ADAPTING TO CLIMATE CHANGE

Solutions to enhance Great Lakes coastal wetland resilience

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Glossary

Adaptation

Adaptation is the deliberate actions taken to adjust to actual or expected climate changes and effects. Its aim is to moderate or avoid harm, maintain and increase resilience, and reduce vulnerability.

> **Incremental adaptation** are adaptation actions where the central aim is to maintain the essence and integrity of a system or process at a given scale.
>
> **Transformational adaptation** are at a scale and ambition greater that incremental approaches, highly collaborative, embrace paradigm shifts and consider innovative responses when historical approaches are insufficient. This includes strategies that anticipate, shape, and facilitate ecological processes, functions, structures, and transitions.

Adaptive capacity

The ability of a system (e.g., coastal wetlands) to adjust, cope, and persist under changing climate conditions.

Adaptive management

A process of iteratively planning, implementing, and modifying strategies for managing resources in the face of uncertainty and change. It involves adjusting approaches in response to observations of their effect and changes in the system.

Anthropogenic

Human impact on the environment including changes to the biophysical environments and to ecosystems, biodiversity, and natural resources.

Biodiversity

The variability among living organisms from terrestrial, marine, and other ecosystems. Biodiversity includes variability at the genetic, species, and ecosystem levels.

Climate change

A change in the state of the usual climate that can be identified by changes in the mean and/or the variability of its properties, and that persists for an extended period.

Climate model

A numerical representation of the climate system based on the physical, chemical, and biological properties of its components, their interactions, and feedback processes, and accounting for some of its known properties.

Climate projection

A simulated response of the climate system based on assumed scenarios of future emission or concentration of greenhouse gases and aerosols using climate models.

Climate variability

The variations in the mean state and other statistics of the climate on all spatial and temporal scales beyond that of individual weather events.

Downscaling

A method that derives local- to regional-scale information from larger-scale models.

Ecological Threshold

A point at which a relatively small change or disturbance in external conditions causes a rapid change in an ecosystem, that when passed, the ecosystem may no longer be able to return to its state by means of its inherent resilience.

Ecosystem services

Ecological processes or functions that benefit individuals or society, classified as: (1) supporting services (e.g., productivity, biodiversity maintenance); (2) provisioning services (e.g., food, fiber, fish); (3) regulating services (e.g., climate regulation or carbon sequestration); and (4) cultural services (e.g., tourism, spiritual, aesthetic appreciation).

Exposure
The nature and degree to which a system is exposed to significant climate variations.

Geodiversity
The variety of rocks, sediments, landforms, and natural processes that constitute and shape the Earth.

Greenhouse Gas
Gaseous constituents of the atmosphere, both natural and anthropogenic, that absorb and emit radiation at specific wavelengths within the spectrum of terrestrial radiation emitted by the Earth's surface, the atmosphere itself, and clouds.

Invasive species
Species that are not native to an area and whose introduction or spread threatens the environment, the economy or society, including human health.

Mitigation (of climate change)
A human intervention to reduce the sources or enhance the sinks of greenhouse gases.

Phenology
The relationship between biological phenomena that recur periodically (e.g., development stages, migration) and climate and seasonal changes.

Projection
A potential future evolution of a quantity or set of quantities, often computed with the aid of a model. Unlike predictions, projections are conditional on assumptions concerning, for example, future socioeconomic and technological developments that may or may not be realized.

Functional Redundancy
The presence of multiple, similar, or overlapping elements or functions that can perform the same function and provide 'insurance' by allowing components to compensate for the loss or failure of others.

Green Infrastructure
Any vegetative infrastructure which enhances the natural environment, including the network of green spaces and water systems that deliver multiple environmental, economical, and social values and benefits.

Nature-based climate solutions
Solutions that combat climate change impacts by protecting, conserving, restoring, and sustainably managing wetlands, forests, and other habitats essential for the removal of greenhouse gasses from our environment, protect us from climate change impacts, and reversing the decline in biodiversity.

Representative Concentration Pathways
Scenarios that include time series of emissions and concentrations of greenhouse gases and aerosols and chemically active gases, as well as land use/land cover.

Resilience
A trait representing the capacity of a system to cope with a hazardous event, trend, or disturbance, responding or reorganizing in ways that maintain essential functions, identity, and structure, while maintaining the capacity for adaptation, and transformation.

Sensitivity
The degree to which a system or species is affected, either adversely or beneficially, by climate variability or change.

Stressors
Events and trends, often not climate-related, that have an important effect on the system exposed and can increase vulnerability to climate-related risk.

Vulnerability
The predisposition to be adversely affected and the degree to which systems are susceptible to, and unable to cope with the adverse effects of climate change. Vulnerability integrates exposure, sensitivity and the capacity to cope and adapt.

Executive Summary

Great Lakes coastal wetlands provide indispensable benefits to the freshwater ecosystem, people, and the economy. These wetlands, however, face a systemic threat because of a changing climate and the multiple and repeated stresses from land-based activities. Changes in climate will likely persist and, in most cases, will intensify over the coming decades. This will result in greater extremes in air and water temperatures, precipitation, ice cover, and lake levels, compounding the existing environmental effects of habitat loss, pollutants, invasive species, alterations to tributary flows and extreme lake levels. As the conservation community and policy makers plan for climate change impacts, it is crucial to ensure that coastal wetlands adjust, reassemble, maintain biodiversity, and function to provide ecosystem services that contribute to beneficial economic, social, cultural, and freshwater ecosystem outcomes.

In this context, coastal wetland managers can no longer focus solely on maintaining the current wetland state or restoring to a preferred historical state. The projected rate and magnitude of climate change necessitates a re-examination of wetland management practices, anticipating new and uncertain climate conditions, adopting forward-looking goals, reshaping policy, and implementing adaptation actions to enhance coastal wetland resilience. Understanding climate change vulnerability, adaptation, and resilience presents an opportunity to advance beyond incremental conservation responses, to strategic, and even transformational approaches.

In response to the climate change challenge, Environment and Climate Change Canada (ECCC) initiated a study to assess and enhance the resilience of Great Lakes coastal wetlands. The multi-year collaboration was funded by the Great Lakes Protection Initiative (2017-2022) in support of Canada's commitments pursuant to the Great Lakes Water Quality Agreement and the Canada-Ontario Agreement on Great Lakes Water Quality and Ecosystem Health. The anticipated outcomes were:

1. An improved understanding of coastal wetland vulnerability to climate change impacts.
2. A complement of possible adaptation strategies, adaptive measures, and options to enhance coastal wetland resilience.
3. Improved engagement, awareness, and consensus on adaptation priorities.

A team of ECCC's scientists produced a series of technical reports on climate and lake level modelling, the development of a coastal wetland response model, methods and results from a coastal wetland sensitivity analysis and an assessment of wetland capacity, and a synthesis report that captures the key findings. These reports can be found in the reference section.

This white paper responds to the second project outcome and provides insights and guidance to advance adaptation efforts to protect coastal wetlands against the unavoidable impacts of climate change. This includes perspectives on resilience thinking, information on climate projections and impacts, and a suite of adaptation options that can be weighed and

implemented. This document is framed as an entry point to provide information and resources essential to understanding and implementing climate adaptation approaches.

Resilience, in the context of this white paper, is the capacity of coastal wetlands to cope with climate disturbance, maintain essential functions, structure, and provide ecosystem services. Resilience is a trait, or dynamic property of wetlands, and managing for it requires exploring ways to prepare for actual and unforeseen climate shocks and disturbances. The fundamentals of resilience thinking include issues of scale, collaboration, partnerships, and governance. Foundational questions like 'resilience of what' (values and issues), and 'resilience to what' (climate trends and impacts) are answered through a synthesis of scientific literature and consultation with the Great Lakes wetland conservation community. In contrast, adaptation is the deliberate actions taken to adjust to actual or expected climate change impacts.

Coastal Wetlands of the Great Lakes Basin: Resilience of What?

Healthy, biologically diverse coastal wetlands provide a suite of ecosystem services that contribute to beneficial economic, social, cultural, and environmental outcomes. Coastal wetlands retain and cycle pollutants, capture and store carbon to reduce atmospheric greenhouse gases, provide resilience to coastal hazards such as storm surges and erosion, and are essential in protecting Canada's biodiversity. Wetland habitat supports an estimated 30 species of waterfowl, 155 breeding bird species, and 30 amphibian species; some of which are at risk of disappearing from the wild. The majority of the Great Lakes commercial and sport fishes harvested annually require coastal wetlands for at least part of their life cycle.

Despite their importance, coastal wetlands continue to be degraded, fragmented, and lost due to the multiple and ongoing stresses from incompatible development and shoreline alteration, urban and agricultural pollution, altered tributary hydrology, lake level extremes, and invasive species. Climate change is an additional threat that exacerbates the impacts of these environmental stressors placing coastal wetland ecosystems and the services they provide at great risk.

Climate Change Trends, Projections, and Impacts: Resilience to What?

Climate changes, such as higher air and water temperatures, reductions in ice cover, shifting seasonal rainfall patterns, extreme storm events, and lake level extremes are affecting the Great Lakes freshwater ecosystem, habitats, native species, and coastal communities. Changes in the climate will continue and, in many cases, will intensify over the coming decades. Climate change causes cascading and interacting impacts that manifest at different scales – from local impacts to broader effects across the Great Lakes Basin. Coastal wetlands respond in various ways depending on local atmospheric, hydrological, biological, and geological characteristics.

Extreme and prolonged lake level changes can lead to more flooding events, shoreline erosion, and loss of wetland habitat and native species under extreme high lake levels, and drying and stranding under prolonged low levels. Coastal wetland vegetation requires space to migrate landward and lakeward in response to lake level changes. Depending on the local topography, the level and the type of development, and physical and natural barriers, wetlands are being “squeezed” between lake level rise and human development.

Water quality is threatened by the cumulative effects of increasing water temperature, intense precipitation events, and runoff of nutrients, contaminants, and sediments. This results in the loss of water clarity, excessive amounts of nutrients, low oxygen levels, and harmful algal blooms. Lower water levels and higher summer water temperatures can also increase the risk of disease in fish and fish-eating wildlife.

Fish and wildlife habitat and species will shift as air and water temperatures increase, and seasonal precipitation patterns change. The geographic ranges of many species are expected to shift northward. A changing climate may lead to population declines and local extinctions if species are unable to adapt. Wetland birds requiring open emergent marsh are vulnerable to low lake levels, and species that nest on or near the water surface are vulnerable to storms and inundation. Birds may also suffer as the insects they rely on for food hatch earlier with warmer springs, or decline as vegetation shifts northward. Fish assemble in distinct cold, cool, and warm water groupings making them sensitive to changes in water temperature. Warmer water temperatures, seasonal weather shifts, and storms that bring a rapid influx of water will affect fish thermal habitat. Excess nutrient and sediment runoff, coupled with warm water temperatures, provide optimal conditions for the growth of algae and the spread of invasive plants like *Phragmites* (*Phragmites australis subsp. Australis)* known as Common Reed, and hybrid cattail (*Typha X glauca)* that out compete native plants.

Adaptation and Resilience: From Concepts Towards Implementation

The demands placed on the Great Lakes freshwater ecosystem, the cumulative impacts from multiple and ongoing stressors, and the simultaneous impacts of climate change warrants a new approach by the Great Lakes conservation community. As wetland managers, communities, and policy makers plan for climate change impacts, it is crucial that they develop strategies to maintain the adaptive capacity of coastal wetland ecosystems such that they remain resilient. Urgent action, supported by a strong commitment by all levels of government, environmental groups, landowners, and land stewards, can help to increase coastal wetland resilience to climate change through adaptation. Key ideas informing coastal wetland resilience include:

- Coastal wetlands are self-organizing systems that adjust and reorganize in response to disturbance. There are limits and thresholds, however, beyond which a wetland’s structure changes, it functions differently, and may not recover.
- Wetlands are linked social, ecological, and economic systems that are vulnerable to the synergistic effects of climate change and anthropogenic disturbances/stresses.

- Wetlands have linked adaptive cycles that function across multiple biophysical and jurisdictional scales. What happens at one scale can influence scales above and below.
- Managing for resilience involves adapting and transforming management goals and approaches, which requires investments and awareness of risks and trade-offs.
- Resilience is not about knowing everything or resisting change, rather a willingness to understand conflicting interests, uses, and needs.
- Resilience is about partnerships, collaboration and learning by doing.

Resilience-based principles have emerged to guide conservation practitioners. Each principle contributes to resilience differently, but collectively they provide management levers that inform the development and implementation of adaptation strategies and actions. Principles include:

- Considering the broader landscape and setting, and the geophysical, biological, and sociocultural aspects that determine constraints on, and opportunities for adaptation.
- Understanding key natural patterns and the physical, biological, and chemical processes that create and sustain wetlands.
- Understanding the landscape context, habitat connectivity, and links between habitats, processes, and populations that enable movement of materials and organisms.
- Maintaining and improving diversity, complexity, and functional redundancy of coastal wetlands and the surrounding landscape elements to provide a range of options for wildlife and management agencies to enhance resilience.
- Facilitating partnerships and collaboration across governments, institutions, organizations, communities, and landowners to conserve, protect, and restore wetlands.

Possible Strategies and Measures to Build Coastal Wetland Resilience

Based on the principles of resilience, the evolving climate system, and the potential impacts to coastal wetlands, this white paper presents six overarching adaptation strategies, 17 detailed adaptive measures, and over 150 options. This includes options that anticipate, shape, and facilitate ecological processes, functions, structures, and transitions to reflect the changing environmental conditions. A climate adaptation framework is presented that allows wetland managers the flexibility to customize options that are best-suited to sustain their local wetlands in a resilient manner, and meet specific management goals and objectives.

Strategy 1. Reduce Non-Climatic Stressors and Enhance Adaptive Capacity

Addressing non-climatic stressors is an ongoing challenge. However, a changing climate exacerbates their negative impacts. An effective method to build resilience is to enhance the natural capacity to cope with impairments to water quality, invasive species, and hydrological and landscape connectivity. The four measures are:

- Maintain and enhance wetland water quality.
- Prevent, detect, and control invasive animals.

- Re-establish hydrologic connectivity.
- Restore and conserve landscape connectivity.

Strategy 2. Protect Littoral Cell Geodiversity and Restore Barrier Landforms

Natural coastal processes are fundamental to coastal wetland creation, maintenance, and long-term protection. Barrier-protected wetlands have formed, evolved, and are currently protected by sand and gravel barrier features in the southeastern portion of Lake Huron and in the Lower Great Lakes. These geologically diverse features are under significant threat due to shoreline hardening and the subsequent loss of sediment supply. Record high lake levels, decreased ice cover, erosion of sandy barriers, and loss of wetland habitat pose additional threats. Strategy 2 focuses on protecting the geodiversity in littoral cells and restoring protective barrier sand spits, barrier beaches, and barred rivermouths crucial for wetland formation and defence. Four measures and 29 options are directed to the following management and policy needs:

- Update land use policies and regulations that negatively impact physical coastal processes.
- Employ integrated coastal zone management principles to develop littoral cell management plans.
- Re-establish sediment supply and alongshore transport in littoral cells.
- Implement local projects to protect and restore barrier systems.

Strategy 3. Maintain and Restore Biodiversity and Functional Redundancy

Human activities and the compounding impacts of climate change are altering the composition of wetland communities with cascading impacts to wetland functions and services. Greater species richness leads to increases in overall ecosystem function, such as biogeochemical activities, energy transfer, ecological services, and production of biomass. The degree to which the loss of an individual species impacts structure and function; however, depends on whether there are other species within the community that can perform similar functions. Biodiversity and functional redundancy promote resilience and stability. The adaptive measures of this strategy focus on enhancing wetland vegetation community structure and the habitats required by wetland wildlife. Three measures and 28 options are provided to maintain and/or create diverse and functional coastal wetlands.

- Enhance community structure and native species populations.
- Control invasive plant species.
- Conserve native plant species and communities.

Strategy 4. Enhance Wetland Capacity to Cope with Altered Hydrology

Recognizing that there will be periods of alternating low and high lake levels is essential for successful climate change adaptation and building coastal wetland resilience. Strategy 4 adaptive measures and options focus on accommodating possible hydrologic shifts, including sustained, rapid, alternating, and extreme lake level changes. Managers can enhance wetland resilience by maintaining, conserving, and enhancing natural processes and desirable wetland structure and functions. This includes preparing for higher highs and lower lows by anticipating both extensive flooding interspersed with drought, and by considering options associated with the following four measures.

- Manage wetlands to cope with sustained periods of high lake levels.
- Manage wetlands to cope with sustained periods of low lake levels.
- Remove, realign, and relocate wetland constraining infrastructure.
- Manage and enhance the resiliency of diked wetlands.

Strategy 5. Identify, Manage, and Protect Climate Change Refugia

Climate change refugia provide a safe haven during periods of unfavourable climate conditions and serve as sources for colonization following climate disturbance. Establishing climate change refugia is a promising strategy which requires the identification and conservation of land where wetlands can transition to under changing water levels, restoration and maintenance of hydrological connections, habitat enhancement, and improved land use policies to support landward and waterward migration of coastal wetlands under different lake level and temperature regimes. There are two key measures with 28 associated options that reflect a climate change refugia conservation approach:

- Identify and manage migration corridors and refugia retreat areas.
- Protect groundwater sources, processes and refugia.

Strategy 6. Improve Great Lakes Coastal Wetland Conservation and Protection

Achieving coastal wetland resilience requires effective conservation, including land securement, protection, and stewardship. Current efforts, especially in the Lower Great Lakes region, may not be sufficient for wetlands and wetland-dependent organisms to adapt, transition, or be resilient to changing climatic conditions. To address this challenge, conservation efforts need to be directed to protecting the remaining coastal wetlands, preventing further fragmentation and land-use impacts, and restoring degraded wetland area and function. These conservation priorities require enhanced knowledge, innovative policies, and improved collaboration, cooperation, and partnership development. The options in this strategy include promoting land securement, increasing the number of protected areas, strengthening legislation for wetland protection, designating climate refugia, and improving wetland conservation governance. An innovative and transformational concept is establishing a “protected coastal corridor” to enhance connectivity and the integrity of natural physical coastal processes to facilitate coastal wetland change under future variable and extreme lake level conditions.

Management and Policy Innovation

Adaptation to address wetland vulnerability and build resilience to a changing climate is an emerging area requiring policy and management innovation. Coastal wetland managers, aquatic habitat experts, and conservation practitioners were engaged in interviews, workshops and focus group discussions to identify challenges, gaps, and needs to develop a robust adaptation approach. Six crucial elements emerged – governance, policy, science and predictive modelling, wetland inventories, assessment and monitoring, data harmonization and visualization, and the design, implementation, and assessment of adaptation actions.

An Optimistic Look to the Future

Coastal wetlands provide indispensable social, cultural, ecological, economic, aesthetic, and recreational benefits that cannot be compromised. Coastal communities must coexist with coastal wetlands and the native species they support. In this white paper, an adaptation framework, with its broad overarching strategies, detailed measures, and the suite of options, represent an important entry way for enhancing Great Lakes coastal wetland resilience. To truly achieve resilience, advancements in conservation practice requires greater integration of climate change science, knowledge of vulnerability, and the design, implementation, and evaluation of adaptation actions. Additionally, it involves innovative policy, linkages with all levels of government, as well as the collaboration and participation of a broad range of partners, stakeholders, and rights holders. Most challenging is the implementation of adaptation projects, some of which may be novel, contested, and transformative.

Fortunately, the services and values of coastal wetlands have gained widespread recognition. There is strong public support for wetland conservation across the Great Lakes Basin. New climate science and modelling results fill a climate adaptation knowledge gap. Unprecedented funding is contributing to biodiversity conservation and climate adaptation through nature-based solutions; coastal wetlands can play an essential role. An extraordinary collection of complementary conservation strategies, plans, assessments, and human resources can also be leveraged. Resource management agencies, conservation authorities, Indigenous communities, environmental non-governmental organizations, land trusts, stewardship groups, and scientists are willing and mobilized to advance coastal wetland resilience through adaptation.

