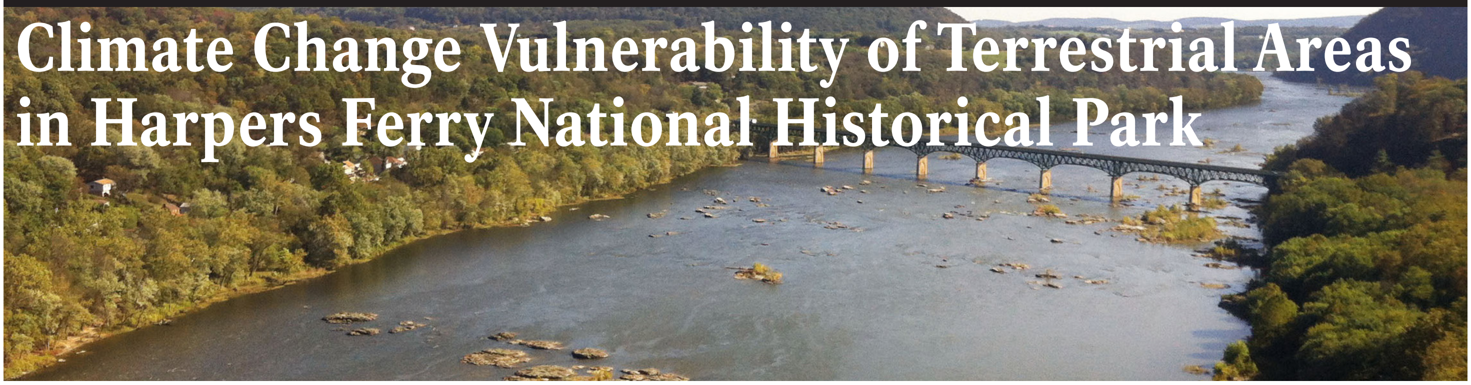
National Park Service
U.S. Department of the Interior

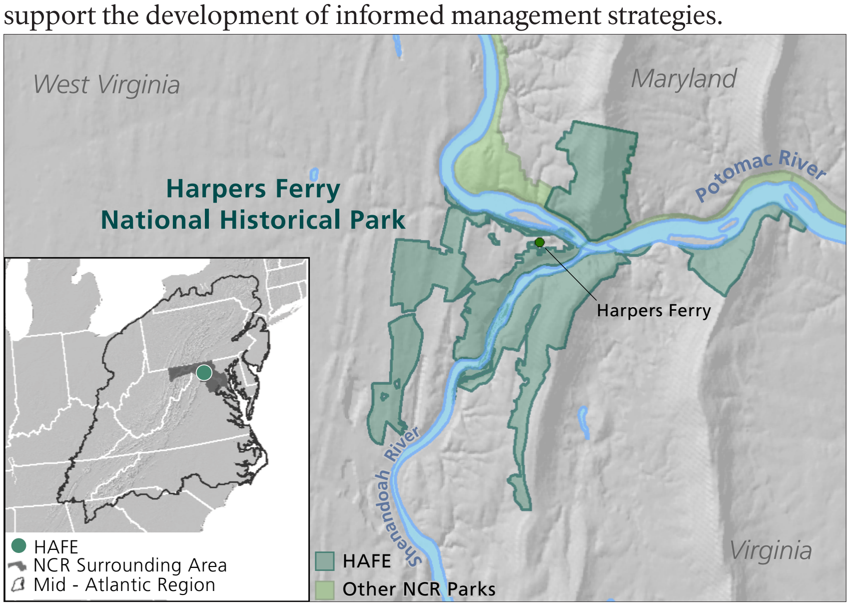
National Capital Region
Natural Resources and Science

Climate Change Vulnerability of Terrestrial Areas in Harpers Ferry National Historical Park



PLANNING FOR CHANGE

Located in a zone of ecological transition, where the Ridge and Valley, Blue Ridge, and Northern Piedmont meet, **Harpers Ferry National Historical Park (HAFE)** supports a diversity of natural communities. As a 3,600 acre protected area within a landscape heavily pressured by development, the park provides opportunities for ecological adaptation in the face of environmental change. However, as global temperatures rise and precipitation patterns become more extreme (Intergovernmental Panel for Climate Change (IPCC) 2013), the ***natural habitats*** (see glossary, page 9, for definition of italicized words) of the park are increasingly vulnerable to climate-driven stresses. To begin to understand how climate change will impact terrestrial habitats in the National Capital Region (NCR), the National Park Service partnered with NatureServe to conduct **climate change vulnerability assessments**. This initial assessment for Harpers Ferry National Historical Park examines how climate and landscape influence vulnerability and identifies areas most and least vulnerable today and in the near future. Our goal is to help park managers and visitors understand climate change vulnerability and support the development of informed management strategies.



IMPORTANT TERMS

VULNERABILITY Describes whether the ecological condition of a region or habitat is at risk from climate change impacts.

EXPOSURE Describes the nature and magnitude of changes in temperature and precipitation by comparing a given time period against a historical baseline.

ADAPTIVE CAPACITY Describes the ability of a region or habitat to maintain species and ecological processes as climate changes. Adaptive capacity at a specific location considers the area's unique physical features and its connectivity to other natural areas.

