Restoring the Great Lakes' Coastal Future

Technical Guidance for the Design and Implementation of Climate-Smart Restoration Projects

Seven Case Studies

2014

NATIONAL WILDLIFE FEDERATION

NOAA Great Lakes RESTORATION

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Restoring the Great Lakes' Coastal Future

Technical Guidance for the Design and Implementation of Climate-Smart Restoration Projects with Seven Case Studies

Michigan Sea Grant

Colleen Brown

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Executive Summary

The Great Lakes region is home to 20 percent of the world's freshwater reserves, a rich array of species and habitats, and tens of millions of people. One of the most significant challenges to the well-being of the region is climate change. The effects of climate change have already begun and will only intensify in the future. As a result, the past climate is no longer a sufficient guide for conservation decisions. To effectively protect, manage, and restore freshwater coastal ecosystems in the Great Lakes current and future climatic changes must be considered. Making projects "climate-smart" in this way will enhance their value and durability over the long term.

This guide describes a ***practiced*** suite of tools and methods to assist in the planning and implementation of climate-smart coastal restoration by NOAA, its partners, and others. The guide is informed by workshops, trainings, on-the-ground projects, and other stakeholder input. The project-based approach to adjusting restoration activities to account for climate change includes the following steps:

1. Identify Restoration Goals, Targets, and Approaches
2. Sketch Climate Smart Process
3. Assess Climate Change Vulnerability
4. Review and Revise Goals, Targets, Approaches
5. Identify and Select Climate-Smart Restoration Options
6. Develop A Monitoring Approach
7. Implement Restoration Options
8. Review, Revise, Reassess, Re-create

Eric Kelly

This guide describes a practiced suite of tools and methods to assist in the planning and implementation of climate-smart coastal restoration by NOAA, its partners, and others.

National Park Service

The example case studies of seven climate-smart Great Lakes Restoration Initiative (GLRI)-supported projects, chosen because of their likely susceptibility to climate change, include:

1. Habitat Restoration of the Lower Black River near Lorain, Ohio

2. Habitat Restoration in Muskegon Lake Area of Concern near Muskegon, Michigan

3. Habitat Restoration of the Clinton River Spillway near Clinton Township, Michigan

4. Habitat Restoration in the Maumee Area of Concern near Ottawa, Ohio

5. Phase II of Habitat Restoration-RiverBend in the Buffalo River Area of Concern near Buffalo, New York

6. Marsh Enhancement in the Crow Island State Game Area near Saginaw, Michigan

7. Habitat Restoration in Little Rapids near Sault Sainte Marie, Michigan

Although developed specifically for climate-smart restoration in the Great Lakes, the general procedures should have broader applicability in other regions. The case studies are specific to the Great Lakes and can inform other coastal restoration projects in the Great Lakes region.

I. Introduction

Climate change has become one of the defining conservation issues of this century. Given current trends, the environment in which the planet's living resources – humans, plants, and animals alike – will exist in the future will be vastly different from the one we have experienced over the past several centuries, during which our conservation traditions evolved. In the United States, we are already seeing changes, from higher average air and water temperatures and greater extremes in precipitation events to sizeable toxic algae blooms and accelerating sea-level rise.[1, 2] Furthermore, these and other physical changes associated with climate change are having a significant biological impact across a broad range of natural systems.[3,4,5]

Scientists and managers are examining how to balance near-term restoration goals for species and habitats with achieving ecologically functional, self-sustaining systems that can persist under likely future conditions.[6] Managers can no longer assume that historical climate will remain unchanged when setting their conservation and restoration goals, and must instead anticipate an increasingly variable and uncertain climate.[7] State and federal agencies, non-governmental organizations, and others concerned with conservation are now challenged with designing and implementing projects that will maximize the effectiveness of restoration investments under both current and expected future climate conditions (i.e., projects that are "climate-smart").

Sharply Done

The National Oceanic and Atmospheric Administration (NOAA) is dedicated to the management and protection of the nation's coastal and marine systems. It is moving forward to safeguard its coastal investments by integrating consideration of climate change into its programs.[8] This Technical Guidance provides guidance and case studies to assist in the planning and implementation of climate-smart restoration by NOAA and its partners, in the Great Lakes region. This guidance is informed by workshops, trainings, on-the-ground projects and other stakeholder-driven efforts from the past two years.

II. Coastal Restoration in the Great Lakes

Setting the Stage

As the single largest source of surface freshwater in the world, with six quadrillion gallons of freshwater and 10,000 miles of freshwater coastline, North America's Great Lakes are a vital ecological and economic resource.[9] More than 33 million U.S. and Canadian citizens call the coastal towns and cities of the Great Lakes Basin home. In addition, its scenic lake shores, unique wildlife, and diverse recreational opportunities draw millions of tourists to the region annually.

Unfortunately, growth in urban development, agriculture, industry, and tourism has brought enormous conservation challenges to the Great Lakes, even before the threat of climate change. Evidence of continuing problems has sparked concerns that the region's ecological systems may be nearing a tipping point of irreversible changes.[10] A legacy of toxic pollution and contamination from substances such as mercury and PCBs threaten the health of people and wildlife alike; populations of important native fish species have seen major declines due to overfishing and invasive species such as sea lamprey, zebra mussels, and common reed *(Phragmites);* the recurrence of anoxia/hypoxia and harmful algal blooms continues to plague coastal waters; and dredging activities and infrastructure development for water diversions, transportation, and other uses have damaged and fragmented habitats for fish and wildlife. Continued human population growth and increasing demands for freshwater are placing additional strain on Great Lakes resources.

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Restoration Programs

In light of the long-term degradation of the Great Lakes, major efforts have been undertaken to restore the Great Lakes across multiple scales – from local, community-based projects to major bi-national initiatives. Today, much of the Great Lakes restoration agenda follows the Great Lakes Regional Collaboration Strategy (GLRC Strategy), which was developed by a team of more than 1,500 people representing federal, state, local, and tribal governments; non-governmental organizations; and private citizens. Building on the GLRC Strategy, President Barack Obama and the former U.S. Environmental Protection Agency (EPA) Administrator

Lisa Jackson, in collaboration with 15 other federal agencies, have made restoring the Great Lakes a national priority. In February 2009, Congress authorized $475 million for a Great Lakes Restoration Initiative (GLRI) with bipartisan support, which is focused on five key challenges identified as the most significant environmental problems in the Great Lakes (other than water infrastructure):[11]

1. Cleaning up toxic substances and Areas of Concern (AOCs)*;

2. Combating invasive species;

3. Promoting near-shore health by protecting watersheds from polluted run-off;

4. Restoring wetlands and other habitats; and

5. Tracking progress and working with strategic partners.

According to the Great Lakes Restoration Initiative Project website, to date more than 1,600 projects are underway or completed, totaling over $900 million. [12] These projects are showing real results creating wetlands, removing barriers to fish passage, and removing toxic sediment, to name a few.[13]

Ducks Unlimited

Notably, the GLRI defines a successfully restored system as one in which potential threats or future damage have been eliminated or reduced as much as possible, and the restored system is able to withstand future threats. This approach does not necessarily mean the system has been changed back to pre-European settlement conditions, but it does acknowledge that "a restored ecosystem does attempt to emulate those conditions to the extent possible under present-day chemical, physical and biological conditions."[14]

NOAA supports the GLRI through a number of offices which plan, implement, and fund coastal habitat restoration projects throughout the country. To date, NOAA has supported about 110 projects.[15] NOAA Restoration Center efforts focus on restoration priorities in AOCs, with the objective of delisting of fish and wildlife-related Beneficial Use Impairments (BUIs).**

* Areas of Concern (AOCs) are formally defined in the 1987 amendments to the Great Lakes Water Quality Agreement as areas "that fail to meet general or specific objectives of the Agreement," with resulting beneficial use impairments (BUIs). Building on earlier work, the U.S. and Canadian governments (in cooperation with the states, provinces, and International Joint Commission) identified 43 AOCs, where a common cause of BUIs is high levels of toxic chemicals. Following remediation and restoration work, two Canadian AOCs and one U.S. AOC have been formally delisted. Information on U.S. Great Lakes AOCs and BUIs are available at: http://www.epa.gov/glnpo/aoc.

** A Beneficial Use Impairment (BUI) is a change in the chemical, physical, or biological integrity of the Great Lakes system sufficient to cause any of 14 use impairments such as restrictions to fish consumption, water consumption or recreational activities covered by Article IV of the Boundary Waters Treaty Agreement. Source: International Joint Commission.

U.S. Geological Survey

Climate Change in the Great Lakes Region

The great success of restoration programs in the Great Lakes can be enhanced by taking into account climate change. Absent consideration of climate change, the attainment of project objectives and the expected life of the project are increasingly likely to be compromised.[16]

Climate in the Great Lakes region has already been changing. Although there are general trends, the magnitude and effects of climate change vary within the region. In the 20th century, significant trends in climate of the Great Lakes include (Appendix A, Table A2):[17,18]

- Increase in average precipitation, especially in winter and spring;
- Increase in the intensity and frequency of heavy rainfall events;
- Increased evaporation and drought conditions in summer;
- Earlier last spring freeze and longer growing season;
- Decrease in lake ice;
- Variability in snow cover and duration, and earlier spring snowmelt;[19] and
- Increase in Great Lakes water temperatures and increase in the duration of summer stratification;[20]

We're committed to creating a new standard of care that will leave the Great Lakes better for the next generation.[21]

Going forward, projections of climate change include (Appendix A, Table A3):

- Increases in air temperatures by 2 to 3ºC by mid-century;[22]
- Increases in winter and spring precipitation by 20 to 30 percent;[23]
- Increasing intensity of extreme precipitation events;[24]
- General declines in water levels;[25]
- Milder winters leading to less ice cover;
- Increased loading of nutrients associated with increased spring storm events.[26]

Many of the habitat restoration efforts funded under NOAA's programs in the Great Lakes region could be vulnerable to a wide variety of climate change impacts (Appendix A, Table A4). For example:

- Changes in water temperatures and flow regimes may result in reduced target species utilization or degradation of restored in-stream habitats.[27]
- Coastal marsh restoration along the Great Lakes may be adversely affected by reductions in the frequency and duration of freshwater inundation due to altered lake levels and streamflows.[28]
- Warming waters may facilitate the invasion and establishment of southern fish species such as smallmouth bass in the Great Lakes or the contraction northward of cold-water dependent species.[29]
- Climate change impacts such as changing temperatures, lake levels, reduced ice cover, runoff patterns, and lake chemistry will interact with a range of issues related to contaminants, including changing the availability or toxicity of a number of contaminants and changing the pattern of input of toxic materials into freshwater systems.[30]
- Toxicants can also increase species' sensitivity to various climate change impacts, for instance by decreasing thermal tolerance.[31]
- Weather extremes may delay actual implementation of restoration approaches.[32]

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III. Characteristics of Climate-Smart Conservation

Climate-smart conservation can vary tremendously across the landscape, given different regional changes in climate and conservation challenges. Making conservation or restoration efforts climate-smart requires that practitioners pay particular attention to several overarching themes. Most important is *acting with intentionality,* through explicitly considering and addressing climate impacts, both direct and indirect, in conservation actions. Second, is *managing for change, not just persistence.* Third, it will be increasingly necessary to *reconsider goals, not just strategies* (see next section). And finally, it is important to *integrate climate adaptation into existing work,* rather than approach it as a separate activity. Supporting these general adaptation principles are a number of key characteristics that collectively define the practice of climate-smart conservation. These characteristics, which draw from a forthcoming guide on the topic,[33,34] build on best practices for conservation and restoration generally but are designed to help practitioners incorporate climate considerations into their work.

- **Embrace forward-looking goals.** Conservation goals focus on future, rather than past, climatic and ecological conditions; strategies take a long view (decades to centuries) but account for near-term conservation challenges and needed transition strategies.

- **Link actions to climate impacts.** Conservation strategies and actions are designed specifically to address the impact of climate change in concert with existing threats; actions are supported by an explicit scientific rationale.

- **Manage for change, not just persistence.** Conservation efforts usually strive to maintain existing conditions or restore back to some historical state. Increasingly, we will be faced with managing system transformations, and may need to focus on recovering or sustaining ecological functions, rather than historical assemblages of plants and animals.

- **Consider broader landscape context.** On-the-ground actions are designed in the context of broader geographic scales to account for likely shifts in species distributions, to sustain ecological processes, and to promote cross-institutional collaboration.

- **Emphasize ecological processes and dynamic systems.** Natural habitats are described by structure and species composition as well as ecological processes. Successful restoration projects must consider establishing healthy ecological processes, even if species composition and structure change.

- **Consider transformation of ecological systems.** Recognize that restoration to a previous ecological state may not be the best strategy. Where the previous ecological state may not viable in a changing climate, restoration should anticipate and facilitate ecological transitions for the greatest success.

- **Recognize uncertainty.** Projections of climate change, like any projections of the future, contain uncertainty about the magnitude and characteristics of climate change, as well as how, when and where it will affect natural systems.

- **Adopt strategies robust in an uncertain future.** Strategies and actions ideally provide benefit across a range of possible future conditions (including extreme events) to account for uncertainties in climate, and in ecological and human responses to climatic shifts.

- **Employ agile and informed management.** Planning and resource management is capable of continuous learning and dynamic adjustment to accommodate uncertainty, take advantage of new knowledge, and cope with rapid shifts in climatic, ecological, and socio-economic conditions.

- **Minimize carbon footprint.** Strategies and projects minimize energy use and greenhouse gas emissions, and sustain the natural ability of ecosystems to cycle and sequester carbon and other greenhouse gases.

- **Account for climate influence on project success.** Managers consider how climate impacts may compromise project success, and avoid investing in efforts likely to be undermined by climate-related changes, unless part of an intentional strategy.

- **Safeguard people and wildlife.** Strategies and actions enhance the capacity of ecosystems to protect human communities from climate change impacts in ways that also sustain and benefit fish, wildlife, and plants.

- **Avoid maladaptation.** Actions to address climate impacts on human communities or natural systems do not exacerbate other climate-related vulnerabilities or undermine conservation goals and broader ecosystem sustainability.

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IV. Planning and Designing Climate-Smart Coastal Restoration Projects

Traditionally, there has been little or no consideration of climate change in the development and execution of conservation and restoration projects. To the degree that such considerations have begun to be incorporated into restoration efforts, often it is in the context of modifying what we do in order to continuing achieving our existing goals. As noted above, however, climate-smart conservation increasingly will require that practitioners not only manage for inevitable change, but also that they reconsider their underlying conservation goals, not just modify conservation strategies and restoration approaches. Figure 1 illustrates the progression in planning that can achieve a more climate-informed alignment of goals and strategies. Stage 1 in this continuum reflects an absence of climate considerations in planning efforts, termed "business as usual." As practitioners have begun to more specifically bring climate change into their thinking, there has been an effort to identify strategies and approaches for continuing to achieve existing goals despite projected changes. This approach can be thought of as a "climate retrofit" of existing work. As more experience is gained, and climate consideration further permeate planning efforts, restoration and conservation efforts ideally should strive to become "climate-aligned," wherein climate change is considered in both determining goals as well as the strategies designed to achieve those goals.

Traditional activities under the GLRI or other restoration programs primarily fall under "Stage One" of climate change integration (Figure 1), or business as usual. This guidance document focuses largely on assisting NOAA and it restoration partners in minimizing the adverse impacts of climate change on particular restoration projects with already defined goals, of "Stage Two" of this continuum. Ultimately, however, reconsidering restoration goals and regional priorities from a climate perspective, and modifying these as appropriate, will be important to ensure the lasting value of these investments. For example, NOAA's report, *Adapting to Climate Change: A Planning Guide for State Coastal Managers,* provides coastal managers with a useful landscape-based approach to help them incorporate climate change in state and local planning.[35]

The process of developing climate-smart coastal restoration projects is not fundamentally different from the process used for restoration projects in general. In addition, there is no single 'right way' for climate-smart restoration. The procedures may vary depending upon the stage of integrating climate into conservation programs, as well as personal preference.

Figure 1. Stages of Climate Change Integration into Goals and Strategies.[36]

Herein we present an eight-step process (Figure 2) that we consider applicable for integrating climate considerations in restoration projects in the Great Lakes, based on the lessons learned from the seven case studies.

Step 1: Identify Restoration Goals, Targets, and Approaches

The development of any restoration project requires, first and foremost, the identification of restoration goals and targets. At a regional level, many restoration efforts currently underway are implemented, funded, or otherwise supported by existing programs, such as the GLRI, which have been developed largely to deal with familiar stressors such as pollution, habitat fragmentation and destruction, invasive species, etc. These problems remain relevant regardless of climate change; it is the combined effects of climate change and existing problems that must be anticipated and addressed in conservation and restoration.[37]

Step1. Identify Restoration Goals, Targets and Approaches

Step 2. Sketch Climate Smart Process

Step 3. Assess Climate Change Vulnerability

Step 4. Review and Revise Goals, Targets, Approaches

Step 5. Identify and Select Climate-Smart Restoration Options

Step 6. Develop Monitoring Approach

Step 7. Implement Restoration Options

Step 8. Review, Revise, Reassess, Re-create

Figure 2. Framework for Developing Climate-Smart Restoration Projects.

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As you look at your targets and goals through a climate change lens, however, some priorities may change. For example, warmer temperatures may enable a potentially problematic invasive species to expand into new areas. Project managers may decide to proactively devote additional resources toward halting the spread of this invasive species before it arrives in the region, something they may not have chosen as a restoration priority without this knowledge. Assessing the vulnerability of your targets and goals to climate change, as described below, will help inform these decisions.

In the Great Lakes region, much of NOAA's restoration work is focused on community-based efforts to address fish and wildlife habitat-related BUIs (e.g., degradation of fish and wildlife population, loss of fish and wildlife habitat, and degradation of benthos) in U.S. Great Lakes AOCs.[38] Under the GLRI, the overarching goal for Habitat and Wildlife Protection and Restoration is the protection and restoration of ecosystems: the Great Lakes, the coastline, wetlands, rivers, connecting channels, and watersheds.[39] The following are identified as Principal Actions to Achieve Progress in this area:

- **Improve aquatic ecosystem resilience.** Protect and restore aquatic habitats for fish and wildlife populations by reconnecting habitats through corridors to enhance biological diversity, reducing sediment and nutrient inputs, restoring natural hydrological processes, improving water quality, restoring ecosystem services, and increasing populations of native fish and wildlife through coordinated management actions.

- **Maintain, improve, or enhance the populations of native species**. Implement restoration actions identified in species recovery and management plans; quantify habitat needs for depleted migratory bird species; propagate lake trout, coaster brook trout, lake sturgeon, and other similar fingerlings for suppressed fish populations; assess fish populations; and protect and restore culturally significant species.

- **Enhance wetlands, wetland-associated uplands, high priority coastal, upland, and inland habitats.** Protect, restore, or enhance habitats by acquiring properties that are important to sustain fish and wildlife populations, restoring natural hydrological regimes, improving water quality, and restoring the chemical, physical, and biological integrity of ecosystems in each Great Lakes basin.

- **Identify, inventory, and track progress on Great Lakes habitats, including coastal wetlands restoration.** Assess progress toward restoring Great Lakes habitats by establishing baseline conditions and tracking trends; highlight the importance of coastal wetland conservation and restoration by implementing a long-term coastal wetland monitoring program and enhancing the National Wetlands Inventory.

- **Restore habitat functioning in areas of concern.** Improve habitats in degraded urban environments and AOCs where BUIs affect ecosystem functioning by restoring habitats for native species populations and removing or isolating contaminants.

The general toolbox of restoration approaches is likely to remain largely unchanged for climate-smart projects, although the risks associated with climate change may require changes in some of the assumptions that go into project design as well as the types of approaches to use. Again, climate change vulnerability assessments will help in determining whether and how certain restoration or management practices might be appropriate to ameliorate the impacts while promoting coastal restoration goals.[40]

Climate-smart restoration underscores the importance of restoring ecological function and resilience – concepts that already are fundamental to the GLRI and other restoration initiatives.[41] As mentioned previously, resilience is generally defined as the ability of a system to recover from a change or disturbance without significant loss of function. In the climate change adaptation literature, the discussion of how to promote resilience typically emphasizes four key strategies:[42]

- Prioritizing connectivity of habitat
- Reducing existing stressors
- Protecting key ecosystem features
- Maintaining biological diversity*

Arguably, these strategies are important for ecological restoration regardless of climate change. The key question is how effective these approaches are likely to be given the multitude of impacts affecting the systems being addressed, including climate change. For example, while it is widely recognized that reducing habitat fragmentation and increasing habitat

* Often, these strategies are articulated as conservation goals, but in this guidance we view them as the “how” question to help achieve the “why” of our conservation efforts, which are ultimately our conservation goals (e.g., recovering native species). Similarly, conservation targets are the “what” you are specifically focusing on (e.g., a particular species, habitat, etc.).

connectivity are important conservation tools, climate change requires managers to look at a range of factors that could determine whether or not these measures will truly be effective in achieving the desired conservation outcome: are we connecting the most beneficial habitats given projections for species range shifts or the movements of individual organisms? Are our target species even likely to shift their range under climate change in the first place?[43]

Similarly, climate change may require us to re-prioritize which existing stressors we address or to address them in different ways. This is not to say that we should ignore existing stressors. In some cases, focusing on those stressors may well be our best restoration or conservation option in the near-term. For species that are already highly endangered, for example, failure to reduce or eliminate immediate threats such as habitat destruction may lead to extinction before climate change becomes a significant factor. In addition, dealing with non-climate stressors may be our only option in cases where our ability to ameliorate some of the more direct impacts of climate change, such as higher air and water temperatures, may be exceedingly difficult, if not impossible. Increasingly, however, we will likely be faced with the need to modify our priorities and actions: current allowable contaminant levels may need to be tightened for contaminants that interact with climate change; fish passage structures may become more or less important under altered streamflow regimes; critical habitat designations may need to include future as well as current population centers; and invasive species control may be more important where habitats are perturbed by extreme events.

Step 2. Sketch Climate-Smart Process

Whether working on an engineering/design plan or already implementing a project, the climate-smart process may vary, even when they are retrofit projects with already established objectives. An engineering/design project allows more consideration of adjusting strategies than projects where that phase is already completed and implementation has begun on the ground.

As part of an initial meeting with project partners, you should design climate-smart processes and actions based upon the timeline of the project itself. These process steps can be as simple as outlining: 1) who is responsible for each action of the project and for overseeing the project; 2) what are the anticipated resources (e.g., financial, staff, and technical) needed for each action and are they secured; and 3) the timeline for each action. An implementation plan could also include information on communication strategies with stakeholders and/or the public, if necessary.

All GLRI projects must have a QAPP,* which is essentially a blueprint or roadmap for the project. Because the

* A Quality Assurance Project Plan (QAPP) documents the planning, implementation, and assessment procedures for a particular project, as well as any specific quality assurance and quality control activities.

QAPP outlines the project steps, data needs, decision criteria, and more, it provides an excellent framework for thinking through, on a detailed level, where and how climate considerations should come into the process. Some mandatory QAPP components and possible climate considerations include:

1. Site background: include historical climate trends and any observed ecological shifts here.

2. Problem definition: include relevant climate considerations as part of criteria for choosing between alternative actions, and as part of the informational inputs needed.

3. Project description and schedule: include the vulnerability assessment as one of the project tasks.

4. Quality objectives and criteria: include the addition of climate change as part of completeness evaluation

5. Data acquisition requirements for non-direct measurements: include climate-related data sources and acceptance criteria

Climate Change Vulnerability Assessment Process in a Restoration Context. Designing climate change vulnerability assessments requires attention to several other key considerations, including selection of the appropriate geographic and temporal scales, the features to be assessed (e.g., species or ecosystems), and level of detail and complexity.[44] In a restoration context, time and resources may be limited. Therefore it will be necessary to outline the process for climate change vulnerability assessments during this step in ways such as: number of assessments being carried out, species or ecosystems examined, resources needed for each assessment, and information required. It may also be necessary to prioritize climate change vulnerability assessments based upon the timeline of implementation.

Step 3. Assess Climate Change Vulnerability

Developing climate-smart restoration projects requires managers to go through an explicit process for bringing climate data and ecological understanding to bear on their planning.[45] A key tool for doing this is climate change vulnerability assessment. In this context, *climate change vulnerability* refers to the extent to which a species, habitat, or ecosystem that is the target of restoration efforts is susceptible to harm from climate change impacts. It also refers to the extent to which climate change impacts might influence the ultimate effectiveness of particular restoration projects in meeting one's conservation objectives. Vulnerability assessment is not an end in itself – it is one step in the broader process of developing climate-smart strategies and projects.

Vulnerability assessment is not an end in itself – it is one step in the broader process of developing climate-smart strategies and projects.