Our decisions and actions in the short-term will determine the ability of coastal wetlands to thrive under a changing climate. Broad collaboration, implementation, and knowledge transfer can contribute to a portfolio of adaptation case studies to learn from and apply on a larger scale. Additionally, Canada has made a range of climate- and ecosystem-related commitments as a signatory to the Convention on Biological Diversity, the Convention on Climate Change, the Sustainable Development Goals and the Paris Agreement, and the Global Commission on Adaptation. The preservation of Great Lakes coastal wetlands and ecosystem services in the face of climate change and the application of adaptation options can help to achieve these goals.

1.0 Introduction

> **Resilience** is a trait representing the capacity of a system to cope with a hazardous event, trend, or disturbance, responding or reorganizing in ways that maintain essential functions, identity, and structure, while maintaining the capacity for adaptation, learning, and transformation (IPCC, 2014).

Great Lakes coastal wetlands provide indispensable benefits to the freshwater ecosystem, people, and the economy. Despite this, they are at risk due to the multiple and repeated stresses from land use changes, coastal development, agricultural intensification, and the emerging and compounding impacts of climate change. As the conservation community and policy makers plan for climate change impacts, it is crucial to ensure that coastal wetlands adjust, reassemble, maintain biodiversity, and function to provide ecosystem services. This necessitates developing a management approach with adaptation and resilience as cornerstones of conservation. How can we enhance and sustain diverse, healthy, and climate-resilient wetlands across the Great Lakes Basin? How can we manage wetlands and land uses while providing benefits to people and wetland-dependent wildlife? These questions are challenging and require complex responses in the face of future climate change. As the conservation community addresses climate change, there is a need to understand the social-ecological value in wetlands (resilience of what), how to deal with climate and non-climatic impacts (resilience to what), and what guidance can assist the planning and implementation of adaptation approaches. Based on a synthesis of scientific literature and consultation with the Great Lakes wetland conservation community, this white paper addresses these questions to provide a suite of adaptation options to initiate dialogue and to advance collective action to enhance coastal wetland resilience to climate change.

> **Adaptation** is the deliberate actions taken to adjust to actual or expected climate changes and effects to moderate harm or take advantage of opportunities (Settele et al., 2014). Its aim is to maintain and increase resilience and reduce vulnerability (IPCC, 2014).

Climate Change: An Accelerating Challenge

Coastal wetlands are vital to the Great Lakes ecosystem and particularly vulnerable to climate change given their location at the land-water interface. Wetland structure and function are dependent on natural water level variation. Future increases in temperature, changes in precipitation and ice cover, more intense storms, and altered coastal processes increase vulnerability. Additionally, degraded wetlands are particularly vulnerable and less resilient to climate change (Environment Canada, 2002; Mortsch et al., 2006; Acreman et al., 2009).

Climate change impacts are wide-ranging, affecting wetland chemical, physical, and biological processes such as nutrient and sediment cycling, water quality, decomposition, thermal habitat, and species diversity and abundance. Coupled with existing stressors such as draining, infilling, pollution, shoreline alteration, hydrological changes, and invasive species (Pearsall et al., 2012), wetlands may be unable to provide important ecosystem services. (**Figure 1**; OMNRF 2017).

Expert panels (Ontario Expert Panel on Climate Change Adaptation, 2009; U.S National Climate Assessment, 2014; Canada's National Issues Report [Warren and Lulham, 2021]) call for an improved understanding of ecosystem vulnerability and a strategic approach to achieving climate resilience through adaptation. This is also reflected in international policies on climate (UN, 2016), biodiversity (IPBES, 2019), adaptation (GCA, 2019), as well as in binational and domestic agreements on Great Lakes water quality and ecosystem health (GLWQA, 2012; COA, 2020). As the rate and magnitude of climate impacts accelerate, adaptation presents an opportunity to advance beyond incremental responses, to a strategic, and even transformational approach to achieve wetland resilience. Failing to take advantage of the benefits of adaptation undermines the vital contributions of wetlands to freshwater, biodiversity, and human well-being.

1.1 Why Climate Change Resilience?

Conservation practice has traditionally focused on maintaining or restoring to an historical state, with assumptions that ecosystems will be best prepared to cope with new conditions if their environment is within the historical range of variability (Stein et al., 2014). However, the projected rate and magnitude of climate change challenges wetland managers to rethink long-held approaches, anticipate new and uncertain climate conditions, adopt forward-looking goals, and implement adaptation actions that enhance ecosystem resilience. Coastal wetland conservation practitioners express a need for support as they seek to understand what they could be doing differently to prepare for and respond to climate impacts (Mortsch, 2019).

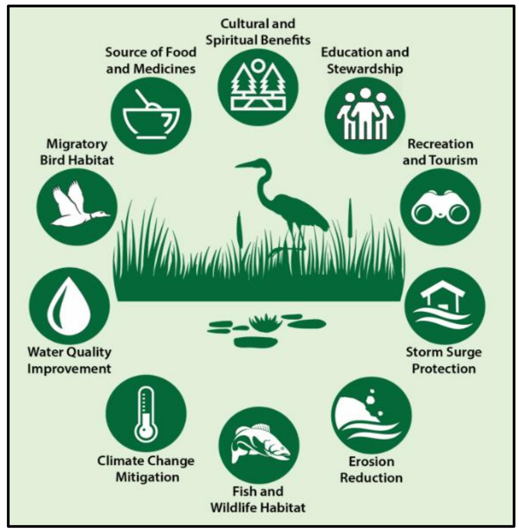


Figure 1. *Coastal and inland wetland functions and values (OMNRF, 2017).*

This white paper provides practical information to ensure that climate change considerations can be incorporated into the planning and implementation of coastal wetland conservation practice. It includes climate change information, perspectives and guidance on resilience thinking, and a suite of adaptation options to enhance coastal wetland resilience. While it is beyond the scope of this paper to address all conceivable management interventions, six overarching adaptation strategies with associated adaptive measures and options are presented for consideration to complement existing Great Lakes conservation goals and plans. It is based on extensive literature review and engagement and framed as an entry point to provide users with information and resources essential to understanding and implementing climate adaptation approaches. This white paper is intended as a resource for natural resource management agencies, policymakers, municipal planners, environmental non-governmental organizations, Indigenous communities, industry, and landowners with a stake in coastal wetland conservation (collectively called wetland managers) and who recognize the need to enhance Great Lakes coastal wetland resilience in light of a changing climate.

1.2 Planning for Adaptation and Assessing Vulnerability

In the Great Lakes wetland conservation context, adaptation is imperative to reduce risks of further wetland loss and degradation from climate change. Adaptation is a challenge faced by all, and a key long-term response to anticipate and cope with impacts projected under different scenarios of climate change to protect coastal wetland ecosystems. Adaptation is an iterative process that involves several key components explained by Stein and colleagues (2014) and the United Nations Climate Change Regime (**Figure 2**). Successful adaptation is guided by the best available science and local knowledge systems with a view to integrating adaptation into relevant socioeconomic and environmental policies and actions.

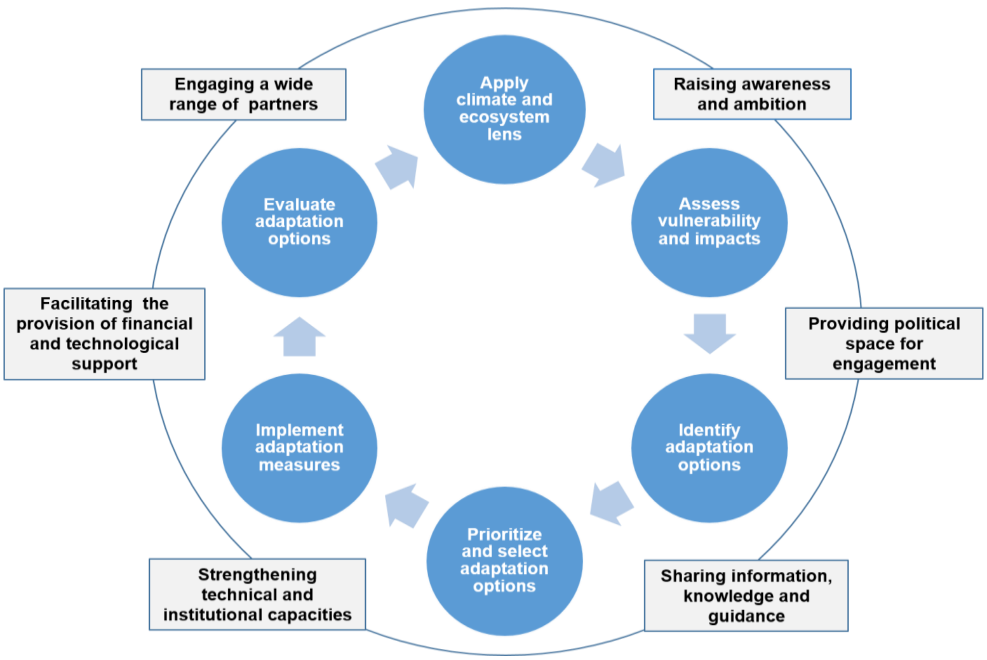


Figure 2. *A general adaptation planning and implementation framework.*

Characterizing the "why" and "how" of vulnerability is critical for generating adaptation options (e.g., so that wetlands can cope with shocks and continue to function and provide ecosystem services). As such, Environment and Climate Change Canada (ECCC) initiated a science-based study to assess the vulnerability of Great Lakes coastal wetlands. This study was supported by the Great Lakes Protection Initiative (2017-2022) and addresses Canada's commitments pursuant to the Great Lakes Water Quality Agreement (GLWQA) and the Canada-Ontario Agreement (COA) for healthy and productive wetlands and resilient native species.

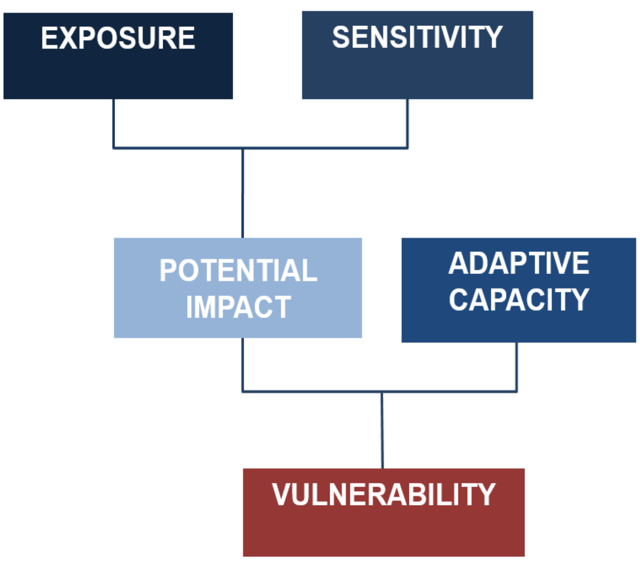
Climate change vulnerability assessments are used in a variety of contexts (Füssel and Klein, 2006; Comer et al., 2012; Gauthier et al., 2014), including wetland ecosystems (Acreman et al., 2009; Gitay et al., 2011). They provide a systematic way of deconstructing the complexity of vulnerability into measurable indicators of exposure, sensitivity, and adaptive capacity (**Figure**

3). A vulnerability assessment of 20 Canadian coastal wetlands was completed with the following outcomes:

1. An improved understanding of coastal wetland vulnerability to climate change impacts.
2. A complement of strategies, measures, and options to enhance wetland resilience.
3. Improved engagement, awareness, and consensus on adaptation priorities.

Environment and Climate Change Canada produced a series of technical reports on each component of the assessment to advance the understanding and application of climate change vulnerability. These include climate and lake level modelling (ECCC, 2022a), coastal wetland response modelling (ECCC, 2022b), coastal wetland sensitivity (ECCC, 2022c), wetland adaptive capacity (ECCC, 2022d), and a synthesis report on key findings (ECCC, 2022e).

Resilience thinking in the context of this white paper involves an understanding of vulnerability and examines how the interacting system of people and coastal wetlands can be managed in the face of climate change impacts, future uncertainty, as well as existing/ongoing stresses. Engagement and consultation with Great Lakes conservation practitioners was integral to the development of this white paper, as adaptation actions are more likely to be implemented if they are co-developed, prioritized, and complement regional priorities, goals, and objectives.



Vulnerability: Degree to which wetlands are susceptible to and unable to cope with the adverse effects of climate change.

Exposure: Amount and rate of climate change to which wetlands are likely to be exposed.

Sensitivity: Degree to which wetlands are likely to be affected by or responsive to climate change.

Adaptive Capacity: Ability of wetlands to cope and persist under changing climate conditions.

Figure 3. *Vulnerability assessment framework showing the relationship between climate exposure, sensitivity, and adaptive capacity (Modified from Glick et al., 2011).*

2.0 Great Lakes Coastal Wetlands: The Resilience of What

Great Lakes coastal wetlands are social and ecological systems. This includes the biogeophysical components of a wetland ecosystem, and the people, society, and economies that interact with and transform them. A central aspect of these interactions involves the benefits of wetland ecosystem services to the natural environment and society (**Figure 1 and 5**). To set the stage for resilience thinking and in considering adaptation needs, coastal wetland significance, functions, and values; or the 'resilience of what', are briefly summarized. Additionally, the main hydrogeomorphic wetland types (**Table 1),** and the issues of wetland loss, protection, and non-climatic impacts are reviewed.

Figure 4. *Coastal wetlands connect Canadians with the Great Lakes.*

2.1 Wetland Functions and Values

Coastal wetlands provide a suite of ecosystem services critical to people and the environment, including absorbing and cycling nutrients, sediments, and pollutants for improved water quality, erosion control, and carbon sequestration (Mitsch and Gosselink, 2000; Zedler and Kercher, 2005; Troy and Bagstad, 2009; Sierszen et al., 2012; **Figure 1**).

Coastal wetlands play a vital role in protecting Canada's biodiversity by providing crucial habitat to an estimated 30 species of waterfowl, 155 species of migratory songbirds (Prince et al. 1992; Howe et al., 2007), 30 species of amphibians (Hecnar, 2004), 80 Great Lakes sport and commercial fishes (Jude and Pappas, 1992; Wei et al., 2004), some of which are endangered and threatened (EC and OMNRF, 2003). Wetlands are also a source of invertebrates, fish, and wildlife to the Great Lakes food web (Brazner et al., 2000; Sierszen et al., 2019).

Healthy, biologically diverse wetlands contribute to positive economic outcomes for the Great Lakes Basin (Austin et al., 2007). Wetland-using fish make up half the biomass and 60% of the dollar value of commercial fish, and 80% of the sport fish annual harvest (Trebitz and Hoffman, 2015). Coastal wetlands provide a livelihood and food to Indigenous communities by supplying wild rice, fish, wildlife, fur and fiber (UOI, 2018). Birding, photography, fishing, and hunting are additional ecosystem services that support local economies. Coastal wetlands also provide climate change mitigation benefits (i.e., carbon sinks) (Mitsch and Gosselink, 2007; Braun et al., 2019) and nature-based climate solutions for broad coastal resilience.

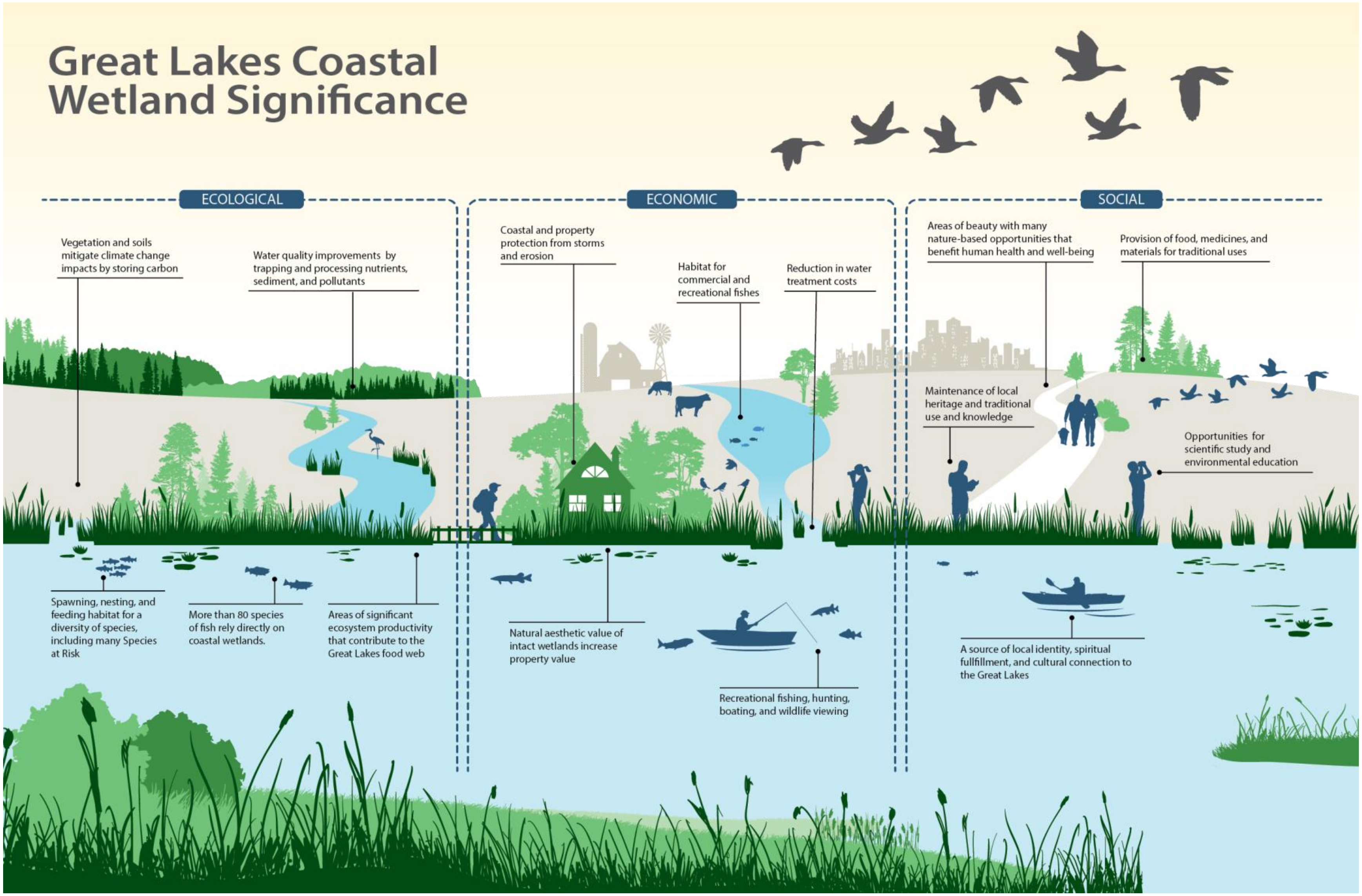


Figure 5. *A conceptual diagram of coastal wetland functions and ecosystem services (ECCC, 2021).*

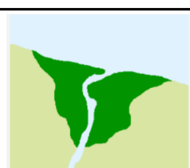
2.2 The Coastal Wetland Ecosystem

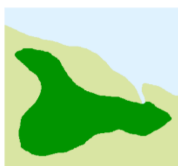
Coastal wetlands are directly connected to and influenced by the waters of the Great Lakes. It is this connection that differentiates coastal wetlands from their inland counterparts. Coastal wetlands are among the most ecologically diverse and productive ecosystems (Environment Canada, 2002; OMNRF, 2017). They are highly complex, dynamic, and self-organizing systems.

> **Wetlands** are lands that are seasonally or permanently covered by water and where the water table is close to surface. Water causes the formation of saturated soils and dominance of water-tolerant plants. The four major types of wetlands are marshes, swamps, fens, and bogs (OMNRF, 2017). *This white paper mostly focuses on Great Lakes coastal marshes.*

Local climate and water levels fluctuations influence wetland distribution, extent, vegetation composition, biodiversity, and function (Environment Canada 2002; Mortsch et al., 2006). Watershed stressors like nutrient and chemical pollution, coastal development and shoreline alterations, and invasive species have a significant impact on wetland condition, structure, and function (Pearsall et al., 2012; Uzarski et al., 2019; Zuzek, 2021a). Great Lakes coastal wetlands are classified into three hydrogeomorphic types (**Table 1**; Albert et al., 2005; Environment Canada 2002) based on characteristics of hydrologic flow, physical attributes, and associated flora and fauna communities. Each is subdivided into a subset of geomorphic types based on shoreline processes and physical attributes (Albert et al., 2005).