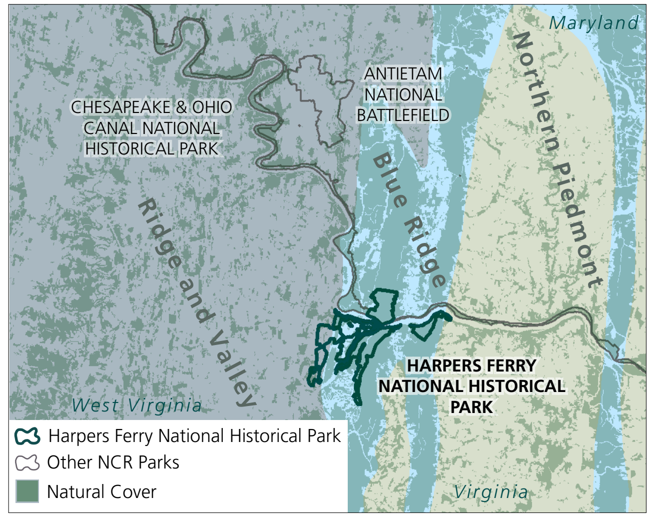
HARPERS FERRY NATIONAL HISTORICAL PARK is located in the northwestern portion of the NCR, where the Potomac and the Shenandoah River meet. We consider the implications of climate change for the park within the context of the NCR surrounding area and the Mid-Atlantic region.

WHAT IS CLIMATE CHANGE VULNERABILITY?

We define **VULNERABILITY** as the risk of losing species and ecosystem processes due to rapid environmental change. We integrate two components of vulnerability, **EXPOSURE** and **ADAPTIVE CAPACITY**, to arrive at a single measure. Areas most at risk are those likely to experience big changes in temperature and precipitation (i.e., high exposure) but have little capacity to adapt (i.e., low adaptive capacity). To understand how the climate of Harpers Ferry National Historical Park is changing over time, we analyzed temperature and precipitation over two time periods: **observed** (1981 – 2014) and **near future** (through 2040), compared to a mid-century **baseline** (1948 – 1980). The results presented here are part of a broader regional assessment of vulnerability for 11 NCR parks and the surrounding National Capital Region, interpreted in the context of regional environmental change in the Mid-Atlantic. Our approach describes drivers of ***climate change*** vulnerability, how vulnerability is spatially distributed, and a framework for park managers to anticipate and address changes in the coming decades.

HOW VULNERABLE IS HARPERS FERRY NATIONAL HISTORICAL PARK?

Harpers Ferry National Historical Park is located where Maryland, Virginia, and West Virginia meet**,** within a highly urbanized and rapidly growing area of the Mid-Atlantic, but an area that also supports important biodiversity. Two ecoregions, the Blue Ridge and the Ridge and Valley, come together within the park, and a third, the Northern Piedmont, is located just to the east. These ***ecoregions***, which represent provinces of unique physiography, soils, climate, and vegetation, together contain a diversity of natural communities. As the climate changes, **the park can play an important role as part of a network of *refugia* and stepping stones,** connecting natural communities and providing opportunities for adaptation. To better understand how management actions can protect park resources and enhance the ecological role of the park in a changing world, we first assess the overall VULNERABILITY of terrestrial habitats at Harpers Ferry National Historical Park by combining measurements of EXPOSURE and ADAPTIVE CAPACITY. Next, we characterize the drivers of EXPOSURE (changes in temperature and precipitation) and ADAPTIVE CAPACITY (landscape characteristics).



HARPERS FERRY NATIONAL HISTORICAL PARK IN CONTEXT. The Blue Ridge (blue) and Ridge and Valley (gray) ecoregions meet within HAFE, and the Northern Piedmont (beige) is just east of the park. Areas of natural vegetation cover are represented by darker shading on the map.

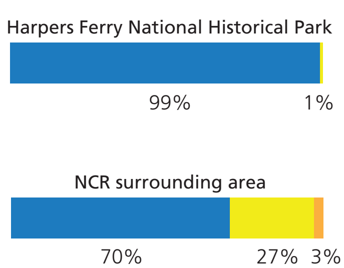
Research Highlights

VULNERABILITY SCORE

- LOW
- MODERATE
- HIGH
- VERY HIGH

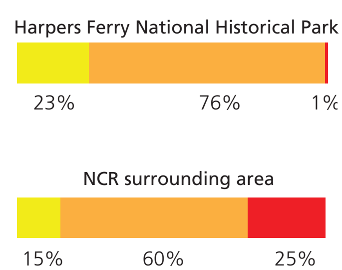
During the **observed** time period (1981 – 2014), we find vulnerability is low for almost all of Harpers Ferry National Historical Park, reflecting low to moderate climate change exposure for most of the area. Differences in vulnerability are primarily driven by differences in adaptive capacity across the landscape. Because of the park's enduring features, and connectivity to other natural areas, adaptive capacity is average to above average for much of the park, particularly when compared to the region as a whole. In the **near future** (through 2040), vulnerability is moderate to high for the park due to a sharp increase in exposure, though not as high as in portions of the surrounding area. Increased exposure is expected to lead to species turnover, but as a result of high adaptive capacity, the park is expected to continue to support healthy communities of diverse plants and animals into the future especially if connectivity to other natural lands is maintained.

Observed Climate Change Vulnerability (1981 – 2014)



OBSERVED VULNERABILITY. Vulnerability is low (blue) for 99% of HAFE. Less than 1% of the park has moderate vulnerability (yellow), and there are no areas of high or very high vulnerability (orange and red). Moderate vulnerability occurs where adaptive capacity, especially connectivity, is below average, such as in areas along roads or near adjacent urban expansion.

Near Future Climate Change Vulnerability (through 2040)



NEAR FUTURE VULNERABILITY. In the future, vulnerability increases dramatically due to increased exposure with moderate to high values (yellow and orange) recorded for HAFE. However, high adaptive capacity means HAFE is less vulnerable than the NCR surrounding area. Less than 1% of the park has very high vulnerability scores (red).

