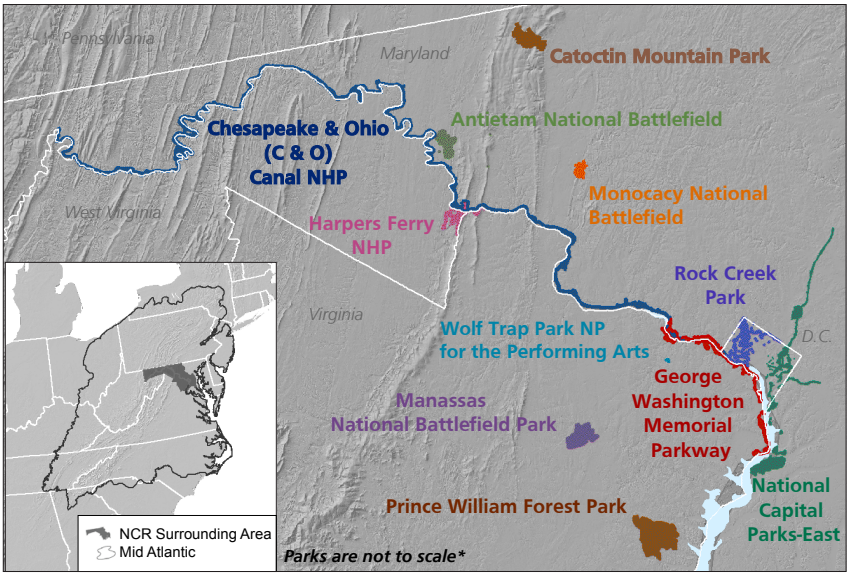
National Park Service
U.S. Department of the Interior

National Capital Region
Natural Resources and Science

Climate Change Vulnerability of Terrestrial Areas of the National Capital Region

PLANNING FOR CHANGE

The National Capital Region (NCR) represents some of the richest features of America's cultural and natural history. Within and around these national park units is a diverse array of forests, mountains, and estuaries that provide resilience to environmental change. However, as global temperatures rise and precipitation patterns become more extreme (IPCC, 2013), our national treasures become increasingly vulnerable. To understand how climate change will impact natural habitats in the NCR, the National Park Service (NPS) has partnered with experts at NatureServe to conduct **climate change vulnerability assessments**. Here, we report the results of an initial assessment of terrestrial vulnerability for the region. We share how climate and landscape influence vulnerability and identify areas most or least vulnerable today and in the near future. Our goal is to provide park managers and visitors an understanding of how the climate is changing in the NCR and support the development of informed management strategies for 11 parks.



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.

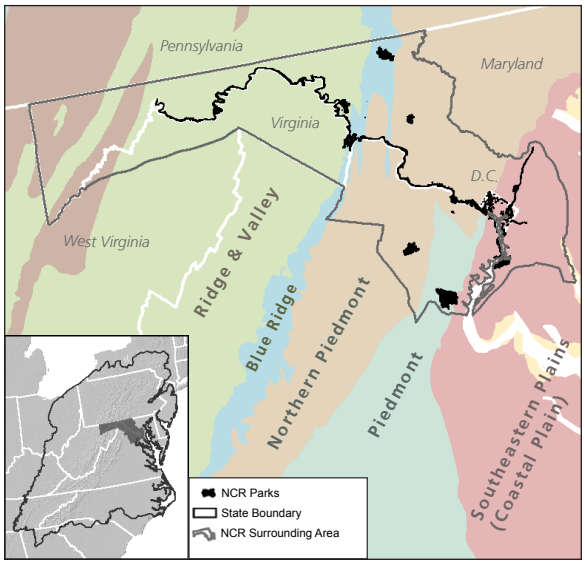
NCR PARKS. These eleven national parks are located within a four-state area in the Potomac Watershed. We analyze these parks within the context of the "NCR surrounding area" and broad "Mid-Atlantic" (see inset).

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 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 the NCR 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-20th century **baseline** (1948 – 1980). To understand park-specific vulnerabilities and the role of the parks within the context of regional environmental change, results are reported at three scales: each of 11 "NCR parks", an expanded "NCR surrounding area", and most broadly, the "Mid-Atlantic region". Our approach describes the drivers of ***climate change*** (see Glossary, p. 10, for definition of italicized words) vulnerability, how vulnerability is spatially distributed, and a framework for park managers to anticipate and address changes in the coming decades.

HOW VULNERABLE ARE NCR PARKS?

The NCR parks are located in a highly urbanized and rapidly growing area of the Mid-Atlantic region that spans five ecoregions. These ***ecoregions,*** which represent provinces of unique physiography, soils, climate, and vegetation, together support high levels of biodiversity in a small geographic area. **As the climate changes, the national parks play important roles as part of a network of potential *refugia,* stepping stones, and connections** for natural communities to adapt. To better understand how resource management actions can enhance the ecological role of parks in a changing world, we first assess the overall VULNERABILTY of the NCR parks and surrounding area by combining measurements of EXPOSURE and RESILIENCE. We then characterize the drivers of exposure (changes in temperature and precipitation) and resilience (landscape characteristics).