Table 1. *Great Lakes coastal wetland hydrogeomorphic classification (Albert et al., 2005; Mortsch, 2006).*

Hydrogeomorphic Type	Geomorphic Type
Lacustrine Directly connected to and controlled by the lake level variability, currents, seiche and ice scour. 	**Open Lacustrine:** variable bathymetry, little or no physical protection from moderate to high wave energy, little accumulation of organic sediment limiting vegetation development and diversity.
	Protected Lacustrine: lake-based and characterized by increased protection by a sand-spit, offshore bar, or till- or bedrock-enclosed bay. Low to moderate wave energy, with broad, high diversity of flora and fauna.
Riverine: River and stream 	**Drowned River-mouth**: water chemistry influenced by lake and river water depending on the season, amount of precipitation, flow, and water level. Protection from coastal processes (e.g., low wave energy) results in deep organic

wetlands that flow into or between the Great Lakes with water quality and sediment input controlled in part by upstream drainage basin and conditions. Water levels and fluvial processes are influenced by lake water backflow into the lower portions of their drainage systems.	soils due to deposition of watershed-based silt loads. Moderate diversity with species of fish and invertebrates tolerant of low oxygen and high temperature.
	Connecting Channel: distinct for their general lack of deep organic soils and strong currents. Found in the St. Mary's, St. Clair, Detroit, Niagara and St. Lawrence Rivers.
	Delta: formed from fine and coarse alluvial materials with fluvial and wave action contributing to the delta morphology. Diverse plant, invertebrate, fish and waterbirds communities.
Barrier Protected:  Protected by barrier beach ridges, sand spits, swales, and bars. Periodically or continuously connected to the lake by a channel or inlet crossing the barrier. When isolated from the lake, they rely on groundwater and precipitation with minor lake influence unless breached.	**Barrier Beach Lagoon:** formed behind sandbars with little mixing of Great Lakes waters. Submergent, emergent and wet meadow zones, invertebrates and fishes tolerant of low oxygen and high temperature; high waterbird diversity.
	Swale Complex: occur between recurved fingers of sand spit swales and between relict beach ridges. Composed of a series of beach ridges separated by narrow swales where there may be an abundance of sediment and a range of vegetation types. Invertebrates and fish tolerant of low oxygen and high temperatures. Moderate waterbird diversity.

2.2.1 Coastal Wetland Loss and Current Protection Status

Despite their ecological and societal values, coastal wetlands continue to be threatened by watershed stressors. Prior to European settlement (c.1800), more than two million hectares of inland and coastal wetlands were distributed throughout southern Ontario. By 2002, only 560,844 ha remained, a reduction of 72%. Between 1982 and 2002, an additional 3.5% (70,854 ha) of the pre-settlement wetland area was lost - an average loss of 3,543 ha per year (DUC, 2010).

A Canadian Baseline Coastal Habitat Survey provides estimates on the current extent of coastal wetlands (ECCC, 2021). Lake Erie has the greatest coastal wetland area at nearly 15%. Lake Huron has the second greatest wetland extent followed by Lake Ontario. Coastal wetlands of

Lake Superior cover less than 1% of the shoreline because the high energy of the lake precludes colonization by wetland plants along most open shorelines **(Table 2)**.

In terms of land protection efforts, the Lake Erie coastal margin has the greatest area of protected coastal wetlands; however, this occurs primarily in national and provincial parks at Point Pelee, Rondeau, and Long Point. Lake Huron has the second greatest extent of protected coastal wetlands, mostly along eastern Georgian Bay and the Bruce Peninsula. Protected coastal wetlands of Lake Ontario are mostly located within Prince Edward County, Thousand Islands National Park, and the Upper Canada Bird Sanctuary. In Lake Superior, protected coastal wetlands are located within Sleeping Giant and Lake Superior Provincial Parks, and Pukaskwa National Park (ECCC, 2021). The current protection network is likely insufficient to allow wetlands and wetland-dependent organisms to be resilient to changing climatic and environmental conditions. Degradation of wetland habitat and loss of landscape connectivity due to agricultural, urban, commercial, and shoreline development, invasive species and altered hydrological connections continue to threaten coastal wetlands (Pearsall et al., 2012; ECO, 2018).

Table 2. *The remaining amount of coastal wetlands and current extent of land protection in the two kilometre coastal margin of the Canadian Great lakes (ECCC, 2021-unpublished).*

Lake	**Total Coastal Margin Area (ha) [a]**	**Total Coastal Wetland Area (ha) [b]**	**Total Protected Lands Area (ha)[c]**	**Number of Protected Areas**	**Total Protected Coastal Wetland Area (ha) [d]**
Erie	149,5701	22,332 (14.9%)	10,372 (6.9%)	17	4,472 (20.0%)
Ontario	226,271	12,241 (5.4%)	5,916 (2.6%)	10	608 (5.0%)
Huron	326,679	12,262 (3.8%)	75,517(23.1%)	41	3,734 (30.5%)
Superior	238,549	2,019 (0.8%)	67,208(28.2%)	26	120 (6.0%)

[a]: Total area of the two km coastal margin. Canadian Baseline Habitat Survey data (ECCC, 2021).
[b]: Estimated amount of existing coastal wetland area and the percentage within the two kilometer coastal margin. This column uses data from the Great Lakes Shoreline Ecosystem Project (MNRF, 2021), Great Lakes Coastal Wetland Consortium (2004), McMaster Coastal Wetland Inventory (McMaster, 2012).
[c]: Amount of protected land within the coastal margin using data from the Canadian Protected and Conserved Areas Database (ECCC, 2021).
[d]: Estimated amount of current coastal wetlands within a protected area.
Note: Estimates do not include lands protected or conserved by non-governmental organizations, conservation authorities, municipalities, and Indigenous communities.

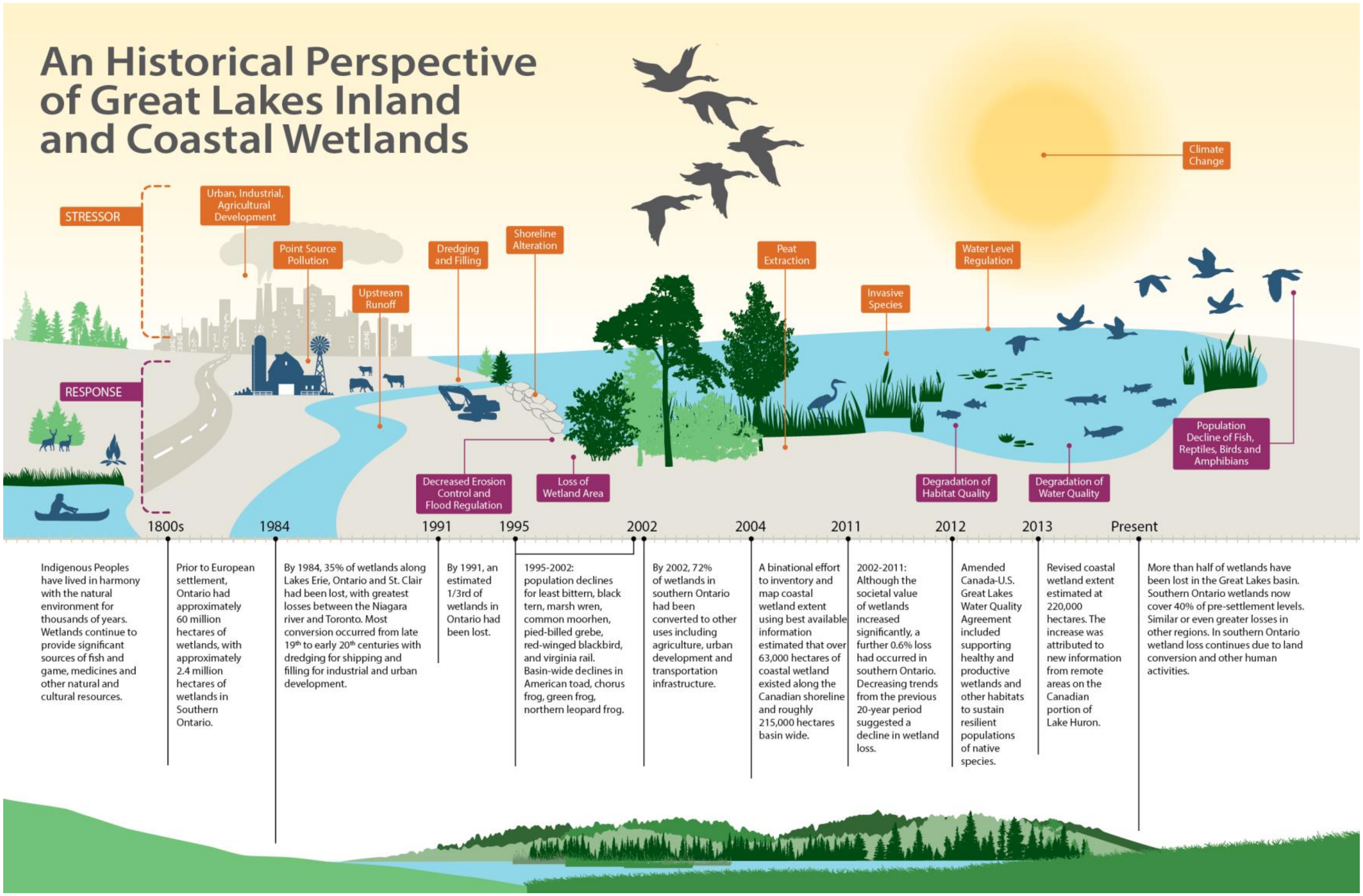


Figure 6. *A brief historical perspective of Great Lakes coastal wetland status and trends In Ontario (ECCC, 2021).*

2.3 Non-Climatic Stressors and Impacts

In addition to the projected climate impacts (Section 3), existing non-climatic stresses are central to the question of how to enhance coastal wetland resilience. Wetland loss, fragmentation, and degradation continue through multiple and repeated disturbances from land conversion, pollution, shoreline alteration and invasive species (**Figure 6**) (Environment Canada, 2002; DUC, 2010; OBC, 2011; OBC, 2015; OMNRF, 2017; ECO, 2018). This section reviews non-climatic influences on coastal wetland health and function to answer the question "Resilience to what" and offer entry points for adaptation planning and implementation. While much of the information below pertains to inland wetlands, it is highly relevant to understanding stresses to coastal wetland function.

2.3.1 Agricultural Land Use Change

Agricultural activities have historically been, and continue to be, a significant cause of wetland loss in southern Ontario, responsible for a 43% reduction in area between 2000 and 2010 (ECO, 2018). Areas with high tile drainage density characterize southern Ontario counties with the greatest reduction in wetland area (Spaling, 1995, Eimers et al., 2020). The Ontario Ministry of Agriculture, Food and Rural Affairs estimates that at least 1,561 km^2 of land was drained from 2006 to 2016 (ECO, 2018). Tile drainage, channelized streams, and ditches are also conduits for pollutant to wetlands. Small wetlands are more likely to be lost in the future to accommodate agriculture (ECO, 2018).

2.3.2 Urban and Shoreline Development

Urban development is associated with an estimated 22% of wetland loss between 2000 and 2010 (ECO, 2018). Of the wetland area lost to development, 20% was converted to hardened surfaces that reduce infiltration of water, groundwater recharge, and increased stormwater flow resulting in the deterioration of downstream hydrological dynamics and water quality (ECO, 2018). Incompatible shoreline development (e.g., infilling, dredging, hardening, groins, jetties) is a critical threat to coastal wetlands (Pearsall et al., 2012) and results in the disruption of natural coastal processes and the loss of geomorphological integrity and geodiversity of the Lower Great Lakes. This is primarily through alterations to sediment dynamics, reductions in sand and gravel to the littoral zone, and erosion risks for once-sandy depositional environments such as barrier-protected wetlands and sand spits (Baird, 2008; Zuzek, 2021). Urban centres are expanding, and residential and commercial development threaten existing coastal wetlands. Shorelines are forever changing, and plans completed in the 1990s require updating using appropriate scientific and engineering analysis with consideration of regional coastal ecosystem implications and the compounding impacts of climate change-related storms and lake level extremes.

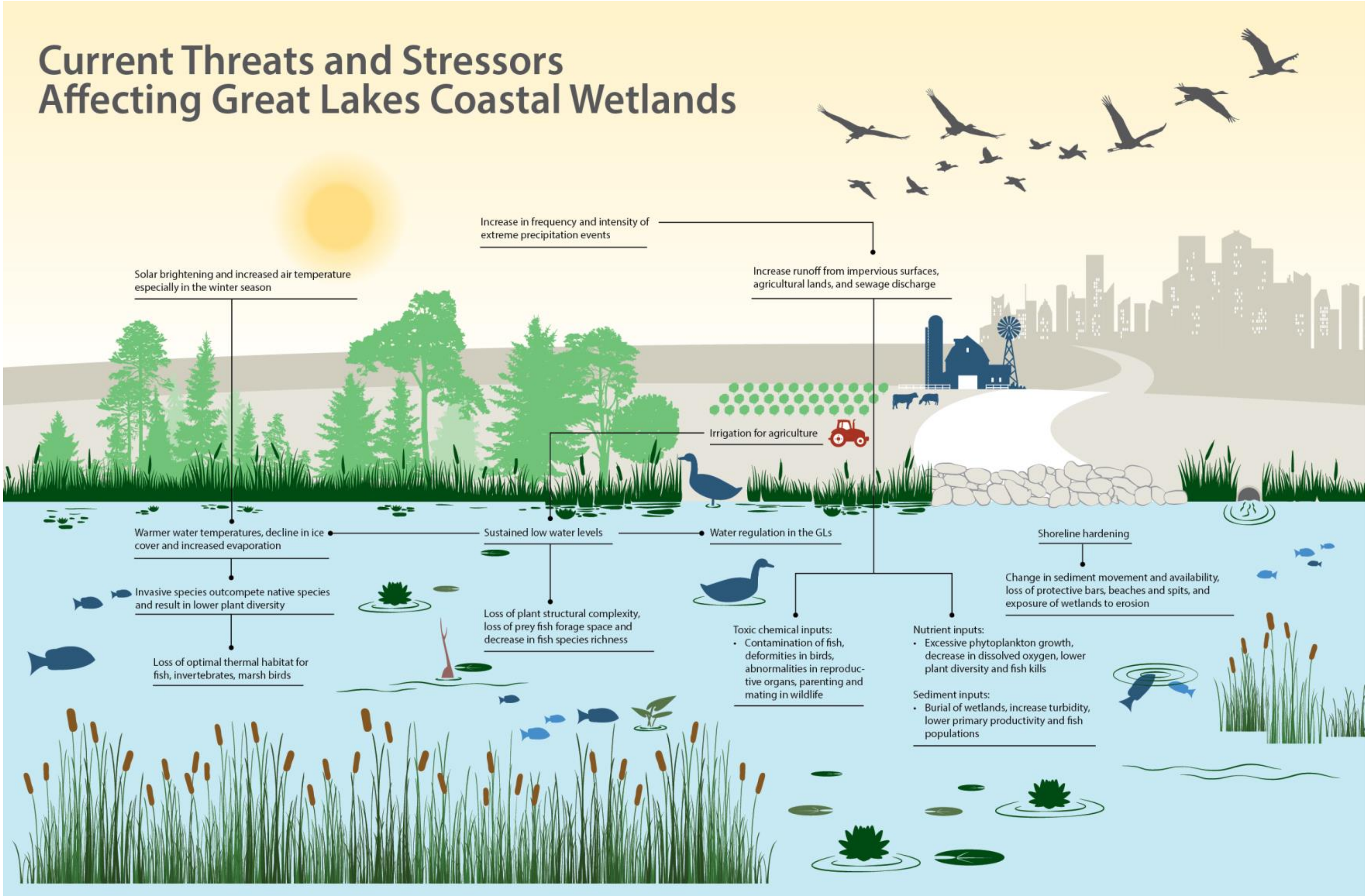


Figure 7. *A brief conceptual narrative of current threats and stressors affecting coastal wetlands (ECCC, 2021).*

2.3.3 Pollution and Wetland Degradation

Coastal wetlands can be degraded or altered from their natural states by chemicals, road salt, sewage, pesticides, and fertilizers (Houlahan and Findlay, 2003; Croft-White et al., 2017; Harrison et al., 2020). High nutrient concentrations increase plant growth, particularly algae, phytoplankton, and invasive species such cattails and non-native *Phragmites* (Tulbure and Johnston, 2007). Toxic chemicals stress wetland biological systems through bioaccumulation and biomagnification, especially for species at the top of the food chain (EC, 2002). Wetlands near farms and urban areas in northwestern portions of Lakes Ontario and Erie and southwestern Lake Huron are particularly vulnerable to degradation from pollution and lack of natural land cover (Harrison et al., 2020). Degraded water quality compromises the species richness of wetland fish (Seilheimer and Chow Fraser, 2006). High turbidity and nutrient enrichment are associated with a decrease in the extent and density of submerged aquatic vegetation (Hudon et al., 2000; Lougheed et al., 2001), which is an important habitat feature for marsh birds and fish (Cooper et al., 2018; Croft and Chow-Fraser, 2007; Grabas et al., 2012; Randall et al., 1996; Seilheimer and Chow-Fraser, 2006). Similarly, macroinvertebrate communities exposed to wastewater and urban stormwater runoff favour mostly species tolerant of turbidity and warmer water temperatures (Dance and Hynes, 2003; Cooper et al., 2012; Kashian and Burton, 2000; Schock et al., 2014).

2.3.4 Invasive Plant and Animal Species

Invasive species in the Great Lakes include fishes, mollusks, crustaceans, plants, and disease-carrying organisms. Three invasive plant species with the greatest ecological and economic impacts are *Phragmites* (*Phragmites australis subsp. australis)*, reed canary grass (*Phalaris arundinacea L.*), and invasive cattail (*Typha X glauca*) (Vaccaro et al., 2009). These species will continue to expand in distribution and displace native flora and fauna in the absence of preventative actions (Carson et al., 2018). Eurasian milfoil (*Myriophyllum spicatum*) and European frog-bit (*Hydrocharis morsus-ranae*) and other invasive plants also threaten coastal wetlands. Invasive Asian carps pose substantial economic and environmental risks given their proximity to potential pathways into the Great Lakes (e.g., Chicago Area Waterways System). No black carp have been captured to date; however, three Bighead Carp were captured in Lake Erie (pre-2000) and by 2019, roughly 650 Grass Carps had been captured throughout the Great Lakes Basin except for Lake Superior (Chapman et al., 2021).

Figure 8. *Dense stand of invasive Phragmites (Janice Gilbert, OMNRF).*

3.0 Climate Trends and Impacts: The Resilience to What

This section presents trends and projections in climate (i.e., temperature, precipitation) and water levels that affect coastal wetland systems (**Figures 9 to 11**) and identifies associated ecological impacts (**Table 3**). This information answers the question, “resilience to what?” It synthesizes new climate change scenarios and associated hydrologic modelling information, scientific literature synthesizing historical trends and projected changes, and insights from coastal wetland conservation practitioners on associated climate change impacts (Mortsch, 2020; OCC, 2019; 2020). Projections of climate variables and resulting lake levels are based on the current understanding of the climate system and assumptions about the future behavior of society that influences the amount of carbon released to the atmosphere. There are uncertainties and assumptions inherent in these projections, but they are necessary to show general trends to understand potential impacts and risks, and guide adaptation planning.

