Climate Change Vulnerability Assessment for the Meyer Project

This document summarizes existing climate change projections and ecological vulnerability assessments for the Upper Midwest and southern Wisconsin, with a focus on grasslands, oak savanna/woodlands, and non-forested wetlands. Results from the TNC Resilient Land Mapping Tool are also summarized for the Meyer Preserve and surrounding TNC Preserves. Future discussions and workshops will help revise and refine this information to guide informed management of the Meyer Preserve.

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Current and projected climate changes for southern Wisconsin and the Upper Midwest

Mean annual temperature is increasing across the Upper Midwest. Since 1950, annual temperatures in southern Wisconsin have increased 2 to 3 °F and are expected to increase an additional 3 to 4 °F by 2050. Seasonally, warm-season temperatures are expected to increase more in the Upper Midwest than in any other region in the U.S[1,2]. The number of extremely hot days (> 90°F) and extremely warm nights (> 70°F) per year will increase substantially, particularly in southern Wisconsin. Winters are expected to warm more than other seasons, a trend that has already been observed in recent decades, and this will result in shorter, milder winters and more precipitation falling as rain rather than snow (*Figures 1,2*). Across seasons, nighttime low temperatures will likely warm more than daytime high temperatures[3]. Overall, the growing season is expected to lengthen.

Mean annual precipitation has also increased by 15 to 20% since 1950 and is projected to increase an additional 5% by 2050. Southern Wisconsin has experienced precipitation increases of 10 to 20% across all seasons, in contrast to northern Wisconsin where summers have been drier since 1950 (*Figure 3*). Future precipitation trends are uncertain, but models project continued increasing precipitation in winter and spring across the state. Additionally, heavy precipitation events are already increasing across the state, and in the future even more of the annual precipitation will fall during increasingly frequent extreme events (*Figure 4*)[4]. Together, this is expected to lead to the paradox of both increased flooding and greater frequency and intensity of late-growing season droughts.

Moreover, the combination of warmer temperatures and altered precipitation regimes will interact to increase drought stress. Warmer temperatures will increase evaporative demand on trees and soil (vapor pressure deficit) and a smaller percentage of precipitation is expected to stay on the landscape due to increased runoff and rapid snowmelt. Therefore, longer growing seasons will be accompanied by increased drought stress.

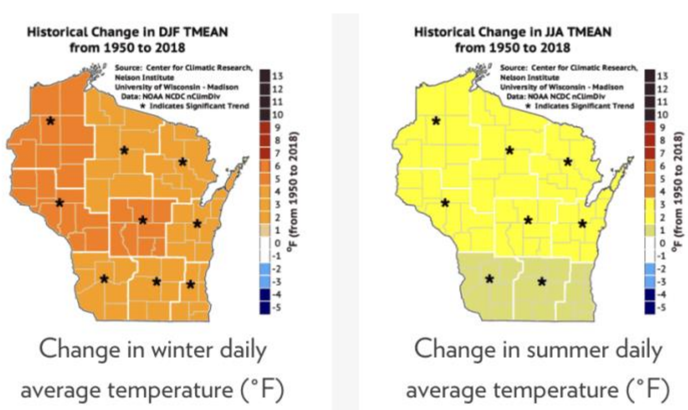


Figure 1. Historical changes in seasonal daily average temperatures across Wisconsin. From 1950-2018, Wisconsin got warmer overall, with greater warming occurring during winters (DJF, left) compared to summers (JJA, right). From Wisconsin Initiative on Climate Change Impacts[5].

