Natural Lands Climate Change Vulnerability Assessment and Adaptation Strategies Synthesis Report

2023

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Meeting the challenges of climate change

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Further information on the Natural Lands Climate Adaptation Project is available on the project website (https://ecoadapt.org/goto/Natural-Lands).

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Introduction

Natural Lands is a non-profit organization dedicated to conserving and stewarding land in eastern Pennsylvania and southern New Jersey, where they care for more than 23,000 acres of open space across 42 preserves and one public garden. However, climate changes such as warmer air temperatures, altered precipitation patterns, reduced snowpack, extreme precipitation, increased heat waves, and drought are already affecting ecosystems and species of the region, as well as the human communities that depend on them. To support Natural Lands staff in addressing these challenges, the organization partnered with EcoAdapt on the Natural Lands Climate Adaptation Project, with a specific focus on ChesLen and Bear Creek Preserves (Figure 1).

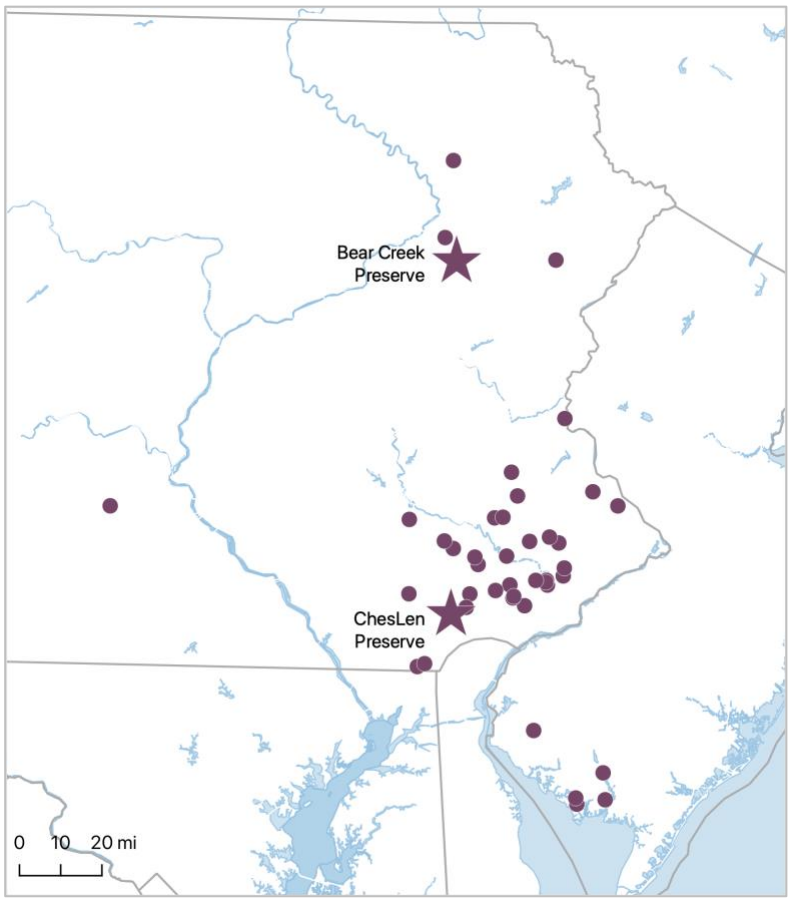

Figure 1. The location of all Natural Lands preserves (Bear Creek and ChesLen preserves are identified by stars).

The goal of the Natural Lands Climate Adaptation Project was to incorporate climate change adaptation into land management planning and stewardship of ChesLen Preserve and Bear Creek Preserve, and to increase staff capacity for climate- informed planning and management across all Natural Lands properties. Project objectives included:

1. Generate a summary of climate change projections for the region, which can be used to inform management across all Natural Lands preserves;
2. Increase understanding of climate-related vulnerabilities for priority habitats within ChesLen and Bear Creek Preserves;
3. Identify adaptation strategies and actions that reduce vulnerabilities and create concrete, actionable plans for implementing priority actions through climate-informed management and restoration on the two preserves; and
4. Increase the capacity of Natural Lands staff to understand and utilize information about climate change impacts and ecosystem vulnerability within preserve stewardship planning and management.

This report synthesizes the results of the major project components – summarizing observed and projected climate changes, assessing vulnerability, and adaptation planning. It includes an **Overview of Climate Adaptation Planning**, which gives a brief description of the iterative process used to incorporate climate change into management activities. The **Project Methods and Workshop** section

describes the methodology used for the climate impacts summary, vulnerability assessments, and adaptation workshop. Finally, the **Vulnerability Assessment and Adaptation Planning Results** section summarizes overall trends and findings for priority habitats within ChesLen and Bear Creek Preserves.

Overview of Climate Adaptation Planning

The impacts of climate change have significant implications for the ecosystems of Pennsylvania and southern New Jersey, particularly within the context of ongoing non-climate stressors such as invasive species, roads and trails, dams, pollution, and recreation, among others. Natural resource managers are now faced with the challenge of developing and implementing strategies that offer a path forward for these habitats and species given changing climate conditions. Strategies undertaken to address the causes and effects of global climate change are classified as either *mitigation* or *adaptation*. *Mitigation strategies* aim to reduce the rate and extent of change by reducing greenhouse gas emissions or enhancing carbon uptake and sequestration. *Adaptation strategies* help people prepare for, respond to, and/or recover from the unavoidable effects of climate change.

Climate change adaptation enables decision-makers to take a deliberate approach to evaluating vulnerabilities and designing adaptation strategies that enable climate-informed conservation and management. The adaptation planning process (Figure 2) reflects the intentional integration of climate change into management and conservation. These actions may include current management approaches, modifications to current strategies, and/or new and novel approaches to address climate change.

Figure 2. Climate adaptation planning process (image modified from Glick et al. 2011).

Project Methods and Workshop

This project used a collaborative, expert opinion-based approach involving preserve managers and other Natural Lands staff. Eliciting expert opinion is an effective approach in situations where there is greater uncertainty about future climate projections and impacts, but conservation professionals working on the ground are able to contribute detailed knowledge and expertise about the ecology, management, and threats to regional resources of concern. This project involved three primary activities, which are described in more detail below:

1. Overview of climate trends and projections,
2. Vulnerability assessment, and
3. Adaptation planning.

Overview of Climate Trends and Projections

EcoAdapt staff reviewed historical climate trends and future projections for the state of Pennsylvania, with an emphasis on the eastern portion of the state where the majority of Natural Lands preserves are located. Most of the information was drawn from the Pennsylvania 2021 Climate Impacts Assessment (ICF 2021) and the U.S. Climate Resilience Toolkit Climate Explorer (U.S. Federal Government 2021), which were used to consider changes in air temperature, precipitation, snowfall and snowpack, extreme weather events, and soil moisture as well as factors such as drought and wildfire. Wherever possible, we presented historical trends in these factors compared to mid- and end-of-century time frames for the state of Pennsylvania as well as for Luzerne and Chester Counties where Bear Creek and ChesLen Preserves are located. For air temperature, extreme heat, precipitation, and extreme precipitation, we presented projected changes for both moderate-emissions and high-emissions scenarios (RCP 4.5 and RCP 8.5, respectively) for all counties where Natural Lands manages a preserve. For all other factors, results presented were focused on the high-emissions scenario (RCP 8.5), because of the readily-available scenarios it most closely matches the current global trajectory. At the end of the document, we also summarized climate change projections for individual tree species in Pennsylvania (NIACS 2023a, 2023b) and modeling results for future changes in plant hardiness zones (Matthews et al. 2018).

This information was compiled within a short report titled “Overview of Climate Trends and Projections for Natural Lands Preserves”, which is available at https://ecoadapt.org/goto/Natural-Lands. This information also provided the foundation for ranking the climate exposure component of the ecosystem vulnerability assessments for Bear Creek and ChesLen Preserves (described in the next section of this report).

Vulnerability Assessment

EcoAdapt evaluated the climate change vulnerability of ten priority ecosystems within Bear Creek and ChesLen Preserves (three full assessments and two additional brief assessments in each preserve; Table 1), with the goal of determining whether and how these systems might be vulnerable to current and future impacts of climate change.

Table 1. Priority ecosystems identified and assessed for the Natural Lands Climate Adaptation Project.

Bear Creek Preserve	ChesLen Preserve
• Early-successional forests • Mature forests • Spruce swamp • Cranberry bog *(brief)* • Water resources *(brief)*	• Afforestation areas • Unionville barrens • Water resources • Agriculture *(brief)* • Meadows *(brief)*

Vulnerability Assessment Model

Vulnerability is defined as a function of the sensitivity of a particular resource to climate changes, its exposure to those changes, and its capacity to adapt to those changes (IPCC 2014; Figure 3). **Exposure** is a measure of how much of a change in climate or climate-driven factors a resource is likely to experience (Glick et al. 2011). **Sensitivity** is a measure of whether and how a resource is likely to be affected by a given change in climate or factors driven by climate (Glick et al. 2011). **Adaptive capacity** refers to the ability of a resource to accommodate or cope with climate change impacts with minimal disruption (Glick et al. 2011).

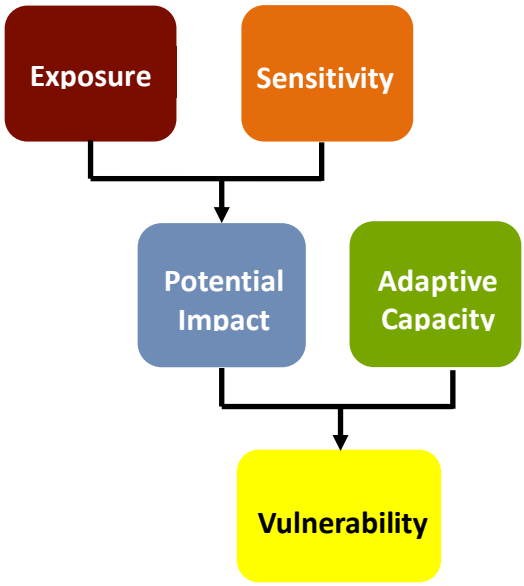

Figure 3. Components of vulnerability (IPCC 2014).

The vulnerability assessment model applied in this process was developed by EcoAdapt (EcoAdapt 2014a, 2014b; Kershner 2014; Hutto et al. 2015),[1] and includes evaluations of relative vulnerability by local stakeholders who have detailed knowledge about and/or expertise in the ecology, management, and threats to regional habitats and species. Natural Lands staff members evaluated vulnerability of each resource by ranking aspects of sensitivity, exposure, and adaptive capacity using a set of worksheets created to walk them through the process.

Natural Lands staff were first asked to describe the habitat, and then were asked to assign one of three rankings (High, Moderate, or Low) for various elements related to sensitivity and adaptive capacity (Table 2). EcoAdapt assigned rankings to climate exposure based on climate projections for the region (compiled during the earlier review of regional trends and projections). Rankings for each component were then converted into scores (High-3, Moderate-2, or Low-1) and the scores for the different elements were averaged (mean) to generate an overall score for sensitivity, exposure, and adaptive capacity. Scores for exposure were weighted less than scores for sensitivity and adaptive capacity

[1] Sensitivity and adaptive capacity elements were informed by Glick et al. 2011, Manomet Center for Conservation Sciences 2012, and Lawler 2010.

because of greater uncertainty about the magnitude and rate of future change. Sensitivity, adaptive capacity, and exposure scores were combined into an overall vulnerability score calculated as:

Vulnerability = [(Climate Exposure*0.5) x Sensitivity] - Adaptive Capacity

Table 2. Elements assessed for each of the three components of vulnerability.

