Atlas http://djlorenz.github.io/astronomy/lp2006/.

The National Park Service is concerned about the contribution to light pollution from within the park and has set policy that seeks to reduce or eliminate the adverse impacts of light pollution within the park. In the fall of 2014, the National Park Service conducted a baseline inventory of night sky conditions and evaluated facilities within the park that pollute night skies. At Shenandoah National Park, staff members are working in cooperation with park concessionaire staff to reduce in-park light pollution. Shields have been installed on a light fixture at the Big Meadows Wayside and additional work will be done on area and walkway lights under the auspices of the Concessionaire's Capital Improvement Program. Park efforts are also underway to replace outdoor fixtures with night sky-compliant lighting, starting with Big Meadows. Since 2000, volunteers and concessionaire employees have hosted night sky programs in the Big Meadows Area.

2.4.11 Unnatural sounds/noise

Unnatural sounds can simply be defined as those sounds that are produced by human activity or the operation of motors and equipment (Figure 2-56). Within the context of park management, sounds that originate with people and that interfere with the ability to hear natural sounds (bird songs, blowing wind, cascading water, etc.) are considered undesirable. In most cases, when noise is present in a park, it is considered a mild aggravation but in other cases, that noise can disrupt the quality of a visitor's experience. Through the study of acoustic ecology, it has been determined noise also has the potential to alter wildlife behavior and is important to species survival. Noise can also detract from the portrayal of historical events and in some circumstances, alter the physical condition of park resources. Examples of this last point, while not applicable to Shenandoah, are the triggering of avalanches or shocking of unstable ruins by sonic booms.

The National Park Service has had limited but longstanding interest in and concern with unnatural sounds or noise. Historically, this has most often been manifest in the regulation of noise in campgrounds (controlling operation of electrical generators or radios). Following passage of the Wilderness Act in 1964, under the direction of Congress, decisions started to be made to prohibit the use of motorized equipment in designated wilderness areas, thus contributing to the wilderness experience of hikers and backpackers. Often this use of motorized equipment was in the form of chainsaws and various power tools by agency personnel.

In more recent years, the perspective has broadened with greater emphasis on things like aircraft overflights, operation of jet skis, snow machines, ultralight aviation, and neighboring industries that have processes that generate noise. A natural sounds assessment is needed for Shenandoah.

Figure 2-56. Motorbiking is popular along Skyline Drive. Photo credit: National Park Service.

2.5 Resource stewardship

2.5.1 Management directives and planning guidance

Fundamental resources

Fundamental resources and values are the features, systems, processes, experiences, scenes, sounds, or other resources that collectively capture the essence of the park and warrant primary consideration by managers because they are critical to achieving the park's purpose. Natural and cultural resources serve as Shenandoah National Park's fundamental resources.

Fundamental values

The legislation that created the National Park Service mandates that the agency operate, maintain, and protect the units of the National Park System such that two general goals are achieved. These are:

> *… to protect and preserve the natural and cultural resources of the parks so they will be available to future generations … and … to provide for the public enjoyment of the parks.*

The Shenandoah National Park Natural Resource Management Program tries to facilitate meeting both of these goals through a wide variety of activities of park staff, cooperators and partners, and volunteers.

Because natural resource management activities in a single park can be numerous and, in some cases, ecologically and scientifically complicated, those activities are frequently grouped as major program components. The following are brief descriptions of each of those components.

Natural Resource Inventories – In addition to the very fundamental information about the presence of a plant or animal in Shenandoah, park staff work on improving understanding of species abundance and distribution (Figure 2-57). They also prepare species lists and collect specimens that vouch for the presence of a particular resource. These activities are grouped together and referred to as "inventories”. Mapping and database development also occur under the auspices of the inventory program. Soils, geology, and vegetation maps are prepared and reports on the condition of air, water, and geologic resources are written.

Resource Conditions and Trends – Inventory activities emphasize the description of natural resources at a single point in time. Condition and trend programs, often referred to as "monitoring," emphasize tracking changes in resource conditions over time. Conclusions regarding the status of park resources and whether or not they are remaining in excellent condition can be developed based on monitoring information.

Stewardship Activities – As a result of inventory, condition, and trend studies, park staff frequently identify problems with park resources. The presence of non-native plants, elevated levels of ozone in the air, and trampling of rare plants are three examples of resource problems at Shenandoah. Park personnel engage in "stewardship activities" in an effort to correct these problems. These activities are wide ranging and include things like restoration of species that are rare or non-existent in the park like peregrine falcons, removal of non-native plants like tree of heaven and Japanese stiltgrass, and reviews of applications for air pollution emission permits.

Research – Support is sought from the academic world and other agencies and organizations to conduct research targeted on those issues. Furthermore, parks are ideal locations for research to be conducted because resource conditions are generally good or pristine, and land use is not changing rapidly. Significant numbers of scientists approach the park each year with interest in conducting research in the park. Thus, the National Park Service supports an active research program.

Resource Education – In the course of gathering information about park resources and managing those resources, park staff improve scientific understanding. Many opportunities are identified to communicate those findings to the public. This is accomplished through close coordination with the park's interpretive and education staff – those rangers who operate the visitor centers, give campfire programs and lead hikes, and present youth and adult education programs. Natural resource management personnel develop materials for brochures, exhibits, and for the park website.

Planning and Compliance – The preservation and management of natural resources found within the parks of the National Park System are guided by two major functional areas – planning and compliance. Each park within the National Park System should have a broad General Management Plan that outlines general objectives and goals and lays out strategies for achieving those. Tiered off of the General Management Plans are more specific plans including the Comprehensive Interpretive Plan and the Resource Stewardship Plan (formerly known as the Resources Management Plan). Finally, tiered below those plans is a set of action plans such as Fire Management Plans and Integrated Pest Management Plans. This latter tier is usually very detailed and specific. Park staff members who are charged with managing resources are generally heavily involved in the development of these plans.

In addition to planning documents, which guide the management of park resources and the development of park facilities, park staff looks to various pieces of environmental legislation to guide management decisions. Primary among those is the National Environmental Policy Act. This and other laws require the National Park Service to evaluate the impacts of management decisions, construction projects, and park operations; to consider alternatives to proposed actions; and, to assess public comments. Specific procedures are often stipulated to assure that ‘compliance’ with the spirit and intent of these laws is met. Resource management staff is charged with the responsibility of implementing the procedures associated with each of these laws.

Desired conditions

Park-wide desired conditions are resource conditions that the National Park Service aspires to achieve and maintain over time, and the conditions necessary for visitors to understand, enjoy, and appreciate those resources. Often desired condition is not fully known due to a lack of information and/or capacity. Desired conditions can also change over time as knowledge and information becomes available.

2.5.2 Status of supporting science

Inventory and Monitoring Program, National Park Service

The I&M program began with the Natural Resource Challenge in 1999. The goals of the Program are to (National Park Service 2009a):

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

The I&M program develops monitoring protocols that provide information about the ecological health of the parks, called “vital signs”. Vital signs are indicators of ecosystem health and include:

- physical, chemical, and biological elements and processes of park ecosystems;
- known or hypothesized effects of stressors; and/or
- elements that have important human values (National Park Service 2012).

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 (National Park Service 2012).

Well before the Resource Challenge, Shenandoah National Park received special designation in the Inventory and Monitoring in 1991 - as a Prototype Monitoring Program park. As a result, several park monitoring programs pre-date the Challenge and a few programs have been consistently monitored for more than three decades. Shenandoah also participates in a number of Federal and State programs that monitor air pollutants of primary concern to the park. These programs are: 1) the National Atmospheric Deposition Program/National Trends Network (NADP/NTN), a nationwide network of precipitation chemistry monitoring sites; 2) the Clean Air Status and Trends Network (CASTNET), the nation’s primary source for atmospheric data to estimate dry acidic deposition; 3) the Mercury Deposition Network (NADP/MDN); 4) State and Federally operated ozone and particulate matter monitors (TEOM); and, 5) the Interagency Monitoring of Protected Visual Environments (IMPROVE) program.

Figure 2-57. Fish sampling within Shenandoah National Park. Photo credit: National Park Service.

Chapter 3. Study Approach

3.1 Preliminary scoping

3.1.1 Park involvement

Preliminary scoping for the assessment of Shenandoah National Park began in October 2012. Archived data for park resources were organized into an electronic library, comprised of published literature, technical reports, management reports, raw data files, and geospatial data (GIS), which provided the primary data resources. Planning and exchange of data occurred through a series of meetings with park staff from Shenandoah National Park, National Park Service Natural Resources and Science, the National Park Service Mid-Atlantic Network Inventory and Monitoring Program, the University of Maryland Center for Environmental Science-Integration and Application Network (UMCES-IAN), and the University of Richmond (UR) Department of Geography and the Environment (Figure 3-1).

Project goals and reporting areas were determined during the initial scoping meeting. Shenandoah National Park staff helped identify key indicators of environmental health. Follow-up conferences solidified indicators and provided input and interpretation of key findings and trends. In conjunction with ongoing monitoring and research, efforts were made to integrate indicators from the National Park Service Inventory and Monitoring Vital Signs framework into this assessment.

Figure 3-1. National Park staff and report authors at the Shenandoah National Park NRCA scoping meeting. Photo credit: National Park Service.

3.2 Study design

3.2.1 Reporting areas

The park was categorized into six reporting areas based on two altitudes and three major geology types underlying Shenandoah National Park (guidance sought from Young *et al.* 2009):

- Low-moderate / Siliciclastic (<915 m elevation)
- Low-moderate / Metabasaltic (<915 m elevation)
- Low-moderate / Granitic (<915 m elevation)
- High / Siliciclastic (>915 m elevation)
- High / Metabasaltic (>915 m elevation)
- High / Granitic (>915 m elevation)

This categorization aimed to further delineate the studies conducted in the past solely on underlying geology. After an initial GIS mapping of the landscape using this modified classification scheme (Figure 3-2), several rounds of comments were solicited with park staff to identify potential misclassifications in the park, and maps were edited accordingly.

3.2.2 Assessment framework

Indicators form the basis of this condition assessment. The I&M program has previously developed a number of ecological monitoring indicators grouped as "vital signs". Fancy *et al.* (2009) defines vital signs as a "subset of physical, chemical, biological elements and processes of park ecosystems that are selected to represent the overall health or condition of Park resources, known or hypothesized effects of stressors, or elements that have important human values".

The I&M vital signs are:

- Air and climate
- Water
- Biological integrity
- Landscapes (ecosystem pattern and processes)
- Human use

For the purposes of calculating natural resource condition in Shenandoah National Park, only the first four vital signs were used, though general features of "human use" and "geology and soil" are discussed throughout the report. Vital sign indicators were chosen by the park in collaboration with UMCES-IAN and UR, and are outlined in Figure 3-3.

Detailed information of relevance, methods, reference condition, and attainment are provided for each indicator in Chapter 4. Each indicator also contains a section describing data gaps and level of confidence, based on best professional judgment. Confidence in assessment did not influence the calculation of attainment or assessment scores.

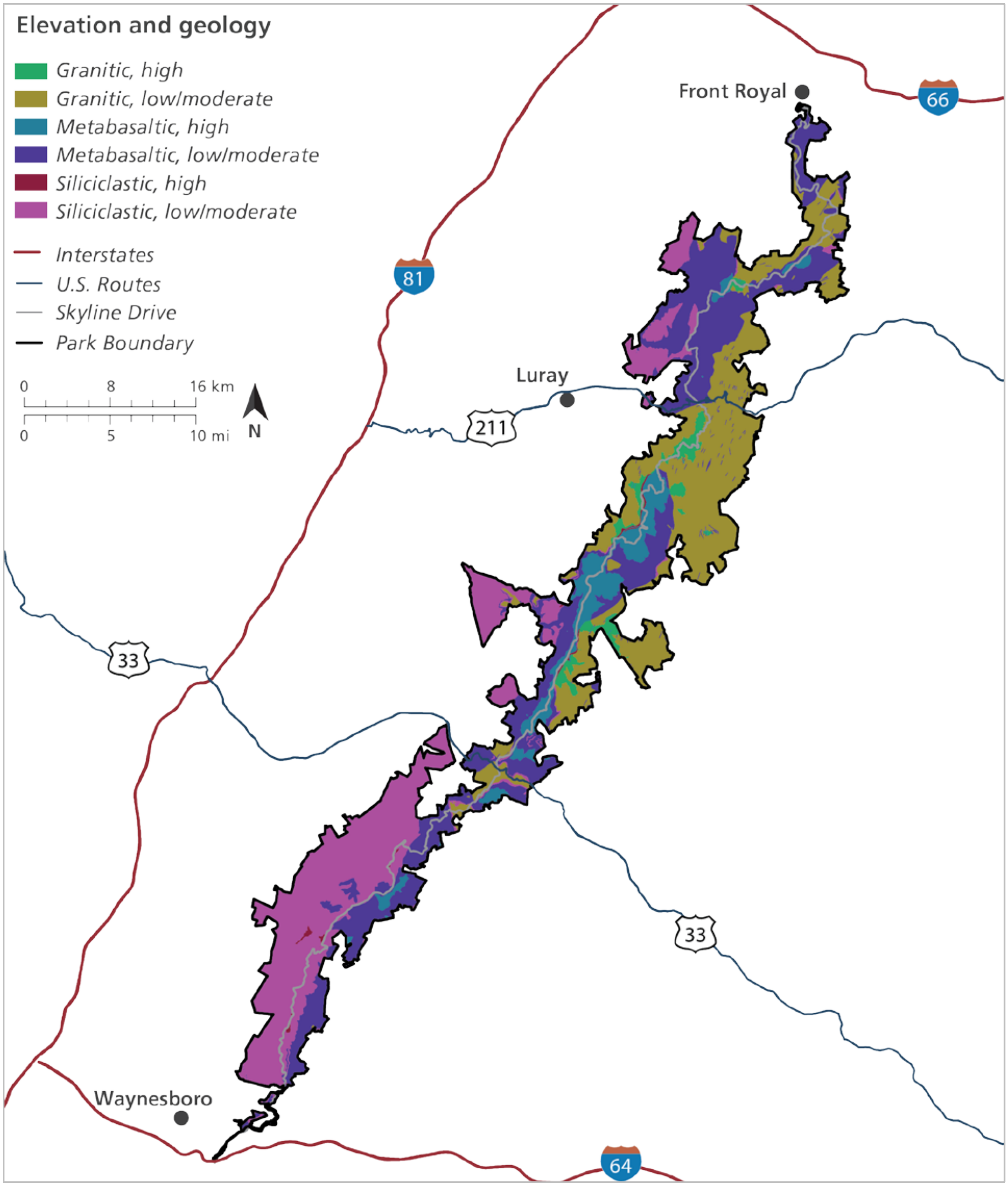

Figure 3-2. Park delineation by geology and elevation. Derived from Young *et al.* (2009).

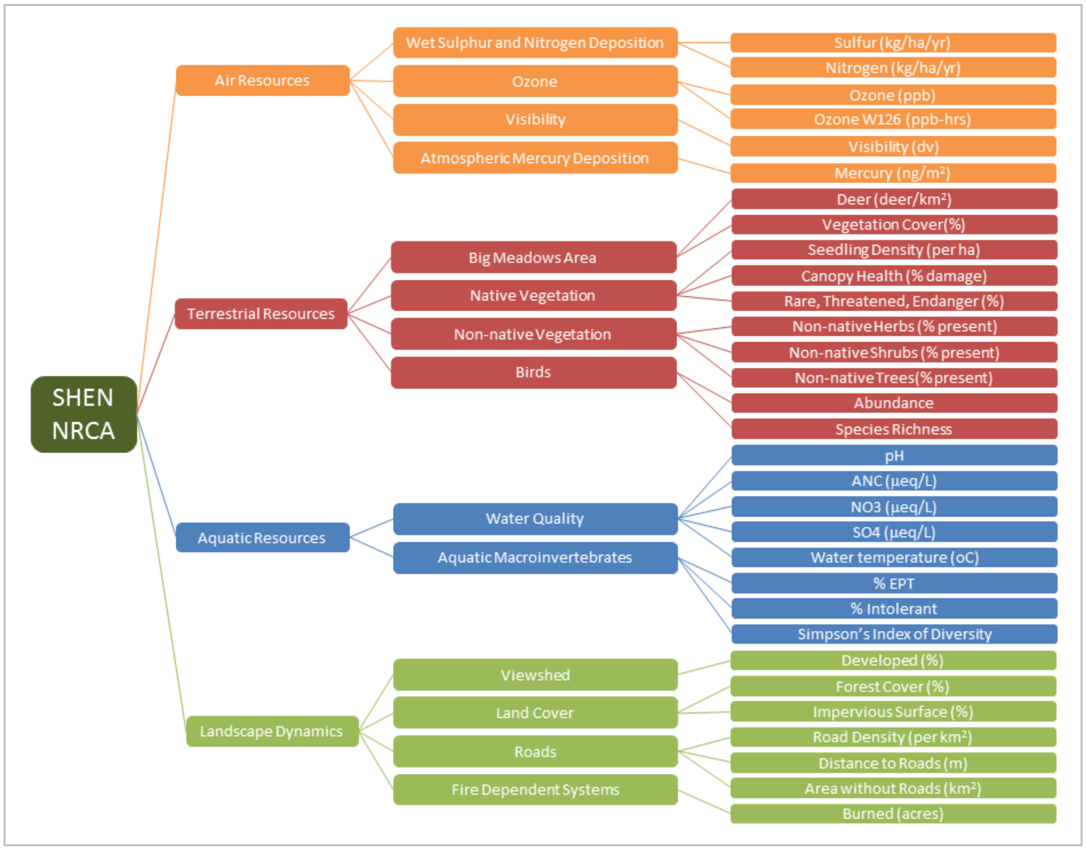

Figure 3-3. Vital sign indicators and associated indicators chosen for this Natural Resource Condition Assessment of Shenandoah National Park.

3.2.3 Reference conditions

A natural resource condition assessment requires the establishment of criteria for defining desired, as well as current, ecological conditions, and the current assessment was based upon explicitly defined reference condition values. Reference conditions represent an agreed upon value or range indicating that an ecosystem is moving away from a desired state and towards an undesirable ecosystem endpoint (Biggs 2004; Bennetts *et al.* 2007). Even though increasing scientific research has been focused upon defining ecological reference conditions, uncertainty in definition as well as spatial and temporal variability has often led to disagreement on specific values (Huggett 2005; Groffman *et al.* 2006). Even with the definition of agreed-upon reference conditions, there is still the question of how best to use these reference condition values in a management context (Groffman *et al.* 2006). Recognizing these challenges, reference conditions can still be effectively used to track ecosystem change and define achievable management goals (Biggs 2004). As long as reference condition values are clearly defined and justified, they can be updated in light of new research or management goals, and can therefore provide an important focus for the discussion and implementation of ecosystem management (Jensen *et al.* 2000; Pantus and Dennison 2005).

3.2.4 Data synthesis

It is increasingly recognized that monitoring data collected for specific purposes, such as assessing the implementation of environmental regulations, does not necessarily allow for regional assessments of ecosystem condition (U.S. Environmental Protection Agency 2000, 2002). As a result, one of the key challenges of large-scale monitoring programs is to develop integrated and synthetic data products that can translate a multitude of diverse data into a format that can be readily communicated to decision-makers, policy developers, and the public (Fancy *et al.* 2009). These timely syntheses of ecosystem condition can provide feedback to managers and stakeholders, so that the effectiveness of management actions as well as future management goals can be determined at multiple scales (Dennison *et al.* 2007). One approach to synthesizing data is the development of multiple-indicator indices to summarize the status of many aspects of a community and then draw inferences on the status of the supporting ecosystem (Karr 1981). Multi-indicator indices improve on the use of just one measure, such as fish biomass or abundance, which often shows complex and variable responses to changes in environmental condition (Karr 1981). Multi-indicator indices are seen as providing greater insight into ecosystem condition than physical measurements alone (e.g., water quality), as biological communities provide an integrated summary of ecosystem condition over time (Roth *et al.* 1998, Harrison and Whitfield 2004).

3.2.5 Condition assessment

A total of 31 indicators were used to determine reporting area condition. The approach for assessing resource condition within Shenandoah National Park (as separate units and the park as a whole) required establishment of a reference condition for each indicator as outlined in Section 3.2.3. Ideally, reference conditions were ecologically based and derived from the scientific literature. However, when data were not available to support peer-reviewed ecological reference conditions, regulatory and management-based reference conditions were used. Instances when best professional judgment was used in consultation with park staff to define reference conditions were clearly identified in the "Data gaps and level of confidence" subsections of Chapter 4.

Reference condition attainment of indicators was calculated based on the percentage of sites or samples that met or exceeded reference condition values set for each indicator. An indicator attainment score of 100% reflected that the indicator at all sites and at all times met the reference condition identified to maintain natural resources. Conversely, a score of 0% indicated that no sites at any sampling time met the reference condition value. Once attainment was calculated for each indicator, an unweighted mean was calculated to determine the condition of each geo-elevation class. Attainment scores were categorized on a scale from very good to very degraded. Attainment scores for each indicator are presented in Chapter 4.

Indicators and reporting areas were assigned a qualitative rating corresponding to the quantitative score:

- Significant concern (0-25% reference condition attainment),
- Moderate condition (26-75% reference condition attainment), and
- Good condition (76-100% reference condition attainment).

Incorporated into the rating system are indications of trends in data and confidence level in findings. These scores were reflected in a park-specific current condition for geo-elevation class with key findings and recommendations provided in Chapter 5.

Chapter 4. Natural Resource Conditions

4.1 Air resources

Shenandoah National Park (NP) is located near, and downwind from, major industrial and urban areas. Air pollution, particularly during the summer season, has significantly degraded the distance, color, contrast, and landscape details of park views from Skyline Drive, the Appalachian Trail, and high points in the park. Congress, in the Clean Air Act, as amended in 1977, set a national goal of preventing any future and remedying existing impairment of visibility in Class I air quality Federal area where that impairment is caused by manmade pollution. Acid deposition has adversely impacted the acid-sensitive blacknose dace (*Rhinichthys atratulus*) and acid-tolerant Appalachian brook trout (*Salvelinus fontinalis*) at the individual, population, and community levels (Atkinson 2003, Newman and Dolloff 1995). Despite improvements in air quality under the Clean Air Act over the past few decades, the park's visibility and most sensitive aquatic systems are still degraded relative to estimated natural or pre-industrial background conditions. Park air quality does meet current ground-level ozone standards set by the U.S. Environmental Protection Agency to protect public health and welfare. Prior to 2012, ozone levels did not meet current ground-level ozone standards and foliar injury caused by ground-level ozone has harmed many of the park's 33 known ozone-sensitive plant species (Hildebrand *et al.* 1996).

Four indicators were used to assess air quality within Shenandoah National Park: Sulfur and nitrogen wet deposition, ground level ozone (4^{th} highest 8-hour concentration and maximum 3-month 12-hour W126) and visibility. A fifth indicator, mercury deposition, has been monitored since 2002 and was included for informational purposes. As there are currently no reference conditions for mercury deposition, this indicator was not included in the overall park assessment.

Data used for this assessment were sourced from within Shenandoah National Park at Big Meadows through a variety of programs that are operated within the Park (Table 4-1).

Table 4-1. Indicators, source, and data collection site for data used in assessment of air quality resources within Shenandoah National Park.

Indicator	Agency	Site	Source
Sulfur & Nitrogen deposition	NADP/NTN	Big Meadows	http://nadp.sws.uiuc.edu
Ozone	EPA CASTNET	Big Meadows	http://epa.gov/castnet/javaweb/index.html
Visibility	IMPROVE	Big Meadows	http://vista.cira.colostate.edu
Mercury	NADP/MDN	Big Meadows	http://nadp.sws.uiuc.edu

Air quality data were compared to reference condition values sourced from National Park Service Natural Resource Program Center – Air Resource Division (National Park Service ARD 2011a). Current condition was determined by comparing the latest five years of data available for each indicator to reference condition categories, to obtain a percent attainment of reference condition conditions (Table 4-2). Multiple reference condition categories were used in accordance with

National Park Service ARD documentation (National Park Service ARD 2011a) (Table 4-1, Table 4-2). To assess trends, annual data prior to the data used in the assessment (where available) is presented and discussed.

Table 4-2. Air quality reference conditions used to assess air resource condition of Shenandoah National Park.

Air quality indicator	Number of sites	Period of observation	Reference conditions	Percent attainment applied
Wet sulfur deposition (kg/ha/yr)	1 (Big Meadows)	2009-2013	< 1; 1-3; > 3	< 1 = 100% 1-3 = 0-100% scaled linearly > 3 = 0%
Wet nitrogen deposition (kg/ha/yr)	1 (Big Meadows)	2009-2013	< 1; 1-3; > 3	<1 = 100% 1-3 = 0-100% scaled linearly >3 = 0%
Ozone (ppb)	1 (Big Meadows)	2011-2013	≤ 60; 60.1-75; >75	≤ 60 = 100% 60.1-75= 0-100% scaled linearly >75= 0%
Ozone (W126; ppm-hrs)	1 (Big Meadows)	2009-2013	< 7; 7-13; >13	< 7 = 100% 7-13= 0-100% scaled linearly >13 = 0%
Visibility (dv)	1 (Big Meadows)	2009-2013	<2; 2-8; > 8	<2 = 100% 2-8= 0-100% scaled linearly > 8 = 0%
Mercury deposition (ng/m2)	1 (Big Meadows)	2005-2011	N/A	N/A

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

4.1.1 Wet sulphur and nitrogen deposition

<u>Relevance and context</u>

Since 1970, it has increasingly been recognized that significant ecosystem impacts from atmospheric sulfur and nitrogen deposition are occurring that include acidification and nutrient fertilization of waters and soils (National Park Service ARD 2011b). Impacts resulting from this atmospheric deposition include such measurable effects as the disruption of nutrient cycling, changes to vegetation structure, loss of stream biodiversity, and the acidification and eutrophication of streams and coastal waters (Driscoll *et al.* 2001; Porter and Johnson 2007). Wet sulfur and nitrogen deposition is significant in the eastern parts of the United States (Sullivan *et al.* 2011b) (Figure 4-1).

Shenandoah National Park receives elevated deposition of both sulfur and nitrogen of all monitored national parks. Consequences at the park include acidification of stream waters and changes in condition of sensitive species (Figure 4-2). The prognosis for future recovery of damaged aquatic resources in Shenandoah National Park was evaluated in a recent study that analyzed “critical loads” for sulfur (S) deposition (Sullivan *et al.* 2003b). The critical load represents a reference condition below which significant harmful effects to sensitive ecosystems components are not likely to occur. It was determined necessary for S deposition to be reduced substantially below current levels in order to prevent further acidification and associated biological impacts in acid-sensitive streams within the park.

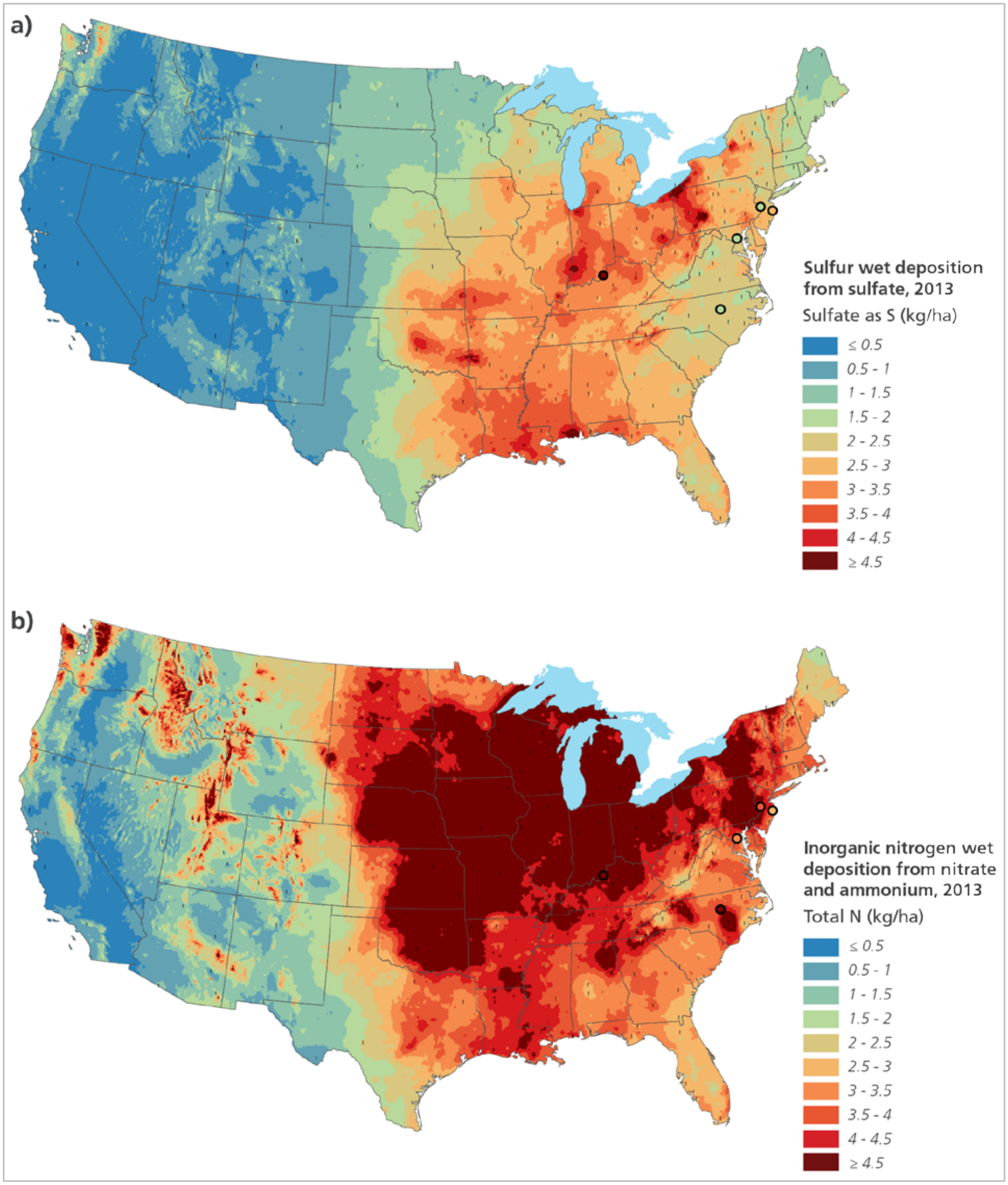

Figure 4-1. Total wet deposition for the continental United States in 2013 for a) sulfate, and b) nitrate and ammonium. Source: http://nadp.sws.uiuc.edu/ntn/cladmaps.aspx#2013.

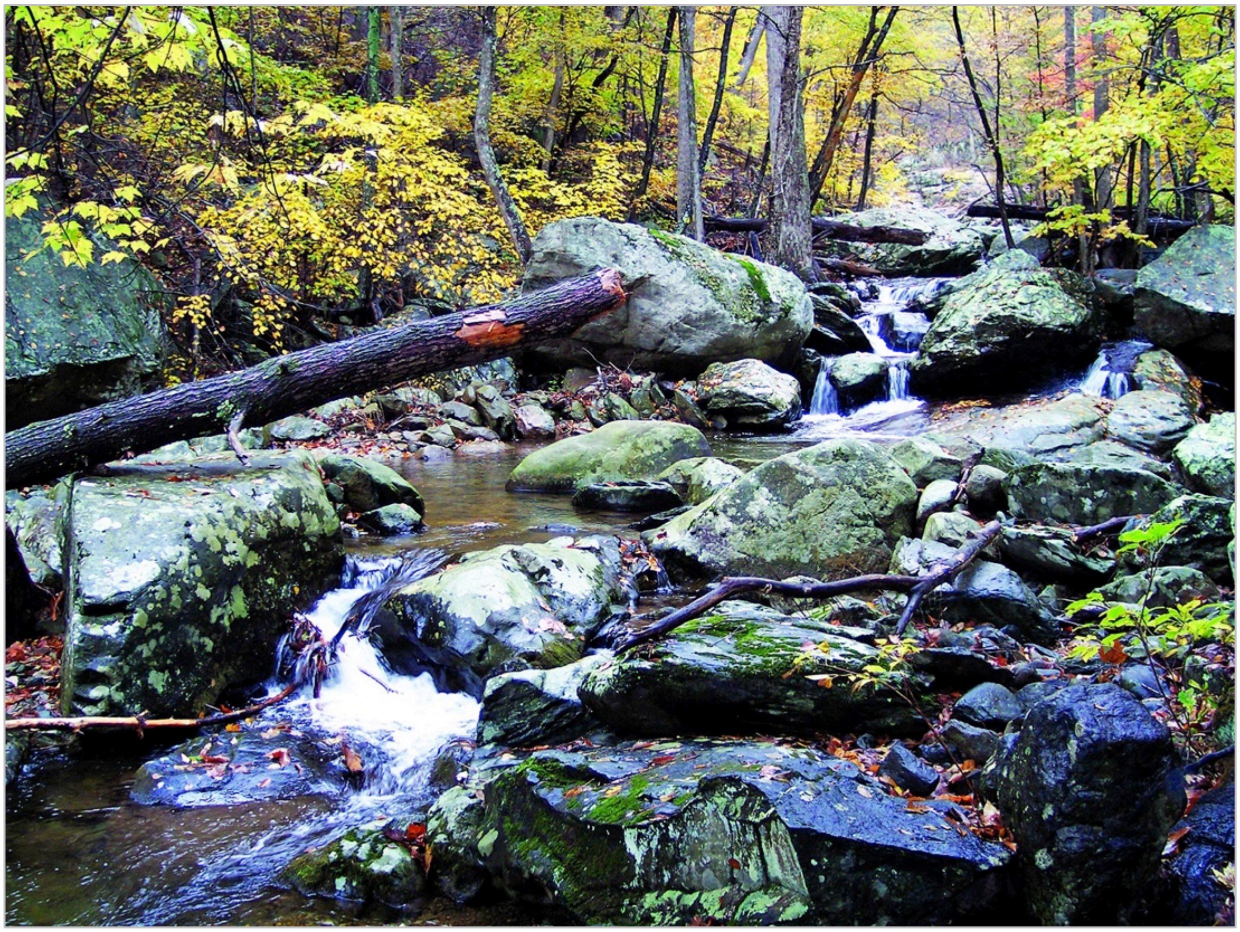

Figure 4-2. High elevation streams in Shenandoah National Park in Virginia are highly sensitive to acidification resulting from nitrogen and sulfur pollution. Photo credit: National Park Service.

Documented effects of sulfur and nitrogen deposition at Shenandoah National Park include:

- Acid rain with an average acidity (pH) of rainfall as low as 5.6 – 10 times more acidic than normal rainfall (Rice *et al.* 2006).
- Many streams have a pH as low as 5 – 10 times more acidic than the pH of park streams prior to human-caused pollution (Jastram *et al.* 2013, Rice *et al.* 2014).
- Fewer species of fish that live in acidification-affected streams as compared to park streams with a higher ability to neutralize acids (Bulger *et al.* 1999).
- Trout species impacted by stream acidification, with particular concern regarding impacts on brook trout, and other sensitive fish including dace, chub, sculpin, darter, and bass (Webb *et al.* 2004; Bulger *et al.*1999).
- Aquatic insect community degradation as a result of acidification in some park streams – a particular concern given that these insects are important food sources for trout (Moeykens and Voshell 2002).

- Soils weakened against the ability to buffer sulfur with subsequent declines of essential nutrients calcium and magnesium, suggesting the potential that toxic aluminum could leach into streams (Welsch *et al.* 2001; Sullivan *et al.* 2003b).

High ridgetop ecosystems at Shenandoah National Park are particularly vulnerable to acid deposition due to more deposition from rain, fog, and clouds than lower elevation areas; but low buffering capacity, short growing seasons, and shallow soils make higher elevation areas even more sensitive to acid inputs (http://www.nature.nps.gov/air/).

Although nitrogen is an essential plant nutrient, surplus levels of atmospheric nitrogen deposition can stress ecosystems. Excess nitrogen acts as fertilizer, favoring some types of plants and leaving others at a competitive disadvantage. The long-term effects of these changes may include shifts in plant and animal species composition, increase in insect and disease outbreaks, and disruption of ecosystem processes such as nutrient cycling and wildfire frequency. Some vegetation communities in the park, including wetland and grassland plant communities, may be sensitive to excess nitrogen deposition (Sullivan *et al.* 2011c; Sullivan *et al.* 2011d).

Natural background total wet deposition for both sulfur and nitrogen in the eastern 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; National Park Service 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).

Pardo *et al.* (2011) suggested a critical load of 3.0−17.5 kilograms nitrogen per hectare per year (kg N/ha/yr) atmospheric deposition to protect forest vegetation, herbaceous plants, lichens, and mycorrihizal fungi in the Eastern Temperate Forests ecoregion, which includes Shenandoah National Park. To maintain the highest level of protection in the park, the lower end of this range would be an appropriate management goal. The estimated maximum 2010–2012 average for total nitrogen deposition (wet plus dry) in the Eastern Temperate Forests ecoregion of Shenandoah National Park was 17.0 kg/ha/yr (NADP 2014). Therefore, total nitrogen deposition levels in the park are well above ecosystem critical loads for some park resources, suggesting that lichens, herbaceous plants, and forest vegetation are at risk for harmful effects.

Data and methods

Annual wet sulfur and nitrogen deposition data used for this assessment of current condition were taken from the National Atmospheric Deposition Program-National Trend Network (http://nadp.sws.uiuc.edu) which has collected air quality information within Shenandoah National Park since 1981 at Big Meadows (VA28). Wet sulfur deposition comprised of SO_4 and wet nitrogen deposition comprised the sum of NH_4-N and NO_3-N.

Condition and trend

The average of the available past five years of wet deposition data (2009-2013) was used towards the assessment for current condition of air resources in Shenandoah National Park. The average wet deposition between 2009 and 2013 for sulfur and nitrogen was 2.7 kg/ha/yr and 3.9 kg/ha/yr, respectively. These values result in 13% reference condition attainment for wet sulfur deposition and 0% reference condition attainment for wet nitrogen deposition (Figure 4-3). This supports the findings from a national assessment (using interpolated data) that ranked Shenandoah National Park at very high risk of acidification which is reflected by existing evidence that streams and soils in the park are very vulnerable to acidification (Sullivan *et al.* 2011a,b).

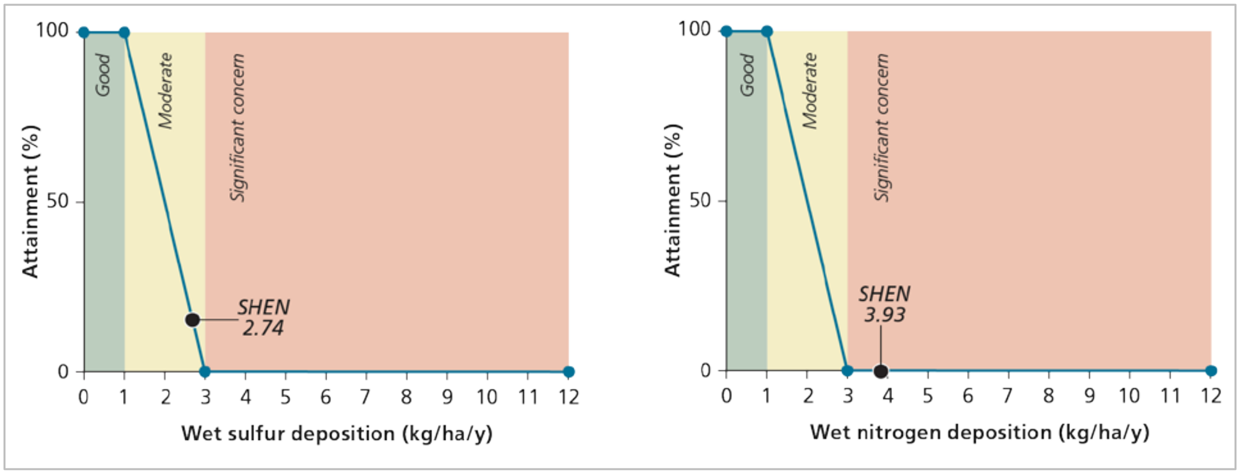

Figure 4-3. Percent reference condition attainment for wet sulfur and nitrogen deposition rates.

Trend data for nitrogen and sulfur wet deposition since 1981 does show variability in both parameters, though a visible decline in both (more-so for sulfur deposition) can be observed since 1989 with wet deposition values approaching, or falling below, the major impact reference condition post 2010 (Figure 4-4).