Common climate change factors to which conservation projects may be vulnerable include:

- Warmer air temperatures
- Flooding/drought
- Erosion and runoff
- Water level changes
- Stream temperatures
- Extreme events

Like other vulnerability or risk assessments, climate change vulnerability assessments can vary considerably in terms of scope and complexity – from general, qualitative assessments based on expert knowledge, to formalized expert elicitation processes, to highly detailed, quantitative analysis using ecological models. There is no single right approach, and greater levels of complexity do not necessarily mean greater accuracy or utility. Rather, the design and execution of an assessment must be based on a firm understanding of the user needs, the decision processes, and the availability of resources such as time, money, data, and expertise.

Three central components[46] in a vulnerability assessment include:

- Sensitivity: degree to which a species, habitat, or ecosystem is or is likely to be affected by climate change;

- Exposure: character, magnitude, and rate of change in climate variables to which a species, habitat, or ecosystem is exposed;

- Adaptive capacity: ability of a species, habitat, or ecosystem to accommodate/ cope with climate change impacts with minimal disruption.[47]

Appendix A provides a detailed overview of climate change vulnerability assessment, including some examples of relevant information for Great Lakes species and habitats. The following is a brief summary of the key steps and questions that restoration project planners must address to determine whether, how, and to what extent your restoration projects and goals might be vulnerable to climate change and related impacts.

Scope and objectives

- What are your current restoration goals?

- What are your restoration targets?

- What is the current status of your restoration target (e.g., what factors are contributing to BUIs)?

- What restoration approaches are you planning/implementing to improve the status of your target?

- What is the expected lifetime of your project?

Components of vulnerability

- How and to what degree is your restoration target sensitive to climate conditions/variables?

- How and to what degree is your restoration approach sensitive to climate conditions/variables?

- How are climate conditions projected to change in the area, and is there evidence of climate change already being observed in your planning area?

- What is your system's adaptive capacity relative to climate change?

Vulnerability summary

- What is the relative vulnerability of your restoration project (including your targets, goals, and approaches) and what are the primary reasons?

Step 4. Review and Revise Goals, Targets, Approaches

Climate change vulnerability assessments provide information for revising original goals and strategies. Although the goals of restoration projects in this guide were already set, the vulnerability assessment could reveal possible serious problems with the goals necessitating reconsideration. Alternatively, climate-aligned project goals can more readily be adjusted on the basis of vulnerability assessments. Although reconsidering goals and objectives can be intimidating, breaking one's goals into discrete components can help identify where changes may be necessary and appropriate. Specifically, distinguishing among the following four components of a goal can be helpful in determining whether modifications may be needed:

- **What** (the conservation *target* or subject of the goal);
- **Why** (the intended *outcomes* or desired condition);
- **Where** (the relevant *geographic scope*); and
- **When** (the relevant *timeframe*).

Importantly, crafting climate-informed goals and objectives may not require wholesale revisions to one's goals. Rather, climate-focused modifications may only be necessary to one or more of these specific components.

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Step 5. Identify and Select Climate-Smart Restoration Options

There are numerous examples of management strategies that can help address climate change in coastal restoration. It is important to recognize that, to date, much of the literature on adaptation options for species and ecosystem management focus on general principles rather than specific, actionable measures.[48] Often, these include: reduce other non-climate stressors; manage for ecological function and protection of


Don Breneman

biological diversity; establish habitat buffer zones and wildlife corridors; implement proactive management and restoration strategies; and increase monitoring and facilitate management under uncertainty.[49] While these measures are intuitively correct, applying them in practice, especially for specific, on-the-ground restoration, requires consideration of some of the unique features and systems that influence your particular project site.[50]

Once you have a sense of how climate change and related impacts are likely to affect your particular restoration targets and objectives and what the primary sources of vulnerability are, the next step is to develop a possible strategy or set of strategies to achieve your overarching conservation goals in the face of climate change. At this stage, be creative rather than selective. Information on the various components of vulnerability should guide the identification of possible conservation/restoration decisions to reduce that vulnerability. This might include efforts to reduce sensitivity, reduce exposure, and/or increase the adaptive capacity of your restoration target. For example:

- A strategy to reduce the sensitivity of a riverine wetland being restored might be to plant a diversity of species that can tolerate a range of flow conditions and disturbances (i.e., flooding and drought).

- A strategy to reduce the exposure of a target cold-water fish species facing increases in stream temperatures might be to identify and protect areas of potential cold-water refugia or enhance riparian vegetation.

- A measure to improve the adaptive capacity of a coastal marsh to withstand greater extremes in lake levels might be to remove existing barriers that limit the ability of the marsh to migrate. Another strategy could be to design coastal marsh water management structures to facilitate optimal marsh conditions under a range of hydrologic extremes.

Potential climate change adaptation options (Table 1) were identified for many different vulnerabilities in the seven case studies. These are only a sampling of adaptation options that may be suitable in the restoration projects in the Great Lakes. Many others can be developed based on specific project vulnerabilities, goals and strategies.

Table 1. Potential Climate Change Adaptation Options.

Restoration Project	Relevant Vulnerabilities to Climate Change	Potential Adaptation Options
1. Fish Passage Restoration	*Medium/High.* Some changes in flow regimes are already occurring, and more extremes in the future may make it more difficult for fish to navigate the river barrier (e.g., low flows may make navigation around/over barrier difficult/impossible in summer; high flows may prevent passage of species that are not able to expend the necessary energy).	Design fish passage based on projected low/high flow levels as well as shifts in timing of flows to at least mid-century, based on expected lifespan of infrastructure. Consider benefits to multiple species.
2. Drowned River-Mouth Wetland Habitat Restoration	*Medium.* Heavy rainfall events may contribute to upstream erosion and additional sediment loading in the lake if runoff is by-passed around the diked wetland area. Perturbations can alter the natural succession of plants in wetlands, which influences the species, diversity, and number of fish and wildlife a wetland can support. Ultimately, conditions may become favorable for some species and detrimental to others (e.g., shallow wetlands with greater coverage by emergent vegetation may benefit some water birds such as yellow rails but would be less favorable for waterfowl). In terms of the restoration approach, water flow management is sensitive to changes in lake level and streamflow; lower water levels encourage the spread of invasive plant species.	Design restoration infrastructure that has potential to accommodate high variability in lake levels and streamflows over the short term and lower average lake levels over the longer term. Increase awareness of possible spread of new invasive species. Timing of dewatering and reflooding of managed wetlands should consider the diverse needs of target species under a changing climate (e.g., facilitate flooding of key waterfowl areas during drought or low lake level events). Plans also should consider costs of maintaining/ adapting water control infrastructure under changing conditions.
3. Coaster Brook Trout Habitat Restoration	*High.* Higher lake temperatures could reduce favorable spawning habitat and juvenile incubation; longer periods of lake stratification in summer may limit availability of nutrients and phytoplankton; near-shore water quality could decline. Altered streamflow regimes and higher stream temperatures will reduce quality of stream habitat.	Increase areas of riparian vegetation over open water and connecting stream channels to moderate temperatures. Add woody debris or other shade-providing in-stream materials. Create adjacent cool, deep pools to provide refugia.
4. Whitefish Habitat Restoration	*High.* Reduced ice cover could mean greater mortality of whitefish eggs, which rely on the formation of ice over shallow waters for protection from wind and waves. Increased variability associated with climate change could make spawning/nursery conditions unfavorable for this species in some areas. Measures to ameliorate loss of ice cover are likely to be limited.	Construct spawning areas with as little surface area as possible so that ice will remain and thicken. Reduce water temperatures by shading waterways. Redouble efforts to reduce phosphorus loading. Consider possible upstream/upland actions that enhance habitats to filter nutrients. Restoration efforts may require looking for alternative spawning sites in areas that might provide refugia and protection during low ice cover years.

Table 1. Potential Climate Change Adaptation Options (continued).

5. Invasive Species Management (Sea lamprey control)	*Low/Medium.* A continued increase in lake temperatures and longer periods of stratification may exacerbate sea lamprey predation.	Increase sea lamprey control efforts in areas of high lake temperatures. Initiate early detection/rapid response measures.
6. Water Quality Restoration	*Medium/High.* In all lakes, the duration of summer stratification is projected to increase, adding to the risk of oxygen depletion and dead zones. These changes could alter the dominant species found in a lake and potentially contribute to the extirpation of some fish species such as lake trout.	Redouble efforts to reduce nutrient loads, with consideration of changes in precipitation/flow regimes. Identify and protect possible areas of refugia from thermal stratification.
7. Oil spill Damage Assessment, Remediation, Restoration	*Low.* The increased potential for flooding during spill events is a concern, as it could pass oiled sediment and materials downstream or into neighborhoods. Cleaning up the initial spill is the priority regardless of climate change but should consider existing trends/conditions.	Design oil barriers and absorbent booms to accommodate more extreme flood events given recent trends.
8. Amphibian Habitat Restoration	*Medium.* Changes in the timing of runoff may reduce availability of water inputs to floodplain pools at key times for amphibian breeding; higher temperatures and increased drought conditions in summer may adversely affect these temperature-sensitive species. Success of habitat restoration efforts is sensitive to climate change, although there is relatively high adaptive capacity for accommodating climate impacts via project design.	Location/design of pool connections to the mainstream will need to consider altered flow regimes; depth of constructed pools may need to be altered to provide additional refugia; consider enhancing forest cover for summer habitat to help modify temperatures.
9. Wild Rice Habitat Restoration	*Medium.* Access for human harvest may be limited during extreme low water events. Greater fluctuations in lake levels in the near term and decreases in average levels over the longer term could make current habitat areas unfavorable. Deep or flooding waters in early spring could delay germination of seed, leading to crop failures. Lower water levels late in summer could lead to more competition with other shallow water species. Long-term reductions in average lake levels may contribute to loss in wild rice habitat overall.	Management of wild rice habitat may require great consideration of extreme events, including protecting areas against excessive flooding and aggressively controlling invasive species in low level periods. Long term efforts may include planting species in new areas.

Dealing with Uncertainty in Developing Climate-Smart Restoration Projects – A Role for Scenario-Based Planning

As highlighted in Overarching Principles, resource managers often must make conservation decisions under uncertainty, particularly where information about future conditions must be considered. This is true not just for climate change, but for factors such as land use, population trends, and invasive species as well. Some management responses will be effective in meeting conservation goals under a range of potential climate futures, while others may need to be tailored to more specific conditions.[51] When future conditions are fairly certain, it makes sense to ask: Which actions will produce the single best outcome? When there is significant uncertainty about future conditions, answering that question becomes increasingly difficult because the answer depends on which future comes to pass. In such situations it may make more sense to ask: Which actions give me the best chance of an acceptable outcome? This approach is called robust decision making; it is essentially a bet-hedging strategy. Rather than maximizing the chance of the single best outcome, it seeks to maximize the likelihood of an acceptable outcome. One tool that can help you navigate through such decisions is scenario-based management planning.

Scenario-based management planning is based on explicitly identifying a suite of plausible futures and exploring management options across that suite of futures. Just as the use of a range of scenarios (including not just climate change but ecological and societal responses to it) can help address inherent uncertainty in assessing vulnerability, they also can provide a useful framework for informing possible climate-smart restoration options, particularly in cases where the levels of uncertainty about potential future conditions are especially high and uncontrollable.[52] The goal here is to consider a broad range of possible responses to the array of future scenarios, and what management or restoration mechanisms you can put into place that will allow you the maximum likelihood of success and flexibility given the array of possible futures. Scenarios, at their simplest, are descriptions of some plausible future. They are not predictions or forecasts, are not necessarily limited to the climatic changes themselves, and scenario planners make no assumptions about which scenario is most likely (if you knew which was most likely, you would not need scenario planning).

Scenario planning exercises typically use around three to five scenarios. Ideally, they will: 1) bracket the range of plausible futures, and 2) highlight those elements of uncertainty most important to management and planning outcomes. “Bracketing the range of plausible futures” does not mean simply choosing several values along a single continuum; ideally the scenarios will represent divergent possibilities along two or more axes. Having developed the scenarios, managers and planners then brainstorm possible management options and look at the performance of those options across all scenarios. Are there management approaches that are effective in all scenarios? Are there management options that are highly effective in one but disastrous in others? As you go through this exercise, you can highlight areas where uncertainty about climate change or the system's response to it is more or less important. Box 1 provides a simplified example of how scenario-based planning might inform restoration in the face of changing Great Lakes water levels.

Having identified possible management options for your project, it is time to choose which ones to implement. Your choice may depend on a range of factors, depending on your particular needs, interests, and resources. One or more of the following criteria will likely be important:[61]

Box 1. Coastal Restoration under Uncertainty: The Case of Great Lakes Water Levels

Addressing possible changes in Great Lakes water levels will no doubt be one of the major factors under consideration when planning climate-smart restoration, as the implications for greater extremes in water level fluctuations as well as possible changes in long term averages are significant for both project design and ultimate conservation objectives. While there is moderate confidence among scientists that Great Lake water levels may decline, on average, toward the latter half of this century, it is not so clear cut in the shorter-term.[53] Under a handful of plausible scenarios, water levels in some lakes may even increase.[54,55] Certainly, this makes restoration planning for the next few decades somewhat tricky.

Despite uncertainty in determining an overall trend, however, lake levels themselves will continue to fluctuate seasonally and annually, as they have historically. Great Lakes water levels are influenced by several natural and anthropogenic factors, including climatic variability. Lake levels tend to decline during periods of high air temperatures and low ice cover and rise during periods with cooler, wetter conditions.[56] It is also important to recognize that the water levels of Lake Superior and Lake Ontario are formally regulated, though levels are still significantly driven by climatic drivers.

To a certain extent, both coastal habitats and human communities are adapted to seasonal and inter-annual fluctuations in lake levels, within a certain range, duration, and rate of change.[57] Understanding how different wetland types respond to these fluctuations can help inform proactive restoration responses under a range of potential future conditions.[58] For example, coastal marshes adapt more readily to lower levels than swamps because their vegetation can establish itself more quickly.[59] If climate change contributes to a decline in the mean annual water level, as some models suggest, restoration efforts may need to include more hands-on measures to facilitate swamp regeneration. On the other hand, wetlands in gradually sloped, open shores may have more room to migrate upland during higher levels – or shoreward during lower levels – than those in enclosed bays and in areas with natural or human barriers.[60] Given either of these potential scenarios, a robust restoration approach might be to remove and/or prevent coastal armoring or other infrastructure to enable habitats to shift in response to fluctuating water levels and then monitor the situation to determine when/where swamp regeneration efforts might be warranted in the future.

- **Importance.** What is at stake if you do not do anything? Are there unique or critical resources whose vulnerability should be reduced?

- **Urgency.** What are the costs of delaying action, both in terms of what you might lose and in terms of what it would cost to implement later rather than now?

- **No regrets* and co-benefits.** Do the benefits (including non-climate-related benefits) exceed the cost of implementation? Will there be significant beneficial outcomes even if the adaptation benefits do not pan out as expected?

- **Economic efficiency.** What are the expected benefits of this project relative to using the same resources elsewhere? Are there possibilities to pool resources by engaging other stakeholders?

- **Cost.** How costly will the strategy be in terms of time, money, or other resources?

- **Unintentional effects on climate change.** Will the suggested action increase the emission of greenhouse gases, or lead to undesirable changes in the local or regional climate?

- **Performance under uncertainty.** What is the project's likely performance across the range of plausible changes in climate for your region?

- **Equity.** Does the project benefit some people, places, or interests at the expense of others? Will this project have strong negative effects on any people, places, or interest?

- **Institutional feasibility.** Is the proposed project possible given existing institutions, laws, and regulations? To what degree is the public likely to accept the project?

- **Technical feasibility.** Is the project technically possible to implement? Do we have or can we access the necessary tools and other resources? Will the weather/climate conditions allow for project implementation?

- **Feasible alternatives.** Does the project have feasible alternatives in the cases where approaches cannot or will not be implemented? Is there a range of potential options?

- **Consistency.** Is the proposed project consistent with existing national, state, community, or private values, goals, and policies?

Step 6. Develop Monitoring Approach

Because climatic changes, their impacts, and the effectiveness of various management options are uncertain, monitoring will be especially important. Create a monitoring approach that will support medium- and long-term evaluation of how well the project performed, and test hypotheses and assumptions behind project design to increase understanding of how the species, habitats, and restoration measures in question perform in a changing climate.

* "No regrets" actions can be defined as actions that meet existing priority conservation needs but also address climate change; this term is also used to refer to actions that are robust across multiple climate change scenarios.

U.S. Environmental Protection Agency

Monitoring may require significant commitment and resources, but it is likely to reduce costs stemming from climate change-related surprises. Monitoring allows for testing project assumptions and evaluating effectiveness of project actions(e.g., about how the system in question will respond to climate change, what climate changes may happen, and the effects of particular management actions). In turn, monitoring results allow project managers to refine project goals or actions as needed – a fundamental step in adaptive management (Box 2).[62]

While monitoring is not a new concept for restoration projects, climate-smart monitoring does entail some new ways of thinking about some of the key elements of your monitoring approach. The Estuary Restoration Act, for example, identifies five key elements critical to monitoring restoration projects:[63]

1. Monitoring parameters must be directly linked to the goals established for the project and/or the restoration of the watershed as a whole.

2. Methods for evaluating results must be established (for example, statistical tests of hypotheses, trend analysis, or other quantitative or qualitative approaches) that directly relate to the goals for the project and/or watershed.

3. To establish initial conditions for each measure included in the monitoring plan, pre-construction or pre-design (baseline) monitoring must occur.

4. Project sites should be compared to a reference site or historical data representing a reference condition in order to evaluate progress toward reaching goals.

5. Monitoring must be conducted in a timely fashion with a frequency and length of time appropriate to each parameter in the context of project goals and the status of the project.

In thinking about each of these five elements for developing a monitoring plan, there are several key places where it will be imperative to integrate climate change considerations and variables. For example, when establishing initial baseline conditions, it will be important to consider the fact that historical conditions and trends may no longer be sufficient. Similarly, the choice of reference sites and conditions against which to measure progress will need to factor in the potential impacts climate change will have on that site over time. Finally, it will be increasingly important for restoration project managers to monitor conditions over the long term, which will require a commitment of time, effort, and resources.

Step 7. Implement Restoration Options

Implementation steps for a climate-smart project are almost identical to any restoration project. At this point these options are well-informed by local

Box 2. When Climate & Weather Work Against Restoration Implementation

In some cases, climate and weather variability may work against your timeline for implementation. For example, heavy flooding may de-stabilize stream bank construction or prevent tree seedlings from being planted. Climate-smart restoration must therefore account for this variability by having a back-up plan for implementation such as an extended timeline or a bank of resources, but also project funders must recognize that delays are a part of the process and support extending timelines for completion. Though these delays may hinder short-term success, they will ultimately enhance long-term project success, thus reducing future costs.

expertise, project partner brainstorming, climate change vulnerability assessment, and climate change science.

Step 8. Review, Revise, Reassess, Re-create

Most restoration projects are funded for relatively short periods of time, making longer-term reviewing and revising difficult within the context of a single project. If the thought process, hypotheses, and assumptions underlying restoration design have been explicit, however, and if the monitoring plan is designed to test assumptions and hypotheses as well as measure performance, then it becomes easier for individuals or organizations to do longer-term assessment and learning (Box 3). One strength of the GLRI is that it provides an umbrella under which the collective knowledge from years of restoration can be gathered and reviewed. One key realization from the Buffalo River RiverBend Restoration project, for example, was that creating a way for people to access data from all regional restoration projects would increase the value of data collected from each project. Site-scale monitoring could facilitate identification of regional trends in climate or responses to climatic change, as well as providing a source of ideas for climate-smart practice and information on the relative effectiveness of various approaches over time.

Box 3. Adaptive Management and Climate-Smart Restoration – New Impetus for a Familiar Concept

Adaptive management is defined as a systematic approach for improving resource management by learning from management outcomes.[64] It is useful not only when the future is uncertain, but when there is uncertainty about which management approach is best or how the system being managed functions even under today's conditions. Although it provides a mechanism for natural resource managers and other decision makers to develop restoration or conservation projects with incomplete information, simply picking up one management approach and adjusting it as needed is not, in the narrow sense, adaptive management. True adaptive management involves exploring alternative ways to meet management objectives, predicting the outcomes of alternatives based on the current state of knowledge, implementing one or more of these alternatives, monitoring to learn about the impacts of management actions, and then using the results to update knowledge and adjust management actions.[65] Adaptive management may be particularly useful in cases where immediate action is required to address short-term and/or potentially catastrophic long-term consequences, such as the collapse of important ecosystem services, or where management actions are likely to have no regrets near-term benefits.[66,67]

V. Case Studies

Given the recent and continuing development of climate-smart conservation methods, there have been few case studies of actual climate-smart conservation. A key component of this guidance is that seven restoration projects vulnerable to climate change (Figure 3) are included. These illustrative case studies are summarized (Table 2) as well as described in detail (Appendix D).

Figure 3. Great Lakes Climate-Smart Restoration Partnership Projects.

Table 2. Projects, Expected Outcomes, Main Climate Considerations, & Some Climate-smart Restoration Recommendations.

Project	Expected Outcomes	Main Climate Considerations	Some Climate-smart Restoration Recommendations
1: Little Rapids Habitat Restoration[68]	Restore 70 acres of rapids habitat and associated ecosystem processes. Represents 50% of the delisting target for the fish and wildlife related Beneficial Use Impairments in the Michigan waters of the St. Mary's River Area of Concern and directly addresses both the AOC and Habitat focus areas of the GLRI Action Plan. Reduce climate change vulnerability of fish habitat by integrating precipitation projections into flow models.	Changes in water flows due to causeway removal may change ice cover. Increasing water temperatures.	Increase and maintain shady riparian vegetation near the rapids. Expand the habitats restoration area to provide greater resiliency to climate change amongst all stressors, including pollution, land use change, and invasive species.
2: Muskegon Lake AOC Habitat Restoration[69]	Remaining restoration needed to remove the Beneficial Use Impairment (BUI) Targets, including for fish and wildlife habitat. Potential climate change impacts have been considered as part of both near-term monitoring and the main restoration design plan to increase likelihood of meeting wildlife habitat and water quality restoration objectives for the area. Focus has been on mill debris removal in Muskegon Lake and hydrological reconnection of wetlands to Bear Creek.	Lower water levels may expose debris sites in Muskegon Lake to increased wave action, ice scour. Wetland reconnection (and higher flow events) may lead to increased phosphorus and nitrogen transport to creek, then to Bear Lake, exacerbating eutrophication problems.	Determine extent and urgency of debris removal (in improving habitat quality), and approaches to revegetation. Consider more limited connection of wetlands to Bear Creek, treatment to reduce phosphorus release and transport, or full wetland restoration with water control structures.
3: Crow Island State Game Area Marsh Enhancement Program[70]	This project when implemented will significantly enhance management capability and therefore productivity to 1,250 acres of Saginaw River emergent wetlands. This project is located within the Saginaw River/ Bay Area of Concern and when implemented is expected to make significant progress toward the delisting of three BUIs.	Shifting of wind patterns such that Seiche events were less common would mean decreased water supply.	For the units east of the river, potential accommodation of drier periods (and lower water levels) led to consideration and incorporation of altered designs (e.g., pump depth for the pump drawing river water, and in culvert placement elevation between the two major units). Though not formally part of project, options to provide more secure water supply to west units were also identified.
4: Clinton River Spillway Habitat Restoration[71]	The restoration design will address three BUIs: the Loss of Fish and Wildlife Habitat, Degraded Fish and Wildlife Populations and Degradation of Benthos BUIs. Climate change projections will help to assess the vulnerability of wildlife to changes in water flow and temperature and project partners will apply tools to facilitate identification of vegetation in a changing system.	Higher water temperatures due to heat waves and low flow events threaten target fish species. Increased runoff upstream could contribute pollution.	<u>In-Stream:</u> Incorporate recent trends and projections for precipitation and streamflow when designing structures such as rock veins and riffles. Identify ways to create in-stream refugia from high temperatures, such as deep pools and off-channel habitats.

Table 2. Projects, Expected Outcomes, Main Climate Considerations, & Some Climate-smart Restoration Recommendations (continued).