Sensitivity
• **Climate and Climate-Driven Factors:** e.g., air temperature, precipitation, freshwater temperature, soil moisture, snowpack, timing of snowmelt, altered streamflow, heat waves, drought • **Disturbance Regimes:** e.g., wildfire, flooding, storms and related impacts, insect and disease outbreaks • **Non-Climate Stressors:** e.g., residential or commercial development, agriculture, pollution and poisons, transportation corridors (e.g., roads, highways, trails), fire exclusion/suppression, invasive and other problematic species, pollution, etc. For non-climate stressors, participants were asked to evaluate sensitivity and the degree to which the resource is currently exposed to that stressor.
Exposure
• **Future Climate Exposure:** Projected direction and magnitude of climate factors (e.g., temperature and precipitation) and climate-driven changes in disturbance regimes (e.g., altered fire and flooding regimes). Participants were also asked to identify any areas of potential refugia
Adaptive Capacity
• **Extent, Integrity, and Continuity:** e.g., widespread distribution vs. occurrence in small areas; high structural and functional integrity vs. degraded habitats; highly continuous vs. isolated/fragmented • **Landscape Permeability:** e.g., permeable landscapes with few to no barriers to dispersal and/or movement vs. landscapes with multiple barriers that affect continuity/dispersal • **Habitat Diversity:** e.g., diversity of physical and topographical characteristics as well as component native species and functional groups in the habitat • **Resistance and Recovery:** *Resistance* refers to the stasis of a habitat in the face of change, while *recovery* refers to the ability to "bounce back" from stressors once they do occur • **Management Potential:** e.g., ability of resource managers to alter the adaptive capacity and resilience of a habitat; includes consideration of public value and societal support for management actions as well as management capacity and ability to alleviate impacts

Elements for each component of vulnerability were also assigned one of three confidence rankings (High, Moderate, or Low). Confidence rankings were converted into scores (High-3, Moderate-2, or Low-1) and the scores averaged (mean) to generate an overall confidence score. These approximate confidence levels were based on the Manomet Center for Conservation Sciences (2012) 3-category scale, which collapsed the 5-category scale developed by Moss and Schneider (2000) for the IPCC Third Assessment Report. The vulnerability assessment model applied here assesses the confidence associated with individual element rankings, and uses these rankings to estimate the overall level of confidence for each component of vulnerability as well as overall vulnerability.

Rankings and scores presented should be considered measures of relative vulnerability and confidence such that comparisons between habitat and species vulnerability should only be made within the context of this project.

Vulnerability Assessment Summaries

Vulnerability and confidence rankings and scores provided on worksheets by Natural Lands staff were supplemented with information from the scientific literature. The final vulnerability assessment summary for a given resource includes rankings, confidence evaluations, and narratives integrating information from the scientific literature with preserve-specific details provided by on-the-ground staff. The draft vulnerability assessment summaries were reviewed by Natural Lands staff to help address discrepancies and uncertainties.

Links to the final vulnerability assessment summaries are available at https://ecoadapt.org/goto/Natural-Lands.

Adaptation Planning

The final stage of the project was an adaptation workshop for Natural Lands staff, held on May 30th and June 1st, 2023, with each session lasting for four hours. The purpose of the workshop was to identify priority adaptation strategies and actions for priority habitats in ChesLen and Bear Creek preserves, and then create detailed, actionable plans for implementing those strategies and actions within preserve management and restoration activities.

Types of Adaptation Strategies and Actions

Climate change adaptation refers to adjustments in natural or human systems in response to changing climate conditions. Adaptation strategies are efforts to reduce climate change vulnerability by decreasing climate impacts (sensitivity and exposure) and/or increasing resilience (adaptive capacity). These strategies typically build on existing management, conservation, and restoration of natural resources, and can include taking advantage of opportunities provided by climate change. Climate adaptation approaches typically fall into one or more of the following categories:

Climate change adaptation actions are organized into three general management approaches (Schuurman et al. 2021):

- **Resistance/Resilience** actions are focused on managing for persistence of existing ecosystems. This is generally a management-intensive approach with a near- to mid-term planning horizon. Examples include preventing the spread of invasive species that may proliferate under changing climate conditions, or removing barriers to allow species migration in response to climate change.
- **Acceptance** actions are focused on accommodating change in response to novel conditions. These actions generally utilize a long-range planning horizon, and involve no management action beyond observation. Examples include accepting transition from one habitat type to another (e.g., grassland to forest) in response to changing climate conditions.
- **Direct/Response** actions are focused on actively facilitating change/transformation in response to novel conditions. They may be management-intensive, and generally utilize a long-term

planning horizon. Examples include introducing native (and regionally-appropriate) species that are well-adapted to future conditions but were not historically present on the site.

Two additional approaches describe adaptation strategies that support management efforts and may be precursors to implementing a strategy that falls under one of the approaches above:

- **Knowledge** actions are focused on gathering more information about climate changes, impacts, and/or the effectiveness of management actions in addressing the challenges of climate change. The goal of these strategies is to gather and use the best available information to help determine which actions to implement and how. Examples include expanding research on silviculture techniques for drought- and heat-tolerant species or monitoring the long-term effectiveness of rare species management and restoration.
- **Collaboration** actions are focused on coordinating management efforts and/or capacity across organizational, departmental, or jurisdictional boundaries. Examples include developing and/or strengthening new and existing collaborative networks in order to leverage resources.

Description of the Natural Lands Climate Adaptation Workshop

The first day of the workshop began with welcoming remarks from EcoAdapt, followed by an overview of the Natural Lands Climate Adaptation Project. The workshop organizer then introduced the facilitator team, and reviewed the workshop objectives and the day's agenda. Next, EcoAdapt presented an overview of climate trends and projections for the region covering Natural Lands preserves, and then an introduction to vulnerability and review of the vulnerability assessment findings and trends. Following these presentations, the concept of adaptation planning was introduced and then workshop participants split up into breakout groups based on four of the six habitats that were fully assessed: (1) afforestation areas in ChesLen Preserve, (2) the Unionville barrens in ChesLen Preserve, (3) mature forests in Bear Creek Preserve, and (4) the spruce swamp in Bear Creek Preserve. Each breakout group consisted of a brainstorming session to identify potential adaptation strategies, and then selecting 1–3 of those strategies to develop several adaptation action steps that could be carried out within the preserves. Workshop participants also evaluated the feasibility (i.e., ability to implement the action, given financial cost, staff capacity, and other required resources), effectiveness (i.e., likelihood that successful implementation of the action would reduce the vulnerability of the habitat and help Natural Lands achieve their management goals in the context of climate change), and potential co-benefits or potential conflicts/unintended consequences of implementing the action. Finally, participants noted where and how the action could be implemented, identifying management considerations or site and ecological conditions where the action would be best applied. At the conclusion of the day, workshop participants reconvened in a large group to share their strategies and actions with one another.

Day 2 began with brief welcoming remarks, followed by an introduction to the adaptation implementation planning activity. The majority of the day was spent in breakout group sessions, where workshop participants were asked to develop detailed adaptation implementation plans for the same habitats that each breakout group had worked on during Day 1. The adaptation implementation plans included background information on the project site selected (e.g., key climate-related vulnerabilities, potential barriers to adaptation), implementation steps (e.g., adaptation actions to take place along with information on timeline, leads and potential partners, and existing/needed resources), monitoring

and evaluation (e.g., desired outcomes/restoration targets, metrics to determine whether those outcomes/targets are being achieved, thresholds that might indicate management intervention is needed), and funding and communications. Following the breakout group activity, participants reconvened to share their implementation plans. EcoAdapt staff presented an overview of additional tools and resources that could be used for planning and implementation, and then a short wrap-up presentation concluded the workshop.

The workshop agenda, presentations, and supporting materials can be accessed through the workshop support page: https://ecoadapt.org/workshops/natural-lands-workshop.

Because there were only four breakout groups during the workshop, preserve managers met with EcoAdapt staff in July 2023 to identify adaptation strategies and actions for the two priority habitats that were not addressed during the workshop: Bear Creek Preserve early-successional forests and ChesLen Preserve water resources. These are included in the following section; however, implementation plans were not created for these two additional habitats.

Vulnerability Assessment and Adaptation Planning Results

Vulnerability Assessments

The vulnerability rankings for all habitats assessed for Bear Creek and ChesLen Preserves are summarized in Table 3 and Figure 4. Of the ten habitats assessed for this project, nine of them received overall vulnerability rankings of moderate (Table 3).

Table 3. Overall vulnerability rankings and confidence scores for Bear Creek Preserve and ChesLen Preserve habitats assessed for the Natural Lands Climate Adaptation Project.

HABITAT	VULNERABILITY	CONFIDENCE
Bear Creek Preserve		
Water resources *(brief)*	High	High
Early-successional forests	Moderate	High
Mature forests	Moderate	High
Cranberry bog *(brief)*	Moderate	High
Spruce swamp	Moderate	Moderate
ChesLen Preserve		
Agriculture *(brief)*	Moderate	High
Meadows *(brief)*	Moderate	High
Afforestation areas	Moderate	Moderate
Unionville barrens	Moderate	Moderate
Water resources	Moderate	Moderate

In Figure 4, the vulnerability of each habitat is plotted with potential impact (sensitivity and exposure) on the x-axis and adaptive capacity on the y-axis in order to illustrate which components of vulnerability are driving the overall vulnerability score. Thus, habitats appearing towards the lower right corner of the graph (i.e., those with high sensitivity/exposure and low adaptive capacity) are the most vulnerable, while those placed towards the upper-left corner (i.e., those with low sensitivity/exposure and high adaptive capacity) are the least vulnerable.

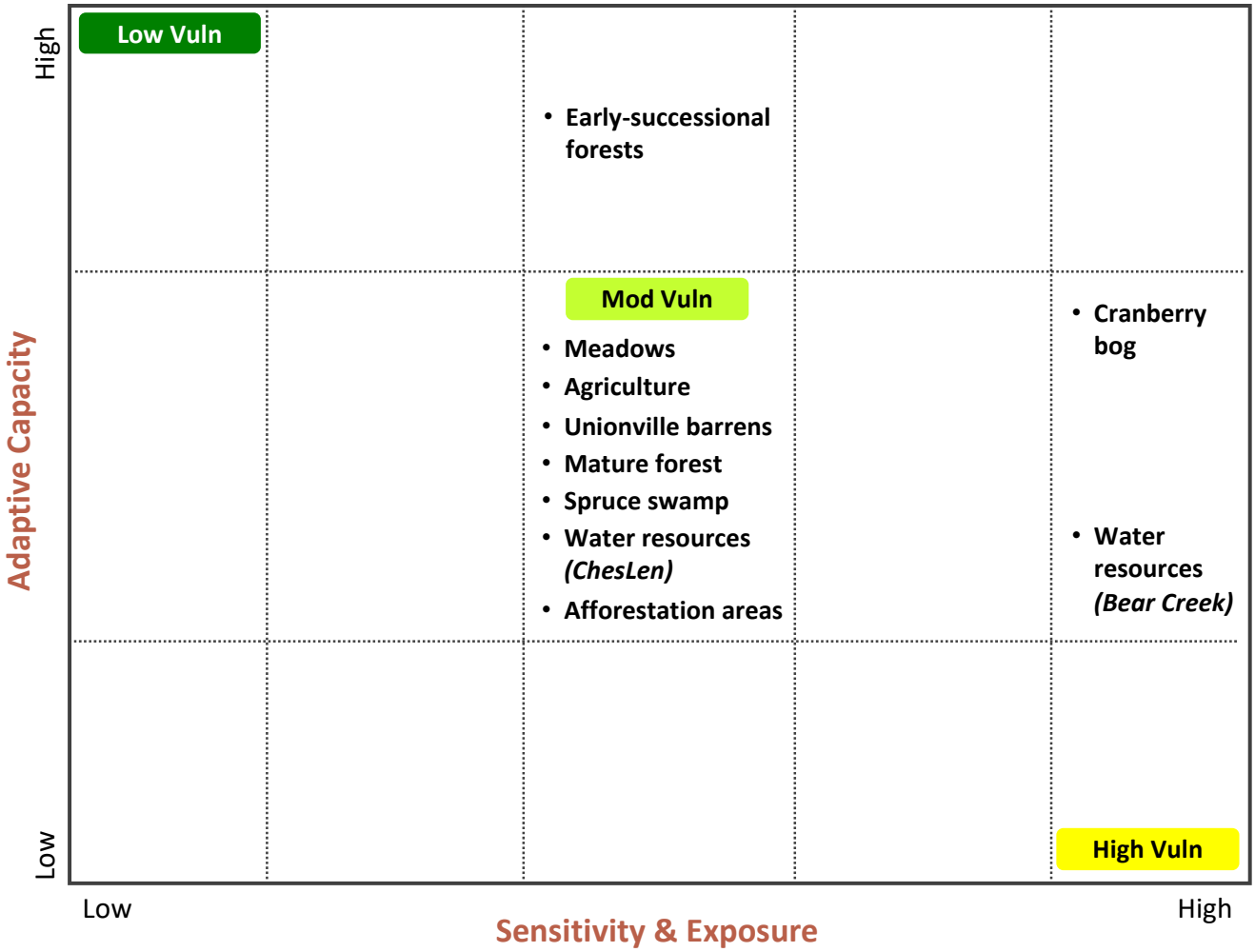

Figure 4. Sensitivity and exposure (impact) and adaptive capacity rankings plotted for Bear Creek Preserve and ChesLen Preserve habitats. Habitats with high vulnerability to climate change (high impact/low adaptive capacity) are located in the lower right, while those with low vulnerability (low impact/high adaptive capacity) are in the upper left.