COMPONENTS OF VULNERABILITY

Exposure

To understand how global climate change impacts Harpers Ferry National Historical Park, we analyze **EXPOSURE,** defined as the **nature and magnitude of changes in patterns of temperature and precipitation.** Analyses of annual and seasonal climate data reveal that the park is already experiencing climate change and indicate that park managers can anticipate significantly more change in the near future.

EXPOSURE is measured by analyzing annual and seasonal changes in temperature and precipitation over three time periods. We first characterize a mid-20th century **baseline** (1948 – 1980) and quantify its natural variability. We then compare **observed** climate (1981 – 2014), and **near future** climate (through 2040) to baseline conditions and measure the changes. Baseline and observed climate data is derived from weather station measurements, which reduces uncertainty. Near future projections are derived from an ensemble of 15 global climate models from the IPCC 5th Assessment Report (Taylor et al. 2012, IPCC 2013). Full methods will be documented in a technical report available on the NPS IRMA portal after project completion.

SIGNIFICANCE OF CHANGE (temperature): warmer — high to low — no change

Baseline Mean Temperature	Observed Change	Near Future Change		Baseline Total Precipitation	Observed Change	Near Future Change
11.8°C (53.2°F)	+0.6°C (+1.1°F)	**+1.7°C (+3.1°F)**	**Annual**	1012 mm (39.9 in)	+38.1 mm (+1.5 in)	+48.9 mm (+1.9 in)
22.5°C (72.5°F)	+0.7°C (+1.3°F)	**+1.9°C (+3.4°F)**	**Summer (warmest/wettest quarters)**	371 mm (14.6 in)	+3 mm (+0.1 in)	-53.1 mm (-2.1 in)
0.4°C (32.7°F)	+0.7°C (+1.3°F)	+1.6°C (+2.9°F)	**Winter (coldest/driest quarters)**	149 mm (5.9 in)	+7.4 mm (+0.3 in)	**+67.5 mm (+2.7 in)**

SIGNIFICANCE OF CHANGE (precipitation): wetter — high — low — high — drier

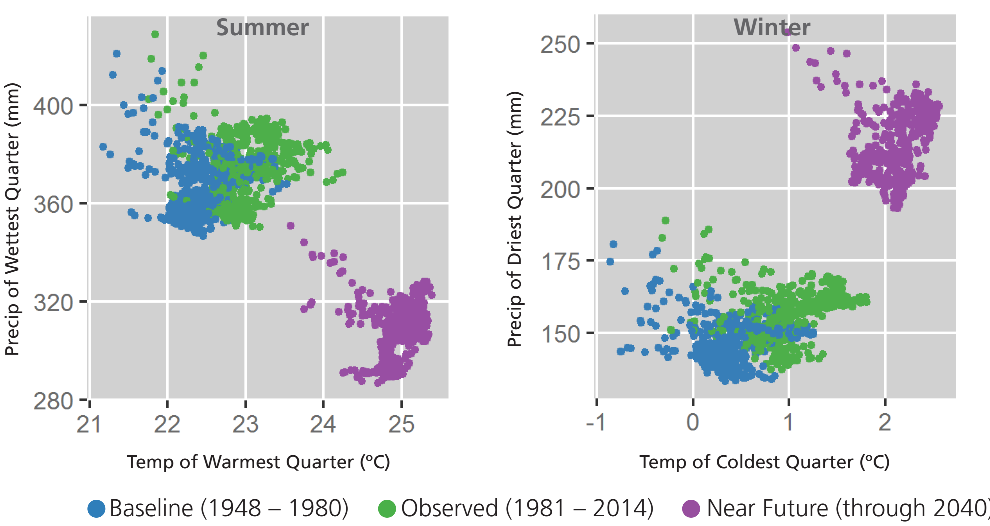
CHANGES IN TEMPERATURE. Between the baseline and observed periods, an annual temperature increase of 0.6°C (1.1°F) has already occurred at HAFE, pushing the mean observed temperature up to 12.4°C (54.3°F). Continued increases are expected in the near future, especially in summer where the average temperature is nearly 2°C (3.4°F) higher than that of the baseline. These increases in near future temperature are a statistically significant departure from baseline conditions, as indicated by greater saturation in color (dark red).

CHANGES IN PRECIPITATION. In the observed period, slight increases in precipitation were recorded across both seasons. In the near future, that pattern is projected to change with decreases in precipitation for the wettest quarter (summer) and increases for the driest (winter). Greater saturation in color represents values that are more statistically significant. The most notable change is a near future increase of 2.7 inches in winter precipitation which represents a statistically significant departure from baseline conditions (dark green).

Research Highlights

At Harpers Ferry National Historical Park, temperatures in the **observed** period (green) already show evidence of warming when compared to the baseline. Modest increases in both summer and winter precipitation are detected.

In the **near future** (purple), we anticipate shifts to warmer and drier summers and warmer and wetter winters. Models indicate that by 2040, precipitation may decrease by almost 15% in the summer as temperatures rise nearly 2°C (3.4°F). In the winter, precipitation is forecast to increase by 45% while temperatures rise 1.6°C (2.9°F).