PHYSIOGRAPHIC PROVINCES OF THE NCR SURROUNDING AREA AND PARKS

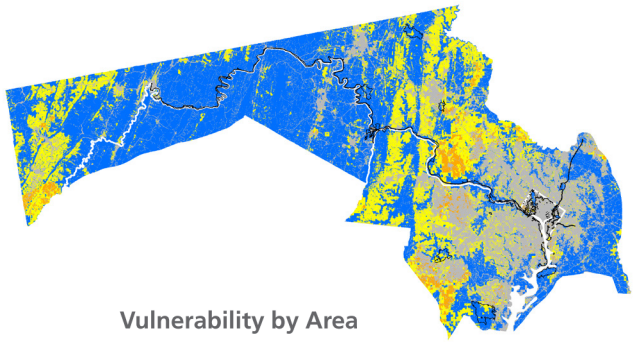
Research Highlights

VULNERABILITY SCORE

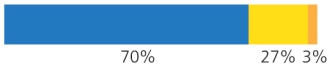
- LOW
- MODERATE
- HIGH
- VERY HIGH

During the **observed** time period (1981 – 2014), we find vulnerability is generally low for the NCR surrounding area. Climate change exposure is relatively low for most of the area, and the range in vulnerability is primarily driven by differences in adaptive capacity across the landscape. The NCR parks contain pockets of highly resilient landscapes, resulting in a greater proportion of low vulnerability areas than for the region as a whole. In the **near future** (through 2040), vulnerability is high for the NCR surrounding area. While vulnerability in most NCR parks is projected to increase, the parks are partially buffered against the effects of climate change in the coming decades due to their high landscape adaptive capacity.

Observed Climate Change Vulnerability (1981 – 2014)



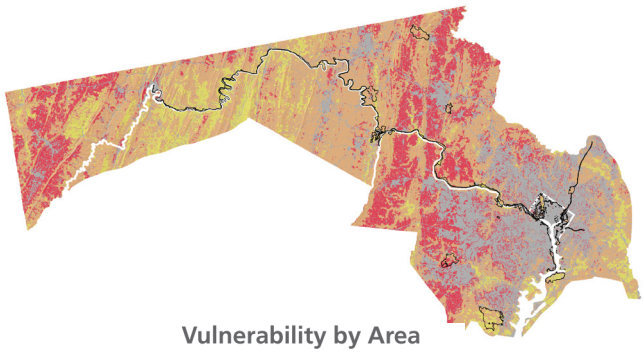
Vulnerability by Area



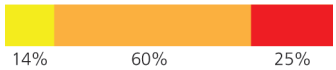
NCR surrounding area

NCR parks

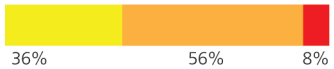
Near Future Climate Change Vulnerability (through 2040)



Vulnerability by Area



NCR surrounding area



NCR parks

OBSERVED VULNERABILITY. Vulnerability is generally low (blue) for both the NCR parks and NCR surrounding area. Areas of higher vulnerability (yellow and orange) already exist where adaptive capacity, especially connectivity, is low, including areas experiencing urban expansion. There are no areas of very high vulnerability. Areas in gray are developed and excluded from this analysis.

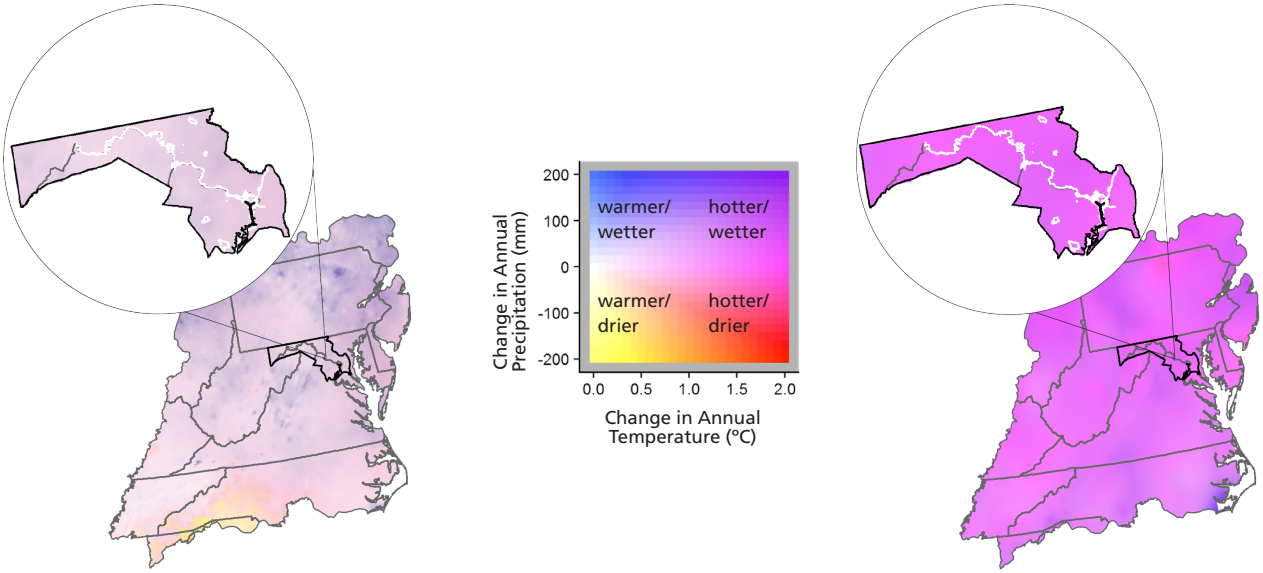
NEAR FUTURE VULNERABILITY. In the future, vulnerability shifts dramatically higher, with moderate to very high values (yellow to red) for both the NCR surrounding area and the NCR parks. NCR parks are less vulnerable than the region as a whole, largely due to diverse landscapes and higher connectivity. Areas in gray are developed and excluded from this analysis.