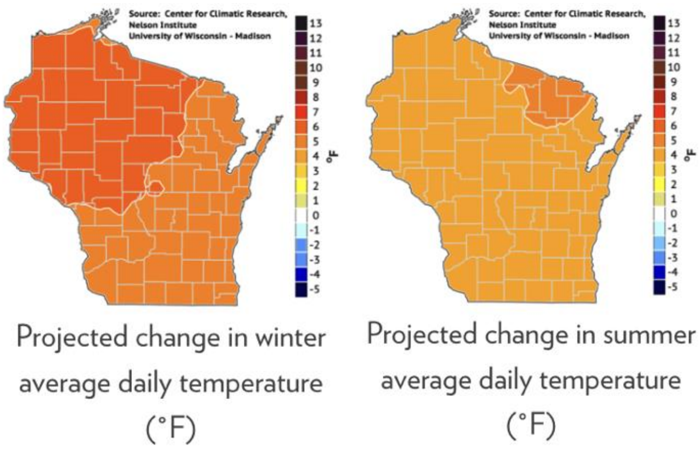


Figure 2. Projected changes in seasonal daily average temperatures across Wisconsin by mid-century. Wisconsin is expected to continue to warm, with warming greater in winter (DJF, left) compared to summer (JJA, right). From Wisconsin Initiative on Climate Change Impacts[5].

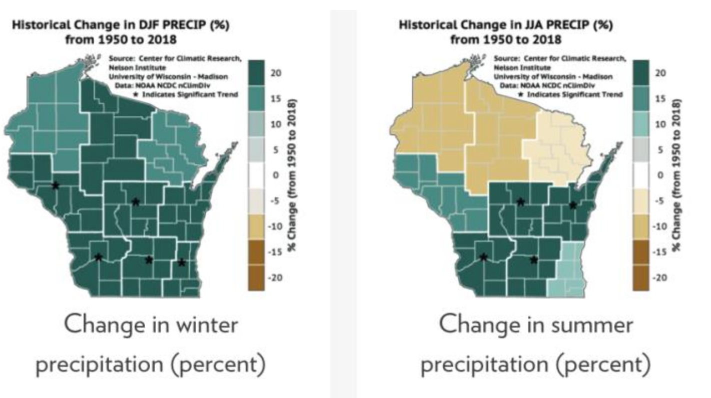


Figure 3. Historical changes in seasonal precipitation across Wisconsin. From 1950-2018, winters (DJF, left) have gotten wetter across most of the state, whereas in summers (JJA, right) southern Wisconsin has gotten wetter and northern Wisconsin has become drier. From Wisconsin Initiative on Climate Change Impacts[5].

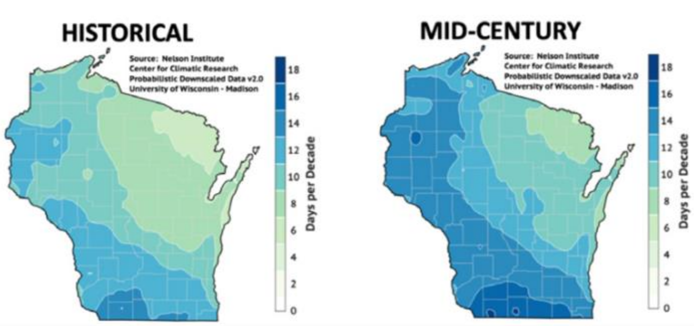


Figure 4. Frequency of extreme precipitation across Wisconsin since 1950 (left) compared to projections to 2050 (right). Extreme precipitation is defined here as days per decade with 2 or more inches of precipitation in a 24-hour period. From Wisconsin Initiative on Climate Change Impacts 2021 Assessment Report[5].

Resilient Land Mapping Tool

What is the Resilient Land Mapping Tool?

The Resilient Land Mapping Tool was developed by The Nature Conservancy in collaboration with a diverse suite of external scientists and conservation planners. This tool aims to identify sites predicted to be resilient to future climate change and to sustain biodiversity and ecological function given a site's physical geography (i.e., topographic position, slope, aspect, moisture index, and presence of wetlands), regardless of future changes in vegetation. These places are valuable to identify because they, "may have new climates and different species in the future but they are likely to sustain their biological diversity and ecological functions."[6]

The Resilient Land Mapping Tool estimates landscape resilience as the average of landscape diversity and local connectedness. *Landscape diversity* is a function of "the number and variety of topographically-derived microclimates present at a site." *Local connectedness* is a measure of landscape permeability or the inverse of resistance to flow of a variety of organisms. Resilience scores are relative to a given ecoregion (e.g., the Prairie-Forest Border that spans much of southern Wisconsin and encompasses the Meyer Preserve). Relative scoring is intentional to avoid biasing scores in favor of large intact ecosystems present in only some ecoregions. Quantitative relative scores are given in z-units, representing how many standard deviations the area of interest is from the mean of the entire ecoregion. A qualitative relative score is also provided (e.g., "slightly above average") based on the quantitative score. Overall, the tool emphasizes the importance of microclimates in sustaining local biodiversity, as the diverse habitats that emerge from microclimates can serve as holdouts, stepping stones, and microrefugia for species experiencing regional climate change.