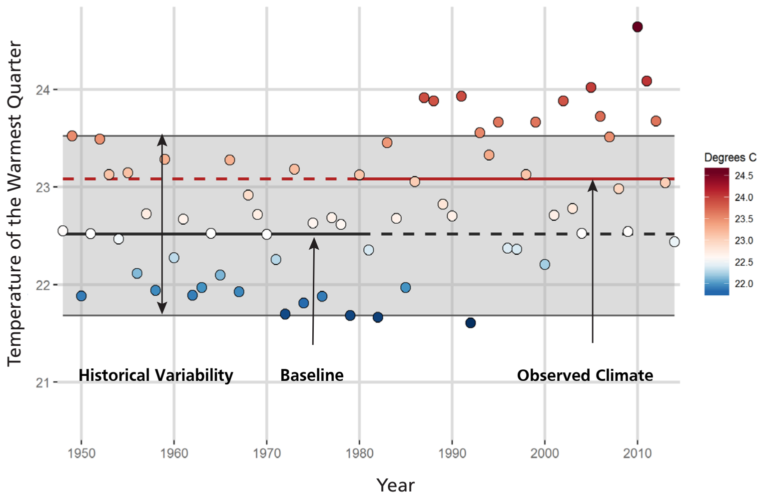


SEASONAL TEMPERATURE AND PRECIPITATION PATTERNS. Each dot represents the 30-year average for a sample point falling with in HAFE and the immediate surroundings.

COMPONENTS OF VULNERABILITY

Exposure

The Magnitude of Change

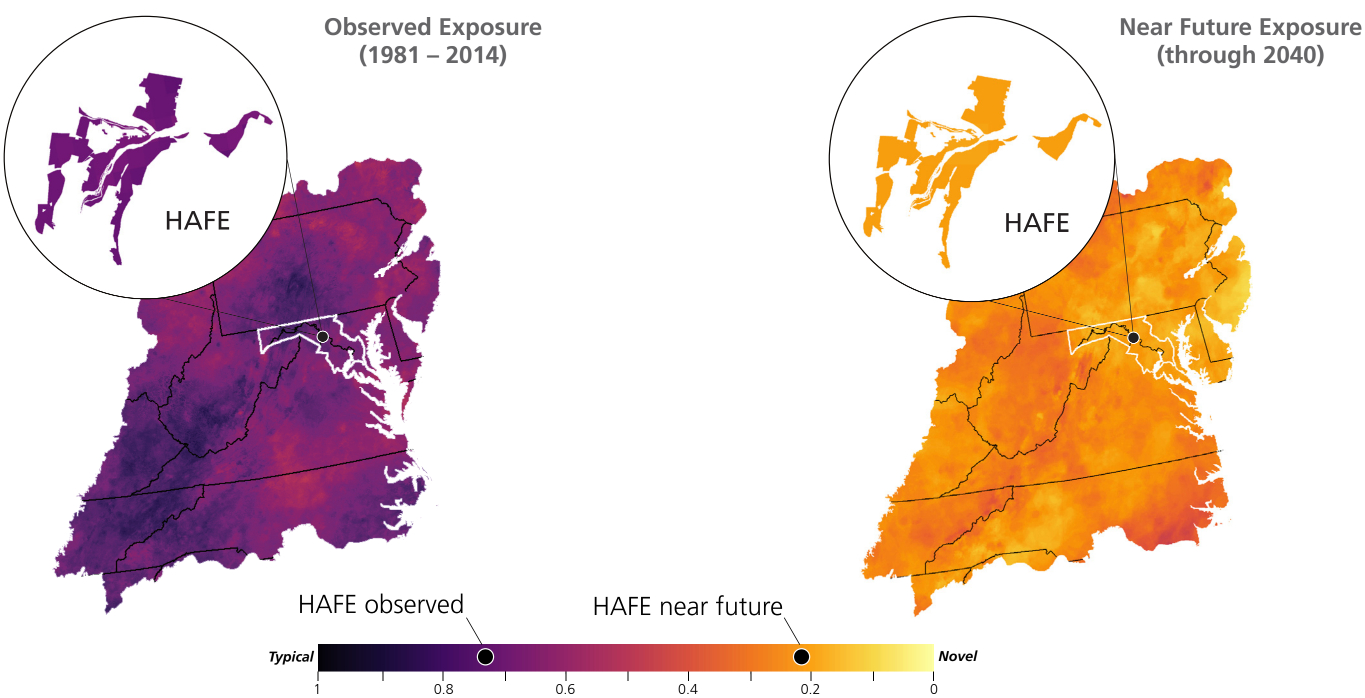


MEASURING THE MAGNITUDE OF CHANGE. The summer temperature for HAFE has increased since the mid-century baseline. The average temperature for the observed period (solid red line) is higher than recorded average annual temperatures (dots) for most years in the baseline, falling towards the top of the range of historical variability (shaded gray bar). The average summer temperature for the near future (not shown) is projected to be over 24.4°C (76°F), and falls completely outside the range of historical variability.

The magnitude of change refers to **how much EXPOSURE** Harpers Ferry National Historical Park has experienced in recent decades and how much is projected for the near future. By comparing the climate in the **observed** (1981 – 2014) time period to the historical variability in the **baseline** (1948 – 1980), we can understand whether temperature and precipitation patterns today are ***typical*** of the range of conditions experienced in the past. Temperature and precipitation values falling completely outside their historical range would indicate ***novel*** climatic conditions, to which ecosystems may not be adapted. The projected climate of the **near future** is assessed against the baseline in the same way. Analyzing and mapping EXPOSURE gives managers an understanding of the nature and magnitude of climate change, how it may vary across the landscape, and how exposure contributes to overall vulnerability.