COMPONENTS OF VULNERABILITY

Exposure

To understand how global climate change impacts the NCR parks, we analyze **EXPOSURE**, defined as the **nature and magnitude of changes in temperature and precipitation patterns.** Analyses reveal that NCR parks are already experiencing climate change and indicate that park managers can anticipate significantly more change in the near future.

The nature of change (EXPOSURE) is measured by analyzing annual and seasonal changes in temperature and precipitation over three time periods (Smyth et al. in prep). We first characterize a mid-20th century **baseline** (1948 – 1980) and quantify its natural variability. We compare **observed** (1981 – 2014) climate of recent decades, and **near future** (through 2040) climate to measure departures in these two time slices from the range of values in the baseline. Historical climate data is derived from weather station measurements, which reduces uncertainty, and the 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).

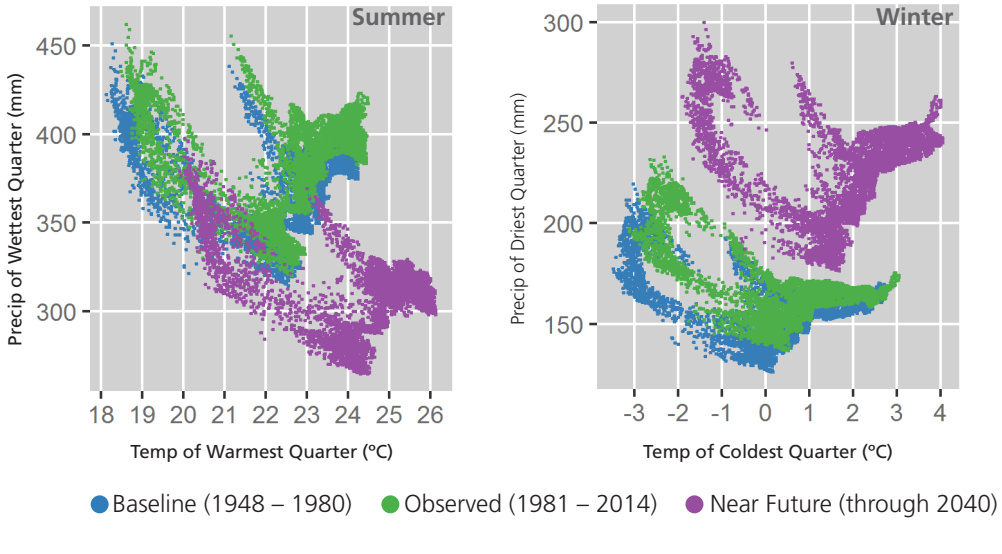


OBSERVED ANNUAL EXPOSURE (1981 – 2014)
There is already clear evidence of some warming in the NCR surrounding area, but less evidence of changes in precipitation (light purple). Elsewhere in the Mid-Atlantic, climatic changes to warmer and drier (yellow) or warmer and wetter (blue - purple) are observed.

NEAR FUTURE ANNUAL EXPOSURE (through 2040)
Both the Mid-Atlantic and NCR surrounding area are projected to experience much warmer conditions. The NCR surrounding area is expected to be hotter and slightly wetter, while Mid-Atlantic future climates may range from hotter and wetter (dark purple) to hotter and slightly drier (pink - purple).

The Nature of Seasonal Climate Change

A general pattern of warmer than baseline temperatures is already occurring across all seasons in the **observed** period for the NCR. Modest increases in both summer and winter precipitation are detected. In the **near future**, temperatures are projected to further increase, and seasonal differences in precipitation patterns emerge. An ensemble of models suggests precipitation of the wettest quarter (summer) may decrease by 15-20% by 2040, though this decrease is offset by an increase in precipitation in the driest quarter (winter) by even greater amounts.

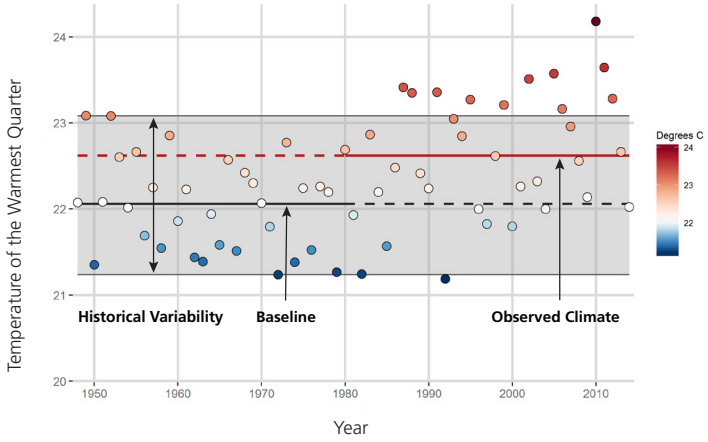


SEASONAL TEMPERATURE AND PRECIPITATION PATTERNS. Each dot represents values for a 1-square kilometer pixel within the NCR surrounding area.