3.1 Future Great Lakes Temperature, Precipitation and Water Levels

As part of ECCC’s coastal wetland vulnerability assessment, future climate conditions or scenarios for the region were developed from Regional Climate Model (RCM) simulations forced by Global Climate Models (GCMs) using four Representative Concentration Pathways (RCPs) for future greenhouse gas (GHG) conditions. Future projections are presented here under a moderate pathway (RCP4.5) and under a high pathway (RCP8.5) for two time periods: mid-century or the 2050s (2035-2065) and late century or the 2080s (2066-2095). These climate scenarios were used to model the hydrologic impact on future lake levels. For more detail, the reader is directed to a technical report by the Meteorological Service of Canada, a branch of ECCC (ECCC, 2022a) and the highlights report with data visualizations by the Ontario Climate Consortium (Lam and Dokoska, 2022).

3.1.1 Over-Land Air Temperature

Over-land air temperature refers to air temperature measured over the land portion of the Great Lakes Basin. An historical analysis of average annual over-land air temperature reveals a warming trend over the period 1950 to 2010 of 0.11°C per decade in the Midwest region of the United States, which includes much of the Great Lakes basin (Byun and Hamlet, 2018). From a climatological perspective (1961-2000), the annual average air temperature has a range of 2.4˚C over the Lake Superior basin, the northern-most lake, to 9˚C in the Lake Erie basin, the southern-most lake (Lam and Dokoska, 2022; Dehghan, 2021). Over-land air temperatures are projected to increase significantly across the Great Lakes Basin compared to historical conditions (1961-2000). Under the moderate pathway RCP4.5, annual average land air temperatures could increase by approximately +3˚C over the Lake Erie basin to +3.5˚C over the Lake Superior basin by the end of the century. While under RCP8.5, annual average land air temperatures are expected to increase by +4.8˚C over the Lake Erie basin to +5.6˚C over the Lake Superior basin by the end of the century (Dehghan, 2019; ECCC, 2022a; **Figure 9**).

The greatest temperature increases are projected for the fall and winter seasons, and in the northern and western portion of the Great Lakes Basin. Changes in average land air temperatures are expected to bring warmer winters, earlier spring-time warming, extreme heat, a longer growing season, heavier precipitation, and less ice cover (Dehghan, 2019; Lam and Dokoska, 2022). As over-land air temperatures continue to warm, an increased frequency and intensity of extreme heat events are expected (Wuebbles et al. 2019; Byun and Hamlet, 2018).

3.1.2 Over-Lake Precipitation

Over-lake total precipitation refers to the aggregate precipitation that falls on the lake's surface over the period of a year. The amount is generally similar to precipitation that falls over the lands surrounding the Great Lakes, but differences can be observed based on wind patterns and local topography (ECCC, 2022a). The average (1961-2000) annual total over-lake precipitation has been 755 mm over Lake Superior to 909 mm over Lake Erie.

The greatest increase in total over-lake precipitation is projected for Lake Superior under both RCPs, followed by Lake Ontario. For RCP4.5, annual total over-lake precipitation increases by 9 percent over Lake Erie to 20 percent over Lake Superior by the end of the century. While under RCP8.5, annual total over-lake precipitation increases by 18 percent over Lake Erie to 24 percent over Lake Superior by the end of the century (Dehghan, 2019; Lam and Dokoska, 2022). These projections indicate significant increases in annual total precipitation across the basin and is also reflected by increases in all seasons. Projections for over-lake precipitation are highly variable but on the whole future annual total precipitation is projected to increase across the Great Lakes region, especially during the last 30 years of the 21st century under the RCP8.5 scenario (**Figure 10**).

The seasonality of precipitation is also projected to shift, with more precipitation falling in winter, spring, and fall, while potentially drier conditions may persist in the summer. Projections under RCP8.5 indicate possible winter increases up to 16% by mid-century and 33% by late century (Dehghan, 2019). On the other hand, under RCP8.5 summer precipitation may decrease by 12% by mid-century and by 20% by late century (Dehghan, 2019). This is consistent with other studies showing projection increases in winter and spring precipitation and decreases in summer (e.g., Mailhot et al., 2019).

3.1.3 Ice Cover

Assessment of annual mean ice cover from 1973 to 2010 indicates that while the inter-annual variability of ice cover is large, the long-term trend is a decline (Wang et al., 2017). On average, maximum ice cover has been decreasing by 5 percent per decade, and some lakes are losing ice cover faster than others including Lakes Superior, Huron, St. Clair, and Erie (NOAA, 2018).

The analysis of historical annual mean ice cover indicates the largest declines are in Lake Ontario (2.3% per year), followed by Lake Superior and Michigan (2% per year). Lakes Erie and St. Clair had the least decline (1.3% and 1%, respectively). In the future, the annual mean ice cover for mid- and late century is projected to decrease substantially across the Great Lakes. The lakes could be ice-free by the end of the 21st century with greater exposure of coastal wetlands to waves, storms and erosion (Dehghan, 2019). The greatest ice loss is projected in Lake Superior. The projected ice loss for Lake Superior under RCP4.5 in winter is 36% to 86% for mid-century and 57% to 93% for late century. Under RCP8.5 for Lake Superior, the projected ice loss in winter ranges from 27% to 92% for mid-century, and from 68% to 100% for late century.

With climate change, warmer air temperatures and reduced ice cover during the winter are expected to increase evaporation from the open lake surface. This creates conditions that can lead to rapid heat and moisture exchange over the Great Lakes, which in turn can increase lake-effect snowfall depending on air temperature and wind direction (Sharma et al. 2018). Ice cover helps to reduce wave energy/erosion along the coast. It also offers insulation and protection for spawning habitats in shallow areas for species that spawn during the fall and winter (Bartolai et al. 2015). The increasing frequency and intensity of storms over the Great Lakes can generate large waves and extreme storm surges comparable to tidal surges on marine coasts (Gronewold et al. 2013). Lake Erie is particularly sensitive to this effect, due in large part to its east-west orientation.

3.1.4 Water Levels

Water levels on the Great Lakes are continuously monitored by U.S. and Canadian federal agencies using a network of water level monitoring stations in the region. Over the 100-year period (1918 to 2020), lake levels have had a 2-metre range between the recorded maximum monthly average and minimum monthly average. However, in the past three decades, a greater degree of fluctuation has been observed relative to this 2-metre range. For the period 1999 to 2014, average annual lake levels were at near-record low levels across all Great Lakes; however, since that period lake levels have been near record highs (**Figure 11**).

Within a given year there is a seasonal progression from highs in late spring/early summer to lows in winter, the range averages about 40 cm on Lakes Superior, Michigan, and Huron, and about 50 cm and 60 cm on Lakes Erie and Ontario, respectively. Storm surges and wave run-up can cause short duration hourly fluctuations of up to 50cm (or more) that influence wetland function.

Great Lakes water levels are influenced by several factors, including over-lake precipitation, runoff from the drainage basin, evaporation from the lake surface, inflows from upstream lakes, outflows to downstream lakes, lake water diversions, water use, and regulation plans that control outflows from Lake Superior and Lake Ontario (Lam and Dokoska, 2022; ECCC, 2022a). Future Great Lakes monthly water levels were modelled by integrating downscaled projections of over-lake precipitation, lake evaporation (influenced by ice cover), and land runoff to estimate the net basin supply as a key determinant of water level change (ECCC, 2022a). Based on multi-model climate ensemble averages, ECCC (2022a) demonstrate that projected water levels along the Great Lakes shoreline will have lower lows and higher highs (compared to historical observations). Shaded areas shown in **Figure 11** illustrate the full range of possible future lake level conditions under RCP4.5 and RCP8.5. Notably, however, projected lake levels could increase markedly near the end of the century under RCP8.5 with projected precipitation increases (**Figure 10**).

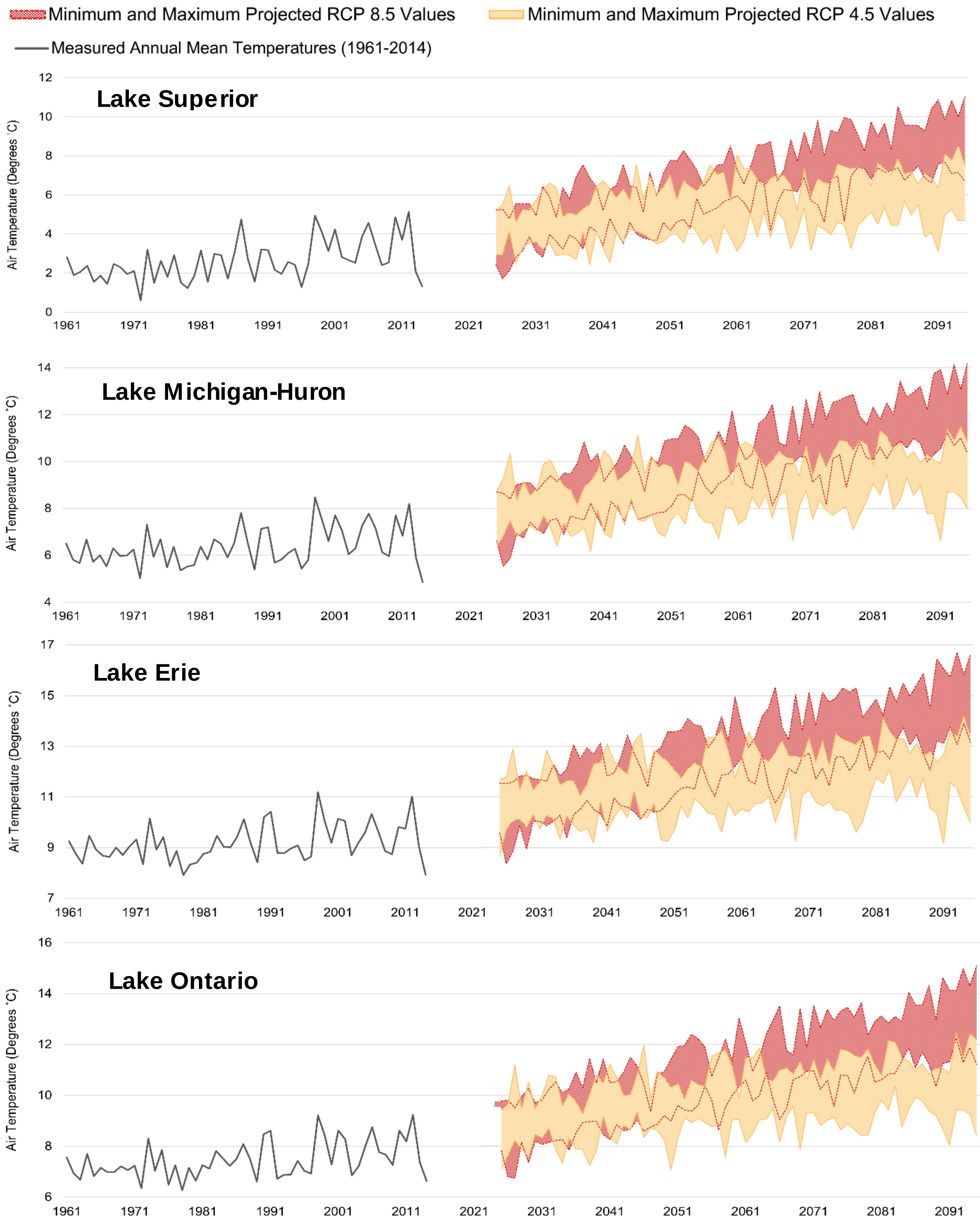


Figure 9. *Great Lakes historical measured and projected annual mean over-land air temperature under RCP4.5 (orange) and RCP8.5 (red) (Lam and Dokoska, 2022).*

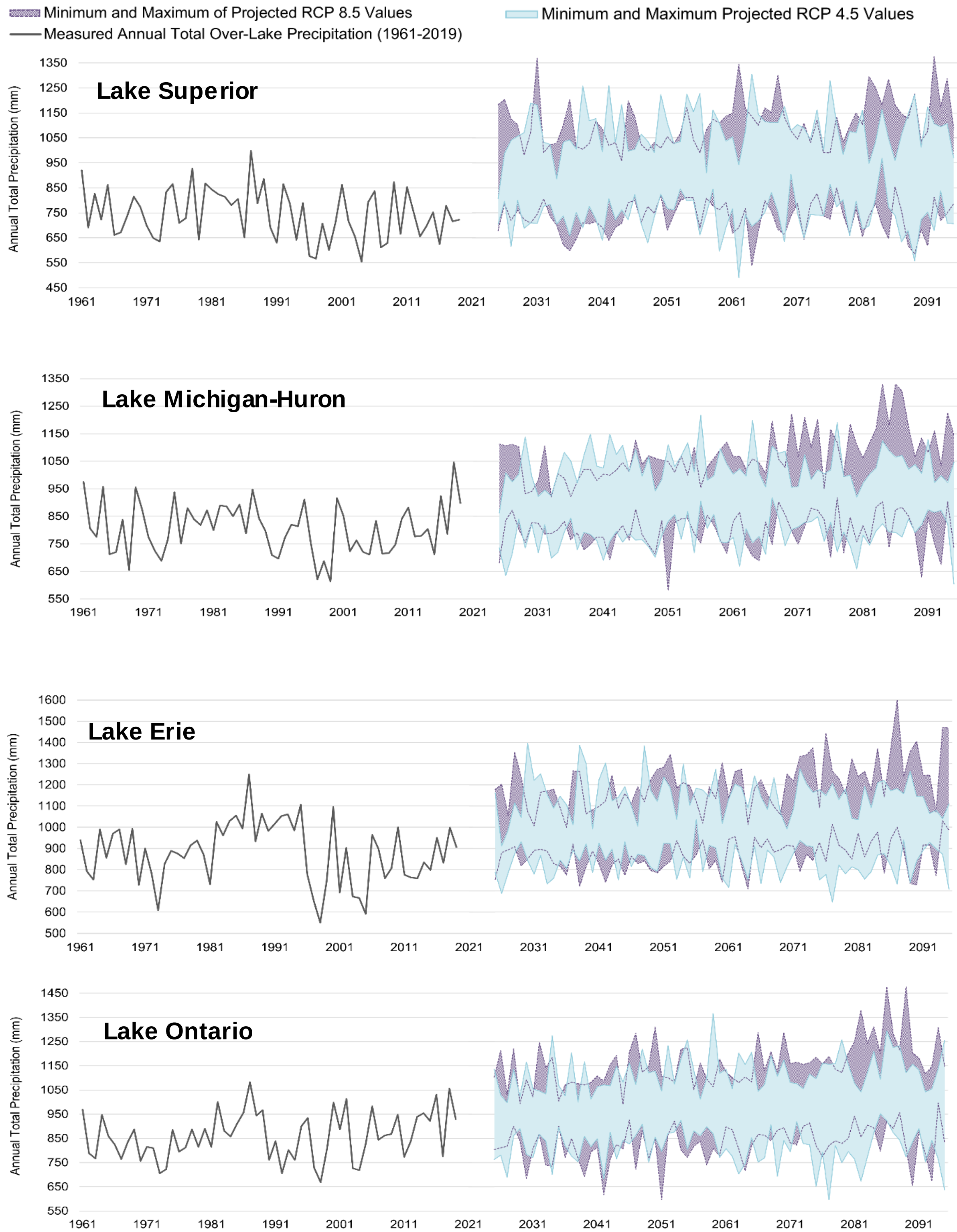


Figure 10. *Great Lakes total over-lake annual precipitation - historical measured and projected under RCP4.5 (blue) and RCP8.5 (purple) (Lam and Dokoska, 2022).*

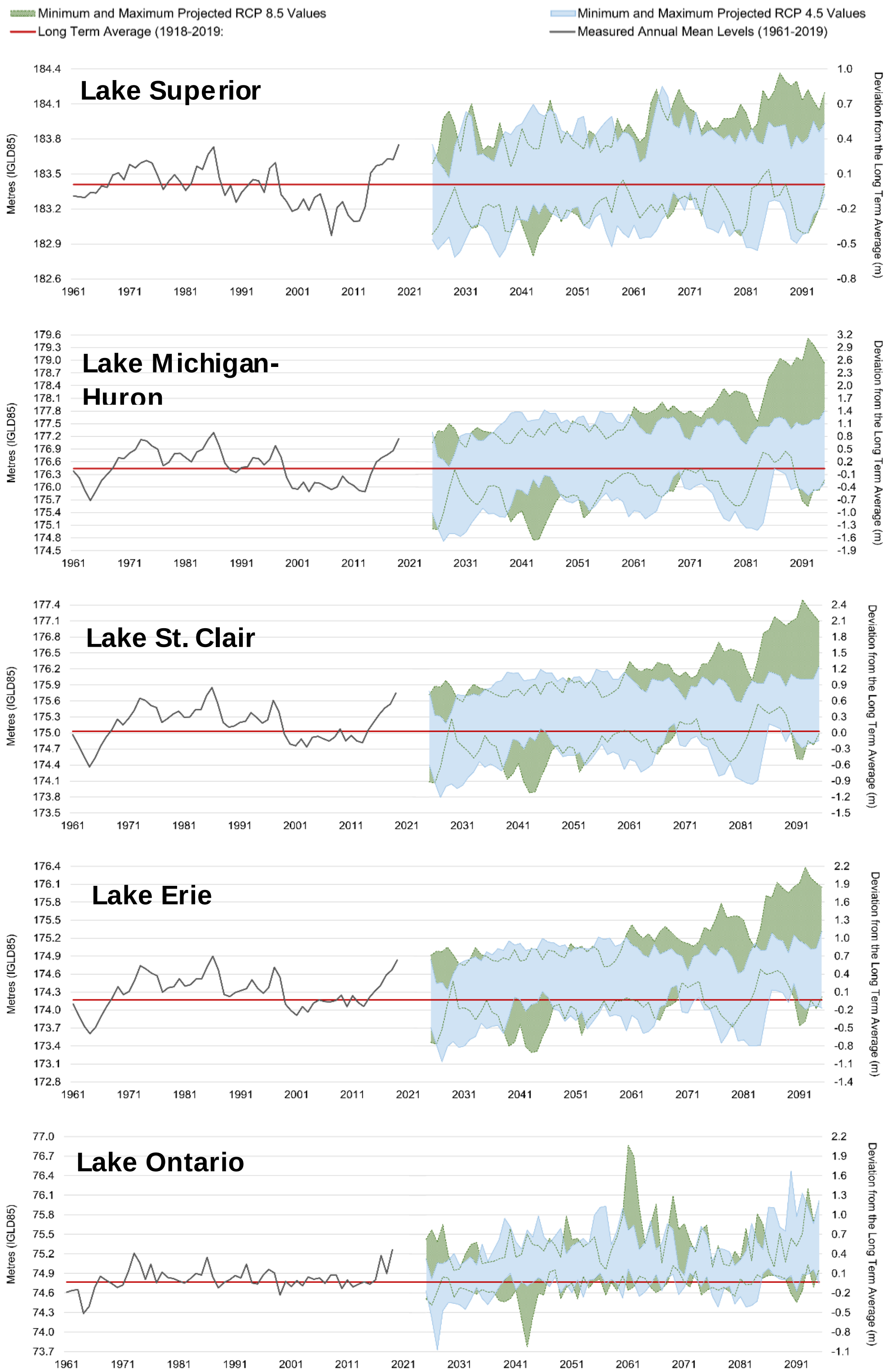


Figure 11. *Great Lakes average annual lake levels: historical measured (1961-2019) and projected (2025-2095) under RCP4.5 (blue) and RCP8.5 (green) (Lam and Dokoska, 2022).*

3.2 Climate Change Impacts on Coastal Wetlands

The projected changes in Great Lakes climate described above can cause many cascading impacts to coastal wetlands (**Figure 12 and Table 3**). Climate impacts may manifest at different scales, from local, regional, or across the Great Lakes Basin. Coastal wetlands may not respond consistently, or at the same rate, due to differing physical factors, hydrology, surrounding land cover, and human activities. The information in this section provides examples of climate impacts on coastal wetlands.