Research Highlights

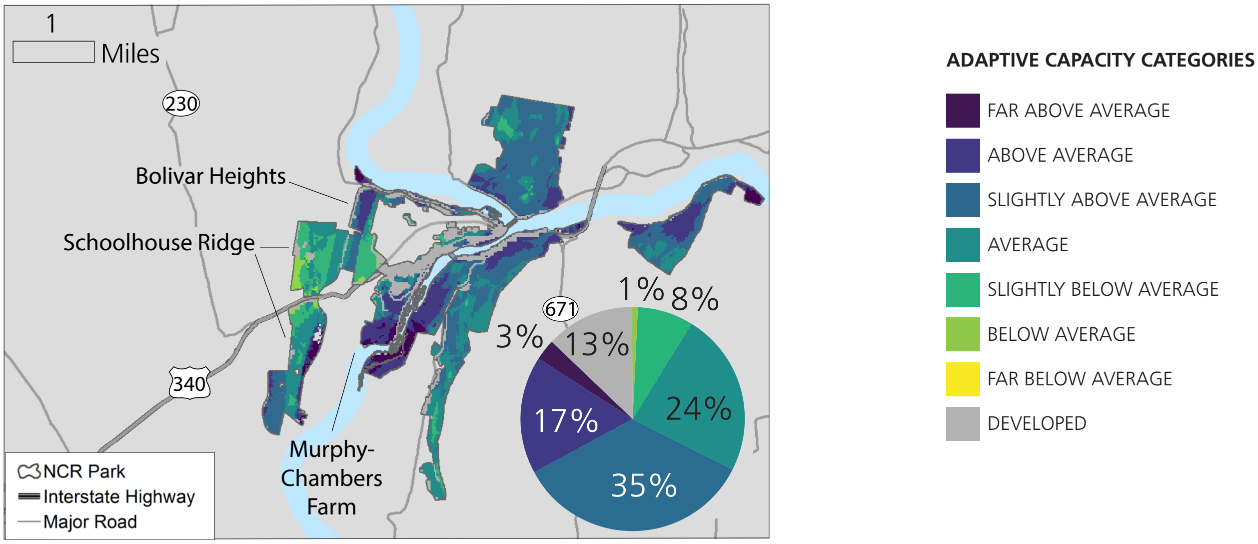
There is already evidence of changing climate in parts of the Mid-Atlantic region (pink), though observed climate averages do not fall completely outside the range of variation experienced in the past. Temperatures in the **observed** period have risen, but precipitation patterns are close to historical norms, and overall exposure for Harpers Ferry National Historical Park is relatively low (purple). In the **near future**, the Mid-Atlantic region and this park rapidly move towards high levels of exposure and novel climate conditions (yellow). The overall exposure score of 0.21 for the near future indicates that by 2040, conditions at the park are likely to be more extreme than in 79% of the baseline years. Extreme temperatures are the primary driver of the exposure score, though shifts in precipitation towards drier summers and wetter winters also contribute.



COMPONENTS OF VULNERABILITY

Adaptive Capacity

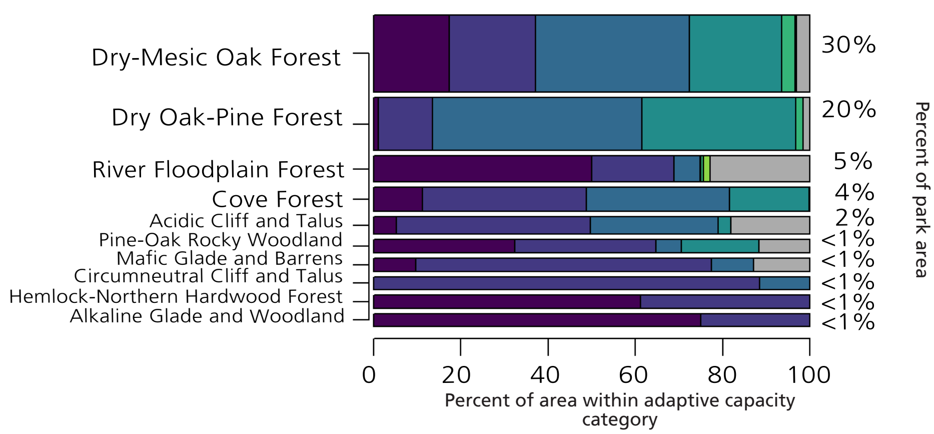
Adaptive Capacity is the ability of a region or habitat to maintain species and ecological processes as the climate changes. In this study, we focus on two key characteristics of adaptive capacity, ***LANDSCAPE DIVERSITY*** and ***LOCAL CONNECTEDNESS*** (Anderson et al. 2016), to assess Harpers Ferry National Historical Park and the terrestrial habitats within it. We identify places that are more or less resilient to the disturbances associated with climate change to help park managers develop informed adaptation strategies.



ADAPTIVE CAPACITY AT HAFE. On balance, adaptive capacity at HAFE is average to above average when compared to similar settings in the region. Areas of higher adaptive capacity are found where a diversity of physical conditions is present, including steep ridges and floodplains along the two major rivers. Lower adaptive capacity is found in areas with far below average connectivity, especially those areas bordering major roads like Schoolhouse Ridge and Bolivar Heights.

Landscape Diversity

Areas with high **LANDSCAPE DIVERSITY** contain a range of physical conditions and habitats that can support species as they adapt to a changing climate. Within a specific geophysical setting, landscape diversity is scored highest if there is a diversity of landforms (e.g., high ridges, steep slopes, coves, and floodplains), wide ranges in elevation, and a range of soil types. These ***enduring features*** are the foundation upon which ecological systems are built.



LANDSCAPE DIVERSITY BY ECOLOGICAL SYSTEM. For the ecological systems occurring at HAFE, the graph displays the proportion of area in each of 8 adaptive capacity categories based on landscape diversity. Dark colors indicate higher landscape diversity and thus higher adaptive capacity. Taller bars designate ecological systems that occupy a greater percentage of the park. Some of the more uncommon ecological systems (shortest bars) have the highest landscape diversity. The River Floodplain occupies only 5% of the park, but most of this ecosystem has landscape diversity that is far above average (dark purple).