5: Lower Black River Habitat Restoration (Phase III)[72]	In the short-term, 2,800 feet of fish shelves, 1,570 feet of streambank stabilization, 1.8 acres of aquatic habitat, 2.3 acres of riparian habitat, 45,000 cy of slag removed. In the longer-term, 30% increase in abundance of top carnivore fish species, 10% increase in fish species richness. Overall benefits, improvements in recreational fishing and aquatic habitat, advance the delisting of 3 habitat related BUIs, and to advance the delisting of the Black River AOC. Assessing climate change vulnerability of tree planting species, as well looking at flooding events to determine streambank stability with climate change.	Warmer air temperatures affect the current tree list for planting: 80 not suitable for current and future climate, 34 suitable in current and future climate.	Install fish shelves at different levels below water surface. Prioritize revegetation of bank to accelerate natural bank development to deal with variable water flow rates.
6: Buffalo River AOC Habitat-Riverbend Restoration (Phase II)[73]	Design and engineering specifications will be developed for 1,520 linear feet of shoreline and 3.5 upland acres within a 100-foot buffer. These designs, when implemented, will bring the Buffalo River AOC 10% closer to delisting. Climate change information will help toward plant selection, looking at changes in water levels and effects on erosion and will inform the monitoring component of the project.	Changing temp and precipitation affect the suitability of tree and shrub species. Long-term changes in river level from changes in precipitation and evapotranspiration. Buffalo is heavily affected by lake-effect snow.	Document climate-related assumptions and thought process behind project design to facilitate any needed changes later. Select climate-smart riparian plant species, selecting from list provided.
7: Habitat Restoration in the Maumee AOC[74]	Natural vegetative cover will be well established within two years of the restoration work. 127 acres will be reconnected to Lake Erie, thus expanding fish habitat, particularly for spawning and nursery areas. Expected project outcomes include improvement in IBI/MIwb scores for fish community species, increased populations of bird/animal species, and contribution to the delisting of three BUIs within the Maumee River AOC. To integrate climate change, vulnerability assessments are being run to help pick tree species and also to identify restoration options to deal with heavy rain events.	Springtime flooding and summertime drought Winds and Seiche events Warmer air temperatures	Install climate-smart fish passage to deal with variable water levels. Reforest with climate-smart tree species, selecting from list provided.

VI. Lessons Learned

Integrating climate considerations into seven coastal restoration projects in the Great Lakes was instructive in that the experience brought to light important lessons learned. Many were specific to each of the seven projects and their respective characteristics (Appendix D). However, there were general lessons learned across the projects that can help inform inclusion of climate change considerations in restoration projects regardless of the particular setting.

1. Project partners understood that climate change could affect their restoration efforts. Although relatively uninformed about climate change and its affects, project partners generally thought it should be considered.

2. How to integrate climate change considerations were not "intuitive" to project partners. While there was general understanding that the Great Lakes region is warming and precipitation patterns and lake levels are changing, it was unclear to project partners where and how these and other projected climate changes might be relevant to their specific project(s).

3. Inherent uncertainty in projections of climate change and its affects was a stumbling block for project partners. Although there are always unknowns in projects, the uncertainty of climate change initially left many project partners with the feeling that it was simply too uncertain to consider. The concept of developing robust projects in an uncertain climate future was not initially understood.

4. Project partners did not have the knowledge, skills and training to consider climate change. Vulnerability assessments and identifying ways to integrating climate consideration into projects was conducted primarily by the National Wildlife Federation, not the partners receiving the restoration grants. Incorporation of climate change into future restoration projects may continue to require outside expertise. In addition, training restoration partners in climate-smart conservation would facilitate its consideration in restoration projects.

5. Funding is a limiting factor for incorporating climate change considerations into restoration projects. Climate change considerations were not a part of the original proposals for restoration. It was incorporated into the seven projects only because it was a condition of the grant reward, separate funding was provided, and climate expertise was made available.

6. The short-term nature (several years) of the restoration projects preclude or inhibit long-term monitoring. Ideally restoration funders should support periodic monitoring of sites over the medium and long term; otherwise it will be difficult to know if the climate smart elements are working.

Eyecrave, LLC.

VII. Looking Ahead: Green Infrastructure for Community Resilience in the Great Lakes

Coastal areas are among some of the nation's most productive habitats for fish and wildlife and have long been a magnet for economic activity and desirable places for people to live. In fact, over 50 percent of the U.S. population lives in coastal counties, which account for only 17 percent of the country's geographical area. Increases in roads, development, and pollution due to population growth and changes in land use patterns are stressing many of our fragile coastal system. Although the proportion of people living near coastal areas is expected to remain relatively constant, current projections forecast an overall growth in the U.S. population of nearly 50 percent by 2050,[75] which means we will need to accommodate a growing population along our coasts while still protecting and maintaining fragile ecosystems on which humans and wildlife alike depend.

While most coastal zones in the U.S. must prepare for higher water levels, communities throughout the Great Lakes region must prepare for a *decline* in water levels. Ice cover has declined by an average of 71% across the Great Lakes, resulting in higher rates of evaporation from the open water. Lake Superior reached a record low water level in 2007. Lake Huron and Lake Michigan hit their lowest water levels in January 2013 while the other lakes were well below average. As water levels continue to fluctuate, coastal erosion will become increasingly problematic. In the past, some coastal communities have used gray infrastructure to armor coastlines, preventing natural revitalization from occurring and causing the coastline to retreat.[76]

Looking ahead, coastal communities should be working with nature, not against it, to increase their success resilience to the impacts of climate change, while also providing wildlife habitat and in many cases, reducing costs. The National Wildlife Federation's Climate-Smart Communities program is encouraging coastal communities to adopt this approach.

Some communities in the Great Lakes region are already using green infrastructure to prepare for climate change impacts. For example, in Milwaukee, Wisconsin the Metropolitan Sewage District (MMSD) has a long history of using green infrastructure as part of its stormwater management strategy. In 2000, MMSD developed the Greenseams program to purchase land that can capture and store stormwater without the use of gray infrastructure. Grand Rapids, Michigan developed a sustainability plan that acknowledges the importance of public parks and wetlands for managing stormwater. The plan sets a goal to increase the number of these areas in the city. In another case, the National Wildlife Federation developed climate-smart habitat restoration options for the Clinton River Spillway in Michigan, which recommends the removal of coastal armoring along lakeshores and riparian habitats. This will increase connectivity of lakes and streams which may be vulnerable during low level lake events (Appendix D, Case Study 3).

NOAA

VIII. Conclusion

Climate change can no longer be ignored. The long-term success of conservation efforts, in this case restoration of coastal habitats in the Great Lakes, is dependent on accounting for climate change in project objectives, design, and execution. In the interest of maximizing success with utilizing limited resources, NOAA and many other government agencies across the country are beginning to consider climate change in conservation efforts.

U.S. Fish and Wildlife Service

Successful restoration in a changing climate requires learning from past conservation experiences, while at the same time accounting for how the climate will change and how these changes will potentially impact target conservation areas. Resource managers will need to consider dynamic changes in climate rather than supposing future conditions similar to past climate for restoration projects to continue to be successful.

Given that species will respond in individualistic ways to climate change, ecological communities will not remain intact. It may no longer be effective or appropriate to manage systems based on a paradigm of maintaining a pre-existing condition, or restoring species or habitats to a previous desired state. This is especially important given the uncertainty about future conditions, as well as the likely greater extremes in various climatic factors (such as temperatures and rainfall events).

Climate-smart restoration follows the same basic principles of any good management system, which includes: defining goals, assessing current status and challenges, identifying and implementing appropriate strategies, and managing and assessing project performance. Projects become climate-smart when at each step of the process the potential effects of climate change are considered as another factor.

While a diversity of management techniques exist, a changing climate is likely to increase the importance of certain priority approaches, including maintaining or re-establishing connectivity of habitats, reducing key existing stressors, protecting key ecosystem features, and maintaining diversity. These approaches are likely be particularly effective at providing fish, wildlife, and plants with the greatest opportunity to survive climate change and thus meet appropriate conservation objectives.

Assessment of climate change impacts at the various stages of management requires information on projected climate changes and an assessment of those changes on existing species, habitats, and conservation objectives. Modeling and expert opinion are both options to find this information, either alone or combined. Once likely impacts are assessed, then managers have the means by which to adjust conservation objectives if necessary, and select appropriate management techniques that are likely to be most effective in light of expected climate impacts. As is necessary in any good management system, monitoring of results and adjustment of management techniques to account for lessons learned, and now for continuing changes in climate, is necessary.

Climate change neither renders past conservation efforts useless nor precludes continuing restoration efforts. Instead, we must take climate change into consideration to improve our conservation successes and protect our restoration investments.

Michigan Sea Grant

Appendix A. Climate Change Vulnerability Assessment: A Key Tool for Climate-Smart Restoration

Climate change vulnerability assessments provide an essential tool for informing the development of climate change adaptation plans and strategies. There is no single right approach to vulnerability assessment that applies to all situations. Rather, the design and execution of your assessment may depend on a host of factors, including availability of already existing information, the level of expertise, time and budget constraints, and so on. For example, while there is a growing number of models available that can project the impacts of climate change on plant and animal ranges, the ability to conduct more detailed analyses such as modeling the dynamic ecological responses among diverse species within and among ecosystems is still relatively limited. In many cases, focusing quantitative assessments more broadly on habitat changes and then applying qualitative assessments of potential species responses may be the best approach given existing information. Additional studies can then be undertaken as information and resources allow.

Components of Vulnerability

Vulnerability to climate change, as it is commonly defined, has three principal components: sensitivity, exposure, and adaptive capacity (Figure A1).[77] Understanding these individual components of vulnerability (whether explicitly or implicitly) is important in that it can help project planners identify more clearly *which* of your target species, habitats, and/or ecosystems are vulnerable to climate change and, perhaps more importantly, *why* they are vulnerable.

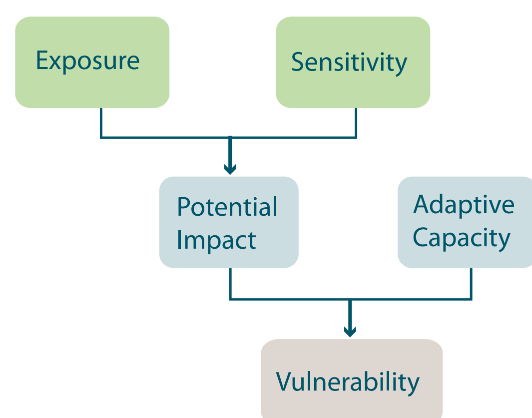

Figure A1. Key components of vulnerability, illustrating the relationship among exposure, sensitivity, and adaptive capacity.

- **Sensitivity.** Sensitivity is the degree to which a system (whether built, natural, or human) is or is not likely to be affected by or responsive to changes in climate and/or its related impacts.[78] Sensitivity of a particular species may depend on innate physiological or biological variables. For example, a species with a narrow temperature tolerance range may not be able to survive increases in the average temperature of its habitat due to climate change. That species is therefore considered "sensitive" to at least one element of climate change: higher average temperature. Sensitivity may also be a factor of specific physical or ecological factors. For example, a local river habitat that depends on snowmelt to maintain sufficient instream flows for fish is likely to be sensitive to reductions in average snowpack due to climate change, as well as to changes in the timing and intensity of precipitation.

- **Exposure.** Even if a particular species or system (human or natural) is inherently sensitive to climate change, its vulnerability also depends on the character, magnitude, and rate of changes to which it is exposed. For example, a specific population of a temperature-sensitive species may inhabit an area likely to be sheltered from rapid temperature increases, such as a north-facing, highly vegetated forest or high-elevation headwater stream (i.e., refugia). In such instances, the population may have a lower vulnerability than others of its species given its lower level of exposure. The use of projections at various scales as well as understanding current factors creating climatic differences across the land- or waterscape can help managers get a sense for where and how much change might be expected to affect a given conservation target.

- **Adaptive Capacity.** Adaptive capacity refers to the ability of a species or system to accommodate or cope with climate change impacts with minimal disruption. Broadly, adaptive capacity reflects both particular internal traits, such as the ability of a species to move in search of more favorable habitat conditions, adapt evolutionarily, or modify its behavior as climate changes, and external conditions, including the existence of structural barriers such as urban areas, bulkheads, or dikes that may limit the ability of that species or habitat to move.

The distinctions among sensitivity, exposure, and adaptive capacity are not always clean. Species mobility, for example, could reasonably be included in all categories. There are no hard-and-fast rules for where each of these components should explicitly fit as part of the overall vulnerability assessment. However, explicitly considering all three components of vulnerability may be particularly useful for informing management responses, especially when the influence of other stressors (e.g., overharvest, increased impervious surfaces) are evaluated.

Depending on the scope and nature of your project, assessing sensitivity or vulnerability to climate change could range from a less involved "thought exercise" up to a process that involves commissioning new model results. No matter what level of complexity your assessment entails, the following are key steps to guide the process:[79]

1. Determine objectives and scope.
2. Assess components of vulnerability.
3. Summarize vulnerability

Key Steps for Climate Change Vulnerability Assessment

A. Determine Objectives and Scope

Assessment Targets

A critical first step in conducting a vulnerability assessment is to define your specific restoration targets, goals, and approaches. First, consider relevant mandates, goals, and objectives that already exist. As highlighted in Section II, many of these goals and objectives have been identified under the GLRC Strategy and the GLRI. From here, you can identify your relevant assessment targets (i.e., species, habitats, and/or ecosystems of concern). For example, one of your restoration objectives may be to restore connectivity of tributary spawning habitat for native fish species in a particular AOC. To determine the vulnerability of this project to climate change (e.g., whether and how climate change might affect your ability to reach your objectives) you will want to assess the vulnerability of the stream habitat in the area and, perhaps, the native fish species itself. You also may need to assess the vulnerability of your various restoration approaches themselves (e.g., culvert infrastructure).

Geographic Scale

It also will be important early on to determine the appropriate scale for your assessment. Again, this may be informed or pre-determined by an existing policy or program. For example, the GLRI is focused on specified AOCs; many project-specific assessments will start at that scale. Projects more broadly targeted to ecosystem resilience, on the other hand, will likely focus on a larger scale. Even in the former case, however, it will be important to look beyond the confines of a specific jurisdictional line. By its nature, climate change will require that we think and plan within the context of larger landscapes, even when our management needs are very local. The appropriate geographic scale must reflect both particular management jurisdictions or requirements, and the geographic requirements of the species or ecosystems you are targeting.

Temporal Scale

Another primary consideration is your timeframe. One question that restoration planners will need to ask is: Will significant climate changes occur during the life span of the project? For many restoration projects, anticipated life span – the length of time that ecological services or other benefits are expected to accrue from the project – is long enough that significant changes will almost certainly occur. A restored wetland, for instance, would be expected to remain functional as a wetland for decades; restoration should thus be carried out in a way that maximizes the chance the wetland will remain functional regardless of future changes in factors such as lake level and precipitation. Indeed, as noted below, many regions, including the Great Lakes, are already experiencing changes consistent with climate change. Accordingly, even projects that might be considered over a shorter life span should at least recognize any of the climate conditions under which they are being developed that likely no longer reflect historical conditions.

Once you have determined your objectives/targets and geographical/temporal scales, gather the relevant data and expertise to help you assess the vulnerability of your project. For many projects, much of the information you will need may be available in scientific literature. You also may want to inquire with outside experts for their input. In addition to the citations referenced in the following tables, Appendix E of this report identifies some useful sources for more information.

B. Assess the Components of Vulnerability

Assessing Sensitivity

Assessing the sensitivity of your restoration targets/goals to climate change requires knowledge of how factors such as the life-cycle and habitat needs of species, the components and structure of habitats, and ecosystem processes are affected by climatic variables. In many cases, restoration project planners will already have at least a general sense of whether and how their targets are likely to be sensitive to general changes in these types of variables. Factors related to sensitivity to climate change will vary depending on whether your targets are species, habitats, or ecosystems (Table A1).

The recognition that many freshwater and marine fish species have specific temperature tolerances is a useful example of species' sensitivity to climatic variables. In the Great Lakes, for instance, common species are classified as either warm-, cool-, or cold-water fish, depending on their optimal temperature ranges (Figure A2). Changes in temperatures can contribute

Table A1. Factors Associated with Climate Change Sensitivity among Species, Habitats, Ecosystems.

Biological Level	Sensitivity Factor	Examples
Species	Physiological factors	Changes in temperature, moisture, CO_2 concentrations, pH, salinity may affect a specie's sensitivity to climate change.
	Dependence on sensitive habitats	Species that breed in vernal pools, ephemeral wetlands, intermittent streams and species that live in low-lying coastal zones are examples of species that will be more sensitive to climate change.
	Ecological linkages	Impacts on predators, competitors, prey, forage, host plants, diseases, parasites, etc. will affect sensitivity.
	Phenological changes	Events such as leafing and flowering of plants, emergence of insects, migration of birds may be affected by climate change.
	Population growth rates	Species that can quickly recover from low population numbers are likely to be less sensitive to climate change/disruptions.
	Degree of specialization	Generalist species, such as those that use multiple habitats, have multiple prey, etc. are likely to be less sensitive than specialists.
	Reproductive strategy	Species with long generation times and fewer offspring are likely to be more sensitive to climate change.
	Interactions with other stressors	Some factors may exacerbate sensitivity (e.g., exposure to pollutants may increase sensitivity to temperature changes).
Habitats	Sensitivity of component species	Sensitivity of dominant species, ecosystem engineers, keystone species, etc. will influence sensitivity of habitat type.
	Community structure	The level of diversity and redundancy of component species and functional groups may affect sensitivity to climate change.
	Degree of intactness	Degraded habitats may have insufficient species diversity or population sizes to resist or recover from flood or drought.
Ecosystems	Sensitivity of component species	As with habitats, sensitivities of dominant, keystone, and indicator species are likely to have large influences on sensitivity of the ecosystem.
	Sensitivity of ecosystem processes	Many ecosystem processes, such as decomposition, nutrient transport, sedimentation, streamflow, etc. are sensitive to changes in temperature and precipitation.

to changes in fish distribution as well as fish productivity. Another example of sensitivity to climate change is the extent and composition of wetland vegetation types and associated wildlife species, which may be sensitive to changes in average water depths. For example, many waterbird species have certain preferred water depths for foraging.[80] Accordingly, these species may be considered vulnerable to changes in average water depths due to altered temperature or precipitation patterns and relevant changes in wetland habitat.

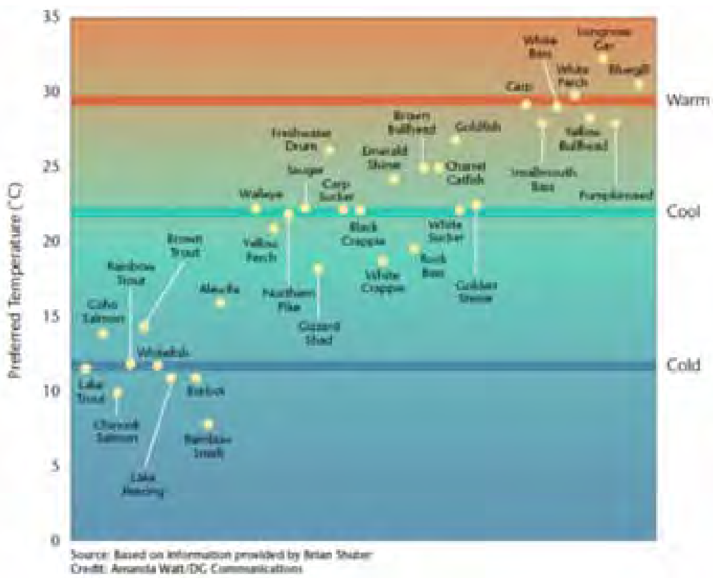

Figure A2. Common Fish Species of the Great Lakes Region, Grouped into Thermal Guilds.[81]

Assessing Exposure

The primary ways to assess exposure to climate change and related impacts is through a solid understanding of current regional climatology and the use of climate and ecological models. However, in all likelihood, those involved in the design and on-the-ground implementation of restoration projects will not be conducting sophisticated and complex climate modeling themselves but will instead rely on existing scenarios and make use of available downscaled projections. In some cases, project managers may rely on application of ecological models, although even those models may be supplanted or bolstered by existing studies in the scientific literature or by means other than modeling, such as consulting experts.

Climate-Related Changes

Here, we provide a few examples of the key climate-related changes that have been observed and projected for the Great Lakes region. In addition to the studies referenced in the following tables, Appendix A identifies several useful resources for identifying both observed and projected climate change impacts in the region. Note that for many of the variables, both past and future exposure may be strongly influenced by land use change.

Observed Trends

One of the most important things to consider is the fact that climate change is not just about what will happen decades from now. The Great Lakes region is already experiencing significant changes consistent with climate change, as highlighted in Table A2.[82,83] Many of these trends are relevant for consideration in restoration project design and implementation in the short term, even as projections remain unavailable or uncertain.

Projected Climate Change

While many planners, designers, and others commonly integrate future conditions, including uncertainty, into their thinking, doing so is novel for many, and climatic uncertainty has been less commonly addressed than political or social uncertainty. Table A provides a general (i.e., not comprehensive) list of projections that

Table A2. 20th Century Climate Trends for the Great Lakes Region.

Temperature	Average annual temperatures have increased across the region since the mid-1950s, especially in winter months.[84]
	The date of the last spring freeze occurs about one week earlier and the length of the growing season is about one week longer than it was in the early 20th century.[85]
Precipitation	Increases in fall precipitation since the mid-1900s is resulting in increased annual mean and low flow of streams, without any changes in annual high flow.[86]
	There has been an increase in average annual lake effect snow during the 20th century, which may be a result of warmer Great Lakes surface waters and decreased ice cover.[87]
	There has been a doubling in the frequencies of heavy rain events (defined as occurring on average once per year during the past century) and an increase in the number of individual rainy days, short-duration (1-7 days) heavy rain events, and week-long heavy rain events.[88,89]
Hydrology	Since 1960, average spring snow cover has decreased, followed by earlier dates for spring melt, and peak stream flow and lake levels.[90]
	Ice and snow cover and duration have decreased across the Great Lakes, more rapid than any changes that have occurred over at least the last 250 years.[91]
	There has been a significant shift in the timing and range of the seasonal hydrological cycle for Lake Michigan-Huron over the past century, with greatest changes occurring during winter and spring as snowmelt and runoff are shifting earlier in the year.[92,93]
	The formation of ice on inland lakes is occurring later in the year than it did a century ago, and a there is a shorter overall duration of winter lake ice, with some years being entirely ice-free.[94]
	There has been a significant decrease in Lake Michigan annual maximum ice concentration from its long-term (1963-2001) average of 33% to the most recent 4-year average (1998-2001) of 23%, setting a new record low.[95]
	Great Lakes near-shore water temperatures (measured at Sault Ste. Marie and Put-In-Bay) have been rising about 0.1 degree C per decade, accompanied by an increase in the duration of summer stratification of more than two weeks, since the early 1900s.[96]
	Lake Superior summer (July-September) surface water temperatures have increased approximately 2.5 degrees C over the interval 1979-2006, significantly in excess of regional atmospheric warming. The discrepancy is caused by declining winter ice cover, which is causing the onset of the positively stratified season to occur earlier and increasing the period over which the lake warms during summer months.[97]
Ecological Impacts	Plants are leafing out and blooming up to two weeks earlier in spring than they did in the early- to mid-1900s.[98]

will be important for restoration project design. These are not predictions of what will be – no one has a crystal ball. Rather, they are projections based on studies using a range of models, approaches, and assumptions, and they represent a range of levels of uncertainty. For example, some projections – such as for temperatures – show considerable agreement across multiple studies, while others – such as for Great Lakes water levels – do not. These discrepancies can be due to a number of factors, such as which emissions scenarios and/or models are used. One way to interpret these discrepancies is from the perspective of the level of confidence you might place on any given set of projections.

Before highlighting some of the recent projections for climate change in the Great Lakes region, we address three key questions project developers should ask about climate scenarios: how much detail they really need, at what scale they need it, and, if they need detailed scenarios, what set of scenarios to use.

- **Level of Detail.** In general, the level of detail you need in projections of future climate is roughly the level of detail about current climatic conditions you typically use in developing project plans. If you use hard numbers for maximum expected rainfall per 24-hour period, first frost date, or growing degree-days, it may be useful to you to get numerical projections for the variables you use. For many planning decisions, however, it may not be essential to know the specific climate projections. In many cases, knowing the general direction and range of likely changes (e.g., warmer water temperatures, higher spring streamflows, less winter ice cover) will be sufficient to make some general planning decisions. Often, people become too invested in the details of the particular scenarios they are using, or become distracted from their overall goals in favor of debating the certainty or plausibility of particular scenarios. People may also invest significant time and resources on issues related to getting downscaled climate projections only to find that they have not even begun to address other critical issues such as how species may respond to changing conditions.

- **Downscaled Climate Projections.** One of the primary concerns that resource managers frequently express in terms of incorporating climate change into their respective activities is the perceived lack of sufficiently "downscaled" studies in terms of both localized projections of climate change and the potential responses of species and ecosystems to those changes.[99] There have been considerable advances in model development in recent years, including methods to synthesize results from global climate models (GCMs) to a geographic scale considered to be better suited for resource management decisions. Many of the resources cited in this Appendix include studies using downscaled approaches.