<u>Sources of expertise</u>

- Air Resources Division, National Park Service; http://www.nature.nps.gov/air/
- National Atmospheric Deposition Program; http://nadp.sws.uiuc.edu
- Ellen Porter, former National Park Service biologist with the Air Resources Division, research and monitoring branch
- Holly Salazer, National Park Service air resources coordinator for the Northeast Region

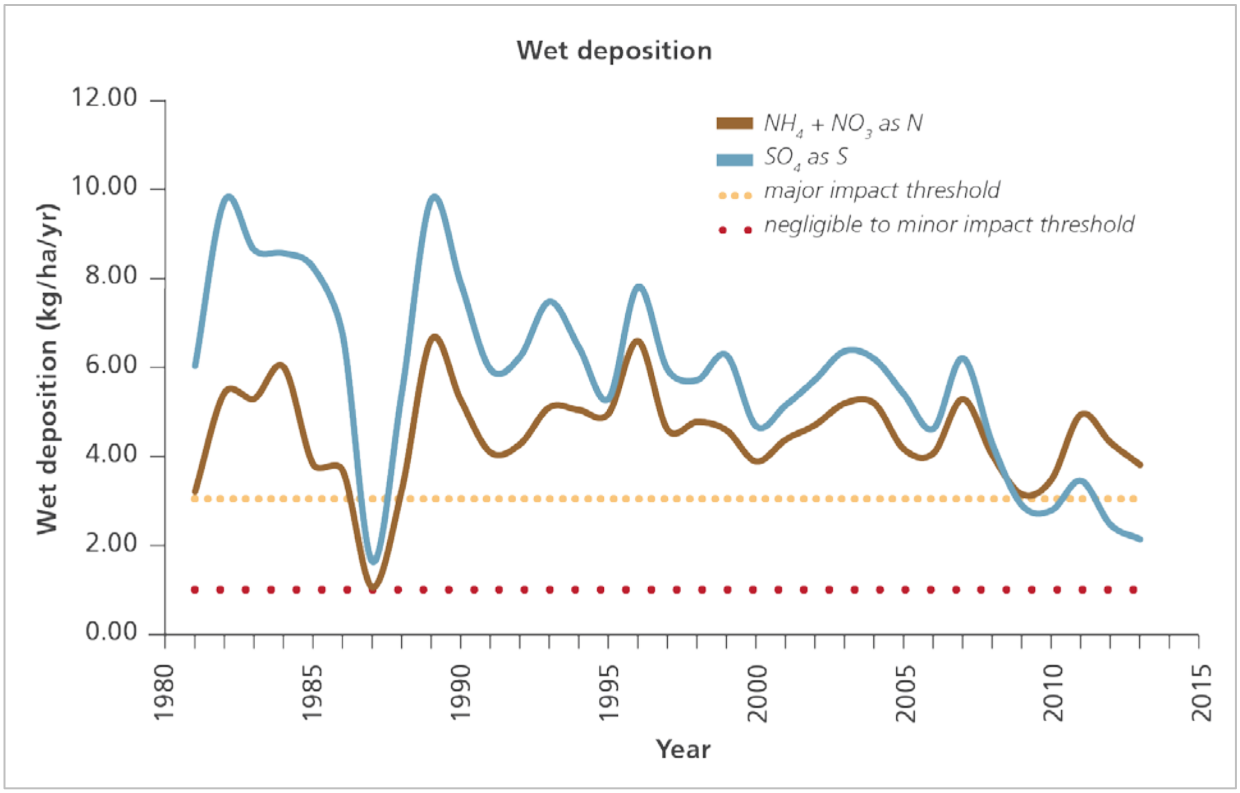

Figure 4-4. Annual data for nitrogen and sulfur wet deposition collected within Shenandoah National Park since 1981. Source: NADP/NTN.

4.1.2 Ozone

Relevance and context

Ground-level ozone is a secondary atmospheric pollutant that forms through a sunlight-driven chemical reaction between nitrogen oxides and volatile organic compounds. These precursor emissions come largely from burning fossil fuels (Haagen-Smit and Fox 1956). In humans, ozone causes a number of health-related issues such as lung inflammation and reduced lung function. Ozone concentrations of 120 parts per billion (ppb) can be harmful with only short exposure during heavy exertion such as jogging, while similar symptoms can occur from prolonged exposure to concentrations of 80 ppb ozone (McKee *et al.* 1996). The U.S. Environmental Protection Agency's 2007 review of the human health standard for ozone concluded that levels between 60 and 70 ppb would likely be protective of most of the population although very sensitive groups (e.g., elderly and children) may be impacted at lower levels (U.S. Environmental Protection Agency 2007). Ozone concentrations above these values are well documented in the eastern parts of the United States (Figure 4-5).

Park managers at Shenandoah National Park have instituted an ozone advisory program aimed at educating employees and park visitors about the risks of exposure to ozone and precautions that can be taken. Visitor experience and visitor and employee health and safety are, or can be, impaired when summertime ozone exposures exceed the human health protection standards established by the U.S. Environmental Protection Agency.

In 2010, the U.S. Environmental Protection Agency proposed strengthening the primary (human health) standard to a value in the range of 60-70 ppb, and establishing a separate secondary (welfare) standard to protect vegetation, based on an ecologically relevant indicator, the W126. Some plant species are more sensitive to ozone than humans. Elevated ozone exposure levels can damage plant leaves, 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. In a study of 28 plant species exposed to ozone for 3–6 weeks, foliar impacts, including premature defoliation were reported in all species at ozone concentrations between 60-90 ppb (Kline *et al.* 2008). As a consequence, a wide variety of vegetation in Shenandoah National Park may be vulnerable to elevated ozone concentrations.

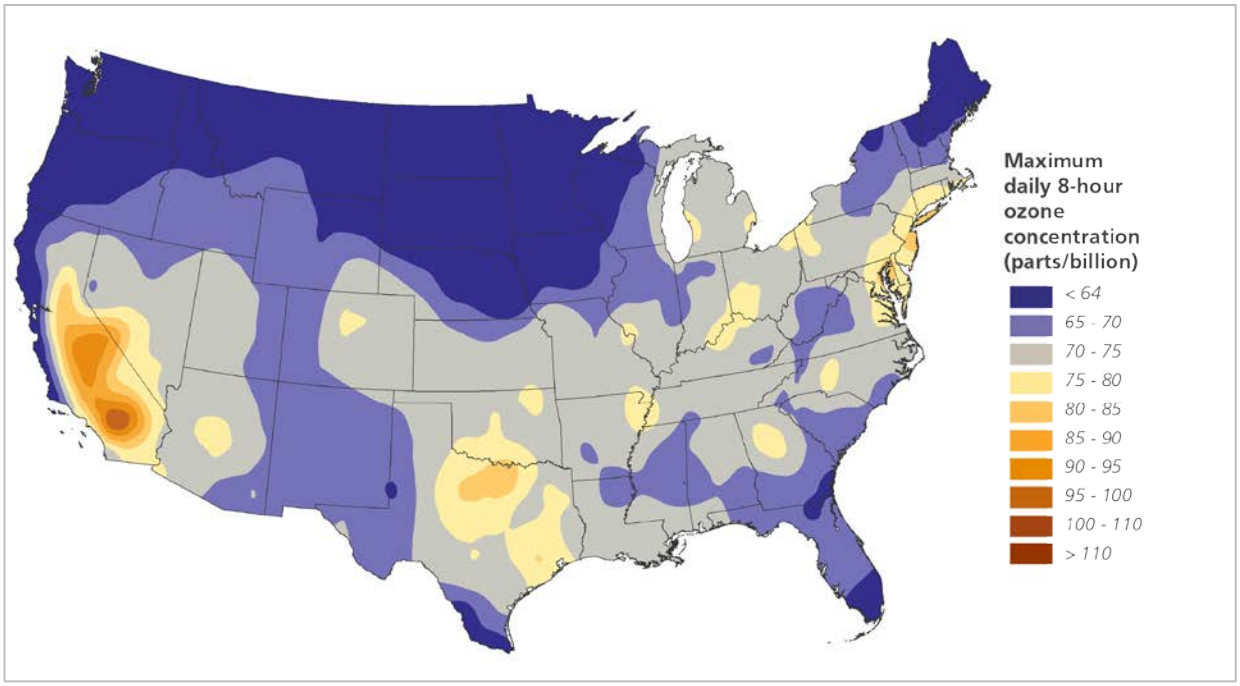

Figure 4-5. Air Atlas 2005-2009 displaying the fourth highest annual value of the maximum daily 8-hour ozone concentration in parts per billion. Source: http://www.nature.nps.gov/air/maps/AirAtlas/ozone.cfm.

Since the late 1980s, summertime ground-level ozone at Shenandoah National Park has consistently exceeded levels that are harmful to vegetation. Ozone damage to leaves has been documented on several of the 33 known ozone sensitive plant species found at the park, and there is concern about potential effects of ozone on forest growth and health (Figure 4-6).

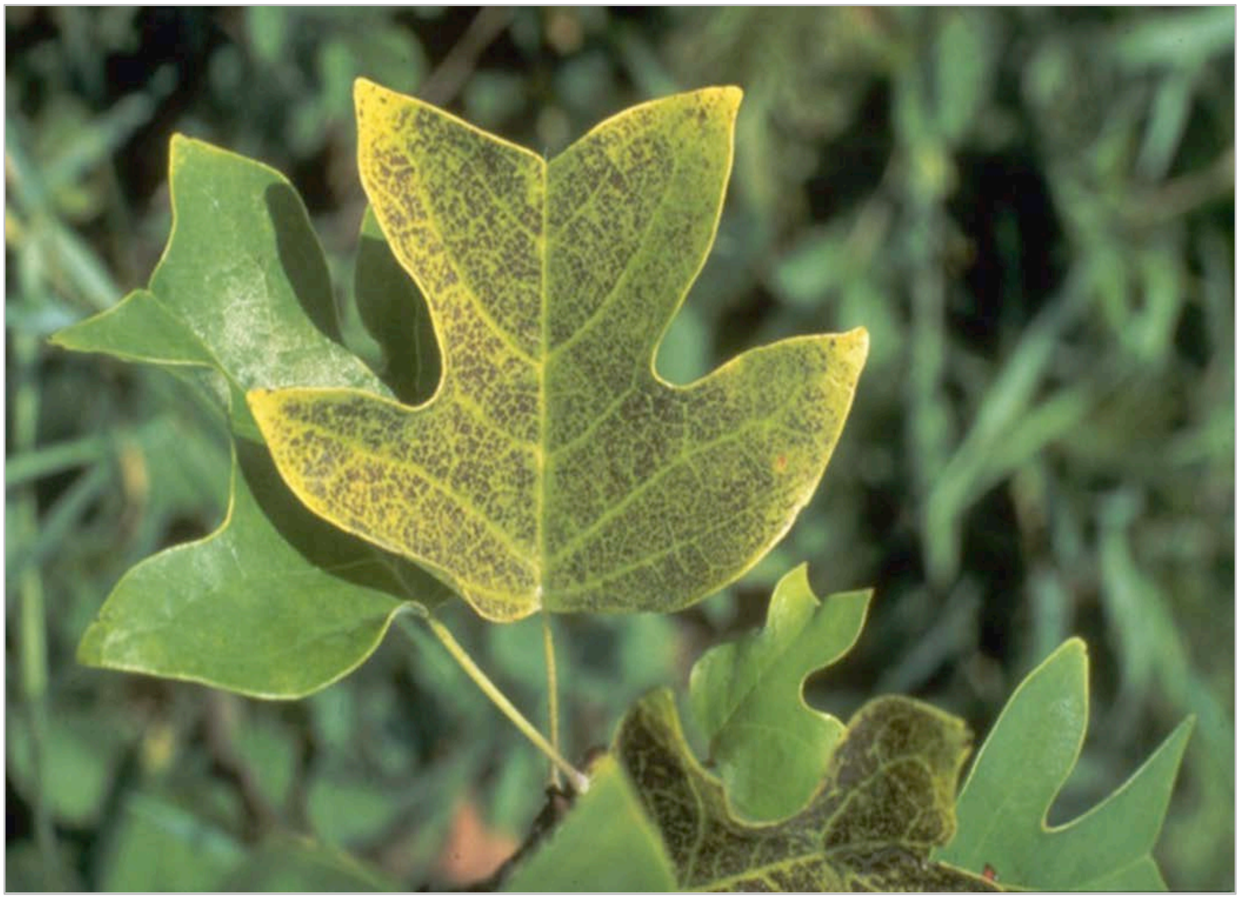

Figure 4-6. Stipling of tulip tree leaf caused by ozone. Photo credit: U.S. Forest Service.

Documented effects of ozone on vegetation at Shenandoah National Park include:

- Visible injury to leaves of trees, tree seedlings, and understory plants including black cherry, tulip tree, white ash, green ash, sweetgum, milkweed, virgin's bower, black locust, and wild grape (Sullivan *et al.* 2003a; Hildebrand *et al.* 1996; Winner *et al.* 1989; Duchelle *et al.* 1982) (Figure 4-6);
- Reduced average height growth of tulip tree, green ash, white ash, black locust, Virginia pine, eastern white pine, table mountain pine, and eastern hemlock (Duchelle *et al.* 1982);
- Reduced above-ground biomass production of native vegetation (Duchelle *et al.* 1983);
- Increased foliar ozone injury with increased elevation on virgin's bower, black locust, and wild grape (Winner *et al.* 1989); and,
- Increased foliar ozone injury with increased ambient ozone exposures on black cherry and white ash (Hildebrand *et al.* 1996).

<u>Data and methods</u>
Ozone data have been collected within Shenandoah National Park since 1983 by the Clean Air Status and Trends Network (CASTNET) at station SHN418 located at Big Meadows (http://epa.gov/castnet). Ozone data were also collected from 1983-1994 at Dickey Ridge and

Sawmill Run. National Park Service ARD uses data from the Big Meadows site to assess condition and trends for ozone.

Ground-level ozone is regulated under the Clean Air Act and the U.S. Environmental Protection Agency is required to set National Ambient Air Quality Standards for ozone (U.S. Environmental Protection Agency 2004a). The ozone standard is violated when the 3-year average of the annual fourth-highest daily maximum 8-hour average ozone concentration is greater than 75 ppb. An exceedance occurs when the daily maximum 8-hour average is greater than 75 ppb on a given calendar day (NAAQS 2008).

National Park Service ARD has established more protective ozone concentrations (fourth-highest daily maximum eight-hour ozone concentration, averaged over three years) as guidelines where

- ≤ 60.0 ppb indicates good ambient ozone condition,
- 60.1–75.0 ppb indicates moderate condition, and
- 75 ppb warrants significant concern
(U.S. Environmental Protection Agency 2007, National Park Service ARD 2011d).

Condition attainment scores were scaled linearly from 0 to 100% between the reference points for moderate condition, 60.1–75.0 ppb (Table 4-2).

National Park Service ARD also looks at the W126 ozone metric as a more biologically relevant measure to assess the risk for ozone-induced foliar damage to sensitive plants. The W126 metric preferentially weights the higher ozone concentrations most likely to affect plants and sums all of the weighted concentrations during daylight hours. The highest 3-month period that occurs during the growing season is reported. Values less than 7 parts per million-hour (ppm-hrs) are considered safe for sensitive plants (or 100% attainment of reference condition). National Park Service ARD has established criteria for assessing potential impacts to park resources as outlined in Table 4-2 (National Park Service ARD 2011c) that have been adopted for this assessment.

Data used for the assessment were the 5-year average of the annual 4th highest daily maximum 8-hour ozone concentration measured between the years 2009-2013. This value was assessed against the reference condition (ozone metric) for the quantification of current condition. For assessment of trends, CASTNET data of the annual 4th highest daily maximum 8-hour concentration and annual maximum 3-month 12-hour W126 were considered dating back to the years 1988 and 1989, respectively.

Both the annual fourth-highest daily maximum eight-hour concentration (averaged over five years) and the plant-exposure indicator, W126, were used to assess ozone condition within Shenandoah National Park (National Park Service ARD 2011c).

<u>Condition and trend</u>

The 3-year average of the annual 4th highest daily maximum eight-hour concentration between 2011 and 2013 for Shenandoah National Park was 69 ppb that resulted in 40% reference condition attainment or caution condition (Figure 4-7). The 5-year average of maximum 3-month 12-hour

W126 between 2009 and 2013 for Shenandoah National Park was 9.0 ppm-hrs that resulted in 66% reference condition attainment of reference condition, or moderate condition (Figure 4-7).

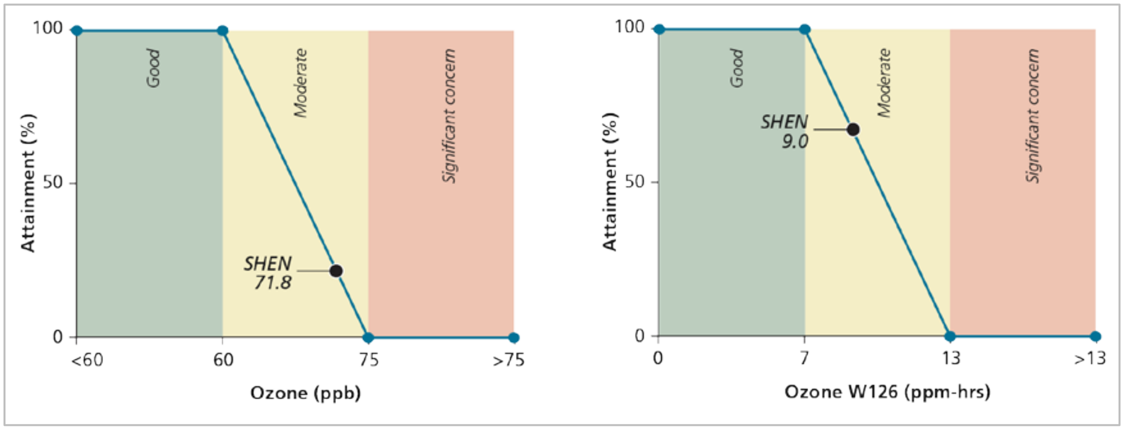

Figure 4-7. Percent reference condition attainments for 2009-2013 Average 4th Highest Daily Max 8hr ozone ppb (left) and average ozone W126 (right).

Ozone levels have been decreasing over the past decade of monitoring and dropped below the upper guideline of 75 ppb for the first time in 2010, with continued improvement since then (Figure 4-8). The Ozone W126 metric also shows a declining trend though this appears much more variable than the declining trend in the fourth-highest eight-hour concentration. (Figure 4-8).

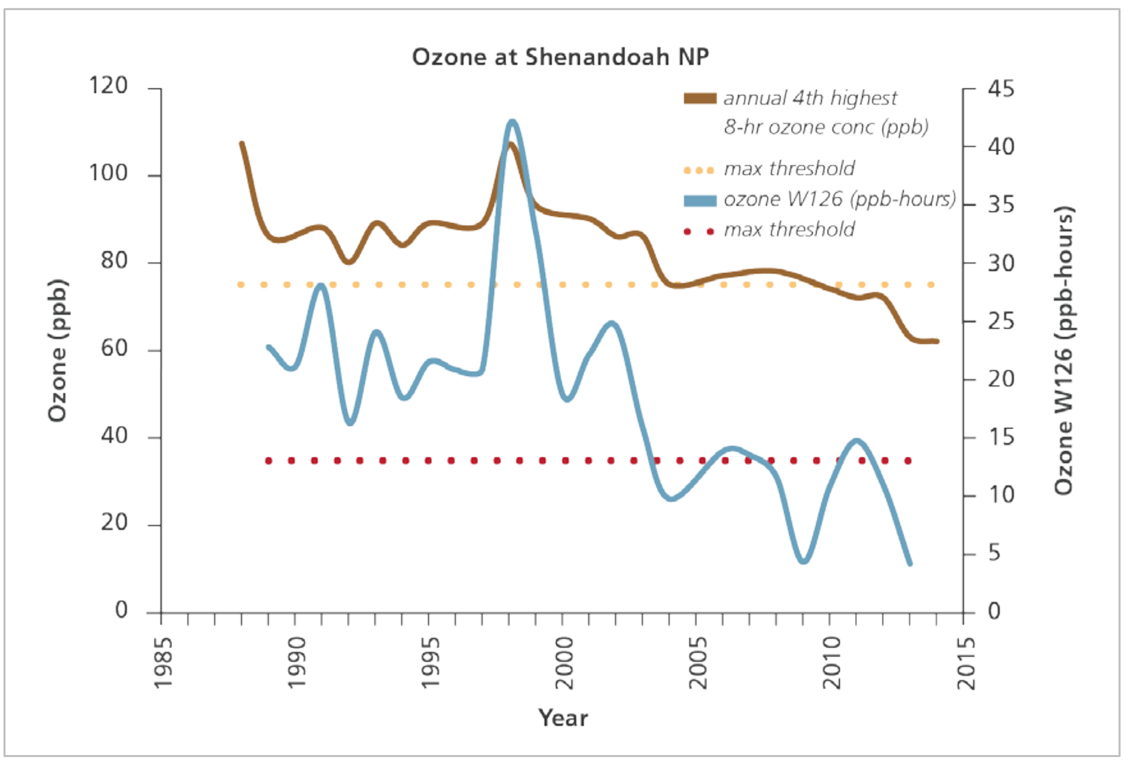

Figure 4-8. Trends in ozone concentrations since 1991. Source: Environmental Protection Agency CASTNET.

This trend is consistent with the 10-year trend reported in the 2009 Annual Performance and Progress report (National Park Service ARD 2010), which found that no park units in the eastern U.S. show a degrading trend, with many parks showing no trend, but a majority showing significant or possible improvement in atmospheric ozone concentration (Figure 4-9; National Park Service ARD 2010).

Sources of expertise

- Air Resources Division, National Park Service; http://www.nature.nps.gov/air/
- Ellen Porter, former National Park Service biologist with the Air Resources Division, research and monitoring branch
- Holly Salazer, National Park Service air resources coordinator for the Northeast Region.

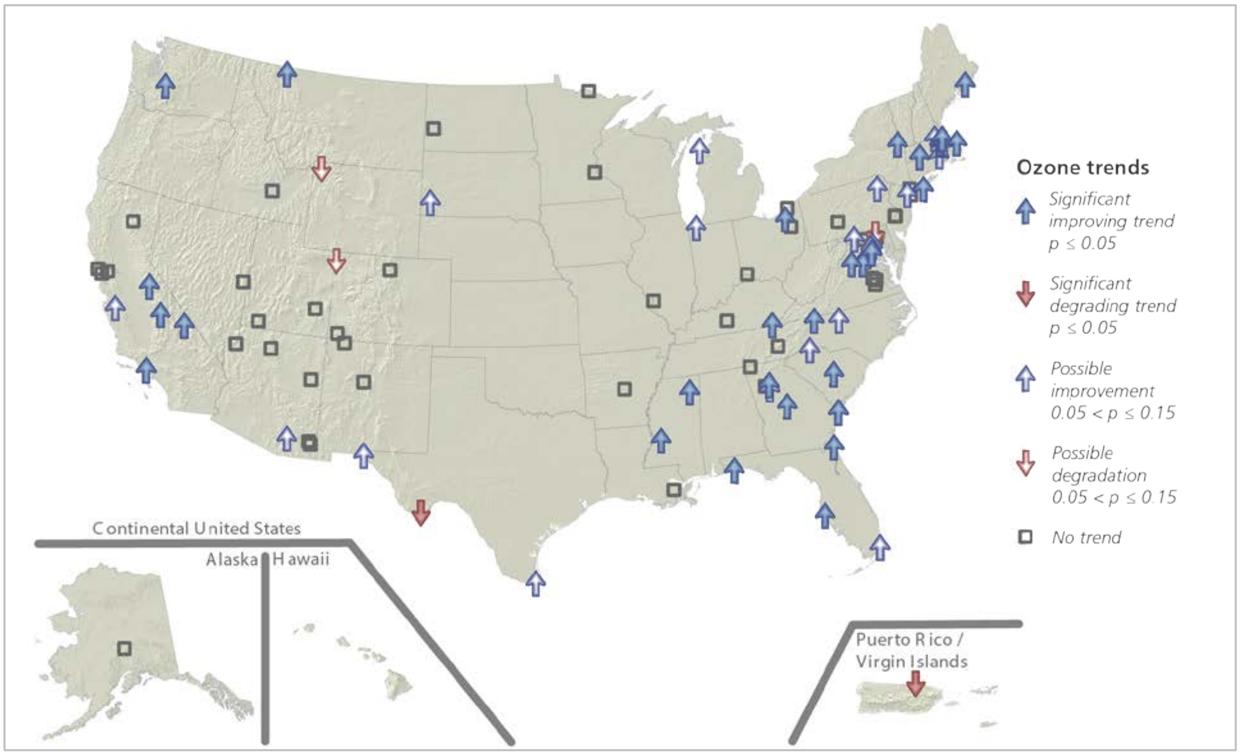

Figure 4-9. Trends in annual fourth-highest eight hour ozone concentration (ppb), 1999-2008. Source: National Park Service ARD 2010.

4.1.3 Visibility

Relevance and context

Shenandoah National Park is famous for its exceptional vistas dotted along the length of Skyline Drive. These vistas are often obscured by haze caused by fine particles in the air (Figure 4-10). Many of the same pollutants that ultimately fall out as nitrogen and sulfur deposition contribute to this haze and visibility impairment. Organic compounds, soot, and dust reduce visibility as well. Pollution-caused haze typically appears as a uniform whitish haze, different from the natural haze caused by organic compounds released by trees over the Blue Ridge Mountains of the eastern United States. In the eastern US, the major cause of reduced visibility is sulfate particles formed from SO_2 emitted from coal combustion (Sullivan *et al.*l 2003a). The Clean Air Act includes visibility as one of its national goals as it is an indicator of emissions (U.S. Environmental Protection Agency 2004a).

Figure 4-10. Regional haze at Shaver Hollow (split image), looking west into Shenandoah Valley. Good visibility on the left and poor visibility on the right. Photo credit: National Park Service.

Concentrations of fine particles in the park's air sometimes exceed the National Ambient Air Quality Standards set by the U.S. Environmental Protection Agency to protect public health. Fine particles (smaller than 2.5 microns) originate from either direct emissions from a source, such as construction sites, power plants, and fires, or are formed downwind from sources by reactions with gases and aerosols that react in the atmosphere. For example, power plants, industries, and automobiles emit gases such as sulfur dioxides and nitrogen oxides that form particles of sulfate and nitrate in the atmosphere.

Because of their small size, fine particles can get deep into the lungs and cause serious health problems. Numerous scientific studies have linked particle pollution exposure to irritation of the airways, coughing, difficulty breathing, aggravated asthma, chronic bronchitis, heart attacks, and premature death in people with heart or lung disease.

Human-caused haze frequently impairs scenic vistas at the park.

Data and methods

Natural visibility conditions represent the long-term degree of visibility that is estimated to exist in a given mandatory Federal Class I area in the absence of human-caused impairment. Natural visibility conditions are calculated from conditions on the average or best visibility (20% clearest) days monitored over several years.

Visibility is measured using the Haze Index in deciviews (dv). As the Haze Index increases, the visibility worsens. The visibility condition in deciviews (dv) equals the difference between current group 50 visibility (mean of the 40^{th}–60^{th} percentile data) and the natural group 50 visibility (estimated visibility in the absence of human-caused visibility impairment) (U.S. Environmental Protection Agency 2003; National Park Service ARD 2011c).

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 (National Park Service ARD 2010). National Park Service has adopted this goal for all parks, including Shenandoah National Park and all others designated as a Class I air quality Federal area under the Clean Air Act.

National Park Service ARD has established visibility guidelines as ≤ 2 dv above natural conditions 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. For the current assessment, the reported visibility value was assessed against these guidelines (National Park Service ARD 2011d) (Table 4-2).

The haze index data used for the assessment of current condition were taken from the National Park Service Air Resources Division (ARD) Air Quality Estimates (National Park Service ARD 2011c). These estimates were calculated on a national scale between 2005 and 2009 using an interpolation model based on monitoring data. The value for Shenandoah National Park was taken from monitoring data directly from the park.

Condition and trend

The haze index between 2009-2013 for Shenandoah National Park was 8.3 dv, which resulted in 0% reference condition attainment and is classified as of significant concern (National Park Service ARD 2011a) (Figure 4-11).

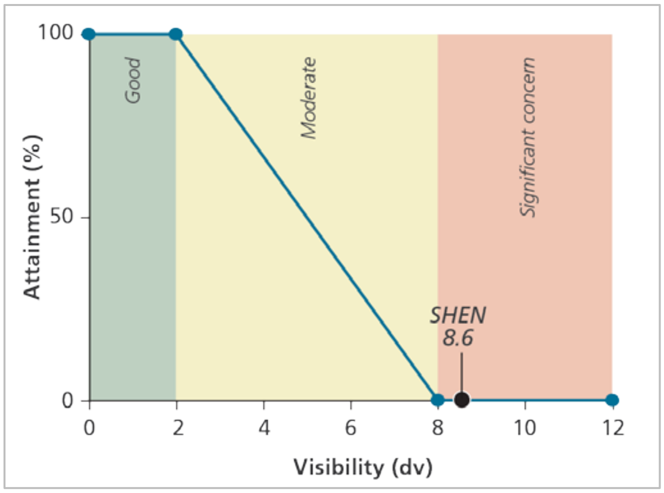

Figure 4-11. Percent reference condition attainments for visibility.

An improving trend in visibility can be seen in Figure 4-12 as demonstrated by a reduction in deciviews particularly evident over the past decade for both the clearest and haziest days. This trend is supported by a nationwide assessment of visibility trends between 1999 and 2008 within 157 parks, which found an improving trend in visibility at Shenandoah National Park (National Park Service ARD 2010) (Figure 4-13). Although a majority of the observed trends over the long-term are favorable (either improving or not degrading), visibility at all parks suffers from at least some impairment, particularly on the haziest days. Eastern sites such as Shenandoah National Park have consistently experienced annual mean deciview values on the haziest days well in excess of estimated natural conditions (Figure 4-13).

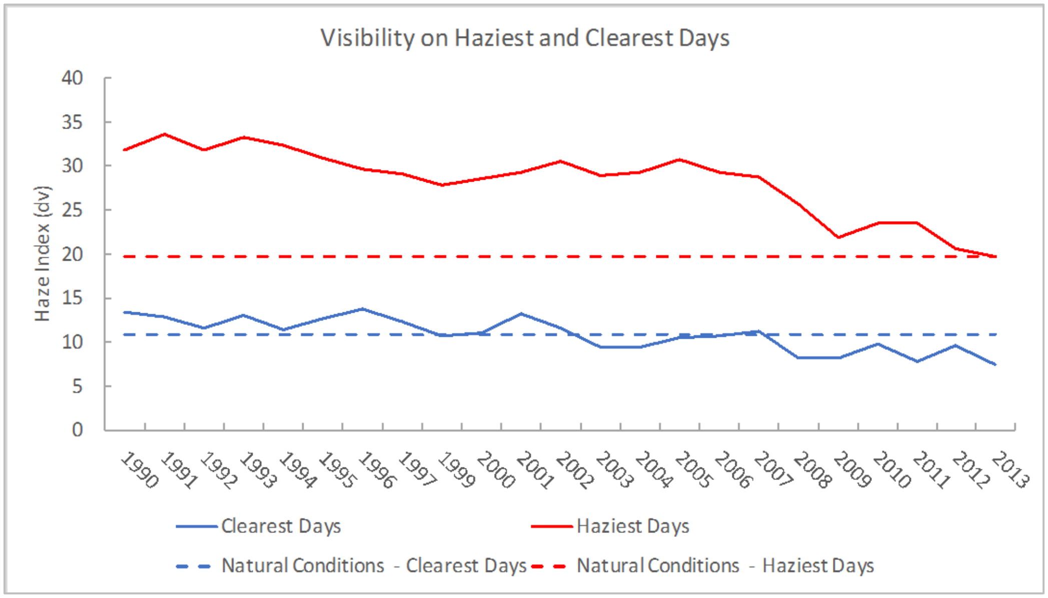

Figure 4-12. Shenandoah Haze Index from 1990-2013 for clearest (Group 10 - means of the best 20% visibility days) and haziest days (Group 90 - means of the worst 20% visibility days), including natural conditions expected for both. Source: IMPROVE Monitor ID: SHEN VA.

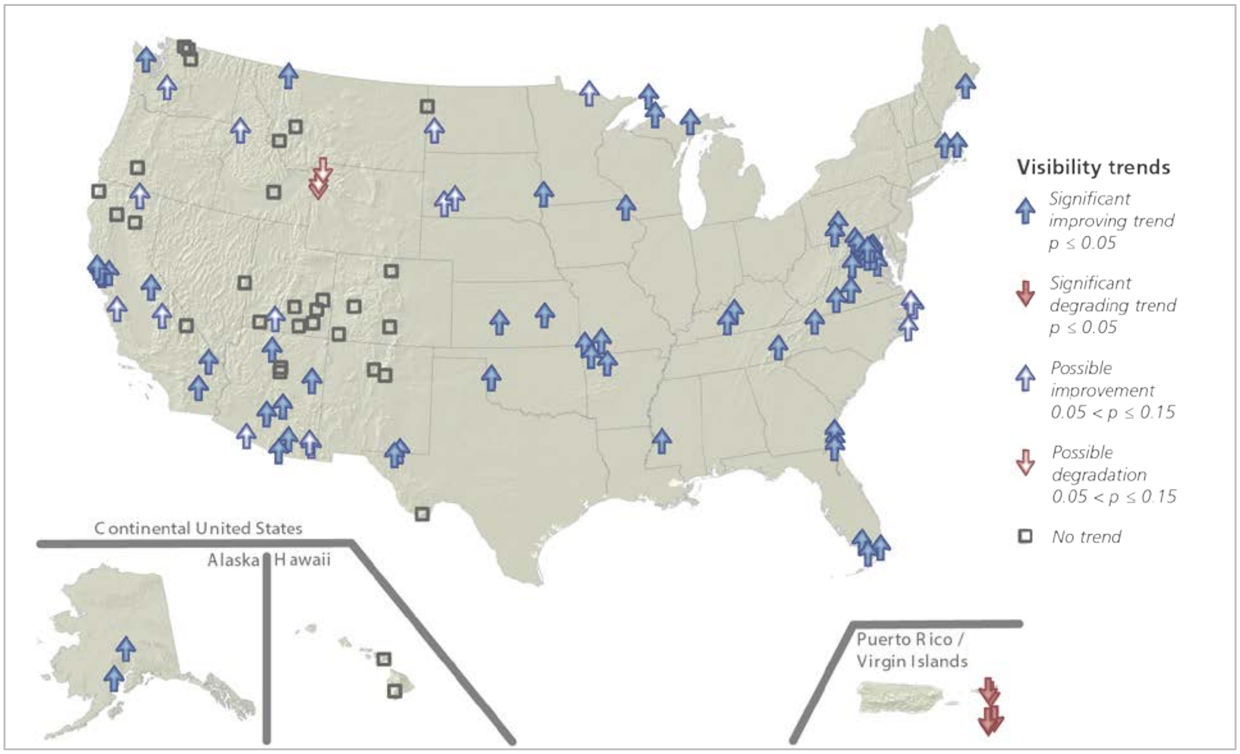

Figure 4-13. Visibility trends measured by the haze index (deciview) on haziest days 1999-2008. Source: National Park Service ARD 2010.

Sources of expertise

- Air Resources Division, National Park Service; http://www.nature.nps.gov/air/
- Ellen Porter, former National Park Service biologist with the Air Resources Division, research and monitoring branch
- Holly Salazer, National Park Service air resources coordinator for the Northeast Region

4.1.4 Atmospheric mercury deposition

Relevance and context

Atmospheric mercury (Hg) comes from natural sources, including volcanic and geothermal activity and geological weathering, and anthropogenic sources, such as burning of fossil fuels, processing of mineral ores, and incineration of certain waste products (UNEP 2013). According to global models, current anthropogenic sources contribute approximately 30 percent of emissions to air, natural sources contribute ~10%, and re-emission from soil and surface waters contributes the remainder. This re-emission is largely from legacy pollution; thus it too can be considered anthropogenic (UNEP 2013). The total estimated inventory of current (2010) anthropogenic mercury emissions to the air is 1,960 tonnes per year; mercury emissions from North America in 2010 are estimated at 60.7 tonnes (UNEP 2013). Exposure of humans and other mammals to mercury in utero can result in mental retardation, cerebral palsy, deafness, blindness, and dysarthria (speech disorder), and exposure as adults can lead to motor dysfunction and other neurological and mental impacts (Järup 2003). Avian species' reproductive potential is negatively impacted by mercury, and measured trends in mercury deposition, from west to east across North America (Figure 4-14), can also be measured in the common loon (*Gavia immer*), and throughout North America in mosquitos (Evers *et al.* 1998, Hammerschmidt and Fitzgerald 2006). Mercury is also recorded to have a toxic effect on soil microflora, although no ecological depositional reference condition is currently established (Meili *et al.* 2003).

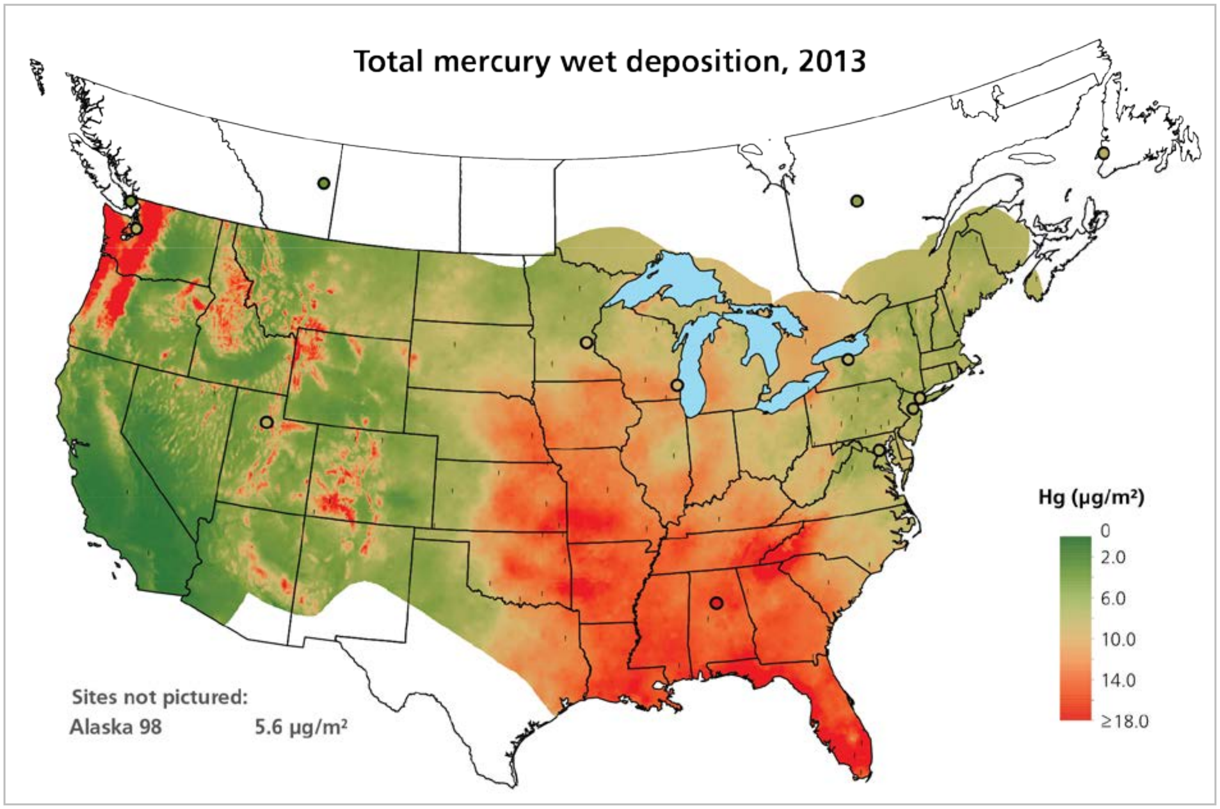

Figure 4-14. Total mercury wet deposition across the United States in 2013. Source: NADP/MDN 2015.

<u>Data and methods</u>

Data were obtained from the National Atmospheric Deposition Program, Mercury Deposition Network (Table 4-1), which has a site within Shenandoah National Park at Big Meadows (VA28). Samples are collected weekly 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.

Mercury must first be methylated in the environment to pose a true threat to food webs and therefore there are no published reference conditions for wet deposition of mercury. However, a National Park Service -wide methylmercury risk assessment and numerous in-park studies suggest that mercury threatens resources at Shenandoah National Park.

<u>Condition and trend</u>

Annual mean mercury deposition calculated from precipitation at VA28 over the past decade range from ~111 to 258 ng/m^2 (Figure 4-15). If it is assumed that precipitation constitutes all of the flow in streams in the park, then it can be assumed that mercury concentrations would be comparable to the range observed in precipitation (3.7 – 10.3 ng/L). The U.S. Environmental Protection Agency does provide National Recommended Water Quality Criteria for the protection of aquatic life. Criteria for total dissolved mercury are 1400 ng/L (acute criteria) and 770 ng/L (chronic criteria) (U.S. Environmental Protection Agency 2009). These criteria values are 2-3 orders of magnitude greater than what has been recorded in rainfall at Big Meadows, suggesting a low risk to aquatic life. However, because stream mercury concentration data within the park is not available, mercury has not been included in the overall assessment.