Resilient Land Results for the Meyer Preserve (including all TNC Mukwonago Preserves)

The Resilient Land Mapping Tool allows users to spatially examine overall estimated resilience as well as view component data that collectively inform resilience scores. Component data include: landscape diversity, local connectedness, fragmenting features, geology and soils, and landforms, as well as elevation and migration space for tidal habitat (the latter two being less relevant to the Prairie-Forest Border ecoregion given the minimal variation in elevation across the region and lack of tidal habitat).

Here, we briefly examine overall resilience and some relevant component layers for the TNC Mukwonago Preserves (which includes the Meyer Preserve) in comparison to the broader Prairie-Forest Border ecoregion. Specifically, the spatial extent of our analysis (hereafter referred to as the "Mukwonago Preserves") is defined as the area included in the Mukwonago_Preserves_2021 shapefile provided by TNC. This discontiguous area of interest includes ~2000 acres, most of which is land with small patches of open water. Approximately 5% of the land area is developed.

Overall resilience score

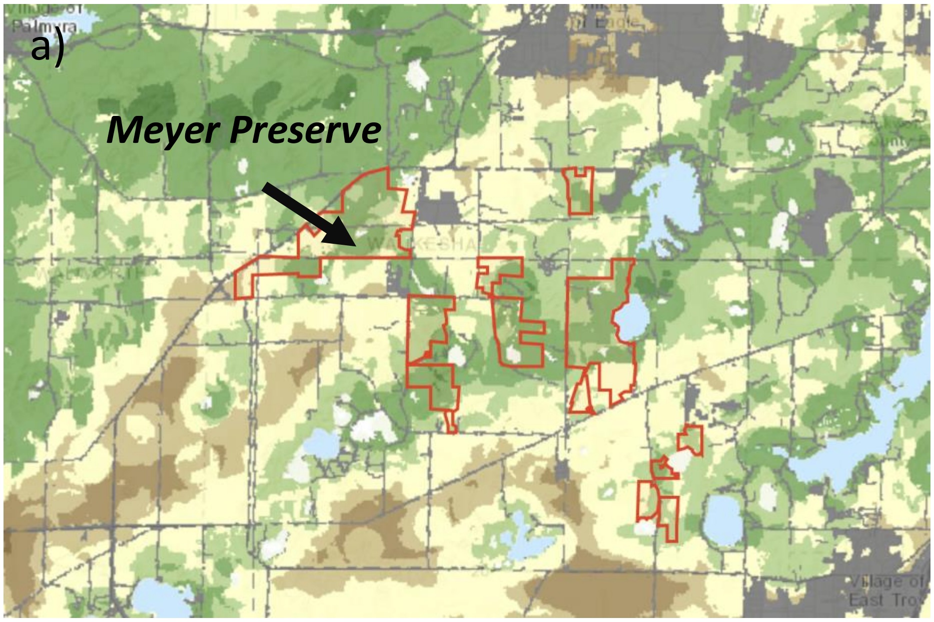
The overall resilience score for the Mukwonago Preserves was slightly above average compared to the rest of the ecoregion (z-score = 0.68). At a finer spatial scale, most patches within the Mukwonago Preserves were "slightly more resilient" to "more resilient" (46% and 28% of total area, respectively), with very little land area "below average" in terms of resiliency. In comparison, the broader Mukwonago watershed's resilience score was "average" (score = -0.3), with the vast majority of patches identified to have above average resilience occurring within the protected TNC Mukwonago Preserves (*Figure 5a*).

Landscape diversity and biodiversity

The Mukwonago Preserves have "slightly above average" landscape diversity (score = 0.78), with ~45% of the area "above average" and only ~6% of the area"far below average" (*Figure 5b*). The entire Mukwonago Preserves area has recognized biodiversity value.