3.2.1 Changes in Hydrologic Regime

One of the most significant influences on coastal wetlands is the changes in timing, duration, and magnitude of seasonal and long-term water levels. Water level regimes define coastal wetland processes, moisture conditions for the development of wetland soils, vegetation dominance, and maintain shoreline marshes in an early successional stage (Wilcox and Meeker 1995; Mortsch 1998; Environment Canada, 2002). Variable and gradual water level change can increase plant diversity, and influence wetland structure, function and extent. However, lake level changes that occur frequently, or result in extreme and prolonged change, alter plant communities and wetland function (Mortsch 1998; Gathman et al., 2011; Midwood and Chow-Fraser, 2012; Smith et al., 2020). When water levels rise above historic maxima, wetland habitat can be lost in cases where land beyond the shoreline is not available for wetland transition into new upland habitat. For example, Canadian Shield shorelines, and hardened/developed shorelines often do not allow wetlands to dynamically migrate upslope (see strategy #5). Low lake levels, in conjunction with higher air temperatures and evaporation, alter the plant or animal life found within a wetland, or shift wetland type, potentially resulting in loss of biodiversity and ecosystem services (Midwood and Chow-Fraser, 2012). Wetland vegetation that was unable to germinate under high lake levels can rapidly sprout and grow in exposed mudflats and shallow water areas in low water conditions. However, prolonged low lake levels can lead to wetland drying and stranding. In Georgian Bay, stands of coniferous trees transitioned downslope when water levels were recorded at their lowest levels in 2013. Dead and dying coniferous stands continue to occupy formerly biologically productive shallow water areas of some Georgian Bay wetlands despite the significant increase in lake levels in recent years (P. Chow-Fraser, personal communication, February 2020).

3.2.2 Water Quality Impairments

Urban and agricultural land use influences on water quality are strongly linked to hydrology and climate, especially to changing precipitation patterns (i.e., more intense precipitation events). Nutrient loading to the Great Lakes waters is generally expected to increase because of climate change (ELPC, 2019).

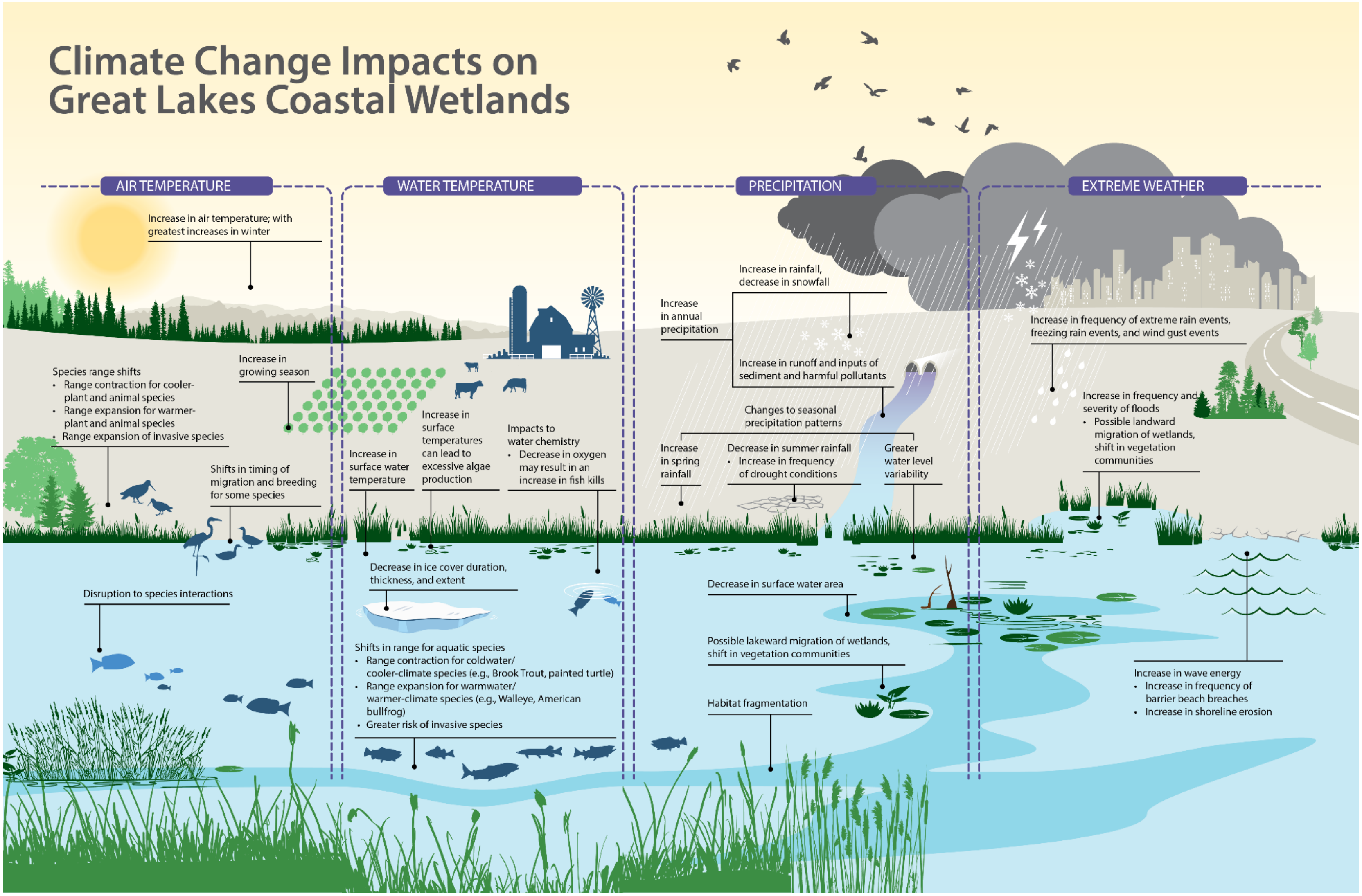


Figure 12. *A conceptual diagram showing potential climate change impacts on Great Lakes coastal wetlands (ECCC, 2021).*

The cumulative impacts of increasing water temperature, precipitation, and storm-related runoff of nutrients, contaminants, and sediments cause water quality impairments such as turbidity, eutrophication, hypoxia, and harmful algal blooms, including toxin-forming cyanobacteria (Michalak et al., 2013, ELPC, 2019). Excess sediment loading can bury wetland plant communities, decrease light penetration and photosynthesis, and cause fish die-off due to lack of oxygen (Environment Canada, 2002). Primary producers (i.e., algae, macrophytes, and plants) are particularly sensitive to chemical changes and warming water temperatures. These changes are expected to impact the rate of primary production (Magnuson et al., 1997). In shallow coastal areas, increased primary production and warmer water temperatures can lead to more rapid decomposition and summer hypoxia.

3.2.3 Altered Coastal Processes

Warming air and water temperatures have reduced the ice cover across the Great Lakes (Notaro et al. 2015; Wuebbles et al., 2019). Sandy shore systems of the Lower Great Lakes are most vulnerable to longer ice-free winters because of intense storm events that generate extreme storm surges, particularly during periods of high lake levels. The typical human response is to protect property by armouring shorelines, which in turn disrupts the natural erosion, sediment supply, transport, and deposition. Protective sand barrier features (as well as other wetlands) at Point Pelee, Hillman Marsh, Rondeau, Long Point and Lynde Creek have already been breached and damaged due to high water levels, such as those observed in 2019 and 2020. These shoreline reaches and others will continue to be vulnerable to sand starvation due to shoreline hardening and jetties that trap sediment (Zuzek, 2021). This will result in poor outcomes for wetland resilience and biodiversity.

3.2.4 Loss of Wetland Biodiversity

The overall impact of climate change on native wetland species is dependent upon wetland hydrogeomorphic type, surrounding land use(s), adaptive capacity, and the rate and magnitude of change in temperature, precipitation, and water levels. A vulnerability assessment of Great Lakes species showed that 175 of the 280 assessed species are vulnerable to climate change (Brinker et al., 2018). Of the 10 taxonomic groups assessed, those depending on water (molluscs, fishes, amphibians, lichens) were most vulnerable. Species dependent upon wetland habitat are more vulnerable to changes in seasonality of precipitation and altered water levels. The highest concentrations of the most vulnerable species are associated with coastal wetland and dune complexes of Lakes Erie and Huron, and large rivers draining into Lake Erie (Brinker et al., 2018).

Exceedance of air and water temperature thresholds can result in loss of or variability in species productivity, recruitment, abundance, and overall community composition (Michalak et al., 2013). For example, Audubon’s (2019) climate report, “Survival by Degrees: 389 Species on the Brink", concludes that under a 3°C average global temperature increase, the percentage of vulnerable bird species per U.S. state range from 27% to 55%. Arrival of migratory birds to their breeding grounds is a critical phenological event that sets the stage for the remainder of the breeding season, impacting offspring survival. Asynchrony between food availability and timing of migration has already led to songbird population declines (Mayor et al. 2017). Changes in thermal and chemical conditions are also expected to alter fish habitat, fish populations, and the Great lakes fishery (Collingsworth et al., 2017). Northward range expansions have been documented for warm-water fishes at a rate of 13 km per decade over a recent 30-year period (Alofs et al., 2014). Similarly, nearly half of the 80 species of Great Lakes mammals occur at either their southern or northern range and are expected to shift northward with increasing temperatures (Myers et al., 2009).

Diversity of wetland bird communities is associated with the diversity and interspersion of wetland vegetation with open water. Prolonged lows and highs in water levels, and other ecological processes that homogenize wetland habitat, or alter the balance of vegetation to open water, will impact breeding success (Steen et al., 2006; Timmermans et al., 2008; Chin et al., 2014). Forster's and Black Terns, Pied-billed Grebes, Rails, and Bitterns nest on or near the water surface are vulnerable to extreme high water levels (Meyer et al. 2006). Lower water levels and higher summer water temperatures can also impact fish and fish-eating wildlife by encouraging diseases such as botulism (Lafrancois et al. 2011; Michigan Sea Grant, 2018). Excess nutrients and sediments, coupled with warm water temperatures provide conditions for the growth of algae and the spread of invasive plants like *Phragmites* and cattails.

Table 3. *Summary of major climate variables as drivers of change, likely impacts, and associated intensifying factors summarized from workshops, discussions, interviews, and literature reviews.*

Climate Driver and Change	**Likely Impacts**	**Intensifying or Confounding Variables**
Higher Lake Levels	Vegetation in wetlands is dominated by flood-tolerant plants. Floating and submerged plants less likely to persist, reducing fish and wildlife habitat. Severe storms and high lake levels result in nest abandonment and loss of wetland bird habitat. Shoreline erosion and damage to all geomorphic forms of wetlands, including diked, managed wetlands.	Shoreline armouring and protection alters wave energy, sediment dynamics, inhibits the formation of sand spits, bars, and beaches that protect barrier-enclosed wetlands, and prevents landward wetland migration.

Climate Driver and Change	Likely Impacts	Intensifying or Confounding Variables
Lower Lake Levels	Wetland drying and stranding depending on bathymetry. Reduced hydrologic connections to riparian zones and groundwater recharge. Vegetation becomes dense and less diverse. Establishment, and prominence of invasive *Phragmites* and hybrid cattail. Loss of winter underwater habitat. Loss of spawning access and submerged aquatic vegetation for fish. Fish communities become more homogenized. Decrease in the integrity of bird communities - loss obligate marsh-nesting birds.	Encroachment of agriculture and development exacerbate habitat fragmentation. Shoreline "grooming" and increase in dredging for boat access. Indirect effects of lower lake levels include an increase in the oxidation of wetland soils and seed germination. Upland vegetation colonize former marsh habitat.
Increasing and Extreme Air and Water Temperatures	Exceedance of optimal temperature ranges and thresholds for wetland organisms. Possible phenology mismatches (e.g., timing of flowering, seed setting and food availability) may affect migration patterns and other ecological functions. Loss of native species, particularly at the southern edge of their ranges, and increases in species at the northern edge. Introduction and predominance of temperature tolerant species, including non-native invasive species. Possible emergence and proliferation of pests and disease such as botulism.	Conversion of natural land cover to agriculture and urban development influences regional air temperatures. Increased evaporation/evapotranspiration during the growing season reduces water stored in the surrounding landscape. A warmer climate increases the risk of drought, the rate of decomposition, and release of stored carbon. Warmer water reduces dissolved oxygen.
Increasing Precipitation, Less Snowfall and More Winter Rain, Frequent Storm Events	Increased frequency, duration, and magnitude of runoff of sediment, nutrients, and contaminants that degrade water quality. Wetland flooding and erosion. Diminished wetland capacity to recycle nutrients and trap suspended organic matter. Changes in timing and volume of seasonal streamflows produce negative impacts to the diversity and abundance of aquatic invertebrates, fishes, and wetland-nesting birds.	Increases in the human population, land conversion, and impervious surfaces, along with loss of natural land cover and lack of cover crops exacerbate overland runoff. Increase in nutrient levels encourage Phragmites and cattails to dominate over native species in the emergent zone.

Climate Driver and Change	Likely Impacts	Intensifying or Confounding Variables
Decreasing Precipitation in Summer with Greater Evaporation	Decrease in wetness during the growing season and potential drying of wetlands. Lower tributary flows with decreased transport of organic matter, suspended sediment, and materials that nourish wetlands. Loss of deep-water refugia during longer or severe droughts threaten populations of amphibians and less-mobile species. Extreme drought with persistent disturbance to wetland structure, function, decomposition, productivity.	Changes in timing and amount of water flowing through wetlands can be compounded by riverine dams and other forms of hydrological disruption.
Decreasing Ice Cover	Greater erosion of fringing wetlands from storm events heightened by ice-free lake. Overwash and breaching of barrier-beach protected wetlands. Potential for increased coastal recession. Less wave attenuation; change in amount and direction of sediment drift. Lengthening of the erosion season, longer period of wave effects on coast; increases exposure; more erosion of wetland vegetation leading to destabilize fish spawning habitat.	Typical human response is to armour shorelines, which in turn disrupts the natural sediment supply to barrier-features (sand spits, barriers, and beaches) that protect wetlands. Breaching of barriers and dikes ensues, with loss and damage to the wetland vegetation community and habitat of wetland-dependent organisms.
Increasing Storm Frequency, Intensity and Duration	Wetlands exposed to stronger waves, greater erosion and recession rates, breaches in barrier-protected wetlands, and damage to wetland vegetation during crucial periods of growth or breeding or spawning seasons.	

3.2.5 Imperative for Adaptation and Resilience

A changing climate is causing impacts across the Great Lakes Basin (McDermid et al., 2015; GLISA, 2016; ELPC, 2019). Conservation practitioners can no longer focus solely on maintaining the current wetland state or restoring to a preferred historical state. Climate change necessitates a re-examination of resource management practices and a reshaping of policy. It is vital to take transformative approaches in improving coastal wetlands resilience and in supporting their ability to adjust, reassemble, maintain biodiversity, and function. In simple terms, there is a need to plan for climate change, develop adaptation solutions, and implement actions that respond to the impacts of climate change that are already happening, as well as prepare for future risks. In so doing, coastal wetlands will continue to provide the ecosystem services that contribute to positive economic, social, cultural, and freshwater ecosystem outcomes.

4.0 Adaptation and Resilience: From Concepts to Implementation

Resilience is a trait, reflecting the capacity of a system to cope with disturbances and respond in ways that maintain its functions and structures, whereas adaptation defines how society deals with climate impacts (IPCC, 2014; Agard et al., 2014). Although resilience is used to describe desired ecosystem outcomes, a description of what this entails is often vague. This is because the concept has been developed in many disciplines and applied across natural, built, and social systems (Gallopín, 2006; Joakim et al., 2015; Masselink and Lazarus, 2019). This section summarizes key principles of resilience relevant to Great Lakes coastal wetlands, which informed the development of adaptation strategies for building resilience presented in Section 5.

4.1 Exploring Ecosystem Resilience

Enhancing ecosystem resilience is perceived as a desirable management outcome because a resilient system is better able to cope with disturbances than a system with limited capacity to respond (Walker and Salt, 2012; Biggs et al., 2015; Beller et al., 2019; Chambers et al., 2019; Masselink and Lazarus, 2019). Resilience is often prescribed in ecosystem management and policy. For example, efforts pursuant to the Great Lakes Water Quality Agreement (2012) seek to

"…contribute to the achievement of the General Objectives of the Agreement by conserving, protecting, maintaining, restoring, and enhancing the resilience of native species and their habitat, as well as by supporting essential ecosystem services".

Figure 13. *Coastal wetland creation at Tommy Thompson Park, Toronto made resilient to the forces of Lake Ontario.*

However, the interacting and cumulative impacts of climate change and non-climatic stressors creates a complex scenario that constrains achievement of resilience (Aslan et al., 2018). Operationalizing resilience is difficult, and efforts have primarily focused on definitions and broad conceptualizations (Gunderson, 2000; Walker et al., 2004, Walker and Salt, 2006; Folke, 2006; Gunderson et al., 2010). When moving from theory to practice, wetland conservation practitioners can consider several points that capture the essence of resilience thinking identified by Walker and Salt (2012) and modified here for framing coastal wetland resilience:

1. Coastal wetlands are self-organizing, able to adjust and reorganize in response to disturbance and change.
2. There are limits (e.g., tipping points or thresholds) to the self-organizing capacity and ability to recover. Beyond these limits, wetlands enter a different state and function.
3. Coastal wetlands are part of a complex social-ecological system with linked social, economic, and biophysical spheres of influence.
4. Wetlands change over time and move through adaptive cycles (e.g., responses to water levels, nutrient loads, invasive species etc.).
5. Linked adaptive cycles function across multiple scales. What happens at one scale can have an influence on scales above and below (e.g., adjacent land use pressures and nutrient assimilation and cycling, coastal littoral zones, upstream watershed).
6. Working with wetland resilience involves maintaining, adapting, and transforming, all of which come with investment, monetary costs, risks, and trade-offs.
7. Resilience is not about knowing everything, or resisting change, but rather a willingness to acknowledge uncertainty, learning by doing, negotiating conflicting uses and needs, and collaboration through an adaptive management process.

4.1.1 Preconditions and Principles of Resilience

The resilience-based principles presented in **Table 4** have been formulated to guide conservation practitioners in moving from theory to practice. Each principle uniquely contributes to resilience. Collectively, the lines of questioning guides the development of important management options to address climate impacts. These principles have been applied to the adaptation strategies, measures, and options for enhancing coastal wetland resilience presented in Section 5.

Table 4. *Resilience-based management principles and components that inform the development of adaptation strategies, measures, and options (adapted from Glick et al., 2011; Walker and Salt, 2012; Stein et al., 2014; Biggs et al., 2015; Beller et al., 2015;Simonsen et al., 2016; Beavers et al., 2016; Sterk et al., 2017; and Chambers et al., 2019).*

Principle	Questions & Components to Guide Adaptation
Consider Broad Landscape and Setting *Geophysical, biological, and sociocultural aspects of a landscape determine constraints on and opportunities for resilience.*	• What geophysical elements (geology, soils, and topography) support wetland habitats, ecological function, and diversity? • What biotic legacies (e.g., seed banks) are present? • What are the dominant and rare/unique vegetative communities? • How have land use history and change influenced the wetland and surrounding landscape? Where are persistent processes, structures, habitats, or biota (e.g., high groundwater, remnant habitat patches, and locally adapted wildlife populations) that represent areas of resilience? • Are there features (e.g., managed wetlands, green infrastructure, wetland migration spaces) that could support resilience in modified conditions?