COMPONENTS OF VULNERABILITY

Exposure

The Magnitude of Change

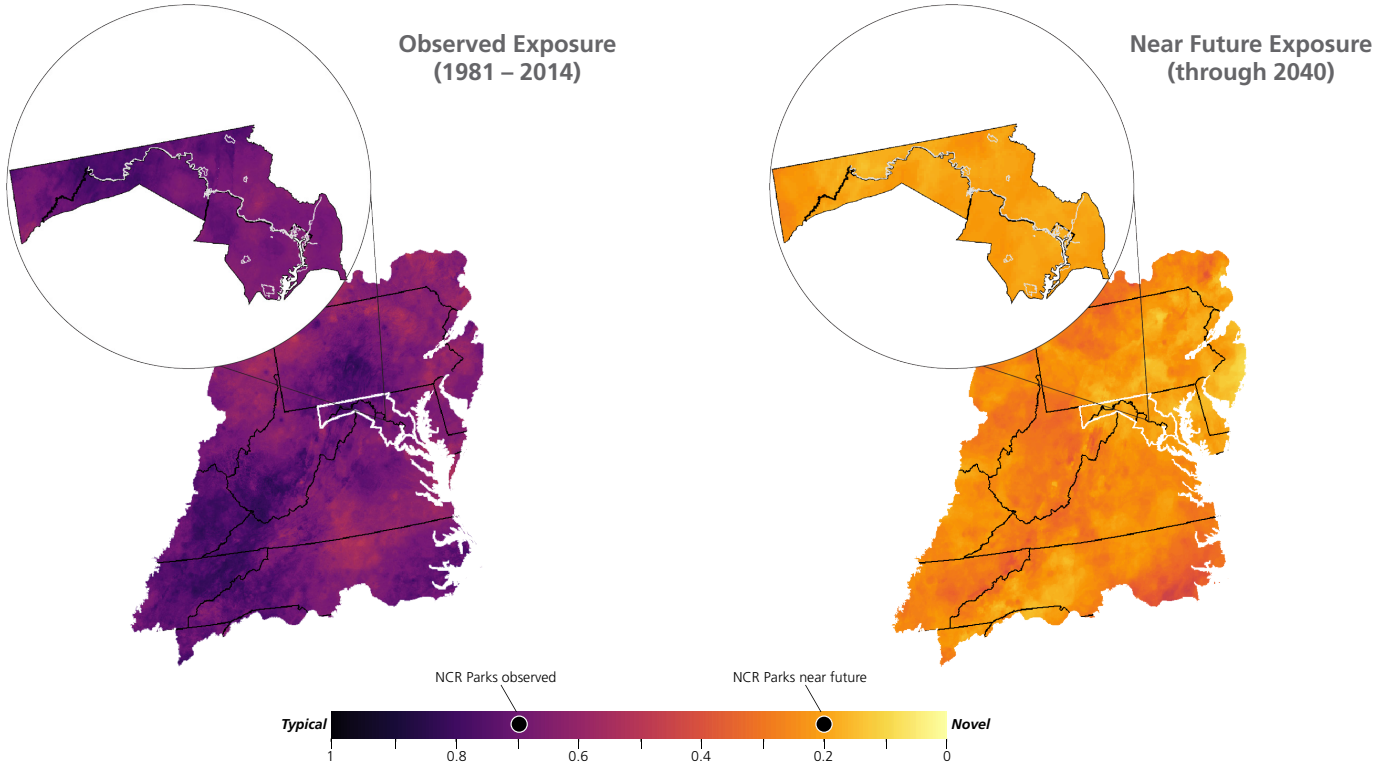


MEASURING THE MAGNITUDE OF CHANGE. Since the mid-20th century, the summer temperature for the NCR surrounding area has been increasing. The average temperature for this time period (solid red line) is higher than recorded temperatures for almost all years in the baseline, falling nearly outside the range of historical variability (shaded gray bar). The average summer temperature for the near future is projected to be over 24.3°C (not shown), and does fall completely outside the range of historical variability.

The magnitude of change refers to **how much EXPOSURE** the NCR 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 a spatial understanding of the nature and magnitude of climate change and how this contributes to overall vulnerability.

Research Highlights

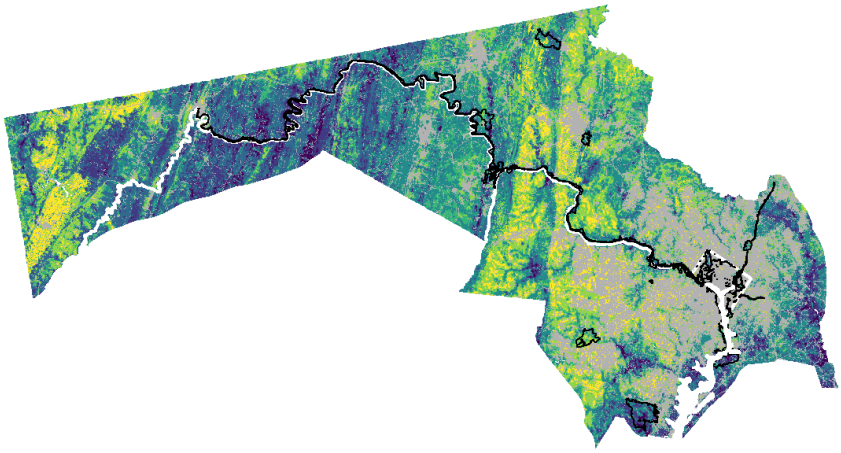
Across the Mid-Atlantic region and within the NCR surrounding area, there is already evidence that the climate is changing. However, climate patterns do not fall completely outside the range of variation experienced in the past. Temperatures in the **observed** period have risen, but precipitation patterns are close to historical norms, and overall EXPOSURE is relatively low (purple). In the **near future**, the Mid-Atlantic region and the NCR surrounding area rapidly move toward high levels of EXPOSURE and novel climate conditions (yellow). This is driven both by temperatures that are more extreme than those ever experienced in the baseline past, and a shift in precipitation patterns towards drier summers and wetter winters.