Research Highlights

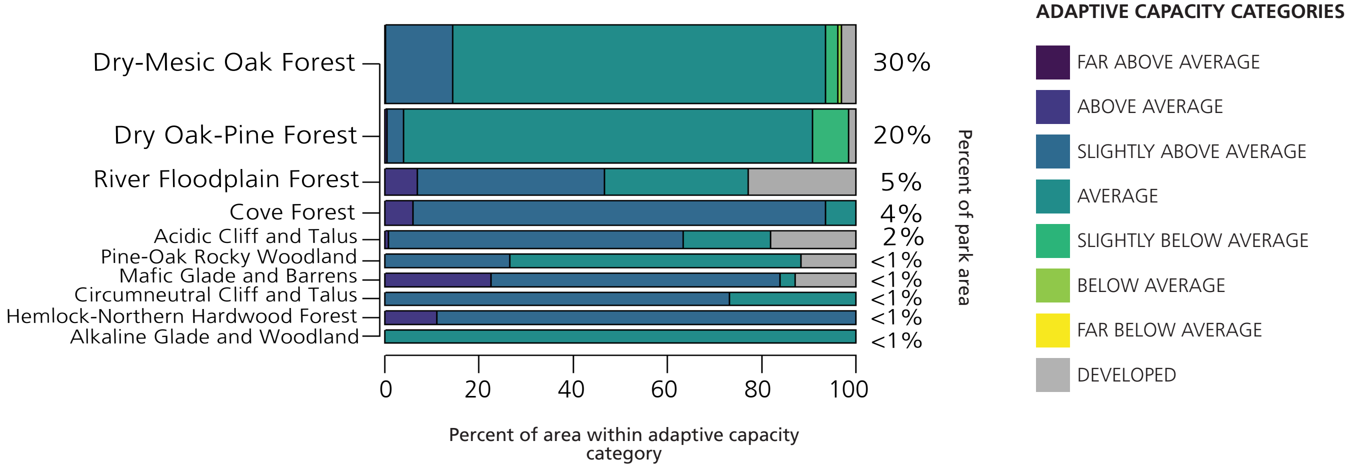
Landscape diversity is the biggest driver of high adaptive capacity at Harpers Ferry National Historical Park. Steep ridges, floodplains, and a variety of other physical conditions present at the park provide more microhabitat variation than is found in similar geophysical settings elsewhere.

COMPONENTS OF VULNERABILITY

Adaptive Capacity

Local Connectedness

LOCAL CONNECTEDNESS measures the degree to which current land cover patterns (e.g., agriculture, forest, wetlands) are likely to support important ecological processes and the movement and dispersal of species. When natural areas are connected, opportunities are present for climate change adaptation, and vulnerability is reduced.



LOCAL CONNECTEDNESS BY ECOLOGICAL SYSTEM. For the ecological systems occurring at HAFE, we show the proportion of area in each category of adaptive capacity based on local connectedness. Dark colors indicate higher connectivity and thus higher adaptive capacity. Taller bars designate ecological systems that occupy a greater percentage of the park. Connectivity is mostly average to above average (blue-green to purple) for all systems. The Dry-Mesic Oak Forest occupies 30% of the park and has only average connectivity (blue-green). The (Hemlock)-Northern Hardwood Forest has above average connectivity but only occupies 0.1% of the park.

Research Highlights

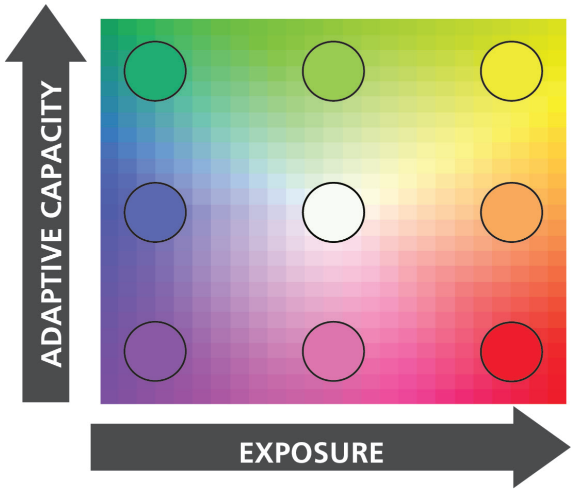
Local connectedness is average to above average for most of Harpers Ferry National Historical Park. Vegetation along Appalachian ridges and two major rivers may provide migration corridors for species movements induced by changing climatic conditions. Roads and developed areas present some challenges for local connectedness at the park.

The Shenandoah River is one of two major rivers that pass through Harpers Ferry National Historical Park.

PATTERNS OF VULNERABILITY

Local Trends

Understanding how climate change (EXPOSURE) and local landscape characteristics (ADAPTIVE CAPACITY) influence vulnerability is a central goal of this assessment. We quantified and mapped these relationships for Harpers Ferry National Historical Park and the NCR surrounding area to identify what areas are most or least vulnerable today, and what we can expect in the near future. ADAPTIVE CAPACITY and EXPOSURE scores were divided into low, moderate, high, and very high categories and combined into the overall VULNERABILITY scores as presented on page 2 of this document and as illustrated below.