Principle	Questions & Components to Guide Adaptation
Understand Key Patterns and Processes *Movement of energy and materials that create and sustain landscapes and wetlands through physical, biological, and chemical drivers.*	• What are the abiotic processes (e.g., lake levels, tributary flows, groundwater, and coastal processes) and biotic processes (e.g., gene flow, adaptation, evolution, food-web dynamics) that influence wetland size, heterogeneity, structure, and function, and that can accelerate recovery after disturbance and create opportunities for adaptation? • What are key biotic–abiotic feedback loops that might enable recovery and persistence (e.g., water-sediment–vegetation interactions)? • What changes in patterns, processes, and recovery rates provide insight into ecological and spatial resilience; what characteristic ecosystem processes and higher recovery rates of those processes serve as indicators of higher adaptive capacity and resilience? • What is the historic range of variability in patterns and processes that can provide a baseline for evaluating changes in disturbance? • How will climate change impact these variables?
Understand the Landscape Context and Manage Connectivity *Links between habitats, processes, and populations that enable movement of materials and organisms.*	• Where are the opportunities to preserve or create structural and functional links between wetlands and landscapes to support physical processes, facilitate wildlife to avoid unfavourable conditions, make use of new resources, re-establish after disturbance, and exchange genetic material? • How might the spatial configuration of wetlands decrease the sensitivity of populations to disturbance, facilitate movement, or hasten recovery (e.g., connectivity across physical gradients in temperature or moisture)? • Where might isolation or disconnection be important to minimize the spread of undesirable disturbance, invasion, or disease? • How can linkages between wetlands, processes, and populations be maintained/established to enable movement of materials and organisms?
Maintain Functional Diversity, Complexity & Redundancy *Multiple similar or overlapping elements or functions that provide insurance against loss of key functions or features.*	• What is a locally appropriate variety of surrounding landscape features, including a representative diversity of wetland types, abiotic heterogeneity (e.g., topography, groundwater, and soils), and within-habitat heterogeneity (e.g., refugia)? • Where are opportunities to increase structural redundancy for key features (i.e., multiple discrete wetland habitat patches or structures)? • What are the functional redundancy traits, or the presence of multiple components that can perform the same function, and provide 'insurance' by allowing components to compensate for the loss or failure of others? • Where might species of conservation concern be supported to provide population redundancy? • What spatial information on ecological and spatial resilience, disturbances, and locations can be used to ensure that areas selected for management actions support species populations and are beneficial.
Establish Partnerships	• Broaden participation by active engagement of stakeholders, rights holders, and partners in projects to allow individuals to make necessary connections and decisions to self-organize and boost overall resilience.

Principle	Questions & Components to Guide Adaptation
The individuals, communities, and institutions that shape and steward landscapes.	• Partnerships increase the effectiveness of decisions and reduce uncertainty. • Broad and well-functioning participation across jurisdictions can build trust, create a shared understanding and uncover perspectives that may not be acquired through more traditional scientific processes.
Improve Governance *Well connected people, institutions and governance structures can better deal with change and disturbance.*	• Provide a governance structure that enables working principles, especially learning and experimentation, participation, connectivity, and diversity and redundancy within a social setting. • Collaboration across institutions and scales improves connectivity and learning across scales and cultures. • Include a diversity of agencies and groups with complementing goals and objectives in the development and implementation of adaptation actions.
Encourage Adaptive Management *Learn by doing through design, implementation, assessment of actions and adjusting as needed.*	• Adaptation approaches are most effective when developed in the context of an adaptive management framework: assess > design > implement > monitor > evaluate >adjust • Implementing management actions as experiments provides information on strategies that can increase adaptive capacity. • Learning and experimentation through adaptive and collaborative management is an important mechanism for building resilience, ensuring that different types and sources of knowledge are considered.

4.1.2 Characteristics of Resilience in Coastal Wetlands Systems

Figure 14. *Rondeau Bay Provincial Park with shoreline marsh vegetation.*

Ecosystem resilience is not easily discernable, as resilience reflects a range of responses to probable or unforeseen future shocks and stresses. Resilience depends on the capacity of wetlands to recover after disturbance. Describing a resilient coastal wetland is further complicated by the variety of hydrogeomorphic types within the Great Lakes Basin (**Table 1**), the underlying biogeochemical processes (Rezanezhad et al., 2020), and the desired states expressed by wetland managers. Historical stressors and management actions also influence present or future resilience to climate shocks and disturbance (Chambers et al., 2019).

Despite the complexities associated with coastal wetlands, general characteristics of a resilient wetland system include:

- **High ecological condition, intact structure, composition, and natural biotic and abiotic processes**:
  - A self-sustaining ecosystem able to accommodate stress and change.
  - Key processes, such as nutrient cycling, plant community succession, water levels and flow patterns, and intact sediment dynamics, all functioning to accommodate a wide range of variability.
  - Biologically, wetland plant and animal communities are representative of the native communities and diversity found within the Great Lakes.
  - Structurally, physical features are stable.

Figure 15. *Eastern Georgian Bay coastal wetland set within the Canadian Shield.*

- **Low exposure to climate extremes:**
  - Refugia with air and water temperatures that support native aquatic biota.
  - Naturally fluctuating wetland water levels (temporary, seasonal, and multi-year).
  - Abundant micro-refugia where abiotic and biotic conditions and processes persist.

- **Low wetland sensitivity:**
  - Large wetland and wetland complexes with a diverse assemblage of native wetland vegetation communities and topography.
  - Interspersion of vegetation and open water (1:1 ratio) to support native species.
  - Redundancy, or a high number of species (plant, animal, micro-organism) that perform similar functions that contribute to wetland function and ecosystem services. One species loss is compensated by other species contributing similarly to function diversity.

- **High adaptive capacity:**
  - High water quality with no, or low concentrations of chemical and nutrient pollutants.
  - Accommodation space for wetland migration (inland or waterward).
  - Extensive connectivity across scales to facilitate movement of material and species:
    - Hydrological connectivity to open lake waters.
    - Longitudinal tributary connectivity with lateral floodplain connections.
    - Landscape connectivity, with other wetlands, and diverse habitat patches.
    - Natural erosion and intact littoral sediment transport and deposition.

- High social, political, and financial capital for wetland restoration, protection, governance, and science.

4.2 Relevance of Ecosystem Thresholds to Wetland Resilience

Underpinning resilience thinking is the premise that there are limits to how much a self-organizing ecosystem can be disturbed without switching to a qualitatively different state controlled by a different set of processes. These limits are known as 'thresholds or tipping points' (Holling, 1973). When ecosystem resilience is sufficiently degraded, there is risk of shifting from a desirable state to an "alternate or undesirable state, regime, or domain" (Walker and Salt, 2012). While resilience practice involves understanding thresholds, the science of coastal wetland thresholds is a management gap (Gunderson, 2010; Walker and Salt, 2012; Standish et al., 2014). However, shifts in coastal wetland state, structure, and function have been observed over time that are related to internal (e.g., water depth and quality, vegetation change and abundance) and external drivers (e.g., climate, lake levels, and invasive species). These observations can be used to help identify thresholds by retrospective analysis of disturbances associated with observed switches between wetland states. Given the current focus on resilience as a beneficial property of ecosystems, it is important to underscore that, when coastal wetlands pass a threshold and transition to another state, the new stable state may be highly resilient in an unhelpful or undesirable way. The following examples illustrate transitions to alternative coastal wetland states/regimes.

Lake Ontario coastal wetland quality and function deteriorated due to altered natural lake level variation under regulation Plan 1958D and 1958DD. The system was no longer dynamic, and wetlands evolved to a new stable regime with large monotypic stands of cattail (*Typha X glauca* and *Typha angustifolia)* as the dominant vegetation community (**Figure 16**). This resilient state resulted in a general loss of wetland vegetation diversity (Wilcox and Bateman, 2018). A new regulation plan (Plan 2014) now manages water levels to create a more variable regime to ensure dynamic disturbance conditions for Lake Ontario wetlands to reorganize and develop greater plant and animal diversity and resilience (IJC, 2014). The Great Lakes-St. Lawrence River Adaptive Management Committee (2020) is currently undertaking monitoring, modeling, and assessment to support evaluation of the regulation of water levels and flows[1].

Figure 16. *Lake Ontario coastal wetland dominated by cattails (USGS. Public domain).*

[1] https://www.ijc.org/en/glam

Cootes Paradise Marsh is a large (250-ha) drowned river mouth marsh located in Hamilton Harbour. At the turn of the 20th century, over 90% of this wetland was covered with diverse vegetation; however, the marsh receded to less than 15% cover by the 1990s due to agricultural, urban development, discharge of sewage effluent resulting in hypereutrophic conditions, and invasion of common carp. The spawning and feeding behaviours of common carp resulted in loss of aquatic plants and some of the most turbid water conditions in a Great Lakes coastal wetland supporting only pollutant-tolerant species (Chow-Fraser et al., 1998). The installation of the Cootes Paradise Fishway in 1996 reduced carp density and the marsh ecosystem improved in water quality and wetland vegetation in sheltered inlets (Thomasen and Chow-Fraser, 2012; Leisti et al., 2016). However, the main flow through the marsh remains hypereutrophic with high algal concentrations and unable to support the growth of submerged aquatic vegetation (Thomasen and Chow-Fraser, 2012; Yang et al., 2020). The transition of Cootes Paradise to a less degraded wetland system will depend on improvements in water quality and an increase in the diversity and abundance of native submerged and emergent/meadow marsh vegetation through continued restoration and stewardship efforts (Yang et al., 2020).

Hillman Marsh is a 340 ha barrier-protected coastal wetland near Point Pelee National Park. A one kilometre barrier-beach once protected the marsh from Lake Erie. In 1973, the barrier was in a natural state and the wetland featured dense stands of emergent vegetation, even during periods of high lake levels (Zuzek, 2021a). By 1988, cottages and homes were constructed on the barrier and shoreline hardening cut off the natural sediment supply that nourished and maintained the barrier beach. Following a 2018 storm, a breach developed in the barrier reducing it to a narrow ribbon of sand devoid of vegetation. Record high lake levels and storms in 2019 caused the breach to widen to over 500m. By spring of 2020, the barrier-protected wetland system reached a tipping point and a new regime emerged. The barrier beach lagoon and wetland system is no longer sheltered from Lake Erie and has transformed to an open muddy embayment (**Figure 17;** Zuzek, 2021a).

Figure 17. *Breach and inundation of the Hillman Marsh barrier-protected wetland (Zuzek, 2020).*

In all the wetland cases presented above, disturbances resulted in a regime shift, with an alternate stable state emerging with its own form of resilience and a wetland with different structure, function, and biodiversity. Consequently, the transition from one state to the other may be unacceptable in some socioeconomic and conservation contexts, necessitating actions to improve ecological conditions and resilience. For additional information on multiple stable states and shifts in coastal tidal wetlands, see Moffett at al., (2015), or Mushet and colleagues (2019) who explore the concept in the prairie pothole region.

4.3 Pathways to Resilience

The pursuit of climate-resilient pathways involves identifying vulnerabilities to climate impacts, assessing opportunities for reducing risks, and taking adaptation action (Denton, et al., 2014). Communicating adaptation options is complicated by the complex nature of ecosystem management, the multitude of options to address climate change at different scales and geographies, and the varied uses and interpretations of terms (Joakim et al., 2015; Peterson St-Laurant et al., 2021). This section focuses on three resilience pathways that frame the broadest level in a continuum of options (**Figure 17**; Glick et al., 2011a; Millar et al., 2007 in Lawler 2009). The classification enables comparisons between pathways and outcomes, and generates insights by measuring change over time (Peterson St-Laurant, 2021).

Resistance represents the ability of a system to withstand a disturbance or change without significant loss of ecological function. Resistance strategies may be appropriate for resisting the trajectory of change, maintaining, or restoring ecosystem processes, function, structure, composition, or high-value species (e.g., controlling new invasive species).

Recovery is the ability of a system to bounce back and recover from disturbances or changes. It may change in response to external forces but returns to a similar state. The supposition is that systems that are more "resilient" are those that are better able to adapt to changes in climate and will continue to function, although potentially differently.

Transformation has emerged as a climate-resilient pathway because the rate and magnitude of climate change could exceed the capacity of a social-ecological system to cope (City of Toronto, 2019; Mortsch, 2020). Transformation can change the fundamental attributes of social-ecological systems in response to actual or future climate to enable systems to be resilient (Noble et al., 2014; City of Toronto, 2019). At the core of this approach is embracing uncertainty, enabling dialogue, co-producing knowledge, adaptive management, and participative learning by doing (City of Toronto, 2019).

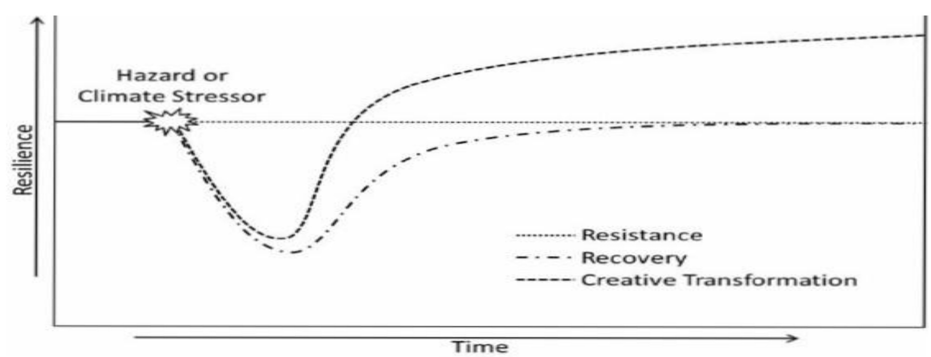


Figure 18. Conceptualizations of resilience (Joakim et al., 2015).

4.4 Transformation: Case Examples

Traditionally, adaptation has been a process of incremental adjustments to climate change. From a conservation perspective, incremental approaches tend to be site-specific, within a given jurisdiction, and/or between two jurisdictions when it comes to planning, monitoring, protection, and policy development (e.g., as a result of finite resources, policy constraints, etc.). In contrast, transformative actions are at a scale and ambition greater that incremental approaches, highly collaborative, embrace paradigm shifts (Noble et al., 2014; Lonsdale et al., 2015), and consider innovative responses when historical approaches are insufficient (Prairie Climate Centre, 2019). This includes strategies that anticipate, shape, and facilitate ecological processes, functions, structures, and transitions to reflect the changing environmental conditions (e.g., use of species or genetic material in replanting that are optimized for future, rather than historical conditions). Transformation can advance changes to societal paradigms, visions, goals, rules, and knowledge to respond to actual and anticipated change that is outside current management experience (Díaz et al., 2019). These approaches are designed to help move a system to an improved state of resilience (Lawler, 2009, 81; Glick et al., 2011; Schuurman et al., 2020). However, they can also be contentious compared to existing practice (Mortsch, 2020). The Intergovernmental Panel on Climate Change (IPCC, 2014) conveys the importance of learning by re-framing constraints of a problem, and/or re-setting the context to facilitate transformation. Here the process of designing flood protection is used to illustrate the different outcomes from reacting, reframing, and transforming (**Figure 19**).

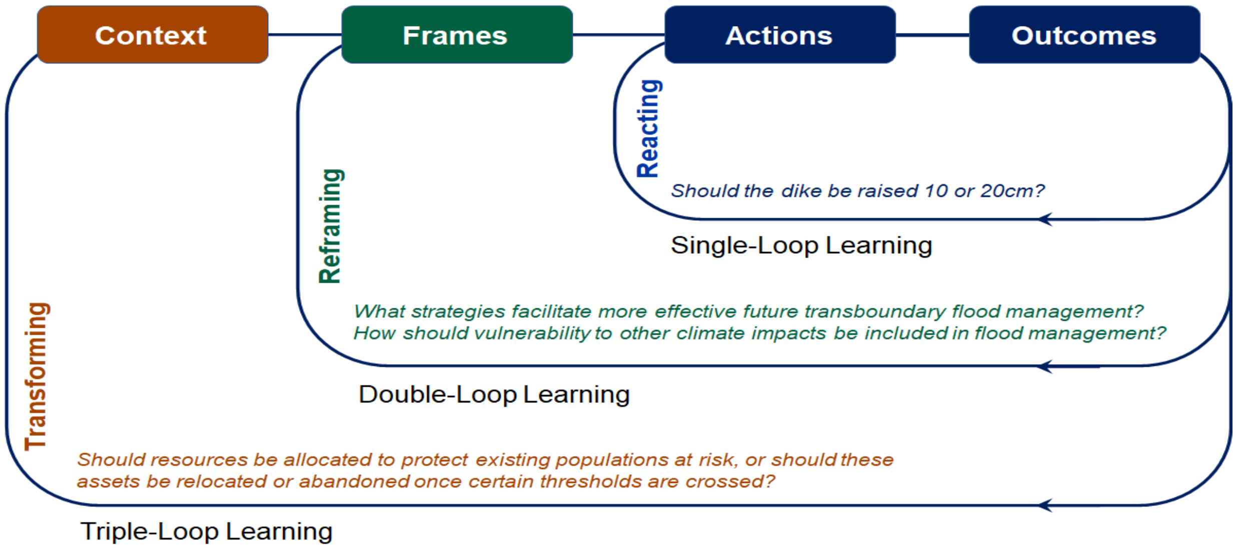


Figure 19. *Moving from reacting, to reframing, and transforming (IPCC, 2014; Lonsdale et al., 2015).*

Reacting (single-loop learning) involves the maintenance or adjustment in design to meet a target in a given policy context but does not re-frame or consider re-evaluating policies or governance conditions. Reframing (double-loop learning) involves re-evaluating the assumptions and relationships that contextualize a given action, and encourages consideration of policy alterations (Chapin et al., 2009). Transformation (triple-loop learning) uses the same re-evaluation of assumptions as double-loop learning but also considers whether to alter norms, institutions, and paradigms in ways that require fundamental change in governance (Chapin et al., 2009).

While transformation is needed to enhance coastal wetland resilience, there is a limited understanding of what this looks like for social-ecological systems and when it can be implemented (Fedele et al., 2019), especially for the Great Lakes. An example of transformation could be managed retreat, which allows for the realignment and restoration of land to its original natural state or assisted migration of species to anticipate and facilitate ecological transitions that reflect the changing and emerging environmental conditions (Sáenz-Romero et al., 2021). Similarly, coastal land use planning policy could support a connected network of protected areas, a coastal corridor concept, a land use and development buffer, or other measures that go beyond traditional regulatory authorities and/or responsibilities by conservation practitioners.

4.4.1 Nature-based Solutions

Climate change and the loss of biodiversity are connected, and transformation through nature-based solutions (NbS) addresses both issues simultaneously. Nature-based solutions are measures that protect, sustainably manage, and restore natural or degraded ecosystems with the goal of maintaining or enhancing ecosystem services, simultaneously providing human well-being and biodiversity benefits (Cohen-Shachan et al., 2016, 2019; Seddon et al., 2020). The Government of Canada has committed to NbS by funding Nature Smart Climate Solution projects that sequester carbon through restoring and protecting wetlands, grasslands, and peatlands.

Examples of NbS include an innovative "sand engine" implemented in the Netherlands that improved sand nourishment in sediment-deprived coastal areas and protect against coastal flooding. The co-benefits included recreational space and ecosystem improvements (Stive et al., 2013, **Figure 20**).

Figure 20. *Mega-sand nourishment at the Delfland Coast, Netherlands.*

A transformative project undertaken at Truro, Nova Scotia, involved stakeholders opting for managed retreat, dike breaching, realignment, and restoration of land to its original marsh state - now protecting communities, businesses, a World Heritage Site, and roughly 20,000 hectares of farmland from floods (Sherren et al., 2019).

In the Great Lakes, the U.S. Army Corps of Engineers installed 55 offshore reefs and underwater natural breakwalls to protect the perimeter of the sand spit and reduce erosion at Presque Isle State Park (**Figure 21).** Restoration of the eroded barrier-beach at Braddock Bay (Monroe County, NY) was achieved by constructing a 1,700-foot-long continuous rubble mound breakwater spine with two 180-foot-long rubble mound terminal groins attached, a headland beach, and two long headland rubble mound breakwaters. The project also included excavation of channels, potholes, habitat mounds, native seed mixes, and invasive species treatment to restore the diversity of the existing and new emergent marsh (**Figure 22).**

Figure 21. *Presque Isle Park barriers.*

Other nature-based solutions and adaptation options for the Canadian Great Lakes are highlighted in "Long-term Conservation of Barrier-protected Coastal Wetlands (Zuzek, 2021a) and 'Options to Increase Coastal Resilience with NbS" (Zuzek Inc. 2021b). Possibilities include bypassing sand trapped behind jetties, strengthened shoreline regulations, improved science, partnerships, and restoring barrier-protected wetlands (Zuzek Inc. 2021a; also see Strategy 2).