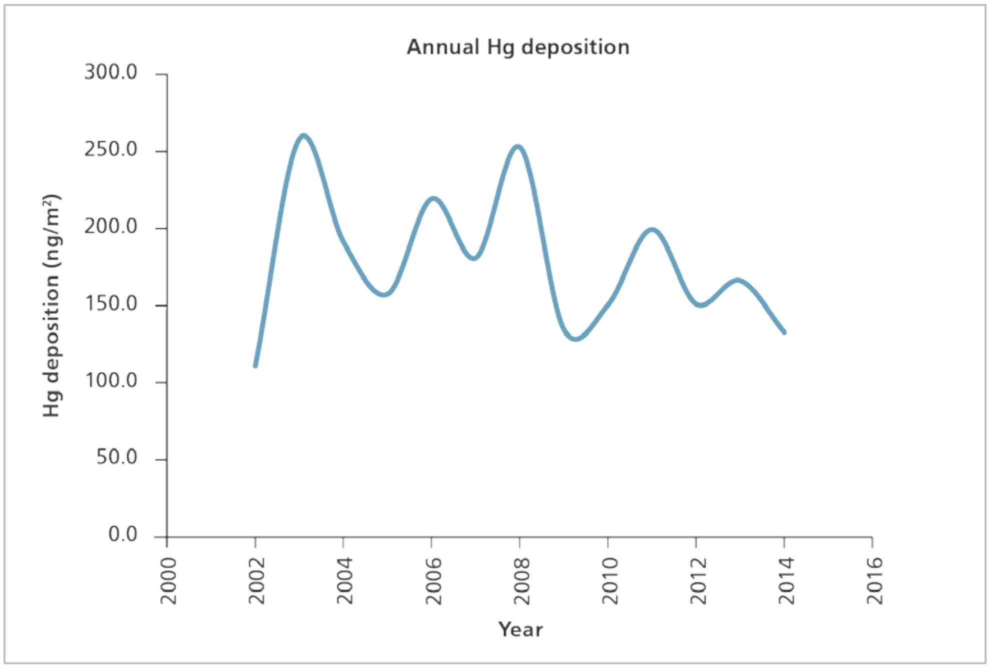

Figure 4-15. Trends in mercury deposition concentrations since 2002.

Previous studies found mercury in predatory bird eggs and salamander larvae (Clark *et al.* 2009; Bank *et al.* 2005). Concentrations of mercury in tree swallow blood and feathers were elevated near headwater areas of the Shenandoah River, with possible implications for reduced reproductive success (Brasso and Cristal 2009). Levels of mercury in brook trout (primary game fish) at the park were below the Environmental Protection Agency human health threshold, but levels of mercury in other species commonly taken for consumption from park streams (brown trout, smallmouth bass, and rock bass) were found to have high mercury concentrations (Snyder *et al.* 2006). Although Shenandoah National Park has minimal data on toxics, including mercury, the park is near several stationary and nonpoint sources and Superfund sites, and there are fish consumption advisories related to PCBs and mercury, and some pesticides, including imidacloprid in nearby watersheds. Imidacloprid is used at the park and appears to be moderately to highly toxic to amphibians and birds (Rattner and Ackerson 2006). The analysis of mercury in dragonfly larvae from Shenandoah National Park will shed further light on the risk of mercury in the park's varying water bodies (National Park Service 2014, Eagles-Smith *et al.* 2013).

Furthermore, the predicted concentrations of methylmercury in surface waters at the park range from moderate to high, as compared to other National Park Service units (Krabbenhoft *et al.* 2011). Given results of the screening assessment and in-park studies, mercury/toxics deposition warrants moderate concern at Shenandoah National Park. The degree of confidence level in this condition is medium given Shenandoah National Park has a limited amount of park-specific studies examining contaminant levels in certain taxa from park ecosystems.

For 2003–2012, the trend in total wet mercury concentrations in rain and snow at Shenandoah National Park remained relatively unchanged (no statistically significant trend). While measuring atmospheric mercury deposition over time and space is valuable for understanding temporal and spatial trends, atmospheric deposition of mercury is not directly related to methylmercury production and bioaccumulation in ecosystems. This is because the conversion of mercury to methylmercury is controlled by sulfate-reducing bacteria that are more active under certain environmental conditions, such as the presence of wetlands, high dissolved organic matter, and high sulfate concentrations.

Sources of expertise

- National Atmospheric Deposition Program, Mercury Deposition Network. http://nadp.sws.uiuc.edu/MDN
- Colleen Flanagan Pritz, National Park Service ecologist with the Air Resources Division, research and monitoring branch

4.2 Terrestrial resources

The large tracts of forest in Shenandoah National Park are distinctive within the highly populated Mid-Atlantic U.S. The park contains 1,406 species of vascular plants including globally and regionally significant rare, threatened and endangered species. The Big Meadows Area (BMA) stands in contrast to the more forested regions of the park. The human maintained meadows located here are home to the rarest plant communities in the park. The native plant communities of the park are under increasing threat from non-native plant invasions. Insect pests and disease have also been a long-standing concern to the integrity of the park's terrestrial ecoystems. The increase in deer populations within recent decades represent yet another potential stressor of concern to terrestrial resources. Park vegetation provides valuable habitat to a diverse fauna including over 200 species of resident and transient birds.

Four indicators were used to assess the terrestrial resources within Shenandoah National Park: Big Meadows Area (meadow vegetation and deer), native vegetation (regeneration, canopy cover, and rare plant species), the presence of non-native plants, and birds (abundance and richness) (Table 4-3). Data used for this assessment were sourced from the Shenandoah Inventory and Monitoring (I&M) Program and the U.S. Geological Survey (USGS) Breeding Bird Survey (Table 4-4). The scientists who have collected these data have devoted many years to obtaining, managing and summarizing the data used in this report.

Table 4-3. Indicators, source, and data collection sites for data used in assessment of terrestrial resources within Shenandoah National Park.

Terrestrial resource	Indicator	Agency	Source
Big Meadows Area	Vegetation	National Park Service	Shenandoah I&M Program
	Deer	National Park Service	Shenandoah I&M Program
Native Vegetation	Seedling density	National Park Service	Shenandoah I&M Program
	Canopy cover	National Park Service	Shenandoah I&M Program
	Rare plant species	National Park Service	Shenandoah I&M Program
Non-native Vegetation	Occurrence frequency	National Park Service	Shenandoah I&M Program
Birds	Abundance	U.S. Geological Survey	Breeding Bird Survey
	Species Richness	U.S. Geological Survey	Breeding Bird Survey

Table 4-4. Terrestrial resource categories, indicators, and summary of data used in the natural resource condition assessment of Shenandoah National Park.

Terrestrial resource	Indicator	Elevation	Geology	Number of sites	Number of measurements	Period
Big Meadows Area	Vegetation			79	948	1998 - 2012
	Deer			5 routes	172 survey days	1999 - 2012
Native Vegetation	Seedling density	< 915m	Granitic	46	138	2003 - 2011
			Metabasaltic	53	159	
			Siliciclastic	41	123	
		> 915m	Granitic	6	18	
			Metabasaltic	12	36	
			Siliciclastic	2	6	
	Canopy cover	< 915m	Granitic	46	138	2003 - 2011
			Metabasaltic	53	159	
			Siliciclastic	41	123	
		> 915m	Granitic	6	18	
			Metabasaltic	12	36	
			Siliciclastic	2	6	
Non-native Vegetation	Occurrence frequency	> 915m	Metabasaltic	46	138	2003 - 2011
			Siliciclastic	53	159	
			Granitic	41	123	
		< 915m	Metabasaltic	6	18	
			Siliciclastic	12	36	
			Granitic	2	6	
		> 915m	Metabasaltic	-	-	
			Siliciclastic			
			Granitic			
Birds	Abundance and species richness			4	7158	2009 - 2013

4.2.1 Big Meadows Area

Relevance and context

The Big Meadows Area (BMA) contains some of the most unique natural landscape features and rarest plant communities in the park. The area consists of 182 ha (450 ac) of second growth forest surrounding two wetlands and several developed areas. Within this area is one of the few remaining open grassland communities in Shenandoah National Park, referred to as Big Meadows. This 54 ha (135 ac) depression is located at an elevation of over 1,000 m at the crest of the Blue Ridge Mountains. The site is fed by several springs within the BMA, and surrounding land drains into the site, creating hydric, marshy conditions. The meadow is home to the highest concentration of rare species per unit area within the entire park. Populations of 18% of the park's state rare plants are found in Big Meadows.

There is evidence to suggest that the meadow was formed by extended forest clearing activities of early humans (Ahlgren and Ahlgren 1960; Cooper 1961; Thompson and Smith 1970). Lightning and anthropogenic ignitions of fire also have contributed to the development of this unique environment (Shelford 1963; Otto et al. 1977). Both Native Americans and early European settlers burned areas to control wildlife, to encourage the growth of fruit-bearing plants, and to make the soil more friable (Wilhelm 1968). Today, the park manages fire for multiple objectives, including natural resource benefit (National Park Service 2006c). Management activities also include regular mowing within the meadow, a longstanding method used by the National Park Service to maintain clearings (Figure 4-16). Before the current management plan was put in place in 2000, woody vegetation encroached on the meadow as documented by aerial photographs of the site (McNulty-Huffman 1990; Figure 4-17). The loss of open and early seral communities threatened the existence of several plant and animal species, and park management has since emphasized the maintenance of ecologically diverse open areas in the park. Active management since 2000 has taken the form of prescribed burning and mowing on three-year rotations with the goals of decreasing the cover of shrubs and other woody vegetation and stabilizing the meadow boundary. A time-series of photopoints are collected annually as a complement to vegetation sampling in order to track progress towards these goals (Figure 4-17). In addition to its ecological significance, the wide clear expanse of meadow now offers a spectacular view of park landscapes.

Wetlands in the Big Meadows Area (BMA) support several state-listed rare species (Ludwig *et al.* 1993) including gray birch (*Betula populifolia*), Canada burnet (*Sanguisorba canadensis*), and field sedge (*Carex conoidea*). The Northern Blue Ridge mafic fen, a globally-rare wetland plant community, is located at two locations within the BMA, an eight ha (20 ac) swamp north of Skyline Drive, and an eight ha (20 ac) wet meadow in the center of Big Meadows. State-rare plant species occurring in the fens include linear-leaved willowherb (*Epilobium leptophyllum*), Canada burnet (S*anguisorba canadensis*), blue flag iris (*Iris versicolor*), and brown bog sedge (*Carex buxbaumii*) (Figure 4-18). The wetlands are at risk of slowly, through succession, transitioning to a shrub community, resulting in a decline of wetland vegetation, and indeed, over the last 20 years, parts of Big Meadows Swamp have transitioned to a thick shrub community. Today, rare plants only survive on the edges of small pools surrounded by wet meadow. In addition, invasive species are competing with native and rare species. Garlic mustard (*Alliaria petiolata*), oriental lady's thumb (*Persicaria longiseta*), and Japanese stilt grass (*Microstegium vimineum*) are of notable concern (Figure 4-18).

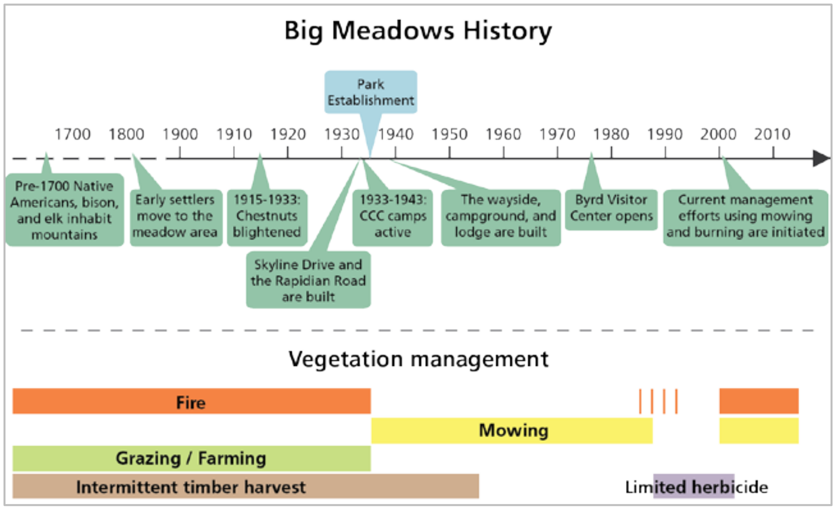

Figure 4-16. Timeline showing the history of Big Meadows and the management of its vegetation from pre-1770 to the present. Source: Wendy Cass, National Park Service.

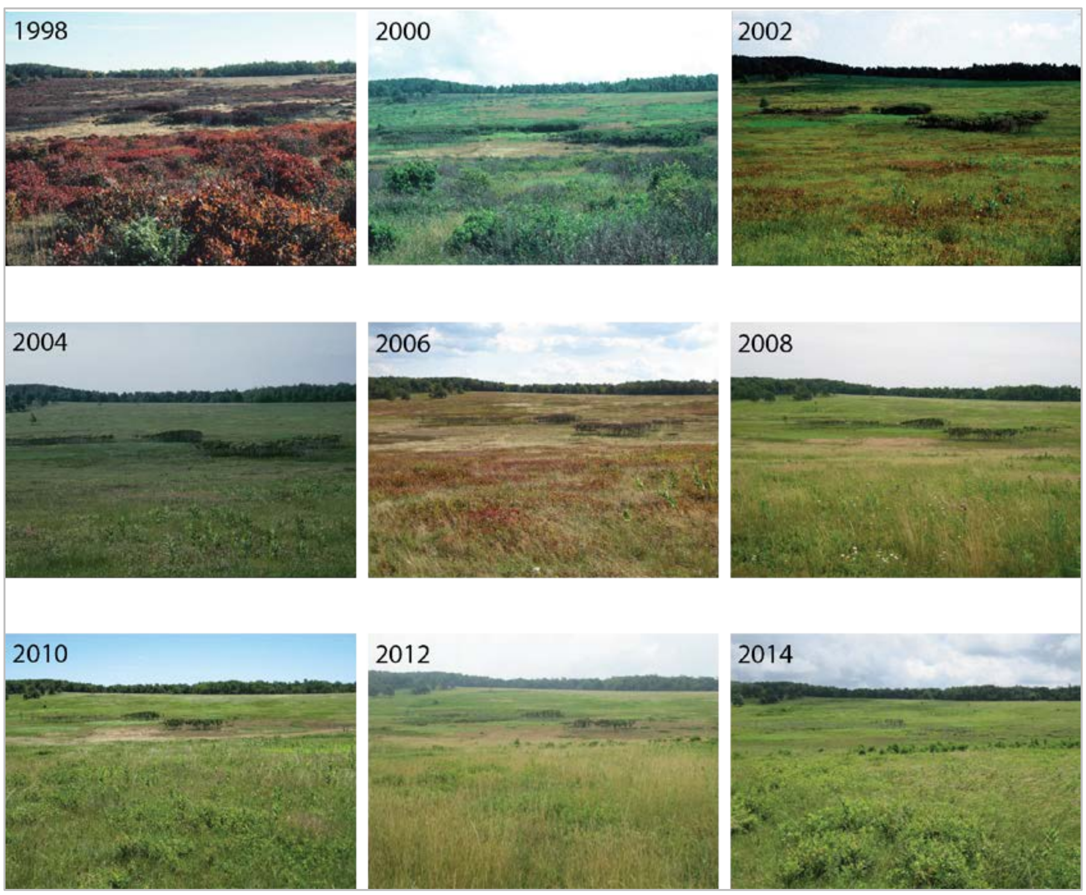

Figure 4-17. Time-series photographs of Big Meadows document changes in vegetation from 1998-2014. Photo credit: Wendy Cass, National Park Service.

Figure 4-18. (Top row L to R): Example state rare plants found in Big Meadows Swamp - brown bog sedge (*Carex buxbaumii*), blue flag iris (*Iris versicolor*), Canada burnet (*Sanguisorba canadensis*), and buckbean (*Menyanthes trifoliata*). (Bottom row L to R): Example invasive plants found in Big Meadows Swamp - Japanese stilt grass (*Microstegium vimineum*), oriental lady's thumb (*Persicaria longiseta*), and garlic mustard (*Alliaria petiolata*). Photo credit: Wendy Cass, National Park Service.

Deer are the dominant megafauna of BMA. White-tailed deer (Odocoileus virginianus) are the smallest members of the North American deer family, Cervidae, and are the most abundant species of ungulate on the North American continent (Russell et al. 2001) (Figure 4-19). They are common throughout the eastern United States and can be found at densities of 20 deer/km2 or greater (Bowers 1997). Due to their generalized diet, broad habitat preferences, and high densities, white-tailed deer can drastically affect the forest ecosystems in which they live (Bowers 1997; Kain et al. 2011). Deer directly affect the growth, reproduction, and survival of plant species by browsing, often with specific preferences, on the leaves, stems, flowers, and seeds of select plant species (Côté et al. 2004). For example, preferential grazing by deer can facilitate the establishment of nonnative invasives amongst forest understory herbs (Knight et al. 2009). Deer also have been shown to disturb populations of threatened or endangered plants (Miller et al. 1992). In addition, changes in undergrowth due to deer herbivory can account for a decrease in the sensitive species of birds that depend on those areas for nesting, foraging, and protection (McShea and Rappole 1997).

Figure 4-19. White-tailed deer (*Odocoileus virginianus*) are abundant in Shenandoah National Park, especially within the BMA. Photo credit: National Park Service.

Estimates of pre-colonial deer populations in Virginia range from 313,000–433,000 (3.1- 4.2 deer/km2) (Knox 1997). The decline in deer during colonial times is widely attributed to overharvesting for food and hides by settlers (Knox 1997). The early 1900s marked the lowest white-tailed deer densities, with deer in the highland physiographic provinces of Virginia almost completely extirpated (Knox 1997; Horsley et al. 2003; Côté et al. 2004). Management strategies in the early and mid-1900s emphasized encouraging growth of white-tailed deer populations throughout Virginia and the southeastern United States. Strict hunting regulations and changes in land use subsequently contributed to the rise of deer populations (Russell et al. 2001). A deer restoration program, initiated by the Virginia Department of Game and Inland Fisheries (VDGIF) in 1926, focused on repopulating Virginia's deer by importing and stocking forests with deer from other regions and states (VGDIF 2007). Most restocking was conducted west of the Blue Ridge Mountains. These management techniques proved effective as Virginia's population of deer grew from approximately 25,000 in 1931 to approximately 215,000 in 1970 according to VDGIF estimates (VDGIF 2007). Over the last 30 years, white-tailed deer populations have become increasingly abundant in Shenandoah National Park, especially in the park's developed and mowed areas (Big Meadows, Loft Mountain, Piney River, and Skyland) (Gubler et al. 2011).

A variety of factors contributes to the success of white-tailed deer in the eastern United States. The most significant contributing factors are increased forage and habitat availability. Increased range expansion can be attributed to large-scale land use changes from dense forest to fragmented forest and agricultural areas (Côté *et al.* 2004). White-tailed deer thrive in transitional habitats like wooded areas with openings for foraging. Forests adjoining developed and open areas, as are found in the

BMA, provide deer their preferred habitat. In addition, natural predators are no longer prevalent for deer population control (Côté *et al.* 2004). Parks and other privately owned areas that prohibit hunting also contribute to high densities of deer throughout the southeastern United States (Porter and Underwood 1999). Protected from hunting, and without significant natural predators, deer in parks have exhibited explosive population growth (McCullough 1997). Knox (1997) showed that populations of deer exhibiting highest densities corresponded directly to federal and state properties.

Data and methods

Vegetation cover of Big Meadows was assessed from 1998 to 2012 to determine how the meadows were responding to the 2000 management plan. As part of the management strategy, the meadow is treated as three distinct management zones: the 14.4 ha (35.6 ac) West Zone, the 22.5 ha (55.7 ac) Central Zone, and the 17.7 ha (43.7 ac) East Zone (Figure 4-20). Vegetation monitoring occurs at 79 permanent 50 meter transects on a three-year rotation that corresponds to the three management zones (Figure 4-21). In each transect, the percent cover of shrubs taller than 0.5 meter, the percent cover of shrubs shorter than 0.5 meter, and the percent cover of herbaceous species are recorded. The change in shrub and herbaceous cover from the 1998 baseline to the 2010-2012 rotation was assessed for each of three regions, roughly corresponding to the management zones. The West Zone was evaluated separately. Because the Big Meadows Swamp runs through the Central and East Zones, these zones were grouped and then the 34.0 ha (84.1 ac) Uplands and 6.3 ha (15.3 ac) Wetlands were evaluated independently for the region. This approach yielded six separate evaluations of vegetation cover in the region: shrubs and herbs in the West, Uplands, and Wetlands. Current condition of this metric was determined as the percentage of these six evaluations that met the threshold criteria. Trend was determined as the slope of the changes observed in vegetation over the past decade.

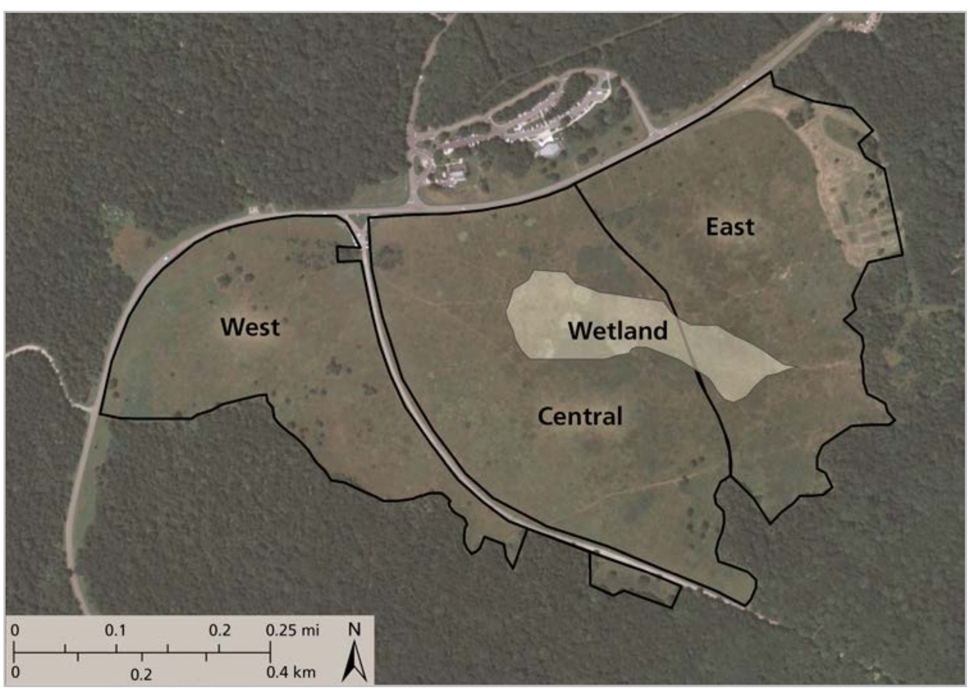

Figure 4-20. Management zones of Big Meadows. The Central and East zones were combined and evaluated as Wetlands and Uplands for this assessment. Source: ESRI Maps.

Figure 4-21. Vegetation monitoring in Big Meadows. Photo credit: Wendy Cass, National Park Service.

In response to ongoing impacts to the BMA from deer overbrowsing, the park established a spotlight count sampling design within the BMA survey area and began conducting nighttime spotlight counts in 1999 (National Park Service 2009b). Nighttime spotlight counts are a cost-effective means of determining deer abundance estimates in areas that are accessible by vehicle (Figure 4-22). The purpose of these spotlight counts was to show long-term deer population trends in the BMA and to document temporal and spatial trends. The count is specific to the BMA and in no way reflects deer abundance anywhere else in the park. Current condition of the deer population in the BMA was assessed using data from the 2012 counts, the latest available survey year. A trend was assessed from the fall 1999-2012, which include 123 surveys over 14 years.

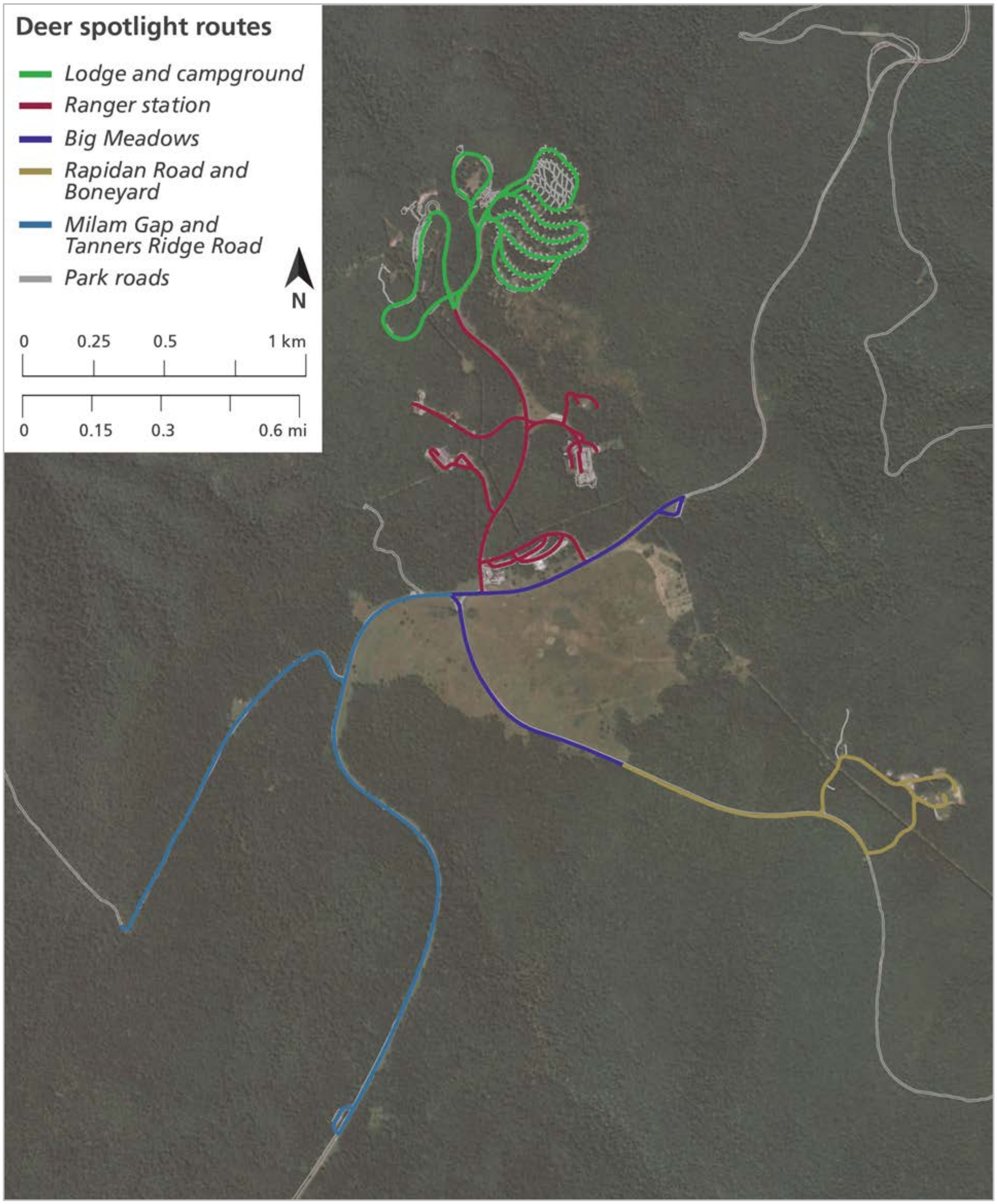

Figure 4-22. Big Meadows Area (BMA) deer spotlight survey routes. The full extent of the BMA is shown in the figure with the Big Meadows itself observable as the clearing in the underlying aerial photo. Source: Alan Williams, National Park Service.

Reference condition value

The management objective of the mowing and burning activities that began in Big Meadows in 2000 is to return the meadow to its historical open landscape. Specifically, the goals are to reduce shrub cover while maintaining the existing herbaceous cover that is an important cultural and natural resource to the park. Current conditions were compared to the 1998/1999 vegetation sample as a background reference. Current shrub cover less than these reference levels were considered indicative of successful management, while success for herbaceous management required current herbaceous cover at or above the reference levels.

According to Knox (1997), the environmental carrying capacity for deer in Virginia is 1.9–9.7 deer/km^2. Any densities exceeding this reference condition are considered an overly abundant population and can significantly affect the structure and composition of forest ecosystems (Rossell *et al.* 2005). As densities approach 8.0 deer/km^2, plant species are significantly reduced and songbird populations may be affected (DeCalesta 1997). Experimental studies in northwestern Pennsylvania indicate a reference condition for white-tailed deer of 8.0 deer/km^2, over which forest ecosystems begin to exhibit negative effects due to overbrowsing (Horsley *et al.* 2003). An ecosystem manipulation study in central Massachusetts found that deer densities of 10–17 deer/km^2 inhibited the regeneration of understory species, and densities of 3–6 deer/km^2 were optimal for supporting a diverse and abundant forest understory (Healy 1997). Based on the weight of evidence from these studies, a reference condition of 8.0 deer/km^2 was used for this assessment.

Condition and trend

In comparison to the 1998/1999 reference condition, only the Wetlands region of Big Meadows (i.e., Big Meadows Swamp) has shown a significant decrease in shrub cover (Figure 4-17; Figure 4-23). High shrubs decreased 86% in the Wetlands from 45% cover to 6% cover, and low shrubs decreased to less than 3% cover. Neither of the uplands regions (Uplands nor West) exhibited the same long-term decrease in shrubs. However, all three regions have sustained their herbaceous cover throughout the management actions. The West and Wetlands regions are slightly higher in herbaceous cover than they were in 1998/1999, and the Uplands region decreased by less than 7%. Therefore, the condition score for vegetation was assigned a value of 66.7% based on shrubs meeting the management objective in one of the three regions and herbs meeting the management objective in all three regions.

The trend in vegetation cover is towards deteriorating conditions over the past 10 years. After an immediate decline in shrubs in 2000, when all regions were both mowed and burned, the Uplands and West regions have undergone a slow recovery of shrubs (Figure 4-23). The increase in shrub cover is especially notable since 2003, the last time that all regions were burned every year. Herbaceous cover in the Uplands and Wetlands has also declined following adoption of the less frequent burning regime. In 2014, a shift from spring to fall burning was considered by the park. The potential effects of this shift are undetermined.

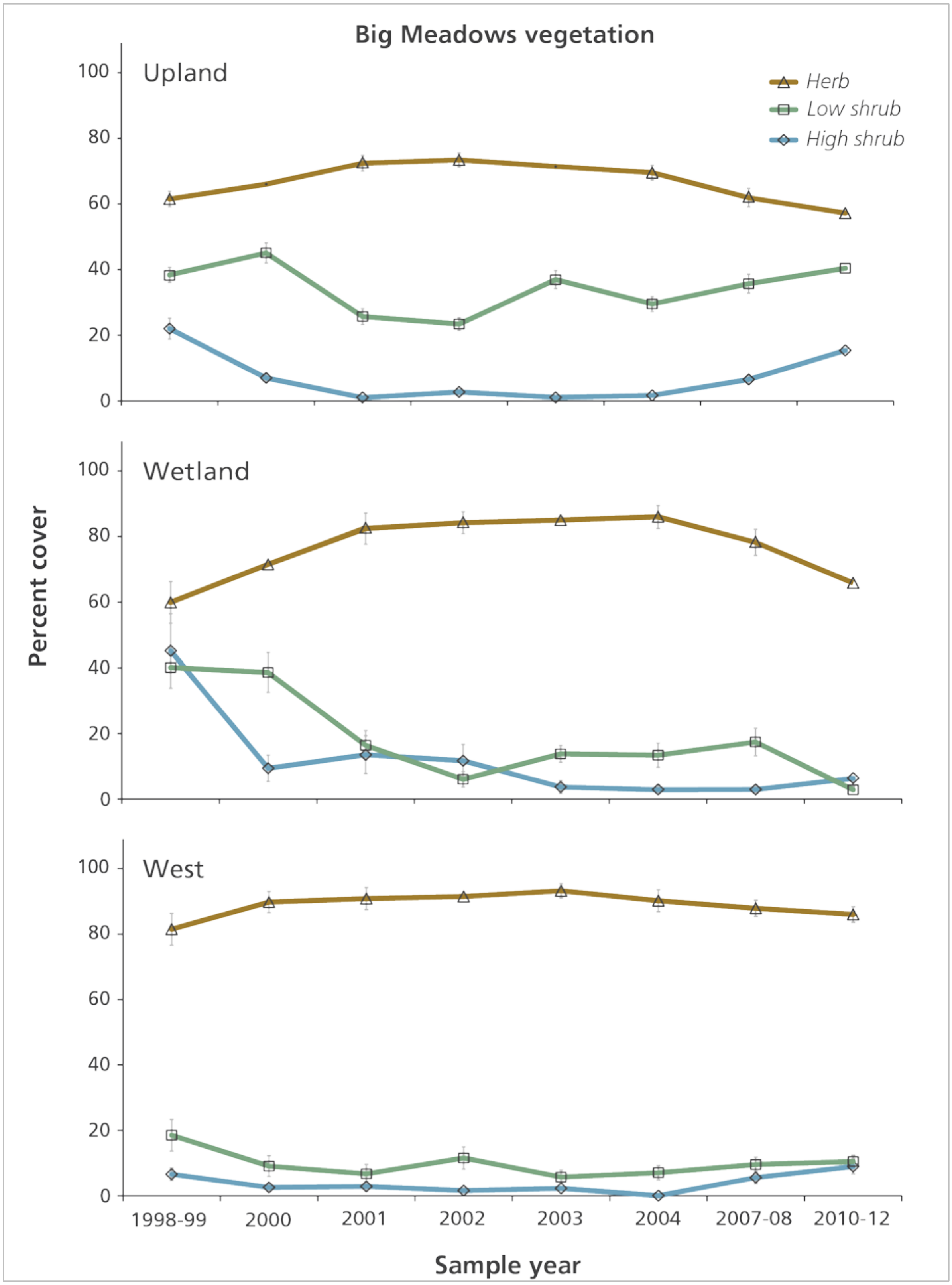

Figure 4-23. Mean percent cover of shrubs and herbs in Big Meadows from 1998-2012. Source: Wendy Cass, National Park Service.

The 2012 fall deer counts yielded an average of 53 deer/km^2 for the BMA. This count results in a percent attainment of 0% for current condition. The 1999-2012 fall deer counts (n=14 years) yielded an average of 76 deer/km^2. The data suggest a moderate downward trend in the deer population of the BMA with a potential stabilization of the population since 2004 (Figure 4-24). There have been no deer surveys done in the spring since 2008 due to lack of resources. From 2000 to 2008, spring surveys recorded slightly more deer than fall surveys, though this pattern was not consistent among all years and could be explained by numerous factors including the high public visitation in the fall (Gubler *et al.* 2011).

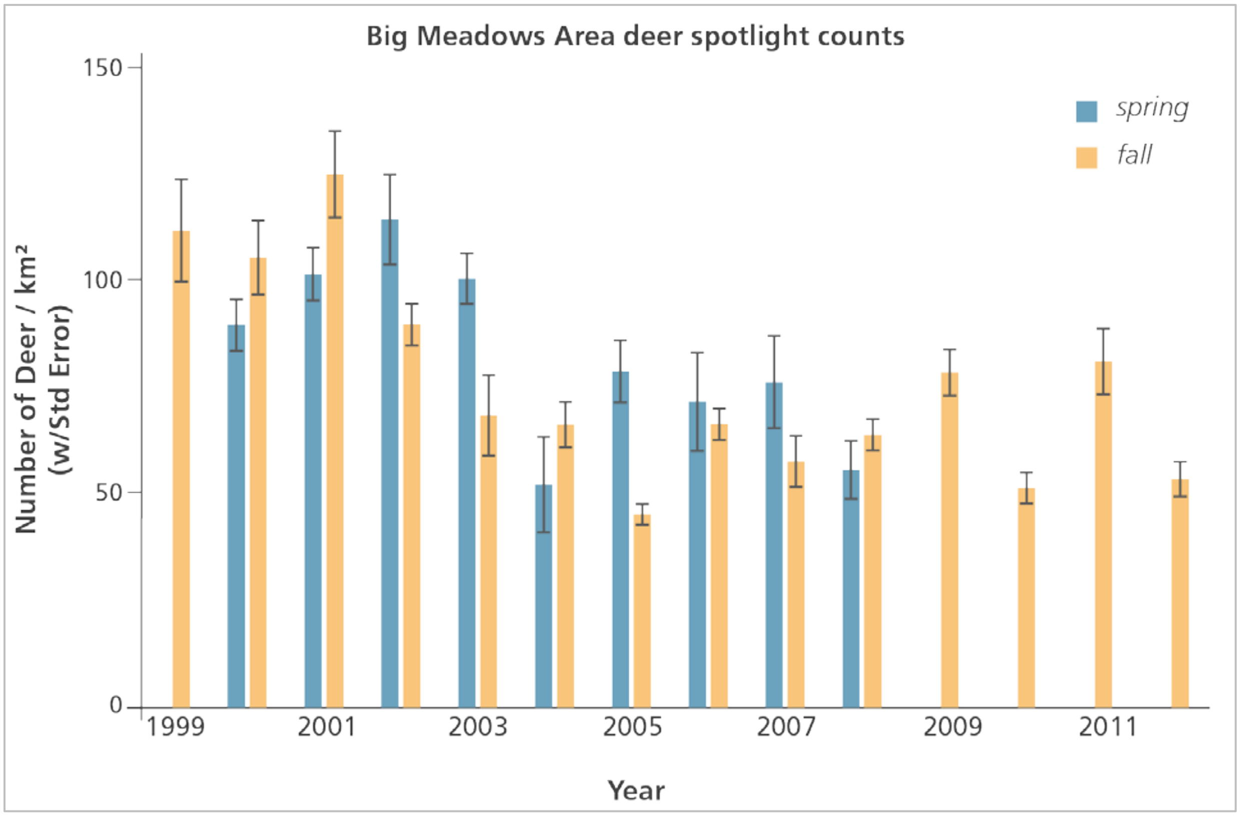

Figure 4-24. Deer spotlight counts in the Big Meadows Area (uncorrected observed data). Source: National Park Service 2009b and personal communication.

Combining the vegetation score of 66.7% with the deer score of 0% yields an overall score of 33.4% for the BMA. No significant trends were observed.

<u>Data gaps and level of confidence</u>

The reference condition used to assess the deer population for BMA was developed for forest ecosystems and therefore underestimates the carrying capacity of the BMA, which includes ideal deer habitat - a combination of meadow, mature forest, forest edge, old orchard, dense cover, and permanent water. Nevertheless, the observed values far exceed all published carrying capacities for the region and confidence that the deer population is above desired levels is high. It is worth reemphasizing that the deer monitoring in the BMA is not representative of deer populations elsewhere in the park, which is much more forested. Information on deer abundance in other parts of the park remains a data gap.

Confidence in the vegetation data used to assess Big Meadows is also high. However, more information is needed on the interactions between deer and the park's vegetation. For example, a recent exclosure study in the park points to somewhat surprising increases in growth of mature red oaks (*Quercus rubra*) in the presence of deer, potentially due to indirect effects associated with nutrient inputs from fecal and urine deposits (Lucas *et al.* 2013). Further study is also needed to better understand the effects of the frequency and timing (e.g., spring vs. fall) of burning and mowing treatments in Big Meadows.

<u>Sources of expertise</u>

- Wendy Cass, Botanist, National Park Service, Shenandoah National Park
- Rolf Gubler, Biologist, National Park Service, Shenandoah National Park

4.2.2 Native vegetation

<u>Relevance and context</u>

Shenandoah National Park is uniquely situated to host a diverse native plant community. The distribution of these plants is influenced by park topography, geology, climate, disturbance regime, and land-use history (Stephenson *et al.* 1991; van Manen *et al.* 2005). The north-south orientation within the Mid-Atlantic region straddles a major climatic boundary. This climatic variability is accentuated by the over 1,000 m of elevation spanning the park. Several species occur near their southern limits including balsam fir (*Abies balsamea*), bunchberry (*Cornus canadensis*), and bearberry (*Arctostaphylos uva-ursi*), while others, such as catawba rhodondron (*Rhododendron catawbiense*), occur at the northern edge of their range limits. Topography is another important control on the vegetation of the park, and other species occur as disjunct, isolated populations in high elevation forests (Harrison *et al.* 1989; Young *et al.* 2009). Several rare plants are found on the high-elevation, rocky outcrops of the park. The Adopt-an-Outcrop volunteer monitoring program tracks changes in these plants, which are vulnerable to hiker disturbance (Figure 4-25). In general, disturbance is a key factor influencing the vegetation in the park. At the time of its establishment, only 2% of its forest land remained in old-growth condition (Fievet *et al.* 2003). The composition of Shenandoah's vegetation has changed considerably over the last few centuries and should be considered within this dynamic context.

The park is home to 1,406 species of vascular plants (https://irma.nps.gov/NPSpecies/Search/SpeciesList/SHEN). Approximately 95% of the park is forested with the largest unfragmented stands dominated by the Chestnut Oak / Northern Red Oak Forest community type (Table 4-23). The loss of American chestnut due to the chestnut blight (*Cryphonectria parasitica*) pathogenic fungus in the early 1900s, and more recent oak mortality from gypsy moth caterpillars (*Lymantria dispar dispar*) infestations, has had considerable effect on the composition of the forests (Stephenson *et al.* 1991; Townsend *et al.* 2012). Of the 53 species of tree recorded on forest monitoring plots in the park, oaks are generally most abundant, followed by hickories and substantial populations of red maple (*Acer rubrum*), sweet birch (*Betula lenta*), black gum (*Nyssa sylvatica*), and tulip tree (*Liriodendron tulipifera*) (Cass *et al.* 2015). White ash (*Fraxinus Americana*) comprise four percent of the trees observed in forest monitoring and are at significant threat from the recent emergence of emerald ash borer (*Agrilus planipennis*), which was confirmed in the park in 2014.