Overall, Bear Creek Preserve water resources were ranked as the most vulnerable, with high sensitivity to direct climate factors (e.g., temperature, precipitation, etc.), climate-driven changes in disturbance regimes (e.g., flooding, wildfire), and non-climate stressors (e.g., dams, roads, etc.). Adaptive capacity was ranked as moderate; however, elements related to the impact of barriers on hydrological connectivity and resistance/recovery from stressors and disturbance regimes both received low scores,

though public/societal support for management was ranked as high. The habitat assessed as the least vulnerable was early-successional forests in Bear Creek Preserve, largely because it was the only habitat that received a score of high adaptive capacity. Although this habitat is still moderately sensitive to climate stressors, disturbance regimes, and non-climate stressors, and is expected to be exposed to changes in these factors over the coming century, high species and structural diversity, ability to recover from disturbances, and ample opportunities for implementing climate-informed management actions with relatively high public and societal support reduce the overall vulnerability of this habitat to climate change.

A few key trends emerged across all habitats assessed within the project, highlighting opportunities to develop adaptation strategies and actions that may benefit multiple ecosystems. All habitats were identified as being sensitive to changes in precipitation patterns (e.g., shifts in the timing and amount of seasonal rain or snow) and increased drought, and the majority were also identified as sensitive to warmer air and water temperatures as well. There were no disturbance regimes selected for every habitat assessed, but commonly-identified challenges included insects and disease, extreme storms and associated flooding, and wildfire. The most important non-climate stressors across all habitats assessed were invasive species, the presence and use of roads/highways/trails, and pollutants.

Several factors common to several habitats that have the potential to enhance adaptive capacity include:

- Ample public and societal support for the preserves, both of which are likely to lead to increased support for climate-informed management and conservation under changing conditions;
- Relatively high ability and capacity of preserve managers and Natural Lands staff to manage/cope with climate impacts; and
- Many habitats function as critical habitat for birds, pollinators, and other wildlife species, and have the potential to serve as movement corridors and/or climate refugia.

Factors that were common to several habitats and have the potential to undermine adaptive capacity include:

- Low resistance to insect pests, diseases, and invasive species, particularly in forests where young native plants have not yet become well-established;
- Natural and manmade barriers (e.g., roads/trails, pipelines, dams), which are associated with hydrologic disconnection and inhibit habitat shifts and species movement in response to climate change; and
- Limited ability of managers to control pollutants coming in from outside the preserve, increasing challenges related to water quality.

Prioritizing adaptation strategies and actions that address some of these common vulnerabilities across multiple ecosystems and/or at larger spatial scales (e.g., through collaboration with external partners) will be critical, given the scale of the challenges associated with climate change. However, Natural Lands staff are well-equipped to leverage existing funding and programs to increase the resilience of priority habitats to climate change. It will be important for staff and preserve managers to pay

attention to the varying rankings of individual adaptive capacity elements, in addition to the climate factors, disturbance regimes, and non-climate stressors that the habitat is most sensitive to. For example, addressing barriers to connectivity for water resources at Bear Creek Preserve will improve the structural and functional integrity of streams and associated floodplains and wetlands in the area, but is also likely to reduce sensitivity to flooding, increasing water temperatures, and other stressors.

The results and trends presented here are comparable only within the findings of this project, and are not standardized in any way to other climate change vulnerability assessments. The information supporting these results is available in the individual vulnerability assessment summaries, and should be referred to before using the overall results and trends in decision-making.

Links to the final vulnerability assessment summaries are available at https://ecoadapt.org/goto/Natural-Lands.

Adaptation Strategies and Actions

During the adaptation workshop, each breakout group was asked to identify adaptation strategies and actions that reduce vulnerabilities and/or increase resilience of the habitat that group was focusing on. An *adaptation strategy* is a broad or general statement of how to reduce vulnerabilities or increase resilience, while an *adaptation action* is a specific activity that takes into account site and ecological conditions to facilitate progress towards achieving an adaptation strategy.

Participants were encouraged to consider adaptation strategies that would help them continue to make progress towards site management goals in the context of climate change (Table 4). Several themes emerged from across habitats, such as:

- Restoring and protecting habitat structure and function, particularly in degraded systems;
- Removing invasive species to reduce stress on native plants and wildlife;
- Addressing existing issues with pollutants and water quality;
- Monitor habitat responses to climate change in order to better understand the actions necessary for effective management in the context of climate change; and
- Increasing public outreach and education to improve awareness about the importance of these habitats and the management actions necessary to maintain them in a changing climate.

Table 4. Adaptation strategies for six priority habitats in Bear Creek and ChesLen Preserves, grouped by habitat.

Adaptation Strategies for Bear Creek Preserve
Early-successional forests

• Ensure effective management and monitoring of invasive species in high-density areas near residential homes, particularly those adjacent to the preserve and with drainage systems
• Maintain and enhance existing early-successional habitat and monitor habitat/species changes to inform future management (in order to maintain the presence of early-successional habitat within the preserve)
• Enhance ecosystem resilience through species selection and diversity
  ○ Identify highly vulnerable species
  ○ Identify resilient species and support the natural regeneration of these species
  ○ Support diversity in species and age
 	
Management goals addressed: All goals listed in the Bear Creek Stewardship Plan and Forest Management Plan, as well as the reduction of invasive species seeds that are brought onto the property
 	
Current status of early-successional forests in Bear Creek Preserve: The managers are currently allowing the sites to grow without implementing new plantings. The habitat is situated in an area that was previously logged, and the plots display varying degrees of tree growth. This habitat remains important for many bird species

Mature forests
• Facilitate natural succession to promote mature forest growth • Create refuges and/or limit disturbances • Plan for possible decline of Eastern Hemlock (combine with next strategy) • Plant southerly species • Explore techniques for early detection and reduction of forest pests and the spread of invasive species seeds (but could contract out for invasive species management) • Set up a monitoring program to identify populations and/or individuals that are least resistant to pests and/or disease • Reduce public access to areas that are particularly susceptible to pests and invasive species • Identify and monitor canopy gaps throughout the preserve, and focus on reducing sunny spots on waterways • Maintain relationships with surrounding municipalities and help leaders to make informed decisions on natural resources • Set up a monitoring plan to understand climate impacts to the preserve – focus both on pests and changes in vegetation *Management goals addressed*: All goals listed in the Bear Creek Stewardship Plan and Forest Management Plan, as well as the reduction of invasive species seeds that are brought onto the property
Spruce swamp
• Add buffer from dam water and along roadways to reduce input of road pollutants • Monitor current health of native plants in the system • Monitor water quality – road salt, road runoff, residential runoff with chemicals • Monitor water quantity • Monitor amphibian populations • Litter removal • Improve early detection of invasive species, followed by monitoring and removal (in coordination with

Adaptation Strategies for Bear Creek Preserve

native species replanting)
- Monitor for plant community changes with hydrologic change
- Identify baselines for major functional species groups and ecosystem functions
- Manage/mitigate impacts of adjacent recreational opportunities in the dam/reservoir area

Management goals addressed: Maintain/improve water quality, reduce pollutants (road runoff), Create/protect/preserve habitat, reduce/prevent invasive species, monitor and maintain spruce swamp hydrology under climate change (particularly on the margins)

Adaptation Strategies for ChesLen Preserve

Afforestation areas

- Reduce the influx of contaminants from outside sources to improve/protect water quality
- Manage for invasive species (current and future) to reduce stress on natives
- Maintain and enhance species diversity within the habitat
- Increase public engagement and education (specifically around invasive species management)

Management goals addressed: Protect and enhance forested habitat – maintain afforestation areas

Unionville barrens

- Identify which herbaceous/species of concern in the Unionville Barrens that will be most vulnerable to climate change
- Collect seed of vulnerable species to allow propagation
- Determine whether prescribed fire season/techniques will need to change in the future
- Re-route trails that are vulnerable to erosion during heavy rain events
    - Also consider runoff coming from paved roads bordering the barrens, and whether that needs to be addressed (would need to work with town?)
- Create a network and act as a resource for barrens management in the face of climate change (NL is one of the only organizations that actively manages serpentine barrens with staff and resources)
    - Bring together volunteers who are familiar with barrens management to ensure that knowledge is shared/passed on
- Increase invasive management efforts in serpentine barrens
- Maintain and enhance highest-quality sites (e.g., gravel forbs) within the barrens – manage succession, etc.
- Get more information about how climate changes (e.g., increased temperatures, drier conditions, more disturbances) may expand opportunities for serpentine species into areas where more productive species become more stressed
    - What is the threshold for when even serpentine species can't tolerate the temperature, etc.?
- Monitor changes to help inform future management, particularly where knowledge is lacking
    - Include monitoring of insect/mammal relationships, particularly if there are species introduced from other zones/areas

Water resources

- Enhance water resources through riparian buffer protection and enhancement
- Early detection and rapid response for invasive plants
- Preserve the Brandywine Creek ecological integrity by addressing soil erosion and sedimentation issues in open areas adjacent to the Creek
- Preserve and restore wetland area to improve capacity

Adaptation Strategies for Bear Creek Preserve
• Safeguard and improve the quality of water resources through monitoring and addressing emerging/existing issues (e.g., herbicides) *Management goals addressed:* Protect and enhance forested habitat – maintain afforestation areas

For each of the six priority habitats, a subset of these adaptation strategies were selected, and participants outlined 3–5 concrete adaptation action steps that can be implemented to accomplish the strategy (Tables 5–10). In addition to identifying adaptation actions, participants noted additional information about action implementation, including likely feasibility and effectiveness, where/how the action could be implemented, and whether there were likely co-benefits or potential conflicts that may arise as a result of implementation.

Table 5. Adaptation actions and additional information for priority adaptation strategies focused on early-successional habitats in Bear Creek Preserve.