  Despite their level of specificity and detail, downscaled models are not necessarily more "accurate" than models focused at a larger scale. Rather, the degree of uncertainty in these models may be equal to or greater than that in broader-scale models, and no model will ever predict the future with complete certainty. In some cases, broader regional projections may suffice in informing restoration decisions. In others, even downscaled model results might not be sufficient, such as in areas where there is considerable diversity in geographical features or other factors that might contribute to "micro-climates" (e.g., north-facing, highly-vegetated slopes). In these cases, supplementing information from models with on-the-ground knowledge and/or monitoring may be particularly important. In all cases, managers should avoid falling into a "predict and provide" mental framework based on the output of one or a few model projections. Nevertheless, it will be important for restoration project planners to work with scientific experts in the region to assist in identifying and/or developing downscaled projections relevant for project design at a localized level. The newly-formed Landscape Conservation Cooperatives (LCCs) (including the Upper Midwest/Great Lakes LCC) and Climate Science Centers (including the Northeast Climate Science Center) will be important resources for scientific information on climate change (see Appendix D for contact information).

• **Considerations for Choosing Climate Change Scenarios.** Which scenarios are most appropriate depends on factors such as the length of your planning horizon, the sensitivity of key species or processes, the level of confidence in the projections, and the level of acceptable risk.

The suite of climate change scenarios on which most projections are based comes from a set of scenarios developed by the Intergovernmental Panel on Climate Change (IPCC) in its *Special Report on Emissions Scenarios* (SRES) in 2000.[100] The scenarios span a range of possibilities for future greenhouse gas emissions. The low-emissions scenarios (e.g., B1) are no longer plausible, given current and likely near-term future emissions. Current emissions trajectories are higher than those in the IPCC's highest emissions scenario, A1FI, but strong emissions reduction initiatives would allow us to track moderate emissions scenarios such as the IPCC's A2 and A1B scenarios. These are the most commonly used scenarios, and have the richest data available for modeling and projections.

Ideally, restoration investments will endure for many decades to come – from that perspective, knowing what the climate might look like 50-100 years from now is important. However, some changes are likely to happen gradually over time, and the most significant impacts may not be realized within the realistic lifespan of project-related infrastructure. In such cases, it might be sufficient to plan for projected changes in the relative near term, say 20-30 years, with the understanding that modifications in project design and/or implementation might be necessary down the road. Also, typically, near term projections of climate change scenarios have a higher degree of certainty than those that look farther out. This is true for many reasons, not least because it is difficult to anticipate how greenhouse gas emissions might change in the future, whereas the climate change we experience over the next few decades will be heavily influenced by past emissions. On the other hand, not all climate change impacts will happen gradually – in fact, it is likely that we will experience extreme events and even surprises along the way. Accordingly, designing projects to be robust to climatic variability and disturbances from the start will be important in some cases.


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Table A3 provides a summary of some of the general and downscaled climate change projections that have been developed for the Great Lakes region. These projections should not be considered recommended scenarios for your assessment. Rather, they represent a range of information based on the best available science to date.[101]

Table A3. 21st Century Climate Change Projections for the Great Lakes Region.

Temperature	Based on statistical downscaling methods applied to a relatively coarse-scale atmosphere-ocean GCM (AOGCM), annual temperatures in the U.S. Great Lakes region are projected to increase 1.4 +/- 0.6 degrees C over the near term (2010-2039), by 2.0 +/- 0.7 C under lower and 3 +/- 1 C under higher emissions by midcentury (2040-2069) and by 3 +/- 1 C under lower and 5.0 +/- 1.2 C under higher emissions by end-of-century (2070-2099), relative to the historical reference period 1961-1990. Simulations also suggest seasonal and geographical differences in warming, consistent with recent trends.[102]
Precipitation	The region is projected to see Increases in winter and spring precipitation of up to 20% under lower and 30% under higher emissions are projected by end-of-century, while projections for summer and fall remain inconsistent.[103]
	Average annual precipitation is projected to increase across the majority of Great Lakes basins by 2050, ranging from a 4.1% increase (+/- 4.9% uncertainty) for Lake Superior, 12.5% (+/- 4.5%) for Lake Michigan, 10.9% (+/- 4.8%) for Lake Huron, 21.8% (+/- 8%) for Lake Erie, and 19% (+/- 5%) for Lake Ontario.[104] Precipitation may decrease along the Southwestern edge of the Great Lakes region, however.[105]
Hydrology	Downscaled regional projections of precipitation and air temperature changes in the four states surrounding Lake Michigan based on IPCC emissions scenarios suggest that impacts on streamflow on early- (water years 2010-2039) and mid-century (water years 2040-2069) streamflow was highly variable; however, by the late-century period (water years 2070-2099) annual streamflow was found to have increased in all rivers studied.[106]
	Summer and fall low flows in some river basins are projected to become even lower due to higher air temperatures, greater evapotranspiration losses, a longer evapotranspiration/evaporation season and reductions in groundwater base flow.[107,108]
	As air temperatures increase, Great Lakes surface water temperatures are projected to increase, along with increases in the duration of summer stratification.[109]
	Average lake temperatures are projected to increase 1.5 degrees C above the base case (1960-2000) by 2050 in Lake Superior, 0.2 degrees C in Lake Michigan, 0.3 degrees C in Lake Huron, 0.8 degrees C in Lake Erie, and 0.37 degrees C in Lake Ontario.[110]
Great Lake Water Levels	Studies using scenarios from two of the primary GCMs project significant declines in mean Great Lake water levels by the 2030s due to a combination of increased evaporation and decreased runoff, including a 22-centimeter decline under the baseline level for Lake Superior; a 72-centimeter decline for Michigan-Huron; a 60-centimeter decline for Erie; and a 35-centimeter decline for Ontario.[111,112]
	Competing effects of shifting precipitation and warmer temperatures suggest little change in Great Lakes levels until the mid- to late-21st century, when significant net decreases are expected under higher emissions.[113]
	According to a 2009 study that applied the output of 565 model runs from 23 different GCMs to a lake-level model developed by the Great Lakes Environmental Research Laboratory, the impact of climate change on Great Lakes water levels will vary based on which emissions scenario is used. For Lake Michigan-Huron, the median changes in lake levels in 2080-2094 were -0.25, -0.28, and -0.41 meters for low, medium, and high emission scenarios, respectively. Similar trends were projected for Lakes Erie and Ontario, while Lake Superior showed a relatively smaller response. Under some scenarios, lake levels rose by up to 1.5 meters.[114]

Ecological Responses to Climate Change

In addition to projecting climate changes themselves, models can provide an important means for projecting possible responses of species, habitats, and ecosystems to those changes. Ecological response models are a critical part of the overall vulnerability assessment process, and there are numerous types of models available, ranging from basic conceptual models that provide qualitative descriptions and diagrams of key attributes and processes related to species or systems

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of concern, to detailed ecological models that can evaluate how climate change variables affect fundamental ecological processes.

However, as with climate change, it is unlikely that on-the-ground restoration planners and managers will actually conduct extensive modeling as part of the planning process. More often, it will be important to rely on existing information from the scientific literature, much of which is based on the more complicated modeling work. Several additional sources of information are cited in Appendix A. It is important to recognize that many of the impact studies incorporate two of the three components of vulnerability: sensitivity and exposure. Thus, they fit into the top three boxes of the framework illustrated in Figure A1. As we describe below and elsewhere in this guidance, assessing the other key component – adaptive capacity – may require additional attention in the restoration planning process.

Assessing Adaptive Capacity

Determining the adaptive capacity of your restoration targets/objectives entails asking several questions, including: whether and how much those targets are already able to accommodate changes in climate (e.g., innate features such as dispersal abilities); whether and to what extent barriers exist that limit your targets' adaptive capacity (e.g., natural or physical structures that prevent habitat

Table A4. Summary of Impacts of Climate Change on Great Lakes Coastal Wetland Hydro-geomorphic Site Types.[115]

Wetland Site Type	Major Characteristics	Main Impacts of Climate Change
Lacustrine	Open to and most affected by Great Lakes, including water level fluctuations, near-shore currents, ice scour, and seiches (standing waves). Wetlands in open and protected bays. Varying degrees of organic sediment and vegetation development. Bathymetry, gentle to steep slope, dependent on degree of protection from lake effects and geology (ice scour and seiches).	Potential for more exposure to extreme winter storms and less ice protection. Aquatic, submergent and emergent vegetation may migrate lakeward with lower levels if suitable sediment, slope, and seed banks exist. Drier vegetation communities (sedges, grasses, and shrubs) expand in current wetland. Warmer temperatures may result in vegetation community shifting over decades and centuries, starting with changes in species composition and dominance, if seed access (e.g., corridor, birds). Cumulative stresses may encourage spread of invasive species. Loss and contamination from increased demands for dredging. Mud flats exposed. Less interspersion.
Riverine	Occur near the mouth of tributaries to and connecting channels of the Great Lakes. Water quality, inflow and sediment loading are strongly influenced by runoff from the watershed but also affected by the lake. Often protected from waves. Types include: open to the lake, along connecting channels, behind barrier bars, and in delta. Steep river bank and river channel, with flat flood plain.	More variable river flooding regimes affect wetland which can lessen influence of lake levels. More sedimentation from more extreme precipitation events causing more erosion upstream; vegetation covered with sediments and fish and wildlife habitat adversely affected. Lower flows may increase pollutant concentrations. Warmer water temperatures decrease dissolved oxygen. May be able to migrate toward river-mouth as levels decline but dependent on sediment, slope, and seed bank. Warmer temperatures may result in vegetation community shift over decades and centuries, starting with changes in species composition and dominance. Cumulative stresses may encourage spread of invasive species.

Barrier-Enclosed	Occur behind a barrier beach formed by coastal processes. Gradual slope but barrier beach is an obstruction to downslope vegetation movement once a particular water level threshold has been reached. Generally protected from waves but may be lake-connected during high water periods (or extreme storms). Varying connectivity to lake and influence by lake water levels. Includes barrier beach and swale complexes between relic beach ridges with decreasing lake level influence as move landward. More prevalent in lower lakes where more coastal sediments are available.	Unable to shift lakeward with lower lake levels so gradual drying of wetland; dominated by meadow, shrub, and tree communities with associated shift in diversity, productivity, and habitat value. Drying may increase risk of fire. Shifting coastal processes may alter barrier or re-form a lakeward one. Warmer temperatures may result in vegetation community shift over decades and centuries, starting with changes in species composition and dominance, if seed access (e.g., corridor, birds). Warmer water temperatures decrease dissolved oxygen. Cumulative stresses may encourage spread of invasive species. Wetland area decreases.

migration, or institutional restrictions such as inability to manage impacts beyond existing jurisdictional boundaries); and whether there are additional stressors that limit the adaptive capacity of your targets (e.g., the presence of an opportunistic invasive species that outcompetes restored vegetation).[116] Table A5 (page 46) highlights elements of adaptive capacity for restoration targets.

Many of the resources available on species/ecosystem sensitivity also will be useful for determining innate features that might contribute to or limit adaptive capacity. Similarly, for regions such as the Great Lakes in which existing stressors have been extensively analyzed and documented, there will likely be a considerable body of information available to help determine how they might come into play with climate change as an added stressor.

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Table A5. Factors Associated with Adaptive Capacity among Species, Habitats, and Ecosystems.

Biological Level	Adaptive Capacity Factor	Examples
Species	Plasticity	The ability for a species to modify its physiology or behavior to synchronize with changing conditions or coexist with different competitors, predators, etc.
	Dispersal abilities	Some species may be able to disperse over long distances (e.g., seeds may be carried to new areas by birds). Other species, such as those that have evolved in patchy or rare habitats, may have lower dispersal ability.
	Evolutionary potential	Traits such as generation time, genetic diversity, and population size can affect the ability of species to adapt evolutionarily to climate change. For example, populations with high genetic diversity for traits related to climate tolerance are more likely to contain individuals with heritable traits that reduce sensitivity.
Habitats	Permeability of landscape	More permeable landscapes with fewer barriers to dispersal and/or seasonal migration will likely result in greater adaptive capacity. Relative permeability of a landscape may depend on natural and anthropogenic factors
Ecosystems	Redundancy and response diversity within functional groups	In ecological communities, functional groups can include primary producers, herbivores, carnivores, decomposers, etc. In systems where each functional group is represented by multiple species and the response to environmental change varies significantly among species in the group, the system's resilience to climate change is likely to be higher.

C. Summarize Vulnerability

Once you have an understanding of the how each of the components of vulnerability applies to your project goals/approaches, the next step in the assessment process is to summarize overall vulnerability based on your findings.[117] Vulnerability assessments can provide two essential types of information needed for restoration planning: 1) identifying which species or systems are likely to be most strongly affected by projected changes, and 2) understanding why they are likely to be vulnerable. This information will help you set priorities as well as provide a basis for developing appropriate management responses. How to characterize the results of your vulnerability assessment may range from a general determination of the relative degree of vulnerability (e.g., low, medium, high), to detailed narratives that delve into specific information regarding your assumptions, results, etc. The more descriptive you are in your assessment results, the more useful the information is likely to be in helping you determine possible management approaches. Examples 1-9 of this section illustrate how one might characterize vulnerability for several hypothetical Great Lakes restoration projects.

More detailed information about climate change vulnerability assessments, along with a number of case studies, can be found in Glick, P., B.A. Stein, and N.A. Edelson, editors. 2011. *Scanning the Conservation*

Horizon: A Guide to Climate Change Vulnerability Assessment. National Wildlife Federation, Washington, D.C.: **www.nwf.org/vulnerabilityguide.**

Box A1. Addressing Uncertainty in Vulnerability Assessments

Assessing the vulnerability of species, habitats, or ecosystems to most stressors, and certainly to climate change, is complex, and there are different levels of certainty and confidence in each piece of scientific information and expert knowledge that are integrated together to produce a vulnerability assessment. Uncertainty is a reality: no one knows exactly how climate may change or how ecological or human systems may respond to change in any particular location. Nevertheless, management decisions can proceed in the face of uncertainty. A useful way to characterize uncertainty in the assessment process is the level of confidence in a given input or outcome. In some instances we will have a high level of confidence in some or all of the parts determining climate change vulnerability, and in other cases we may be less certain in one or more of the vulnerability factors.

The goal should be to use the best available information on the uncertainties involved in estimating vulnerability, while recognizing that it may be necessary to reassess vulnerability and the associated uncertainties in an iterative fashion as new information becomes available. Being transparent about the general magnitude of uncertainty and understanding the range of possibilities given the uncertainty allows managers to articulate the reasoning for making a decision.

Sample Illustrative Examples of Vulnerability Assessments of Various Restoration Projects

Examples A1-A9 provide some general, hypothetical examples of how the various components of vulnerability might come into play for coastal restoration efforts supported by NOAA and others.[118]

These illustrative examples include the following projects (table number is adjacent):

1. Fish Passage Restoration
2. Drowned River-Mouth Wetland Habitat Restoration
3. Coaster Brook Trout Habitat Restoration
4. Whitefish Habitat Restoration
5. Invasive Species Management
6. Water Quality Restoration
7. Oil Spill Damage Assessment, Remediation, Restoration
8. Amphibian Habitat Restoration
9. Wild Rice Habitat Restoration
10. Watershed scale perspective from the Chesapeake Bay

Much of the information included in the tables is based on a preliminary review of existing literature. There are a number of readily available studies that can provide you with information to determine one or more of the components of vulnerability for species and systems in the Great Lakes region (Appendix E). In cases where we were unable to find relevant information, we used our best judgment. Furthermore, we did not explicitly express levels of confidence in these sample answers. Rather, *the information provided in these tables is illustrative – they do not represent comprehensive assessments for direct use by project planners. Individual projects*

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will have unique needs that warrant a more thorough, targeted process than these examples suggest. However, the table framework served as the basis for a recent expert elicitation driven vulnerability assessment process for a sub-watershed in Maryland and proved a very effective template for a more detailed assessment (NWF 2013).

Each table examines the vulnerability of targets/goals and approaches of various restoration projects. For every example, vulnerability is examined by a set of questions outlined below:

Scope and Objectives

- *What are your current restoration goals?*
- *What are your restoration targets?*
- *What is the current status of your restoration target (e.g., what factors are contributing to BUIs)?*
- *What restoration approaches are you planning/implementing to improve the status of your target?*
- *What is the expected lifetime of your project?*

Components of Vulnerability

- *How and to what degree is your restoration target sensitive to climate conditions/variables?*
- *How and to what degree is your restoration approach sensitive to climate conditions/variables?*
- *How are climate conditions projected to change in the area, and is there evidence of climate change already being observed in your planning area?*
- *What is your system's adaptive capacity relative to climate change?*

Vulnerability Summary

- *What is the relative vulnerability of your restoration project (including your targets, goals, and approaches)? What are the primary reasons?*

Example A1. Illustrative Vulnerability Assessment for Fish Passage Restoration Project.

A. Scope and Objectives	
What are your current restoration goals?	Maintain, improve, or enhance populations of native species.
What are your restoration targets?	Stream habitat for native fish species.
What is the current status of your restoration target (e.g., what factors are contributing to BUIs?)	Existing dam has altered natural river flows and blocked fish passage.
What restoration approaches are you planning/ implementing to improve the status of your targets?	Improve habitat connectivity; reduce existing stressors; restore/emulate ecosystem functions through construction of fish passage structure and flow management.
What is the expected lifetime of the project?	Infrastructure elements of project are expected to last 30-50 years before they need to be repaired/ rebuilt.
B. Components of Vulnerability	
Sensitivity	
How and to what degree are your restoration targets sensitive to climate conditions/variables?	Streamflows are sensitive to precipitation patterns, groundwater input (base flow), and evaporation.[119] Target fish species are sensitive to timing and volume of streamflows for migration and spawning, although sensitivity varies by species.[120]
How and to what degree are your restoration approaches sensitive to climate conditions/variables?	Effectiveness of fish passage design is sensitive to changes in the extent and timing of high and/or low flows.
Exposure	
How are climate conditions projected to change in the area?	Continuing trend of heavier rainfall events in fall/winter; reduced precipitation, lower streamflows/groundwater input in summer.[121]
Is there evidence of climate change already being observed in the area?	Heavier rainfall events are becoming more frequent.[122] Snowmelt and runoff are occurring earlier in the year.[123]
Adaptive Capacity	
What is your system's adaptive capacity relative to climate change?	The existence of a dam limits the natural adaptive capacity of the river system and associated species. Adaptive capacity of various project approaches will depend on relative ability to alter project design. Changes in flow management may face constraints due to other demands for water resources in the region.
C. Vulnerability Summary	
What is the relative vulnerability of your restoration project (including your targets, goals, and approaches)?	Medium/High
What are the primary reasons?	Some changes in flow regimes are already occurring, and more extremes in the future may make it more difficult for fish to navigate the river barrier (e.g., low flows may make navigation around/over barrier difficult/impossible in summer; high flows may prevent passage of species that are not able to expend the necessary energy). There is relatively high adaptive capacity for this project if design takes into consideration the projected changes, but effectiveness will depend on overcoming possible management constraints.

Example A2. Illustrative Vulnerability Assessment for Drowned River-Mouth Wetland Habitat Restoration Project.

A. Scope and Objectives	
What are your current restoration goals?	Improve aquatic ecosystem resilience, enhance wetland habitat.
What are your restoration targets?	Drowned river-mouth wetland habitat for multiple species.
What is the current status of your restoration target (e.g., what factors are contributing to BUIs?)	Part of project area has wetland disconnected from lake influence due to existence of a dike. This has reduced habitat quality for target species.
What restoration approaches are you planning/ implementing to improve the status of your targets?	Improve habitat connectivity; maintain/improve diversity; reduce existing stressors; restore/emulate ecosystem functions by constructing and maintaining structures to allow for optimal water level and river flow processes in diked wetland.
What is the expected lifetime of the project?	Infrastructure expected to last 30-50 years before it needs to be repaired/rebuilt.
B. Components of Vulnerability	
Sensitivity	
How and to what degree are your restoration targets sensitive to climate conditions/ variables?	These wetlands are sensitive to changes in the timing, duration, and height/elevation of annual and seasonal lake water levels and river flows.[124]
How and to what degree are your restoration approaches sensitive to climate conditions/ variables?	Effectiveness of water flow management structures is sensitive to changes in average lake levels as well as changes in extremes in both lake levels and streamflows.
Exposure	
How are climate conditions projected to change in the area?	In general, average Great Lakes water levels are projected to decline by mid-century due to a combination of increased evaporation and decreased inflow from surface and groundwater.[125] Evapotranspiration is likely to increase in all seasons. Continuing trend of heavier rainfall events in fall/winter; reduced precipitation, lower streamflows in summer.[126]
Is there evidence of climate change already being observed in the area?	The region is experiencing higher average air and lake surface temperatures and reduced duration and extent of lake ice cover/increased stratification.[127] This is considered to be a precursor to declining average lake levels. Heavier rainfall events are becoming more frequent.[128] Snowmelt and runoff are occurring earlier in the year.[129]
Adaptive Capacity	
What is your system's adaptive capacity relative to climate change?	Annual and perennial vegetation of marsh wetlands in undiked areas may be able to migrate in response to water level declines, depending on sediment, slope, seed bank, existence of other barriers[130] On the other hand, changes in temperature or hydrological regime that benefit invasive species may further stress native wetland species (e.g., low water levels correlate with greater abundance of Phragmites).[131] Adaptive capacity of various project approaches will depend on relative ability, time needed and/or resources available to alter project design if necessary.
C. Vulnerability Summary	
What is the relative vulnerability of your restoration project (including your targets, goals, and approaches)?	Medium.
What are the primary reasons?	Recent extreme low lake level events, while not necessarily linked directly to climate change, illustrate how these wetland systems are likely to respond to extreme water level change. Perturbations can alter the natural succession of plants in wetlands, which influences the species, diversity, and number of fish and wildlife a wetland can support.[132,133,134] Ultimately, conditions may become favorable for some species and detrimental to others (e.g., shallow wetlands with greater coverage by emergent vegetation may benefit some water birds such as yellow rails but would be less favorable for other waterfowl).[135] Water flow management is sensitive to changes in lake level and streamflow; lower water levels encourage the spread of invasive plant species. There is relatively high adaptive capacity for this project if design takes into consideration the projected changes, but effectiveness will depend on the types of species restored and other management issues.

Example A3. Illustrative Vulnerability Assessment for Coaster Brook Trout Habitat Restoration Project.

A. Scope and Objectives	
What are your current restoration goals?	Maintain, improve, or enhance populations of native species.
What are your restoration targets?	Coaster brook trout habitats.
What is the current status of your restoration target (e.g., what factors are contributing to BUIs?)	Historical population declines due to over-fishing, habitat loss, human activities such as logging and mining, and invasive species.
What restoration approaches are you planning/implementing to improve the status of your targets?	Reduce existing stressors; protect key ecosystem features; maintain diversity by building or maintaining spawning areas; mitigating siltation that may have occurred following agricultural clearing or other development; beginning/continuing/modifying hatchery stocking; and creating/continuing/modifying restrictions on recreational harvest.[136]
What is the expected lifetime of the project?	Indefinite.
B. Components of Vulnerability	
Sensitivity	
How and to what degree are your restoration targets sensitive to climate conditions/variables?	Coaster brook trout rely on both lake and stream habitats and are sensitive to higher water temperatures and changes in oxygen levels.[137]
How and to what degree are your restoration approaches sensitive to climate conditions/variables?	Spawning habitat restoration efforts are likely to be sensitive to altered temperature and flow regimes.
Exposure	
How are climate conditions projected to change in the area?	Average lake temperatures are projected to continue to increase; average stream temperatures also are projected to increase (with localized variation due to factors such as shade, and water flow regimes).[138]
Is there evidence of climate change already being observed in the area?	The region is experiencing higher average air and lake surface temperatures and reduced duration and extent of lake ice cover.[139,140] Heavier rainfall events are becoming more frequent.[141] Snowmelt and runoff are occurring earlier in the year.[142]
Adaptive Capacity	
What is your system's adaptive capacity relative to climate change?	Cool/cold water fish species may be able to accommodate periodic increases in water temperature if they have access to refugia such as deep pools, tributaries, or shaded riparian areas.[143] Adaptive capacity of various project approaches will depend on relative ability to alter project design (e.g., costs, planning needs), potential for institutional changes to fisheries management, etc.
C. Vulnerability Summary	
What is the relative vulnerability of your restoration project (including your targets, goals, and approaches)?	High.
What are the primary reasons?	Higher lake temperatures could reduce favorable spawning habitat and juvenile incubation; longer periods of stratification in summer may limit availability of nutrients and phytoplankton; near-shore water quality could decline.[144] Altered streamflow regimes and higher stream temperatures will reduce quality of stream habitat. Success of stream restoration efforts is sensitive to climate change, although there is relatively high adaptive capacity for accommodating climate impacts via project design.