Figure 4-25. Images from the park's Adopt-an-Outcrop volunteer monitoring program. The two pictures taken on the summit of Stony Man Mountain show the changes in cover of three toothed cinquefoil (*Sibbaldiopsis tridentata)* from 2009 to 2014 (red arrows). Photo credit: Wendy Cass, National Park Service.

Insect pests and disease have been a long-standing concern to the native plant species of the park. In addition to chestnut blight, gypsy moth, and emerald ash borer, dogwood anthracnose (caused by the fungus *Discula destructive*) has resulted in a 90% decrease in dogwoods (*Cornus florida*). The small aphid-like hemlock woolly adelgid (*Adelges tsugae*) presents a significant concern to another one of the park's iconic species, the eastern hemlock (*Tsuga canadensis*). At least two studies, dating back to 1990, indicate that over 95% of the park's hemlocks have been eradicated (Meyerhoeffer *et al.* 2009, Cass *et al.* 2015). The park continues to monitor hemlock health closely as part of its forest vegetation monitoring (Cass *et al.* 2011a), and have observed that areas with treated trees have seen some canopy stabilization and that other areas are seeing some regeneration in the understory. As hemlocks die off, they are typically replaced by a mix of early succession hardwood species (Perez 2006).

Shenandoah National Park also supports a variety of rare, threatened and endangered (RTE) species (Figure 4-26) and is home to 145 Natural Heritage Conservation Sites, representing key areas of the landscape for protection because of the natural heritage resources and habitat they support (VDCR 2014). Specifically, 58 state and globally rare plant species (status determined by the Virginia Natural Heritage Program; see Townsend 2014) are found in the park, including three globally rare species (Cass *et al.* 2011b, Cass *et al.* 2015). Many of these species are specifically adapted to the park's montane habitats. There are constant threats to the health of the rare plant species in the park including changes in climate and natural disturbance regimes (Gawtry and Stenger 2007); deer and other wildlife herbivory (McShea *et al.* 1997); and anthropogenic disturbances, non-native insects and diseases, and invasive plants (O'Hanlon-Manners and Kotanen 2004). Several species, including American ginseng (*Panax quinquefolius*), bloodroot (*Sanguinaria canadensis*), and black cohosh (*Cimicifuga racemosa*), are potentially at-risk because of illegal harvesting by the growing herbal remedy market (Cass 2005, van Manen *et al.* 2005). Other concerns include the harvest of fern "fiddleheads" in the spring, and the collection of fungi for consumption and medicinal uses.

<u>Data and methods</u>

Long-term ecological monitoring of native forest vegetation began in the 1980's, with the current methods initiated in 2003 (Cass *et al.* 2012). Changes in plant species abundance and distribution over time has been well documented in Shenandoah National Park since the forest monitoring program was initiated in 1987 as part of the park's Long-term Ecological and Monitoring (LTEM) program (Smith and Torbert 1990, Diefenbach and Vreeland 2003, Mahan *et al.* 2007, Cass *et al.* 2011a). A list of observed vascular plant species within the park boundaries is updated after each monitoring cycle (https://irma.nps.gov/NPSpecies/Search/SpeciesList/SHEN).

Between 2003 and 2011, the Shenandoah National Park I&M program, part of the Mid-Atlantic I&M Network, completed three sampling rotations of 160 long-term forest monitoring plots (Figure 4-27). Plots are stratified based on elevation, aspect, and bedrock geology, and located away from trails, roads, and developed areas in the park. The initial sampling was completed from 2003-2005 (Table 4-5). Plots were revisited in 2007 and again from 2008-2011 (Cass *et al.* 2012). Monitoring of these plots is ongoing, but these years represent the most recent complete rotations available at the time of the assessment.

Each site was evaluated on changes in forest composition, structure, regeneration, and growth (Cass *et al.* 2011a). Vegetation structure was assessed at multiple strata on the plots: trees, shrubs/saplings, and seedlings/sprouts. Variables recorded on the 24 x 24 m (576 m^2) plots or smaller subplots within each site included basal area; density; density by tree crown health, height and class; and frequency of occurrence for trees, shrubs/saplings, and seedlings/sprouts. Field sampling was completed from mid-May through September.

Figure 4-26. Sword-leaf phlox (*Phlox buckleyi*) is an example rare plant species (GS2 / S2) that is endemic to Virginia and West Virginia. Photo credit: Wendy Cass, National Park Service.

Table 4-5. Number of vegetation monitoring sites sampled per year.

Year	Number of sites sampled
Initial Sample	
2003	27
2004	30
2005	103
First Resample	
2007	160
Second Resample	
2008	44
2009	51
2010	56
2011	9

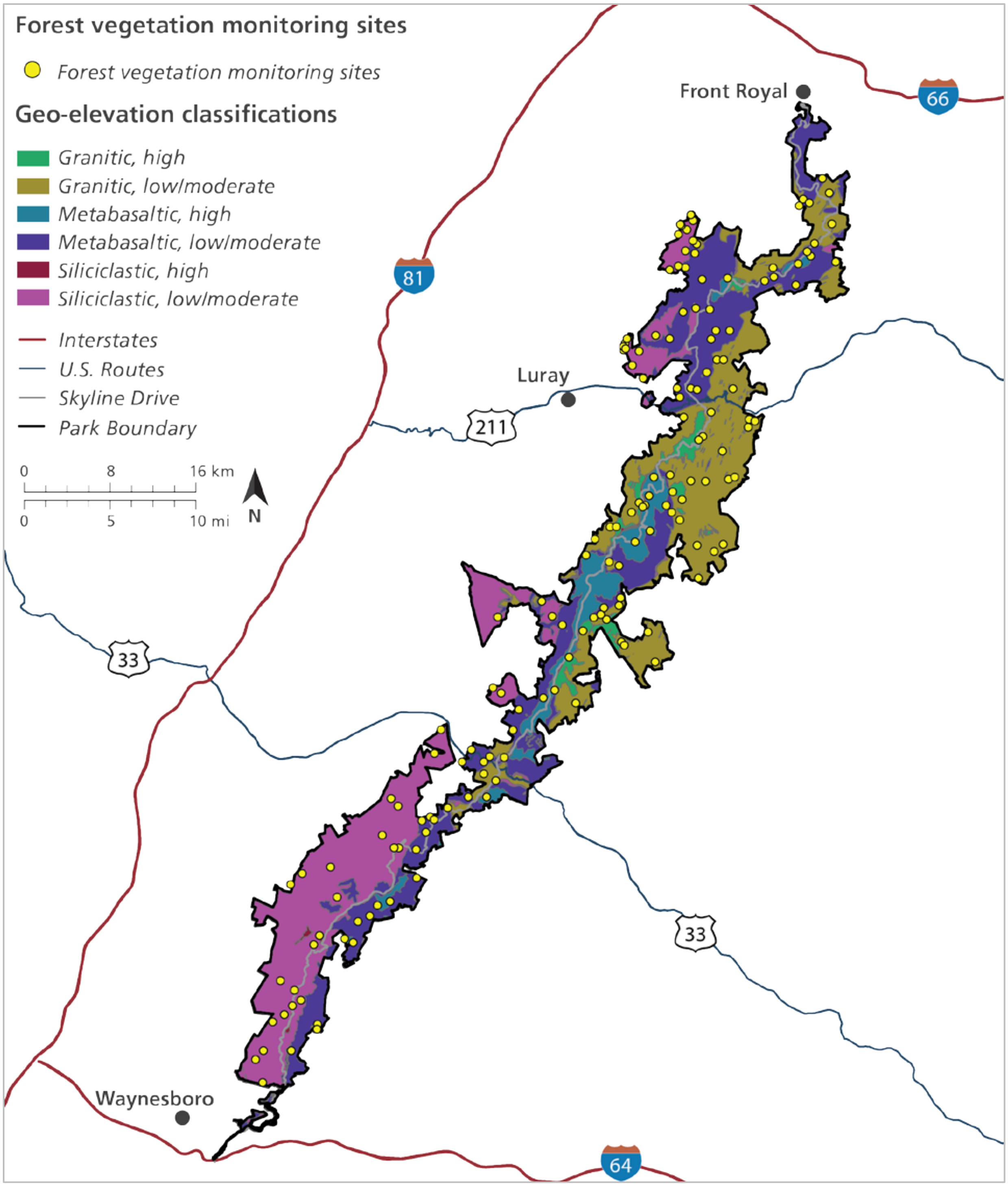

Figure 4-27. Plot locations for forest vegetation monitoring in Shenandoah National Park.

The forest vegetation monitoring data were used to rank species observed in the parks' forest by importance value, a measure of how dominant a species is in the forest based on a combination of the relative frequency, relative density and relative basal area of the species (Cass *et al.* 2015, Stevens 2015). Density was calculated as the mean number of stems of the species per hectare as estimated from the forest vegetation monitoring plots. Basal area is the sum of the cross sectional area of all the trees of the species in the plots divided by the total plot area. Frequency is the percent of plots containing the species. All species were ranked by importance value for each of the three rotations (Figure 4-28), and the trend and current basal area and density of the twelve species with the highest importance values were assessed for context.

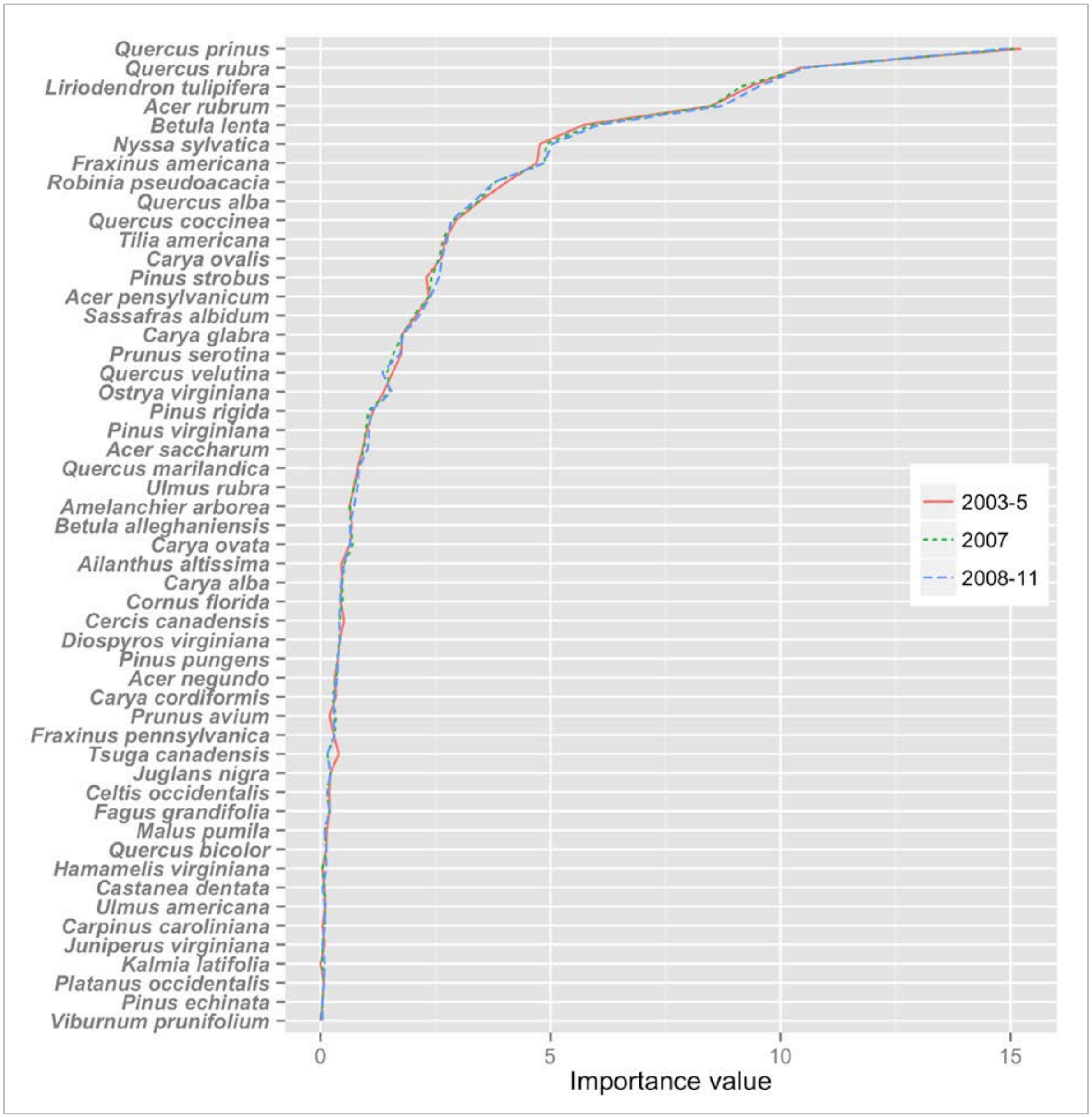

Figure 4-28. Ranked importance values of trees observed on forest vegetation monitoring plots. Source: Cass *et al.* 2015, Stevens 2015.

The quantitative assessment of the tree strata in this NRCA used data on tree crown health (Cass *et al.* 2011a). Crown health was assessed categorically for each canopy stem on each plot. The crown of each tree on the plots was observed and placed into one of five classes (Table 4-6). Current condition was evaluated using data from the most recent survey of the vegetation plots (2008-2011). Trend was assessed for the three rotations.

Table 4-6. Crown health was assessed in discrete classes on the 160 vegetation monitoring plots.

Class	Crown health description
1	90%-100%
2	50%-89%
3	1%-49%
4	Recently Dead
5	Dead

The seedling strata were assessed using data on seedling counts within two 0.5 m x 12 m (12 m^2) belt transects for each forest vegetation monitoring plot. Linear transects were used instead of square quadrats to better represent the environmental heterogeneity of the plots. Seedlings were defined as a woody plant stem with a DBH < 10 cm and height < 1.5 m (Cass *et al.* 2011a). For the purposes of this assessment, the seedling counts observed on the plots were converted to density per hectare. Values for stems of non-native species and non-tree species such as *Vaccinium spp*. were excluded from the assessment. Current condition was evaluated using data from the most recent survey of the vegetation plots (2008-2011). Because the rate of mortality in the smallest seedling class is so high, counts of these seedlings are not necessarily representative of overall reproductive health of the forest. Therefore, both all seedlings and only seedlings greater than 15 cm in height were assessed. Data on the different size classes of seedlings were only collected for the second and third sample rotations (e.g., 2007-2011). Trend was assessed for the three rotations.

Rare plant monitoring in Shenandoah National Park began in 1998, based on an inventory conducted by the Virginia Natural Heritage Program from 1989 to 1991 (Ludwig *et al.* 1993). In 2002, the current rare plant monitoring protocols were established to track 565 rare vascular plant populations that are known in the park (Cass *et al.* 2011b) (Figure 4-29). Populations are defined as individuals of a species that are within a specified distance of other individuals of the same species (< 200 m for woody species, < 20 m for herbaceous species not on rock outcrops, and < 2 m for herbaceous species on rock outcrops). Status and trend of populations are monitored using seven sampling protocols ranging from general stratum-based (trees, shrubs, herbs) to species specific. Areas subject to greater disturbance or threats are sampled at higher frequency. The most recent summary data available at the time of this assessment were from 2009 (Cass *et al.* 2011b), though surveys are ongoing. Temporally consistent data are available for certain taxa, and trends were assessed using the data for sword-leaved phlox.

Rare plant communities have also been identified using Young *et al.*'s (2009) vegetation community mapping of the park. This section provides the percent area of the park at the time of Young's mapping that was covered by vegetation communities considered to be rare or threatened. The analysis of rare plant communities is provided for context but is not quantitatively included in the final park assessment.

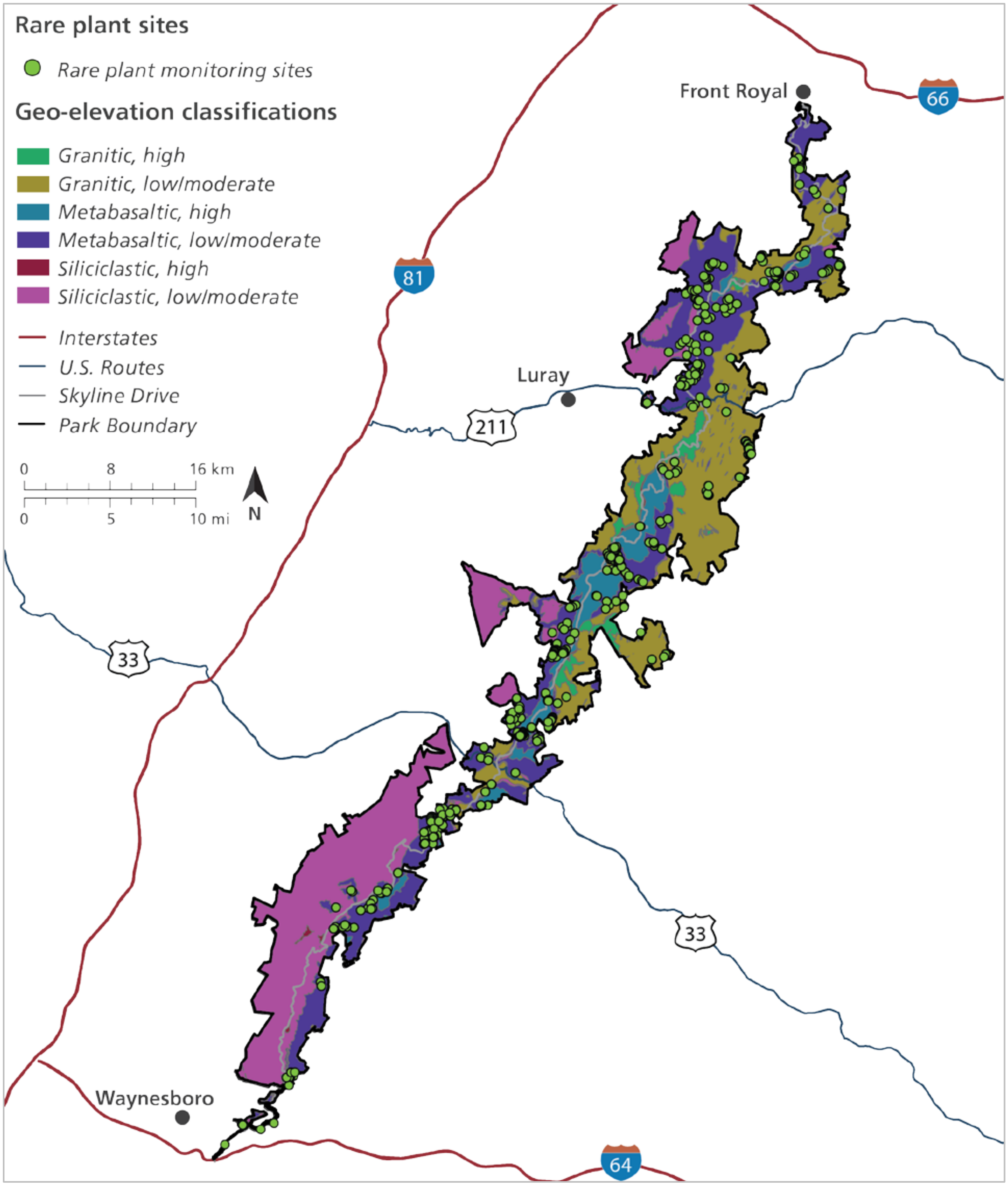

Figure 4-29. Locations for rare plant monitoring in Shenandoah National Park. Source: Dan Hurlbert.

Reference condition value

Following guidance from the park (Cass *personal communications*) and the Mid-Atlantic I&M Network (Comiskey and Wakamiya 2012), trees were deemed to be in "good" canopy health if they fell into a Crown Health Class of 1 or 2 (i.e., greater than 50% of canopy foliage intact). Trees in Class 1 and Class 2 are often confused among samples from different years, and we treated these categories as equivalent. Therefore, the percentage of individual trees in Crown Health Class 1 and Class 2 was used as the percent attainment.

Studies of hardwood forests in Pennsylvania have documented increased probabilities of regeneration failures given seedling-stocking densities of less than 35,000 seedlings of all desirable species per hectare (Marquis and Bjorkbom 1982, McWilliams *et al.* 1995). These studies were largely undertaken under conditions of low deer herbivory. Large white-tailed deer populations can further reduce regeneration success (Marquis 1981, Côté *et al.* 2004) and would increase the recommended threshold density. For this assessment, a reference condition seedling density of 35,000 seedlings per hectare was used. Each plot measurement was assessed against this reference condition and assigned a pass or fail result. The percentage of passing results was used as the percent attainment.

Several forest monitoring programs use a weighted approach to assess seedling densities based on combinations of stems of varying height classes (Shirer and Zimmerman 2010, Comiskey and Wakamiya 2011). McWilliams *et al.* (1995, 2005) established these methods starting with a height class of 5 cm. This level of data resolution was not available for the Shenandoah data. Instead all seedlings were assigned a weighting of 1 based on recommendations from Shirer and Zimmerman (2010). In 2007, monitoring data in the park began recording seedlings in two size classes: less than 15 cm and greater than 15 cm. Unfortunately, seedlings taller than 15 cm are still assigned a value of 1 by most weighting schemes (McWilliams *et al.* 1995, Shirer and Zimmerman 2010, Comiskey and Wakamiya 2011). For comparison purposes, the unweighted density of seedlings greater than 15 cm in height is provided in this assessment where available.

The Virginia Natural Heritage Program lists 120 RTE plant species that are potentially found within the Northern Blue Ridge Physiographic Province (VDCR 2014). There are many limitations on species distributions and many reasons why a species that occurs elsewhere in the Northern Blue Ridge would not be observed in the park. To evaluate RTE species in Shenandoah National Park, the number of state rare or watch-listed species observed in the park in the 20-year period ending in 2014 (derived from Cass *et al.* 2011b, Cass *et al.* 2015) was compared to a list of species historically recorded in the park. A species was determined as historically present if a specimen or reliable record exists for the species (Cass *et al.* 2011b). These records may date back prior to the initiation of rare plant monitoring. The quantitative assessment of percent attainment was calculated as the percentage of species confirmed present in the most recent ten years relative to those species historically present in the park.

Condition and trend

Mean tree density for the 2008-2011 sample for the 12 species with highest importance values in the forest vegetation monitoring plots ranged from 12.2 stems/ha for red hickory (*Carya ovalis*) to 72.6 stems/ha for chestnut oak (*Quercus prinus*) (Figure 4-30). Four of the top 12 species were oaks, and the mean density of all oaks (*Quercus spp*.) in the latest rotation was 147.4 stems/ha. Chestnut oak appears to be decreasing in density for the three sample periods, while the mean density of black gum (*Nyssa sylvatica*) and sweet birch (*Betula lenta*) has increased slightly. During the same time interval, the mean basal area of chestnut oak has increased slightly on the monitoring plots (Figure 4-31); however, all of these trends are within the 95% confidence intervals of the data. Notably, the importance of northern red oak (*Quercus rubra*) and especially tulip poplar (*Liriodendron tulipifera*) are a function of their relatively high basal areas rather than their densities.

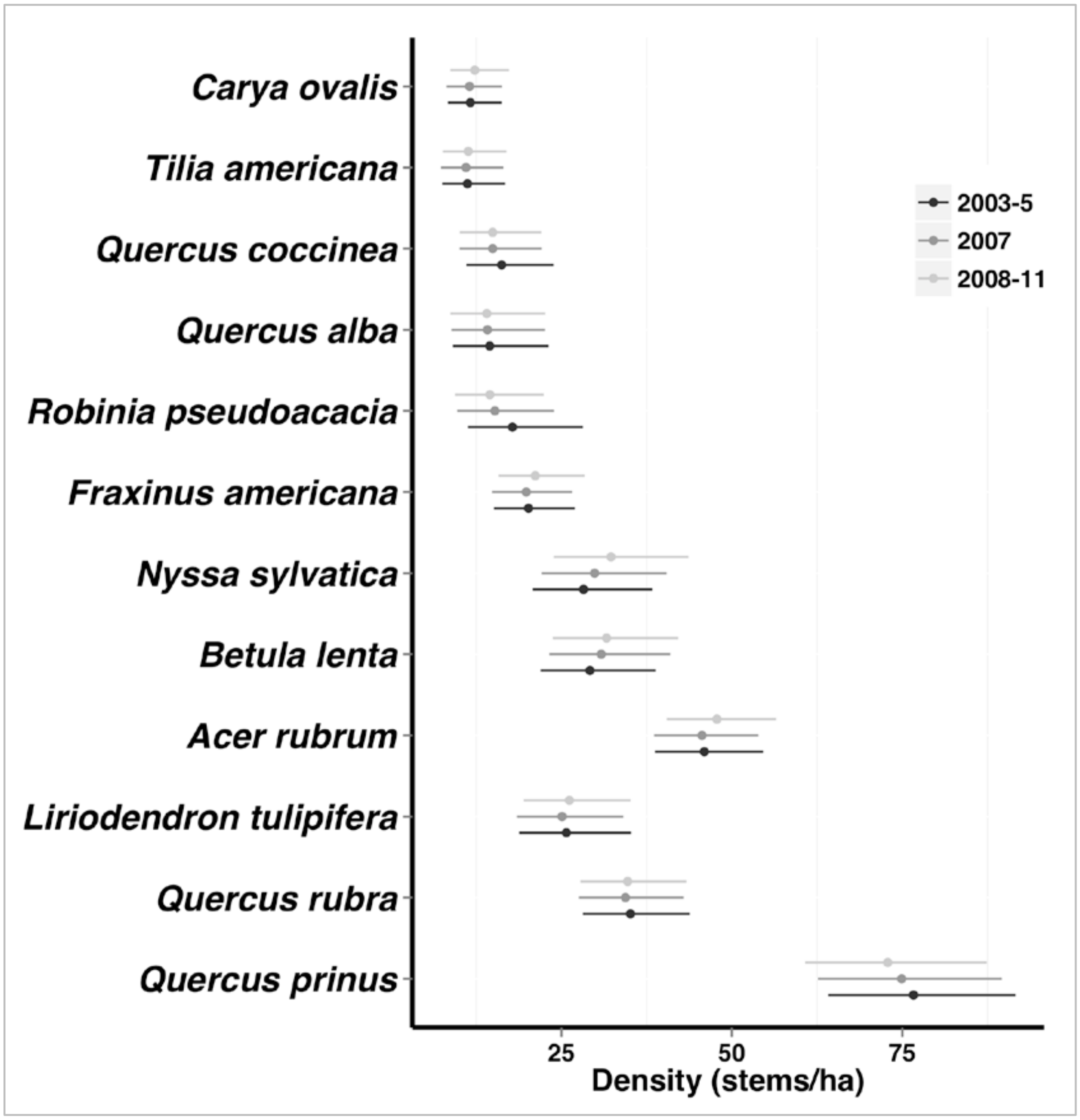

Figure 4-30. Mean tree species density (stems/ha) with 95% CIs for the 12 tree species with the highest park-wide importance values in Shenandoah National Park displayed for three sample periods (2003-2005, 2007, and 2008-2011). Source: Cass *et al.* 2015, Stevens 2015.

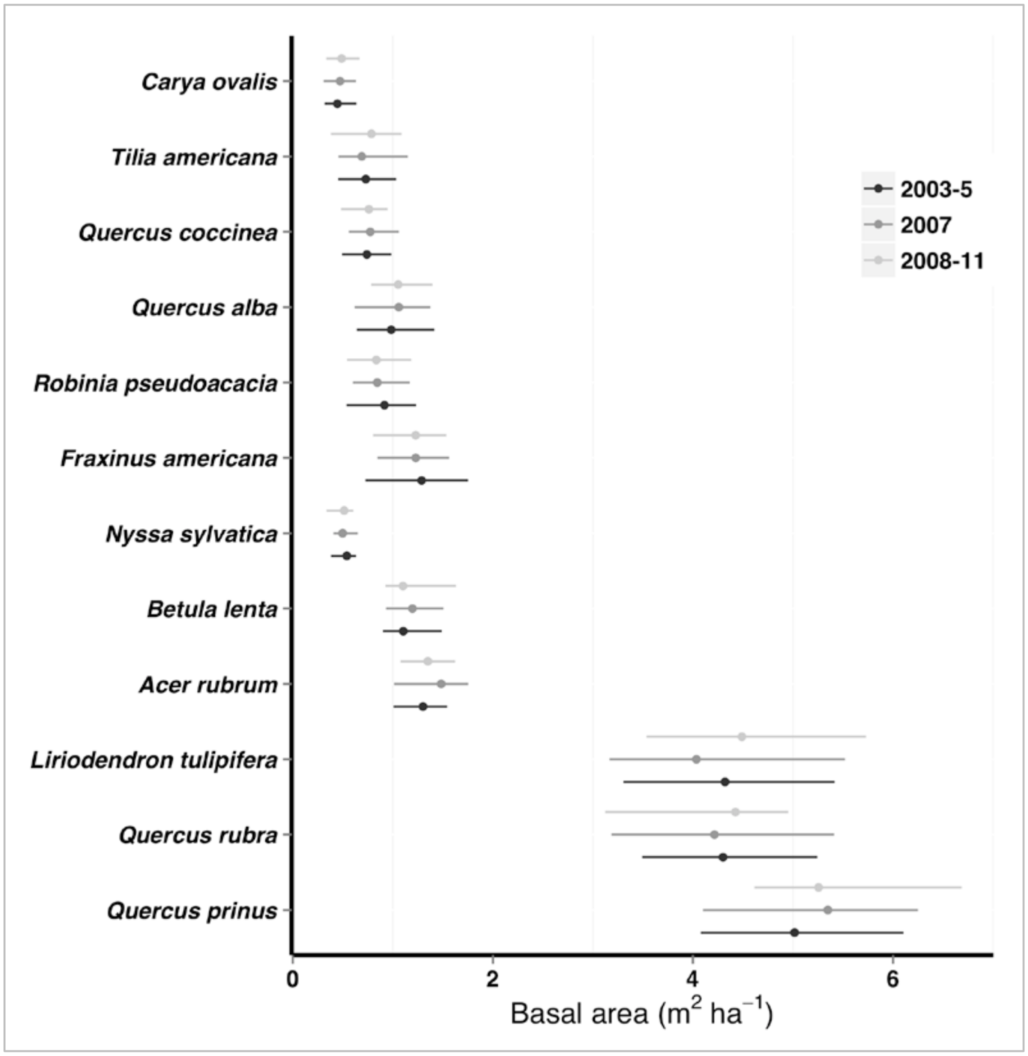

Figure 4-31. Mean tree species basal area (m^2/ha) with 95% CIs for the 12 tree species with the highest park-wide importance values in Shenandoah National Park displayed for three sample periods (2003-2005, 2007, and 2008-2011). Source: Cass *et al.* 2015, Stevens 2015.

A total of 4,141 trees were sampled from 2008-2011. Of these individual trees, 1,391 were identified as belonging to Crown Class 1 and 2,200 were identified as belonging to Crown Class 2 for a total of 3,611, or 87% of all trees. All geo-elevation classes had attainment scores of greater than 75% for all sample rotations except for the 2008-2011 samples on high elevation siliciclastic plots (Figure 4-32). Of the 48 trees measured on high elevation siliciclastic plots from 2008-2011, only 54% were in Crown Class 1 (1 tree) or Crown Class 2 (25 trees). Averaging the 2008-2011 scores for the six separate geo-elevation classes yielded an overall percent attainment score of 82.0% for current condition. A total of 12,261 measurements were taken over the three sample periods (average of 4,087 trees per sample period). The total number of trees in Crown Class 1 or 2 decreased from 3,846 in the first sample to 3,611 in the most recent sample. Given this decrease, the trend was assessed as worsening. The trend was strongest for the High Siliciclastic class, which decreased from 100% attainment to 54%, but was observed for nearly all geo-elevation classes (Figure 4-32).

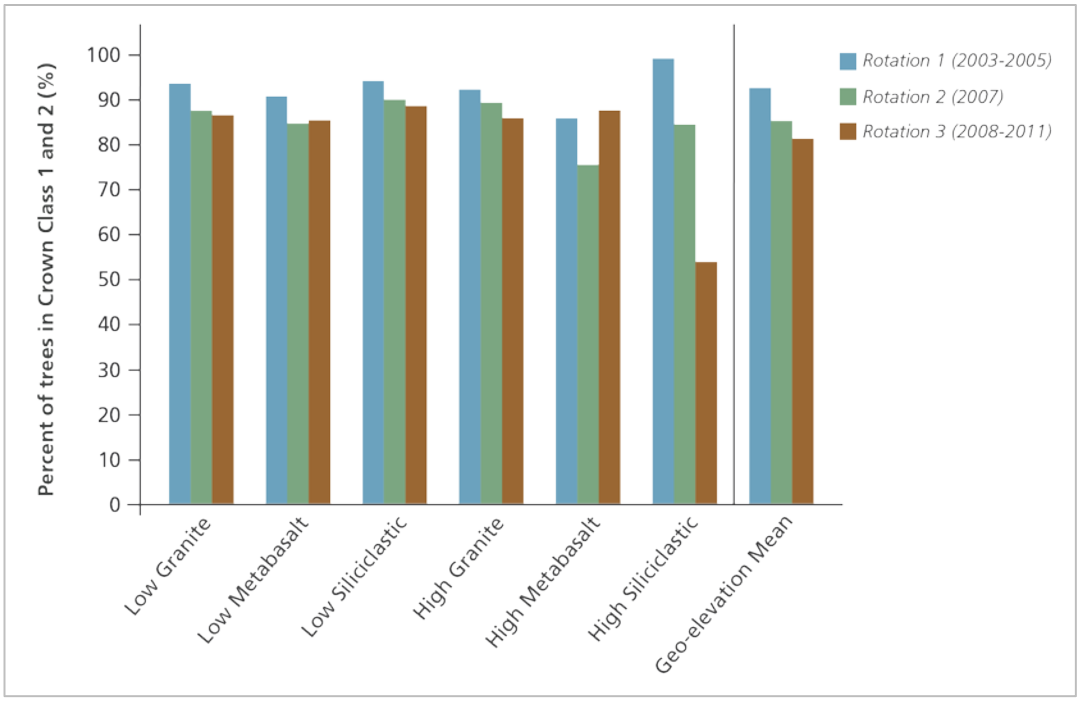

Figure 4-32. Percent of trees on vegetation monitoring plots with Crown Class 1 or 2 (signifying > 50% of the canopy was intact) for the three sample periods. Source: Shenandoah I&M Program.

The mean seedling density for the 160 forest vegetation monitoring plots for the most recent sampling rotation (2008-2011) was 84,828 seedlings/ha. Although this mean value exceeds the reference condition of 35,000 seedlings/ha and is higher than all other parks in the region (Comiskey and Wakamiya 2012), there was considerable variation among plots (minimum of 0 seedlings/ha; maximum of 957,500 seedlings/ha). In total, 102 plots met the reference condition density required to be considered in good condition. Weighting the plots by the six geo-elevation classes yielded a percent attainment score of 52.6% for current condition (Table 4-7). Comiskey and Wakamiya (2011) recommend that greater than 70% of all plots should meet seedling density reference conditions. The park falls slightly below that standard at the present time.

Slight differences were apparent among the three sample periods (2003-2006, 2007, 2008-2011). Three of the six geo-elevation classes had decreases over time in the percentage of plots exceeding the established reference condition density (Table 4-7). Considering only the seedlings greater than 15 cm in height, the mean density has decreased slightly from 24,156 seedlings/ha in 2007 to 22,979 seedlings/ha for the 2008-2011 sample rotation. However, given the small sample size of only three time periods and the relatively small changes in densities, no significant trend is reported.

Of the 565 populations of rare plants monitored by the park, more than 50% are found in the High Metabasaltic geo-elevation class (Figure 4-29). Park and state records indicate that Shenandoah National Park has currently, or historically, supported 73 plant species classified as rare or watch-listed by the state of Virginia (Ludwig *et al.* 1993; Cass *et al.* 2015). Monitoring data from 1995 to 2014 has confirmed the presence of 58 of these rare plant species (Appendix A), with the additional 15 species being classified as unconfirmed historic sightings older than 20 years (Cass *et al.* 2015)

(Table 4-8). This translates to an overall attainment score of 79% for all rare plant species for which records exist. For context, field monitoring data from 2010-2014 included survey work for 50 of the confirmed rare species. During this monitoring, the presence of 47 species was re-confirmed (Cass *et al.* 2015). The remaining three species could not be re-located.

Table 4-7. Percent of forest vegetation plots with seedling density > 35,000 seedling/ha

Elevation	Geology	Number of Plots	Visit 1 % (2003-2005)	Visit 2 % (2007)	Visit 3 % (2008-2011)	Condition
< 915 m	Granitic	46	63.0	63.0	58.7	Moderate
	Metabasaltic	53	62.3	64.2	71.7	Moderate
	Siliciclastic	41	75.6	70.7	68.3	Moderate
> 915 m	Granitic	6	50.0	66.7	0.0	Significant concern
	Metabasaltic	12	66.7	66.7	66.7	Moderate
	Siliciclastic	2	50.0	50.0	50.0	Moderate
Shenandoah National Park		**160**	**61.3**	**63.5**	**52.6**	**Moderate**

Table 4-8. Fifteen species that have historically been observed in the park, but have not been confirmed in the field in the past 20 years.

Species	Common name	Global rank	State rank
Botrychium oneidense	Blunt Lobed Grape Fern	G4Q	S2
Carex interior	Inland sedge	G5	S1
Corallorhiza maculata var. occidentalis	Western spotted coralroot	G5T3T5	S1
Crataegus succulenta	Fleshy hawthorn	G5	S1
Cuscuta rostrata	Beaked dodder	G4	S2
Cyperus houghtonii	Houghton's flatsedge	G4?	SH
Elymus trachycaulus spp. trachycaulus	Slender wheatgrass	G5T5	S2
Galium boreale	Northern Bedstraw	G5	S3
Geum aleppicum	Yellow avens	G5	SH
Mimulus moschatus	Muskflower	G4G5	S1
Packera paupercula	Balsam groundsel	G5	TNRS3?
Penstemon hirsutus	Hairy beardtongue	G4	S2
Pyrola chlorantha	Greenish-flowered shinleaf	G5	SH
Quercus prinoides	Dwarf chinquapin oak	G5	S2
Wisteria frutescens	American wisteria	G5	S2

Park monitoring data show that the majority of rare plant populations in the park are stable between monitoring visits (Cass *et al.* 2015). Detailed census data for certain species, such as sword-leaf phlox (*Phlox buckleyi*), indicate yearly variability, but an overall trend of stable survival (Figure 4-33). Some rare plant populations in areas undergoing changes in forest composition have been lost or decreased in size. Examples of this may be seen with western spotted coralroot (*Corallorhiza maculata*), a rare plant which appears to be extirpated from the Park following habitat change caused by hemlock morality, and by the reduced number of surviving stems of twisted stalk (*Streptopus* *amplexifolius*) in areas that have experienced severe hemlock canopy tree mortality (Cass *et al.* 2011b). Other examples of decline may be seen in high elevation species such as balsam fir, and are likely due to acid deposition and climate change (Cass *et al.* 2012).

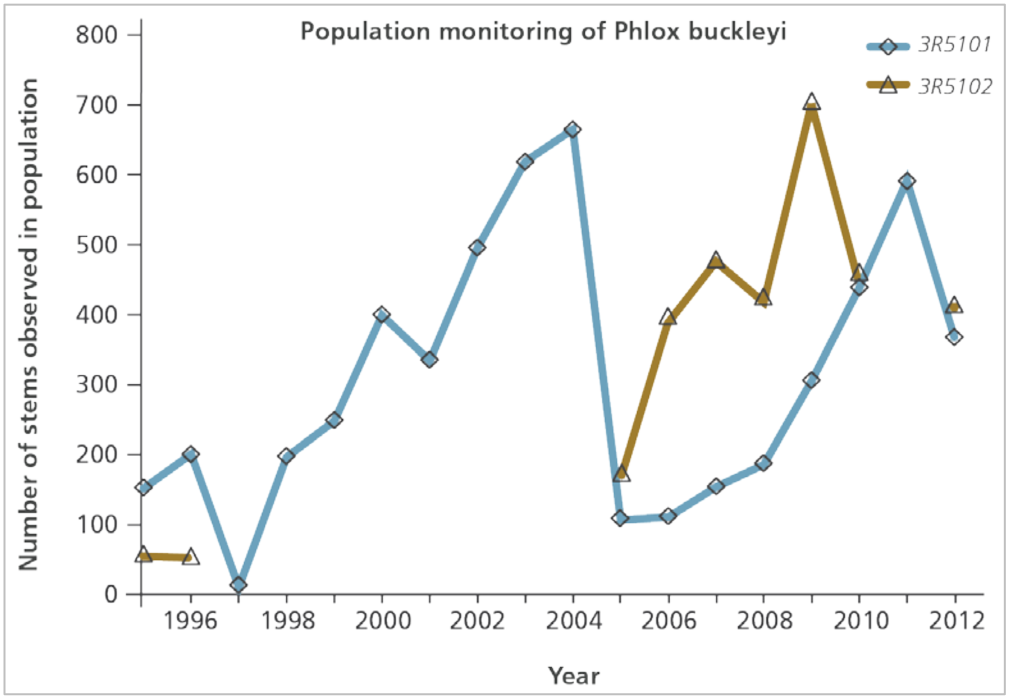

Figure 4-33. Rare plant monitoring data for two populations of sword-leaf phlox (*Phlox buckleyi*). Source: Cass *et al.* 2011b.