Adaptation Strategy #1: Ensure effective management and monitoring of invasive species			
	Adaptation Action #1:	**Adaptation Action #2:**	**Adaptation Action #3**
Adaptation action	Engage and educate the local community in effective invasive species management thorough outreach initiatives > Hold community meetings. This have been effective for past projects. > The majority of nearby residents have owned the properties for many years. They purchased knowing that they have a preserve in their back yard. This could be a motivator for engagement. > There are ~20-30 neighbors near the preserve over all. There are ~10 near the early-successional forest sites.	Prevent the spread of invasive species and their seeds by creating physical barriers through the installation of silt fences or berms in strategic locations	Early Detection and Rapid Response for Invasive Species Management > Detect invasives early and prevent spread/establishment
Feasibility (H, M, L)	High > There is an existing relationship with most neighbors	High > It would be relatively easy to remove if there are issues after implementation	High
Effectiveness (H, M, L)	High	High	High
Where/how to implement	> There are strategies that the community could easily implement to help with removal of invasives in their own yards that may help with spread into	> Location: along the northern border of the preserve (~quarter mile) > Could use staff to implement it and it	> Could implement monthly: check and monitor how far down invasives have traveled

	the preserve (e.g., pulled with a shovel). > Community meeting can discuss management efforts currently underway in the preserve and incorporate invasives into the conversation > Provide residents near the preserve / the greater. Community with suggestions of what to plant in their yards instead of invasives > Time of the year when outreach may be most impactful for engaging residents near the preserve: spring/fall. Some of the home owners are vacationers and summer may be too busy > Stilt grass and barberry may be the best species to highlight (barberry harbors ticks; thorns and impact on kids, etc.)	would not be difficult to get the necessary supplies and gear to the implementation site > The habitat has rocky ground which may make installation difficult. However, the ground tends to be wet (enough) where this would be installed, so it could still work > Choose suitable materials. Consider factors like durability, environmental impact, and effectiveness in preventing dispersal > Establish a monitoring program to assess the efficiency (or potentially harm)	> There is currently staff capacity to monitor > Rapid response: – set date (e.g., once every two weeks to spot spray) > Could utilize volunteer involvement in monitoring efforts > Some species are already well established > May need: training for staff; tools, equipment; additional expertise > Prioritize known areas of high density invasives for response
Co-benefits and conflicts	*Co-benefits* > Educate landowners about forest management and available resources > Natural Lands can be dedicated place where land owners know they can go for more information *Conflicts* > Public concerns about herbicides > Absentee vacation home owners: The neighbors are not the ones taking care of the property > Residents surrounding the preserve are	*Co-benefits* > Filter runoff > Erosion control > Blocking debris and oil that may also travel via water > Reduce time spent on dealing with invasives pressure to allow more time to address other issues > Could decrease encroachment from neighbors as it acts as a clear barrier between properties > Easy barrier to communicate with public	*Co-benefits* > May help/benefit neighbors

	largely there for the aesthetics of the area and not necessarily because they want to protect the health of the forest (not enough motivation)	where the herbicides are being sprayed in the preserve *Conflicts* > Potential negative impacts to hydrology	
Additional notes	Overall staff capacity to manage for invasives: access to this area is ideal (for people, equipment, etc.). Invasives are moving in this habitat mainly through water (versus wind) Current herbicides being used are mainly in the water		
Adaptation Strategy #2: Maintain and enhance existing early-successional habitat and monitor habitat/species changes			
	Adaptation Action #1:	**Adaptation Action #2:**	**Adaptation Action #3**
Adaptation action	Assess and monitor the extent of early-successional habitat within the preserve > Allow the current habitat to keep aging to promote age diversity > 10-20% of the areas designated for maintenance for bird species (~800 acres) -Audubon study >Considering natural disturbances (can mimic existing staff actions) and staff efforts in maintaining this ecosystem >Is it desirable to keep the percentage of early-successional habitat that exists within the preserve?	Maintaining the early-successional habitat that already exists > Selective clearing > Utilize controlled burns as a management tool to maintain and enhance existing early-successional habitat, ensuring its ecological integrity and promoting biodiversity >> Funding dependent. This strategy could be expensive. >> Past prescribed fire efforts were mostly grant funded with some private funding	Creating additional/new early-successional forest habitat within the preserve > allowed to do selective cuts of timber
Feasibility (H, M, L)	High	High (w/o prescribed fire)	High

Effectiveness (H, M, L)	High	High	High
Where/how to implement	> Monitoring every 5 years > Use aerial photography and on the ground observations > Choose easy-to-manage sites > There is existing staff capacity for monitoring > Funding: past work with Cornell/Audubon was easy for NL team and was successful (reporting, decent mount of funds) >> How these projects be scaled up >> Search for additional funders	> Prescribed fire every few years (funding dependent) > Currently implementing mechanical removal of unwanted species and spraying with herbicides > Continue to monitor presence of bird species with E-Bird application (Cornell/Audubon). Can inform ecosystem health information > The area has good drainage with a slope, flooding not major issue at these sites > Challenge: New plantings/seedlings are expose benefits of shade (if canopy opens significantly and temperatures increase past thermal tolerance of some species)	> Currently have three plots within the burned area that can be expanded to beginning building additional habitat > Forest management plan for bear creek includes goals for the creation of additional early-successional habitat (can further incorporate climate information into existing management goals) > Set a minimum size of new habitat created > Timber harvest > Leveraging natural blow down / take advantage of natural disturbance events > Prescribed fire > Opportunity to introduce new species into existing communities that may be more resilient to projected climate impacts > Frequency: creating more habitat every 5-10 years
Co-benefits and conflicts	*Co-benefit* > Monitoring this site could help to identify other target areas (other needs within the preserve)		*Co-benefit* > Bringing in new species, building these populations > Building resilience throughout whole forested area of preserve

			Conflict > Could invite in new pests > Negative feedback from the public if selective harvest is implemented
Adaptation Strategy #3: Enhance ecosystem resilience throughs species selection and diversity			
	Adaptation Action #1:	**Adaptation Action #2:**	**Adaptation Action #3**
Adaptation action	Use available tools to identify what to plant under changing conditions, when to plant them, and implement planting > Resilience to heat > Identify new species and determine the vulnerability of existing species (what will decline, what may thrive under projected conditions)	Long-term monitoring of plantings > If the planting of new species is successful, it could be replicated on different preserves and see how they compare	
Feasibility (H, M, L)	High > Feasibility is high for determining what to keep and adding additional native species and existing species already in the preserve that are considered resilient > It will be more difficult to introduce new species (e.g., more southernly species)	High (if there are dedicated staff to do the monitoring) Medium (if implementing the strategy using current staff capacity)	
Effectiveness (H, M, L)	Medium (there are uncertainties regarding which species will be successful)	High	
Where/how to	> Location for planting: along trails where there may be more invasive pressure;	> Could contract someone to do monitoring – this would address current	

implement	wherever it is decided to put early-successional habitat and where it occurs naturally > Must be intentional about how many new species to plant and finding a balance between new and existing > Availability of native plant species that could be options for plantings is adequate > Ability to plant new species could depend on availability of species in the nurseries (if they have species targeted for planting) >> There is a nursery near the preserve that is taking climate change into consideration and has information available on potential appropriate species. This could be reliable supplier. The nursery owner is receptive to opinions and the needs of surrounding community. > Use tree and shrub selection tool developed by Natural Lands' volunteer (the tool takes into consideration many factors impacting the future of the species and also contains additional sites/information – similar to DCNR resources) > Depending on scale of plantings – staff capacity is good for action	staff limitations > Increasing amount/frequency of monitoring/maintenance in this habitat could be a challenge >> Could incorporate a dedicated group to do this monitoring (can incorporate volunteers) >> However, the action would work well in early-successional forests in terms of need for frequency of monitoring, as it would probably be low > Seasonal monitoring (once a quarter) to determine survival rates and how new species are being impacted. Are there interactions between new and existing plantings? > Need: control plot of current species. Are climate changes impacting everything or this there a difference with the new plantings	

Co-benefits and conflicts	*Co-benefit* > Opportunity to research which species will be resilient and which were successful after planting. Natural Lands can spread/disseminate this information (what worked and what didn't)	*Co-benefit* > Providing data to the public and other organizations about what is working, what is growing, and hat is not or not > Increase institutional knowledge	

Table 6. Adaptation actions and additional information for priority adaptation strategies focused on mature forest habitats in Bear Creek Preserve.

Adaptation Strategy #1: Facilitate natural succession to promote mature forest growth			
	Adaptation Action #1:	**Adaptation Action #2:**	**Adaptation Action #3**
Adaptation action	Control invasive species in the area > Removal technique (e.g., mechanical, chemical) will depend on the species on the site	Manage deer grazing to promote succession	Plant desired species to help speed up succession **Would likely be done in tandem with action #1*
Feasibility (H, M, L)	Low – Medium > Bear Creek is a large preserve with a small staff (the group completing this worksheet does not work there, and are unsure what they can realistically accomplish) > Compared to other preserves, may have fewer invasives to manage and/or can just focus on specific invasives > As Eastern Hemlock populations decline, light from canopy gaps will likely allow more invasives in the short term,	Low – Medium > Challenging because of how large the preserve is – hunting will only decrease the population modestly and deer fencing is expensive	Low – Medium > Costs can be expensive > Can be difficult to establish trees with dense shade

	which makes management more challenging		
Effectiveness (H, M, L)	Medium - High	High > Effective, but best combined with other actions	Low – Medium > Even well-cared for trees may not survive due to site suitability issues
Where/how to implement	> Start in the core of the property – areas with the least amount of invasive pressure and then circle outward > Focus on areas where you actually think you'll see success (areas too overrun with invasives may not be appropriate or realistic to target)	> Success of hunting programs on other preserves can be variable from year to year (closing on specific days or closing specific areas can help the program do better) > Bear Creek is part of a patchwork of public land where hunting may occur, which could help with managing deer populations > Exclosures could be utilized on small scales (20x20 is generally the size of exclosures)	> Would likely want to identify critical habitats where this could be done; these habitats could likely be maintained with a good amount of effort > Volunteers can help with plantings > Need to determine where plants are sourced from – on site or more southerly populations? (on site plants may not be adapted to future conditions; more southerly conditions may be better adapted, but may muddy genetics in the native population)
Co-benefits and conflicts	> Supports more desired plant species, and increases habitat for wildlife dependent on native species > Manages future seed bank (even for areas you are not targeting)		

Adaptation Strategy #2: Plan for possible decline of Eastern Hemlock + plant southerly species			
	Adaptation Action #1:	**Adaptation Action #2:**	**Adaptation Action #3**
Adaptation action	Create a hazard tree program to remove dying trees preemptively Create a plant healthcare program to identify diseased trees and treat them for hemlock woolly adelgid	Create protected areas around high-value hemlock stands to reduce other stressors	Look into different silviculture techniques to increase success of plantings in interspersed, declining forests
Feasibility (H, M, L)	High (for tree hazard program) > The tree hazard program is a pre-existing program and this action would be especially feasible if only a subset of trees were removed > Feasibility not explicitly discussed for plant healthcare portion of the program.	Medium - High	High
Effectiveness (H, M, L)	Medium > On this large property, decline will occur quickly once it begins	Low – Medium > Just focuses on reducing stressors for an already-vulnerable species; effectiveness could be improved by combining with other adaptation actions	Low – Medium > Past plantings have declined over time, so it may be a challenge to do this successfully
Where/how to implement	> Overall, need to evaluate where these strategies are going to be successful > Consider focusing on areas that are in the most decline	> Closing or rerouting trails; reducing public access to these areas	> Luke is climate change coordinator – might be within his scope of work to do this type of research

Co-benefits and conflicts	> Benefit: Reducing public access to areas can reduce pest access to areas > Preserve is safer for recreation by removing hazardous trees > Potential conflict: If woolly adelgid is controlled via biological means (i.e., predator introduction) it could lead to unintended consequences – not currently planned because so such predator has been identified	> Benefit: Creating a landscape of cultural significance by protecting the state tree	
Adaptation Strategy #3: Set up a monitoring plan to understand impacts to the preserve – focused both on pests and vegetation control			
	Adaptation Action #1:	**Adaptation Action #2:**	**Adaptation Action #3**
Adaptation action	Take pictures of different stands each quarter to monitor changes	Identify sampling methods for emerging insect pests	Create test plots with different species of trees to understand which species thrive (given pests and climate stressors), which could help pinpoint which species to plant on a larger scale
Feasibility (H, M, L)	*Not developed further*	*Not developed further*	*Not developed further*
Effectiveness (H, M, L)			
Where/how to implement			
Co-benefits and conflicts			

Table 7. Adaptation actions and additional information for priority adaptation strategies focused on spruce swamp habitats in Bear Creek Preserve.