Connectedness and flow

The Mukwonago Preserves also have slightly above average local connectedness, as assessed at 30m resolution (score = 0.68; *Figure 5c*). At a broader spatial scale (250m resolution), there is one primary conduit of connectivity that runs across the center of the Mukwonago Preserves, comprised of contiguous forest and wetlands (*Figure 6*). The Meyer Preserve (to the west) and the southeastern tracts of the broader Mukwonago Preserve network have low connectivity as assessed at the broader spatial scale due to the presence of both high intensity agriculture and development as well as small patches of divergent land covers (as determined from the fragmenting features data within the Resilient Land Mapping Tool). The area has no natural diffuse flow (which would confer greater resiliency) as determined by the Resilient Land Mapping Tool.



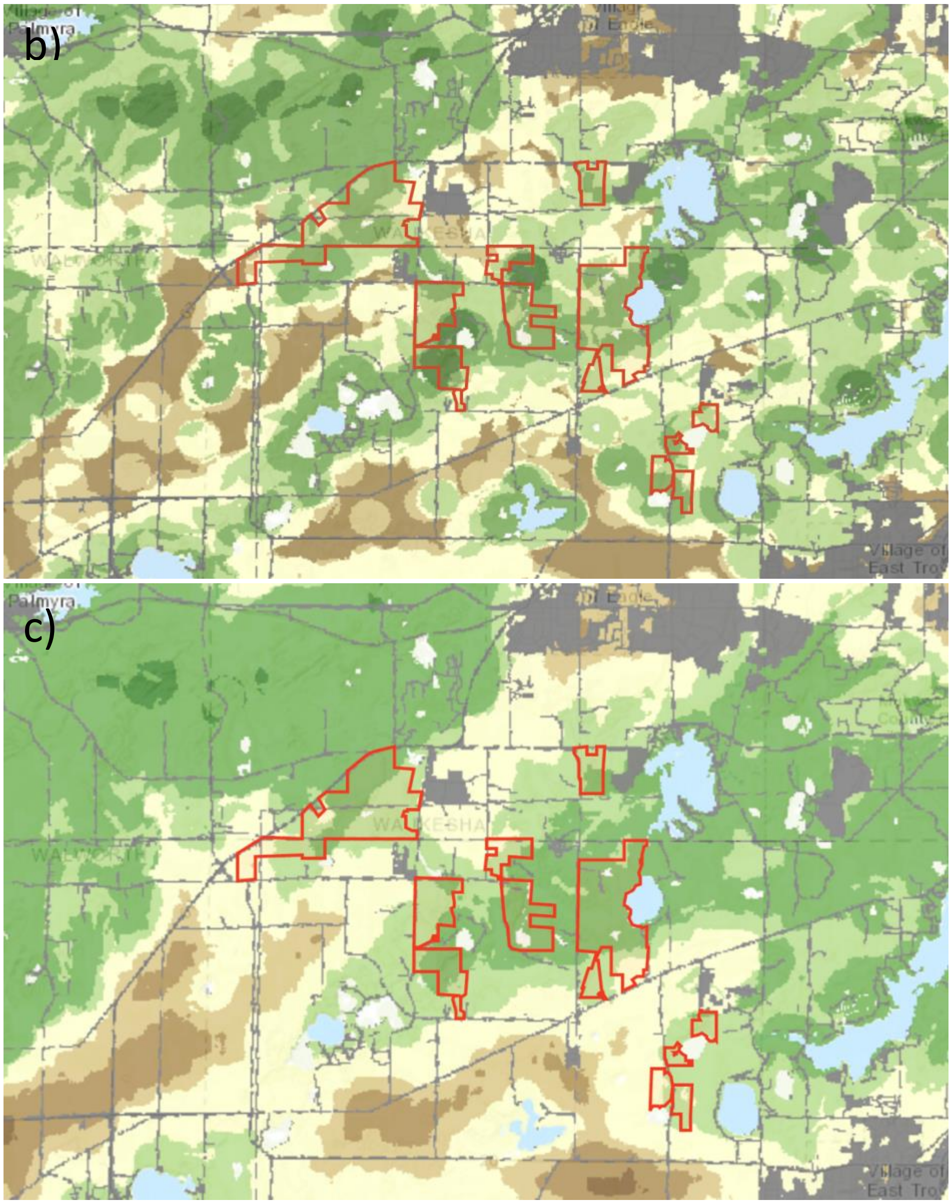


Figure 5. Resiliency of Mukwonago Preserves compared to the Prairie-Forest Border eco-region. Panel a shows overall resiliency and panels b and c show component data layers (b = landscape diversity and c = local connectedness). Green indicates above-average scores, brown indicates below-average scores, and darker hues indicate greater deviation from the average (e.g., dark green in panel a indicates "most resilient" sites). The Mukwonago Preserves are outlined in red. The Meyer Preserve is the upper left preserve, as indicated by an arrow in panel a.

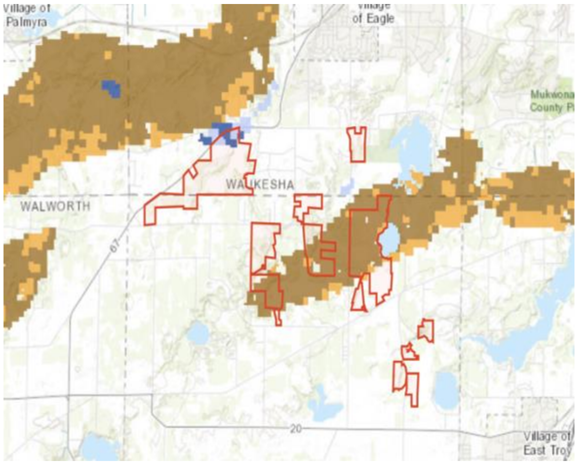


Figure 6. Connectivity and climate flow map of Mukwonago Preserves. Preserve boundaries are outlined in red. Dark brown cells indicate areas of concentrated flow (i.e., flow restricted to corridors due to landscape fragmentation) with "climate informed linkage" (i.e., the local connectivity follows natural climate gradients that are important for supporting species range shifts). Orange cells indicate areas of concentrated flow that are not climate informed, and are therefore expected to be more vulnerable to climate change.