Figure 22. *Braddock Bay barrier restoration.*

5.0 Adaptation Options to Build Coastal Wetland Resilience

Adaptation in the context of this white paper refers to adjustments in wetland, social, or policy systems in response to climatic risks and impacts. This includes changes in processes and practices to moderate potential damages associated with climate change. This section presents a coastal wetland adaptation framework that organizes a continuum of approaches, ranging from general resilience pathways (Section 4.3), to overarching adaptation strategies, adaptive measures, and options for consideration by wetland managers (**Figure 23**). This continuum is adapted from Staffen and colleagues (2019) that was patterned after similar works (Millar et al., 2007; Shannon et al., 2019; Swanston et al., 2015).

5.1 Coastal Wetlands Adaptation Framework

The adaptation framework developed in this white paper for advancing adaptation and coastal wetland resilience is based on a nested hierarchy of adaptation options ranging from the various resilience pathways (**Figure 19**) to broad adaptation strategies, more specific adaptive measures, and associated options. Each has a specific definition, role, scale of influence, and outcome as illustrated in **Figure 23**. This framework offers coastal wetland managers the following benefits:

- A framework from which wetland managers can select potential resilience pathways, and adaptation strategies, adaptive measures, and options best suited to their specific wetlands, management goals, and objectives.
- A broad spectrum of possible adaptation options that can help sustain healthy wetlands and achieve management goals in the face of climate change.
- A platform for comparing and discussing climate adaptation approaches, as well as identifying policy and science gaps and needs.

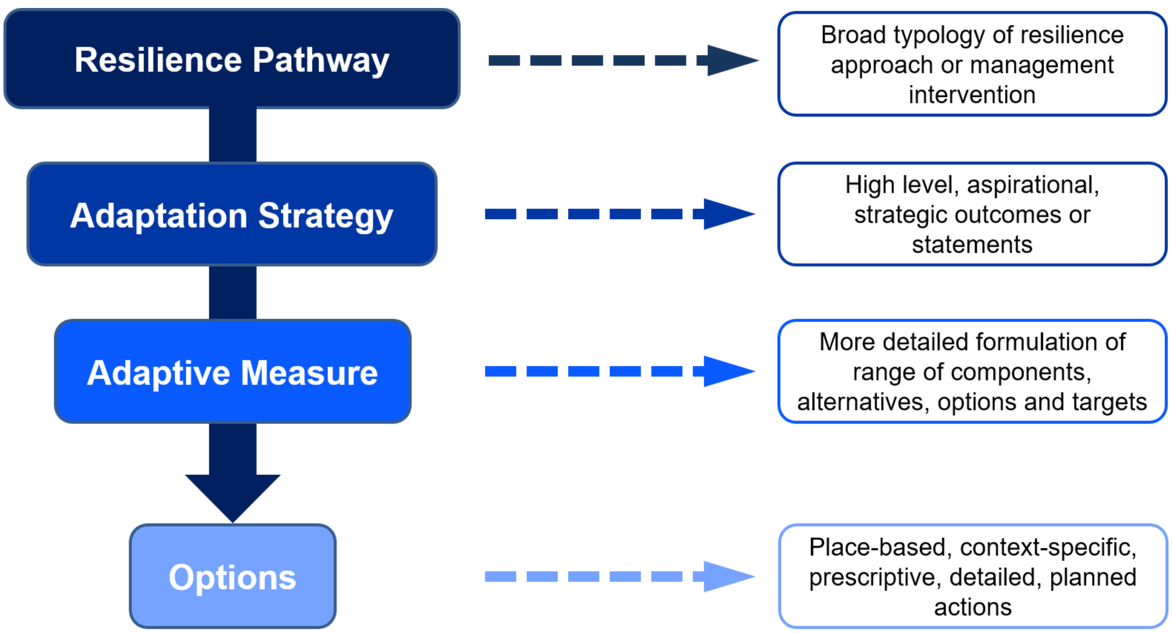


Figure 23. *A framework for coastal wetland resilience and adaptation ranging from broad resilience pathways, adaptation strategies, adaptive measures, and options.*

Coastal wetland resilience can be realized through the prioritizing, planning, designing, and implementing of no regrets and transformational adaptation actions. Use of an adaptive management framework (**Table 4**) can facilitate the process of piloting new initiatives, building interest, and fostering learning and momentum for real world application. Design and implementation of adaptation strategies, measures, and actions must consider the geophysical and ecological processes within the wetland ecosystem, as well as the socioeconomic and cultural (including Indigenous values and knowledge) context. Additionally, local, provincial, and federal reviews, and legislative, regulatory, policy, and permitting requirements should be considered prior to implementation. Several scales (e.g., site-specific, littoral cell, region) have been identified within this white paper that reflect the importance of considering natural processes that occur within a wetland, watershed drainage area, coastal reach, or Lake Basin

(**Figure 24**) which influence the appropriate choice of adaptation options for implementation.

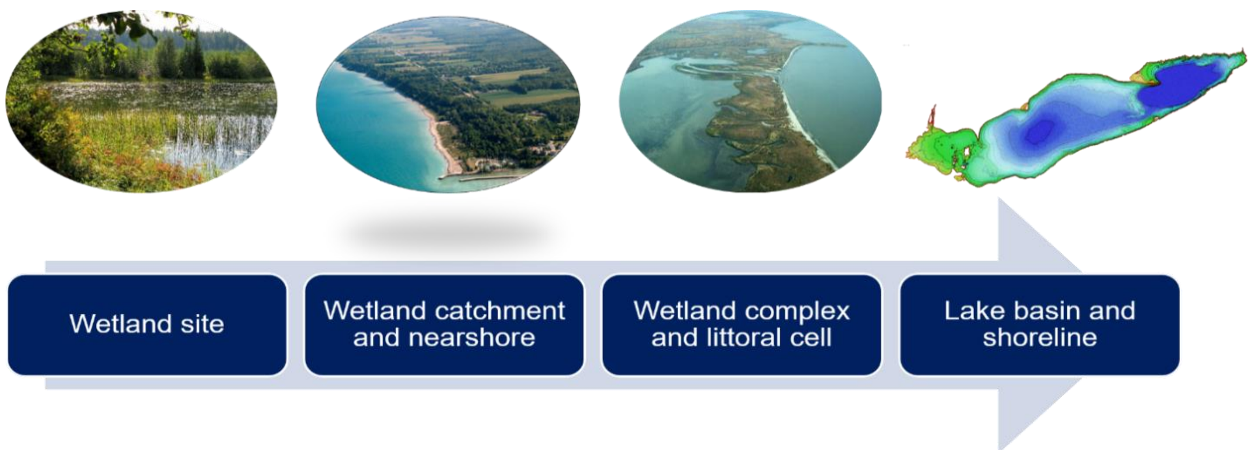


Figure 24. *Scales of adaptation action used in this white paper, ranging from local (left) to Basin-wide spatial scope (right).*

Six adaptation strategies with associated adaptive measures and options were developed based on the principles of resilience thinking, as well as natural heritage systems planning, integrated watershed management, and integrated ecosystem management. They were designed to address the direct impacts of climate change on coastal wetlands, and additionally, the potential for compounding effects of non-climatic stressors. Key information was synthesized from journal articles, reports, website content, and the input from representatives of resource management agencies, wetland managers, regional policy advisors, Conservation Authorities, Indigenous Peoples, ecologists, and non-governmental environmental organizations who participated in workshops, focus group discussions, and interviews (OCC, 2019, 2020; Mortsch, 2019, 2020). To ensure the range of adaptation options were relevant and practical, an Advisory Committee provided guidance, review, and oversight.

5.2 Strategy #1: Reduce Non-Climatic Stressors and Enhance Adaptive Capacity

The measures of this strategy provide options for reducing the impacts of anthropogenic stressors that constrain the adaptive capacity of coastal wetlands to adjust or cope with climate change (e.g., wetland adaptive capacity; Glick et al., 2009; Krishnapillai, 2018; United States Agency for International Development [USAID], 2009). Great Lakes climate projections show continued warming and variable precipitation, with wetter winters (i.e., less snow cover and more rain), drier summers, and more intense storm events. These climate impacts have a multiplying effect on existing wetland stressors such as a disruption of surface and subsurface hydrology, nutrient and sediment loading, the spread of invasive species, and habitat fragmentation (Gregg et al., 2012; Smith et al., 2015). A reduction in, or removal of existing stressors is considered to be an effective strategy for enhancing the resilience and adaptive capacity of coastal wetlands (Brooks and Adger, 2005). Each stressor may occur within, or outside a wetland (e.g., invasive common carp vs. non-point source pollution) and exert direct or indirect impacts. As such, the adaptive measures and options below span multiple scales and jurisdictions (i.e., local to Basin-wide), demonstrating the need for improved governance, collaboration, and a holistic approach for the long-term conservation of coastal wetlands.

5.2.1 Measure 1A: Maintain and Enhance Wetland Water Quality

This measure emphasizes the need to improve tributary and groundwater quality impacting wetland condition. Runoff from agricultural lands degrades wetland water quality by increasing concentrations of nutrients, sediment, and agrochemicals (Trebitz et al., 2007). As of 2018, 53% of the land in southern Ontario is classified as agriculture; the majority of which is tile-drained. Tile drainage circumvents bioretention and accelerates phosphorus and nitrogen loss from soils (Boesch, 2019; McCrackin et al., 2017). The negative effects of urbanization are also widespread (Croft-White et al., 2017). Built-up and impervious areas (e.g., roads, parking lots) account for 4% of southern Ontario's land cover (Eimers et al., (2020); **Figure 25**), and impedes infiltration of precipitation, and increases surface runoff of nutrients, suspended solids, and dissolved ions (e.g., road de-icing salts). This in turn increases turbidity, temperature, salinity, oxygen demand and pathogens (Howell et al., 2012; Paul and Meyer, 2001; Seilheimer et al., 2007).

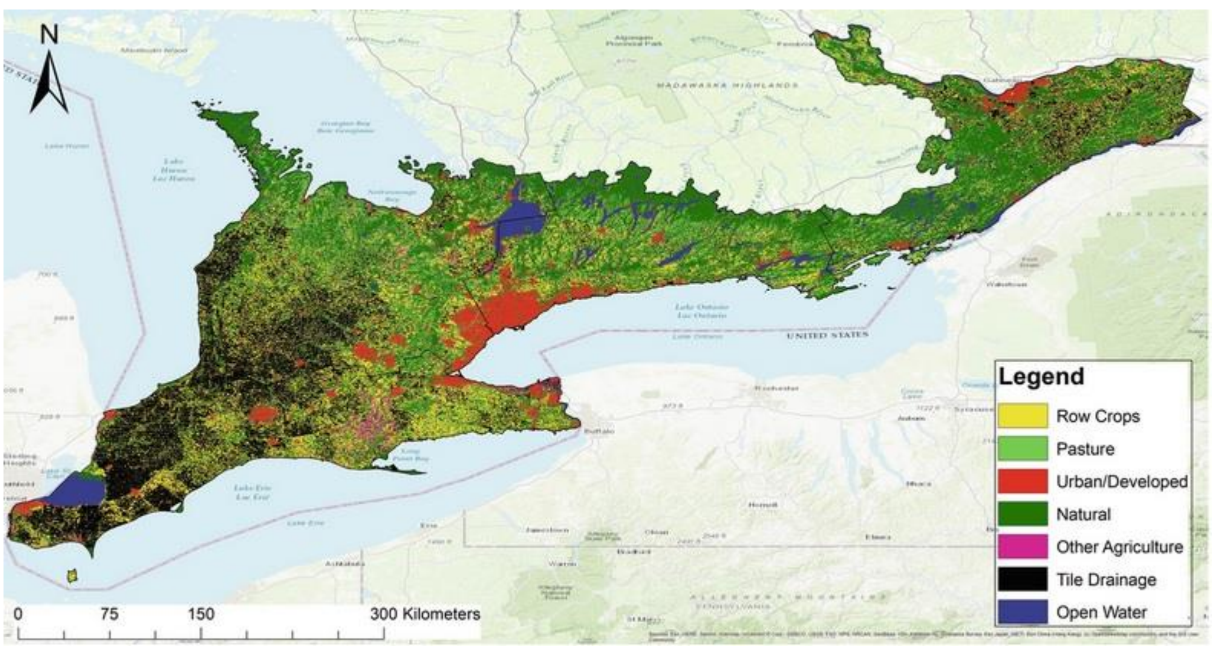


Figure 25. *Land cover and tile drainage in southern Ontario (Eimers et al., 2020).*

Harrison et al. (2020) found that water quality from 511 U.S. and Canadian wetland sites was correlated with the land use and land cover. Wetland water quality at Canadian sites was poorest in portions of northwestern Lake Ontario and Lake Erie, and southeastern Lake Huron.

Conversely, many wetlands of Georgian Bay, the North Channel, Manitoulin Island and Lake Superior had the highest scores for both water quality and land cover (**Figure 26**).

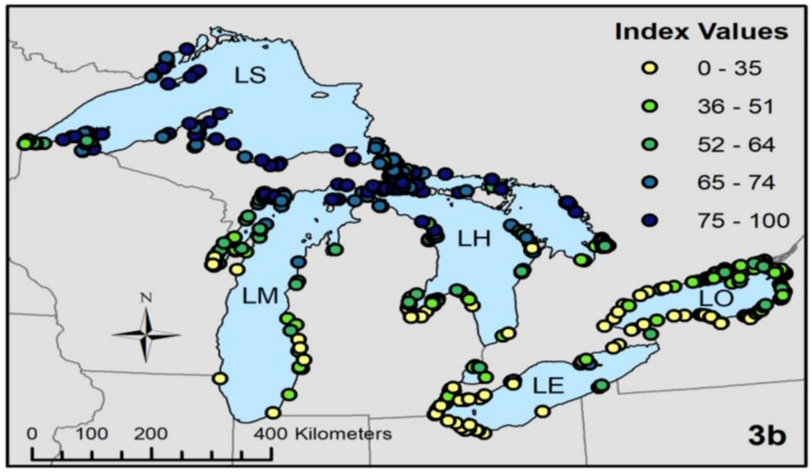


Figure 26. *Distribution of wetland water quality and land use index scores for the Great Lakes Basin. Yellow circles represent the poorest water quality and dark blue circles represent the highest water quality (Harrison et al., 2020).*

Sediment loading, nutrient enrichment, and chemicals from agricultural and urban runoff degrade aquatic habitat and negatively affect wetland biota (Gleason et al., 2003; Relyea, 2005; Sharpley and Withers, 1994, 2013). High turbidity and nutrient enrichment are associated with a decrease in the extent and density of submerged aquatic vegetation, which is an important habitat feature for marsh birds and fish (Hudon et al., 2000; Lougheed et al., 2001; Croft and Chow-Fraser, 2007; Grabas et al., 2012; Cooper et al., 2018). Macroinvertebrate communities exposed to wastewater and urban storm water runoff are less abundant and diverse and are dominated by species tolerant of turbid and warm water temperatures (Dance and Hynes, 2003; Kashian and Burton, 2000; Schock et al., 2014). The application of road de-icing salts can reduce the structure and richness of native vegetation, and disrupt trophic dynamics (Dananay et al., 2015; Hintz et al., 2017; Hintz & Relyea, 2019).

Options for urban and agricultural lands focus on preventing and reducing nutrient and sediment loading at their sources through sustainable land-use planning, alternative farming practices, and green infrastructure. Effective implementation requires collaboration across municipal boundaries where headwaters originate, and stewardship by local conservation-minded organizations (government and non-governmental) to garner the support of public and private landowners (e.g., farmers, municipal urban planners).

Table 5. *Measure 1A Adaptation Options.*

Options for Rural and Agricultural Settings	
1	Create upland and riparian vegetated buffer strips to stabilize eroding streambanks and reduce runoff of sediments and nutrients to coastal wetlands. Example: Buffer strip installation in Perth and Middlesex Counties, ON (UTRCA, 2016).
2	Integrate environmental design into municipal drains adjacent to coastal wetlands (e.g., less drainage adjacent to coastal wetlands, less drain maintenance, wide buffers with

	native species, direct field drainage towards wide vegetated buffer strips for increased nitrogen and phosphorus removal. Example: Bear Creek Watershed, Hamilton County, North-central Iowa (Janes and Isenhart, 2014). Harvest vegetated buffer strips annually to further reduce nutrient leaching (Hille et al., 2018).
3	Incorporate two-stage drainage systems in low-lying areas that mimic natural floodplains, decreasing soluble phosphorus concentrations, turbidity, and increase denitrification (Mahl et al., 2015; Powell et al., 2007).
4	Identify floodplain locations where wetlands can be created, restored, or enhanced to capture and control non-point pollution loads. Example: Lower Sheboygan River, WI, Lake Michigan (Flessner, 2014; Hansen et al., 2018)).
5	Use nutrient sorbing materials (e.g., lime-sand filters) between wetlands and agricultural fields to trap phosphorus-rich soil particles (Hoffman et al., 2009; Kirkkala et al., 2012; Stutter et al., 2012). Remove soluble, bioavailable phosphorus by using of phosphorus sorbing media, such as steel furnace slag or nano-engineered media (Buda et al., 2012; Hauda et al., 2020). Remove nitrate by using mixed reactive media such as woodchips or seashells (Bruun et al., 2016; Vymazal et al., 2020). Examples: Ditch-style phosphorus removal with aluminum-treated steel-slag Fort Recovery, OH (Shedekar et al., 2020).
6	Engineer wetlands in low-lying agricultural fields to facilitate upstream nutrient removal, and stormwater and sediment retention, while also increasing habitat connectivity (Ducks Unlimited Canada [DUC], 2013; Rozema et al., 2016). Example: Edge-of-field wetland restoration in Lake Erie watershed (Page et al., 2020). Example: Small, precisely sited wetlands adjacent to ditches or small tributaries on farms near coastal wetlands (The Wetlands Initiative, 2016).
7	Employ contour farming (e.g., in steep terrain) to slow run-off, reduce erosion and increase infiltration. Where possible, apply no-till practices to minimize mechanical soil disturbance (Janowiak et al., 2018; Lucke et al., 2014). Example: Huronview Farm near Clinton, ON (Huron County, Huron Soil & Crop Improvement Association and Ausable Bayfield Conservation Authority, 2020).
8	Plant cover crops and leave crop residues on fields to preserve topsoil, reduce water and wind erosion, reduce loss of nutrients, enhance the biodiversity of organisms, and promote water storage and carbon sequestration (Kaspar et al., 2012).

9	Grow the Alternative Land Use Services (ALUS) program to additional agricultural watersheds to compensate farmers for transitioning portions of farmland into coastal wetlands, riparian buffers, grasslands, and uplands with the goal of habitat, biodiversity, and water quality improvement.
Options for Urban Settings	
1	Install and maintain green infrastructure or low impact development to promote stormwater retention and infiltration in urban areas adjacent to coastal wetlands and waterbodies that drain to the Great Lakes (Ahiablame et al. 2012; Keller and Ketcheson, 2015). Examples include green roofs, bioswales, permeable pavement, and perforated pipe systems (TRCA and CVC, 2010).
2	Improve existing stormwater infrastructure and best management practices such as erosion or sedimentation silt-fence barriers versus straw bale barriers during construction (Department of Fisheries and Oceans Canada [DFO], 2017).
3	Reduce impacts to wetlands from new developments through i) phased land clearing approach that minimizes the surface area of exposed soils, ii) enhanced topographic variability to lengthen flow path of stormwater, and iii) matching pre- and post-development surface and groundwater balance to coastal wetlands (CVC and TRCA, 2012, Stormwater Management Criteria Document – Appendix C - Water Balance Guidelines for the Protection of Natural Features, https://cvc.ca/wp-content/uploads/2014/09/cvc-swm-criteria-appendices-Aug12-D-july14.pdf
4	Utilize 'Direct Liquid Application' as a road de-icing pre-treatment, to reduce required chloride concentrations by as much as ten times (Ontario Good Roads Association and Conservation Ontario, 2018). Sand, gravel, or pumice can be used as de-icing alternatives for residential and commercial walkways and parking lots (Scarfone, 2019).
5	Continue to upgrade wastewater treatment plants and optimize treatment processes to reduce phosphorus loadings (e.g., transition from primary or secondary treatment to secondary or tertiary treatment; ECCC and OMECC, 2018).
6	Where possible, retire septic tanks/beds and establish a connection to a reticulated sewer system to mitigate the leaching of household waste (Polyakov et al., 2017).