Example A4. Illustrative Vulnerability Assessment for Whitefish Habitat Restoration Project.

A. Scope and Objectives	
What are your current restoration goals?	
What are your restoration targets?	Whitefish spawning habitat.
What is the current status of your restoration target (e.g., what factors are contributing to BUIs?)	Excess nutrients, degraded spawning habitat, impacts from invasive species (e.g., dreissenid mussels).
What restoration approaches are you planning/implementing to improve the status of your targets?	Reduce existing stressors; restore habitat to more favorable conditions, including reducing phosphorus loads and controlling invasive species to enhance health of spawning areas.
What is the expected lifetime of the project?	Indefinite.
B. Components of Vulnerability	
Sensitivity	
How and to what degree are your restoration targets sensitive to climate conditions/variables?	Whitefish are sensitive to the availability of ice cover during the spawning season, as well as sensitive to temperatures outside their optimal water ranges and changes in water quality.[145]
How and to what degree are your restoration approaches sensitive to climate conditions/variables?	Efforts to address nutrient loading will be sensitive to changes in flow regimes (e.g., heavy rainstorm events may lead to greater runoff and increased pollutant loads into lake systems); invasive species controls may be sensitive to similar changing conditions.
Exposure	
How are climate conditions projected to change in the area?	The duration of ice cover is projected to decline by several weeks to several months by mid- to-late century.[146]
Is there evidence of climate change already being observed in the area?	Ice and snow cover and duration have decreased across the Great Lakes, more rapidly than any changes that have occurred over at least the last 250 years.[147] Increases in near-shore water temperatures of the Great Lakes are lengthening the period of summer stratification.[148]
Adaptive Capacity	
What is your system's adaptive capacity relative to climate change?	These species are likely to have relatively low adaptive capacity, as they are specialists with respect to their dependence on cold water and lake ice.
C. Vulnerability Summary	
What is the relative vulnerability of your restoration project (including your targets, goals, and approaches)?	High.
What are the primary reasons?	Reduced ice cover could mean greater mortality of whitefish eggs, which rely on the formation of ice over shallow waters for protection from wind and waves. Increased variability associated with climate change could make spawning/nursery conditions unfavorable for this species in some areas.[149]

Example A5. Illustrative Vulnerability Assessment for Invasive Species Management Project.

A. Scope and Objectives	
What are your current restoration goals?	Improve aquatic ecosystem resilience;maintain, improve, or enhance populations of native species.
What are your restoration targets?	Sea lamprey control to reduce decimation of native fish species populations.
What is the current status of your restoration target (e.g., what factors are contributing to BUIs?)	Sea lamprey were first observed in Lake Erie in the 1920s and have since colonized the upper lakes and contributed greatly to the decline of native salmonid populations.
What restoration approaches are you planning/implementing to improve the status of your targets?	Reduce existing stressors, including sea lamprey populations. Aggressive sea lamprey control programs already exist, so it is important to focus on how to enhance or improve these programs. Two ways to control lamprey population include: construction of low-head dams to block upstream migration and extensive use of lampricides in spawning tributaries.
What is the expected lifetime of the project?	Indefinite.
B. Components of Vulnerability	
Sensitivity	
How and to what degree are your restoration targets sensitive to climate conditions/variables?	Sea lamprey and host species (lake trout, whitefish) are sensitive to water temperatures.[150] Sea lamprey thrive (both size and reproduction) in warmer temperatures while host species require colder temperatures.
How and to what degree are your restoration approaches sensitive to climate conditions/variables?	Effectiveness of lamprey control may be sensitive to changing conditions that affect lamprey productivity. For example, studies suggest that variations in streamflows due to rainfall events may increase risk of dilution and lead to sublethal applications.[151]
Exposure	
How are climate conditions projected to change in the area?	Average lake/stream temperatures are projected to continue to increase, as is the length of the summer stratification period.[152] More-extreme precipitation events are likely.
Is there evidence of climate change already being observed in the area?	Average lake temperatures are increasing.[153] Increases in near-shore water temperatures of the Great Lakes are lengthening the period of summer stratification.[154] Heavier rainfall events are becoming more frequent.[155] Snowmelt and runoff are occurring earlier in the year.[156]
Adaptive Capacity	
What is your system's adaptive capacity relative to climate change?	Sea lampreys appear to have been able to capitalize on changes in lake conditions in some areas as higher temperatures to increase their metabolic rate.[157] In addition, scientists believe that longer periods of lake stratification increase the amount of time in which lake trout spend in their preferred thermal range, which is providing sea lampreys with more time to feed on this important host species.[158,159]
C. Vulnerability Summary	
What is the relative vulnerability of your restoration project (including your targets, goals, and approaches)?	Medium.
What are the primary reasons?	A continued increase in lake temperatures and longer periods of stratification may exacerbate sea lamprey predation if host species are restricted to areas that overlap lamprey. As lake temperatures rise, host species may face declines due to factors additional to lamprey.

Example A6. Illustrative Vulnerability Assessment for Water Quality Restoration Project.

A. Scope and Objectives	
What are your current restoration goals?	Improve aquatic ecosystem resilience.
What are your restoration targets?	Aquatic fish and wildlife.
What is the current status of your restoration target (e.g., what factors are contributing to BUIs?)	Hypoxia/anoxia events have long been a concern in Great Lakes waters, primarily due to phosphorus pollution.
What restoration approaches are you planning/ implementing to improve the status of your targets?	Reduce existing stressors; restore/emulate ecosystem functions, including reduction in anoxia/hypoxia events through efforts to reduce nutrient loading.
What is the expected lifetime of the project?	Indefinite.
B. Components of Vulnerability	
Sensitivity	
How and to what degree are your restoration targets sensitive to climate conditions/variables?	Higher lake temperatures and increased stratification can exacerbate anoxia/hypoxia events.[160] Increased runoff into lakes during heavy precipitation events could introduce additional pollutants.
How and to what degree are your restoration approaches sensitive to climate conditions/variables?	Efforts to reduce pollutants are likely to be sensitive to runoff (e.g., heavier downpours may carry more phosphorus into lake waters).
Exposure	
How are climate conditions projected to change in the area?	Average lake temperatures are projected to continue to increase, as is the length of the summer stratification period. Heavy precipitation events will increase in frequency and intensity.
Is there evidence of climate change already being observed in the area?	Increases in near-shore water temperatures of the Great Lakes are lengthening the period of summer stratification.[161] Heavier rainfall events are becoming more frequent.
Adaptive Capacity	
What is your system's adaptive capacity relative to climate change?	The adaptive capacity of species that may be affected by longer periods of stratification/dead zones will depend on their ability to find refugia.
C. Vulnerability Summary	
What is the relative vulnerability of your restoration project (including your targets, goals, and approaches)?	Medium/High.
What are the primary reasons?	In all lakes, the duration of summer stratification is projected to increase, adding to the risk of oxygen depletion and dead zones.[162] These changes could alter the dominant species found in a lake and potentially contribute to the extirpation of some fish species such as lake trout.[163]

Example A7. Illustrative Vulnerability Assessment for Oil Spill Damage Assessment, Remediation, Restoration.

A. Scope and Objectives	
What are your current restoration goals?	Restore habitat function in areas of concern.
What are your restoration targets?	Affected habitat/species.
What is the current status of your restoration target (e.g., what factors are contributing to BUIs?)	Dealing with polluting spills of chemicals, oil, hydrocarbons, and wastes are a relatively common problem in some areas.
What restoration approaches are you planning/ implementing to improve the status of your targets?	Reduce existing stressors; restore/emulate ecosystem functions through installation of containment and absorbent booms, physical clean-up of ecologically sensitive areas.
What is the expected lifetime of the project?	As needed, short term.
B. Components of Vulnerability	
Sensitivity	
How and to what degree are your restoration targets sensitive to climate conditions/variables?	If spill is located in floodplain, the area is sensitive to extreme precipitation events and flooding. Toxicity of the spill may be sensitive to temperatures.[164]
How and to what degree are your restoration approaches sensitive to climate conditions/variables?	Effectiveness of barriers and absorbent booms will be sensitive to extreme events such as storms.
Exposure	
How are climate conditions projected to change in the area?	Continuing trend of heavier rainfall events in fall/ winter; reduced precipitation in summer; higher average temperatures.
Is there evidence of climate change already being observed in the area?	Heavier rainfall events and flooding are becoming more frequent.
Adaptive Capacity	
What is your system's adaptive capacity relative to climate change?	There may be some adaptive capacity of the coastal habitat If the spill occurs in an area that has natural buffers/filters (e.g., dunes and beach grass). Adaptive capacity of response will depend on ability to anticipate and accommodate for possible extreme events.
C. Vulnerability Summary	
What is the relative vulnerability of your restoration project (including your targets, goals, and approaches)?	Low.
What are the primary reasons?	The increased potential for flooding during spill events is a concern, as it could pass oiled sediment and materials downstream or into neighborhoods. That said, cleaning up the initial spill is the priority regardless of climate change but should consider existing trends/conditions, especially extreme rain events.

Example A8. Illustrative Vulnerability Assessment for Amphibian Habitat Creation Project.

A. Scope and Objectives	
What are your current restoration goals?	Maintain, improve, or enhance populations of native species; enhance wetlands, wetland associated uplands, and high priority habitats.
What are your restoration targets?	Native amphibian species, floodplain pool habitat.
What is the current status of your restoration target (e.g., what factors are contributing to BUIs?)	River modifications (e.g., channelization and filling, reduction in riparian vegetation) have reduced the quality and availability of seasonal and permanent floodplain pools used as breeding habitat.
What restoration approaches are you planning/ implementing to improve the status of your targets?	Improve habitat connectivity; restore/emulate ecosystem functions by constructing floodplain pools, with connection to associated stream.
What is the expected lifetime of the project?	Infrastructure expected to last 30-50 years before it needs to be repaired/rebuilt.
B. Components of Vulnerability	
Sensitivity	
How and to what degree are your restoration targets sensitive to climate conditions/variables?	Timing and quantity of water available for pond habitat is sensitive to flow regimes. Water temperatures in pools are sensitive to changes in air temperatures. Many amphibian species are sensitive to changes in temperature and/or precipitation.[165]
How and to what degree are your restoration approaches sensitive to climate conditions/variables?	Effectiveness of project design will be sensitive to consideration of future streamflows and temperatures.
Exposure	
How are climate conditions projected to change in the area?	Continuing trend of heavier rainfall events in fall/winter; earlier peak flows in spring; reduced precipitation in summer; higher average temperatures.
Is there evidence of climate change already being observed in the area?	Greater extremes in precipitation events in the region as well as earlier peak snowmelt are altering the timing and volume of streamflows.
Adaptive Capacity	
What is your system's adaptive capacity relative to climate change?	Availability of refugia from high temperatures and altered flows will enhance adaptive capacity.
C. Vulnerability Summary	
What is the relative vulnerability of your restoration project (including your targets, goals, and approaches)?	Medium.
What are the primary reasons?	Changes in the timing of runoff may reduce availability of water inputs to floodplain pools at key times for amphibian breeding; higher temperatures and increased drought conditions in summer may adversely affect these temperature-sensitive species.[166] Certain habitat features may provide refugia.

Example A9. Illustrative Vulnerability Assessment for Wild Rice Habitat Restoration Project.

A. Scope and Objectives	
What are your current restoration goals?	Enhance wetlands, wetland associated uplands, and high priority coastal, upland, and inland habitats.
What are your restoration targets?	Wild rice habitat for harvest/wildlife conservation.
What is the current status of your restoration target (e.g., what factors are contributing to BUIs?)	Changes in hydrology due to dams/dikes, road construction; loss of vegetation cover to coastal development; invasive species encroachment (e.g., purple loosestrife).[167]
What restoration approaches are you planning/ implementing to improve the status of your targets?	Reduce existing stressors; restore/emulate ecosystem functions through construction of water flow control structures;periodic beaver dam removal to maintain optimal water levels; sowing wild rice seeds.
What is the expected lifetime of the project?	Indefinite.
B. Components of Vulnerability	
Sensitivity	
How and to what degree are your restoration targets sensitive to climate conditions/variables?	Wild rice habitats are sensitive to changes in the timing, duration, height/ elevation of annual and seasonal lake water levels and water flows.[168]
How and to what degree are your restoration approaches sensitive to climate conditions/variables?	Effectiveness of water flow management structures is sensitive to changes in average lake levels as well as changes in extremes.
Exposure	
How are climate conditions projected to change in the area?	In general, average Great Lakes water levels are projected to decline by mid-century due to a combination of increased evaporation and decreased inflow from surface and groundwater.[169] Evapotranspiration is likely to increase in all seasons. Continuing trend of heavier rainfall events in fall/ winter; reduced precipitation, lower streamflows in summer.[170]
Is there evidence of climate change already being observed in the area?	The region is experiencing higher average air and lake surface temperatures and reduced duration and extent of lake ice cover/increased stratification.[171] This is considered to be a precursor to declining average lake levels. Heavier rainfall events are becoming more frequent.[172] Snowmelt and runoff are occurring earlier in the year.[173]
Adaptive Capacity	
What is your system's adaptive capacity relative to climate change?	Adaptive capacity over the long term Is somewhat limited, as wild rice generally prefers minimal annual fluctuations in water level and stable or gradually receding water levels during the growing season.[174]
C. Vulnerability Summary	
What is the relative vulnerability of your restoration project (including your targets, goals, and approaches)?	Medium.
What are the primary reasons?	Access for human harvest may be limited during extreme low water events. Greater fluctuations in lake levels in the near term and decreases in average levels over the longer term could make current habitat areas unfavorable. Deep or flooding waters in early spring could delay germination of seed, leading to crop failures. Lower water levels late in summer could lead to more competition with other shallow water species. Long-term reductions in average lake levels may contribute to loss in wild rice habitat overall.[175,176]

Appendix B. Key Characteristics of Climate-Smart Conservation

How will conservation practice need to evolve to remain effective in light of rapid climate change? While these are qualities of good conservation generally, this list reiterates Chapter III to highlight attributes especially significant for climate adaptation.

- **Link actions to climate impacts.** Conservation strategies and actions are designed specifically to address the impact of climate change in concert with existing threats; actions are supported by an explicit scientific rationale.

- **Embrace forward-looking goals.** Conservation goals focus on future, rather than past, climatic and ecological conditions; strategies take a long view (decades to centuries) but account for near-term conservation challenges and needed transition strategies.

- **Consider broader landscape context.** On-the-ground actions are designed in the context of broader geographic scales to account for likely shifts in species distributions, to sustain ecological processes, and to promote cross-institutional collaboration.

- **Emphasize Ecological Processes and Dynamic Systems.** Natural habitats are described by structure and species composition as well as ecological processes. Successful restoration projects must consider establishing healthy ecological processes, even if species composition and structure change.

- **Consider Transformation of Ecological Systems.** Recognize that restoration to a previous ecological state may not be the best strategy. Where the previous ecological state may not be viable in a changing climate, restoration should anticipate and facilitate ecological transitions for the greatest success.

- **Recognize Uncertainty.** Projections of climate change, like any projections of the future, contain uncertainty about the magnitude and characteristics of climate change, as well as how, when, and where it will affect natural systems.

- **Adopt strategies robust in an uncertain future.** Strategies and actions ideally provide benefit across a range of possible future conditions (including extreme events) to account for uncertainties in climate, and in ecological and human responses to climatic shifts.

- **Employ agile and informed management.** Planning and resource management is capable of continuous learning and dynamic adjustment to accommodate uncertainty, take advantage of new knowledge, and cope with rapid shifts in climatic, ecological, and socio-economic conditions.

- **Minimize carbon footprint.** Strategies and projects minimize energy use and greenhouse gas emissions, and sustain the natural ability of ecosystems to cycle and sequester carbon and other greenhouse gases.

- **Account for climate influence on project success.** Managers consider how climate impacts may compromise project success, and avoid investing in efforts likely to be undermined by climate-related changes unless part of an intentional strategy.

- **Safeguard people and wildlife.** Strategies and actions enhance the capacity of ecosystems to protect human communities from climate change impacts in ways that also sustain and benefit fish, wildlife, and plants.

- **Avoid maladaptation.** Actions to address climate impacts on human communities or natural systems do not exacerbate other climate-related vulnerabilities or undermine conservation goals and broader ecosystem sustainability.

Anne de Haas Photography

Appendix C. Climate-Smart Worksheets: Climate-Smart Restoration Checklist & Climate Change Parameters

Worksheet 1. Climate-Smart Restoration Checklist

This worksheet was utilized with project partners as a framework for developing and scheduling climate-smart restoration projects.

Climate-Smart Action	Project Partners Involved	Notes	To Complete By	Complete (Y/N)
Identify Restoration Goals, Targets, and Approaches				
Sketch Climate Smart Process				
Assess Climate Change Vulnerability				
Review and Revise Goals, Targets, Approaches				
Identify and Select Climate-Smart Restoration Options				
Develop Monitoring Approach				
Implement Restoration Options				
Review, Revise, Reassess, Re-create				

Worksheet 2. Climate Change Parameters

This worksheet was utilized with project partners to better understand their concerns with certain climate change parameters and how they affect what's happening on-the-ground. This information directly informed the information needed to examine exposure as part of the climate change vulnerability assessment.

Parameter	**Relative Importance to Project** (extremely high, high, medium, low, or none)
Changes in precipitation patterns, e.g.:	
Increased intensity	
Greater winter/spring total	
Change in type	
Less summer total	
Greater fall total	
"Swings" between extremes wet and dry	
More frequent wet periods	
Change in intensity/frequency of extreme events	
Higher overall humidity	
Changes in ice conditions, e.g.:	
Longer ice-free periods	
Earlier break-up of ice	
Changes in air temperatures, e.g.:	
Higher average air temperature	
More total hot days	
More periods of consecutive hot days	
"Swings" between extreme hot and cold	
Fewer total cold days	
Higher low temperatures	
Change in seasonality of temperature rise	
Higher average water temperatures	
General change in water levels	
Other extreme events	
Other:	
Other:	
Other:	
Other:	

Appendix D. Case Studies - Climate-Smart Restoration in the Great Lakes

Eric Kelly

Case Study 1. The Lower Black River Climate-Smart Habitat Restoration Project

Introduction

The Lower Black River in Lorain, Ohio flows into southern Lake Erie just west of Cleveland. For more than 100 years there was heavy industry along the river's banks. It carries runoff from a 467 mi2 watershed, about half of which is agricultural. The river's water quality, aquatic life and in-stream habitats were severely impacted by these activities. Through the Great Lakes Restoration Initiative (GLRI) the Black River, an Area of Concern (AOC) because of many Beneficial Use Impairments (BUIs), is a focus area for restoration.

Several GLRI restoration projects are underway near the mouth of the river where by-product from steel production buried most of the site in millions of tons of slag and severely contaminated the river and adjacent uplands. On two adjacent sites one has been restored and another is in progress. The Phase III project (Project) is the assessment, engineering, and design for restoration of a third site, which was initiated in 2011 with a $350,000 grant. Restoration is intended for 4 to 7 acres of riparian habitat and 1,200 to 1,600 linear feet of river bank.

Climate change has the potential to affect the success of restoration of the Black River. Climate change is projected to cause more frequent and greater extremes in both droughts and floods. Stream temperatures will rise as air temperatures rise. These and other aspects of climate change were considered in the Phase III design for restoration, which is expected to improve the likelihood of meeting restoration objectives, increase longevity of the restoration, and reduce long-term maintenance costs.

Taking into account climate change in this restoration project was essentially a retrofit because it could be considered and accommodated only within the already established project objectives and methodologies. As in the two adjacent restoration projects, these objectives and methods were primarily restoration of fish habitat using various in-stream structures and bank stabilization, and restoration of riparian habitat by removing the slag from the floodplain and re-establishment of vegetation.

Assessment of the vulnerability of the site and restoration efforts to climate change was initiated by developing a matrix of various components of climate change

Don Breneman

Table D1. Suggested Climate-Smart Restoration Options for the Lower Black River Restoration Project.

Stream Restoration		
Project Component	Climate Change Vulnerabilities	Climate-Smart Options
Bank Restoration	Higher Water Velocity	Consider stronger structures
		Adjust height above water to account for generally increasing flows
		Revegetate to accelerate natural bank development
Fish Shelves	Greater water depth fluctuations	Install at different levels below water surface
Boulder Piles	Higher water velocity	Larger Boulders
Water Quality		
Temperature	Increasing air temperature	Stream-side revegetation
		Reconnect waterways
		Remove low-head dams
Nutrient Enrichment	None	Minimize sewage effluent
		Minimize urban runoff
		Minimize agricultural runoff
		Minimize non-climate stressors
Toxics	Increasing Precipitation and Flooding	Increase capacity of water collection and treatment systems
		Increase structural integrity of water collection and treatment systems
	Increasing temperature/flooding	Account for changing toxic transport and bio-availability
Riparian Restoration		
Project Component	Climate Change Vulnerabilities	Climate-Smart Options
Slag Removal	Flooding Increase	Maximize slag removal
Reforestation	Overall climate shift (especially temperature and precipitation)	Select species suitable in existing and projected climate
		Maximize species diversity
Herbaceous Revegetation	Overall climate shift (especially temperature & precipitation)	Maximize Species Diversity
Invasive Species	Overall climate shift (Especially Temperature and Precipitation)	Awareness and monitoring
		Aggressive action

with restoration objectives and methods (Table D1). This facilitated identification for further assessment of the mostly likely potential influences of climate change on the restoration project and the river itself.

Fish Vulnerability to Rising Temperatures

The most obvious characteristic of climate change is rising air temperatures. This is a concern for aquatic restoration projects because of the known sensitivity of fish and other aquatic organisms to stream temperatures. The initial vulnerability matrix identified this as a potential issue which necessitated more in-depth investigation.

The vulnerability of fish in the Black River to rising temperatures was assessed by determining the sensitivity of the present fish species to water temperature and their likely exposure to rising water temperatures. In 2010 and 2011 approximately 35 fish species, predominantly warm water species, were reported as present near the project site. High weekly mean water temperature thresholds of 22 of these species were found in the scientific literature. Projections of rising air temperatures and information on historic water and air temperatures were used as a basis for determining likely future water temperatures. The projected increase in air temperature by mid-century would likely cause a 3.1 ºF to 6.2 ºF (1.7 ºC to 3.4 ºC) increase in weekly mean water temperature.

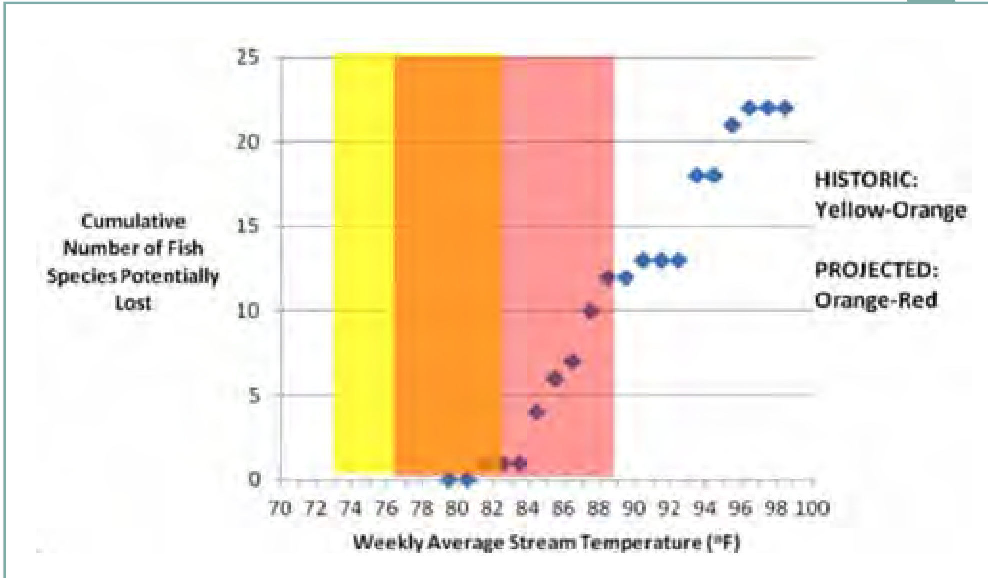

Figure D1. Cumulative Number of Species Potentially Lost with Temperature Increase.