Summary of climate change vulnerability for southern Wisconsin ecosystems

Key climate change vulnerabilities

Vulnerability to climate change can be defined as the degree to which a system is susceptible to and unable to cope with adverse effects of climate change[7,8]. Vulnerability can be thought of as the combination of a system's *exposure* (the degree of stress on a system) and *sensitivity* (the degree to which a resource will be affected by that stress) to climatic changes, as well as the *adaptive capacity* of the system, i.e., its ability to accommodate or cope with the impacts of climatic changes with minimal disruption[8,9].

Key climate change vulnerabilities for ecosystems in the Upper Midwest (including prairies, savannas, and non-forested wetlands) include[1,3]:

- Climate is shifting faster than plants can shift their ranges.
- More frequent and intense precipitation events can increase run-off and decrease consistent groundwater storage, thereby also driving more and longer droughts.
- Increasing CO_2 concentrations, warmer temperatures, and more variable precipitation may give non-native invasive species (typically more ruderal species) a competitive edge over native species, and non-native invasives may increase their productivity and range.
- Phenological mismatch between species (e.g., plant-feeding insects and migratory birds not shifting timing with spring green-up) can drive a decline in species viability over time
- Declines in native pollinator species and phenological mismatches can inhibit plant reproduction and reduce ecosystem biodiversity.

- Increases in seasonal precipitation and frequency of heavy precipitation events will increase flooding and erosion risk, and the loss of wetlands due to land conversion further compounds this risk.