COMPONENTS OF VULNERABILITY

Adaptive Capacity

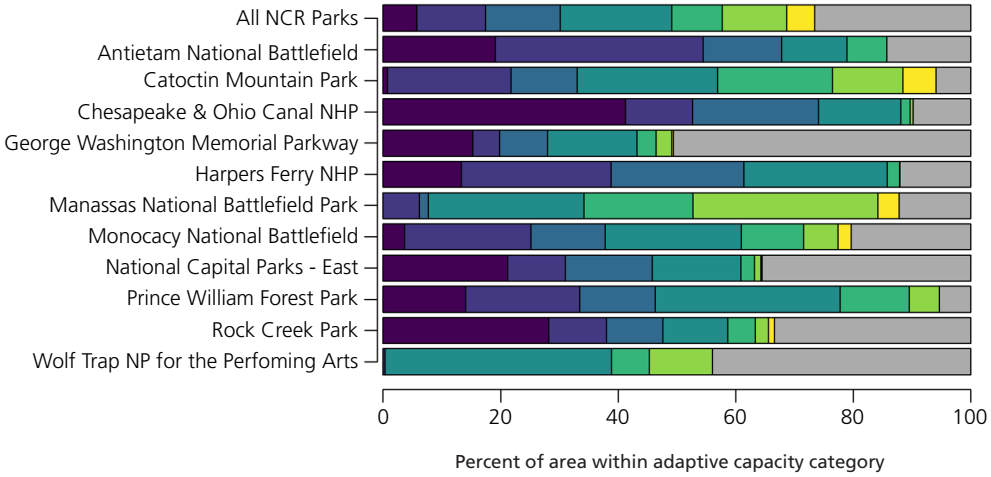
ADAPTIVE CAPACITY is the ability of a region or habitat to maintain species and ecological processes as the climate changes. In this study, we focus on two key characteristics of adaptive capacity, ***LANDSCAPE DIVERSITY*** and ***LOCAL CONNECTEDNESS*** (Anderson et al. 2016), to assess the NCR parks and surrounding area. We evaluated places for their adaptive capacity to the disturbances associated with climate change so park managers can develop informed, place-based adaptation strategies.



ADAPTIVE CAPACITY IN THE NCR SURROUNDING AREA. Highest adaptive capacity (darker colors) is generally found where there is diverse topography and less development. Areas with lower adaptive capacity (yellow to grey) occur where there is greater fragmentation of natural areas. Many pockets of high adaptive capacity throughout the region coincide with NCR park lands.

Landscape Diversity

Areas with high **LANDSCAPE DIVERSITY** within the NCR surrounding area contain a range of physical conditions and habitats for species as they adapt to a changing climate. Diversity of landforms or ***enduring features*** (e.g., high ridges, steep slopes, coves, river floodplains), wide ranges in elevation, and a range of soil types increase the landscape diversity of the region.



Research Highlights

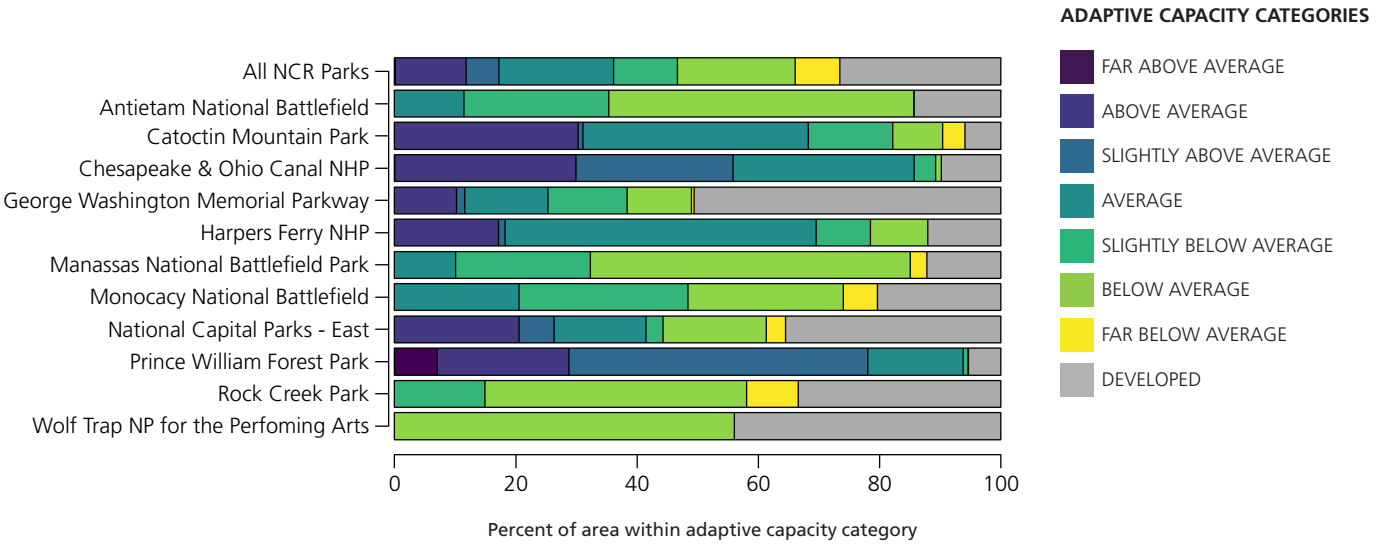
Although there is some variability within individual parks, levels of landscape diversity are average or above (purple to dark green) for many NCR parks. Antietam National Battlefield, Catoctin Mountain Park, C&O Canal NHP, Harpers Ferry NHP, and Prince William Forest Park are particularly notable for the large proportion of their land with higher than average ratings. Other parks, including National Capital Parks-East and Rock Creek Park, have a high proportion of developed or altered landscapes (gray), but retain high landscape diversity in remaining natural areas.