Adaptation Strategy #1: Manage/mitigate impacts of adjacent recreational opportunities in the dam/reservoir area			
	Adaptation Action #1:	**Adaptation Action #2:**	**Adaptation Action #3**
Adaptation action	Continue to limit public access to the swamp	Conduct outreach to explain why access is limited to this area (i.e., meant to protect native/rare plants and water quality	Coordinate upstream invasive species management with the U.S. Army Corps of Engineers (USACE) to limit chemical impacts related to invasive species control and management
Feasibility (H, M, L)	High	High	High
Effectiveness (H, M, L)	High	Medium	High
Where/how to implement	There is already signage and a chain across the entrance that prohibits vehicle and pedestrian access and explains where they can go on the site to recreate	Use social media	Informal face-to-face communication through established relationships between preserve managers and USACE managers The USACE Integrated Pest Management protocols are consistent with those of Natural Lands
Co-benefits and conflicts		Teaching the general public about climate change as well as about Natural Lands and the preserve	No conflict with treatment approach

Adaptation Strategy #2: Improve early detection of invasive species, followed by monitoring and removal (in coordination with native species replanting)			
	Adaptation Action #1:	**Adaptation Action #2:**	**Adaptation Action #3**
Adaptation action	Find dominant tree species that are functionally equivalent to hemlock (e.g., maintains ecosystem services such as shading and water quality)	Actively remove new invasive species that are detected, and do regular monitoring	Keep up to date on novel invasives that may move into the area, and on what to be on the lookout for
Feasibility (H, M, L)	Medium (if the information exists) Low (for actual implementation, cost, sourcing)	High (but how might this change with climate change?)	High
Effectiveness (H, M, L)	Depends on the goal- shade? Food? Habitat? Unknown how functional equivalents might fare in terms of resistance to disease, especially to novel pathogens	High (but unknown how this might change)	High
Where/how to implement	This action it critical to support long-term planning and adaptation; doing the baseline research is key	Many of the invasive species in the swamp are on the margins and can currently be accessed for treatment/control Seasonality and chemical/IPM approach may shift with climate change	Already doing this, have a specific coordinator on invasive species issues Use information from Penn State Extension, RISCC group
Co-benefits and conflicts	Lots of unknowns around interactions with other species (e.g., pollinators), possible impacts on water quality associated with organic matter inputs	Risk to water quality – must be very careful about herbicide applications	

Table 8. Adaptation actions and additional information for priority adaptation strategies focused on afforestation areas in ChesLen Preserve.

Adaptation Strategy #1: Manage for invasive species (current and future) to reduce stress on natives			
	Adaptation Action #1:	**Adaptation Action #2:**	**Adaptation Action #3**
Adaptation action	Remove invasives through mechanical and chemical means (e.g., through mowing, removal by contractors or volunteers, etc.) while also trying to minimize any negative impacts these actions could cause to native species	Maintain and improve intact forest canopy to make the forest more resistant to non-native plant invasions	Prevent future invasions by ensuring management actions are not spreading invasive plant material or seeds
Feasibility (H, M, L)	Low (could be moderate, depending on the exact location and species)	Medium/high	High
Effectiveness (H, M, L)	Low (could be moderate, depending on the exact location and species)	High	Medium/high
Where/how to implement	Need to consider complications due to the presence of Brandywine Creek and invasives coming through; it is also difficult when landowners north of the stream are not managed invasives Poison hemlock is not controlled outside of the preserve, so has the potential to spread	Focus on filling in the gaps in older afforestation areas – plant young trees as earlier plantings mature, and use tree shelters/fencing to prevent deer grazing and other factors that might affect new planting survival/growth Specifically, plant native species and select species that are adaptable/well-adapted to future conditions Could be implemented throughout all afforestation areas	All areas Clean equipment before moving it (both for actions involving removal of invasive species and general management of the preserve) Incorporating these practices into management planning

Co-benefits and conflicts	Neighbors surrounding preserve could benefit from invasives removal Potential harm to non-target species from some actions related to invasives removal (e.g., mowing) One invasive is replaced by another…	Co-benefits: established canopy along riparian zones could help to cool water temperature Native plant species with seeds will help to spread the native seed throughout preserve (seeking out prolific species that spread seeds effectively)	Happy staff Staff time/capacity – could possibly slow operations. Ensuring staff take time to do this…
Additional notes	Contractors, volunteers doing removals Time-consuming task with the amount of invasives, current and future. Risk and possibility we are going to lose what we are trying to save when/if something else comes in e.g., EAB) Reduce stress on natives – can look different in different areas – you won't be removing all, but implementing to the best of your ability to give native species a chance. Mowing between rows of trees to manage for invasives – current action	Many plantings don't have mid-story trees – an area where invasive can take advantage of Understory can become invaded by problematic/invasives if not careful	
Adaptation Strategy #2: Reduce the influx of contaminants from outside sources to improve/protect water quality			
	Adaptation Action #1:	**Adaptation Action #2:**	**Adaptation Action #3**
Adaptation action	Remove highly erodible farmland near riparian zones from agricultural production and convert to afforestation land		

Feasibility (H, M, L)	High Similar actions are already being implemented within the preserve. This could increase the chances of implementation for the proposed adaptation action as managers and farmers are already familiar with the process. However, it is notable that *currently*, climate change is not a major consideration in the actions. Over time, continued maintenance of additional plantings may strain staff capacity, making further implementation of this action increasingly difficult		
Effectiveness (H, M, L)	Moderate		
Where/how to implement	Agricultural areas that are near existing afforestation areas (especially riparian) It is currently possible to remove roughly 10% of agricultural lands from production each year without legal challenges (has been done successfully in other preserves)		
Co-benefits and conflicts	Potential conflicts with farmers, although Natural Lands currently has great relationships with them Would increase biodiversity on the land taken out of agricultural production		

Additional notes	Recently removed ~20 acres near agricultural areas with the goal of increasing pollinator meadow/grassland habitats		

Table 9. Adaptation actions and additional information for priority adaptation strategies focused on the Unionville barrens in ChesLen Preserve.

Adaptation Strategy #1: Identify which herbaceous/species of concern in the Unionville Barrens that will be most vulnerable to climate change			
	Adaptation Action #1:	**Adaptation Action #2:**	**Adaptation Action #3**
Adaptation action	Identify species (natives and invasives) that are currently present on the site and their relative abundance > Note species that play a critical ecological role in the barrens (e.g., as pollinator host plant, etc.) – these may be prioritized for management	Work with an expert to come up with a prioritized list of native and non-native species and their relative response to future conditions (e.g., ability to survive under expected temperature range, etc.) > Will consider population augmentation for species that are considered resilient to climate change	
Feasibility (H, M, L)	High - inventory w/ info on relative abundance may already exist!	Medium	
Effectiveness (H, M, L)	High	High	

Where/how to implement	Barrens are divided into 6 management units – consider within those units Note which species' seeds are collected, propagation rates, etc.	Start by looking at the PA Natural Heritage Program Climate Change Vulnerability Index (CCVI) Search for the best expert to accomplish this text – discuss with Roger Latham, could approach universities to find out if someone is interested in research	
Co-benefits and conflicts	Benefits specialist pollinators	Could identify invasives whose management could be deprioritized to free up resources for restoration of natives	
Adaptation Strategy #2: Determine whether prescribed fire season/techniques will need to change in the future			
	Adaptation Action #1:	**Adaptation Action #2:**	**Adaptation Action #3**
Adaptation action	Look at whole prescribed fire program to ensure that management goals can continue to be met (e.g., if fire window changes in length or timing) > May need to ensure that prescribed burns in the barrens are prioritized in years where it isn't possible to complete all planned burns		
Feasibility (H, M, L)	Medium		
Effectiveness (H, M, L)	High		

Where/how to implement	> Make sure there's an opportunity for input from folks who are newer to the program and will be here over the coming years > Include consideration of backup plans in case there is a year when weather conditions mean burning isn't possible		
Co-benefits and conflicts	All systems where prescribed burns occur would benefit		
Adaptation Strategy #3: Collect seed of vulnerable species to allow propagation			
	Adaptation Action #1:	**Adaptation Action #2:**	**Adaptation Action #3**
Adaptation action	Create a plan for which species seed will be collected from and how feasible propagation is for them > Is species going to be viable under future conditions? How easy/successful is propagation?	Expand cold storage for collected seed and ensure that long-term storage options are secured	Collect seed
Feasibility (H, M, L)			
Effectiveness (H, M, L)			

Where/how to implement	Already have GPS locations for stored seed, but sometimes it is a very small number of seeds Consider additional species that aren't currently included (perhaps shrubs that could be planted on the edges of the barrens to provide shade) Refer to inventory/assessment to determine likely success of propagated species under future conditions	Right now have MOU with Mount Cuba Center for storage, and they are getting a new greenhouse (however, that relationship may change); Stoneleigh garden greenhouse expansion may also allow storage and production space (i.e., for propagation) Consider expanding amount of seed that is stored	Would need to free up staff time or use volunteers to collect, clean, sort, and label seeds Unionville Barrens is already on the southern edge of the region's extent of serpentine ecosystems, so can't collect seed from areas that are farther south
Co-benefits and conflicts			
Adaptation Strategy #3 (CON'T): Collect seed of vulnerable species to allow propagation			
	Adaptation Action #1:	**Adaptation Action #2:**	**Adaptation Action #3**
Adaptation action	Collaborate with other organizations that manage barrens to share knowledge and potentially seeds or opportunities for collection	Create process/standardized procedures around seed collection and storage (that explicitly incorporate climate change)	
Feasibility (H, M, L)	*Not developed further*	*Not developed further*	
Effectiveness (H, M, L)			
Where/how to implement			

Co-benefits and conflicts			

Table 10. Adaptation actions and additional information for priority adaptation strategies focused on water resources in ChesLen Preserve.

Adaptation Strategy #1: Enhance water resources through riparian buffer protection and enhancement			
	Adaptation Action #1:	**Adaptation Action #2:**	**Adaptation Action #3**
Adaptation action	Plant 300-400 trees annually, with the potential to adjust based on the size of trees to address survival and rooting issues, and drought susceptibility > Consider the scale of planting based on the organization's capacity. > Focus on larger trees in smaller areas, especially in high-need areas with significant erosion problems. > Prioritize planting trees that can withstand large flood events to prevent washouts during such occurrences. > Ensure the capacity to respond promptly to address debris and siltation effects on trails caused by planting activities.	Increase shrub density to improve erosion control and prevent debris movement > Prioritize building density and buffers near Brandywine Creek to address invasive species and minimize flood damage > Explore cost-effective strategies as trials, especially if expensive solutions are not feasible initially > Focus on floodplain areas adjacent to Brandywine Creek, as they are particularly vulnerable during flood events	Implement caging in upland riparian areas to test its effectiveness in managing potential > Installing protective barriers (cages) around newly planted or sensitive vegetation to shield them from disturbance.

Feasibility (H, M, L)	High > There are volunteer groups that could help with implementation, but they usually are most interested when they can work on a variety of projects. It might become tedious to focus solely on plantings > There are existing potential funding sources for future projects > Can also show the success of past projects (e.g., meadow plantings) to solicit more funding > Staff and managers are pro-planting	High (planting shrubs would not be difficult and is a good way to engage the public) > There are shrub species already present (native and invasive)	
Effectiveness (H, M, L)	High (There is existing evidence that this strategy is effective generally) Medium (Mature riparian buffer)	Low (Maintenance will be difficult and the action will not be effective if shrubs get washed away)	
Where/how to implement	> Management would ideally happen in January/February when the ground is solid >> Consider possible changes in conditions affecting implementation times during the year > Assess if any equipment adjustments are necessary for efficient implementation > Determine the number of workdays required to implement the proposed actions successfully. Having the adequate	> Start planting in upland areas initially. > Focus on building density and buffer near Brandywine Creek to manage invasives introduced by floods. > Address the most destructive floodplain area adjacent to Brandywine during events. > Consider cost-effective trial strategies for management. Regarding public use/access and funding:	> Choose appropriate cage materials/sizes based on target species and potential threats > Test caging in upland riparian areas where issues are less severe.

	time/capacity may be a challenge for staff. > Implement a growing buffer approach, where the buffer zone is expanded gradually year-to-year, rather than attempting one large planting event > Prioritize spring plantings based on flooding history, as they tend to be more effective. Severe flooding events occur in winter and late summer/fall. Consider earlier spring planting, but assess risks like late frost and fire during that time >> It may be more difficult to access trees earlier as well > Prioritize planting BMB trees, which are of substantial size and offer numerous ecological benefits. Identify potential sources within the county, considering availability and accessibility of the target trees. > Assess and select climate-resilient tree species.	> Secure funding for riparian buffer restoration. > Collaborate with the local canoe company for public access. > Focus on strategic locations for riparian buffer construction. > Implement practices to manage water quality impacts.	
Co-benefits and conflicts	*Co-benefits* > Cooler water temperatures beneficial for aquatic life > Trail visitors' shade, enhancing recreational experience. > Pollution reduction > Achievement of funder goals	*Co-benefit* > Improved habitat > Stream corridors are important for species movement – moving north. Making habitats healthy, greenways	*Co-benefit* > Improved water and habitat quality *Conflicts* > Aesthetics

	Conflicts > Some visitors may express concern that trees obstruct their view of streams from the trails. > Managing deer-browsing poses challenges, requiring adjustments to current protection methods (e.g., deer wraps) to avoid littering issues		
Additional notes	Agriculture along stream banks, including row crops and hay, has caused issues during flood events, with hay washing downstream and accumulating in trees and shrubs. Approximately 16-17 acres were removed last spring, and a pollinator area was established. However, removing all agricultural activity from the area is currently not feasible due to capacity limitations.		