Vulnerability summaries for specific ecosystems

This section summarizes climate vulnerabilities for specific ecosystems, drawing heavily from the WICCI Plant and Natural Communities Working Group Climate Change Vulnerability Assessments as well as the Climate Change Field Guide for Southern Wisconsin Forests[4]. WICCI has published "Broad Community Group Fact Sheets" summarizing vulnerabilities of general ecosystem types (e.g., grasslands, savannas, non-forested wetlands), along with more detailed "Technical Bulletins" for specific natural communities (e.g., wet-mesic prairie, oak opening). These documents are available at the WICCI link above, and the relevant resources are referenced in each section below. The vulnerability ranges assigned to each ecosystem below were determined by WICCI's vulnerability ratings for all specific natural communities within a given community group found within the Mukwonago Preserves. For example, the vulnerability rating for tallgrass prairies incorporates the WICCI rating for dry-mesic, mesic, and wet-mesic prairies.

Tallgrass prairies. *Vulnerability to climate change: moderate to high*

Tallgrass prairies, including dry-mesic, mesic, and wet-mesic prairies, are dependent on fire. Climate change may decrease opportunities for prescribed fires and make planning for such burns more difficult due to more variable conditions, thereby threatening the biodiversity and persistence of tallgrass prairies. Additionally, increased frequency and intensity of storm events, along with more winter precipitation falling as rain on frozen soils, will likely increase nutrient runoff and soil erosion. Nutrient pollution and sedimentation are degrading mesic and wet prairies and can also favor invasive species. Overall, these grassland communities are well adapted to warm and drought conditions, but management challenges include effective burning and control of invasive species. Fragmented landscapes, common for tallgrass prairies in the region, exacerbate both climate change vulnerability (e.g., increased nutrient pollution from nearby agricultural runoff) and management challenges (e.g., effective prescribed burns in small areas) (*Figure 7*).

Site-level vulnerabilities of the Meyer Preserve

At the Meyer Preserve, the ability to carry out effective prescribed burns is a key concern and point of uncertainty. Challenges related to prescribed burns stem from both a changing climate (more narrow and less predictable windows of opportunity for burning) and a fragmented landscape (nearby residents may not be supportive of burns due to fear of fire escape and poor air quality from the smoke). Current management practices do include prescribed burns, indicating burning is a feasible and beneficial management tool at this site. More generally, fragmented landscapes threaten the Meyer Preserve in many of the ways detailed above;

however, given that the Meyer Preserve is located in the headwaters of the Mukwonago watershed rather than further downstream may protect the prairies from the most severe effects of accumulated runoff pollution and sedimentation.

WICCI Resources: Grassland Fact Sheet; Technical bulletins for dry-mesic prairies, mesic prairies, and wet-mesic prairies

Figure 7. Prairie on western edge of the Meyer Preserve. Photo credit: Adrienne Keller, NIACS

Oak savannas. *Vulnerability to climate change: moderately low to moderate*
Oak savannas, including oak openings and oak woodlands, are highly sensitive to fire regime. Fragmented landscapes and reduced opportunities for prescribed burns due to climate change may limit fire and result in rapid woody encroachment in savanna ecosystems. Invasive species, including common buckthorn and other woody invasives, may benefit from CO_2 enrichment and longer growing seasons. However, several factors may reduce the risk of woody encroachment including increased a) summer droughts, b) freeze-thaw events that can damage tree roots, and c) pests and pathogens. Overall, savanna species are generally well adapted to warmer temperatures and drought, suggesting that oak savannas may fare well in future climate conditions especially in connected landscapes that confer resilience over time and space. White and bur oak species are expected to have stable or slightly increasing populations with climate change (Climate Change Tree Atlas). Key uncertainties include how competitive woody invasive and forest species will be in future climates and how the changing climate will impact prescribed burns (*Figure 8*).

Site-level vulnerabilities of the Meyer Preserve
Woody encroachment on oak savannas across the Meyer Preserve ranges from minimal to extensive. Invasive common buckthorn and fast-growing black walnut are two common woody species driving much of the woody encroachment. There are not substantial obstacles to oak regeneration in this part of the state, and deer browsing is minimal. The long-term (decadal)

trajectory of these oak savannas will be driven in large part by interactions between climate change and disease outbreaks, yet the nature of these interactions is difficult to predict. Areas where prescribed burns can consistently and effectively be carried out (e.g., due to topography, total acreage, etc) will be more resilient over time, and current prescribed burn management practices can inform these spatial considerations.