An evaluation of the vegetation communities described by Young *et al.* (2009) found that 18 were of global conservation concern (G1-G3). Taken collectively, G1-G3 communities cover 13.2% percent of the park. This distribution is highly unbalanced spatially, with the smaller, higher elevation geo-elevation classes covered by a much higher percentage of rare plant communities than the larger in area, lower elevation classes (Table 4-9). Only a small fraction of the park (0.04%) is covered by the nine plant communities considered Critically Imperiled (G1) or Imperiled (G2) (Table 4-10). Many of these communities are found on rock outcrop areas heavily threatened by human uses.

Table 4-9. Distribution of rare plant communities among six geo-elevation classes.

Elevation	Geology	Number of G1-G2 communities	Number of G1-G3 communities	Percent of Geo-elevation class in G1-G3 Communities (%)
< 915 m	Granitic	4	7	9
	Metabasaltic	7	8	43
	Siliciclastic	2	5	12
> 915 m	Granitic	3	10	47
	Metabasaltic	6	7	74
	Siliciclastic	3	6	73

Table 4-10. List of G1 and G2 plant communities located in Shenandoah National Park

G1 and G2 plant communities in Shenandoah National Park
Central Appalachian Basic Woodland (CEGL 3683)
Central Appalachian Circumneutral Barren (CEGL 6037)
Central Appalachian Heath Barren (CEGL 3939)
Central Appalachian High-Elevation Boulderfield Forest (CEGL 8504)
Central Appalachian Mafic Barren (CEGL 8529)
Central Appalachian Mafic Boulderfield (CEGL 4143)
Northern Blueridge Mafic Fen (CEGL 6249)
High-Elevation Greenstone Barren (CEGL 8536)
High-Elevation Outcrop Barren (CEGL 8505)

Averaging together the park-wide attainment values for the three native plant indicators provides an assessment score of 73% for native plants in the park as a whole (Table 4-11). The High Granitic geo-elevation class had the lowest overall score (55%). The other five geo-elevation classes range from 61% to 83%. No major trends are observable at this time. Confidence in this assessment will be greatly improved as a longer temporal record becomes available and more robust vegetation indicators can be incorporated into future assessments.

Table 4-11. Native vegetation attainment scores for Shenandoah National Park and geo-elevation classes.

Elevation	Geology	Seedling Density (%)	Canopy Health (%)	Rare Plants (%)	Average Score (%)
< 915 m	Granitic	58.7	87.2	79.5	83.4
	Metabasaltic	71.7	86.1	79.5	79.1
	Siliciclastic	68.3	89.3	79.5	79.0
> 915 m	Granitic	0.0	86.6	79.5	55.4
	Metabasaltic	66.7	88.4	79.5	78.2
	Siliciclastic	50.0	54.2	79.5	61.2
Shenandoah National Park		**52.6**	**82.0**	**79.5**	**72.7**

Data gaps and level of confidence

The level of confidence in the assessment of native plants is high. These data sets are some of the longest running and most meticulously collected in the park. Nevertheless, the summarization of complex native plant dynamics into three indicators inherently raises concerns. More detailed analysis is needed to evaluate the condition and trends of the park's native vegetation from the vast quantity of monitoring data that are being collected (see for example Cass *et al.* 2015). Additional attention is needed to assess species- and issue-specific concerns such as the potential impacts of new emerald ash borer infestations, deer overbrowsing, fire suppression, and illegal harvesting of native plants.

Confidence in the seedling density indicator is the lowest of the three indicators evaluated. Seedling data are by their nature highly variable. Power analysis of the woody seedlings has shown limited ability to detect change in the density of seedlings (Diefenbach and Vreeland 2003, Mahan *et al.* 2007). In 2007, the park began differentiating seedling counts by two separate size classes: seedlings below and above 15 cm in height. Tracking any trends in the upper size class would provide greater confidence in future assessment of forest regeneration. Other parks in the region (e.g., Comiskey and Wakamiya 2011) have been collecting seedling data in multiple size classes and creating weighted scoring systems to determine stocking densities that are more directly comparable to the methods established by McWilliams *et al.* (1995). A similar approach would improve the confidence in this indicator. A total of six seedling height classes is recommended (McWilliams *et al.* 2005).

Despite the rigorous sample design used to establish plot locations, the assessment is limited by the spatial distribution of samples relative to the geo-elevation structure of this report. The two regions of greatest concern (High Granitic and High Siliciclastic) are also the two regions containing the fewest sample plots (six and two plots respectively for the forest vegetation monitoring). As a result, the 0% attainment value for seedling density for the High Granitic class raises a flag, but should be considered within the context of the small sample size. Similarly, only 48 of the 4,141 trees sampled as part of the most recent vegetation sample were located in the High Siliciclastic region. Nevertheless, the decrease in canopy health from 100% to 54% for this geo-elevation class from the 2003-2006 to 2008-2011 sample periods is noteworthy.

Our confidence in the assessment of the status of rare, threatened and endangered plants is high due to the well-established protocols for sampling an estimated 80% of the park's rare plant populations (Cass *et al.* 2011b). The assessment does suffer from lack of geographic specificity. Due to data limitations of this assessment, the rare plant indicator was not evaluated spatially across all six geo-elevation classes. However, the majority of rare plants are found on the metabasaltic geologic class, mostly at higher elevation.

<u>Sources of expertise</u>

- Wendy Cass, Botanist, National Park Service, Shenandoah National Park

4.2.3 Non-native vegetation

<u>Relevance and Context</u>

The introduction and spread of non-native plant species, also known as exotic or alien species, typically occurs as the result of both intentional and unintentional human activities. Some of these introduced species compete with native plants and disrupt ecological communities by, for example, displacing native species, degrading native habitats and altering ecosystem processes (Mack *et al.* 2000; Anson *et al.* 2013). The subset of non-native species that are likely to cause economic or environmental harm or harm to human health are deemed invasive (Langkilde *et al.* 2012). Invasive non-native species are one of the most significant threats facing national parks today (Wilcove *et al.* 1998; Stein *et al.* 2000). The National Park Service estimates that over 2.6 million ac of park lands are infested with invasive plants, covering nearly 5% of the total area of the parks (National Park Service 2004). Due to the prior settlement and occupation of Shenandoah National Park dating back to the earliest European immigrants, non-native plants have been present in Shenandoah National Park since its establishment in 1935. Approximately 25% of all plant species currently found within the park are non-native (Hughes 2011). Of these approximately 350 non-native species, 10% are considered invasive (Hughes 2011). The Virginia Department of Conservation and Recreation's Natural Heritage Program currently identifies 90 invasive plant species, of which 38 are deemed to be of high risk (see Appendix B). Several of these are coastal species, but at least 28 of the 38 high-risk invasive species represent potential threats to ecosystems found in the park (Heffernan and Richardson 2015).

Prevention and early detection of new introductions are primary management strategies used by the park, with an emphasis on eradication efforts in areas of high-ecological value (Hughes 2011). Park-wide eradication for many species of widespread abundance such as garlic mustard (*Alliaria petiolata*), Japanese stiltgrass (*Microstegium viminium*) and tree-of-heaven (*Ailthanus altissima*) are considered unrealistic (Rejmanek and Pitcairn 2008). Given limited time and funding, species that are not yet well established often make better management targets (VISWG 2012). Wavyleaf basketgrass (*Oplismenus hirtellus* ssp. *undulatifolius*) is an example of an emerging invasive grass that has dispersed into Mid-Atlantic forests within the last few years (Westbrooks and Imlay 2009). Other non-native plant species that are potentially harmful and not yet well established in the park (and thus potential targets of eradication efforts) include jetbead (*Rhodotypos scandens*), Chinese yam (*Dioscorea opposita*), and Norway maple (*Acer platanoides*).

Shenandoah National Park began conducting surveys of areas likely to be infested with non-native invasive plants in 1997. By 2003, 531 plots had been visited along 255 transects radiating in from the park boundary as part of a large-scale effort (Arsenault *et al.* 2004; Hughes & Akerson 2006; Akerson 2009). These early inventory data identified 43 non-native plant species. Non-native trees were observed in more than a quarter of the plots, non-native shrubs were observed in more than a half of the plots, and non-native herbs were observed in 57% of the plots (Arsenault *et al.* 2004). The park has a robust program of invasive plant treatment. Polygons of treatment locations are available on an annual basis (Figure 4-34). However, the intensity of treatment and locations of these polygons changes from year to year based on resources and threats, and these data are not used in our long-term assessment of park condition and trend.

<u>Data and Methods</u>

Long-term ecological monitoring of non-native herbs, shrubs, and trees was initiated in 2003 and is conducted as part of the forest vegetation monitoring in the park (Cass *et al.* 2012). Between 2003 and 2011, the I&M forest vegetation monitoring program completed three sampling blocks at 160 stratified random sites (Figure 4-27). Sites are stratified to represent a combination of elevations, aspect, and bedrock geology, and located away from trails, roads, and developed areas in the park. Because of this, these data provide a very conservative sample of park invasive non-natives. The frequency of non-native species occurrence on these plots for the 2011 sampling block was used to evaluate current condition. This trend was assessed for any changes in frequency for the three sampling blocks.

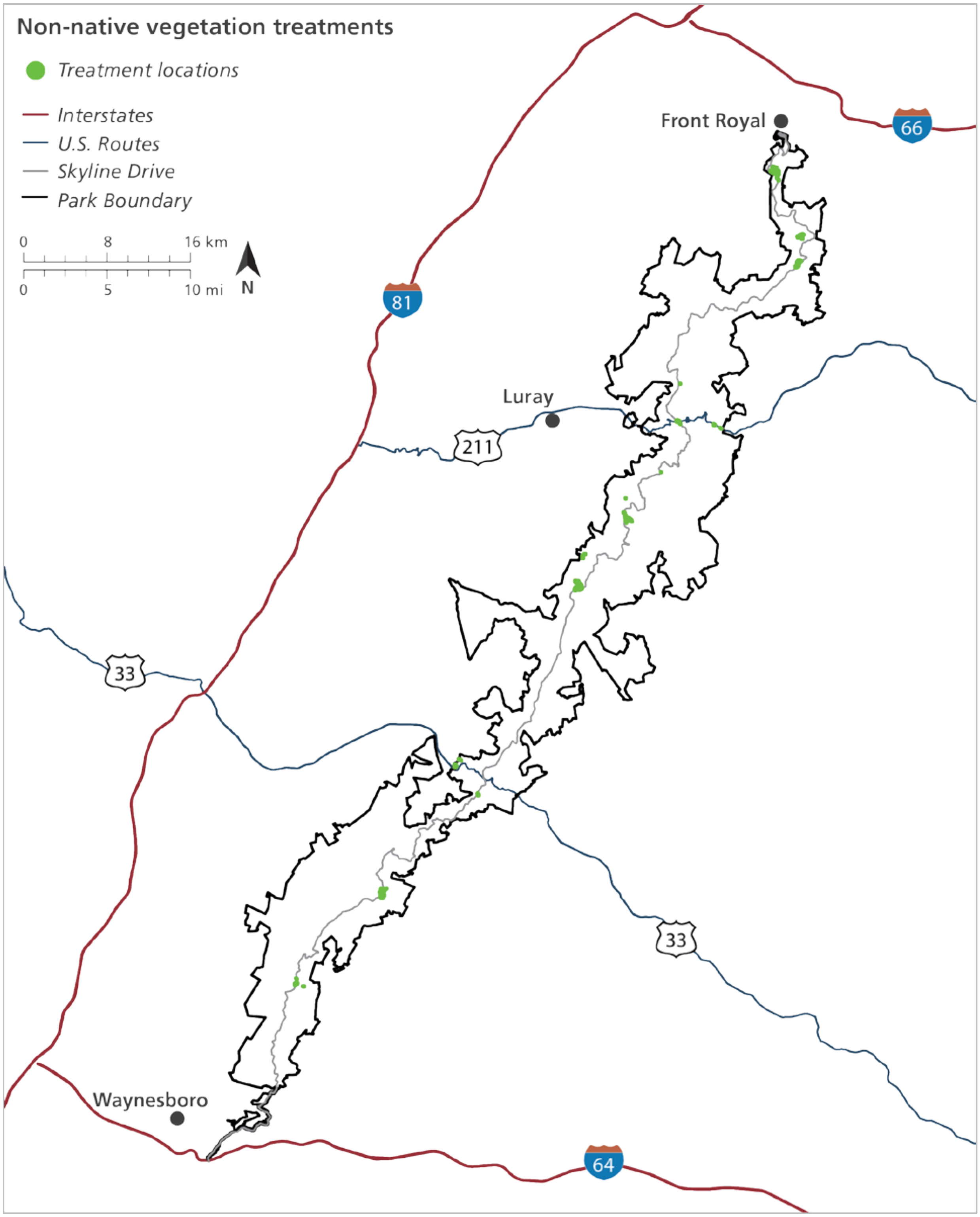

Figure 4-34. Non-native invasive plant management treatment locations from 2012. Source: Dan Hurlbert.

Threshold
The threshold condition is based on the percent of I&M forest vegetation monitoring plots with non-native plant species absent. Although this threshold is used for assessment purposes, it is noted that the complete absence of non-native species is likely not a realistic management goal. Therefore, the percent of plots having no species with greater than 10% cover on the plot is also reported. This additional information provides additional context for the condition assessment of non-native invasive plants in the park.

Condition and Trend
Using the most recent sampling rotation of the I&M forest monitoring data, non-native plant species were observed on 91 of 160 plots for a current condition score of 43.5%. No discernable patterns were observed among either the elevation or geology classes (Table 4-12). Low elevation siliciclastic plots had the highest condition score (87%). The scores for the high elevation plots should be interpreted relative to their low sample sizes. Herbaceous plants were the most common life form, observed on 51% of the plots. In comparison, non-native trees (primarily tree-of-heaven) were observed on 31% of the plots. A large number of these occurrences were seedlings and saplings suppressed in the forest understory.

Table 4-12. Non-native vegetation attainment scores for Shenandoah National Park and geo-elevation classes.

Elevation	Geology	Number of Plots (2008-2011)	Number of Plots without Non-native Plants	Attainment %	Condition
< 915 m	Granitic	46	17	37.0	Moderate
	Metabasaltic	53	6	11.3	Significant concern
	Siliciclastic	41	36	87.8	Good
> 915 m	Granitic	6	5	83.3	Good
	Metabasaltic	12	5	41.7	Moderate
	Siliciclastic	2	0	00.0	Significant concern
Shenandoah National Park		**160**	**69**	**43.5**	**Moderate**

When considered collectively as a group, the frequency of occurrence of non-native plants was relatively stable for the three sampling frames with a slight increase in frequency in the most recent sample period (Figure 4-35). Some individual species did increase in frequency during the period of monitoring, such as tree-of-heaven which was observed on 32 plots in the first rotation and 48 in the third rotation. Shrubs were the only life form to show an increase for both time intervals examined. Across all life forms, a total of 261 occurrences of non-native plants were observed in the first sampling frame, 275 in the second sampling frame, and 306 in the third sampling frame.

Most occurrences of non-native plants were at low percent cover. The largest number of heavily infested plots occurred in the second sampling frame when 19% of the plots contained a non-native plant species that covered more than 10% of the plot (Table 4-13). Two herbaceous species are responsible for the majority of these high-cover occurrences: garlic mustard and Japanese stiltgrass.

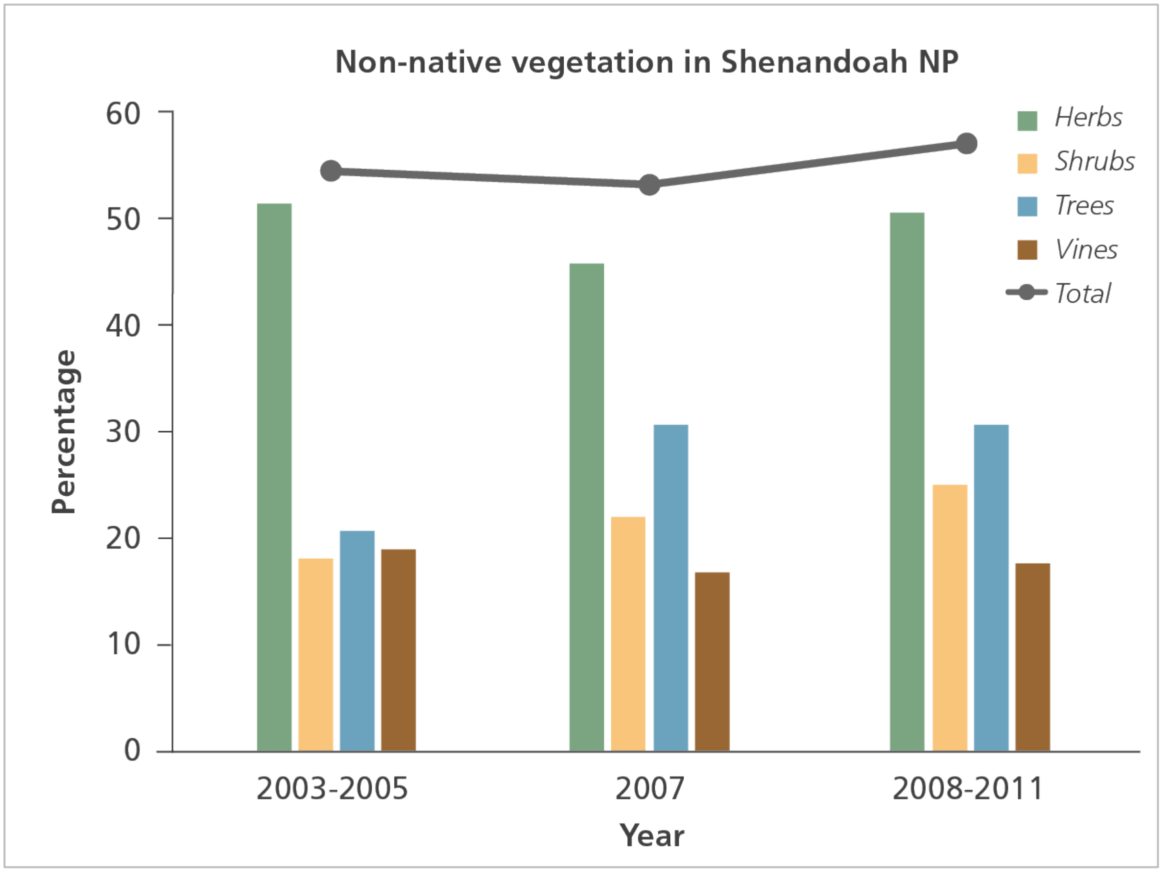

Figure 4-35. Frequency of occurrence of non-native plants on I&M forest vegetation monitoring plots. All three sampling frames are presented with the total percent of plots containing any form of non-native plant indicated by the line graph. Source: Shenandoah I&M Program.

Table 4-13. Number of I&M forest vegetation monitoring plots containing a non-native plant species that covered more than 10% of the plot. Values are out of a total of 160 plots per sampling frame.

Life form	2003-2005	2007	2008-2011
Any	18	30	17
Herbaceous	14	27	15
Shrubs	0	1	2
Trees	3	1	0
Vines	3	2	2

Data Gaps and Level of Confidence

Clearly 160 plots is not sufficient to monitor and predict emerging non-native invasive threats for a park the size of Shenandoah. Randomized, permanent plot sampling is useful to provide an unbiased assessment of coarse-scale (i.e., park-wide) trends. These coarse-grained, parkwide data are useful in revealing species for which eradication or parkwide control is not feasible, and even using environmental and other correlates of to predict invasions. However, these data are not especially useful for guiding park treatment actions, which are necessarily performed at much finer scale and at specific locations within the park (Lookingbill *et al.* 2014). One way of addressing the inefficiency of permanent monitoring plots to capture highly dynamic spatial processes that occur at spatial scales that do not necessarily match those of the monitoring sites is through multi-stage sampling (e.g., Nusser *et al.* 1998). Another approach to address these deficiencies is through hybrid monitoring designs that combine a fixed set of permanent monitoring sites with, for example, additional, potentially "roving" sites whose locations are selected based on dynamic modeling of the spatial-temporal processes of interest (here, the invasion processes of specific species) and address shorter-term management priorities (Hooten *et al.* 2009, Lookingbill *et al.* 2012).

<u>Sources of Expertise</u>

- Jake Hughes, Lead Biological Science Technician, Shenandoah National Park
- Wendy Cass, Botanist, Shenandoah National Park

4.2.3 Birds

<u>Relevance and context</u>

During the past 30 years, severe decline of North American bird populations and their habitats has caused great concern among the bird conservation community. Birds are recognized as critical components of local and global genetic, species, and population diversity, providing important ecological and cultural values. Their status and conservation is a focus of worldwide conservation efforts. Direct or indirect threats to birds in North America (and Shenandoah) are; loss of habitat due to changes in land use, forest clear- cutting, the draining of wetlands, and development. Other threats include mining, pollution, and invasive non- native species (which include predators, plants, insects, diseases, and other birds). Because the most significant dangers are habitat- based, large areas of protected refugia like those found in Shenandoah National Park have become increasingly important to neotropical migrants and resident woodland species. (National Park Service 2008a).

Shenandoah National Park is home to over 200 species of resident and transient birds. Approximately half of these species breed in the park including 18 species of warblers. Roughly 30 species are year-round residents including slate- colored juncos, red- tailed hawks, Carolina chickadees, wild turkeys, ruffed grouse and barred owls. Due to the park's location along the crest of the Blue Ridge and the extent of the forested habitat, Shenandoah provides essential habitat for neotropical migratory birds, both for nesting and as a travel corridor (National Park Service 2008a).

<u>Data and methods</u>

The Breeding Bird Survey (BBS) is a long-term, large-scale, international avian monitoring program initiated in 1966 to track the status and trends of North American bird populations. The U.S. Geological Survey Patuxent Wildlife Research Center and the Canadian Wildlife Service, National Wildlife Research Center jointly coordinate the BBS program. Breeding Bird Surveys are conducted during the peak of the nesting season, typically in June. Participants skilled in avian identification collect bird population data along roadside survey routes. Each survey route is 39.4 km long with stops at 0.8 km (0.5-mile) intervals. At each stop, a 3-minute point count is conducted. During the count, every bird seen within a 0.25-m radius or heard is recorded. Surveys start one-half hour before local sunrise and take about five hours to complete. Over 4,100 survey routes are located across the continental U.S. and Canada. (Sauer, et al. 2014).

Annual bird abundance and species richness data (1993-2013) were sourced from four routes within Shenandoah National Park (Pardieck et al. 2014): BBS Route 88907 (Shenandoah National Park, VA); BBS Route 88921 (Big Meadows, VA); BBS Route 8892 (Loft Mtn, VA); and BBS Route 88923 (Front Royal, VA). This limited number of routes for a park the size of Shenandoah National Park likely under-represents the full story related to birds, but this does represent the best data set available for the scale of this park.

Reference condition value

Reference conditions for bird abundance and richness were calculated as the 80th percentile of total values between 1993 – 2008, per site. The most recent 5-yr mean value (2009 – 2013) for bird abundance and richness at each site was assessed as a percentage of the reference conditions calculated for each site.

Condition and trend

The 2009-2013 average breeding bird abundance and richness values were relatively uniform across each of the four sites assessed in Shenandoah National Park. This did not reflect trends observed in the abundance reference condition calculated from 1993-2008 data that showed typically more birds were expected at BBS Route: 88907, and least birds at BBS Route: 8892. Subsequently, the abundance attainment scores varied between 58% - 79% with an average abundance attainment of 71% (Table 4-14). Species richness reference conditions, calculated from 1993-2008 data, were less variable and subsequently resulted in less variable attainment scores ranging from 88% - 95% with an average species richness attainment of 92% (Table 4-1). This resulted in an overall bird attainment score of 82%.

Table 4-14. Breeding Bird Survey analysis results for bird abundance and species richness within Shenandoah National Park.

BBS Route	Bird abundance (2009-2013)	Abundance reference condition (1993-2008)	Abundance percent attainment (2009-2013)	Bird species richness (2009-2013)	Species richness reference condition (1993-2008)	Species richness percent attainment (2009-2013)
88907 (Shenandoah National Park)	353.6	604.8	58%	41.6	45	92%
88921 (Big Meadows)	372.8	501.8	74%	44.2	47	94%
8892 (Loft Mountain)	354.8	447.2	79%	45	47.2	95%
88923 (Front Royal)	352	484.4	73%	42.4	48	88%
Average			**71%**			**92%**

As reflected in the attainment scores, trends in abundance (represented as Total Individuals in Figure 4-36) and species richness (represented as Total Species in Figure 4-36) are more stable across sites and over time (1993-2013) for species richness than abundance that shows a steady decline at all sites over the examined timeframe.

Figure 4-36. Total number (top) and species abundance (bottom) of birds spotted annually between 1993 - 2013 at four locations within Shenandoah National Park. Source: Breeding Bird Survey.

Data gaps and level of confidence

The level of confidence in the assessment of birds is moderate. More detailed analysis is needed to evaluate species-specific concerns that may be occurring in the park and the causes of bird number decline over the examined timeframe. Also the limitation of only four survey routes, limits full inference to park conditions.

Sources of expertise

- North American Breeding Bird Survey. U.S. Geological Survey Patuxent Wildlife Research Center www.pwrc.usgs.gov/bbS/

4.3 Aquatic Resources

The streams, wetlands, springs, and seeps within Shenandoah National Park represent important and unique habitat for plants, invertebrates, fish, and amphibians, as well as an important water source for mammals and birds (Figure 4-37).

Figure 4-37. Aquatic resources within Shenandoah National Park represent important and unique habitat and water source. Photo credit: Nick Fisichelli, National Park Service.

Deposition of atmospheric sulfate and nitrogen are a significant regional concern, and freshwater habitats within certain areas of the park have been shown to be impacted by acidification (Sadinski and Dunson 1992; National Park Service ARD 2010; Jastram *et al.* 2013). A recent study of historical water quality data in the park showed an overall decrease in acidity of freshwater habitats over the past 20–30 years, despite an increasing acidification trend observed over the past five years. The study also found that watersheds with an underlying siliciclastic and granitic geology were more affected by acidification than watersheds with an underlying basaltic and carbonate geology (Jastram *et al.* 2013). This is due to the fact that basaltic and carbonate rocks do not weather base cations as readily and therefore the soils derived from these types of rocks have low buffering capacity for acidic deposition. Effects of acidification on streams in siliciclastic watersheds were evident in benthic macroinvertebrate and fish communities (Jastram *et al.* 2013). Park-wide increases in water temperatures (+1.2 ^{o}C over the last 30 years) have also been identified and deemed biologically meaningful based on responses in benthic macroinvertebrate communities (U.S. Geological Survey 2013). Cold-water-adapted aquatic species are very sensitive to increases in stream temperatures, which can cause local extirpations or even mortality if suitable cold water refuge cannot be found.

Two categories of indicators were used to assess water resources in Shenandoah National Park including water quality and macroinvertebrate populations (Table 4-15). Specific indicators for each of these categories are as follows:

- Water quality (pH, acid neutralizing capacity, water temperature, nitrates (NO_3^-), and sulfates (SO_4^3))
- Macroinvertebrates (Simpson Index of Diversity, %EPT, % Intolerant)

Data used for this assessment were sourced from within the boundary of Shenandoah National Park collected as part of multiple monitoring programs operated within the Park (Table 4-15; Figure 4-38).

Table 4-15. Data collection agencies and sources for indicators used in assessment of aquatic resources within Shenandoah National Park.

Indicator	Agency	Source
Water Quality		
pH	National Park Service	NPSTORET/ EPASTORET
ANC	National Park Service	NPSTORET/ EPASTORET
Temperature	National Park Service	
NO3	National Park Service	EPASTORET
SO4	National Park Service	NPSTORET/ EPASTORET
Macroinvertebrates		
Simpsons Diversity Index (1-D)	National Park Service	NPSTORET
% EPT	National Park Service	NPSTORET
% Intolerance	National Park Service	NPSTORET

Current condition was assessed using the latest five years of data available for each indicator, in relation to reference conditions, to obtain a percent reference condition attainment (Table 4-16).

Table 4-16. Water resource indicators and summary of data used in the natural resource condition assessment of Shenandoah National Park.

Indicator	Elevation	Geology	Number of sites	Number of measurements	Period
pH	< 915m	Granitic	19	620	2008-2012
		Metabasaltic	20	447	
		Siliciclastic	16	815	
	> 915m	Granitic	1	1	
		Metabasaltic	3	22	
		Siliciclastic	-	-	

Table 4 16. (continued) Water resource indicators and summary of data used in the natural resource condition assessment of Shenandoah National Park.

Indicator	Elevation	Geology	Number of sites	Number of measurements	Period
ANC (□eq/L)	< 915m	Granitic	19	620	2008-2012
		Metabasaltic	20	447	
		Siliciclastic	16	815	
	> 915m	Granitic	1	1	
		Metabasaltic	3	22	
		Siliciclastic	-	-	
NOx (□g/L)	< 915m	Granitic	19	620	2008 - 2012
		Metabasaltic	20	447	
		Siliciclastic	16	815	
	> 915m	Granitic	1	1	
		Metabasaltic	3	22	
		Siliciclastic	-	-	
SO_4 (mg/L)	< 915m	Granitic	19	620	2008 - 2012
		Metabasaltic	20	447	
		Siliciclastic	16	815	
	> 915m	Granitic	1	1	
		Metabasaltic	3	22	
		Siliciclastic	-	-	
Temperature (°C)	< 915m	Granitic	19	620	2008 - 2012
		Metabasaltic	20	447	
		Siliciclastic	16	815	
	> 915m	Granitic	1	1	
		Metabasaltic	3	22	
		Siliciclastic	-	-	
Macroinvertebrates % Intolerant	< 915m	Granitic	15	72	2008 - 2012
		Metabasaltic	7	30	
		Siliciclastic	13	65	
	> 915m	Granitic	0	0	
		Metabasaltic	1	5	
		Siliciclastic	0	0	
Macroinvertebrates %EPT	< 915m	Granitic	15	72	2008 - 2012
		Metabasaltic	7	30	
		Siliciclastic	13	65	
	> 915m	Granitic	0	0	
		Metabasaltic	1	5	
		Siliciclastic	0	0	
Macroinvertebrates Simpson's Index of Diversity	< 915m	Granitic	23	72	2008 - 2012
		Metabasaltic	14	30	
		Siliciclastic	20	65	
	> 915m	Granitic	0	0	
		Metabasaltic	1	5	
		Siliciclastic	0	0	

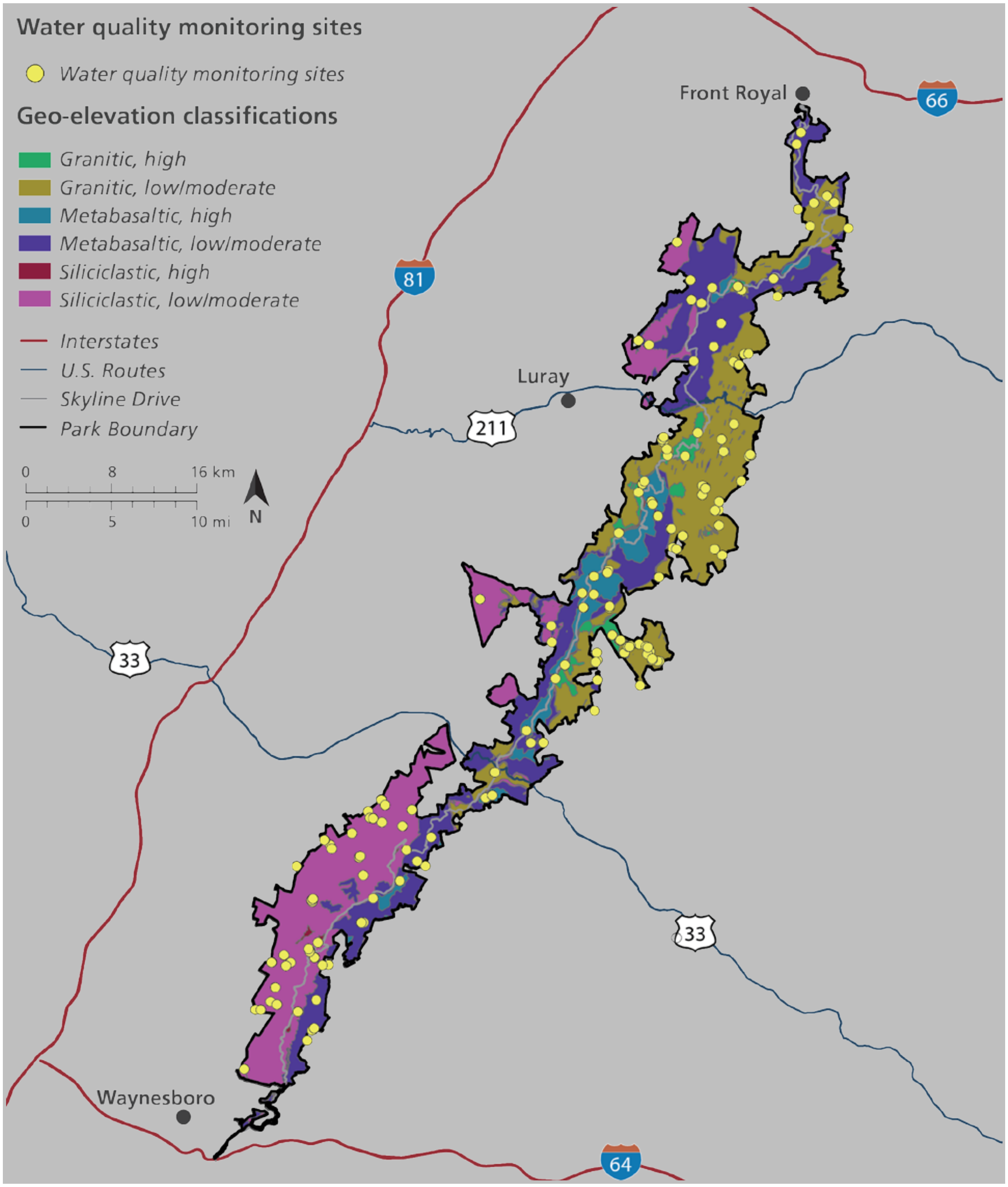

Figure 4-38. Location of water quality sites overlaid with the geo-elevation classes. Source: Dan Hurlbert.

4.3.1 Water quality

Relevance and context

Five water quality indicators were used to evaluate the condition of Shenandoah National Park's aquatic ecosystems, including: oxides of nitrogen (NOx), sulfates (SO_4), pH, acid neutralizing capacity (ANC), and temperature (Table 4-17). These indicators were chosen for their relevance to the stresses faced by the park's aquatic resources from acid rain and climate change.

Acid rain is caused primarily by oxidation of sulfur and nitrogen emissions from the combustion of fossil fuels and the formation of sulfuric and nitric acids. Contaminants from power-plant emissions are primarily responsible for sulfuric acid, whereas contaminants from motor vehicle emissions are primarily nitric acid (Rice *et al.* 2006). These acids are returned to the landscape via wet and dry deposition, and can result in the acidification of surface waters that is measured as changes in pH.

ANC is the capacity of a solution to neutralize strong acids and is defined as the equivalent sum of all bases or base-producing materials, solutes plus particulates, in an aqueous system that can be titrated with acid to an equivalence point. Streams with low ANC values indicate little capacity to neutralize acidity and display low pH in response to acid rain, whereas streams with high ANC values indicate greater capacity to neutralize acidity and maintain a near-neutral pH in response to acid rain. A stream's ANC value is dictated by the underlying geology of the stream and its watershed. Rocks that weather easily (e.g., limestone) yield streams with higher ANC relative to rocks that are resistant to weathering (e.g., quartzite). The more acidic the streamwater, the less likely it will be able to support a diversity of aquatic life such as fish, aquatic insects, and amphibians (e.g., Bulger *et al.* 2000; Grant *et al.*2005; Baldigo and Murdoch 1997; Baldigo and Lawrence 2000).

Changes in the climate projected for the United States over the next 100 years will cause significant changes to temperature regimes and precipitation patterns across the United States (Poff *et al.* 2002). Average global surface temperatures are projected to increase by 1.5–5.8 ^{o}C by 2100 (Houghton *et al.* 2001), but increases may be higher in the United States (Wigley 1999). Elevated water temperatures can affect aquatic organisms by: a) reducing the solubility of dissolved oxygen; b) increasing the demand for oxygen by increasing metabolism and respiration of fish and other aquatic life; c) increasing the solubility and toxicity of many toxic substances; d) favoring the growth of sewage fungus and the putrification of sludge deposits; e) increasing the prevalence of fish diseases; and, e) direct death as a result of elevated temperatures.

Data and methods

Water quality data collected from 173 sites within Shenandoah National Park were sourced online from the EPA STORET Central Warehouse. Trends in data from 2000 are presented graphically, though the current condition assessment score is restricted to five years of available data (i.e., 2008 – 2012).

Reference condition value

Rivers and streams within Shenandoah National Park are classified as belonging to Nutrient Ecoregion XI (sub-ecoregion 66) (U.S. Environmental Protection Agency 2000). Reference conditions for this Level III ecoregion indicate NO_2+NO_3 is 0.058 mg/L (= 0.94 μeq/L), which was adopted the reference condition for this assessment of NO_3.

Reference conditions for pH (6-9) and temperature (max. 20 ^oC) were sourced from the Virginia Department of Environmental Quality – Water Quality Criteria Water Quality Standards (9VAC25-260-50) for Class VI Water (Natural Trout Waters) (http://lis.virginia.gov/cgi-bin/legp604.exe?000+reg+9VAC25-260-50).

The reference condition for acid neutralizing capacity required to protect reproducing brook trout populations (ANC >50 μeq/L) were sourced from Bulger *et al*. 1995.

The most relevant reference condition for dissolved sulfate (50 mg/L SO_4 = 1041 μeq/L) was sourced from the Canadian Ministry of Environment Ambient Water Quality Guidelines for protection of freshwater aquatic life (http://www.env.gov.bc.ca/wat/wq/BCguidelines/sulphate/sulphate.html).

<u>Condition and trend</u>

Water quality within Shenandoah National Park was moderate based on median data between 2008-2012 across the whole park. Poorest percent attainment of reference conditions were identified for pH and ANC in siliciclastic geologies. There is low confidence in the low scores for high elevation (>915 m) granitic geo-elevation class due to a very low sample count. Water quality indicators showing stress across all geo-elevation classes were oxides of nitrogen concentrations (NOx) and water temperature (Table 4-17).

Table 4-17. Summary of water quality resource condition assessment at Shenandoah National Park.

Indicator	Elevation	Geology	Calculation	Value	Reference condition	% Attainment	Condition
pH	< 915m	Granitic	Median (5 yr)	6.6	6 - 9	99	Moderate
		Metabasaltic		7.1		100	Good
		Siliciclastic		5.8		31	Significant Concern
	> 915m	Granitic		6.9		100	Good*
		Metabasaltic		6.9		100	Good
		Siliciclastic		ID		ID	ID
ANC (eq/L)	< 915m	Granitic	Median (5 yr)	78.1	50 μeq	88	Good
		Metabasaltic		202.4		100	Good
		Siliciclastic		10.7		10	Significant Concern
	> 915m	Granitic		262.9		100	Good*
		Metabasaltic		147.3		100	Good
		Siliciclastic		ID		ID	ID
NOx (μeq /L)	< 915m	Granitic	Median (5 yr)	0.05	0.94 μeq	68	Moderate
		Metabasaltic		0.05		59	Moderate
		Siliciclastic		0.05		77	Good
	> 915m	Granitic		2.23		0	Good*
		Metabasaltic		1.82		42	Moderate
		Siliciclastic		ID		ID	ID

Table 4 17. (continued) Summary of water quality resource condition assessment at Shenandoah National Park.

Indicator	Elevation	Geology	Calculation	Value	Reference condition	% Attainment	Condition
SO_4 (μeq /L)	< 915m	Granitic	Median (5 yr)	49.8	1041 μeq /L	100	Good
		Metabasaltic		66.7		100	Good
		Siliciclastic		103.1		100	Good
	> 915m	Granitic		20.6		100	Good*
		Metabasaltic		45.4		100	Good
		Siliciclastic		ID		ID	ID
Temperature (°C)	< 915m	Granitic	Maximum (5 yr)	24.5	20 °C	65	Moderate
		Metabasaltic		28		60	Moderate
		Siliciclastic		26.5		70	Moderate
	> 915m	Granitic		0.0		0	Significant Concern*
		Metabasaltic		22.5		68	Moderate
		Siliciclastic		ID		ID	ID

* Low confidence (n=1); ID = insufficient data

Over the time period sampled, a mixed trend was seen for water quality indicators in Shenandoah National Park depending on future timeframe examined and watershed size (Table 4-18).

Table 4-18. Summary of water quality trend analysis (1979-2009) by geology class. Adapted from (Jastram *et al.* 2013).