Adaptation Implementation Plans

During the second day of the workshops, Natural Lands staff developed climate adaptation implementation plans for the four priority habitats that breakout groups were focusing on (mature forests and spruce swamp in Bear Creek Preserve, and afforestation areas and Unionville barrens in ChesLen Preserve). The plan template is adapted from Gregg (2021), and includes sections to help users identify the rationale for restoration (including desired outcomes/restoration targets), actionable steps (e.g., tasks, responsible parties and roles, resources needed, and anticipated costs), adaptive management options (e.g., performance metrics and management triggers associated with restoration targets), and funding and communications/outreach requirements. The template was designed to answer critical questions typically posed by funders (e.g., foundations, state and federal agencies) in requests for proposals, many of which are shifting towards supporting “shovel-ready” climate adaptation projects. More information about each of the questions and categories in the implementation plans can be found in Appendix A.

Implementation plans for four priority habitats are presented below.

Adaptation Implementation Plan for Mature Forests in Bear Creek Preserve

SECTION 1. BACKGROUND

SELECTED PROJECT SITE/ECOSYSTEM: Mature forests, Bear Creek Preserve

Other preserves: Crow's Nest has second growth forest they want to transition to old growth forest

Overarching management goal (current or future, does not necessarily have to be climate change related): Transition to an old growth forest

Adaptation strategy: Facilitate natural regeneration to promote mature forest growth

Key climate-related vulnerabilities that will impact ability to meet management goal:

- Unpredictable precipitation patterns – increased drought and flooding
- Heat stress due to rising temperatures
- Shifts in forest composition over time (e.g., transition from mesic to more xeric species)
- Changes in the growing season –plant species may end up out of sync with pollinators, frost could impact seed production, non-natives (invasives) may be able to grow better
- Pathogen, pest, fungus, and insect pressure may increase
- Increased risk of forest fires, driven by drought and buildup of understory vegetation

Other potential challenges to meeting management goal:

- Herbivory from wildlife species (e.g., deer eating new trees/understory vegetation)
- Trampling from recreational use
- Very long timescale for successful project completion (beyond a human lifespan)
- Not enough staff time, and will likely need training and new equipment
- Need for funding
- Increased need to provide recreational space for people

Potential conflicts or unintended consequences with non-target ecosystems/species, human communities, and/or other management goals:

- Sectioning off part of the preserve from recreational use will likely increase traffic in other areas
- Declines in species dependent upon early successional communities
- Potential for extending a lot of time and effort and not ending up with the desired outcomes
    - More likely if incorrect assumptions are made about the best course of action, in which case it can do more harm than good. This has happened at other NL sites: 1) Polonia tree projects – planted valuable non-native trees in an effort to raise money, but they ended up being invasive and created a management challenge; 2) Hedge rows – planted these and then ripped them out; 3) Pond creation –realized wetlands were better

SECTION 2: IMPLEMENTATION STEPS

PROJECT DESCRIPTION/ADAPTATION STRATEGY: Facilitate natural regeneration to promote mature forest growth

Adaptation Actions	Timeline	Existing/Needed Resources	Implementation Costs	Potential Partners
Conduct an initial survey to identify higher quality areas to focus plantings > Higher quality = fewer invasives, more diverse, species that are only found in old growth forests > Also need to consider hydrology and soil type + access to infrastructure	Do this action first	***Existing*:** Botanical survey and floristic quality assessment (used at Crow's Nest to assess quality of parcels) LiDAR to monitor forest density (check with GIS specialist to see if it's freely available), but would still need to process the raw data; USGS did a lot of LiDAR monitoring after Hurricane Floyd Botanical data may be available from the state ***Needed:*** Botanical survey? Potentially additional staff capacity	***Initial:*** 5-year survey of 500 acres (cost $8,000 for botanical survey at Crow's Nest) Staff time for GIS coordinator ***Maintenance:*** Need to return periodically to ensure you're not just getting a snapshot in time (included in survey costs above)	Natural Lands GIS specialist Contractor or university to do survey work State agencies – DCNR, forestry, PGC may have good data PA Natural Heritage Program Morris Arboretum – has worked in state parks, could be hired to do this work

Control invasive species in the area	After site selection and initial survey – but would need to be repeated throughout the course of the project	***Existing:*** Staff ability (but maybe not capacity); volunteers Have good awareness and understanding of the invasive species in the area; but not always aware of the threat level of the species ***Needed:*** Staff capacity	***Initial*****:** Staff time (built in); more time intensive than cost intensive ***Maintenance:*** Same as above (successful implementation would reduce maintenance costs)	Weeds Inc. Volunteers Partner with the state to get grant funding for invasives removal (state can create weed management areas – considering in NW PA, makes funding available)
Manage deer grazing to promote regeneration	After site selection and initial survey – but would need to be repeated throughout the course of the project	***Existing****:* Existing deer hunting program (exists at most preserves including Bear Creek) ***Needed:*** Protective or exclusionary equipment (e.g., tree tubes, fencing, etc.) Staff time for maintaining or increasing hunter numbers (either # of hunters or harvest totals)	***Initial:*** Low-cost hunting program already exists ($), but hiring out for a cull would be quite expensive ($$$ - ChesLen may have done this in the past) Tree stakes/ties, tree tubes, fencing, etc. is going to be more costly, particularly when done at larger scales ***Maintenance:*** Staff time and volunteer management	Important to maintain existing relationships with hunters and recruit new hunters (perhaps by reaching out to sports clubs or providing info about the program to preserve visitors) USDA (can be hired to cull deer population) PA Game commission
Plant desired species to help speed up regeneration > Need to consider planting strategy to avoid pest infestation (e.g., don't plant alternative pathogen hosts together)	Do this after the initial survey and big effort to remove invasives Depending on the site, this step may not be needed until a decline in native species is seen Plant in the fall or spring (spring may be	***Existing:*** Tree planting equipment (shovels, machinery); volunteers Growing facility at Stone Leigh could provide plants; also have relationship with wholesale distributors of plant material ***Needed:*** Nurseries that can propagate local ecotypes;	***Initial:*** Plants (smaller plants tend to be not too expensive per unit); deer protection (see above); staff time and management of volunteers ***Maintenance:*** Deer management (see above); irrigation costs (a minor cost right now, but could	Growing facility at Stone Leigh Whole sale distributors Ongoing relationships with Mount Cuba Center, Game Commission, and Morris Arboretum – to propagate native plants from preserves

	less ideal now that summers are drier)	funding for plants and staff time (beyond normal preserve budget)	increase as irrigation need increases)	
Reroute trails/limit access to planted areas > May be able to reallow access once trees reach a certain level of maturity	Implement while plantings are occurring and after plantings are done	***Existing:*** Likely already have the resources needed for this (e.g., signage, staff capacity to monitor) ***Needed:*** If rerouting requires building a new trail, additional resources would be needed (additional staff time, potential equipment rental)	***Initial:*** Low cost of limiting access Rerouting trails would require additional costs (staff time, equipment rental) ***Maintenance:*** Staff time for monitoring	Trail clubs
Research tree species that will be better able to withstand the stressors that climate change will introduce > Follow up with test plots to see what trees do well	Before the start of the project (or at the same time as the initial survey) Definitely do a pilot project before upscaling	***Existing:*** NIACS Climate Change Projections for Individual Tree Speices tables (provided by EcoAdapt); USDA Climate Change Tree Atlas; PA big tree website ***Needed:*** Additional staff for test plots or university partnership Understanding of climate change impacts to herbaceous species	***Initial:*** Funding for additional staff time; funding for test plots (staff time or university group) ***Maintenance:***	Partnership with university to look at test plots (Penn State Extension? Also reach out to more southern organizations who might want to learn how trees will survive further north) Penn State Naturalist program (may be looking into herbaceous species and climate change)
Adjust roads to allow vehicle access for tree irrigation	Would need to be done in the initial phase of the project	***Existing:*** Trucks with water storage, pumps, hoses Some trails are UTV accessible (so could use tanks on UTVs) ***Needed:*** Time and staff capacity	***Initial:*** Irrigation itself does not cost a lot; if roads need to be built to accommodate irrigation, costs could be quite high ***Maintenance:*** Maintenance of roads should be low cost	Communication needed with local township in order to make roadway adjustments

SECTION 3: MONITORING & EVALUTION

Adaptation Actions	Desired Outcomes/Restoration Targets	Metrics to Measure Outcomes/Targets
Conduct an initial survey to identify higher quality areas to focus plantings	Identification of high-quality sites to focus use of resources	Sites that scoring high on one or more assessment tools (redundancy in quality assessments)
Control invasive species in the area	Reduced cover and density of invasive species Prevention of new invasive species introductions Reduced amount of time needed to manage invasives in subsequent years	Species diversity (pre, post removal) Time per year spent managing invasives
Manage deer grazing to promote regeneration	Maintenance of a deer population small enough that it does not have a negative impact on vegetation	Understory regeneration (growth rates, abundance of smaller trees in the understory); presence of ground and mid-level vegetation Survival rate of planted trees
Plant desired species to help speed up regeneration	Survival of planted trees to the age where they are producing seeds	Survival rate of planted trees
Reroute trails/limit access to planted areas	Little or no evidence of recreational impacts on tree plantings	Tree health – understory regeneration and survival of tree plantings
Research tree species that will be better able to withstand the stressors that climate change will introduce > Follow up with test plots to see what trees do well	Test plots are successful, giving confidence to move to a larger scale project	Species survival rates under a variety of different climatic conditions
Adjust roads to allow vehicle access for tree irrigation	Staff are able to water all the trees in a timely and safe manner	Yes/no we were able to water the trees in a timely and safe manner

Thresholds that would indicate intervention/additional action is needed (what/when/how to respond):

- Catastrophic event (e.g., wildfire that burns the whole site; 500- or 1,000-year flood that deposits a large amount of sediment in the forest) – would require the scale of intervention to be larger
- Presence of a new invasive species from a watch list – would need to make a decision about whether or not to manage

Adaptation Implementation Plan for Spruce Swamps in Bear Creek Preserve

SECTION 1. BACKGROUND

SELECTED PROJECT SITE/ECOSYSTEM: Spruce Swamp, Bear Creek Preserve

Overarching management goal (current or future): Support the health and persistence of native plant species and associated taxa of the spruce swamp

(*Additional notes:* Bear Creek is further north than many other properties, its impact on downstream systems is extremely important; preserving this landscape could be an increasing priority; focusing first on inventorying and monitoring conditions under climate change in order to make informed prioritization and management decisions)

Key climate-related vulnerabilities that will impact ability to meet management goal:

- Flooding/extreme weather conditions, shifts in seasonal precipitation
- Temperature – both loss of cold and extreme heat
- Shifts in form of precipitation- less snow/more rain
- Increased drought frequency
- Pests/pathogens, invasive species
- Wildfires

Other potential challenges to meeting management goal:

- Staff capacity (interacts with increased climate stressors, which may increase staffing needs)
- Possible increases in recreational pressure, along with more extreme temps; changes in seasonality of when people might be visiting
- General public access – currently restricted

Potential conflicts or unintended consequences with non-target ecosystems/species, human communities, and/or other management goals:

- Climate refugees? Would create additional pressure for development in surrounding areas, but currently there is a buffer including U.S. Army Corps of Engineers (USACE), state game lands, other land trusts, private conservation easements- pretty protected right there

SECTION 2: IMPLEMENTATION STEPS

ADAPTATION STRATEGY: Support native plant and wildlife species while evaluating baseline conditions and how they may change under climate change