WICCI Resources: Savanna Fact Sheet; Technical bulletins for oak openings and oak woodlands

Figure 8. Oak savanna at the Meyer Preserve (left), with evidence of initial woody encroachment nearby (right). Photo credit: Adrienne Keller, NIACS

Non-forested wetlands. *Vulnerability to climate change: low to high*
Altered hydrology will confer the most prominent effects of climate change on non-forest wetlands, yet predicting the nature of these effects remains challenging. Increased frequency and intensity of storm events, along with more winter precipitation falling as rain on frozen soils, will likely increase nutrient runoff and soil erosion. These conditions could also decrease groundwater recharge. However, if soils remain unfrozen for a greater percentage of the year, precipitation infiltration and groundwater recharge may actually increase. Thus, climate change effects on groundwater recharge remains a key uncertainty in non-forested wetlands. Nutrient pollution and sedimentation, along with longer growing seasons and increased atmospheric CO_2, can favor invasive species such as non-native cattails, Phragmites, and woody invasives such as common buckthorn (*Figure 9*).

Site-level vulnerabilities of the Meyer Preserve
Given the fragmented landscape of the Meyer Preserve and the predominance of surrounding agricultural lands, nutrient run-off is of particular concern for the Meyer Preserve. Several invasive species, including cattails and common buckthorn, already have a stronghold in many of the non-forested wetlands on the Meyer Preserve.

WICCI Resources: Non-forested Wetlands Fact Sheet; Technical bulletins for Calcareous Fens, Shrub-carr, Southern Sedge Meadows

Figure 9. Non-forested wetland at the Meyer Preserve experiencing some encroachment of invasive and woody species. Photo credit: Adrienne Keller, NIACS

Additional Resources

Further Reading

This document is meant to serve as a springboard for additional reading and exploration of regional and site-specific climate change vulnerabilities. Some key additional resources are summarized below for your reference.

Climate Change Field Guide for Southern Wisconsin Forests
https://forestadaptation.org/field-guide-southern-wisconsin
This field guide is a quick reference on climate change for southern Wisconsin forests, including savannas (as well as one section on forest carbon management). This guide intends to highlight key information that can help land managers consider climate change risks together with local site characteristics.

Climate Change Tree Atlas
Complete atlas: https://www.fs.usda.gov/nrs/atlas/
Summaries for southern Wisconsin Ecological Sections:
https://forestadaptation.org/learn/resource-finder/tree-species-projections-ecological-sections-southern-wisconsin
The Climate Change Tree Atlas is a tool that combines tree species traits and suitable habitats for individual tree species with future climate scenarios to project how climate change will affect tree species distributions across the continental United States.

Impacts, Risks, and Adaptation in the United States: Fourth National Climate Assessment Volume II (Chapter 21: Midwest Region)
https://nca2018.globalchange.gov/chapter/21/
The National Climate Assessment is a report issued (at minimum) every four years by the U.S. Global Change Research Program, as mandated by federal law. Volume I describes the state of climate change science and Volume II addresses the human, societal, and environmental vulnerabilities to those climatic changes described in Volume I. Chapter 21 of Volume II focuses on vulnerabilities of the Midwest region and also offers opportunities for climate adaptation in the region.

Wisconsin Initiative on Climate Change Impacts (WICCI) and their 2021 Assessment Report: Wisconsin's Change Climate: Impacts and Solutions for a Warmer Climate
https://wicci.wisc.edu/
WICCI is a statewide collaboration of scientists and stakeholders that focuses on evaluating climate change impacts across the state and advancing solutions. Along with the 2021 Assessment Report, climate change vulnerability assessments are also available online for the many diverse plant and natural communities found across the state.

WICCI Plants and Natural Communities Working Group
https://wicci.wisc.edu/plants-and-natural-communities-working-group/climate-change-vulnerability-assessments-ccvas/
Here is the landing page for the Plant and Natural Communities Working Group. Specific documents relevant to the Meyer Preserve are linked in the main text of this document.

WICCI Forestry Working Group
https://wicci.wisc.edu/forestry-working-group/
The WICCI Forestry Working Group has also summarized and published state-specific resources related to climate vulnerability.

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