The cumulative loss of fish species as temperatures rise indicates that 50% of the species could disappear at the higher end of projected water temperature increases (Figure D1). Among the first species to be extirpated from the area would be the cool water species such as white sucker, yellow perch, and rock bass.

Once the high vulnerability of fish in the river to rising temperatures was determined, it provided direction for management actions to minimize exposure to increasing water temperatures. Restoration of streamside vegetation following removal of slag may help minimize increases in stream temperatures. If upstream areas have significant loss of stream cover, revegetation of these areas may be beneficial. Actions that maintain higher summer stream flow, such as reconnecting upstream waterways to the river where they have been lost, may minimize stream temperature increase because of the great thermal inertia of larger volumes of water.

Species Used for Reforestation

The initial vulnerability matrix also identified that tree species for reforestation of the riparian habitat also required further assessment. Using the U.S. Forest Service Tree Atlas we assessed the likely suitable climate of various tree species for reforestation. Ideal species would be those wherein both existing and future climates are suitable. Species less desirable for restoration are those wherein the current climate, and/or especially the future climate, are not suitable. The restoration site has a suitable existing climate, as well as for most projections of future climate, for 18 of the 20 tree species that have previously been used for restoration on nearby tracts (Figure D2).

Lessons Learned and Recommendations

1. Climate change considerations were not initially "intuitive" to project planners. While there was general understanding that the region is expected to warm and that precipitation patterns and lake levels could change, it was initially unclear where and how such changes might be relevant to the specific project. The framework highlighted in Restoring the Great Lakes Coastal Future offered an extremely useful guide to at least help the project leaders ask some of the right questions, such as whether and how restoration targets as well as approaches are likely to be sensitive to climatic variables.

Species Previously Used for Restoration	Scientific Name	Suitability in Historic Climate	Suitability in Future Climate	USFS Model Reliability
Black Walnut	*Juglans nigra*	Okay	Okay	Medium
Black Willow	*Salix nigra*	Okay	Okay	Low
Chokecherry	*Prunus virginiana*	Okay	Okay	Low
Eastern Cottonwood	*Populus deltoides*	Okay	Okay	Low
Eastern Redbud	*Ceras canadensis*	Okay	Okay	Medium
Eastern White Pine	*Pinus strobus*	Okay	Low	High
Flowering Dogwood*	*Cornus florida*	Okay	Okay	High
Northern Red Oak*	*Quercus rubra*	Okay	Okay	High
Pin Oak	*Quercus palustris*	Okay	Okay	Medium
Red Maple*	*Acer rubrum*	Okay	Okay	High
River Birch	*Betula nigra*	Okay	Okay	Low
Serviceberry	*Amelanchier spp.*	Okay	Okay	Medium
Shagbark Hickory	*Carya ovata*	Okay	Okay	Medium
Shortleaf Pine	*Pinus echinata*	Low	Okay	High
Silver Maple	*Acer saccharinum*	Okay	Okay	Medium
Slippery Elm*	*Ulmus rubra*	Okay	Okay	Medium
Swamp White Oak	*Quercus bicolor*	Okay	Okay	Low
Sycamore	*Platanus occidentalis*	Okay	Okay	Medium
Wild Plum	*Prunus americana*	Low	Low	Low
Yellow-Poplar	*Liriodendron tulipifera*	Okay	Okay	High
* Species Likely to fare best in both existing and future projected climate				

Figure D2. Species Suitability for Planting.

2. Vulnerability assessment work was conducted primarily by NWF under the climate-smart grant, not by the restoration project planners. While the original project proposal for Clinton River Spillway that was submitted to and funded by NOAA indicated that a vulnerability assessment would be part of the project activities, the actual assessment was conducted by NWF, in consultation with the project partners. This was appropriate given NWF's climate change expertise, the relative lack of expertise among project planners, and the relatively short timeframe and funding available. For future projects it might be worth investing in some Assessing vulnerability and developing climate-smart approaches to the Phase III Black River restoration project were done by consultants (in this case, the National Wildlife Federation). An initial onsite meeting familiarized NWF with the project as well as personnel of Coldwater Consulting, the project implementers. In turn, Coldwater Consulting increased its awareness of the need to consider climate change in design and implementation of restoration projects.

3. Although conducted by NWF, project partners were eager to incorporate the climate assessment results into their project because climate-smart options were site specific, they didn't need to themselves engage in the intricacies of climate projections, and costs of modifying the restoration practices for the site were minimal. Another restoration project in progress adjacent to Phase III was quickly modified to account for climate change.

4. The climate-smart assessment for this project should have applicability to other restoration projects on the Black River. Although assessments used information specific to the Black River and locality, the general approach is a model for making restoration projects in other areas climate-smart. The special expertise required for assessing climate vulnerabilities and management options indicates suggests that in most cases restoration managers will need to seek outside assistance.

Case Study 2: Climate-Smart Habitat Restoration in Muskegon Lake Area of Concern

Introduction

Muskegon Lake is a 4,150 acre drowned river mouth lake on the eastern shore of Lake Michigan. The Muskegon River is the major tributary to the lake, which is connected to Lake Michigan via a navigational channel, and additional tributaries include Mosquito Creek, Ryerson Creek, Ruddiman Creek, Green Creek, and Four Mile Creek. Bear Lake is a shallow lake connected via a channel to Muskegon Lake. A number of factors, including historic industrial and municipal discharges, have contributed to longstanding impairments in the lake, which was identified as an Area of Concern (AOC) in 1985.[177] Sawmill, commercial, and industrial wastes and materials have been in place at nearly 800 acres of the lake and wetlands, and shoreline hardening has affected three-quarters of the lake.[178] As of spring 2013, seven beneficial use impairments (BUIs) remain in place at the AOC, including eutrophication or undesirable algae, degradation of benthos, and loss of fish and wildlife habitat.[179] Remedial Action Plan (RAP) work for the AOC has been coordinated by the Muskegon Lake Watershed Partnership, with support from the Muskegon Conservation District and the Natural Resources Conservation Service.[180] Restoration work in recent years has been augmented by substantial federal funding, including a $10 million grant through the American Reinvestment and Recovery Act in 2009.[181] In spite of extensive restoration work, impairments in Muskegon Lake remain, including contaminated sediments, altered/degraded habitat, and presence of invasive species.[182]

In 2011, the West Michigan Shoreline Regional Development Commission (WMSRDC), partnering with the Great Lakes Commission and Annis Water Resources Institute (AWRI) of Grand Valley State University, were awarded a Great Lakes Restoration Initiative (GLRI) habitat restoration grant through the National Oceanic and Atmospheric Administration (NOAA).[183] One major emphasis of the grant is fish and wildlife habitat restoration, and following implementation it is envisioned that three of the remaining

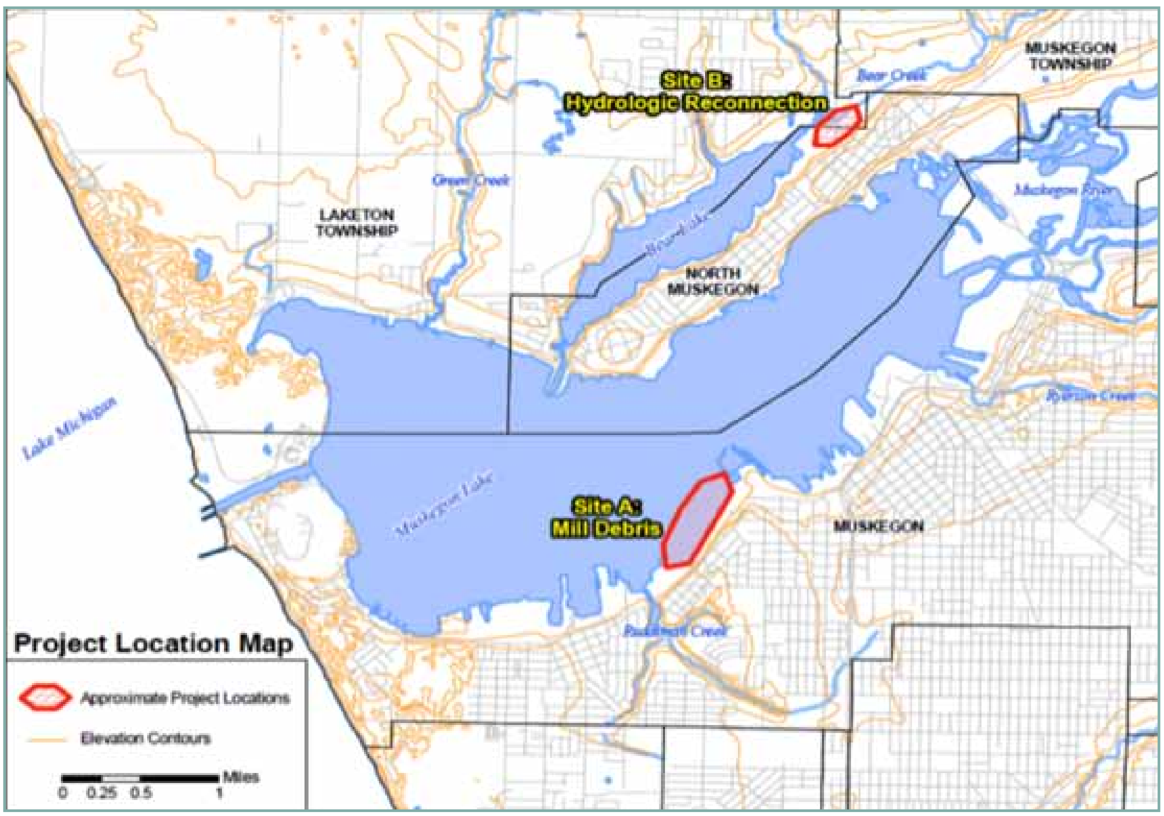

Figure D3. Location of mill debris and hydrologic reconnection sites for habitat restoration engineering and design project, Muskegon Lake AOC. (Figure from West Michigan Regional Shoreline Development Commission).

BUIs would be removed (loss of fish and wildlife habitat, degraded fish and wildlife populations, and degraded benthos). The habitat restoration work has two distinct components – removal of mill debris along the southern shoreline of Muskegon Lake, and hydrologic reconnection of wetlands adjacent to Bear Creek, the major tributary to Bear Lake (Figure D3). The mill debris removal component addresses slab wood and other debris on approximately 40 acres of shallow lake bottom, thought to be impairing habitat for aquatic plants and other aquatic life (Figure D4).

The hydrologic reconnection project aims to reconnect a diked, 43-acre wetland site (formerly used for celery farming) to Bear Creek (the main tributary to Bear Lake). One potential concern with the project is elevated nutrient levels (in particular phosphorus) in the wetland sediments, and potential for increased mobilization into Bear Creek, and subsequently Bear Lake. Bear Lake is a lake with frequent harmful algal blooms (HAB),[184] and increased phosphorus loads could exacerbate the HAB problems. In addition to the habitat restoration emphasis of the overall project, the other emphasis in the NOAA project is broader regional outreach on lessons learned from the marine debris operations, to be shared in support of the NOAA marine debris program addressing similar sites in near-shore areas throughout the U.S. portion of the Great Lakes Region.[185]

Climate Change Vulnerabilities

As with other coastal areas in the Great Lakes, the Muskegon Lake AOC will be subject to threats from climate change, with potential to cause direct stresses and exacerbate other stresses. Given the different contexts for the two restoration sites, vulnerabilities were considered for the two sites separately.

Figure D4. Slabwood mill debris from south shoreline near Site A.

The mill debris site is located in generally shallow water (i.e. typically less than about 3 meters, and commonly less than one meter) (Figure D4; also nautical chart [186]). Given the shallowness, an important factor affecting the site is water levels, and thus Lake Michigan water levels. Water levels in Lakes Michigan and Huron (considered one body hydrologically) have varied by over 1.9 meters over the instrument record (since the 1860s), though the lakes have seen persistently low levels for over a decade, and there has been an overall decline of approximately 0.8 meters in the head difference between Lakes Michigan-Huron and Lake Erie since 1900, due to a combination of differences in net basin supplies (between the lake basins), conveyance changes in the St. Clair River, and glacial isostatic adjustment.[187] Indeed, Lakes Michigan-Huron set a record low level of 175.57 meters for January 2013,[188] though the levels have since rebounded significantly. Lake level projections out several decades with climate change have varied, though most models and scenarios have typically predicted a decline in Lakes Michigan-Huron levels;[189] however, a recent modeling effort using an alternative approach to estimate evaporation and an A2 climate change scenario (i.e. high emissions) resulted in lower declines (e.g. approximately one meter for Michigan-Huron using one model, and an increase of approximately 0.4 meter using another model, in the 2081-2100 period).[190]

In a recent study on sediment-water nutrient exchange in Great Lakes coastal wetlands, it was noted that with a one meter water level decline, much of the area within the proposed mill debris removal site in Muskegon Lake would be above water.[191] An additional issue with changing water levels and climate change would be any changes in wave action and ice scour (e.g. moving lakeward with decreased water levels and potentially affecting slabwood more regularly).

In addition to water levels, an additional factor relevant to target conditions is water temperature. Though not as directly tied to the presence of the mill debris, some coolwater fish species in the area could in the future potentially be at risk from elevated summer temperatures, and thus increased refuge (potentially including new wetland habitat in the area currently occupied by mill debris) could be important. In addition, sediment-bound contaminants can be released at higher rates with increasing temperature,[192] and this process would be compounded with lower water levels. A related climate impact would be increased length of the stratified period in Muskegon Lake, potentially leading to more extensive oxygen depletion in the bottom waters, with implications for fish species seeking thermal refuge there.

In contrast to the lacustrine environment of the mill debris site, the wetlands that make up the proposed hydrologic reconnection site are (potential) riverine wetlands along Bear Creek (Figure D3), and thus streamflow is an important variable in considering vulnerability to climate change. Streamflow in the region has generally increased over the past 5-7 decades, in particular for low and moderate flow events.[193] In contrast, there has been a general decline in peak streamflow and one-, three-, and seven-day maximum discharge in Bear Creek for the period 1966-2012,[194] as determined using the Indicators of Hydrological Alteration tool.[195] Concerning projected changes with climate change, results have varied between models and efforts, though there has been a general finding of increase in annual mean precipitation in the region, in particular in winter months.[196] Modeling of streamflow and a number of other parameters for the Muskegon River watershed found increased streamflow (up to 18% for maximum flow) using the A1B scenario and business as usual (concerning development/land use changes) by the end of the 21st Century.[197] This study also identified the importance of considering potential land use changes as well as climate; for example, a scenario with identical climate forcings but reduced urban sprawl would lead to an increase of the 5th highest percentile flow event by only 7%, compared to 22% for the A1B scenario with business as usual (i.e. continuation of recent trends) in urbanization.[198]

Regarding the hydrological reconnection project, connecting the wetlands to Bear Creek would potentially allow for increased phosphorus movement from the old celery fields into the creek, and then Bear Lake. In a recent study of wetlands just upstream of nearby Mona Lake, there was an increase in total phosphorus concentrations by a factor of 2.6 downstream as compared to upstream of the flooded celery fields. Direct measurements of phosphorus in the former celery fields indicated high phosphorus levels, and other evidence supported the hypothesis that the fields were contributing the phosphorus to the creek, and subsequently leading to the elevated loads to Mona Lake.[199] Though the paper did not reference climate change, increased storm events would have the potential to mobilize additional phosphorus from the Bear Creek wetlands into the creek and Bear Lake. An additional issue would be for extremes on the lower end (e.g. droughts leading to lower levels, followed by rewetting), with additional potential for phosphorus mobilization.

Design Considerations

For the mill debris site, research in the engineering and design phase has included sampling, both by the NOAA Great Lakes Environmental Research Laboratory (GLERL) involving an acoustic sediment survey, and by the Grand Valley State University Annis Water Resources Institute (AWRI) to assess benthic condition. The surveys were intended to help identify the extent of debris removal necessary to restore habitat at the site. Implicit in planning has been the assumption that the mill debris is impairing habitat for aquatic plants and other biota.[200] Sampling to date has shown mixed results concerning both biotic conditions in general and any relationship to mill debris presence, and project partners have been trying to better understand potential resource benefits of more widespread debris removal in the area.[201] Outstanding questions include to what extent the debris, though unnatural, is allowing for establishment of a limited benthic invertebrate community, and whether debris removal may simply lead to establishment of aquatic plants (whether invasive or not) that do not contribute to improved habitat condition.

General water level decline would potentially lead to increased emergent vegetation or wet meadow habitat; if other research in the area has shown potential impairment by mill debris material on such vegetation development, debris removal may be recommended in the medium-term (if not carried out in the near-term), to provide this additional habitat, in particular if it could provide refuge for fish near their temperature thresholds in summer months. A related issue would be increasing water temperature (which could potentially be exacerbated with lower water levels), and the potential to enhance contaminant loss from sediments. If such a scenario were considered to be significant enough following modeling, this could have implications for decisions on timing of debris removal.

Similarly, generally lower water levels lead to the potential for increased wave action and ice scour affecting the debris, with additional implications for any contaminants remaining in the debris or associated sediments. If subsequent work confirms significance of these threats, it may be advisable to remove debris (possibly targeted in areas of greater amounts) to reduce vulnerabilities to the impacts of continuing presence of the debris. Lower water levels in general would lead to increased exposure of the debris, with potential implications for some aquatic life or wildlife. An additional issue of concern is the presence of aquatic invasive species in the area, including *Phragmites australis,* and prevention of spread/encroachment (regardless of decisions regarding debris removal) will be an additional management concern, in particular with persistent lower water levels. Finally, during and following debris removal operations, there would be the potential for enhanced mobilization of contaminants; timely revegetation if possible would help stabilize sediments, and potentially reduce mobilization. These vulnerabilities and design options are summarized in Table D2 below.

For the hydrologic reconnection site, one principal design question has been to what extent the wetlands would be connected to Bear Creek (e.g., breaching in selected locations vs. complete removal of the dikes separating the wetlands from the creek). As part of this phase of the project, additional sampling for phosphorus (by AWRI) has been conducted at nine locations in the two wetlands; very high concentrations at several sites indicate significant quantities of phosphorus potentially available for release.

In order to prevent excessive phosphorus and nitrogen release from wetland sediments following connection, three options would include considering more restricted connections, implementing phosphorus treatment, or full conversion of the ponds to riverine wetlands, with associated water control structures. In the first case, selective breaching of the current dikes could potentially restrict to some extent phosphorus transport into the creek. Alum treatment has been used to address elevated phosphorus levels in lake sediments in the region,[202] though given the severity of this intervention, it would be advisable to have additional modeling work conducted to assess the potential magnitude of phosphorus mobilization otherwise prior to implementation. A final measure would be full restoration of the adjacent wetlands to the creek, with inclusion of water control structures, to help manage flow (and potentially phosphorus transport) from the wetlands into the creek, ensure Bear Creek has sufficient flow, and limit water transport from the creek into the wetlands during high flow periods.

In addition to concerns about impacts of higher flows in the creek, there would be concern with extremely low flows (in particular in the context of fish passage). Ensuring dike removal and/or breaches to sufficient depth would help ensure optimal fish passage conditions. An additional concern that may be even more pressing than at the Muskegon Lake mill debris is the threats from aquatic invasive species, in particular from *Phagmites australis,* which is already present in the Bear Lake and lower Bear Creek area.[203] Potential management options (e.g. early detection and rapid response efforts) to address this invasive plant should be considered as part of broader restoration planning and management for the wetlands, and would be carried out in any case (independent of climate change considerations).

As with the Muskegon Lake site, an additional climate stress may be warming water. Ensuring connectivity is maintained to the wetlands could help

Table D2. Climate Change Vulnerabilities and Potential Design Considerations.

Site	Climate Change Vulnerabilities	Potential Climate-Smart Options
Mill Debris	Potential sensitivity of some fish species to warming temperatures	Potential decision on earlier debris removal (if otherwise delayed), if research clarifies benefits
	Potential for increased mobilization of contaminants with increasing temperatures	Potential decision on earlier debris removal (if otherwise delayed), if research clarifies benefits
	Potential increased wave action and ice scour of debris with decreased water levels	Potential decision on earlier debris removal (if otherwise delayed); would likely require further research on significance of impacts, potential benefits
	Potential exposure of debris with decreased water levels	Potential decision on earlier and broader debris removal (if otherwise delayed), if research clarifies benefits; would also need to consider potential encroachment by invasive plants (such as *Phagmites*)
	Potential for increased mobilization of contaminants during/following debris removal	Timely revegetation could help stabilize sediments
Hydrologic Connection	Potential increased mobilization of phosphorus and nitrogen with increased number/magnitude of storm events, variability of flows	Consider more restricted connections (e.g. breaching rather than complete dike removal) Consider removal or chemical treatment (e.g. application of alum) prior to breaching to address phosphorus Consider full restoration of the wetlands, with water control structures to limit water/phosphorus movement from wetlands, and water loss from creek during high flow events
	Potential loss of connectivity between creek and wetland during low flows	Ensure excavation of dike/breaches at levels to allow water movement even during low flow periods
	Potential increased risk of spread of AIS, including with lower water levels	Ensure have plan (with monitoring, early detection, rapid response, and additional management) to address any incipient invasion by AIS (e.g. *Phragmites*).
	Some fish species may be sensitive to warming temperatures in Bear Creek, Bear Lake	Ensure maintain connectivity, for fish species that may seek refuge in wetlands
	Potential for increased HAB formation with warmer water temperatures	Consider potential for increased phosphorus mobilization in establishing any operating conditions of water control structures, or as part of broader reconsideration of loads to Bear Lake through Bear Lake TMDL

for fish species seeking some refuge in the wetlands. Finally, warmer water temperatures could exacerbate the harmful algal bloom problems in Bear Lake; thus reconsideration of nutrient reduction targets (with potential implications for nutrient losses from the wetlands complex) would be helpful in ensuring that HAB targets can be met even in a warming climate. Again, vulnerabilities and design options are summarized in Table D2 above.

Lessons Learned and Recommendations

1. Though climate change considerations had not been a major focus of planning within most of the myriad restoration efforts in the Muskegon Lake AOC prior to this project, project partners had a clear interest in exploring these issues, including drawing on potential related experiences they may have had in related projects.

2. In the case of the mill debris site, potential near-term climate change implications did not appear to be as critical in restoration planning, though the potential for significant declines in water levels over the medium-long term were recognized (as well as further research on the potential implications, including with respect to the timing of debris removal and any associated benefits).

3. In the case of the Bear Creek hydrologic reconnection project, the climate change implications were clearer, and a major concern identified was potential for increased mobilization of phosphorus from sediments in the former celery ponds into Bear Creek (and Bear Lake) during higher flow events. With partners, several options were identified to address this concern, including more restricted connection to the river, alum treatment of sediments, or full wetland restoration (but with water control structures).

In addition to addressing the two key components in the current restoration project, it was recognized that numerous other efforts will continue in the Muskegon Lake AOC in the near- to medium-term,[204] and it will be important that climate change considerations be incorporated into planning across these numerous restoration and remediation activities.

Case Study 3. Climate-Smart Habitat Restoration of the Clinton River Spillway, Michigan

Introduction

In 2011, NOAA granted $339,500 to the Macomb County Public Works Office to conduct engineering and design work for restoration of fish and wildlife habitat in the Clinton River Spillway. This project was chosen to be part of the NOAA climate-smart restoration effort for two reasons: 1) the system itself is highly sensitive to climatic variables, including higher temperatures, altered precipitation patterns, and increased variability in lake levels – as such, the project design will need to take those variables into consideration; and 2) the system also illustrates one way in which human communities may respond to climate change in the future, and underscores the importance of trying to find ways to support multiple ecological goals for both people and wildlife. This is an interesting case of the complex interrelationships between human and natural systems, whereby hydrologic and ecological challenges due to rapid urbanization throughout the Clinton River Watershed led to engineering approaches, such as construction of dams and drainage canals, to alleviate adverse impacts such as downstream flooding, but created other ecological problems as a result. The Clinton River Spillway itself is not a "natural system" in the traditional sense. As such, the restoration effort is more of a renovation effort looking to provide ecological benefits such as fishing and other recreational opportunities to nearby communities.

To help develop this into a climate-smart project, NWF and EcoAdapt worked with project leads over the past two years to apply the principles and approaches laid out in *Restoring the Great Lakes Coastal Future.*[205] After an initial scoping meeting and site visit, we engaged staff at Hubbell, Roth, & Clark, Inc., the consultants leading the project, in an ongoing dialogue to identify key areas of vulnerability to climate change and ways to address them in designing the project, as described below. This effort was intended to provide a general climate change context for the project and offer a suite of possible management options for consideration as the project moves forward to implementation, which is conditional upon additional funding.