Adaptation Actions	Timeline	Existing/Needed Resources	Implementation Costs	Potential Partners
Conduct a baseline inventory to identify key native plant species in the spruce swamp > Need baseline information to understand what to prioritize for protection (e.g., general info on range and local adaptation, ability to persist)	Do this first	*Existing:* Consultants (mostly in house) have established baselines for some of the plant species *Needed:* Additional expertise to expand this knowledge; seasonal inventory to understand full suite of plants Needs to be done in a repeatable way so it feeds into monitoring (next step)	*Initial:* Possible to do it ($-$$) *Maintenance:* Some costs if inventory is repeated (e.g., seasonally)	Roger Latham, David Steckel, independent consultants

Monitor native swamp plant species > Include a focus on abundance and distribution of listed species	Do this second, using internal and/or external assistance	*Existing:* Nothing currently in place *Needed:* A plan! Contingent on above step	*Initial*: in-house staff, could be rolled in to current budgeting and not expensive *Maintenance:* Ongoing staff time	Volunteers Possibly use consultants for monitoring rare species
Identify other taxa that might be high priority for conservation (e.g. vulnerable reptile species such as timber rattlesnake that has den sites in proximity to the spruce swamp)	Currently happening – spring and fall monitoring, long-term monitoring	*Existing:* Monitoring is currently occurring through a local college, but need to get that data so that it is also in-house knowledge *Needed:* There might be a need to identify new people/organizations to continue this work if the current researcher retires; probably not an in-house job because methods are specialized	*Initial:* None *Maintenance:* None, provided someone can continue this work externally	Wilkes University is doing annual monitoring, at least 10 years of data exists; it's a specific professor's data and project so this could end without an institutional plan?
Identifying other taxa that might be high priority > Not sure at this point which specific taxa- all of it? (wood turtles?- northern turtle in decline, high priority for monitoring)	Can start concurrently with plant monitoring	*Existing:* Nothing currently in place *Needed:* Need to first identify top species- maybe start with Natural Heritage Society E&T species list and use this to determine baseline and monitoring	*Initial:* ? if in-house roll into staff capacity, possible $$ for expertise *Maintenance:* Ongoing staff resources	USACE may have research studies on neighboring properties PA Natural Heritage Program for T&E species; could be accomplished by a combination of internal staff, consultants, volunteers

Determine priority species/assemblages in swamp based on above inventory and management	Dependent on the above actions	*Existing:* Do not currently have this list *Needed:* To be developed	*Initial:* *Maintenance:*	Both in-house and external expertise needed
Manage/control invasive species under current and projected conditions	Currently happening	*Existing:* Staff are doing *Needed:* Adequate staffing at this time; external resources for knowing what species are coming down the pipe ;	*Initial:* $ - (right now it is mostly spot-treatments of small plant populations) *Maintenance:* $$	In-house because specialized equipment is needed NE RISCC Network; Penn State Extension
Communicate with land managers to the north to understand how species (e.g., red spruce) are doing throughout their range, monitor for stress and change	Can start now or soon	*Existing:* Does not currently exist, but current conservation easements extend north so there is the opportunity to talk to those landowners during site visits (done by Josh) *Needed:* Staff dedicated to understanding current research on this issue – no one currently has that in their job description at NL		Networks that could be joined (e.g., native plant network, NIACS, other extant groups that are meeting regularly on these topics)

SECTION 3: MONITORING & EVALUTION

Adaptation Actions	Desired Outcomes/Restoration Targets	Metrics to Measure Outcomes/Targets
Baseline inventory to identify key native plant species in spruce swamp	A completed inventory of native plants in the spruce swamp, conducted by a consultant with the right expertise	
Monitor native swamp plant species > Include a focus on the abundance and distribution of listed species	Staff/volunteers conduct and record the monitoring Standardized, repeatable method for collecting data at regular intervals about plant populations Understanding of population trends for individual species within the spruce swamp – are they stable, increasing, decreasing?	
Identify other taxa that might be high priority (e.g. vulnerable reptile species such as timber rattlesnake that has den sites in proximity to the spruce swamp)	In-house data and knowledge of specialized techniques to allow the work to be carried on if the current person leaves Understanding of population trajectory over time – if there is decline, would need to consider next steps, ties into establishment of conservation priorities below	
Identifying other taxa that might be high priority	Species/taxa list of high priorities for monitoring	
Determine priority resources in swamp based on above inventory and management	List of priority species for management (and the development of management strategies and actions)	

Manage/control invasive species under current and projected conditions	Low levels of invasive species over time	Current monitoring is opportunistic, though there are a few GPS'd areas to track current and future outbreaks – not highly detailed, might need to be more formalized if these issues increase
Communicate with land managers to the north to understand how species at the southern margin (e.g., red spruce) are doing throughout their range, monitor for stress and change	Good understanding of trends for vulnerable tree species throughout their range Identification of resources for more information about vulnerable species and range contractions/expansions (USDA Climate Change Bird Atlas, National Phenology Network) Improved relationships with other easements, areas	Indicator species for climate vulnerability – within NL there is already some discussion of this, but need to have broader conversations
Thresholds that would indicate intervention/additional action is needed (what/when/how to respond): • If we get notification that there are abrupt or new declines, development of management strategies might need to be re-prioritized		

SECTION 4. FUNDING & COMMUNICATIONS PLAN *(OPTIONAL)*

Funding mechanisms/options:

- Most funding would come from the Bear Creek Preserve budget, but there are always opportunities for grants; more difficult to find funding for monitoring (but maybe improved if there is a climate change lens), and if paired with invasive species control could be successful
- Possibilities includes the Farm Bill and motivated Natural Lands donors; private foundations might be a good fit (especially for monitoring and inventory work)
- Have a good sense of what funding opportunities are already out there

Communication/public outreach plan:

- NL already has a pretty comprehensive communication: website, social media following, email list of 20K people, growing membership, magazine; Force of Nature™ volunteer corps
- It is more difficult to get volunteers for Bear Creek because it is more remote than ChesLen (however there are some) – target is Montgomery and Chester Counties because it is a bigger potential volunteer pool to draw from
- Hold a virtual or in-house workshop to share current/ongoing activities
- Significant monitoring results might provide stories or feel more tangible to a general audience
- Be aware of the kinds of messaging and topics that are more or less effective in different geographies, and be sensitive to how certain terms might be received (e.g., talking about landscape preservation vs. climate change)

Adaptation Implementation Plan for Afforestation Areas in ChesLen Preserve

SECTION 1. BACKGROUND

SELECTED PROJECT SITE/ECOSYSTEM: Afforestation Areas – ChesLen Preserve

Overarching management goal (current or future):

Protect and enhance forested habitat (afforestation areas)
Key climate-related vulnerabilities that will impact ability to meet management goal: • Increased instances of drought threaten survival of drought-intolerant species • Increased flooding / extreme flooding events damage trees (new saplings and older trees), and floodings in riparian zones could increase debris which then poses a challenge to maintenance • Changing seasonal temperatures impact the success of afforestation plantings • Increases in insects/pests/pathogens and invasive species as changing conditions facilitate introduction of new species and establishment/spread of existing ones • Increased temperatures and extreme heat create safety issues for staff, impacting their ability to do this work
Other potential challenges to meeting management goal: • Potential funding, staff capacity/time • Changing or different priorities – other projects on the preserve may take priority over this • Loss of institutional knowledge with long-term staff leaving (stewardship)
Potential conflicts or unintended consequences with non-target ecosystems/species, human communities, and/or other management goals: •

SECTION 2: IMPLEMENTATION STEPS

ADAPTATION STRATEGY: Maintain and enhance species richness/diversity by planting species are well-adapted to future conditions				
Adaptation Actions	**Timeline**	**Existing/Needed Resources**	**Implementation Costs**	**Potential Partners**
Plant & identify drought-tolerant or flood-tolerant species	Identify species before planting (winter / 6+ months before)	*Existing:* Suppliers/sources for saplings; existing staff knowledge and experience; funding to support these efforts *Needed:* Staff and volunteers to do the plantings; supplier for new species if not carried by current supplier	*Initial:* Would need to identify costs and add to annual budget (existing grants could likely cover this) Currently 1 acre = $6,000 w/ tree shelters *Maintenance:* Replacing plantings could be costly	Grant funders Volunteers
Water to ensure survival > Challenge: Freeze in early spring and the scale of plantings > Consider watering smaller areas at a time to make the action more feasible for staff to implement	Following plantings	*Existing:* Water tanks (required to move water to plantings – ChesLen has them but not all preserves do) *Needed:* Staff to do the plantings (consider size of plantings – currently don't do much watering, and it would take a lot of staff time to water trees in a larger area)	*Initial:* Larger cost until plantings are established *Maintenance:* Lower cost once trees are established/as plantings survive	Volunteers

Adapt current maintenance activities to consider changes in growing season and flooding events > Timing and frequency of mowing, herbicides (spraying around tree tubes) > Challenge: Flooding in riparian zones could increase debris	Ongoing during growing season	*Existing:* Equipment, staff *Needed:* May need different equipment, or might have to replace existing equipment if damaged (e.g., in a flooding event)	*Initial:* Managers and staff time *Maintenance:* Potentially more costly to maintain (e.g., if new equipment is needed)	Volunteers
Invasives removal / management (future and current) > Challenge: Increased presence of invasives (e.g., mile-a-minute) would make this challenging (more difficult type of removal that would be tough work for volunteers)	Ongoing	*Existing:* Equipment, experience *Needed:* People; more herbicides and gas to run equipment; training for existing staff (e.g., herbicide application certification, etc.)	*Initial:* *Maintenance:* Higher costs as need for supplies and frequency of removal increases	Volunteers Funders (for increased staff time)

SECTION 3: MONITORING & EVALUATION

Adaptation Actions	Desired Outcomes/Restoration Targets	Metrics to Measure Outcomes/Targets
Plant & identify drought-tolerant or flood-tolerant species	High species survival rate *Information on current monitoring:* The existing surveys/monitoring for species survival is a yearly process, with plantings replaced as needed) *Desired co-benefits:* Increased pollinator habitat, increased canopy cover, cooler water temperatures, higher rate of fruiting/seeding, increased plant health/growth/productivity	Species mortality (aim for less than 50-75% mortality rate, though the agreed-upon range may vary depending on species and manager opinion)
Water to ensure survival	Species survive without larger input of manager time > Will need to consider staff time vs. survival rate – if staff are spending a lot of time, the survival rates would need to be high enough to make the investment worth it	Species survival rate = 60-65+%
Adapt current maintenance activities to consider changes in growing season and flooding events	Native species face reduced competition from invasives Ability to access well-maintained sites for the purpose of monitoring plantings	Amount of time spent for staff and volunteers to monitor (assuming that less time spent is a result of easier access to plantings)

Thresholds that would indicate intervention/additional action is needed (what/when/how to respond):

- Large outbreak of invasives (e.g., after flooding event) would require additional intervention
- Additional intervention may be required if 80+% of tree tubes were damaged from a large flood event
- If species mortality rate is high, they would need to evaluate why so many trees died, survey which species died, and identify if any species were impacted more than others. The results may indicate that they will need to select different species for future plantings. Close monitoring of species mortality should take place for the first 5 years after planting and continue after that as a periodic ongoing practice. Determining whether intervention is needed is primarily dependent on the severity and frequency of impacts (e.g., pests that infest one or two of the primary species planted may result in significant loss of plantings)

SECTION 4. FUNDING & COMMUNICATIONS PLAN *(OPTIONAL)*

Funding mechanisms/options:

- Could write this project into the annual budget for ChesLen
- State/federal grant funding (available funding esp. for riparian zone areas)
- Donor funding
- Tree donations from nurseries

Communication/public outreach plan:

- When conducting tree plantings with volunteers – take advantage of the time to share the "whys" with them
- Public outreach with neighbors with social media and in-house meetings – explanations of why changing meadow habitats to afforestation areas
- The main message currently gives the why and incorporating of climate change. Climate messaging wouldn't necessarily influence one way or another – focus on preserve use/conservation/aesthetics is successful for this audience