Indicator	Geology	Short-term Trend (5 years)	Long-term Trend (10-20 years)
pH	Granitic	Decreasing (i.e. worsening)	Increasing (i.e. improving)
	Metabasaltic	Decreasing (i.e. worsening)	Increasing (i.e improving)
	Siliciclastic	Decreasing (i.e. worsening)	Increasing (i.e improving)
ANC	Granitic	No trend	No trend
	Metabasaltic	Increasing (i.e. improving)	Increasing (i.e. improving)
	Siliciclastic	Declining (i.e. worsening)	Declining (i.e. worsening)
NO3	Granitic	Unsuccessful due to >40% results below laboratory reporting limit	Unsuccessful due to >40% results below laboratory reporting limit
	Metabasaltic		
	Siliciclastic		
SO4	Granitic	Increasing (i.e. worsening)	Increasing (i.e. worsening)
	Metabasaltic	Declining (i.e. improving)	Declining (i.e. improving)
	Siliciclastic	No trend	Increasing (i.e. worsening)
Temperature	Granitic	Highly variable	Increasing (i.e. worsening)
	Metabasaltic	Highly variable	Increasing (i.e. worsening)
	Siliciclastic	Highly variable	Increasing (i.e. worsening)

Data gaps and level of confidence

The level of confidence in the assessment of water quality is high for low elevations (<915 m) and is supported by other recent assessments (Jastram *et al.* 2013). The level of confidence is low for high elevations (>915 m) due to low or absent sample counts. Sampling for water quality in high elevations is recommended.

Source of expertise

- Suzanne Maben. Laboratory Manager - Shenandoah Watershed Study/Virginia Trout Stream Sensitivity Study. University of Virginia Dept. of Environmental Sciences.

4.3.2 Aquatic macroinvertebrates

Relevance and context

Aquatic macroinvertebrates are numerous, have short life cycles, and are directly affected by changes in water chemistry and flow. These factors, coupled with relative ease of sampling, makes them excellent indicators of aquatic ecosystem health. Changes in species composition are relatively easy to detect and can then be used to assess stream decline or recovery.

Aquatic invertebrate sampling has been conducted in the park since 1986. Sampling was a direct response to the wave of gypsy moth (*Lymantria dispar*) defoliation in the southeastern United States. Analyses of samples to date have found macroinvertebrates to be highly correlated with geology and, to a lesser extent, watershed area (U.S. Geological Survey 2013). Temporal trends in benthic macroinvertebrates have shown evidence of change in community structure over time, which in most cases indicated declines in stream condition. Although the overall condition of park streams would be considered by most measures to be relatively healthy, streams in siliciclastic watersheds, in particular, have been and continue to be affected by acidic deposition. In addition, park streams have warmed significantly over the last 20 years and evidence indicates that benthic macroinvertebrate communities have responded to the warming trend (U.S. Geological Survey 2013).

Data and methods

Data from the National Park Service Aquatic Macroinvertebrate Monitoring Program was used to assess the condition of aquatic macroinvertebrates within each altitude/geology zone of Shenandoah National Park (Table 4-19). Macroinvertebrate indicators assessed included percent EPT (Taxonomic orders of Ephemeroptera, Plecoptera, and Tricoptera), percent intolerant organisms and Simpson's diversity index. Percent EPT is the relative abundance of insects in those taxonomic orders – orders which are known to be sensitive to perturbations. Percent intolerant organisms is the percent abundance of macroinvertebrates with low pollution tolerance values (Barbour *et al.* 1999 and Merrit and Cummings 1996). Simpson's diversity index reflects the biotic diversity of a sample and is derived from species richness and abundance. The Simpson's Index of Diversity (1-D), which takes into account the number of species present and the abundance of each species, was used to assess the health of macroinvertebrate populations. Data was assessed from 58 sites between 2008 and 2012.

$$D = \frac{\sum n(n-1)}{N(N-1)}$$

n = total number of organisms of a particular species
N = total number of organisms of all species

With this index, 0 represents infinite diversity and 1 represents no diversity. That is, the bigger the value of D, the lower the diversity. This is neither intuitive nor logical, so instead, D is often subtracted from 1 to give: 1 – D. The value of this index also ranges between 0 and 1, but now, the greater the value, the greater the sample diversity. The output of this index (between 0-1) was converted to 0-100% scale.

The five-year median of each indicator, from all sampling locations and times within each altitude/geology zone, was used as the measure of macroinvertebrate health.

Table 4-19. Summary of aquatic macroinvertebrate resource condition assessment at Shenandoah National Park.

Indicator	Elevation	Geology	Calculation	Value	Reference condition	% Attainment	Condition
% EPT	< 915m	Granitic	Average (5 yr)	64	>50%	100	Good
		Metabasaltic		55		100	Good
		Siliciclastic		47		0	Significant concern
	> 915m	Granitic		ID		ID	ID
		Metabasaltic		58		100	Good
		Siliciclastic		ID		ID	ID
% Intolerant	< 915m	Granitic	Median (5 yr)	64	0-100%	64	Moderate
		Metabasaltic		60		60	Moderate
		Siliciclastic		48		48	Moderate
	> 915m	Granitic		ID		ID	ID
		Metabasaltic		66		66	Moderate
		Siliciclastic		ID		ID	ID
1-D (Simpson's)	< 915m	Granitic	Median (5 yr)	0.86	Ratio 0-1	86	Good
		Metabasaltic		0.86		86	Good
		Siliciclastic		0.79		79	Moderate
	> 915m	Granitic		ID		ID	ID
		Metabasaltic		0.81		81	Moderate
		Siliciclastic		ID		ID	ID

ID = insufficient data

<u>Condition and trend</u>

Current condition of benthic macroinvertebrates in Shenandoah National Park was moderate, with a median Simpson's Index of Diversity of 0.83 (or 83% attainment) for the entire park between 2008-2012.

Over the time period sampled, a mixed trend was seen for aquatic macroinvertebrates in Shenandoah National Park depending on future timeframe examined and watershed size (Table 4-20).

Table 4-20. Summary of macroinvertebrate trend analysis (1979-2009) by geology class. Adapted from (Jastram *et al.* 2013).

Indicator	Geology	Short-term Trend (5 years)	Long-term Trend (10-20 years)
% EPT	Granitic	No trend	Decreasing (i.e. worsening)
	Metabasaltic	No trend	Decreasing (i.e. worsening)
	Siliciclastic	No trend in smaller watersheds Improving trend in larger watersheds	Decreasing (i.e. worsening)
% Intolerant	Granitic	No trend	Decreasing (i.e. improving)
	Metabasaltic	No trend	Decreasing (i.e. improving)
	Siliciclastic	Worsening in smaller watersheds Improving in larger watershed	Increasing (i.e. worsening)
1-D (Simpson's)	Granitic	No trend	Decreasing (i.e. worsening)
	Metabasaltic	No trend	Decreasing (i.e. worsening)
	Siliciclastic	No trend	Decreasing (i.e. worsening)

<u>Data gaps and level of confidence</u>
The level of confidence in the assessment of aquatic macroinvertebrates is high and is supported by other recent studies (Jastram *et al.* 2013).

<u>Source of expertise</u>

- David Demarest. National Park Service.
- Jeb Wofford. National Park Service.
- Craig Snyder. U.S. Geological Survey.
- John Jastram. U.S. Geological Survey.

4.4 Landscape dynamics

The Shenandoah landscape is defined by its intact forests, scenic vistas, and sense of wilderness. Yet the landscape is highly dynamic. Fire has shaped the forest composition and structure for thousands of years (Brose *et al.* 2001). Humans have played an increasingly larger role in dictating landscape dynamics. At its designation in 1935, very little of the park was in old-growth or mature forest condition. Since that time, the park has largely converted back to forest (Reich 2001); while the surrounding landscape has continued to experience significant land conversions away from forest cover (Drummond and Loveland 2010). Much of this land conversion is occurring in the form of suburban and exurban development with associated increases in road construction that exceed any historical precedents (Suarez *et al.* 2012). The effect of roads on the landscape includes fragmenting forest cover, creating barriers to movement of species, and altering the infiltration and hydrologic flow of water (Forman *et al.* 2002). The park itself contains a network of roads that includes the 167 km-long Skyline Drive, which runs the length of the park's spine. Views of the surrounding Blue Ridge Mountains from Skyline Drive's many vistas are central to the park visitor experience.

Four categories of indicators were used to assess landscape dynamics in Shenandoah National Park including the viewshed, land cover, road-based fragmentation, and fire. Specific indicators for each of these categories are as follows:

- amount of development seen from the park's vistas;
- percentage of the park in forest and impervious surface land covers;
- road density, average distance to a road, and size of roadless patches; and
- number of acres burned within fire dependent vegetation associations in seven-year increments.

The assessment also considers land stewardship and cover surrounding the park and the dominant forest vegetation community types in the park as qualitative indicators. Data used for this assessment were sourced from the NPScape program, Shenandoah National Park, and the U.S. Geological Survey (Table 4-21).

Table 4-21. Landscape dynamic categories, indicators, and summary of data used in the natural resource condition assessment of Shenandoah National Park.

Landscape dynamic	Indicator	Agency	Source	Period
Viewshed	View from vistas	U.S. Geological Survey, NPS	National Land Cover Dataset Map of Park Vistas	1992-2006
Land cover	Forest cover and impervious surfaces	U.S. Geological Survey, NPS	National Land Cover Dataset Shenandoahm Vegetation Map	1992-2011
Roads	Road density, distance to roads, and roadless patches	NPS	Shenandoah Roads Layer	2010
Fire dependent systems	Acres burned	NPS	Shenandoah Fire History Data	1923-2013

4.4.1 Viewshed

<u>Relevance and context</u>

Viewsheds, defined as the area of land visible from a fixed vantage point, are considered one of the most important components of a visitor's experience when visiting a national park. Multiple studies indicate that people prefer natural compared to developed landscapes (Han 2010, Kearney *et al.* 2008, Sheppard 2001). The National Park Service recognizes the need to protect the viewscapes of national parks, monuments, and reservations dating back to its mandate to "conserve the scenery" in the Organic Act (16 U.S.C. l); however, defining a desirable viewscape can be a subjective and difficult process, because what is preferable is intrinsically anthropocentric and varies by individual.

Viewsheds are valuable to visitors of Shenandoah National Park because the vistas provided from vantage points along Skyline Drive within the park are some of the only locations in the region where the scenery of the Shenandoah Valley to the west and the Piedmont to the east are easily accessible

(Teetor and Haskell 1992). There are over 130 maintained viewpoints established along Skyline Drive, offering unobstructed views of the terrain below. The primary human footprint observable from these viewpoints are developed properties where housing, impervious surfaces, and other infrastructure are prominent features against the otherwise gentle, natural contours of the valleys and ridges adjacent to the park. Combining viewshed layers that identify areas of undesirable properties on the landscape creates a quantitative description of visual stress on a viewshed (Komp *et al.* 2012).

Data and methods

As current and historic data were available for developed lands, percent developed land was chosen to evaluate the park's viewsheds for desirability of visitors. Agricultural areas were not included in the analysis as these fields were deemed desirable, adding to the pastoral landscape of the Shenandoah Valley. Park viewsheds were evaluated using GIS analysis tools to determine where development is visible from a set of observation points along Skyline Drive. Additionally, the percent of each viewshed's area that is within public lands, such as national forest, wildlife management areas, and state parks, was also calculated, as the protected status of these lands is considered a resource to the park.

Two datasets were required to calculate viewsheds: a digital elevation model (DEM) and point or polyline data defining points in which a person would be viewing the landscape. A total of 133 vista points where visitors view the surrounding landscape were identified along Skyline Drive within the park's boundary. These points correspond to locations identified by the park as managed viewsheds, where maintenance is periodically conducted to keep encroaching vegetation from degrading the limits of the vista. At each of these points, a viewshed was calculated using ESRI's Spatial Analyst Viewshed Tool in ArcGIS 10.1. DEM rasters for the Central Virginia region were mosaicked from the National Elevation Dataset (NED), which has a resolution of 30 m. A 1.83 m offset was applied to each observation point to account for observer height.

The theoretical viewshed layer represents the visible area from each vista point out to 37 km away, or the seasonal average maximum visible range for the region based on pollution levels in the 1990s (Sullivan *et al.* 2003a). Although visibility has continued to improve in recent years due to Federal and State regulations of regional emissions, we use this threshold distance to emphasize the impact of development near the park and in recognition that the visual range on high pollution days can still drop below 16 km (IMPROVE 2010).

Overlaying the viewsheds for all 133 vistas highlights areas where many points have intersecting viewsheds along areas of higher elevation, such as Massanutten Mountain to the west of the park (Figure 4-39). Because underlying geology is not directly relevant to the viewsheds, the 133 vistas were analyzed collectively and subdivided by the two elevation classes: those above 915 m and those below 915 m. The vistas were not subdivided according to geology.

To evaluate developed lands within the viewshed, the National Land Cover Data (NLCD) for 1992, 2001, and 2006 were obtained from the Multi-Resolution Land Characteristics Consortium and extracted for the study area. Because of classification differences between 1992 and 2001, the NLCD 1992/2001 Retrofit Land Cover Change Product (Fry *et al.* 2009) was used to determine the developed land area for 1992. The Virginia Department of Conservation and Recreation's Conservation Lands data (VDCR 2013) and the U.S. Geological Survey Protected Area Database PAD-US v 1.2 (U.S. Geological Survey 2012) were used to assess the stewardship of the viewsheds.

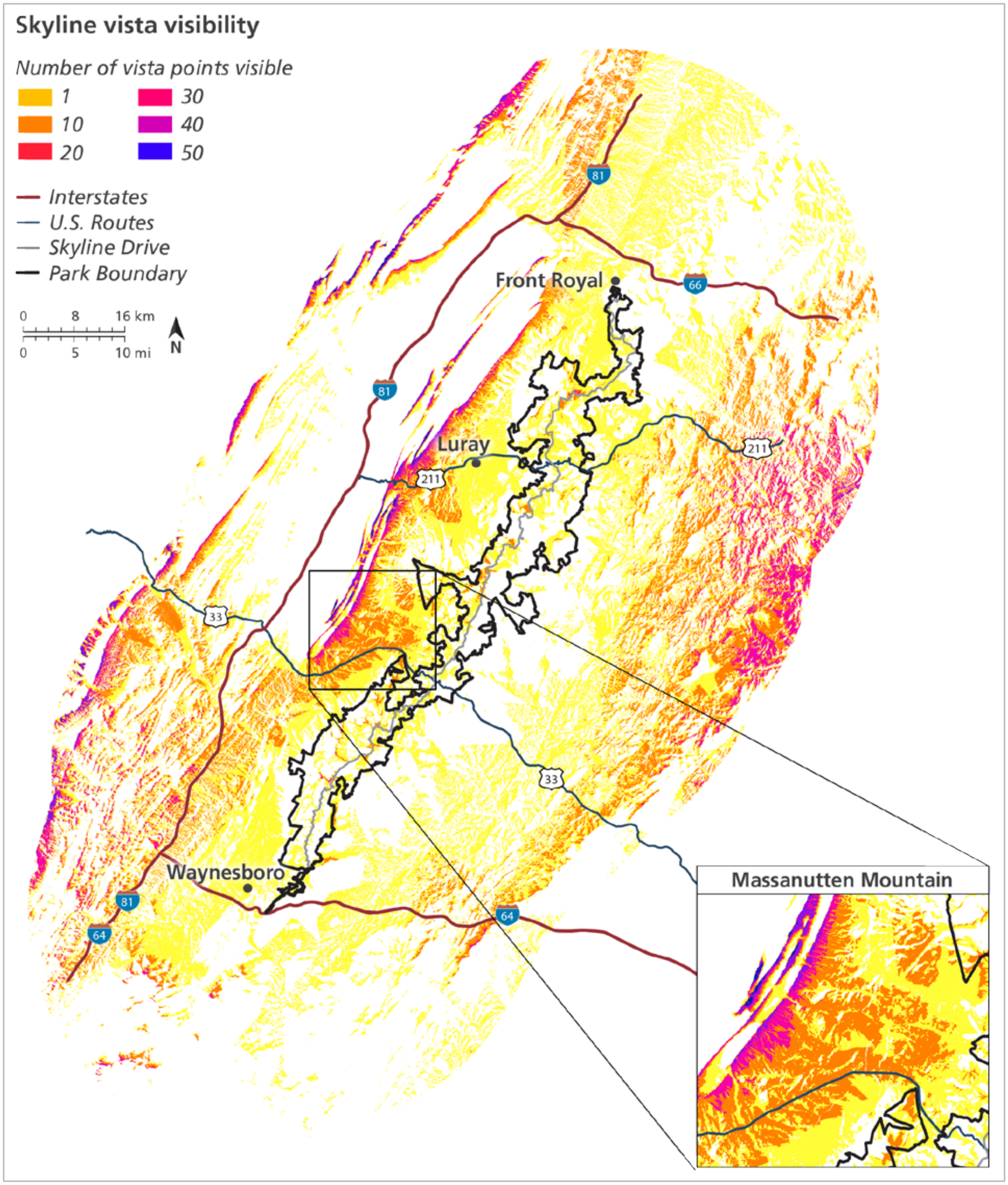

Figure 4-39. Visibility of surrounding landscape from Skyline Drive vista points. Source: Alan Williams, National Park Service.

Reference condition value

A reference condition amount of developed visible area was determined for park vistas based on desirable conditions expressed by park staff. In another viewshed assessment of Capulin Volcano National Monument (Bennetts *et al.* 2011), less than 5.0% developed land was considered an acceptable level of development within a park's natural scenic viewshed. It was determined that this level of development would be overly restrictive for landscapes of the eastern U.S., and a threshold of less than 15% developed land was adopted.

Condition and trends

The 2006 NLCD product (Fry *et al.* 2011) was used to assess the current developed land area within the park's viewsheds. The aggregate area of the 133 vista viewsheds covered 5,873 km^2. Of this total area, 611 km^2 (10.4%) were developed. The developed lands within a 37 km buffer of the park were found to represent 9.0% of the land area, indicating that the land within the park vista viewsheds currently slightly over-represent developed lands within the entire 37 km visible buffer range.

The distribution of individual viewshed scores ranged from 2% to 21% developed using the 2006 NLCD data (Figure 4-40). The proportion of developed land visible was highest from the vista points along the extreme ends of Skyline Drive (*i.e.*, within 6.4 km of the southern end overlooking Waynesboro and Charlottesville, and within 4.8 km of the northern end overlooking Front Royal) (Figure 4-41). One hundred sixteen of the 133 viewsheds were less than 15.0% developed for an attainment score of 87.2%. The viewsheds of the high elevation sites were slightly less developed (mean of 8.2% Developed) than the viewsheds of the low elevation sites (mean of 10.0% Developed) (Table 4-22).

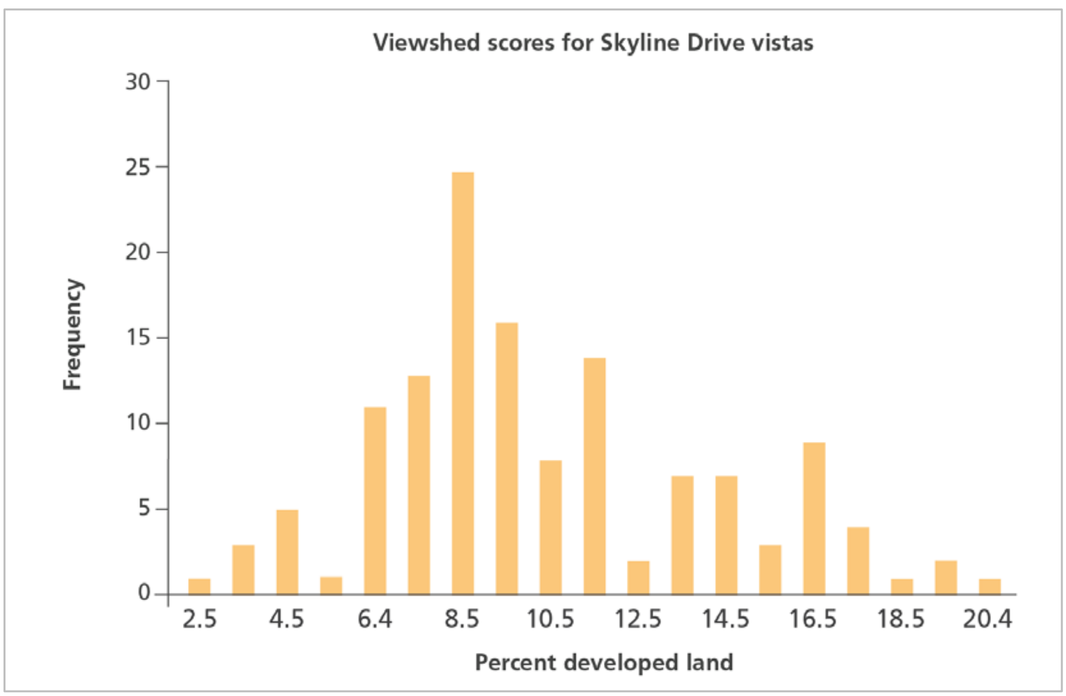

Figure 4-40. Histogram of percent developed land within the viewsheds of 133 vistas along Skyline Drive. Source: NLCD 2006.

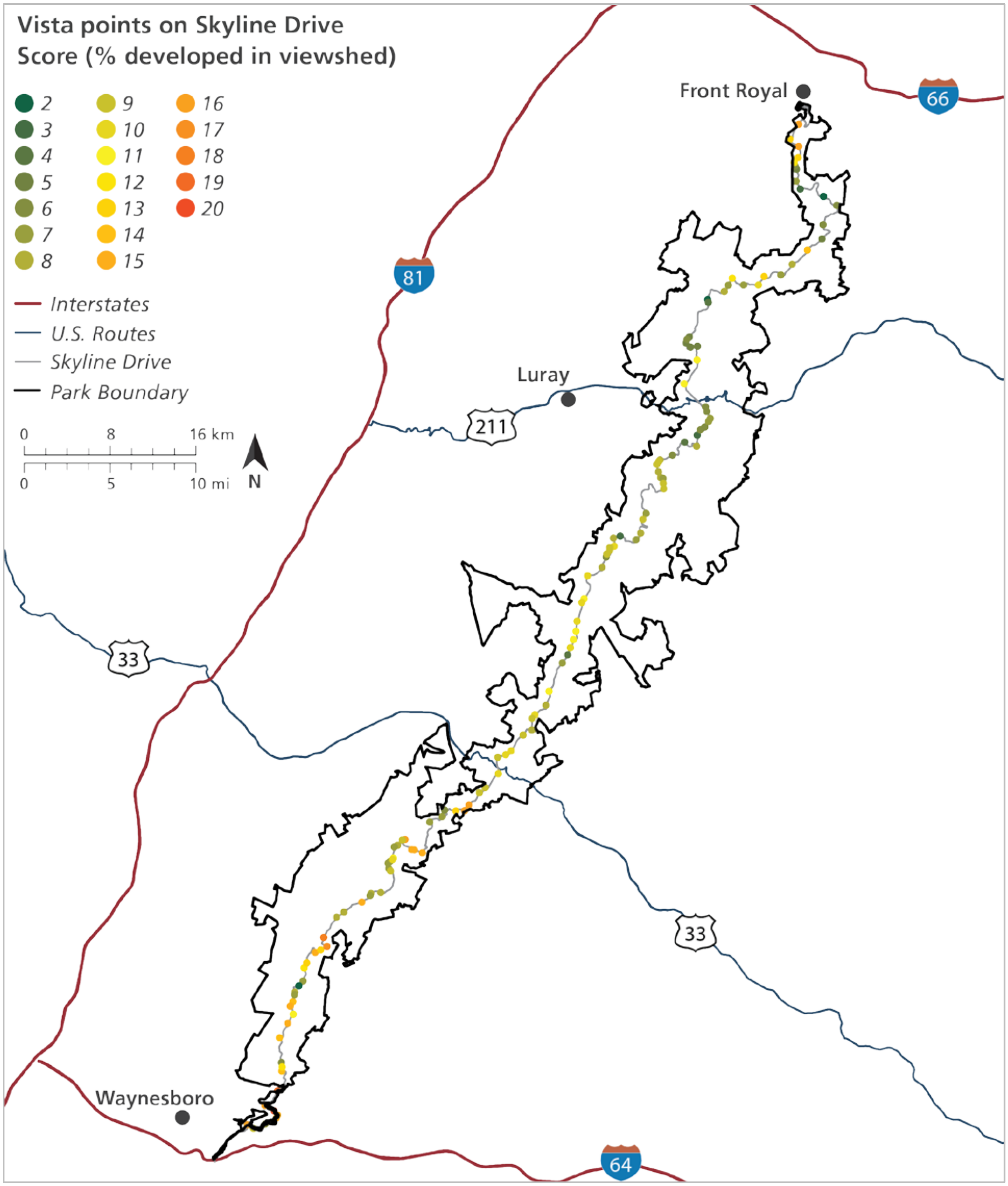

Figure 4-41. Percent of viewshed that was developed for each vista point along Skyline Drive. Source: Alan Williams, National Park Service.

Table 4-22. Percent development within 133 viewsheds for the two elevation classes.

Meaurement	Low elevation	High elevation
Number of viewsheds	91	42
Average percent developed	10.0%	8.2%
Percent of vistas below 15% developed	81%	100%

The analysis of the 1992 and 2001 land cover data indicated a trend of increasing development within the viewsheds. The total amount of developed land cover for 2001 was 594 km^2 (10.1% Developed) for the aggregated viewsheds. The total 1992 developed lands within the aggregated viewsheds was estimated to be 564 km^2 (9.6% Developed). The rate of development for the viewsheds was 3.36 km^2 per year between 1992 and 2001, and 3.44 km^2 per year between 2001 and 2006 (Figure 4-42).

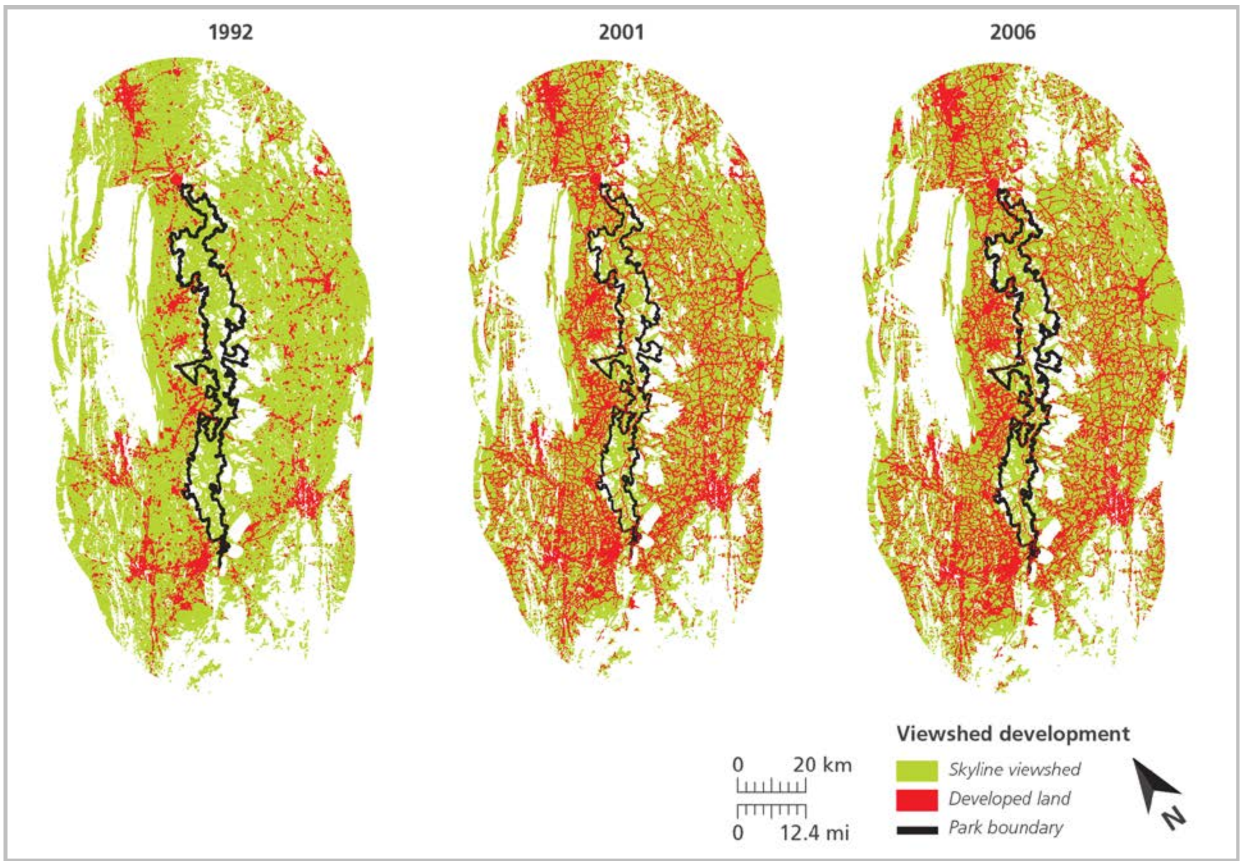

Figure 4-42. Increase in developed land from 1992 to 2006 within the viewsheds of Skyline Drive vistas. Source: National Land Cover Database.

Protected, public lands comprised 22% of the total viewshed area for the 133 vistas (Figure 4-43). The analysis highlights the importance of George Washington National Forest to the west of the park along Massanutten Mountain in preserving the park's viewsheds.

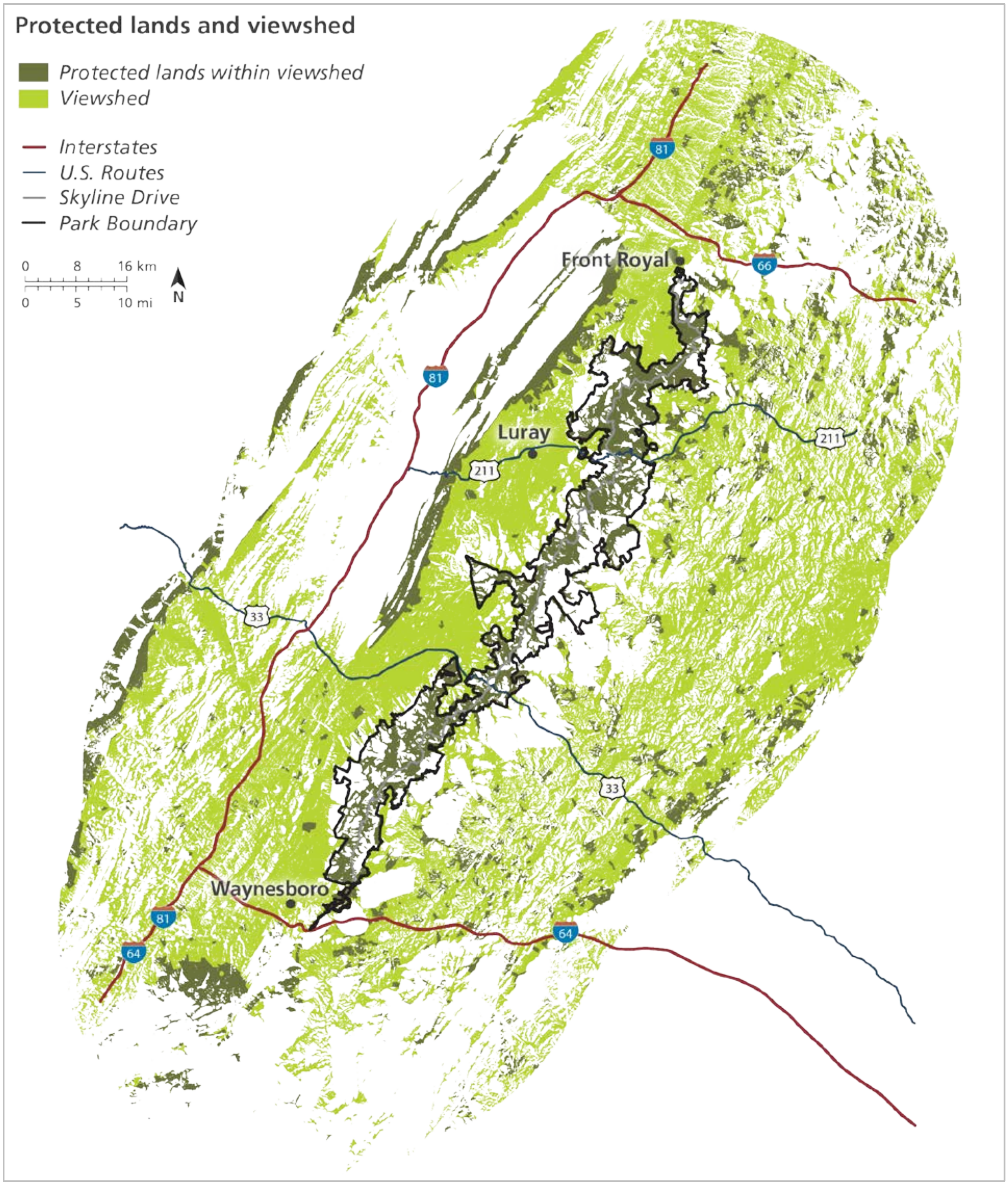

Figure 4-43. Visibility of protected lands from Skyline Drive vistas. Source: PAD-US v 1.2.

<u>Data gaps and level of confidence</u>

Confidence in this indicator is assessed as high. The 133 vista points chosen for the analysis are among the most visited sites in the park; therefore the analysis provides a representative sample of the average park visitor's experience. However, it does not fully capture all vista points within the park's boundaries. There are many more observation points along the Appalachian Trail within the park than could be reasonably cleared or otherwise maintained by the park staff. The viewsheds from the trails are similar to or more obstructed than adjacent observation points from Skyline Drive, so it is expected that the inclusion of trail viewsheds would not substantially change the results.

The NLCD data have a spatial resolution identical to the DEM used in creating the viewsheds (30 m), and are appropriate for the regional scale of the assessment. However, the data do not capture land development from 2006 to present (the 2011 data were not yet available when this analysis was conducted). It is also notable that the 37 km visible range estimate is only 20% of the natural visible range due to degraded regional air quality, is much lower than the range during winter months when the average visible range can extend beyond 64 km, and does not reflect continued improvements in air quality over recent decades (Sullivan *et al.* 2003a, IMPROVE 2010). The use of a 15% development threshold is also based on best judgement and could be more accurately quantified, for example, with surveys of park visitor tolerances.

<u>Source of expertise</u>

- Dan Hurlbert, GIS Specialist, Spatial and Analysis Program, Shenandoah National Park.

4.4.2 Land cover

<u>Relevance and context</u>

Habitat loss is the primary cause of species extinctions in the United States (Czech *et al.* 2000). Forests are the dominant habitat type in the eastern United States and form a key ecosystem component in Shenandoah National Park (Cass *et al.* 2012). From 1973 to 2000, total forest area has decreased by 4.3% nationally (Sleeter *et al.* 2013) and 4.0% in the eastern U.S. (Drummond and Loveland 2010) due to increasing urban, suburban and exurban development. Forests now cover barely 50% of the lands bordering Shenandoah National Park (Figure 2-6). In addition to its effects on species extinctions, loss of forest cover can lead to increased non-native species invasions (Vitousek *et al.* 1997), degraded and diminished water flows (Meyer and Turner 1992), and spread of new diseases (Langlois *et al.* 2001). In Shenandoah National Park, forested watersheds play a critical role in maintaining the quality of the numerous streams and rivers that originate in the park.

The amount of impervious surface is a specific and quantifiable indicator of human activity on the landscape that directly correlates to environmental condition (Arnold and Gibbons 1996). Impervious surfaces include rooftops, roads, and parking lots that decrease infiltration and groundwater storage while increasing runoff and water pollution (Center for Watershed Protection 2003). Studies have indicated that the total percent impervious surface in a watershed has a stronger effect on stream ecosystem integrity than the amount of riparian deforestation, though the two factors certainly interact to degrade stream condition (Walsh *et al.* 2007). Therefore, the percent of a watershed covered in impervious surfaces can provide a good approximation of aquatic habitat degradation, even within areas of little development (Gergel *et al.* 2002).

Data and methods

Large sections of intact forest are a defining feature of Shenandoah National Park. The composition of these forests is described in Chapter 2 and the condition of these forests is also assessed in the section on Terrestrial Resources. In this section, the integrity of the landscape is assessed by quantifying the amount of, and changes in, forest land cover and impervious surfaces in the park and within a 30 km buffer surrounding the park.

Data from Young *et al. (*2009) were used to assess current condition of the forested landscape within the park. This vegetation map represents the best available data on forest cover in the park. The project was initiated in 2000 using hyperspectral remote sensing imagery to map the dominant vegetation communities in the park. Using data from 311 field plots collected by the Virginia Natural Heritage Program and U.S. Geological Survey for ground-truthing, the initial map was completed in 2005. In 2007, the original classification was modified and updated yielding a new map of 35 natural vegetation community types based on 1,160 sample plots (Young *et al.* 2009). Twenty-one of these classes were considered forest vegetation. These classes were aggregated to determine the current amount of forest in the park. The percent forest cover was also calculated from the Young *et al.* (2009) data set for each of the six geo-elevation regions.

Unfortunately, data of lower accuracy were required to assess trend within the park and to assess forest cover in the 30 km buffer surrounding the park due to the cost and time commitment required to create detailed, site-specific vegetation maps. The trend in forest land cover inside the park and within the buffer region was assessed using the National Land Cover Database (NLCD) land cover data from 2001, 2006 and 2011 (Jin *et al.* 2013). As these data were developed for national level assessment, they are considered less accurate than the Young *et al.* (2009) product when applied to park-specific mapping. The NLCD 1992 land cover data were not used for the assessment, as these data were generated using a slightly different classification procedure, which reduces the accuracy of change analysis with this product (Vogelman *et al.* 2001, Ahlqvist 2008).

Impervious surface data were taken from the 2011 NLCD data in which all 30 m pixels were classified into 101 possible values (0–100%) (Homer *et al.* 2007). The mean impervious surface value was calculated for the park and separately for each of the six geo-elevation regions. The percentage of 30-m grid cells that were forested was also calculated for both the park as a whole and each of the six geo-elevation classes. Trend in impervious surface cover within the park and within the 30 km buffer were assessed using the 2001, 2006 and 2011 NLCD data. The use of both forest cover and impervious surface as indicators is consistent with national guidance provided by the NPScape program (Budde *et al.* 2009). The use of the 30 km buffer is also consistent with recommendations from NPScape.

Reference condition value

Simulation studies of forest loss suggest a critical reference condition value of at least 59% of the total landscape area be maintained in forest to assure many ecological functions and services (Gardner *et al.* 1987; Turner *et al.* 2001). Landscapes with lower forest amount tend to lose the characteristic qualities of intact forest required of organisms such as forest interior birds and forest dwelling mammals. Small losses in forest within landscapes near this critical reference condition result in large changes in average patch size, the amount of interior forest, the amount of edge habitat, and related indicators of fragmentation (Fahrig 2003). For this assessment, a reference condition of greater than 59% forest cover was required to achieve 100% attainment.

As a second metric, the assessment used a reference condition value of less than 10% impervious surface cover for achieving 100% attainment. This threshold represents an upper limit based on the historical adoption of this reference condition value within the freshwater conservation community (Booth and Reinelt 1993, Arnold and Gibbons 1996, Lussier *et al.* 2008); however, multiple studies have illustrated significant ecosystem impacts in watersheds with even less than 10% impervious cover. For example, a study in coastal New Jersey revealed that impervious surface cover as low as 2% may have effects on pH and specific conductance (Conway 2007). In a Maryland study, impervious surface cover from 0.5–2% resulted in the decline of the majority (80%) of the stream taxa, while 2–25% impervious cover showed a decline in 100% of the taxa (King *et al.* 2011). Coastal Plain watersheds with 4–23% impervious cover have shown a loss of sensitive aquatic invertebrate taxa (Utz *et al.* 2009), and watersheds with 3–5% cover have shown significant changes in stream flow (Yang *et al.* 2010). Other evidence suggests that sensitive species such as brook trout disappear in watersheds with greater than 4% impervious cover (MD DNR 2012).

<u>Condition and trend</u>

Based on the Young *et al.* (2009) vegetation mapping, forests currently occupy 95% of the park. The dominant vegetation community in the park is Chestnut Oak / Northern Red Oak Forest (Table 4-23). Current forest cover within the park is well above the 59% percent forest reference condition set for intact forest. Therefore, current condition was assigned a 100% attainment score. All six of the geo-elevation classes also were above the reference condition for 100% attainment (Table 4-24).

Table 4-23. Percent forest land cover by vegetation community in Shenandoah National Park (from Young *et al.* 2009). CEGL numbers in parentheses represent community number within the National Vegetation Classification System.

Community Type (CEGL numbers in parentheses)	Forest Type	Acres (> 915 m)	Acres (< 915 m)	Total
Forest				
Central Appalachian Acidic Oak-Hickory Forest (8515)	Dry Forests and Woodlands	0	5660.2	5660.2
Central Appalachian Basic Boulderfield Forest (8528)	Dry Forests and Woodlands	0	6390.9	6390.9
Central Appalachian Basic Oak-Hickory Forest (Submontane/Foothills Type) (8514)	Dry Forests and Woodlands	0	17015.2	17015.2
Central Appalachian Basic Woodland (3683)	Dry Forests and Woodlands	0	71.2	71.2
Central Appalachian Dry Chestnut Oak-Northern Red Oak/Heath Forest (8523)	Dry Forests and Woodlands	0	18662.1	18662.1
Central Appalachian Montane Oak-Hickory Forest (Acidic Type) (8516)	Dry Forests and Woodlands	0	1735.3	1735.3

Table 4-23 (continued). Percent forest land cover by vegetation community in Shenandoah National Park (from Young *et al.* 2009). CEGL numbers in parentheses represent community number within the National Vegetation Classification System.