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. Many NCR parks face challenges related to local connectedness. ***Non-climate stressors*** like roads and development create barriers for species movement and ecological processes, increasing vulnerability to climate change impacts.



Research Highlights

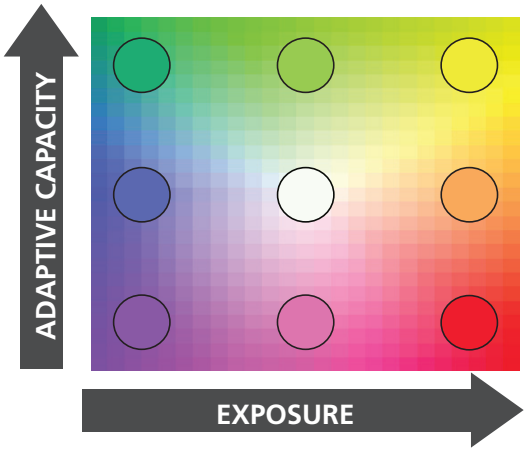
A lack of habitat connectivity presents challenges for conservation management in many NCR parks. This is reflected in below average ratings for parks like Antietam National Battlefield, Manassas National Battlefield Park, Monocacy National Battlefield, Rock Creek Park, and Wolf Trap National Park for the Performing Arts, many of which are located in highly urbanized settings. Other parks, including Catoctin Mountain Park, C&O Canal NHP, George Washington Memorial Parkway, Harpers Ferry NHP, National Capital Parks-East, and Prince William Forest Park, present opportunities to maintain regional connectivity which is essential for climate change adaptation. Supporting connections to surrounding intact natural communities and enhancing ecological processes through restoration will increase adaptive capacity.

George Washington Memorial Parkway, Great Falls Park.

PATTERNS OF VULNERABILITY

Regional Trends

Understanding how climate change (EXPOSURE) and landscape (ADAPTIVE CAPACITY) influence vulnerability is a central goal of this assessment. We quantified and mapped these relationships at the regional and local level 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 VULNERABILTY scores presented earlier in this document.



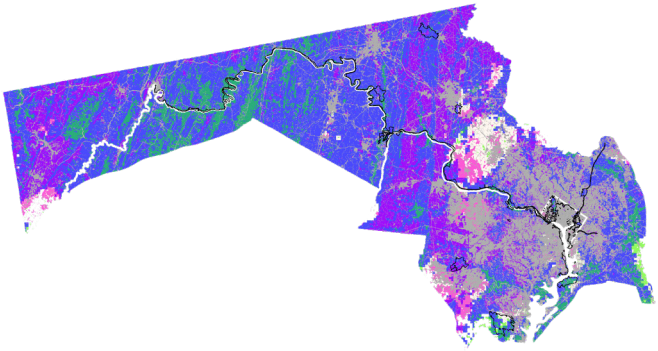
VULNERABILITY SCORE

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

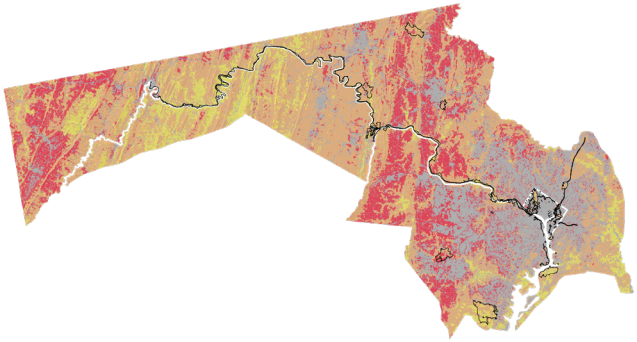
MODERATE
- LOW EXPOSURE / LOW ADAPTIVE CAPACITY
- MODERATE EXPOSURE / MODERATE ADAPTIVE CAPACITY
- HIGH EXPOSURE / HIGH ADAPTIVE CAPACITY

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

VERY HIGH
- HIGH EXPOSURE / LOW ADAPTIVE CAPACITY



Vulnerability in the NCR Surrounding Area Observed (1981 – 2014)*



Vulnerability in the NCR Surrounding Area Near Future (through 2016)*

***developed areas are shown in gray**

Research Highlights

In the **observed** period, the eastern portion of the NCR surrounding area includes some ofthe highest vulnerability in the region (pink). However within this landscape, there are pockets of moderate vulnerability (purple, white, yellow) with high adaptive capacity. These areas contain natural vegetation marked by high landscape diversity and high local connectedness. They have the potential to provide critical habitats and stepping-stones for species movement and adaptation.