Adaptation Implementation Plan for Mature Forests in Bear Creek Preserve

SECTION 1. BACKGROUND

SELECTED PROJECT SITE/ECOSYSTEM: Unionville Barrens, ChesLen Preserve
Overarching management goal (current or future): Restore Unionville Barrens to historical extent
Key climate-related vulnerabilities that will impact ability to carry out project and meet management goal: • Increased erosion – potential for that to be beneficial to the barrens, but can negatively impact streams • Increased stress for native plants and/or increased opportunities for invasion – rare plants especially may not be able to withstand warmer climate • Increase in need for hazard tree management if damage/mortality increases • Unknown impacts to viability of seed bank • High volume rainfall in short periods of time – lots of runoff could bring silt/soil into barrens and deposit it onto exposed rock (would then need to be removed) • Plants might flower and go to seed sooner, which would change collection dates • Inability to conduct prescribed burns if weather is too dry or too wet • Changes in patterns of tree encroachment – species that thrive may be the more aggressive (and/or non-native) ones that are harder to manage
Other potential challenges to meeting management goal: • Foot traffic – as there is less space, more people are concentrated in recreational areas which increase trampling of sensitive areas • Soil depth on top of serpentine rock (up to 3 feet in places!) – deeper soils make removal difficult and cost-prohibitive • Connection to all other systems on the preserve – difficult to isolate concerns about the barrens when so many other systems will also have to be managed

Potential conflicts or unintended consequences with non-target ecosystems/species, human communities, and/or other management goals:

- Erosion may affect waterways

SECTION 2: IMPLEMENTATION STEPS

ADAPTATION STRATEGY:				
Adaptation Actions	**Timeline**	**Existing/Needed Resources**	**Implementation Costs**	**Potential Partners**
Assess likely future changes in the fire season so that this fire prescriptions can be designed to account for these changes > Look at prescribed fire program to ensure that management goals can continue to be met (e.g., if fire window changes in length or timing) > May need to ensure that prescribed burns in the barrens are prioritized > Make sure there's an opportunity for input from folks who are newer to the program and will be here over the coming years > Include consideration of a backup plan in the case that there was a year when weather conditions mean		*Existing:* In-house expertise *Needed:* Staff time from the folks who have expertise	*Initial:* Staff time only *Maintenance:*	Talk with PA Prescribed Fire Council (and members of that council) to see what they're doing

burning couldn't happen > Re-assess every 5-10 years as climate conditions continue to alter burn windows, etc.				
Assess how runoff and erosion are affecting streams that go through the preserve to determine whether management action needs to be taken to address potential impacts to waterways (e.g., can we allow erosion to carry away soil, or does that have too great an impact on streams? If so, how can we counteract that?) > Monitor streams following heavy storms to learn about erosion patterns (scientific study) > Track organic material buildup in current cleared/restored areas (i.e., high-quality exposed bedrock) > Measure soil depth (can be simple) to determine how much is being lost during a heavy rain event	Could take months or years to answer completely	*Existing:* Staff already goes out to check bridges and trails after storms (to ensure safety); water quality monitoring already being done *Needed:* Mayfly data loggers within streams in the barrens to monitor turbidity, etc. (existing data loggers are all located outside the barrens); measurements of soil depth; staff/volunteer time or research project focus	*Initial:* Data loggers (potentially expensive) The actual activities necessary to mitigate erosion could be very expensive *Maintenance:*	Grad student/research partnerships Stroud Water Research Center
Regularly survey/monitor native plant species to track change in populations over time > Have been updating the Unionville Barrens management plan every 5	Simple surveys annually, more intensive surveys could coincide w/ management plan	*Existing:* Already have surveys, but are not tracking changes Force of Nature (volunteer training	*Initial:* Staff time (no add'l cost to existing cost of updating plan every 5 years)	The Gardeners (butterfly count)

years, which includes survey of existing transects, etc. > Potential to engage volunteers through simpler monitoring, focusing on high-priority species > Add additional deer exclosures to isolate whether climate change is affecting these species or whether observed declines are d/t herbivory	updates (every 5 years)	program already being used); two existing volunteers are already knowledgeable about barrens Sugartown is trying to implement some of this monitoring at a volunteer level (time-consuming for NL staff) ChesLen is already monitoring for juniper hairstreak – could do simple citizen science monitoring for other specialist pollinators, and there is also some interest from another butterfly researcher *Needed:* Volunteers (and training for them)	*Maintenance:*	
Re-route trails to minimize erosion risk and mitigate harm to downstream areas > Pay attention to whether sediment is covering exposed serpentine bedrock > Aim for trails to be re-routed		*Existing:* *Needed:*	*Initial:* Staff time to determine where trails should be located and then moving earth, setting up catch basins, etc. Higher costs for actions addressing runoff from	

through areas where trees need to be removed anyway (either because they are undesirable or aren't likely to do well under future conditions) > Consider mitigating runoff entering from impermeable surfaces (e.g., Cannery Rd.) – would need to work through the town, get permits, etc. > Focus on vegetation management around streams to slow runoff and capture sediment			roads *Maintenance:*	
Determine which areas of the barrens may not be able to be restored (e.g., highly disturbed areas, mine sites), and consider using them to mitigate erosion from other areas (e.g., use as catch basin) > Vegetation may still provide value, but wouldn't be maintained in historical condition > Some sections in Unit 4 have already been identified as unlikely to be restored, also Unit 6 seems logistically challenging to scrape > Can still utilize barren indicator species within these areas (e.g, shrubs)				

Remove and replace undesirable trees (e.g., species that would not be present in a serpentine systems and/or are non-native) > Make more explicit decisions/plans around types of herbicide and how it is applied > Current practice is to spot spray undesirable species, but need to consider volatile substances in hotter temperatures, which could draft and affect non-target species – may need to apply at the bottom of the tree/shrub (basal bark application), or cut and paint > Consider species vulnerability when making decisions around removal and replacement > For trees that are unlikely to survive, consider leaving snags behind where trees die > As burn program is reassessed, consider how it might aid in removal of undesirable trees		*Existing:* Already underway A few volunteers who can use power tools may be able to assist *Needed:* No change in resources (apart from those already being used)	*Initial:* *Maintenance:*	
Control other invasives through annual mowing (current action)				

SECTION 3: MONITORING & EVALUTION

Adaptation Actions	Desired Outcomes/Restoration Targets	Metrics to Measure Outcomes/Targets
Assess likely future changes in the fire season so that this fire prescriptions can be designed to account for these changes	All scheduled burns are complete every year	# of scheduled burns completed each year
Assess how runoff and erosion are affecting the streams that go through the preserve to determine whether management action needs to be taken to address potential impacts to waterways	Stormwater management plan relevant to the barrens and surrounding waterways	
Regularly survey/monitor native plant species to track change in populations over time	Data to inform future plantings and management strategies for species of conservation concern	
Re-route trails to minimize erosion risk and mitigate harm to downstream areas	Less erosion from trails and less maintenance required No harm from erosion to downstream areas Trees are growing properly and maintaining stream banks	Vegetation growth along streams Water quality metrics
Determine which areas of the barrens may not be able to be restored (e.g., highly disturbed areas, mine sites), and consider using them to mitigate erosion from other areas (e.g., use as catch basin)	Ecosystems within sacrificed areas are healthy and maintain important services that support barrens (e.g., capturing and filtering runoff, providing shade, etc.)	

Remove and replace undesirable trees (e.g., species that would not be present in a serpentine systems and/or are non-native)	Increased proportion of climate-resilient species Reduced tree mortality overall, and among planted trees (corresponds to overall increased resilience) Elimination of most problematic species (e.g., tree of heaven), particularly those that will proliferate under future conditions	
Current control of other invasives through annual mowing		

Thresholds that would indicate intervention/additional action is needed (what/when/how to respond):

- When monitoring, watch for decline in important species – if this occurs, would need to assess whether survival is likely. If so, increase population (e.g., through propagation and planting); if not, figure out a replacement
- Significant soil buildup on historically-exposed serpentine bedrock – would need to determine why. Rescrape area and determine if it was a one-time issue or whether there is a sediment source or other cause that needs to be addressed
- If secondary succession tree species show up, would indicate that the ecosystem is different than planned (e.g., might need to increase level of disturbance)

SECTION 4. FUNDING & COMMUNICATIONS PLAN *(OPTIONAL)*

Funding mechanisms/options:

Communication/public outreach plan:

- Increase outreach about how special and unique serpentine barrens are! Try to reach the general public, people who live in the area and may not realize they are right there

Concluding Thoughts

The climate change vulnerability assessment and adaptation planning process and results from the Natural Lands Climate Adaptation Project improves understanding of how habitats and species in the region are vulnerable to changing climate conditions and assists natural resource managers, conservation planners, and others in identifying, prioritizing, and implementing adaptation strategies designed to minimize vulnerabilities and/or increase resilience of natural resources. This information can be integrated into management and conservation plans, programs, and projects. As practitioners work toward this integration, it is important to monitor and evaluate climate impacts as well as the implemented adaptation strategies to determine if the strategies are having their intended effect and identify when or where changes might be needed. Monitoring and evaluation plans can be fairly simple – identify a desired outcome for each strategy, a corresponding parameter to track progress and the method to do so, a trigger or threshold that signals diversion from the desired outcome, and possible alternative adaptation strategies to pursue if that threshold is crossed.

Finally, keep in mind that climate adaptation is an iterative process and new research and modeling on projected climate changes and impacts is regularly released. Thus, it is important that managers and planners revisit and/or revise vulnerability assessments and adaptation strategies on a regular basis (e.g., every 5-10 years).

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Appendix A. Adaptation Implementation Plan Guidelines

SECTION 1. BACKGROUND

- **Selected Project Site**
- **Overarching Management Goal**: E.g., increase habitat connectivity, manage fuels to reduce wildfire risk, manage invasives and increase native plant cover
- **Key Climate-related Vulnerabilities**: Vulnerabilities to be addressed by this project, which may include climate stressors, climate-driven changes in disturbance regimes, interactions between climate changes and non-climate stressors, and adaptive capacity factors that will enhance the ability of the resource to cope with or respond to climate change (e.g., genetic diversity, support for climate-informed management)
- **Potential Barriers to Meeting Management Goal** and **Potential Conflicts or Unintended Consequences**: Potential barriers to meeting the management goal and/or conflicts with other species, habitats, ecosystem services, or human communities that may arise as part of the project

SECTION 2. IMPLEMENTATION STEPS

- **Adaptation Actions**: Outline of 3–5 adaptation action steps (i.e., specific, concrete tasks) that would be implemented as part of this project
- **Timeline**: The ideal timeline when initial implementation of this action would occur and/or notes on time-dependent factors (e.g., invasives removal must occur prior to adaptation actions focused on planting)
- **Lead & Potential Partners**: Lead department, agency, or organization and potential partners for each adaptation action
- **Implementation Costs**: The cost of implementing each action step, including initial investment and ongoing maintenance (consider whether climate change may increase the initial cost or require more frequent maintenance)
- **Existing/Needed Resources**: Other resources that would be required for implementation, including things like staff capacity, permits and approvals, and data or technical capacity

SECTION 3. MONITORING & EVALUATION

- **Desired Outcomes/Restoration Targets**: Specific desired outcomes and/or restoration targets for this project. If you were successful in your effort, what would that look like? For example, increased native seed source, flow regime is restored to the habitat within 10 years, multiple partners and stakeholders are engaged in the effort, and costs associated with flooding are reduced.
- **Timeframe**: Target timeframe for achievement of the desired outcomes, including near-term (1–5 years), mid-term (5–20 years), and long-term 20–50+ years.
- **Metrics to Measure Outcomes/Targets**: Identification of specific metrics for each outcome that could be used to monitor change and progress toward the desired outcome(s). Notes may include tools/methods of measurement, data sources to reference, or other specifics.
- **Thresholds Indicating Intervention/Additional Action is Needed**: Management thresholds can be thought of as the point where change is heading towards undesirable outcomes and

intervention may be needed to ensure that the project gets back on track or does not result in further harm. What is the threshold and necessary next steps/time frame for intervention? What are potential adaptive responses? These may include placing the project on hold until further studies/monitoring can be conducting, modifying the management actions already occurring, or implementing new actions.

SECTION 4. FUNDING & COMMUNICATIONS

- **Funding Mechanisms/Options**: Potential funding sources or mechanisms, which may include government support, foundation grants, private funding sources, and in-kind or volunteer support. Consider whether there are existing funding structures that this project could take advantage of.
- **Communication/Public Outreach Plan**: Potential strategies for communications and public outreach about this project. What is the most interesting story or important message? Who is the primary audience that needs to hear it? Consider whether there are existing communications strategies or campaigns that this project could take advantage of.