Community Type (CEGL numbers in parentheses)	Forest Type	Acres (> 915 m)	Acres (< 915 m)	Total
Forest (continued)				
Central Appalachian Montane Oak-Hickory Forest (Basic Type) (8518)	Dry Forests and Woodlands	0	15363.5	15363.5
Central Appalachian/Northern Piedmont Chestnut Oak Forest (6299)	Dry Forests and Woodlands	0	24790.4	24790.4
Central Appalachian Dry-Mesic Chestnut Oak Northern Red Oak Forest (6057)	Dry Forests and Woodlands	0	28937.9	28937.9
Central Appalachian Pine Oak/Heath Woodland (4996)	Dry Forests and Woodlands	0	3844.9	3844.9
Central Appalachian Xeric Chestnut Oak Virginia Pine Woodland (8540)	Dry Forests and Woodlands	0	11.2	11.2
Low-Elevation Mixed Oak/Heath Forest (8521)	Dry Forests and Woodlands	0	3031.2	3031.2
Sweet Birch Chestnut Oak Talus Woodland (6565)	Dry Forests and Woodlands	0	5273	5273
Central Appalachian High-Elevation Boulderfield Forest (8504)	Forest and Woodland	32.7	0	32.7
Northern Red Oak Forest (Pennsylvania Sedge-Wavy Hairgrass Type) (8506)	Forest and Woodland	4160.2	0	4160.2
Central Appalachian Northern Hardwood Forest (8502)	Forest and Woodland	859.9	0	859.9
Central Appalachian Acidic Cove Forest (Hemlock-Hardwood/Mountain-Laurel Type) (8512)	Mesic Forest	0	3346.2	3346.2
Central Appalachian Acidic Cove Forest (White Pine-Hemlock-Mixed Hardwoods Type) (6304)	Mesic Forest	0	4944.7	4944.7
Central Appalachian Rich Cove Forest (6237)	Mesic Forest	0	3725.3	3725.3
Northern Blue Ridge Mafic Fen (6249)	Mesic Forest	0	29.7	29.7
Hemlock-Northern Hardwood Forest (6109)	Mesic Forest	0	2031.9	2031.9
Northern Blue Ridge Montane Alluvial Forest (6255)	Mesic Forest	0	1571.1	1571.1
Southern Appalachian Cove Forest (Typic Montane Type) (7710)	Mesic Forest	0	12839.2	12839.2
Northeastern Modified Successional Forest (6599)	Early Successional and Disturbed	1936.1	9392.4	11328.5
Successional Tulip tree Forest (Circumneutral Type) (7220)	Early Successional and Disturbed	0.57	13070.9	13071.47

Table 4-23 (continued). Percent forest land cover by vegetation community in Shenandoah National Park (from Young *et al.* 2009). CEGL numbers in parentheses represent community number within the National Vegetation Classification System.

Community Type (CEGL numbers in parentheses)	Forest Type	Acres (> 915 m)	Acres (< 915 m)	Total
Forest (continued)				
Virginia Pine Successional Forest (2591)	Early Successional and Disturbed	6.4	45.3	51.7
Non-forest				
Catastrophically Disturbed Forest (N/A)	Early Successional and Disturbed	1055.8	8715.5	9771.3
Cultural Meadow (N/A)	Early Successional and Disturbed	270.7	75.8	346.5
High Elevation Greenstone Barren (8536)	Outcrop and Barren	13	0	13
Central Appalachian Heath Barren (3939)	Outcrop and Barren	2.2	0	2.2
High Elevation Outcrop Barren (Black Chokeberry Igneous/Metamorphic Type) (8508)	Outcrop and Barren	4.4	0	4.4
Central Appalachian Circumneutral Barren (6037)	Rock Outcrops and Barren	0	7.9	7.9
Central Appalachian Acidic Boulderfield (4142)	Rock Outcrops and Barren	0	78.7	78.7
Central Appalachian Mafic Boulderfield (4143)	Rock Outcrops and Barren	0	2.1	2.1
Central Appalachian Mafic Barren (Ninebark/Pennsylvania Sedge Type) (8529)	Rock Outcrops and Barren	0	4.1	4.1

Table 4-24. Forest land cover (%) in each of the six geo-elevation classes.

Elevation	Geology	Young *et al.* 2009	NLCD2001	NLCD2006	NLCD2011
<915 m	Granitic	92.8%	98.3%	98.2%	98.1%
	Metabasaltic	95.2%	96.8%	96.8%	96.7%
	Siliciclastic	96.8%	98.4%	98.4%	98.3%
> 915 m	Granitic	86.1%	95.9%	95.9%	95.8%
	Metabasaltic	96.1%	94.5%	94.4%	94.3%
	Siliciclastic	94.4%	91.3%	90.9%	91.2%

Using the impervious surface estimate from the 2011 NLCD, a total of 0.2% of the grid cells of Shenandoah National Park were covered in > 10% impervious surfaces for an attainment score of 99.8%. Most of the impervious surfaces were associated with Skyline Drive (inset in Figure 4-44). All six geo-elevation classes had less than 0.5% of their area covered by cells with impervious surface of >10% (Figure 4-44).

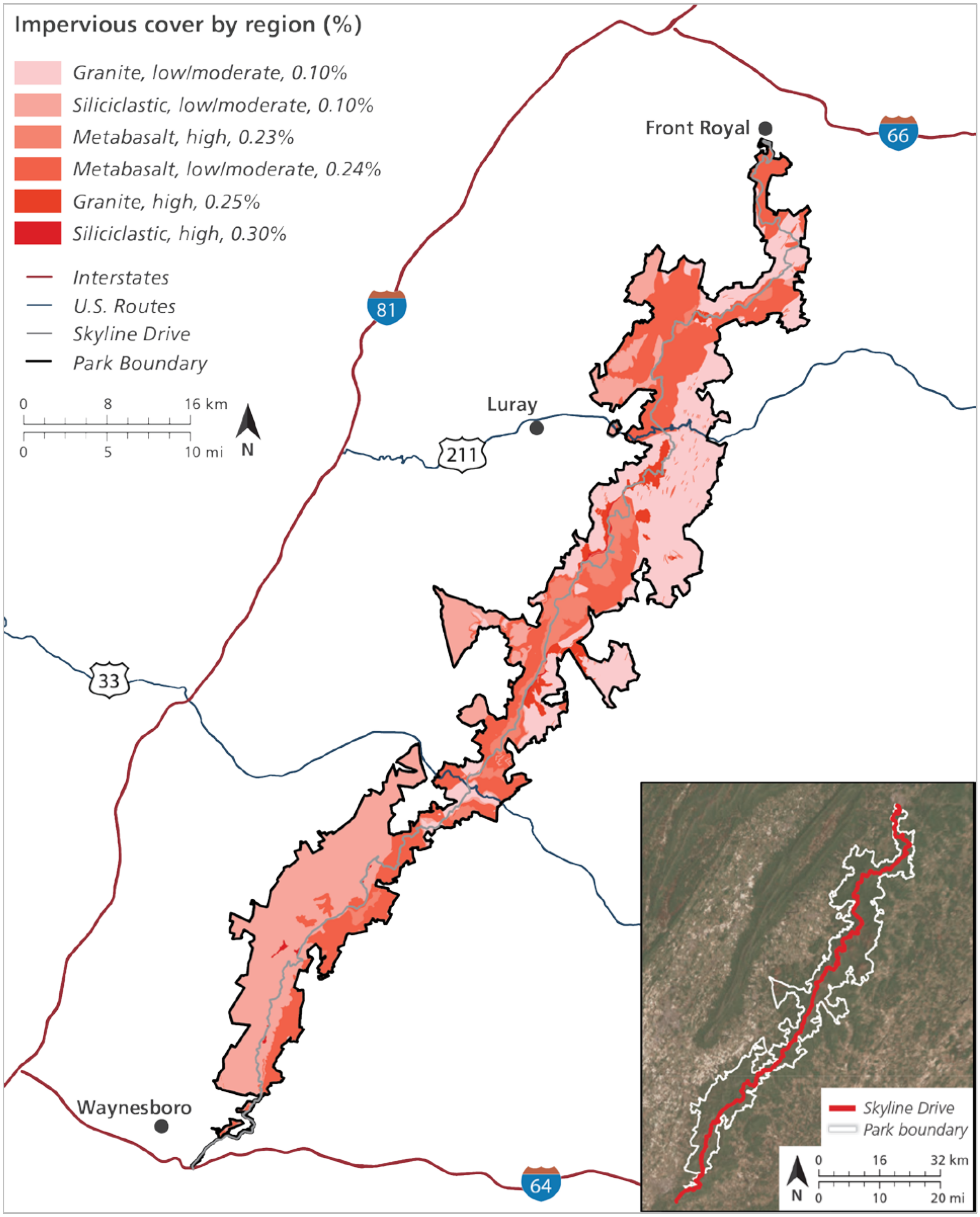

Figure 4-44. Percent of region exceeding 10% impervious surface cover for the six geo-elevation regions of Shenandoah National Park. Skyline Drive shown in the map inset. Source: National Landcover Database 2011.

Averaging together the attainment values for the forest and impervious surface land cover indicators provides an overall attainment score of 100% for the park and each of the six geo-elevation regions. However, this score should be considered in the context of the land cover condition in the buffer region surrounding the park (Figure 2-6). For the 2011 NLCD product, forest covered only 52% of the land within the 30 km buffer (Table 4-25). Outside the park, agriculture had a much larger footprint (36%) than it did inside the park, especially hayfields and pasture (34%). Developed lands comprised 11% of the buffer region, with impervious surfaces covering 2% of the landscape. A total of 5.7% of the grid cells in the 2011 land cover dataset exceeded the >10% impervious surface threshold for the 30 km buffer region surrounding the park (Figure 4-45 Impervious cover in the 30 km buffer around Shenandoah National Park. Source: National Landcover Database 2011.). It is important to note, however, that nearly all of these lands are downstream from the park, so their effect on the park's aquatic resources are expected to be minimal.

Table 4-25. Forest and developed land cover (%) in the 30 km buffer surrounding the park.

Land Cover Type	NLCD2001	NLCD2006	NLCD2011
Forest	52.7%	52.5%	52.2%
Deciduous	43.1%	43.1%	42.9%
Evergreen	5.7%	5.6%	5.5%
Mixed Forest	3.9%	3.9%	3.8%
Development	10.1%	10.4%	10.6%
Developed Open Space	6.8%	6.8%	6.8%
Low Intensity	2.6%	2.7%	2.7%
Medium Intensity	0.6%	0.7%	0.8%
High Intensity	0.2%	0.3%	0.3%

Since 2001, there has been no significant change in forest cover for the park (Table 4-23) nor has there been a change in impervious surface cover for the park (Figure 4-46). However, forest cover has decreased outside the park at a rate that exactly matches the increase in developed lands (Table 4-23). The percentage of grid cells in the buffer region with impervious surface values greater than 10% also has increased from 5.3% in 2001 to 5.7% in 2011 (Figure 4-46). Given these changes surrounding the park and the fact that the amount of forest outside the park (52%) is already below the threshold at which fragmentation effects are predicted to appear (59%), there is a concern that the park could become increasingly isolated in the future. Therefore, trend in land cover resources is assessed as declining.

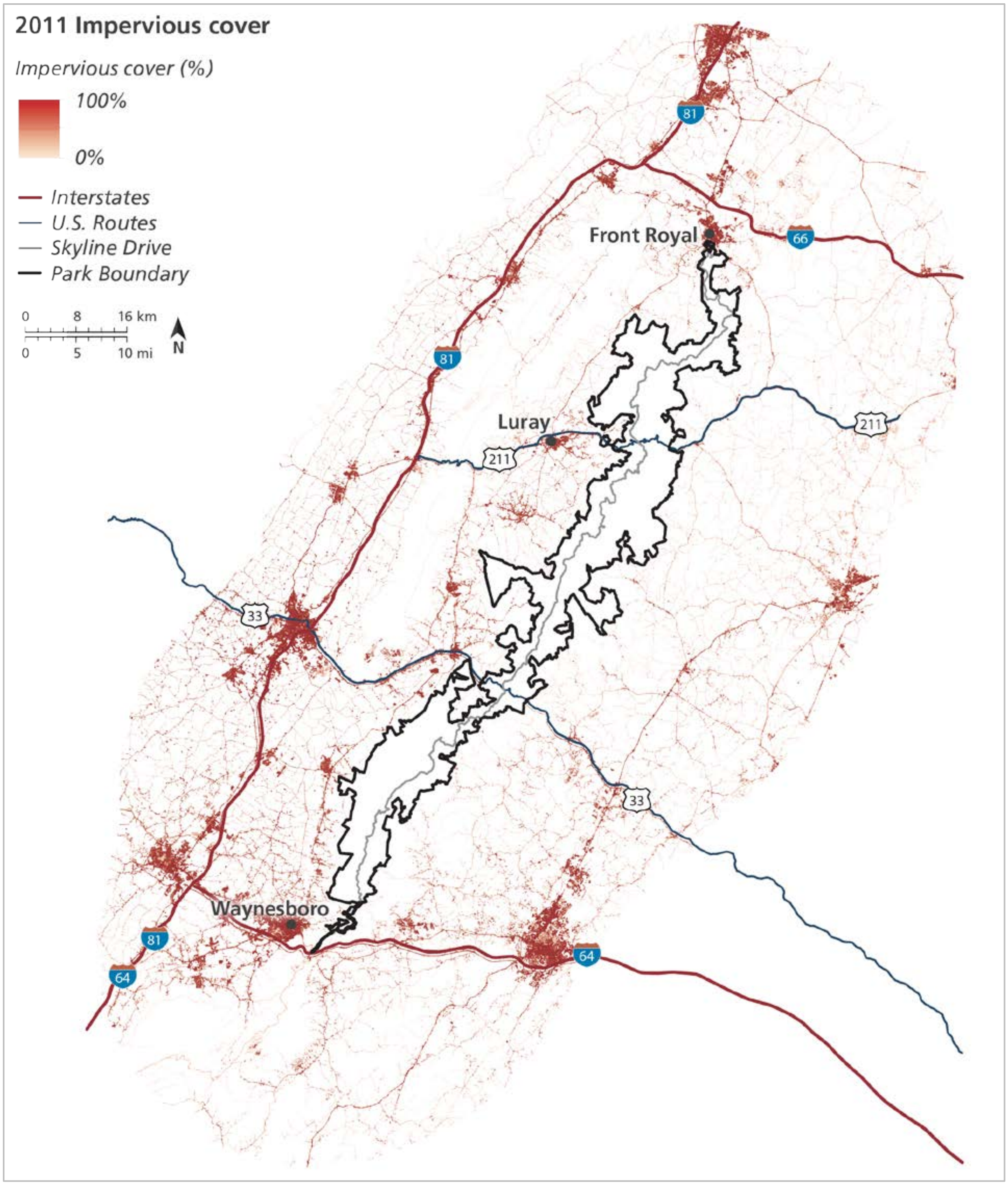

Figure 4-45. Impervious cover in the 30 km buffer around Shenandoah National Park. Source: National Landcover Database 2011.

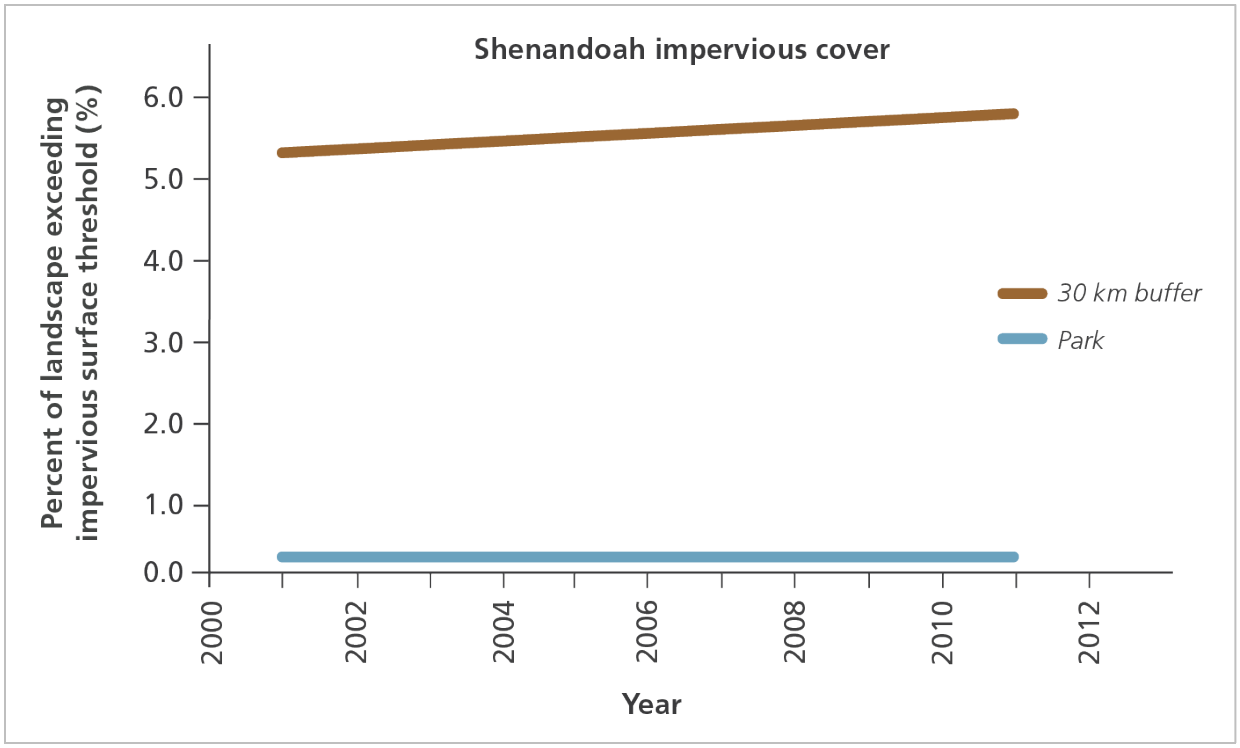

Figure 4-46. Change in impervious cover through time for Shenandoah National Park and 30 km buffer surrounding the park. Impervious surface threshold set at > 10% for any given grid cell in the data. Source: National Land Cover Database.

Data gaps and level of confidence

Although differences in community cover are discussed, the quantitative assessment of land cover treats all types of forest as equivalent. Differences in forest composition and quality are not considered. Similarly, the assessment treats all non-forest cover types equivalently, when different types of non-forest land could have different effects on forest fragmentation. A localized data source rather than the NLCD would allow for improved classification accuracy of impervious surfaces and forest trend. As discussed in the reference condition section, a strong argument also could be made for using a lower reference condition than 10% for the impervious surfaces evaluation. Nevertheless, confidence in this indicator is high because of how far above reference condition values the park is under current conditions.

Sources of expertise

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4.4.3 Roads

<u>Relevance and context</u>

One of the greatest attractions for visitors to Shenandoah National Park is Skyline Drive. This arterial road serves as the primary transportation route for access to visitor centers, trailheads, and scenic vistas. Although the road is located strategically along the crest of the park's contours, the road unintentionally creates a significant barrier for wildlife and has the potential to negatively impact the natural resources of the park. Roads such as Skyline Drive have a number of well-documented negative influences on species and their habitat (e.g., Vos and Chardon 1998; Gerlach and Musolf 2000; Keller and Largiader 2003), including extensive impacts on both terrestrial and aquatic environments (Spellerberg 1998; Ercelawn 1999; Trombulak and Frissell 2000; Forman *et al.* 2003). The effects of these impacts may be undetectable in some taxa for decades (Findlay and Bourdages 2001). Although human population density is relatively low and landscapes are perceived as natural within Shenandoah National Park, the direct and indirect impact of the network of paved and unpaved roads in the park can destroy habitat and be harmful to park wildlife, streams, and vegetation (Saunders *et al.* 2002).

Roads are especially effective barriers for ground dwelling species (Bennet 1991). With 23 amphibian species known to live in the park (National Park Service 2005d), including the Federal and State endangered Shenandoah salamander (*Plethadon shenandoah*), the potential road effects on these species are of special concern. Habitat destruction leading to increased habitat fragmentation is likely one of the most important factors causing amphibian decline in some areas (Blaustein *et al.* 1994). For reptiles and amphibians, over 70% of the decline of populations worldwide is attributable to road mortality (Manning 2001). For reptiles, thermoregulation activities lead to their use of road surfaces to control their temperatures, which contribute to traffic-related mortality. Amphibians are greatly affected by the isolation of habitat patches created by roads (Vos and Chardon 1998), and such isolation can limit gene flow and subdivide or isolate populations (Gerlach and Musolf 2000; Keller and Largiader 2003). Other indirect effects of roads include the impact of salt, gravel and silt runoff on downslope resources such as streams and amphibians (Karraker *et al.* 2008). As an example, the park has found gravel from the Skyline Drive roadside more than 200 meters downslope of the road in a rare plant population.

Several studies have demonstrated a surprisingly large impact of roads even on protected lands with relatively little traffic. Tourism associated with protected lands and protected species may produce a network of roads and consequently an increase in the number of visitors, which in turn can degrade natural resources and result in increased vehicle-related mortality when those roads bisect habitat and provide visitor access to sensitive terrain (Manning 2001). In one study, amphibians and reptiles were found to have the greatest road mortality in protected areas, while birds and mammals had higher rates of road-related deaths in unprotected areas (Garriga *et al.* 2012). In another recent study, approximately 10% of the adult populations of four amphibian species were killed annually by traffic when crossing a low to moderately traveled road (3200 vehicles/day) (Hels and Buchwald 2001).

Roads are pervasive on the American landscape. Nationally, 20% of the total U.S. land area is within 127 m of a road and more than 80% is within 1 km of a road (Riitters and Wickham 2003). Regions with more than 60% of their total land area within 382 m of a road may be at greatest risk of cumulative ecological impacts from roads; in the Blue Ridge, Shenandoah Valley, and Piedmont ecoregions, 60-80% of the land area is within 382 m of a road (Riitters and Wickham 2003).

Data and methods

Road density, measured as the average total road length (km) per unit of area of landscape (km^2), is a common overall measure of the amount of road in an area (Forman *et al.* 2003). Road density was calculated from GIS data provided by Shenandoah National Park on August 4, 2014. The maps included information on both the paved and unpaved roads in the park. Final metrics were calculated for all roads, but information on paved and unpaved roads is also presented.

The total length of roads was divided by the area of the park to determine the density of roads in the park. Road densities also were calculated for each of the six geo-elevation classes of the park. To determine the spatial impact of individual roads, the distance to roads was calculated using the NPScape Road Distance Tool (National Park Service 2013d) in accordance with the Roads Measure SOP (National Park Service 2013c). This tool creates a raster layer with the integer Euclidean Distance to a road computed for each 30 m pixel within the specified area of analysis. Per the SOP, a 30 km buffer around the park unit was included in the area of analysis to ensure the effects of roads outside the park were effectively captured. The resulting raster layer was clipped for the park's boundary extent and summary statistics calculated for the park and each geo-elevation classification. The mean distance to roads was calculated as a quantitative metric for the assessment.

The distance to roads layer was also used to delineate areas with relatively little impact from roads. A distance of 500 m was used to define these "road-free" areas as recommended by the NPScape Road Measure SOP (National Park Service 2013c). This distance is supported by the literature on the effective distance of road effects for many species of concern, as documented in the Reference condition section below. The Areas without Roads Tool (National Park Service 2013d) was used to complete this analysis. The tool excludes patches without roads that are smaller than 100 m^2. The resulting patch size class distributions were then evaluated for the park.

Reference condition

The scale of ecosystem impacts of roads depends on the species of interest, ecosystem characteristics, season, time of day, road width, road surface, proximity to water, and traffic density (Gross *et al.* 2009). For reptiles and amphibians, a road density of less than 1 km/km^2 is desirable for species in the eastern U.S. (Gibbs and Shriver 2002). For comparison purposes, the mean road density within the United States is 1.2 km/km^2 (Forman 2000). For this assessment, the road density was evaluated against a reference condition density of 1 km/ km^2. Geo-elevation regions with a mean road density less than 1 km/ km^2 were designated as passing (100%), and regions with a mean road density greater than 1 km/ km^2 were designated as failing (0%).

The impact of roads on wildlife can extend from a few hundred meters to over a kilometer from the road edge (Forman *et al.* 2003). Riitters and Wickham (2003) found that regions with more than 60% of the total land area within 382 m of a road would have degraded ecosystem conditions. Another study in the northeast U.S. found that certain ground-dwelling bird species' breeding habitats were altered when within 700 m of moderately traveled areas (Forman *et al.* 2002). For soil-dwelling macroinvertebrates, a distance of only 100 m from even small roads was found to impact species habitat (Haskell 2000). For this assessment, regions of the park were assessed against the 500 m distance recommended by the NPScape Road Measure SOP (National Park Service 2013c) for delineating areas with healthy distance to roads. The percentage of each geo-elevation region that was greater than 500 m from a road was quantified.

Defining a desired roadless patch size is contingent on the species of concern, with patch size requirements generally scaling to body size. For example, large birds and mammals require greater habitat area than smaller species (Lindstedt *et al.* 1986; Jenkins 1981). Minor and Lookingbill (2010) reviewed home range requirements for mammals of varying body size and found that minimum habitat patch size requirements were broadly generalizable (0.01 km^2 for small mammals, 1 km^2 for medium sized mammals, and 10 km^2 for large mammals) (Harestad and Brunell 1979, Sutherland *et al.* 2000, Bowman *et al.* 2002, Corry and Nassauer 2005). Using a reference condition patch size of greater than 10 km^2, the percentage of each geo-elevation region comprised of these large roadless patches was assessed.

<u>Condition and trend</u>

At the time of park establishment, many access trails and unimproved roads covered the landscape. The majority of the park's old roads have been allowed to return to a natural state and are now indistinguishable from the surrounding terrain. New road construction within the park has been mostly confined to highly concentrated parking lots at visitor centers and camping areas. The current impact of roads to natural resources will not significantly change without new road construction that bisects intact areas. Therefore, the trend was assessed as stable.

The density of all roads for the entire park was 0.55 km/km^2. In comparison, the road density for a 30 km buffer around the park using the 2005 street layer from ESRI (ESRI 2010) was 1.78 km/km^2. The mean road density of the three high elevation geo-elevation regions were each above the 1 km/km^2 reference condition recommended by Gibbs and Shriver (2002), and the three low elevation regions were below the reference condition for an overall attainment score of 50% for the park (Table 4-26). Excluding the unpaved roads from the analysis, the density of paved roads alone is 0.32 km/km^2.

Table 4-26. Road densities for Shenandoah National Park by geo-elevation classes.

Elevation	Geology	Density, All Roads (km/km^2)	Density, Paved Roads (km/km^2)
<915 m	Granitic	0.34	0.15
	Metabasaltic	0.67	0.37
	Siliciclastic	0.32	0.21
> 915 m	Granitic	1.03	0.77
	Metabasaltic	1.43	0.97
	Siliciclastic	2.09	1.36

The mean distance to a road for all points in the park was 766 m, and the mean distance to a paved road was over a kilometer (1011 m). For comparison, the mean distance to a road within a 30 km buffer around the park was 274 m. The mean distance to a road for the six geo-elevation classes ranged from less than 350 m for the High Metabasaltic class to over 850 m for Low Siliciclastic areas (Table 4-27). Three of the six regions had mean distances to roads greater than the 500 m reference condition. In total, 57% of the park area was greater than 500 m from a road and 71% of the park was greater than 500 m from a paved road.

Table 4-27. Distance to roads for Shenandoah National Park by geo-elevation classes.

Elevation	Geology	All Roads, Mean (m)	Area > 500 m from road (km^2)	Percent of class > 500 m from road	Paved Roads, Mean (m)	Area > 500 m from road (km^2)	Percent of class > 500 m from road
<915 m	Granitic	794	142	64	1067	174	78
	Metabasaltic	623	130	52	877	170	69
	Siliciclastic	873	161	67	1092	185	77
> 915 m	Granitic	497	9	39	899	12	54
	Metabasaltic	348	12	22	522	22	38
	Siliciclastic	382	1	23	522	1	34

Roadless areas were mapped for the park and the surrounding region in accordance with the NPScape Road Measure SOP (2003a). Contiguous roadless patches were then delineated within the park. The mean patch size was 6.78 km2. There were 15 large patches within the park that exceeded the 10 km2 reference condition (Figure 4-47). These patches account for 334.1 km2 or 42.1% of the total park area. In comparison, roadless patches greater than 10 km2 in size comprised only 14.7% of the 30 km buffer region surrounding Shenandoah National Park. None of the high-elevation regions had patches over 10 km2 in area, while each of the three lower elevation classes had at least one patch greater than 10 km2 in size (Table 4-28). Considering only paved roads, roadless patches greater than 10 km2 in size accounted for 516 km2 or 65.1% of the total park area.

Table 4-28. Large roadless patches for Shenandoah National Park by geo-elevation classes.

Elevation	Geology	Percent of class comprised of patches > 10 km^2 in area (all roads)	Percent of class comprised of patches > 10 km^2 in area (paved roads)
<915 m	Granitic	50	77
	Metabasaltic	32	63
	Siliciclastic	60	73
> 915 m	Granitic	0	0
	Metabasaltic	0	26
	Siliciclastic	0	0

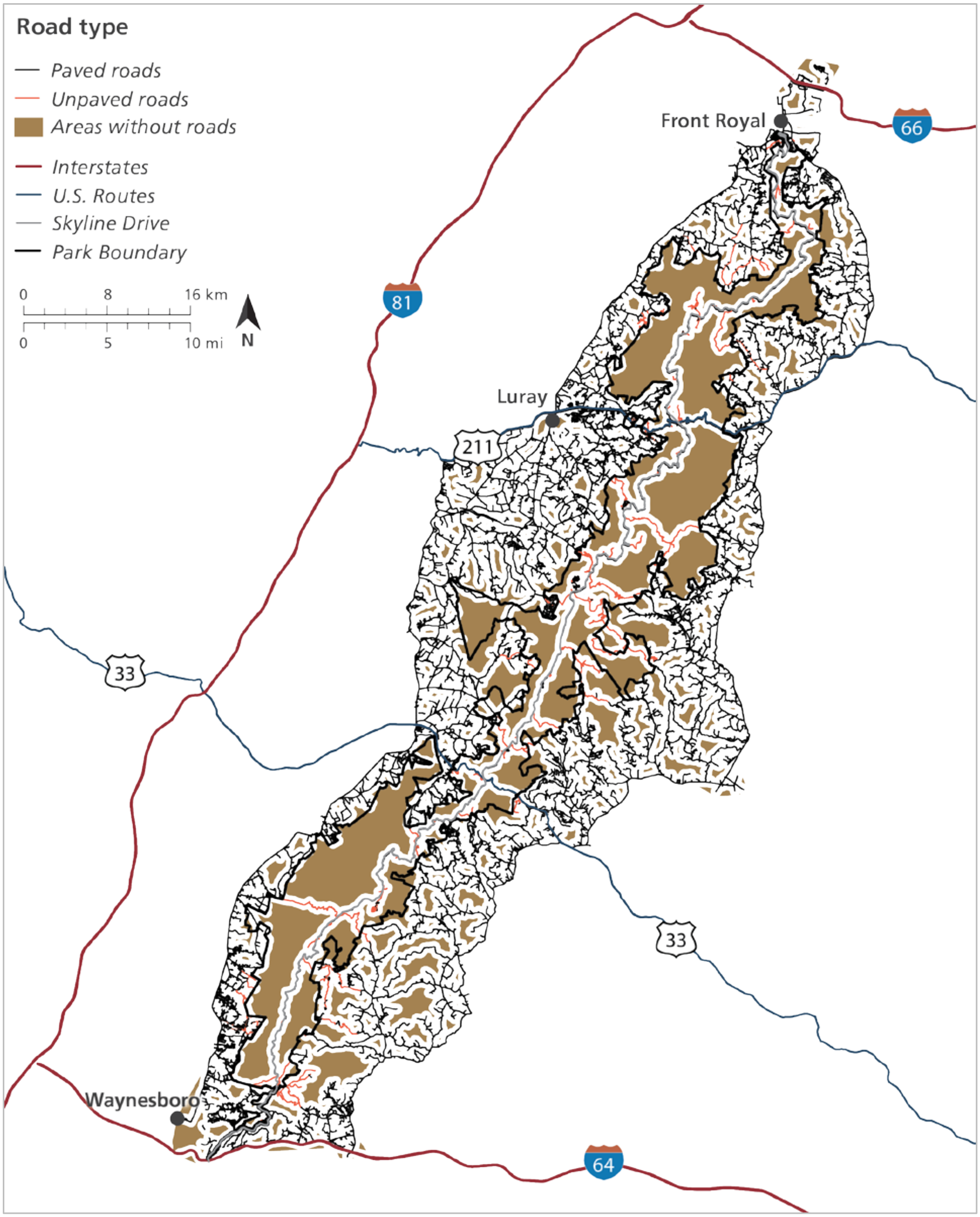

Figure 4-47. Areas of Shenandoah National Park >500 m from a road. Source: Alan Williams, National Park Service.

For this analysis, patches were divided at class boundaries, resulting in the exclusion of areas of patches that might extend outside each class. If the area of the entire patch were used instead of only the area within the class boundary, each of the high elevation classes would contain at least one roadless patch greater than 10 km2 in size, but this method would not capture the limitation of certain species' habitat affinity for high-elevations within the park.

Averaging together the attainment values for the three different road indicators provides an overall assessment score of 40% for the park (Table 4-29). The high elevation regions are the most impacted by roads with a 13% attainment score for High Granitic and an 8% attainment score for High Metabasaltic and Siliciclastic regions. This is due to the location of Skyline Drive splitting these narrow corridors of unique habitat.

Table 4-29. Road attainment scores for Shenandoah National Park.

Elevation	Geology	Road Density (< 1 km / km^2) Metric	Distance to Roads (> 500 m) Metric	Patch Coverage (>10km^2)	Average Score
< 915m	Granitic	100%	64%	50%	71%
	Metabasaltic	100%	52%	32%	61%
	Siliciclastic	100%	67%	60%	76%
> 915m	Granitic	0%	39%	0%	13%
	Metabasaltic	0%	22%	0%	8%
	Siliciclastic	0%	23%	0%	8%
Shenandoah National Park		**50%**	**45%**	**24%**	**40%**

<u>Data gaps and level of confidence</u>

Our confidence in the condition of the park relative to road stressors is moderate. The NPScape SOP for Road Measures (National Park Service 2013d) uses a weighted analysis to better understand the density of roads within areas of analysis. The values assigned to the road weights do not have a strong scientific rational, and the weighting makes comparisons to other non-weighted literature reference condition values difficult. The available data for Shenandoah National Park did not include feature class codes designating road type other than paved or unpaved. Therefore, weighting by road type beyond paved vs. total was not consided in the assessment. Estimating trends with road data is notably difficult because changes could result from construction of new roads, or simply from an update of the map and mapping techniques (Hawbaker and Radeloff 2004). Additionally, the roads layer extends only a few kilometers outside the park border, which could influence the comparison of road density inside the park to areas adjacent to the park boundary.

<u>Sources of expertise</u>

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4.4.4 Fire dependent systems

Relevance and context

Fire is a natural process within Appalachian forests. Fire suppression in the park over the last 80 years (as discussed in Section 2.4.4) shaped the park's current vegetation composition and structure. In addition, the legacy effects of this suppression have an ongoing impact on current fire regimes (e.g., Brose et al. 2001, also discussed in Section 2.4.4). For example, fire suppression has likely limited the regeneration of oaks and some pines (National Park Service 2005f). Fire removes leaf litter and duff, opens the canopy, and reduces competing vegetation, all of which contribute to the maintenance of pine communities (Zobel 1969, Williams 1991). Fire also allows for the persistence and spread of oak communities by removing competing species and facilitating the rapid germination of acorns on fire prepped soil (Abrams 1992, Brose et al. 2001, Brose 2010, Brose et al. 2013). Spatially, the distribution of forest communities that have evolved in the presence of frequent fire can be used as a guide for the restoration of fire disturbance to the park.

Fire season in the Appalachians is typically bimodal and occurs in the spring (February 15 to May 15) and fall (October 15 to December 15); however, fires can occur at any time when weather conditions, dry fuels and an ignition source align. The park's fire history dating back to the 1930's indicates many fires occurring on dry southwest facing slopes, particularly in the South District; however, during dry years fires are able to burn into topographically moist sites. Brose et al. (2014) found that the vast majority of the historic fire studies indicate these fires occurred in the dormant season. However, Cohen et al. (2007) found that xeric pine oak heath forests can ignite from lightning strikes in the summer and the resultant fires can burn for weeks, even with precipitation, covering large landscapes.

Fire effects are highly dependent on the spatial and temporal pattern of burning (Groeschl *et al.*1990). Data on fire effects are available from select burns in the park using Composite Burn Index (CBI) scores. The CBI scores quantify how fire has altered the biophysical conditions of a site based on observations of the following attributes: substrate, vegetation <1 m, vegetation 1-5 m, intermediate trees, and big trees (Key et al. 2004). At present, CBI data are not included in the final assessment of current condition and trend due to their spatial and temporal limitations. However, the CBI data indicate the high degree of variability both within and between fires in the park.

Data and methods

Building upon Young *et al*.'s (2009) classification of the dominant vegetation communities in the park, Mahan *et al.* (2012) describe five vegetation associations of fire tolerance class 1 or 2 (Table 4-30). These communities rely on fire for their persistence and have historically been associated with sites on which the fire return interval is less than seven years (Mahan *et al.* 2012). Notably, these communities are almost entirely located within the lower elevation region of the geo-elevation framework used for this assessment (Figure 4-48). The extent of area burned was interpreted from annual geospatial data on fires from 1923 to 2013 provided by the park. The spatial overlap of these fires was analyzed with respect to the distribution of the five fire-tolerant vegetation classes.

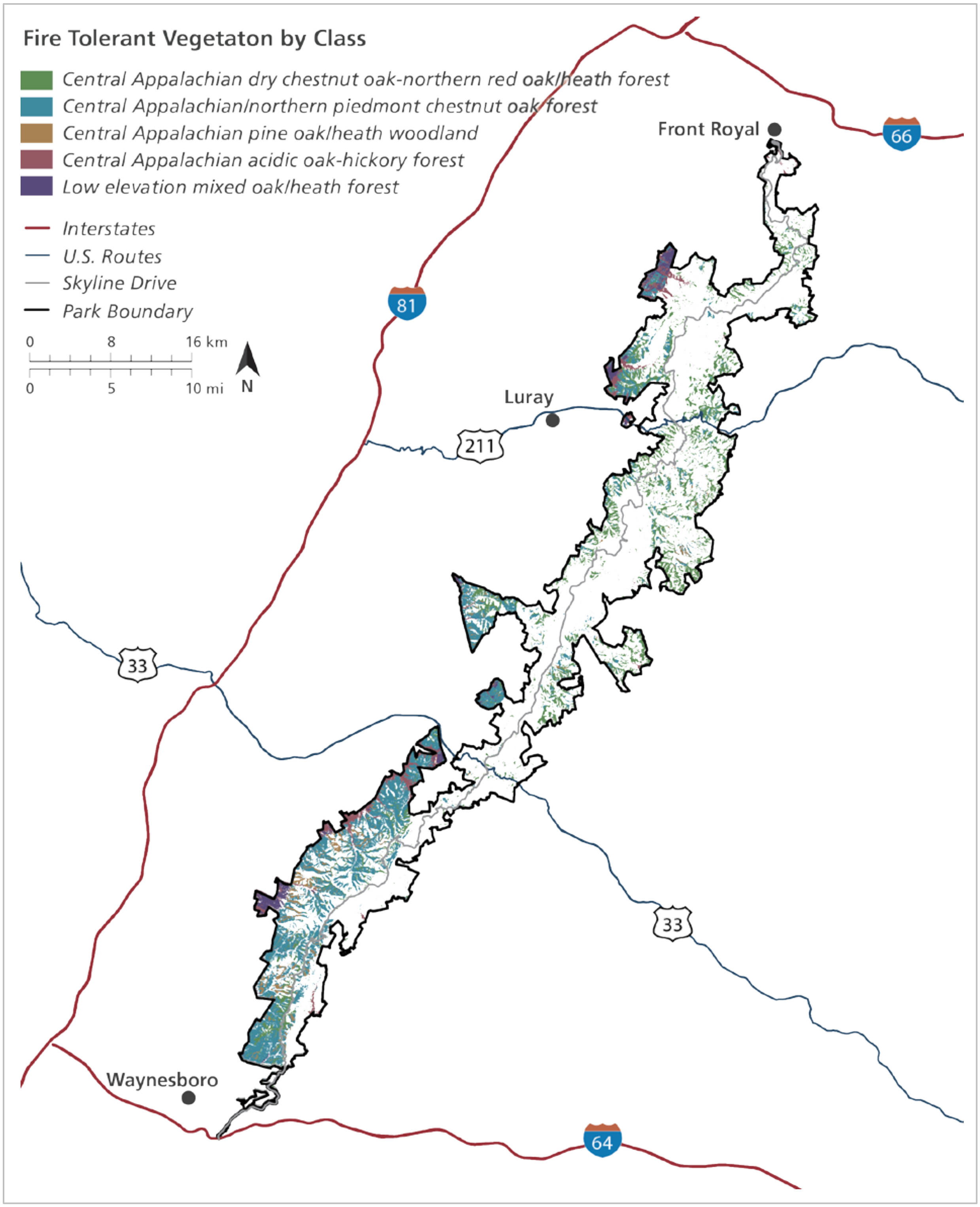

Figure 4-48. Spatial distribution of five fire-tolerant vegetation associations. Source: Young et al. 2009.