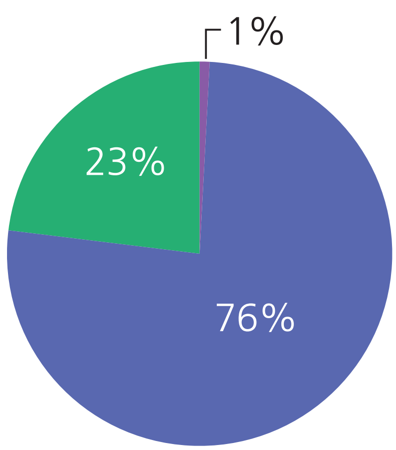
VULNERABILITY SCORE

LOW
- LOW EXPOSURE / HIGH ADAPTIVE CAPACITY
- LOW EXPOSURE / MODERATE ADAPTIVE CAPACITY
- MODERATE EXPOSURE / HIGH ADAPTIVE CAPACITY

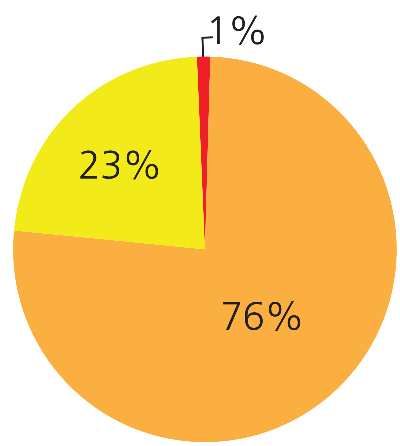
MODERATE
- LOW EXPOSURE / LOW ADAPTIVE CAPACITY
- MODERATE EXPOSURE / MODERATE ADAPTIVE CAPACITY
- HIGH EXPOSURE / HIGH ADAPTIVE CAPACITY

HIGH
- MODERATE EXPOSURE / LOW ADAPTIVE CAPACITY
- HIGH EXPOSURE / MODERATE ADAPTIVE CAPACITY

VERY HIGH
- HIGH EXPOSURE / LOW ADAPTIVE CAPACITY



Observed Climate Change Vulnerability for HAFE (1981 – 2014)



Near Future Climate Change Vulnerability for HAFE (through 2040)

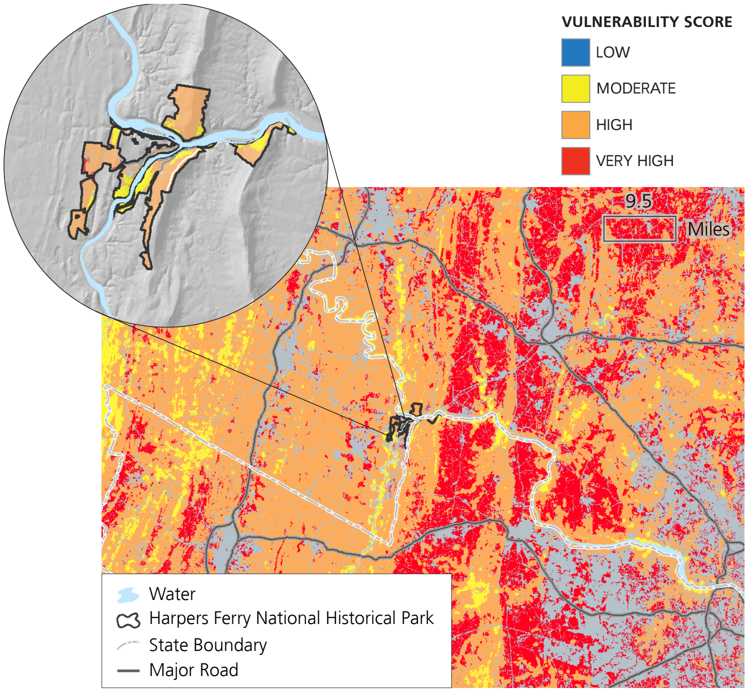
Research Highlights

In the **observed** period, vulnerability of Harpers Ferry National Historical Park is low, owing to generally moderate to high adaptive capacity and relatively low exposure. Only 1% of the park is already classified as having moderate vulnerability due to an area with low adaptive capacity. Areas of higher adaptive capacity provide protective benefits in the form of habitat and stepping stones for species movement and adaptation.

Exposure increases to high levels across the region in the **near future**, resulting in scores of moderate to high vulnerability for most of Harpers Ferry National Historical Park. Differences in vulnerability are driven by differences in adaptive capacity. Vulnerability is lowest (moderate) along the Shenandoah and Potomac Rivers, where above average landscape diversity coincides with bands of connected floodplain forests. Developing forward-looking adaptation strategies aimed at maintaining or increasing adaptive capacity will help ensure that the natural resources of Harpers Ferry National Historical Park can endure the stresses of rapidly changing conditions.

WHAT WE CAN DO

Recommendations & Management Strategies



NEAR FUTURE VULNERABILITY AT HARPERS FERRY NATIONAL HISTORICAL PARK Mapping the spatial pattern of vulnerability can inform site-specific adaptation strategies. Developed areas in the regional map are dark gray. Vulnerability within park boundaries is seen in the inset.

This **climate change vulnerability assessment** analyzed several components of VULNERABILITY for Harpers Ferry National Historical Park and identified the areas that are most and least vulnerable and why. This work represents an important first step in the application of a climate-smart adaptation framework (Stein et al. 2014) through which park managers can identify, evaluate, and implement adaptation strategies suited to observed conditions and adaptable to conditions in the near future. Additional work is needed to refine vulnerability and adaptive capacity to include other direct and indirect impacts of a changing climate.