Background on the Clinton River Spillway

The Clinton River Spillway is a two mile-long canal that extends between the Clinton River confluence and the mouth of Lake St. Clair, northeast of Detroit, Michigan. The Spillway is part of the broader Clinton River Area of Concern (AOC), which has many of the same problems pervasive throughout the Great Lakes region after generations of urban development, agriculture, and industrial activities.[206] The system as a whole is characterized by several Beneficial Use Impairments (BUIs): Loss of Fish and Wildlife Habitat; Degraded Fish and Wildlife Populations; and Degradation of Benthos.

Despite notable improvements in water quality in recent years due to reductions in point-source pollution under the Clean Air Act, rapid urbanization throughout the watershed has resulted in a significant increase in impermeable surfaces and increased runoff into the Clinton River and its tributaries.[207] The result has been significantly increased "flashiness" (increased frequency of higher flows and velocities) throughout much of the lower watershed, as well as nonpoint pollution consisting of sediments, nutrients, bacteria, organic chemicals, and inorganic chemicals.[208,209] This has led to problems such as streambank erosion, deterioration of fish and wildlife habitat, and increased local and regional flooding, which were periodically intensified by high lake levels.[210]

To alleviate associated chronic flooding problems in the City of Mount Clemens and downstream areas in Clinton and Harrison Townships, the U.S. Army Corps of

Engineers (USACE) completed the Clinton River Spillway in 1952, adding a fixed-crest weir in 1954. Although the Spillway has served its originally-intended purpose to reduce historical flooding, it contributed to stagnant river conditions in the natural Clinton River below Mount Clemens. This is because, while most of the discharge was intended to remain in the natural river during low flow conditions, much of the flow still ended up going into the Spillway channel. As a result, fishery runs became concentrated in the Spillway at the expense of the mainstem, which was plagued by sediment deposition and associated water quality and habitat degradation throughout the lower river system and near-shore Lake St. Clair.[211] In response, USACE installed an adjustable (inflatable) weir at the head of the Spillway in 1994 so it could be raised to direct more water down the mainstem when flood control is not required. Within the Spillway itself, poor water quality (e.g. eutrophication) and erosion problems have been primary issues of concern, largely due to high angler traffic in riparian areas, drainage pipe discharges, and stagnant conditions during low flow periods (particularly in summer). Furthermore, baseline surveys conducted for the 2013 Draft *Basis of Design Report* indicated "marginal" instream/riparian habitat, reflecting a system that "lacks suitable habitat complexity."[212]

Vulnerability to Climate Change

NWF conducted a review of existing scientific literature to identify the vulnerability of target species, habitats, and ecological systems associated with the Clinton River Spillway project as well as major climate change drivers projected for the region. In particular, we focused on the key focal areas for restoration: in-stream habitat, riparian/upland habitat, lakeshore habitat, and target fish species. While not exhaustive, the assessment was designed to enhance and compliment information about existing baseline conditions established for the project under its Quality Assurance Project Plan (QAPP), which includes real-time conditions for water quality, water velocity, bank erosion areas, habitat conditions, and species assessments.[213]

Several aspects of climate change vulnerability stood out as especially relevant to the project partners. Among the potential impacts, projected increases in the intensity and frequency of heavier precipitation events and heat waves in the region associated with climate change are expected to exacerbate changes in in-stream hydrological conditions, including increased flooding as well as low flow events.[214] This will likely pose challenges not only for continued flood control in the region, but also for maintaining ecological conditions (e.g. optimal water temperatures) that support target fish and wildlife.[215,216,217,218] Increased variability in Lake St. Clair water levels associated with changes in precipitation patterns are also expected to alter conditions in the Spillway and the mouth of the Clinton River over the next few decades, although overall lake level trends over the long term remain uncertain.[219] Greater extremes in high and/or low lake levels would affect the composition of coastal wetland species sighted for lakeshore restoration, as well as alter the connectivity between the lake and the Spillway. A related concern for this project is the vulnerability of target fish species to higher average temperatures, altered streamflows, variable lake levels, and declining ice cover. Several focal species are highly sensitive to changes in water temperatures, which are projected to rise under climate change.[220,221] Finally, changes in both temperatures and precipitation will affect the climatic suitability of riparian vegetation being considered for restoration.[222,223]

Design Considerations for the Clinton River Spillway Project

Based on the key vulnerabilities, NWF worked with project partners to identify several ways in which proposed restoration design and management options could be made climate-smart (Table D3). These options are being considered as the project design work nears completion, and they will continue to inform restoration decisions for this project as it moves forward to implementation.

Lessons Learned and Recommendations

1. Climate change considerations were not initially "intuitive" to project planners. While there was general understanding that the region is expected to warm and that precipitation patterns and lake levels could change, it was initially unclear where and how such changes might be relevant to the specific project. The framework highlighted in Restoring the Great Lakes Coastal Future offered an extremely useful guide to at least help the project leaders ask some of the right questions, such as whether and how restoration targets as well as approaches are likely to be sensitive to climatic variables.

2. Vulnerability assessment work was conducted primarily by NWF under the climate-smart grant, not by the restoration project planners. While the original project proposal for Clinton River Spillway that was submitted to and funded by NOAA indicated that a vulnerability assessment would be part of the project activities, the actual assessment was conducted by NWF, in consultation with the project partners. This was appropriate given NWF's climate change expertise, the relative lack of expertise among project planners, and the relatively short timeframe and funding available. For future projects it might be worth investing in some dedicated climate-smart conservation training for restoration project team members early on.

3. Project partners were especially interested in climate-smart restoration options that would support target species and habitats under both current and a range of potential future climate conditions. Rather than assume, for example, that average water levels in Lake St. Clair would decline over the longer term, as some models project, project planners are considering a design for lakeshore wetland restoration that will be resilient under variable lake levels as well as variable flows from the Spillway. In addition, they are looking at plant species that can persist under current and projected climate conditions for restoration of riparian areas along the Spillway.

Table D3. Suggested Climate-Smart Restoration Options for the Clinton River Spillway Habitat Restoration Project.

In-Stream Habitat Restoration		
Project Component	Key Climate Change Vulnerabilities	Potential Climate-Smart Options
Creation of river channel geomorphic features	Higher water velocity increases risk of down-cutting Higher water temperatures due to heat waves and low flow events threatens target fish species	Incorporate recent trends and projections for precipitation and streamflow when designing structures such as rock veins and riffles Identify ways to create in-stream refugia from high temperatures, such as deep pools and off-channel habitats
Regulation of water flows through weir operation	Effective weir operation is vulnerable to greater variability in streamflows, affecting relative hydrological conditions in the Spillway and natural river channels	Project partners should consider working with other relevant stakeholders (e.g. the U.S. Army Corps of Engineers) to consider possible re-design of the weir to accommodate impacts of climate change
Water quality improvement	Increased runoff upstream may contribute to greater pollution in the Spillway	Work with the broader community to further reduce impervious surfaces, use of fertilizers and other pollutants
Riparian Habitat Restoration		
Project Component	Key Climate Change Vulnerabilities	Potential Climate-Smart Options
Streambank stabilization	Higher water velocity increases risk of streambank erosion	Consider current and projected trends for stream velocity when designing bank stabilization measures
Removal of invasive species	Some species may gain a foothold with changing climate conditions	Monitor conditions to keep ahead of possible species expansion Consider where invasive species might still provide some ecological function in light of climate change
Revegetation of riparian/upland habitat	Some plant species are vulnerable to changes in temperatures and/or precipitation patterns	Consider planting species for which climatic conditions are currently and projected to be favorable Consider other possible benefits of plantings to ameliorate other climate stressors, such as those that provide shade to help moderate stream temperatures
Lakeshore Habitat Restoration		
Project Component	Key Climate Change Vulnerabilities	Potential Climate-Smart Options
Removal of coastal armoring	Increased variability of water levels in Lake St. Clair increase vulnerability of coastal habitats, especially where armoring hinders migration or alters processes such as sedimentation Connectivity of the lake to the Spillway may be vulnerable during low lake level events	While removal of coastal armoring will allow for more "natural" shoreline conditions, it will be important to consider greater variability (highs and lows) in lake levels when designing slope, use of berms, etc. Consider ways to enhance lake/stream connectivity to enhance fish passage
Revegetation of wetland habitat	Types of wetland species, habitat types are vulnerable to extremes in lake levels and altered streamflows	Consider planting across a relatively broad coastal area to enable plants to move upland or lakeward Choose a diversity of plants, including perennials and annuals, to increase likelihood some functionality can be maintained

Case Study 4. Climate-Smart Habitat Restoration in the Maumee Area of Concern

Introduction

The Maumee Area of Concern (AOC) is located from Ft. Wayne, Indiana spanning 130 river miles to Lake Erie. A majority of the Maumee AOC is within Ohio. The area includes direct drainage into the waters that are within Lucas, Ottawa and Wood counties. This includes Swan Creek, Ottawa River (Ten Mile Creek), Duck Creek, Otter Creek, Grassy Creek, Cedar Creek, and Crane Creek. In 1992, this area was extended to the east to include Turtle Creek, Packer Creek, and the Toussaint River. The Maumee Area of Concern (AOC) covers 775 square miles.[224]

This specific project will restore approximately 600 acres of wetland, forest, rivers and sedge meadow for one of the largest migratory landbird habitats in the country. The project site, which is adjacent to Lake Erie and the Ottawa National Wildlife Refuge, is currently fallow agricultural land. Many nutrients from fertilizers and pest control chemicals remain on and around the site, making it less desirable habitat for fish, birds and other wildlife. Restoration will create areas for fish passage, replant forests, rehabilitate wetlands and control harmful invasive species. The restored habitat will also provide places for visitors to view wildlife like the American black duck, blue-winged teal, king rail, wood thrust, and the Blanding's turtle.

The project is made up of four tracts of land: Blausey, Helle, Kontz, and Moist Soil Unit #2 (MSU#2), each with different restoration goals and approaches. Blausey is 171 acres of fallow agricultural land that is to be restored to wetland, and the approach is to rehabilitate by applying some water and relying on the seed bank. Helle is a 91 acre re-forestation project. Kontz is 70 acres of a hydrologic reconnection project to provide better habitat for fish and benthic organisms that use the area year-round. MSU #2 is 180 acres of restoration of wet woods, primarily for the habitat of landbirds. Maps of the units can be found in the appendices.

Project partners are using vulnerability assessments to determine how much climate change is affecting the site through heavier rainfall, warmer air temperatures, summer drought conditions, and other impacts. Partners are using this information to pick the types of trees to plant on the sites, and choose appropriate water control measures.

Climate Change Vulnerabilities

As an implementation project, the climate change vulnerability assessments needed to be targeted to restoration approaches already outlined in the project plan. As such, one of the first activities NWF conducted with project partners was an in-depth discussion on the climate drivers most affecting the restoration area. Using a climate drivers worksheet (see Appendix C), partners ranked relative importance of climate drivers to the project. These drivers include, for example, changes in precipitation, ice conditions, air and water temperatures. Project partners did a qualitative assessment of the relative importance (extremely high to none) of each climate drivers to the project. Partners found common agreement that changes in precipitation patterns such as increases in intensity and greater winter/spring total, and higher average air temperature are of high relevance to the project's vulnerability. This information helped to guide the type of climate science information needed for the vulnerability assessments.

NWF also conducted a review of existing scientific literature to identify the vulnerability of target species, habitats, and ecological systems associated with northwestern Ohio and the Maumee AOC. In particular, there was a focus on the key focal areas for restoration: wetland restoration, fish passage, and reforestation. While not exhaustive, the assessment was designed to enhance and compliment information about existing baseline conditions established for the project under its Quality Assurance Project Plan (QAPP), which includes real-time conditions for water quality, habitat conditions, and species assessments.[225]

Climate-Smart Implementation Approaches

Based on the key vulnerabilities, NWF worked with project partners to identify several ways in which proposed restoration design and management options could be made climate-smart, as summarized in Table D1. These options are being implemented as the project design work nears completion, and they will continue to inform restoration decisions for this project as it progresses.

Lessons Learned and Recommendations

1. Project partners understood the importance of integrating climate change into their restoration efforts but required guidance to move forward. From the initial meeting with project partners, there was an important discussion of impacts that they are noticing from variable climate and weather patterns. Partners were especially concerned with unpredictable swings of precipitation patterns such as heavy spring flooding and dry summer droughts and how these swings would impact the project. Even with this knowledge and experience, they did need some guidance as to how to integrate this information into project implementation. They generally approved of the approach that was recommended, however, relied on NWF to carry out the vulnerability assessment and make a suite of climate-smart recommendations from which to select Therefore, the actual vulnerability assessment was conducted by NWF, in consultation with the project partners, which was appropriate given NWF's climate change expertise, the relative lack of expertise among project planners, and the relatively short timeframe and funding available. For future projects it might be worth investing in some dedicated climate-smart conservation training for restoration project team members early on.

2. Knowledge of those who work the land is critical for climate-smart project success. Project partners from the Ottawa National Wildlife Refuge, The Nature Conservancy, and NOAA have an extensive knowledge of the land, the wildlife populations, and what constitutes a "normal" climate pattern. This knowledge

Table D4. Climate-Smart Implementation Approaches for Maumee AOC.

Site	Climate Vulnerabilities	Climate-Smart Implementation Approcahes
Blausey	Heavy spring rain causing flooding and runoff Frequency and intensity of seiche events Summer/fall drought	Emphasis on monitoring including: • Wildlife, changes to migration patterns • Wildlife, access of fish and water temperatures • Water flow patterns for proper water control, drought and flood – USGS flow monitors • Nutrient monitoring • Weather station, anemometers
Helle	Warmer air temperatures and more consecutive hot days Drier dry days/seasons Wetter wet days/seasons Intense or extreme flooding	Climate change vulnerability assessment for tree and shrub species to examine: • Types of trees and shrubs best suited for current and future climate • Create and select from a climate-smart tree and shrub list of species for reforestation Monitoring, including early detection for warmer temps and invasive species
Kontz	Heavy spring rain causing flooding and runoff Warmer water temperatures Variable water conditions	Climate change vulnerability assessment for fish habitat • Examine adaptive capacity to variable water flows and warmer water temperatures Recommendations for climate-smart fish passage include a way to deal with variable water conditions (e.g. fish ladder) Restore with shady shrubs species to cool water temperatures Monitoring, including early detection for warmer water temps, flows and invasive species
MSU #2	Warming air temperatures Changes to grasses, trees, and shrubs due to water and air temperature conditions Flooding and poor water quality from runoff	Climate change vulnerability assessment for landbird habitat • Examine adaptive capacity to warming air temperatures Expand monitoring sites to cover greater spatial variation to better understand changes to landbird habitat and behavior

contributes to qualitative data needed for a climate change vulnerability assessment, and also to the selection of climate-smart restoration options. The partners expertise can help make qualified estimates as to what may work and what may fail. Additionally, site visits are essential to view and better understand the project in more detail.

3. Vulnerability assessment work was conducted primarily by NWF under the climate-smart grant, not by the restoration project planners. Due to a short timeline for completion and funding availability, project partners relied on NWF to complete the climate change vulnerability assessments. Without a partner qualified in vulnerability assessments such as NWF, it is possible that project partners may not have the tools and skill set to move forward on their own. Moving forward, GLRI projects should either require a partner to become trained on vulnerability assessments or to engage with a partner who already has this expertise.

4. Climate and weather variability may delay actual implementation, therefore climate-smart restoration must account for this variability. In this case climate and weather variability delayed project implementation on the Helle tract for two reasons: (1) availability of tree seedlings was delayed due to abnormally dry conditions and (2) actual seedling plantings and seeding activities could not take place due to heavily flooded conditions in the winter and spring months (a time when planting is most successful). Climate-smart restoration must therefore account for this variability by having a back-up plan for implementation such as an extended timeline or a bank of resources, but also project funders must recognize that delays are a part of the process and support extending timelines for completion (Box 2). Though these delays may hinder short-term success, they will ultimately enhance long-term project success and reduce future costs.

Case Study 5. The Buffalo River Restoration

Introduction

Buffalo Niagara Riverkeeper was awarded $177,000 from NOAA in FY2011 to conduct habitat restoration design and engineering for RiverBend Phase II, a heavily degraded area in the Buffalo River Area of Concern. Currently there is no natural bank or floodplain habitat on the site, and the upland habitat is virtually barren. The design and engineering specifications would support the restoration of 1,520 linear feet of shoreline and 3.5 acres of upland habitat. Although small, the site is adjacent to several other recent, in process, or proposed restoration projects, both in-channel and upland, which together will create a larger mosaic of restored habitat.

EcoAdapt and NWF have worked with project leads over the past year to explore the application of climate smart restoration principles to this effort. This has included a site visit, the participation of the project lead in an EcoAdapt/Freshwater Future adaptation training workshop, a second in-person team meeting, and ongoing dialog via phone and email. Because project participants are all actively involved in numerous regional restoration projects, one goal of these interactions was to begin building capacity for climate smart thinking in these regional leaders. In particular, Buffalo Niagara Riverkeeper is the federally-designated Buffalo River Remedial Action Plan Coordinator, which should facilitate the transfer of lessons learned from this effort to future restoration work within the AOC.

Background on the RiverBend site

The RiverBend Shoreline Habitat Restoration Project is a two-phase project undertaken as part of a broader set of projects aimed at de-listing the Buffalo River as an International Joint Commission Area of Concern (AOC). Although the AOC extends only up to the confluence with Cazenovia Creek, the area covered by the Buffalo River Ecological Restoration Master includes the Buffalo River and its tributaries up to the first year-round impassible fish barriers on each tributary (Figure D5).

Phase I of the RiverBend Restoration Project includes 2,800 linear feet of shoreline and 6.29 acres of land in the upstream section of the RiverBend site. Restoration of Phase I is funded by GLRI funds from the United States Environmental Protection Agency (EPA). Phase II which is funded by NOAA, and is the primary focus of this report, consists of designing the restoration of 1,520 linear feet of shoreline and 3.5 acres of upland in the downstream section of the RiverBend site. The Army Corps of Engineers has remediated roughly 1 million cubic yards of contaminated

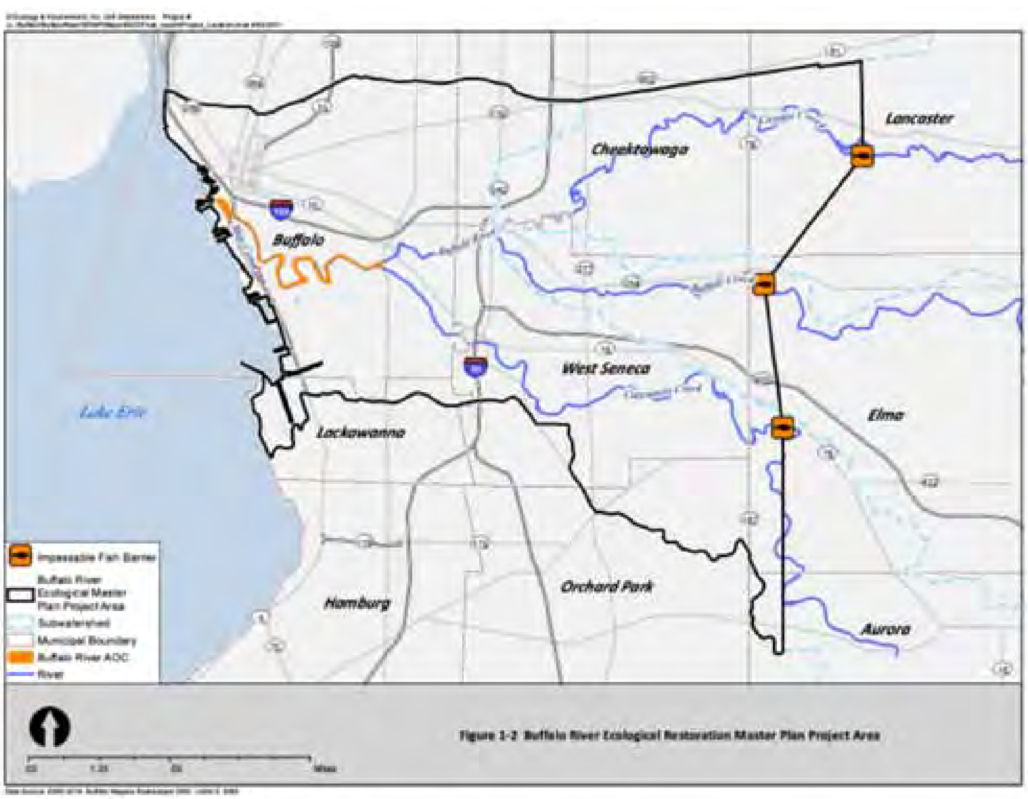

Figure D5. Buffalo River Ecological Restoration Master Plan Project Area. Ecology and Environment, 2011.

sediment in the adjacent channel, and a number of in-river restoration projects have been identified for the Great Lakes Legacy Act, including one directly adjacent to RiverBend Phase II.

The site is extremely degraded, consisting primarily of granular slag and some demolition debris with little or no soil on top of it. The site has been elevated over time, which in combination with extensive shoreline hardening has disconnected the site hydrologically from the river, and removed any floodplain function. The site has limited ability to hold water, limited organic matter, limited beneficial microorganisms, a high pH, and significant contamination with heavy metals and other pollutants. The poor substrate and flat aspect of the site combined with high prevailing winds and cold, long winters limit the ability of the site to support plant communities. Restoration to the pre-industrial state is prohibitively expensive.

This provides both a challenge and an opportunity. The system is so far removed from natural and supports so little life currently that there is the ability to experiment with a range of approaches. Also, the degree of degradation and alteration on this site is found in many other sites in the region slated for restoration. Thus this project could serve as a valuable testing ground for climate-smart restoration concepts that could be adapted and refined in similarly difficult sites.

Climate Change Impacts Critical to Project & Vulnerabilities

Because the Guide provided an overview of regional climate trends, impacts, and vulnerabilities, work for this project focused specifically on any information on local changes and on vulnerabilities specifically linked to project goals, objectives, and proposed design elements. This included reviews of relevant literature, data portals* and conversations with those with regional knowledge. The site is far enough up river that lake level changes, including seiches, are not reflected here; changes in river level result from changes in precipitation or land use within the Buffalo River watershed. Precipitation has increased locally over the past century, and total annual discharge for one of the main tributaries to the Buffalo River has likewise increased, as has variability and peak summer flows during wet years.

Water availability is a major problem for the site. There appears to be only a single area in Phase I uplands capable of holding any moisture, and during most rainfall events it appears that water flows straight down through the substrate with limited surface sheet flow. Restoration will address this to some extent, but it will be some time before enough organic matter is generated to hold significant moisture, leaving the site vulnerable to the potential increase in drought frequency.

*__Project tree species suitability:__ Prasad, A.M. L.R. Iverson, S. Matthews, and M. Peters. 2007-ongoing. A Climate Change Atlas for 134 Forest Tree Species of the Eastern United States [database]. http://www.nrs.fs.fed.us/atlas/tree, Northern Research Station, USDA Forest Service, Delaware, OH; **Temperature and precipitation trends**: The Carbon Dioxide Information Analysis Center (CDIAC) U.S. Historical Climatology Network (USHCN), http://cdiac.ornl.gov/epubs/ndp/ushcn/ushcn_map_interface.html; **Stream gage data**: US Geological Survey, Water Resources Data for the United States. http://waterdata.usgs.gov/nwis

A long-term decline in average river levels could allow establishment of invasive species if the mix of natives is not able to colonize newly exposed riverbed habitat quickly enough. Changes in precipitation regimes could affect how well the surface contouring succeeds in creating areas with sufficient soil moisture to support plant life, although it is likely that under anything but extremely severe drought conditions the restoration will improve soil moisture characteristics.

Climate-Smart Restoration Actions

The overall approach suggested by the project team—creating more contouring and a greater diversity of microhabitats within the site—is inherently adaptable to climatic change and variability. The group discussed whether the proposed mix of plant species could handle floods and droughts, heat waves and cold snaps,

Table D5. Possible Climate-Smart Restoration Options for the RiverBend Phase II Habitat Restoration Project.