Table 4-30. Vegetation associations from Young *et al.* 2009 with a high fire tolerance.

Vegetation Community	Fire-Tolerance Class	Acres in Park
Central Appalachian Pine Oak/Heath Woodland	1	3,808
Central Appalachian Acidic Oak-Hickory Forest	2	5,326
Central Appalachian Dry Chestnut Oak-Northern Red Oak/Heath Forest	2	18,418
Central Appalachian/Northern Piedmont Chestnut Oak Forest	2	24,714
Low-Elevation Mixed Oak/Heath Forest	2	3,029

<u>Threshold</u>

Historical records indicate that the Blue Ridge province was the most fire prone area in the central Appalachian Mountains of Virginia and West Virginia from natural ignitions (Lafon *et al.* 2007, Cohen et al. 2007). In an analysis of 12 fire scar studies, Brose *et al.* (2014) found a pre-European settlement mean fire return interval in the Appalachians of every 5.8 years. Other experimental studies have suggested that return intervals of 15 years may be sufficient to reduce pine competition in fire-dependent oak ecosystems (Arthur *et al.* 2009). After the inception of fire control policies in the 1900's, the modern fire return interval in the Appalachian's has increased to every 32.4 years (Brose *et al.* 2014).

In prioritizing forest communities in the park for the use of prescribed fire, Mahan *et al.* (2012) described general conditions that can be used to guide fire treatments, including historical return intervals for these communities of 3-7 years (based on studies by Aldrich *et al.* 2010, 2014, and others). For the assessment, the percentage of these five communities that burned in seven-year increments was calculated with the assumption that 100% of the area of these forest communities should burn within that interval. Current condition was based on the percent of this fire dependent land that burned from 2007-2014. Trend was assessed by considering the amount of land that burned in seven-year increments dating back to 1923.

<u>Condition and trend</u>

The total number of fires in Shenandoah National Park has varied from an average of 10.3 per year in the 1930s to an average of 5.2 per year from 2000-2009. The distribution of fires in the park varied spatially for the seven-year study intervals depending on the specifics of individual fires (Figure 4-49). No regions of the park were notably more fire prone than others. The greatest acreage burned in the most recent seven-year period was in the Low Siliciclastic geo-elevation class (2,457 ac). The High Siliciclastic class had the highest percentage of its fire-tolerant land burn during the seven-year period (Table 4-31). Only 3,081 of the 55,295 acres of fire-tolerant vegetation communities in the park burned from 2007 to 2014. Averaging together the attainment scores for the six geo-elevation classes yields a current condition score of 4.4% for the park (Table 4-31). Fewer acres were burned in these fire dependent regions within the two most recent intervals relative to the 1993-2000 interval (Figure 4-50). However, after decades of strictly enforced fire exclusion, fire is slowly being introduced to the park. Prescribed fire and the ability to manage fire for multiple objectives, including natural resource benefit, is now supported by park management as described in the current

Fire Management Plan (National Park Service 2006c). Based on these changes in management, the trend was assessed as improving.

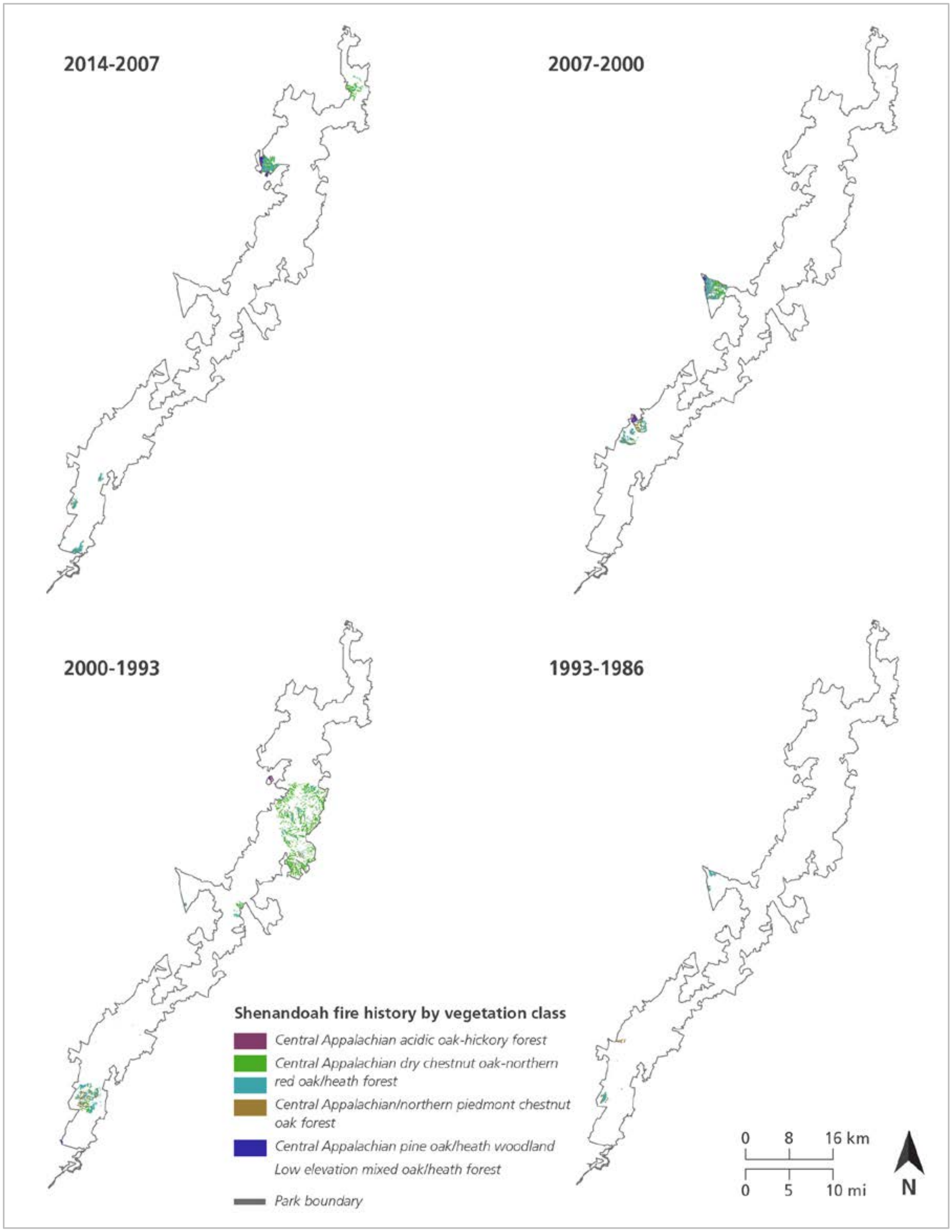

Figure 4-49. Spatial distribution of fires in Shenandoah National Park from 1986-2014. Source: Alan Williams, National Park Service.

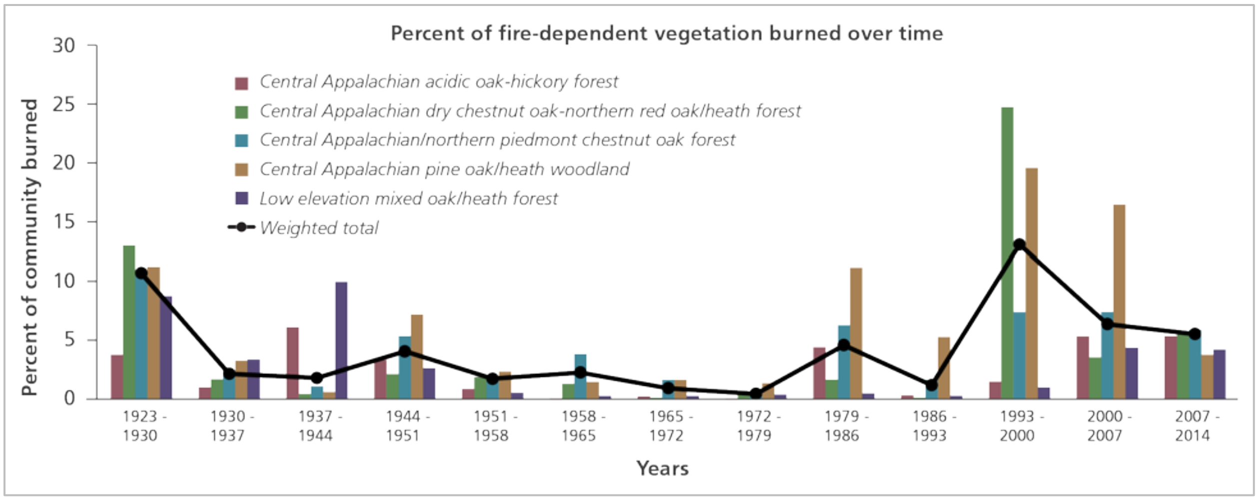

Figure 4-50. Percent of fire-dependent vegetation burned in Shenandoah National Park from 1923-2014. Source: Alan Williams, National Park Service.

Table 4-31. Fire attainment scores for Shenandoah National Park by geo-elevation regions.

Elevation	Geology	Acres of Fire-Tolerant Vegetation	Acres of Fire-Tolerant Vegetation Burned (2007-2014)	Attainment Score
< 915m	Granitic	13514.2	486.5	3.6%
	Metabasaltic	3321.9	130.1	3.9%
	Siliciclastic	37329.3	2,457.2	6.6%
> 915m	Granitic	965.2	0.2	0.0%
	Metabasaltic	100.9	0.0	0.0%
	Siliciclastic	63.8	7.9	12.3%
Shenandoah National Park		**55,295.2**	**3,081.8**	**4.4%**

Data gaps and level of confidence

Confidence in the overall assessment of fire return interval within fire dependent systems is low. Although recent estimates of fire extent are reliable, the spatial accuracy degrades considerably for the historical data, which are primarily point data with circles drawn around them representing the extent of the fires. The threshold estimate of a desirable return interval of seven years has a high level of uncertainty. For example, recent studies of fire dependent forests in the Central and Southern Appalachians have recorded fire return intervals for the entire landscape to be > 30 years (Fesenmyer & Christensen 2010, Brose *et al.* 2014). Using a longer return interval for the threshold would result in an evaluation of better condition for this indicator.

Ultimately, this single metric greatly simplifies the complex role of fire within the park's ecosystems. After more than 70 years of active fire suppression, the current condition of the park is highly compromised as reflected by the attainment score of 4.4%. However, simply reintroducing more frequent fire to the system is not adequate to ensure ecosystem recovery. For example, Mahan *et al.* (2012) provides detailed recommendations of desired future condition for the park's fire-dependent communities. It is important to note that one incident of fire is unlikely to restore these ecosystems to historical conditions. Brose *et al.* (2013) found that single prescribed burns conducted in closed canopy stands had little impact on regenerating oaks and pines in dry oak and pine forests. Multiple burns were shown to increase regeneration, especially when followed by a canopy disturbance.

Additional information on the intensity, timing, and severity of fires and of fire effects also would be useful to the assessment of this indicator. The park Fire Management Plan (National Park Service 2006c) recommends the implementation of growing season fires to best achieve the desired reduction in crown density. Burn severity is difficult to quantify (Jain 2004), and the Composite Burn Index (CBI) is a subjective measure with severity scores dependent upon the point of view of the observer (Lentile *et al.* 2006). Nevertheless, the CBI provides a promising data set for future assessments if additional samples continue to be collected along a broad swath of fires within fire dependent vegetation classes.

Sources of expertise

- Melissa Forder, Fire Ecologist, Shenandoah National Park, National Park Service

Chapter 5. Natural Resource Condition Summary

Shenandoah National Park is unique in that, unlike many other national parks throughout the country, it is a park resulting from managed regeneration. The park was created to enable land that had been heavily used over the centuries for farming, logging and mining to regenerate. The natural resources of the park today represent a remarkable recovery and example of what is possible through proper vision and environmental management. The biggest threat to the park today is not from within, rather from outside the parks' boundaries making management of the park more challenging than ever before. Air pollution, introduced species, disease, and changes in climate are likely to influence the future status of natural resources within the park.

Combining the percent attainment scores for air resources, terrestrial resources, aquatic resources, and landscape dynamics, Shenandoah National Park was determined to be in ***moderate condition*** (54% attainment of reference conditions). As discussed above, this score is strongly dictated by poor scores for indicators originating outside the park such as air quality and its effect on e.g. vistas.

5.1 Air resource summary

Air resources in Shenandoah National Park were of ***significant concern***, with wet sulfur and nitrogen deposition, ozone, and visibility all individually displaying levels of significant concern (Table 5-1, Table 5-2). Despite current poor air quality scores, air quality indicators are showing an overall improvement over recent decades, which will have positive implications for the parks natural ecosystems, particularly those with underlying siliciclastic geology.

Table 5-1. Summary of air resource condition in Shenandoah National Park.

Air resource indicator	Percent attainment of reference condition	Trend	Summary Condition
Wet sulfur deposition (kg/ha/yr)	13%	Improving	24% (Significant concern)
Wet nitrogen deposition (kg/ha/yr)	0%	Stable - improving	
Ozone (ppb)	40%	Improving	
Ozone W126 (ppb-hrs)	66%	Improving	
Visibility (dv)	0%	Improving	
Atmospheric mercury deposition	ID		
Air Resources		**Improving**	**24% (Significant concern)**

Table 5-2. Key findings, management implications, and recommended next steps for air resources in Shenandoah National Park.

Key findings	Management implications	Recommended next steps
Air quality is of significant concern and is a regional problem	• Ecological impacts from acidic deposition (i.e. acid rain).	• Support regional air quality initiatives such as Climate Friendly Parks (www.nps.gob/climatefriendlyparks) • Develop park-specific management actions. • Stay engaged with the wider community in terms of air quality education and activities. • Monitor recovery of ecosystems as/if air quality continues to improve.
Minimal soundscape information	• Traffic noise from roadway potentially affects wildlife distribution and recreational experience. • Effect is greater in fall and winter when foliage not able to dampen noise.	• Conduct a noise/soundscape study to determine if management is required.

5.2 Terrestrial resource summary

Terrestrial resources in Shenandoah National Park were in ***moderate condition*** (Table 5-3, Table 5-4). Birds, forest vegetation, and rare, threatened, endangered plants were generally in stable, good condition. Vegetation conditions in Big Meadows have improved with the implementation of mowing and burning management since 2000, but those gains are in danger of being lost as shrub cover has increased in the upland region of the meadow since 2004. Deer overpopulation is a significant problem throughout the Mid-Atlantic and the population levels observed in the Big Meadows Area fall within the general range of concern observed within other parks of the region. Non-native plant invasions represent an increasing threat throughout the park.

Table 5-3. Summary of terrestrial resource condition in Shenandoah National Park.

Terrestrial resource indicator	Elevation	Geology type	Percent attainment of reference condition	Trend	Summary Condition
Big Meadows Area			33%	Stable	33% (Moderate)
Native Vegetation	< 915m	Granitic	83%	Stable	73% (Moderate)
		Metabasaltic	79%		
		Siliciclastic	79%		
	> 915m	Granitic	55%		
		Metabasaltic	78%		
		Siliciclastic	61%		
Non-native Vegetation	< 915m	Granitic	37%	Worsening	44% (Moderate)
		Metabasaltic	11%		
		Siliciclastic	88%		
	> 915m	Granitic	83%		
		Metabasaltic	42%		
		Siliciclastic	0%		
Birds			82%		82% (Good)
Terrestrial Resources					**58% (Moderate)**

Table 5-4. Key findings, management implications, and recommended next steps for terrestrial resources in Shenandoah National Park.

Key findings	Management implications	Recommended next steps
Overabundant deer populations and continuing problems with shrub encroachment in the Big Meadows Area	• Open landscapes have both natural and cultural resource benefits. • Impaired meadow would reduce visitor experience.	• Continue mowing/prescribed burning management with photopoint and vegetation monitoring of the main meadow with consideration of fall burns. • Extend deer surveys beyond BMA and monitor for chronic wasting disease and effects of increasing coyote population. • Study deer effects on vegetation and interactions with non-native species.
Park is host to at least 58 rare plant species and a biodiverse forest vegetation with stable regeneration of native species but possibly declining canopy condition	• Diversity and health of native vegetation acts as early warning of environmental stress. • Provides habitat for diverse fauna. • Interacts with stream water quality and quantity.	• Continue forest vegetation monitoring and rare plant monitoring protocols that provide vital data on park trends. • Expand monitoring for early detection of non-native species and expand treatment efforts for invasive plants. • Educate public to reduce impacts of emerald ash borer and other harmful introductions.
Bird populations remain diverse though abundance appears to be declining	• Healthy bird populations are vital to visitor experience. • Potential proxy/indicator for changes in habitat suitability within the park or along flight-path. • Provide seed dispersal within the park.	• Investigate causes of declining bird populations. • Investigate impacts of ongoing declines in bird populations to park ecology.

5.3 Aquatic resource summary

Aquatic resources in Shenandoah National Park were in ***moderate condition***, based on water quality and macroinvertebrates assessments (Table 5-5, Table 5-6). Lowest scores for all aquatic resource indicators belonged to the Siliciclastic geology, reflecting the susceptibility of this geology type to acidification. The assessment of aquatic resources was limited by insufficient data at high elevations and particularly in High (>915 m) Siliciclastic geologies, making overall comparisons between elevations not possible.

Table 5-5. Summary of aquatic resource condition in Shenandoah National Park.

Aquatic resource indicator	Elevation	Geology type	Percent attainment of reference condition	Trend	Summary Condition
Water Quality	< 915m	Granitic	84%		74% (Moderate)
		Metabasaltic	84%		
		Siliciclastic	58%		
	> 915m	Granitic	60%*		
		Metabasaltic	82%		
		Siliciclastic	ID		
Macroinvertebrates	< 915m	Granitic	83%		72% (Moderate)
		Metabasaltic	82%		
		Siliciclastic	42%		
	> 915m	Granitic	ID		
		Metabasaltic	82%		
		Siliciclastic	ID		
Aquatic Resources					**73% (Moderate)**

* n =1

Table 5-6. Key findings, management implications, and recommended next steps for water resources in Shenandoah National Park.

Key findings	Management implications	Recommended next steps
Significant concern for pH and ANC in streams with underlying siliciclastic geology classes	• Acidic conditions affect stream flora and fauna. • Reduces biodiversity and quality of visitor experience.	• Gather additional data for water quality in high elevations.
Moderate – significant concern for temperature across all geo-elevation classes	• Affects stream flora and fauna. • Reduces biodiversity and quality of visitor experience.	• Implement stream restoration and shading via restored riparian vegetation in disturbed areas.
Lack of reference condition for native fish size and abundance	• Unable to adequately assess condition of fish in this report. • No clear long-term vision for fish restoration.	• Develop goal for native fish restoration.

5.4 Landscape dynamics summary

Landscape dynamics in Shenandoah National Park were in ***moderate condition*** (Table 5-7, Table 5-8). The viewshed and largely intact forest cover are distinctive attributes of the park, although land cover changes outside of the park are a concern. Paved and unpaved roads bisect the park, especially Skyline Drive at high elevations, but are generally less abundant in the park than in the surrounding landscape. A legacy of fire suppression is a primary concern, and the park has begun conducting prescribed fires in dry oak and pine ecosystems in an effort to restore the ecological resilience and integrity of these forested communities. Prescribed fires will be implemented during dormant and growing seasons with a targeted rotation of every 5-7 years. The park is authorized in the 2006 Fire Management Plan to manage wildfire for multiple objectives, which may include natural resource benefit.

Table 5-7. Summary of landscape dynamic condition in Shenandoah National Park.

Landscape dynamics indicator	Elevation	Geology type	Percent attainment of reference condition	Trend	Summary Condition
Viewshed	< 915m		81%	Worsening	91% (Good)
	> 915m		100%		
Land Cover	< 915m	Granitic	100%	Stable	100% (Good)
		Metabasaltic	100%		
		Siliciclastic	100%		
	> 915m	Granitic	100%		
		Metabasaltic	100%		
		Siliciclastic	100%		
Roads	< 915m	Granitic	71%		40% (Moderate)
		Metabasaltic	61%		
		Siliciclastic	76%		
	> 915m	Granitic	13%		
		Metabasaltic	8%		
		Siliciclastic	8%		
Fire	< 915m	Granitic	4%	Improving	4% (Significant concern)
		Metabasaltic	4%		
		Siliciclastic	7%		
	> 915m	Granitic	0%		
		Metabasaltic	0%		
		Siliciclastic	12%		
Landscape Dynamics					**59% (Moderate)**

Table 5-8. Key findings, management implications, and recommended next steps for landscape resources in Shenandoah National Park.

Key findings	Management implications	Recommended next steps
Viewsheds comprised of nearly 10% developed land	• Worsening trend has potential to impair visitor experience.	• Maintain dialogue with George Washington & Jefferson National Forest and other neighbors about future land use / land cover trajectories, especially for locations viewable from multiple park vantage points. • Monitor how improving air quality affects range of visibility. • Gather additional data on sensitivity of visitors to development in the viewshed; refine "acceptable" level of development threshold value.
Intact forest land cover of diverse community associations is a primary natural resource asset	• Forest core habitat contributes to park biodiversity. • Large forest patches are central to wilderness experience.	• Track any significant changes in forest extent potentially triggered by emergent forest pests and pathogens. • Consider periodically updating the park-level, detailed mapping of forest vegetation associations.
Paved roads concentrated in the upper elevations of the park	• Fragmentation and pollution effects are possible from paved and unpaved roads.	• New road development within the park could consider the spatial balance of existing roads and avoid regions of highest density. • Continue studies of possible runoff effects adjacent and downslope of roads.
Legacy of fire suppression has negatively impacted fire-tolerant forest communities	• Fuel build-ups lead to forest fire danger and potentially hotter fires. • Altered fire regime may affect forest assemblage and habitat quality.	• Manage ignitions for natural resource benefit in identified fire dependent vegetation associations. • Continue monitoring of fire effects and link observations to fire prescriptions. • Consider interactions of fire with other disturbance vectors on the landscape.

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Appendix A: Rare, Threatened and Endangered Plants

Species lists sourced from NPSpecies website - https://irma.nps.gov/NPSpecies/Search/SpeciesList/SHEN

Source: Alan Williams and Wendy Cass

Scientific Name	Common Name	Presence	Status	G_rank	S_rank
Abies balsamea	Balsam fir	CONFIRMED	RARE	G5	S1
Alnus incana (L.) Moench	Speckeld alder	CONFIRMED	RARE	G5T5	S2
Aralia hispida Ventenat.	Bristly sarsaparilla	CONFIRMED	RARE	G5	S2
Arctostaphylos uva ursi (L.) Spreng. ssp. coactilis (Fern. & MacBr.)	Bearberry	CONFIRMED	RARE	G5	S1
Asplenium bradleyi D. Eat.	Bradley's spleenwort	CONFIRMED	RARE	G4	S2
Betula cordifolia	Mountain paper birch	CONFIRMED	RARE	G5	S2
Betula populifolia Marsh.	Gray birch	CONFIRMED	RARE	G5	S1
Botrychium multifidum (Gmel.) Rupr. var. intermedium (D.C.Eat.) Farw	Leathery grape-fern	CONFIRMED	RARE	G5	S1
Botrychium simplex E.Hitchcock.	Least grape-fern	CONFIRMED	RARE	G5T5	S1
Bromus ciliatus L.	Fringed brome grass	CONFIRMED	RARE	G5	S1
Carex buxbaumii Wahl.	Buxbaum's sedge	CONFIRMED	RARE	G5	S2
Carex conoidea Willd.	Field sedge	CONFIRMED	RARE	G5	S1S2
Carex leptonervia Fern.	Finely-nerved sedge	CONFIRMED	WATCH	G4	S3
Carex polymorpha Muhl.	Variable sedge	CONFIRMED	RARE	G3	S2
Clematis occidentalis var. occidentalis	western blue virginsbower	CONFIRMED	RARE	G5T5	S2
Conioselinum chinense (L.) BSP.	Hemlock parsley	CONFIRMED	RARE	G5	S1
Cornus canadensis L.	Bunchberry	CONFIRMED	RARE	G5	S1
Cornus rugosa Lam.	Roundleaf dogwood	CONFIRMED	RARE	G5	S1
Cuscuta coryli Engelm.	Hazel dodder	CONFIRMED	RARE	G5?	S2?
Eleocharis compressa	flatstem spikerush	CONFIRMED	RARE	G4	S2
Epilobium leptophyllum Raf.	Linear-leaved willow herb	CONFIRMED	RARE	G5	S2
Euphorbia purpurea (Raf.) Fern.	Glade spurge	CONFIRMED	RARE	G3	S2

Scientific Name	Common Name	Presence	Status	G_rank	S_rank
Eurybia radula	Rough-leaved aster	CONFIRMED	RARE	G5	S1
Geranium robertianum L.	Herb-robert	CONFIRMED	WATCH	G5	S3
Gnaphalium uliginosum L.	Low cudweed	CONFIRMED	RARE	G5	S1
Gymnocarpium appalachianum	Appalachian oak fern	CONFIRMED	WATCH	G3	S3
Huperzia appalachiana	Appalachian fir clubmoss	CONFIRMED	RARE	G5	S2
Iris versicolor L.	harlequin blueflag	CONFIRMED	WATCH	G5	S3
Isotria medeoloides	Small whorled pogonia	CONFIRMED	RARE	G2LT	S2LE
Juglans cinerea L.	Butternut	CONFIRMED	WATCH	G4	S3?
Juncus trifidus L. var. monanthos (Jacq.) Bluff. & Fing.	Highland rush	CONFIRMED	RARE	G5	S1
Lilium philadelphicum L.	Philadelphia Lilly	CONFIRMED	WATCH	G5	S3
Lonicera canadensis Bartr.	American Fly Honeysuckle	CONFIRMED	WATCH	G5	S3
Menyanthes trifoliata L.	Buckbean	CONFIRMED	RARE	G5	S1
Minuartia groenlandica (Retz.) Ostenf.	Mountain sandwort	CONFIRMED	RARE	G5	S1
Muhlenbergia glomerata (Willd.) Trin.	Marsh muhly	CONFIRMED	RARE	G5	S2
Ophioglossum engelmannii	Limestone adderstongue	CONFIRMED	WATCH	G5	S3
Panax quinquefolius L.	Ginseng	CONFIRMED	WATCH	G3G4	S3S4LT
Paxistima canbyi Gray.	Canby's mountain-lover	CONFIRMED	RARE	G2	S2
Phlox buckleyi Wherry.	Sword-leaved phlox	CONFIRMED	RARE	G2	S2
Platanthera grandiflora	Large purple fringed orchid	CONFIRMED	RARE	G5	S1
Poa paludigena Fern. & Wieg.	Bog bluegrass	CONFIRMED	RARE	G3	S2
Populus tremuloides Michx.	Quaking aspen	CONFIRMED	RARE	G5	S2
Prunus nigra Ait.	Canada plum	CONFIRMED	RARE	G4G5	S1?
Pycnanthemum clinopodioides	basil mountainmint	CONFIRMED	RARE	G1G2	S1
Pycnanthemum torrei	Torrey's mountain mint	CONFIRMED	RARE	G2	S2?
Pyrola elliptica Nutt.	Shinleaf	CONFIRMED	RARE	G5	S2

Scientific Name	Common Name	Presence	Status	G_rank	S_rank
Rhamnus alnifolia L'Her.	Alderleaf buckthorn	CONFIRMED	RARE	G5	S1
Rubus idaeus L. var. strigosus (Michx.) Maxim.	Red raspberry	CONFIRMED	RARE	G5T5	S2
Sanguisorba canadensis L.	Canada burnet	CONFIRMED	RARE	G5	S2
Sibbaldiopsis tridentata	Three-toothed cinquifoil	CONFIRMED	RARE	G5	S2
Solidago rigida L.	Stiff goldenrod	CONFIRMED	RARE	G5T5	S2
Solidago simplex var. randii	Rand's goldenrod	CONFIRMED	RARE	G4	S2S3
Sporobolus compositus var. compositus	tall dropseed	CONFIRMED	RARE	G5/T5	S1S2
Streptopus amplexifolius (L.) DC.	White mandarin	CONFIRMED	RARE	G5	S1
Trifolium virginicum	Kates Mountain clover	CONFIRMED	WATCH	G3	S3
Trisetum spicatum (L.) Richter var. molle (Michx.) Beal	Narrow false oats	CONFIRMED	RARE	G5	S1
Vaccinium myrtilloides Michx.	Velvet leaf blueberry	CONFIRMED	RARE	G5	S1S2
Abies balsamea	Balsam fir	CONFIRMED	RARE	G5	S1
Alnus incana (L.) Moench	Speckeld alder	CONFIRMED	RARE	G5T5	S2
Aralia hispida Ventenat.	Bristly sarsaparilla	CONFIRMED	RARE	G5	S2
Arctostaphylos uva ursi (L.) Spreng. ssp. coactilis (Fern. & MacBr.)	Bearberry	CONFIRMED	RARE	G5	S1
Asplenium bradleyi D. Eat.	Bradley's spleenwort	CONFIRMED	RARE	G4	S2
Betula cordifolia	Mountain paper birch	CONFIRMED	RARE	G5	S2
Betula populifolia Marsh.	Gray birch	CONFIRMED	RARE	G5	S1
Botrychium multifidum (Gmel.) Rupr. var. intermedium (D.C.Eat.) Farw	Leathery grape-fern	CONFIRMED	RARE	G5	S1
Botrychium simplex E.Hitchcock.	Least grape-fern	CONFIRMED	RARE	G5T5	S1
Bromus ciliatus L.	Fringed brome grass	CONFIRMED	RARE	G5	S1
Carex buxbaumii Wahl.	Buxbaum's sedge	CONFIRMED	RARE	G5	S2
Carex conoidea Willd.	Field sedge	CONFIRMED	RARE	G5	S1S2
Carex leptonervia Fern.	Finely-nerved sedge	CONFIRMED	WATCH	G4	S3

Scientific Name	Common Name	Presence	Status	G_rank	S_rank
Carex polymorpha Muhl.	Variable sedge	CONFIRMED	RARE	G3	S2
Clematis occidentalis var. occidentalis	western blue virginsbower	CONFIRMED	RARE	G5T5	S2
Conioselinum chinense (L.) BSP.	Hemlock parsley	CONFIRMED	RARE	G5	S1
Cornus canadensis L.	Bunchberry	CONFIRMED	RARE	G5	S1
Cornus rugosa Lam.	Roundleaf dogwood	CONFIRMED	RARE	G5	S1
Cuscuta coryli Engelm.	Hazel dodder	CONFIRMED	RARE	G5?	S2?
Eleocharis compressa	flatstem spikerush	CONFIRMED	RARE	G4	S2
Epilobium leptophyllum Raf.	Linear-leaved willow herb	CONFIRMED	RARE	G5	S2
Euphorbia purpurea (Raf.) Fern.	Glade spurge	CONFIRMED	RARE	G3	S2
Eurybia radula	Rough-leaved aster	CONFIRMED	RARE	G5	S1
Geranium robertianum L.	Herb-robert	CONFIRMED	WATCH	G5	S3
Gnaphalium uliginosum L.	Low cudweed	CONFIRMED	RARE	G5	S1
Gymnocarpium appalachianum	Appalachian oak fern	CONFIRMED	WATCH	G3	S3
Huperzia appalachiana	Appalachian fir clubmoss	CONFIRMED	RARE	G5	S2
Iris versicolor L.	harlequin blueflag	CONFIRMED	WATCH	G5	S3
Isotria medeoloides	Small whorled pogonia	CONFIRMED	RARE	G2LT	S2LE
Juglans cinerea L.	Butternut	CONFIRMED	WATCH	G4	S3?
Juncus trifidus L. var. monanthos (Jacq.) Bluff. & Fing.	Highland rush	CONFIRMED	RARE	G5	S1
Lilium philadelphicum L.	Philadelphia Lilly	CONFIRMED	WATCH	G5	S3
Lonicera canadensis Bartr.	American Fly Honeysuckle	CONFIRMED	WATCH	G5	S3
Menyanthes trifoliata L.	Buckbean	CONFIRMED	RARE	G5	S1
Minuartia groenlandica (Retz.) Ostenf.	Mountain sandwort	CONFIRMED	RARE	G5	S1
Muhlenbergia glomerata (Willd.) Trin.	Marsh muhly	CONFIRMED	RARE	G5	S2
Ophioglossum engelmannii	Limestone adderstongue	CONFIRMED	WATCH	G5	S3
Panax quinquefolius L.	Ginseng	CONFIRMED	WATCH	G3G4	S3S4LT
Paxistima canbyi Gray.	Canby's mountain-lover	CONFIRMED	RARE	G2	S2

Scientific Name	Common Name	Presence	Status	G_rank	S_rank
Phlox buckleyi Wherry.	Sword-leaved phlox	CONFIRMED	RARE	G2	S2
Platanthera grandiflora	Large purple fringed orchid	CONFIRMED	RARE	G5	S1
Poa paludigena Fern. & Wieg.	Bog bluegrass	CONFIRMED	RARE	G3	S2
Populus tremuloides Michx.	Quaking aspen	CONFIRMED	RARE	G5	S2
Prunus nigra Ait.	Canada plum	CONFIRMED	RARE	G4G5	S1?
Pycnanthemum clinopodioides	basil mountainmint	CONFIRMED	RARE	G1G2	S1
Pycnanthemum torrei	Torrey's mountain mint	CONFIRMED	RARE	G2	S2?
Pyrola elliptica Nutt.	Shinleaf	CONFIRMED	RARE	G5	S2
Rhamnus alnifolia L'Her.	Alderleaf buckthorn	CONFIRMED	RARE	G5	S1
Rubus idaeus L. var. strigosus (Michx.) Maxim.	Red raspberry	CONFIRMED	RARE	G5T5	S2
Sanguisorba canadensis L.	Canada burnet	CONFIRMED	RARE	G5	S2
Sibbaldiopsis tridentata	Three-toothed cinquifoil	CONFIRMED	RARE	G5	S2
Solidago rigida L.	Stiff goldenrod	CONFIRMED	RARE	G5T5	S2
Solidago simplex var. randii	Rand's goldenrod	CONFIRMED	RARE	G4	S2S3
Sporobolus compositus var. compositus	tall dropseed	CONFIRMED	RARE	G5/T5	S1S2
Streptopus amplexifolius (L.) DC.	White mandarin	CONFIRMED	RARE	G5	S1
Trifolium virginicum	Kates Mountain clover	CONFIRMED	WATCH	G3	S3
Trisetum spicatum (L.) Richter var. molle (Michx.) Beal	Narrow false oats	CONFIRMED	RARE	G5	S1
Vaccinium myrtilloides Michx.	Velvet leaf blueberry	CONFIRMED	RARE	G5	S1S2
Abies balsamea	Balsam fir	CONFIRMED	RARE	G5	S1
Alnus incana (L.) Moench	Speckeld alder	CONFIRMED	RARE	G5T5	S2
Aralia hispida Ventenat.	Bristly sarsaparilla	CONFIRMED	RARE	G5	S2
Arctostaphylos uva ursi (L.) Spreng. ssp. coactilis (Fern. & MacBr.)	Bearberry	CONFIRMED	RARE	G5	S1

Appendix B: Virginia Invasive Plant Species List 2014

Species list sourced from NPSpecies website - https://irma.nps.gov/NPSpecies/Search/SpeciesList/SHEN

Citation: Heffernan, K.E., and C. Richardson. 2015. Identifying and Ranking Invasive Plant Species in Virginia. Virginia Department of Conservation and Recreation. Natural Heritage Technical Document, Richmond, VA.

Scientific Name	Common Name	VA Invasiveness Rank
Ailanthus altissima	*Tree-of-heaven*	High
*Aldrovanda vesiculosa**	*Waterwheel*	High
Alliaria petiolata	*Garlic Mustard*	High
Alternanthera philoxeroides	*Alligator-weed*	High
Ampelopsis brevipedunculata	*Porcelain-berry*	High
Carex kobomugi	*Japanese Sand Sedge*	High
Celastrus orbiculatus	*Oriental Bittersweet*	High
Centaurea stoebe ssp. micranthos	*Spotted Knapweed*	High
Cirsium arvense	*Canada Thistle*	High
Dioscorea polystachya	*Cinnamon Vine*	High
*Eichhornia crassipes**	*Water Hyacinth*	High
Elaeagnus umbellata	*Autumn Olive*	High
Euonymus alatus	*Winged Euonymus*	High
Ficaria verna	*Lesser Celandine*	High
Hydrilla verticillata	*Hydrilla*	High
*Imperata cylindrica**	*Cogon Grass*	High
Iris pseudacorus	*Yellow Flag*	High
Lespedeza cuneata	*Sericea Lespedeza*	High
Ligustrum sinense	*Chinese Privet*	High
Lonicera japonica	*Japanese Honeysuckle*	High
Lonicera maackii	*Amur Honeysuckle*	High
Lonicera morrowii	*Morrow's Honeysuckle*	High
*Ludwigia grandiflora ssp. hexapetala**	Large flower primrose willow	High
Lythrum salicaria	Purple Loosestrife	High
Microstegium vimineum	Japanese Stiltgrass	High
Murdannia keisak	Marsh dewflower	High
Myriophyllum aquaticum	Parrot Feather	High
Myriophyllum spicatum	Eurasian Water-milfoil	High

*Early detection species not yet established in Virginia.

Scientific Name	Common Name	VA Invasiveness Rank
*Oplismenus hirtellus ssp. undulatifolius**	Wavyleaf Grass	High
Persicaria perfoliata	Mile-a-minute	High
Phragmites australis ssp. australis	Common Reed	High
Pueraria montana var.lobata	Kudzu	High
Reynoutria japonica	Japanese knotweed	High
Rosa multiflora	Multiflora Rose	High
Rubus phoenicolasius	Wineberry	High
Sorghum halepense	Johnson Grass	High
Urtica dioica	European Stinging Nettle	High
*Vitex rotundifolia**	Beach Vitex	High
Acer platanoides	Norway Maple	Medium
Agrostis capillaris	Colonial bent-grass	Medium
Akebia quinata	Five-leaf Akebia	Medium
Albizia julibrissin	Mimosa	Medium
Arthraxon hispidus var. hispidus	Joint Head Grass	Medium
Berberis thunbergii	Japanese Barberry	Medium
Cirsium vulgare	Bull Thistle	Medium
Dipsacus fullonum	Wild Teasel	Medium
Egeria densa	Brazilian Waterweed	Medium
Euonymus fortunei	Winter Creeper	Medium
Glechoma hederacea	Gill-over-the-ground	Medium
Hedera helix	English ivy	Medium
*Heracleum mantegazzianum**	Giant Hogweed	Medium
Holcus lanatus	Common Velvet Grass	Medium
Humulus japonicus	Japanese Hops	Medium
*Ipomoea aquatica**	Water spinach	Medium
Ligustrum obtusifolium var. obtusifolium	Border privet	Medium
Lonicera tatarica	Tartarian Honeysuckle	Medium
Lysimachia nummularia	Moneywort	Medium
Miscanthus sinensis	Chinese Silvergrass	Medium
Najas minor	Brittle Naiad	Medium
Paulownia tomentosa	Royal Paulowina	Medium
Persicaria longiseta	Long-bristled Smartweed	Medium
Phyllostachys aurea	Golden Bamboo	Medium
Poa compressa	Flat-stemmed Bluegrass	Medium

*Early detection species not yet established in Virginia.

Scientific Name	Common Name	VA Invasiveness Rank
Poa trivialis	Rough Bluegrass	Medium
Pyrus calleryana	Callery Pear	Medium
Rhodotypos scandens	Jetbead	Medium
Rumex acetosella	Sheep sorrel	Medium
*Salvinia molesta**	Giant Salvinia	Medium
*Solanum viarum**	Tropical Soda Apple	Medium
Spiraea japonica	Japanese Spiraea	Medium
Stellaria media	Common Chickweed	Medium
Veronica hederifolia	Ivy-leaved Speedwell	Medium
Viburnum dilatatum	Linden arrow-wood	Medium
Wisteria sinensis	Chinese Wisteria	Medium
Commelina communis	Asiatic Dayflower	Low
Elaeagnus pungens	Thorny Olive	Low
Lespedeza bicolor	Shrubby Bushclover	Low
Lonicera fragrantissima	Winter Honeysuckle	Low
Melia azedarach	Chinaberry	Low
Morus alba	White Mulberry	Low
Perilla frutescens	Beefsteak Plant	Low
Phleum pratense	Timothy	Low
Populus alba	Silver Poplar	Low
Rumex crispus ssp. crispus	Curly dock	Low
Securigera varia	Crown-vetch	Low
Trapa natans	European Water Chestnut	Low
Ulmus pumila	Siberian Elm	Low
Vinca major	Greater Periwinkle	Low
Vinca minor	Periwinkle	Low
Wisteria floribunda	Japanese Wisteria	Low

*Early detection species not yet established in Virginia.

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National Park Service
U.S. Department of the Interior

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