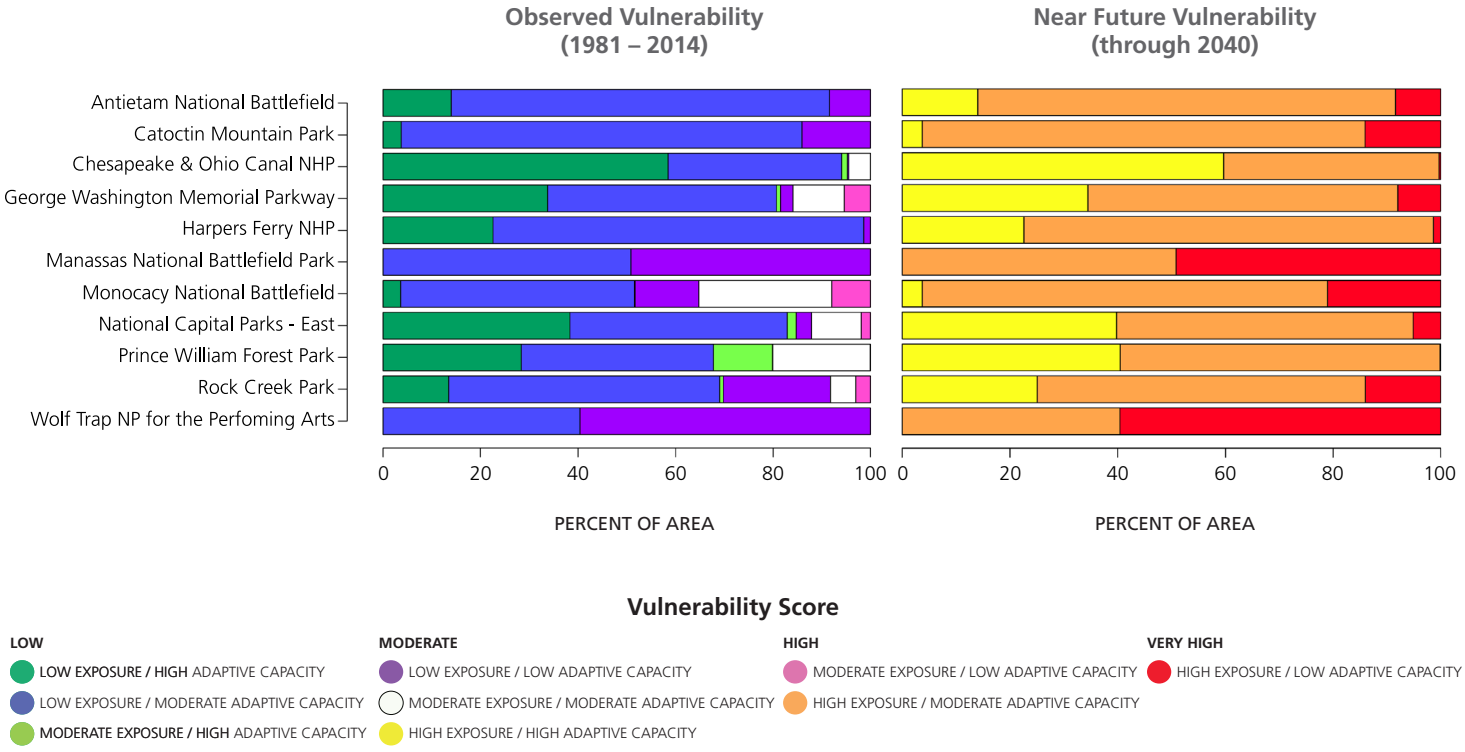
Despite mostly high exposure in the **near future,** differences in adaptive capacity determine which areas are most at risk. Identifying areas with high and moderate adaptive capacity (yellow and orange) in the parks is particularly important in developing forward - looking climate adaptation priorities. Natural vegetation along Appalachian ridges and along the Potomac River and tributaries provide movement corridors allowing species to respond to changing conditions. With thoughtful planning and management today, the enduring features of the region can be enhanced to support adaptive capacity into the future.

Local Trends

Which Parks Are Most Vulnerable?

We analyzed the spatial distribution of climate change vulnerability at local levels within the NCR parks. In the **observed** time period, the NCR parks are generally experiencing low vulnerability to climate change due to low exposure and the prevalence of enduring features in the parks. Areas characterized with moderate vulnerability (low exposure and low adaptive capacity) today, such as Wolf Trap NP for the Performing Arts and Manassas National Battlefield Park, are most at risk. Maintaining or restoring enduring features (those that enhance landscape diversity and local connectedness) will support biodiversity and reduce the parks' vulnerability to changing climatic conditions.