Project Component	Key Climate Change Vulnerabilities	Potential Climate-Smart Options
Grading	Functionality of benches and shoreline undulations could be affected by changes in river level	The proposed undulations along the shoreline will support shallow-water habitat across a range of river levels
Removal of invasive species	Some species may gain a foothold if river levels follow a steady downward trend.	Identify areas at high risk of invasion for focused monitoring, and establish rapid response protocols for anticipated problem species In the shoreline area, plant native species that can rapidly colonize newly exposed riverbed; this may prevent establishment of or at least provide competition for non-native invasive species
Revegetation of riparian/upland habitat	Some plant species are vulnerable to changes in temperatures and/or precipitation patterns	Plant a mix of species that covers a range of climatic suitability. In the near term this means that some species will do well regardless of weather; in the long term it establishes a diverse seedbank. Avoid reliance on tree species likely unsuited to future climatic conditions
Surface contouring	Berms and depressions must be able to withstand periodic heavy rainfall.	Monitor depressions for structural and functional integrity following the first several heavy rain events.

as well as ongoing climatic changes. Uncertainty about climatic conditions at the broad scale was compounded by uncertainty at the site scale. The design plan being developed includes transforming a flat, barren, windswept plain with a step drop to the river and no hydrologic connectivity into a somewhat more contoured landscape, with a more gradual slope to the river and some shallow water habitat. Thus the microclimates and suitability for various species at the site level is unknown. The design team's approach to both site-level and climate-change-related uncertainty was to include a mix of plants with a broad range of tolerance across the site. The goal is to create a diverse mosaic that will allow plant communities to establish themselves across the site with the exact mix determined by what does well at that site. Also, plants able to survive in this highly degraded site are generally fairly hardy and adaptable, providing a base level of resilience.

Discussions amongst EcoAdapt and project team members addressed specific vulnerabilities of project design (Table D5), but also included broader discussions of designing for transition, not just in terms of climate change but in terms of longer-term recovery. Ideally the restoration design will facilitate natural processes that continue site recovery and adaptation over the long term. This includes creating microhabitats, locating proposed berm-depression features to support wildlife connectivity with the river, and focusing on hardy early successional species that will help to create moisture-retaining soil and keep non-native invasive species at bay.

Another topic of discussion following a review of the near final design plans was how to write the design and monitoring plan in a way that would make it easier for BNRK or other site managers to assess and respond to climate change effects. Anticipated implementation funding will cover only two years of monitoring, too little to provide much information about whether the climate smart elements were effective. While a detailed long-term monitoring and adaptive management plan is beyond the scope of this project, providing information about design assumptions or uncertainty will facilitate ongoing understanding of factors influencing project performance. Also, thinking about what information may be useful in five or ten years to assess climate change effects on the site will ensure that baseline monitoring captures the needed variables.

Lessons Learned and Recommendations

1. In the case of highly degraded sites, climate is unlikely to be the biggest consideration for plant selection in riparian or upland areas, since only fairly adaptable plant species will be able to survive site conditions.

2. Two or even four years, the typical monitoring length funded by these projects, isn't sufficient to tell you anything about climate change. Ideally restoration funders should support periodic monitoring of sites over the medium and long term; otherwise it will be difficult to know if the climate smart elements are working. It is also important that initial pre- and post-restoration monitoring collects the data that will allow later evaluation.

3. There is a difference between building capacity and making a single project

climate smart. Having an adaptation expert more thoroughly embedded in the design process might be on way to further enhance capacity-building.

4. Although all members of the project team were supportive of climate smart restoration, having a grant award condition from the funder to include climate change in project design and implementation was an important factor in ensuring climate change was actually addressed. Taking this further, it might be useful for NOAA to request that monitoring plans include a discussion of climate-related issues (ecological or design-related) of particular concern that managers should assess formally or informally over the longer term.

Case Study 6. Climate-Smart Habitat Restoration in Crow Island State Game Area

Introduction

The Crow Island State Game Area (CISGA) is a complex of wetlands and fields straddling the Saginaw River near Zilwaukee, Mich., approximately five miles downstream of Saginaw. Marshes along the Saginaw River have historically been important waterfowl habitat, but significant habitat was lost or degraded following extensive conversion to agriculture and other uses by the early 20th Century. Restoration efforts began following state purchase of land in the area in 1953, and with additional land acquisition, approximately 3,500 acres is now under state ownership and managed by Michigan Department of Natural Resources (MDNR).[226] Due in part to funding sources used in the land purchases, primary management goals have been restoration and management of wild birds and mammals and provision for public use of wildlife resources.[227] The CISGA is also within the Saginaw River and Bay Area of Concern (AOC), for which 12 beneficial use impairments (BUIs) were originally identified in 1987;[228] and two of which have been have been removed.[229]

Through the Great Lakes Restoration Initiative (GLRI), an engineering and design grant was awarded through the National Oceanic and Atmospheric Administration Restoration Center (NOAA) in 2011 to Ducks Unlimited (DU), to identify design options to improve wetland condition in the CISGA. Recent restoration efforts at the CISGA have focused on improving capabilities for water level management, including addressing invasive species (e.g. cattail) presence and spread. The emphasis for the 2011 NOAA project was on units on the east side of the Saginaw River, including addressing a failing pump drawing water up from the Saginaw River, a principal source of water to the 1,200 acres of marshes in the East and Panko Units (Figure D6), that are separated from the river by the elevated Bay Rd. The project included a topographic survey of the units and design work for a new pump and new water control structures along the perimeter that would allow for more effective water level management. Though not a focus of the NOAA grant, DU and project partners have explored options for marshland enhancement on the west side of the river, where principal sources of water are direct precipitation and seiche events (pushing Saginaw River water back upstream and into the units via a drainage ditch on the west side of the units (Figure D6). Following implementation, the NOAA restoration project was anticipated to contribute to delisting of three of the remaining BUIs: loss of fish and wildlife habitat, degradation of fish and wildlife populations, and eutrophication and undesirable algae.

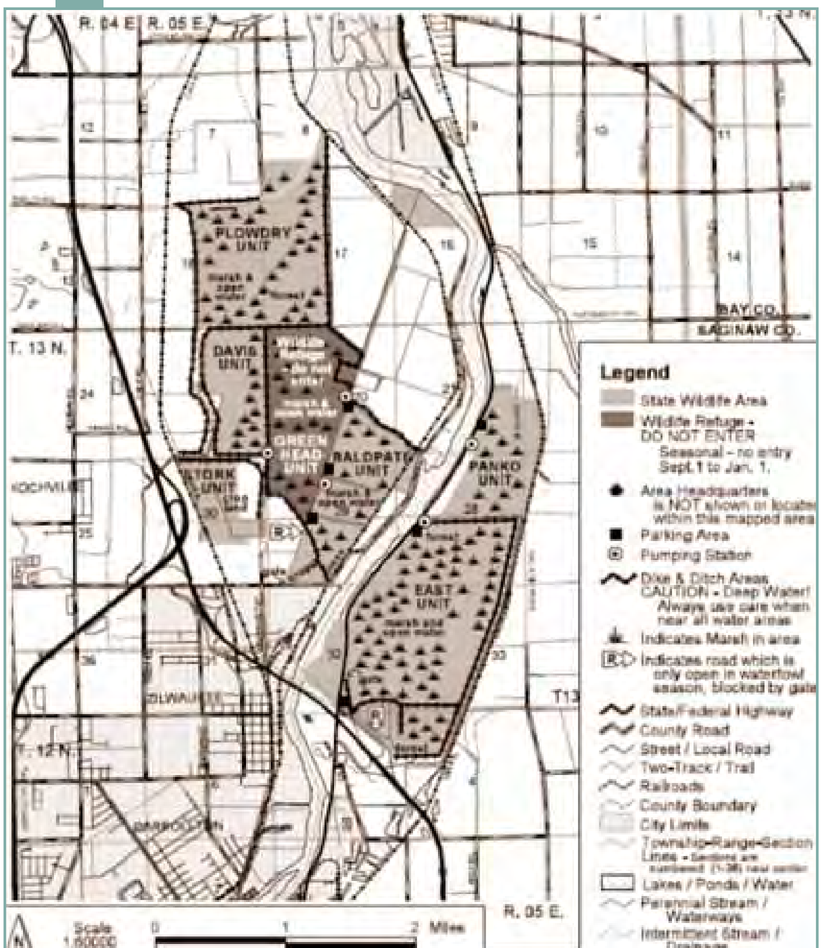

Figure D6. Crow Island State Game Area. (Map courtesy of Michigan DNR).

Climate Change Vulnerabilities

Given the importance of the Saginaw River to water supply in wetlands in both the east and west units, climate change impacts to streamflow were considered to be the most important in this assessment. Streamflow in the Midwest has generally increased over the past half century, in particular for low and moderate flow events.[230] However, data for the Saginaw River show generally decreased *peak* streamflow over the past century. [231] In addition, more recent daily discharge data for the river show relatively wide interannual swings in some parameters, such as one-day minimum flows and frequency of high flow pulses, as analyzed using the Indicators of Hydrologic Alteration (IHA) tool developed by The Nature Conservancy.[232] A recent analysis of historical (1901-2000) data showed that while many stations in the region had significant declines in mean periods without precipitation, the Saginaw Bay watershed showed no significant trends towards increased drier periods.[233] Projected changes in precipitation with climate change have varied between models and efforts, though projections generally show an increase in annual mean precipitation in the region, with most of the increase occurring in winter months.[234] In addition, the total precipitation falling on the wettest five day period is predicted to increase throughout the region.[235]

Extremely high flow events in the Saginaw River could lead to increased direct transfer of water into the east units (and potentially the west units), increasing the need to be able to drain water following flood passage. However, a bigger issue is the potential for increasing periods of low flow or drought;

low Saginaw River levels have implications for water supply for the east units, given the importance of pumping river water into the East Unit (Figure D6). Recent projections for the mid-21st Century show both decreased summertime precipitation across the region, as well as increases in the mean number of dry days in a sequence.[236]

As noted previously, a significant source of water to the west units is seiche events leading to water flows upstream from Saginaw Bay and the Saginaw River; and there is greater potential for supplies via seiche events during periods of higher Lake Huron water levels. Water level changes in Lake Huron differ from other Lakes such as Lakes Michigan and Huron (considered one body hydrologically), which relative to Lake Erie have declined by approximately 0.8 meters since 1900, due to a combination of conveyance changes in the St. Clair River, differences in net basin supplies (between the lake basins), and glacial isostatic adjustment.[237] Lakes Michigan-Huron set a record low level of 175.57 meters in early 2013,[238] but levels have since come back up significantly. Projected changes in Great Lakes levels with climate change have varied, though most models and scenarios have typically predicted declines in Lakes Michigan-Huron levels by mid-late 21st Century. [239] However, a recent modeling effort using an alternative approach to estimate evaporation and a high emissions (A2) scenario resulted in lower declines predicted, and even an increase using one model, in the 2081-2100 period.[240] Wind direction and persistence is another factor that can affect water supply to the CISGA. An earlier study found a decadal shift in summertime wind direction in the Great Lakes, including a shift over Lake Huron from generally southwesterly winds in 1981-1985 to more variable winds in 1995-1999,[241] which has implications for seiche events. Recent data from the weather station at Flint, Mich. show increasing swings in prevailing wind direction over the past 10-15 years.[242] Several factors, including generally lower Lake Huron levels, shifts in wind direction and intensity, and/or decreased overland precipitation (and low Saginaw River levels) could lead to low supplies of water to the west units via seiche events, increasing the importance of other water supplies.

Design Considerations

For the east units, the principal work for the NOAA project concerned replacement of the pumping station for the East Unit and water control structures along the perimeter of the unit. The pump provides water to the East Unit, and with sufficient head in the East Unit, water drains to the Panko Unit to the north via the northeast culvert (the only surface water source to the Panko Unit); there is an additional culvert on the southeast corner of the East Unit. Concerning high flow events and direct movement of water into the east units from the river, the main concern would be ability to drain water from the units to the river following receding floodwater. The northeast culvert between the East and Panko units should be able to provide drainage from the East to Panko Units, the southeast unit would allow additional drainage, and a culvert in the Panko Unit should be able to provide drainage from that unit to the river (Table D2; note that there is currently no operating pump in the Panko Unit). An additional issue is potential transfer of contaminants (including PCBs and dioxins) into the wetlands following entrainment upstream, in particular during high flow events; research in the river has shown the importance of high flow events to mobilize and transport downstream PCBs.[243] One potential option to reduce transfer (for high flow events not topping the road) would be to decrease pumping/transfer while a flood pulse is passing through the CISGA area.

A bigger concern for the east units would be periods of low water levels (e.g. drought or periods of persistently low precipitation), leading to lower Saginaw River water levels. To account for such situations, placement of the pump/culvert at a lower level could ensure ability to keep pumping into the East Unit. Similarly, persistent low levels in the East Unit (due to a combination of low river levels and low precipitation amounts) could lead to lower supply to the Panko Unit. Lowering of the culvert between the East and Panko Units would help address this concern (considerations that have been incorporated into design plans). A separate climate related stress would be general water warming, potentially threatening some fish species. Though adaptation options would be more limited, one option to consider in the units would be planting/seeding of additional native grasses along ditches or creeks, if potential to provide increased shading was confirmed.

Though not part of the current project, for the west units, there is some potential for excessive water supply (e.g. via Saginaw River flooding); however, transfer to more western units (i.e. Davis and Plowdry Units) followed by drainage via the ditch back to the river would likely be adequate to allow for drainage during periods of high water supply. There is also the potential for chemical contaminant transfer during high flow events; one approach to reduce risk would be to reduce pumping/transfer directly from the river, assuming a pumping station were later installed (see next paragraph). A related concern would be breaching of dikes at the Upper Saginaw River Dredged Materials Disposal Facility located just north of the Baldpate Unit, in which dredged sediment from the river is currently being disposed. Proper maintenance of the dikes will be important in preventing contaminant release into the adjacent wetlands.

As with the east units, it is likely that the larger concern is periods of low water supply (e.g. due to lower precipitation periods/drought or to low lake levels/less frequent seiches). In such cases, there may be a need to artificially augment supply, with at least two possible approaches. One option would entail installation of a pump station to the east of the Baldpate Unit to pump Saginaw River water into the unit. Several issues would need to be addressed, including access (e.g. utilizing state property) and finding a suitable location for the road crossing. The design should consider the potential to optimize water usage from the Saginaw River, such as by ensuring sufficiently low pump intake level to be able to draw water during lower flow periods. A second option would be diversion of water from a stormwater ditch on the south side of the units (draining Zilwaukee) into a southern unit, followed by pumping/transfer to the other units, assuming adequate supplies. In either case, sufficiently low culverts between units would be needed to allow water transfer even during drier periods. Similar to the east units, general water warming would potentially threaten some fish species in or near the west units. One adaptation option to consider would be planting/seeding of

Table D6. Climate Change Vulnerabilities and Potential Design Considerations.

Site	Climate Change Vulnerabilities	Potential Climate-Smart Options
East units	Potential for high flow events leading to direct inflow (e.g. topping of road) into east units	Ensure have potential to drain water as necessary back to river (e.g. via culvert in Panko Unit)
	Potential for transfer of contaminants (e.g. PCBs, dioxins) to wetlands during high flow events	Limit pumping/water movement from river during passage of high flow pulse
	Potential for low flow periods/drought	Re-position pump intake to ensure ability to pump river water from lower levels Re-position culvert height between East and Panko Units, to ensure ability to provide water to Panko Unit
	Sensitivity of some fish species to warming temperatures	Consider planting of native grasses along ditches/creeks if potential to increase shading
West units	Potential for high flow events leading to direct inflow into west units	Ensure have potential to drain water as necessary back to river (e.g. via transfer to Davis and Plowdry Units and then drainage via ditch on west side of units)
	Potential for transfer of contaminants (e.g. PCBs, dioxins) to wetlands during high flow events	Limit pumping/water movement from river during events.
	Potential for low flow periods/drought; potential for decreased supply via seiches	Install new pumping station east of Baldpate Unit to pump river water Transfer water from stormwater ditch south of units into Baldpate Unit, then pump/drain to other units
	Sensitivity of some fish species to warming temperatures	Consider planting of native grasses along ditches/streams if potential to increase shading

additional native grasses along ditches or creeks, if research confirmed the potential for such actions to provide additional shading and reduce water temperatures.

Lessons Learned and Recommendations

1. While the potential implications of climate change for the project site were not intuitively obvious at the start, discussions did arise early on concerning potential implications of extreme supply scenarios (in particular low water) in the project area.

2. Identification of potential low water supplies in the area (due to sustained low river levels) led to a decision to incorporate these considerations into the design elements (including both the pump station elevation and culvert elevation between units) for the east units.

3. Additional discussions on the west units also identified potential climate change-driven water supply concerns as a key issue; though not a focus of the current project, the team did explore potential avenues (e.g. direct pumping from the river, or diversion of water from a storm ditch into the units) to augment supply during periods of lower flow in the river.

Additional work (including in the implementation phase) is being pursued in the CISGA. The project lead (DU) received a grant through the Great Lakes Fish and Wildlife Restoration Act in 2012 to carry out implementation of the engineering and design work identified through the NOAA grant.[244] Michigan DNR coordinated water level drawdown in spring 2013 in preparation for the pump/control structure replacement, which was to be followed by a prescribed burn to remove cattail cover.[245] These types of activities will ultimately lead to improved wildlife habitat, and ongoing consideration of potential climate change impacts in the region will help ensure that management goals can be met in light of these changes.

Case Study 7. Little Rapids Habitat Climate-Smart Restoration

Introduction

The Little Rapids project aims to restore rapids habitat in the St. Marys River Area of Concern. The project includes the following pre-construction elements: hydraulic flow modeling to predict the effects of the proposed restoration on water levels in the St. Marys River navigation channel and impact on ice formation in the Sugar Island Ferry lane; engineering design; an environmental assessment to examine the effects of the restoration on the current ecosystem; environmental monitoring plan; stakeholder relations and outreach and education. Once completed, implementation could begin by spring 2014. Restoring the rapids will lead to increased habitat for fish and invertebrates, representing 50% of the delisting target for the fish and wildlife related Beneficial Use Impairments in the Michigan waters of the St. Marys River Area of Concern.

Assessing Sensitivity: Project Targets and Approaches

The project approaches and targets for the Little Rapids project have a broad range of sensitivities to climate change. The target fish species may have limited habitat due to changing water temperatures or ice cover, and there are local concerns over changes in water flow and ice cover that may be exacerbated by climate change.

Target Sensitivities

Specifically, some of the fish species targeted for foraging, spawning, and nursery habitat could be sensitive to increases in water temperatures. Fish with a lower optimal spawning temperature are likely to be more sensitive to increases in water temperature due to climate change. Additionally, Lake Whitefish are sensitive to changes in ice cover, as they prefer ice cover for spawning.

Approach Sensitivities

Due to the nature of this project's approach, i.e. hydrologic reconnection that intends to restore habitat and improve an ecosystem, the approach is not highly sensitive to climate change; however, the proximity of residential property and residential water intake pipes may be sensitive or become more sensitive to the effects of climate change due to alterations to the causeway. Sugar Island residents have expressed concerns over changes in water level, flows, and ice cover with respect to their ability to intake water, walk on ice between islands, and have open water to take the ferry back to the mainland.

Assessing Exposure: Climate Considerations

Water Levels: Climate projections show that Great Lakes water levels may go either up or down, and that they will likely be more variable than they have in the past. While precipitation and lake evaporation does have some impact on water levels in the Great Lakes, water levels in the St. Marys River are heavily controlled by the locks and compensating gates, and so will be less affected by overall lake changes. However, the St. Marys River does ultimately flow into Lake Huron, and so is more affected by Lake Huron's levels. The environmental assessment and hydrologic flow modeling will take into account more water level variability.

Ice Cover: With warmer air and water temperatures, Great Lakes ice cover may be decreasing in the coming years. Residents of Sugar Island are worried that removing the causeway may divert enough water flow from the current channel to slow the current, allowing more ice to form and preventing the ferry from crossing the channel. Less ice cover due to climate change may, in fact, eliminate one challenge in removing the causeway.

Water Temperatures: Since one of the main goals of this project is to re-establish rapids for fish spawning and habitat, there is a need to consider whether anticipated changes in water temperatures will have an effect on the types of fish that will be using the rapids.

Assessing Project Adaptive Capacity

The project is already adapting to climate change by incorporating climate considerations into the planning stages. By providing all parties involved in this project the opportunity to think about the potential effects of climate change on the Little Rapids, the project has already taken important steps towards adapting to climatic changes. In the future, the institutional ability to change project aspects as we understand more and have more certainty regarding the effects of climate change in the Great Lakes will be important.

Water Levels

Because water levels in the St. Marys River are highly controlled, the adaptive capacity in regards to water level at the Little Rapids is relatively high – the river can more easily respond to changes in lake levels than other areas; however, dramatic drops in Lake Huron may be problematic.

Ice Cover

Again, reduced ice cover is not likely to be problematic for fish targeted by this project, with the exception of Lake Whitefish. Winter residents who depend on the Sugar Island ferry in the winter could in fact benefit from less ice cover, but some residents may be upset at the potential loss of walkable ice between islands.

Water Temperature

Fish species, in general, have a higher adaptive capacity than many other, less mobile, flora and fauna, because they have the ability to swim elsewhere. However, they are still sensitive to changes in water temperature.

Climate-Smart Management Options

Climate-smart management actions will reduce sensitivity, exposure, or adaptive capacity of project targets and approaches, or in short: they will reduce a projects' vulnerability to climate change over time. These options may be within or outside of the scope of the project but are included nonetheless as options that will make the project less vulnerable to climate change.

Little Rapids Site Specific: As the biggest stressors for project targets and approaches are likely to be water temperature increases and changes in ice cover, it may be beneficial to keep water temperatures cooler by increasing or maintaining riparian vegetation near the rapids. Furthermore, removing the length of the causeway that leads to most restored rapids habitat will lead to a more resilient habitat in the face of climate change.

Broader options: Restoring more habitat throughout the Great Lakes Basin is one of the most basic ways to make the ecosystem more climate-smart. Restoration in general makes ecosystems more resilient to all stressors, be it climate change, pollution, land use change, or invasive species. Specifically, more restoration projects within the St. Marys River Area of Concern will provide more habitat for fish and other species that will be adversely affected by climate change.

Lessons Learned and Recommendations

1. Meetings with stakeholders are vital for information-gathering. This project has implications for both the public who live in the area and also the potential tourists who will recreate the area in the future. Throughout this project public meetings were held to discuss climate change amongst other project goals. Including the public and their knowledge was important and helped drive the climate change vulnerability assessments. For example, originally water levels were to be the focus, but instead the factor of changes to ice arose as a much bigger problem.

2. Climate change as it relates to water levels is not as large of a factor in a highly man-managed system. In this case, water levels of the Great Lakes have little to no impact on the system. Water levels are managed at Sault Ste Marie, therefore fluctuations are rarely felt. However, other climate change impacts such as changes to ice flows, temperature changes, and extreme events cannot be managed.

3. Uncertainty is still difficult to communicate. Project partners still felt challenged in making decisions under uncertainty. When faced with concrete decisions, e.g. where to place large boulders to create rapids, it is less certain how to consider various futures and more difficult to fix issues through adaptive management. There is currently more information on managing under uncertainty than there is on restoration under uncertainty.

4. Restoration partners are now better equipped but still rely on outside partners to run climate change vulnerability assessments. The restoration partners in this project now feel better equipped to make the project climate-smart; however, they still rely on outside partners such as NWF and EcoAdapt to conduct climate change vulnerability assessments. Going forward, the climate-smart process is not yet embedded enough for them to complete assessments on their own.

Evy Frederickson

Appendix E. Resources for Additional Information and Guidance

Organizations and Web-Based Resources

- The NOAA-funded ***Great Lakes Regional Integrated Sciences and Assessments*** (GLISA) program conducts research on regional and localized impacts of climate change:
http://www.glisa.umich.edu or **http://www.glisa.msu.edu**

- Great Lakes Coastal Resilience Planning Guide website:
http://www.greatlakesresilience.org/

- The Upper Midwest/Great Lakes LCC website:
http://www.fws.gov/midwest/climate/LCC/UpperMidwest

- The Northeast Climate Science Center website:
http://www.doi.gov/whatwedo/climate/strategy/Northeast_CSC.cfm

- Researchers at the University of Michigan have recently compiled an annotated bibliography on some useful resources, including direct links to the respective publications:
http://snre.umich.edu/events/2011-03-31/assisting_great_lakes_coastal_communities_with_climate_change_adaptation_master039

- The ***Climate Adaptation Knowledge Exchange (CAKE)*** website also provides an extensive, searchable selection of climate change information and resources, which is being regularly updated:
http://www.cakex.org.

- Adaptation Collaboratory contains tools, case studies, and resources on adaptation from throughout the country.
http://adapt.nd.edu/

- National Climate Assessment
http://www.globalchange.gov/what-we-do/assessment

- NOAA's ***Coastal Services Center*** has a website dedicated to providing key resources on coastal adaptation, including relevant climate science and impacts:
http://collaborate.csc.noaa.gov/climateadaptation/default.aspx.

- ***Regional Sea Grant*** offices also are a good resource for climate change information:
http://www.glerl.noaa.gov/seagrant/, as is the ***Wisconsin Initiative on Climate Change Impacts:***
http://www.wicci.wisc.edu/.

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