Broad adaptation strategies relevant to Harpers Ferry National Historical Park are provided in the Climate Change Vulnerability Impacts and Strategies table. These strategies can support managers as they begin planning for change. The next phases of the project will provide additional information to guide site-specific adaptation actions aligned with these strategies. This work includes assessment of ecosystem-specific drivers of vulnerability, identification of regional priorities for maintaining connectivity, and evaluation of field data to characterize the local impact of non-climate stressors on ADAPTIVE CAPACITY. Through these actions, we can safeguard the natural treasures of Harpers Ferry National Historical Park and ensure that they are resilient for future generations of park visitors.

CLIMATE CHANGE VULNERABILITY IMPACTS AND STRATEGIES TABLE

VULNERABILITY SCORE	CLIMATE IMPACTS	STRATEGY
Low	With high adaptive capacity and relatively low climate change exposure, these sites are least at risk. In the near future, there are no areas of low vulnerability at HAFE.	**Manage for persistence**, focus actions on preventing impacts by *non-climate stressors* (e.g., habitat loss, fragmentation, and invasive species).
Moderate	With moderate to high adaptive capacity and less exposure, these areas can continue to support diverse natural communities at HAFE. Moderate vulnerability areas, like those that border the two rivers, provide opportunities for species to move and communities to adapt.	**Encourage persistence but accommodate change.** Actions should focus on (1) decreasing *non-climate stressors* to restore or enhance ecological integrity and (2) maintaining landscape connectivity to facilitate transitions.
High	Areas with high vulnerability in the near future have high exposure but moderate adaptive capacity. This includes much of the northern and western portions of HAFE, as well as areas along major roads. *Species turnover* and restructuring of communities is likely.	**Accommodate change and novel communities.** Maintaining connected landscapes will support the persistence of diverse ecosystems, but actions should accommodate turnover of native species. Actions to maintain ecosystem functions and processes and limit biodiversity loss are favored (e.g., aggressive management of invasives, species translocations).
Very High	With high exposure and low adaptive capacity, areas with very high vulnerability may experience transformational changes likely to negatively impact overall biodiversity. Less than 1% of HAFE falls in this category in the near future.	**Accommodate significant change and reevaluate management goals.** Actions can be targeted for maintaining ecosystem functions and limiting biodiversity loss, but efforts aimed at maintaining existing ecological communities may not achieve desired outcomes.

TO LEARN MORE

The information in this report is based on climate change scenarios from the Intergovernmental Panel on Climate Change (IPCC 2013), published climate datasets TopoWX (Oyler et al. 2014) and Prism (Daly et al. 2008), an analysis of terrestrial resilience for the eastern United States (Anderson et al. 2016), and analyses by NatureServe. To explore the data and learn more about our methods and the science behind climate change, please visit the links below.

1. Please visit the NCR Enduring Features Data Basin Gallery to further explore the information about Harpers Ferry National Historical Park presented in this brief. http://bit.ly/databasin_NCR
2. More information about the data and methods used to characterize exposure will be made available in the final project report (Smyth et al, *in prep.*). Contact NatureServe to learn more.
3. More information about the data and methods used to characterize resilience can be found at: http://bit.ly/TNC_resilience
4. Climate Science Special Report. The Fourth National Climate Assessment. U.S. Global Change Research Program. https://science2017.globalchange.gov/
5. U.S. Climate Adaptive capacity Toolkit, NOAA. https://toolkit.climate.gov/
6. National Park Service Climate Change Response Program: https://www.nps.gov/orgs/ccrp/index.htm
7. NatureServe, Climate Change Program http://www.natureserve.org/biodiversity-science/conservation-topics/climate-change
8. National Capital Region, Inventory & Monitoring Network: https://science.nature.nps.gov/im/units/ncrn/
9. National Park Service, National Capital Region, Natural Resources and Science, Urban Ecology Research Learning Alliance: https://www.nps.gov/rlc/urbanecology/index.htm

GLOSSARY OF TERMS	
Climate Change	Changes in weather patterns over relatively long time-scales. In this study, climate is defined based on averages and variability in temperature and precipitation for about 30-year periods.
Ecological System	A standardized ecological unit representing plant communities influenced by similar physical environments and dynamic ecological processes (like fire or flooding). Altered and disturbed vegetation are excluded.
Ecoregion	Provinces of unique physiography, soils, climate, and vegetation, containing geographically distinct assemblages of natural communities and species.
Enduring Features	The physical settings defined by landform, bedrock, soil, and topography are largely unchanged through time and provide the physical underpinnings for ecological diversity.
Landscape Diversity	Complex topography and elevation gradients creating a range of local temperature and moisture conditions, called micro-climates, within a given area.
Local Connectedness	The degree to which land cover patterns (e.g., agriculture, forest, wetlands) provide natural connections, supporting important ecological processes and the movement and dispersal of species.
Natural Habitats	An ecological area supporting native species including forests, wetlands, and native grasslands, but excluding areas with extensive human influence (e.g., regularly mowed meadows).
Novel	In terms of climate change exposure, "novel" refers to conditions that are higher or lower than the historical range of temperature or precipitation conditions observed in the past.
Non-Climate Stressors	External factors, unrelated to climate change, putting species and ecosystems at risk, such as invasive species, land use changes, predation, and disease.
Refugia	An area where environmental conditions allow a species or community to persist, even as unfavorable changes cause it to become extinct from surrounding areas.
Typical	In terms of climate change exposure, "typical" refers to conditions that are close to those experienced in the baseline past.
Species Turnover	Change in the types of plants and animals present at a site as new species move in and others are lost.

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Full documentation of technical methods will be made available in a project report to be posted on the NPS IRMA portal pending project completion. For more information, contact Regan Smyth, NatureServe. Regan_Smyth@natureserve.org

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