In the **near future,** climate exposure will be high across all NCR parks, but there is some variability. Areas characterized with high and very high vulnerability (high exposure and low and moderate adaptive capacity) are most at risk. For some parks, like the C&O Canal NHP, enduring features, such as the diverse landforms carved by the Potomac River and its tributaries, result in higher adaptive capacity and moderate vulnerability. This is particularly true in areas with fewer barriers to connectivity. Elsewhere in the region, maintaining adaptive capacity through connectivity is a challenge due to the highly urbanized landscape. Creating ways to enhance connectivity is a key strategy to reduce climate change vulnerability in the near future.

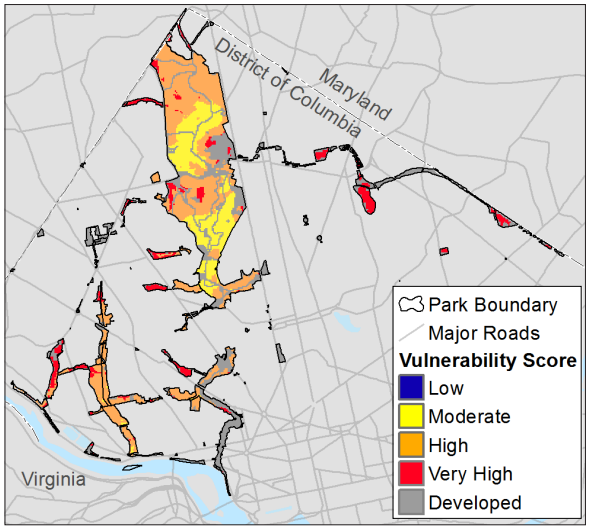


Research Highlights

The effects of climate change are already being felt in parks including Monocacy National Battlefield, Prince William Forest Park, and George Washington Memorial Parkway, where exposure is moderate in some areas (white and pink) in the **observed** period. In other parks, including Antietam National Battlefield, Catoctin Mountain Park, the C&O Canal NHP, and Harpers Ferry NHP, relatively low exposure and moderate to high adaptive capacity (blue and green) mean natural communities are buffered for now from climate change impacts. In the **near future,** a large increase in exposure results in moderate to very high vulnerability across all NCR parks. Natural communities characterized with low adaptive capacity (red), including much of Manassas National Battlefield Park and Wolf Trap NP for the Performing Arts, can expect severe impacts. All other parks contain at least some areas of high adaptive capacity (yellow) where landscape characteristics support adaptation.

WHAT WE CAN DO

Recommendations & Management Strategies



NEAR FUTURE VULNERABILITY AT ROCK CREEK PARK
Maps depicting the spatial pattern of vulnerability, as shown in this example for Rock Creek Park, can inform park-specific adaptation strategies.

Climate vulnerability assessments are one tool for the development of climate adaptation strategies. We analyzed several components of vulnerability for the NCR region and identified what areas are most and least vulnerable and why. These results can be interpreted using a "climate-smart" framework (Stein et al. 2014), enabling park managers to evaluate a series of management recommendations suited to the observed conditions and adaptable to changing conditions in the near future (see Climate Change Vulnerability Impacts and Strategies table).

When identifying climate-informed management actions for parks, consideration should be given to ecosystem-specific drivers of VULNERABILITY (such as habitat loss and fragmentation), as well as site-specific influences on ADAPTIVE CAPACITY (such as landscape diversity and local connectedness). The results presented here, when interpreted in combination with local knowledge, support managers as they begin planning for change. Safeguarding our natural and cultural treasures within the NCR national parks from the impacts of a changing climate is critical to ensuring a resilient future for nature and for generations of park visitors to come.

CLIMATE CHANGE VULNERABILITY IMPACTS AND GENERAL STRATEGIES TABLE

VULNERABILITY SCORE	CLIMATE IMPACTS	GENERAL STRATEGY
Low	Both resilient and subject to relatively low climate exposure, these sites are least at risk. Given high exposure in the near future, areas of low vulnerability are scarce in NCR Parks.	**Manage for persistence**, with actions focused on preventing impacts by *nonclimate stressors* (e.g., habitat loss, frag-mentation, and invasive species).
Moderate	With moderate to high adaptive capacity and less exposure, these areas can continue to support diverse *natural habitats*. These areas provide the best options to accommodate species movement and for 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. *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., in some instances, species translocations, managing with fire).
Very High	With high exposure and low adaptive capacity, areas with very high vulnerability may experience transformational changes likely to negatively impact overall biodiversity.	**Accommodate significant change and reevaluate management goals.** Actions can be targeted for maintaining eco-system functions and limiting biodiversity loss, but efforts aimed at maintaining existing ecological communities may not achieve desired outcomes in the near future.

TO LEARN MORE

The information in this report is based on climate change scenarios from the Intergovernmental Panel on Climate Change (IPPC 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 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 adaptive capacity 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 Resilience 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 ~30-year periods.
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, and thus a variety of 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.

REFERENCES

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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

Acknowledgments

Produced by NatureServe for the National Capital Region with the support of the National Park Service Climate Change Response Program. Special thanks for reviews by the National Park Service.

Suggested citation: Smyth, Regan, Judy Teague, Stephanie Auer, and Healy Hamilton, 2017. Climate Change Vulnerability of Terrestrial Areas, Prince William Forest Park. Unpublished Resource Brief, Department of the Interior, National Park Service. 10 p.