7	Decrease the usage of fertilizers and pesticides on institutional greenspaces adjacent to coastal wetlands, such as golf courses, cemeteries, military bases, hospitals and university campuses (Nakayama et al., 2007; Udeigwe et al., 2015; Yang et al., 2013).
8	Employ dam-regulation best practices to control excessive sediment and nutrient outputs to riverine coastal wetlands without compromising aquatic invasive species management or power generation (Kondolf et al., 2014; ECCC and OMECC, 2018).

5.2.2 Measure 1B: Prevent, Detect, and Control Invasive Animals

Climate change can facilitate the spread and establishment of invasive species by creating favourable climatic conditions outside of their native range (Collingsworth, et al., 2017; Rahel & Olden, 2008; Whitney, et al., 2016). More frequent and extreme climate events (e.g., drier summers, higher lake levels) are expected to decrease the resistance or recovery of habitats and species to invasion. Invaded ecosystems may also be more vulnerable to climate impacts (International Union for Conservation of Nature [IUCN], 2017).
Common Carp (*Cyprinus carpio*) have detrimental effects on waterfowl and native fish habitat (Cahn, 1929; Chamberlain, 1948; Robel, 1961). Carp re-suspend sediments while feeding, a behavior that simultaneously uproots plants, increases suspended sediments, reduces light penetration to near zero, and decreases water quality. This results in loss of emergent plants and low seed germination (Lougheed et al., 1998; Wanner et al., 2009). Asian Carps, particularly Bighead (*Hypophthalmichthys nobilis*), Grass (*Ctenopharyngodon idella*) and Silver Carp (*H. molitrix*), consume large quantities of zooplankton and phytoplankton respectively that are important components of the lower food web and vital food sources to native species. Asian Carp can negatively affect wetland food webs (Irons et al., 2007) by reducing aquatic vegetation biomass and native fishes such as Largemouth Bass (*Micropterus salmoides*) and Bluegill (*Lepomis macrochirus*; Wittmann et al., 2014). They pose an imminent risk to wetlands given their presence in the Chicago Area Waterway System and the favourable environmental conditions of the Great Lakes (Chapman, et al., 2021). Natural reproduction of Grass Carp has been documented in two U.S. tributaries on Lake Erie (Chapman, et al., 2013).

Existing terrestrial invaders of concern to biodiversity and climate resilience of coastal wetlands include Mute Swans (*Cygnus olor*) and Emerald Ash Borer (*Agrilus planipennis*). Mute Swan consume submerged aquatic vegetation as a main food source (Bailey et al., 2008), which can greatly reduce the amount of habitat and refuge available for invertebrates, fish (Allin & Husband, 2003; O'Hare et al., 2007), and migratory waterfowl that rely on fish and invertebrates as food (Gehring et al., 2020). Mute Swans also exert aggression towards and outcompete native waterfowl for food sources (Conover & Kania, 1994).

The Emerald Ash Borer is a wood-boring beetle that is responsible for the decline in native ash tree populations, most notably Green (*Fraxinus pennsylvanica*) and Black (*F. nigra*) Ash which are endemic to Great Lakes coastal wetlands. The loss of black ash trees, which are a culturally significant and threatened species (Costanza, et al., 2017; Government of Canada, 2011), may cause a rise in the water table and increase the duration of water at, or near the soil surface in riparian and low-lying wetland areas (Poland & Mccullough, 2006; Slezak et al., 2014). These changes may threaten organisms and processes associated with black ash ecosystems (Youngquist et al., 2017) and challenge land managers sustaining these ecosystems (D'Amato et al., 2018; Kolka, et al., 2018).

A degree of resistance to invasive species may be possible depending on wetland condition (water quality and biodiversity). For example, wetlands with dense submerged aquatic and emergent vegetation may limit the dispersal of zebra mussels downstream and serve as refuge for endangered native freshwater mussels (Bodamer & Bossenbroek, 2008). Similarly, the soft bottom substrate of wetlands with high biological productivity appears to be more resistant to invasion by Round Gobies than adjacent lake habitats (Cooper et al., 2007).

Prevention and early detection and eradication are of critical importance to invasive species management (N'Guyen et al., 2016). In Ontario, invasive species management is jointly regulated by federal and provincial legislation. Under the Invasive Species Act, the Ontario Government has the right to regulate prevention, early detection and rapid response, control, eradication, monitoring and reporting, education and research, risk assessment, and prevention and response plans regarding invasive species.

Collaborative efforts are needed across federal, provincial, municipal agencies, Indigenous communities, environmental non-governmental organizations (ENGOs), academics, and private corporations to develop timely responses to the spread of invasive species. The options below can be used to detect, prevent, and control invasive animal species. Although all options are intended to benefit coastal wetlands, without careful planning, some options may have potential adverse effects on native flora and fauna (e.g., water level drawdowns, use of piscicides). Implementation may require local, provincial, or federal government authorization or permitting. For adaptation options related to invasive plants, refer to Strategy 3B.

Table 6. *Measure 1B Adaptation Options.*

1	Develop an Ontario Great Lakes watch list of priority invasive aquatic animals and a site prioritization map to identify the highest-risk sites for invasive species under future climate change scenarios to allow agencies and organizations to coordinate where they conduct sampling and prevention activities (Blue Accounting site prioritization map). Report and promote the reporting of any invasive species observations to the Invading Species Hotline, 1-800-563-7711 or https://www.eddmaps.org/ontario/.

2	Develop regional partnerships and strategies to address public awareness, prevention, and control of invasive species in wetlands (e.g., monitoring, best management practices and actions for prevention, removal, control) including the release of aquarium pets.
3	Construct synthetic (e.g., wire or snow fencing) or biological (e.g., Christmas trees) exclusion fencing around submerged aquatic vegetation and wetland plantings. Examples: Rattray Marsh, Credit Valley Conservation, Mississauga, ON; Hendrie Valley/ Grindstone Creek, Royal Botanical Gardens, Hamilton, ON.
4	Erect a physical barrier to adult carp (e.g., dike, gate, and grate) but allow access to native species where hydrologic and geomorphologic conditions permit (e.g., protected or partially enclosed embayments). Examples: Cootes Paradise Marsh Fishway, Hamilton, ON (Lougheed et al., 2004; Thomasen & Chow-Fraser, 2012; Wilcox & Whillans, 1999); and Cell 2 at Tommy Thompson Park, Toronto, ON.
5	Implement carp removal programs such as harvesting (e.g., electrofishing and gill netting) or winter and spring seining when carp aggregations are densest (Bajer et al., 2011; Pinto, et al., 2005). Carp can also be conditioned to aggregate in areas using bait (e.g., corn).
6	Within impounded wetlands, implement seasonal water-level drawdowns that desiccate carp eggs, disrupt adult spawning, or employ the use of legal piscicides such as Rotenone (Meronek, et al., 1996). Careful planning and permits are required to minimize risks to sensitive wildlife. Example: Ventura Marsh, Iowa (Schrage & Downing, 2004).
7	Research and develop genetic technologies (e.g., daughterless carp, female-lethality) and the use of targeted pathogens (Cyprinid herpesvirus-3, KHV) to decrease population size (Escobar et al., 2017; McColl et al., 2014; Thresher, et al., 2014).
8	Assess the potential impact of a Grass Carp invasion on coastal wetlands across tertiary watersheds by identifying the probability of an invasion (i.e., likelihood of introduction or arrival), and by modelling the amount of submerged aquatic habitat available for grass carp survival and establishment under multiple water-level scenarios (Cudmore et al., 2017). Example: Simulated consumption of submersed aquatic vegetation by grass carp in coastal marshes of Georgian Bay, Lake Huron, ON (Marcaccio & Chow-Fraser, 2019).

9	Naturalize, remediate, and reconstruct riparian wetlands to serve as protective barriers against the spread of dreissenid mussels (Bodamer & Bossenbroek, 2008). Use native perennials when revegetating wetlands and riparian areas (Houlahan and Findlay, 2004).
10	Utilize traps baited with plant volatiles (e.g., Z-3-hexenol) or pheromone lures to detect the presence of emerald ash borers adjacent to coastal wetlands. Emerald ash borer can also be detected by collecting and inspecting branch samples (Bowman & Smith, 2012).
11	Prevent the establishment and recruitment of mute swan populations, by conserving and restoring wetland habitat heterogeneity and biodiversity (Gehring et al., 2020). Implement mute swan control programs and measures near urban areas and properties that may contribute to recruitment (Gehring et al., 2020; Jager et al., 2016; Petrie & Francis, 2003). For permits, contact the Canadian Wildlife Service – Ontario Region (ec.faune.ontario-wildlife.ontario.ec@canada.ca). Example: Colonel Sam Smith Park, Toronto, ON; Goose Control Plan, Toronto and Region Conservation Authority.

5.2.3 Measure 1C: Re-establish Hydrologic Connectivity

Under the combined effects of climate change (e.g., higher air and water temperatures, periodic droughts and wetland inundation, and increased lake-level variability) and anthropogenic activities, there can be continuous changes in the hydrologic connectivity pattern within aquatic systems. This measure provides options to restore and enhance hydrologic connectivity to enhance wetland resilience and the conservation of wetland ecosystem services.

Rivers, streams, lakes, ponds, springs, floodplains, and wetlands provide important linkages between Great Lakes aquatic and terrestrial ecosystems. Unimpeded longitudinal and lateral connectivity between these ecosystems facilitate the exchange of sediment, nutrients, plants, animals, and energy (Jones et al. 2019) and creates conditions necessary for the development of refugia. Hydrology is an important factor for the establishment and maintenance of wetland composition, structure, condition, primary productivity, and nutrient cycling (Mitsch and Gosselink 2007; Wilcox, 2011). However, many natural hydrologic connections between coastal wetlands and adjacent lakes and tributaries have been severed or severely altered by various land uses. Dams and weirs reduce or eliminate the ability of aquatic organisms to migrate between up- and downstream habitats, contribute to the loss of coarse bed-load sediments, and increase downstream water temperature (Januchowski-Hartley et al., 2013). Dikes, inappropriately sized culverts, and transportation corridors including causeways and small bridge spans act as hydrologic barriers, limiting water exchange between coastal wetlands and external sources (Pearsall et al., 2012). Decreased flow from upstream tributaries may reduce the size and biodiversity of riverine coastal wetlands, whereas restricted lake exchange may affect the water chemistry and elevation of lacustrine coastal wetlands, which can promote the expansion of invasive plant species (e.g., Phragmites) (Bouchard, 2007; Maynard & Wilcox, 1997, Wilcox, 2011). The recovery and enhancement of hydrological connectivity includes longitudinal communication between the upstream and downstream reaches of a river, the lateral connection of the river–floodplain/wetland and the river–lake system, and the vertical hydrologic exchange of the wetland surface water and groundwater.

Table 7. *Measure 1C Adaptation Options.*

1	Identify, map and rank dams and barriers that negatively impact coastal wetland condition based on metrics of ecological significance, economics, and risks (Great Lakes Fisheries Commission [GLFC], 2015).
2	Restore lost longitudinal hydrological connectivity focusing on the first barrier from a lake, except those that block sea lamprey migration (Januchowski-Hartley et al., 2013). Maintain or restore longitudinal hydrologic connectivity 75% of stream length where possible (Environment Canada, 2013). Appropriate permits may be required.
3	Modify dams and weirs to manage and replicate a more natural water flow regime (i.e., frequency, magnitude, duration, and timing of flood pulses) in riverine coastal wetlands (Yochum, 2017). Appropriate permits may be required.
4	Restore natural meandering channels feeding into riverine coastal wetlands and deltas to improve water level, flow velocity, and nutrient cycling. (Environment Canada, 2002). Example: Rattray Marsh Conservation Area, Credit Valley Conservation, Lake Ontario.
5	Protect, restore, or enhance lateral hydrologic connections with floodplains/wetlands/riparian areas (>30 metres wide) to support the movement of water, wildlife, and sediments (Environment Canada, 2013).
6	Remove or modify causeways, narrow bridges, and culverts to re-establish hydrologic and habitat connectivity, accommodate future flow conditions, and allow for fish and wildlife passage (Yochum, 2017; Molina-Moctezuma et al. 2020). Example: Long Point Causeway Improvement Project, Lake Erie, ON.
7	Restore and maintain connectivity in watersheds terminating at a coastal wetland when constructing road stream crossings (TRCA, 2015; http://www.trca.on.ca/dotAsset/214493.pdf).

8	Restore degraded floodplain habitat and water flow connections where possible to re-vitalize riverine wetland processes influenced by flood pulses (Junk et al., 1989).
9	Re-establish the hydrologic connection between diked wetlands and the adjacent lake or tributary by building water control structures and determining needed improvements to hydrology, water quality, and fish assemblages. Example: Ottawa National Wildlife Refuge, Lake Erie, OH (Kowalski et al., 2014).
10	Develop and test new designs for structures that impound wetland and flow regulators that allow ingress and/or egress of organisms (Wilcox, 2011).
11	Remove concrete-lined channels that flow directly into or upstream of impaired coastal wetlands and replace with natural channel and associate flood plain habitat without interfering with conveyance.

5.2.4 Measure 1D: Restore and Conserve Landscape Connectivity

This measure addresses the need for improved landscape connectivity, defined as the unimpeded movement of species and the flow of natural processes that sustain life on earth (Convention on the Conservation of Migratory Species of Wild Animals [CMS], 2020). Connectivity is a function of the amount, quality, and spatial arrangement of habitat patches, and the factors that influence the movement of species and matter across landscapes (Hodgson et al., 2009). Landscape fragmentation caused by human activities continues to disrupt habitats, threatening biodiversity and impeding climate change adaptation (Hilty et al., 2020). Without connectivity, ecological processes, such as the flow of plants, animals, abiotic materials, and energy cannot occur (Crooks and Sanjayan, 2006). Connected landscapes support species' adaptation by facilitating movement to new areas as climatic niches shift (i.e., range shifts; Chen et al. 2011). Several wetland species require connected, deep aquatic habitat for movement (e.g., Map Turtles, *Grapteyms geographica*; Northern Pike, *Esox lucius*), and wetland amphibians require connected aquatic habitats (Rothermel and Semlitsch 2002, Popescu and Hunter 2011, Nowakoswki et al. 2013).

Agriculture, urban, rural, and shoreline development and hardening are the main causes of habitat fragmentation over a large proportion of the southern Ontario landscape (OBC, 2010, 2015). Terrestrial landscape connectivity in the two-kilometre coastal margin of Lakes Erie and Ontario was assessed based on natural and anthropogenic land cover types (ECCC, 2021), and measured using effective mesh size (Jaeger, 2000).

The Lake Erie coastal margin is highly fragmented, with exceptions being the St. Clair River - Walpole Island Delta, parts of eastern Lake St. Clair, and protected parks (e.g., Point Pelee, Rondeau and Long Point). Much of the landscape at the western end of Lake Ontario is highly fragmented; however, the eastern coastal system (e.g., Prince Edward County) is largely intact (ECCC, 2021; **Figure 27**). Habitat connectivity in the Upper Great Lakes is largely intact, except near urban centres (Burke et al., 2018).

As the climate warms, the need for climate-smart landscape connectivity has been recognized - the aim of which is to connect areas of current habitat to areas of future suitable habitat (Keeley et al., 2018a; 2018b) with deliberate consideration of climate change science, vulnerabilities, and impacts (Stein et al., 2014). Restoring lost connectivity between coastal wetlands, uplands, streams, pools, and ponds is key to wetland biodiversity conservation and the resilience of habitats and species to climate impacts (Environment Canada, 2005, 2013; Griffith et al. 2009; Heller and Zavaleta, 2009; Tu et al., 2017; Hamilton et al., 2018; Hilty et al., 2020).

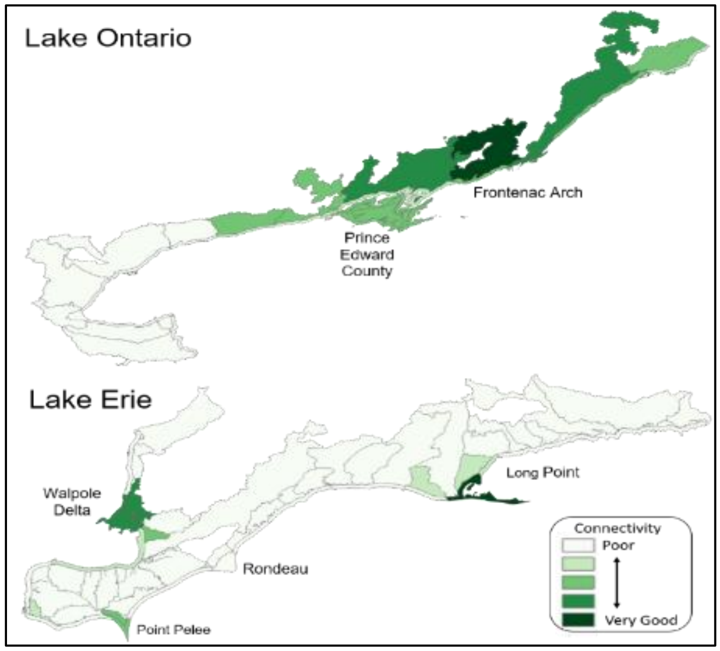


Figure 27. *Landscape connectivity in coastal watersheds of the Lower Great Lakes (Canadian Baseline Coastal Habitat Survey, ECCC, 2021).*

Efforts to increase connectivity include the development and application of sound science, policy solutions, thoughtful land use planning, and targeted land conservation. This will increase landscape habitat, expanding and conserving areas known to facilitate plant and animal movement, re-establishing lost connections (e.g., adding corridors between natural or protected areas, creating stepping stones), removing barriers that prevent movement, or a combination of the above.

Local planning would benefit from considering the unique local context within broader, larger-scale planning efforts, such as conservation blueprints, Great Lakes conservation action plans, unique biogeographic features (e.g., Oak Ridges Moraine), as well as the role that the geodiversity and landscape play in the overall diversity and integrity of ecoregions and ecozones (ECCC, 2013). The options below can help to enhance coastal wetland resilience by improving connectivity within and between wetlands, other aquatic habitat, and the broader coastal terrestrial landscape.

Table 8. *Measure 1D Adaptation Options.*

1	Incorporate a range of climate change scenarios to assess impacts and outcomes when planning for habitat connectivity. Ensure areas being conserved or created contain diverse topography, temperature gradients, wetland types and hydroperiods, and connections with adjacent habitats with different microclimates (Gross et al., 2016; Keeley et al., 2018b).
2	Increase the number of restored, protected, and conserved wetlands and other habitats (valley lands, flood plains) between existing parks and other protected areas to enhance connectivity, maintain ecosystems processes and facilitate species respond to climate change (Mawdsley et al., 2009; Environment Canada, 2005, 2013; Hilty et al., 2020).
3	Identify and prioritize creation and protection of natural corridors between coastal wetland ecosystems and adjacent aquatic and upland habitat to promote plant and animal movement and provision of climate refugia.
4	Reconnect rivers to floodplains by removing barriers (e.g., removing dams, modify culverts, berm, and dike removal) or implement designed ecological flows to mimic natural flow events. (See Measure 1C and Strategy 4C and $D)
5	Establish and protect 'Critical Function Zones' in wetlands and adjacent lands to maintain biophysical functions and attributes for wetland species. Establish and protect perimeter 'Protection Zones' for buffering from land use stressors (Environment Canada, 2013).
6	Identify and establish a mosaic of stepping-stone habitats, larger patches of natural cover, and mixed ecological corridors (shoreline, tributary, and terrestrial) of sufficient size to interconnect habitats and provide climate refugia where connectivity is poor (Environment Canada, 2005, 2013; Mawdsley et al., 2009, Hilty et al., 2020).
7	Support land use planning and protection efforts that maintain and improve coastal connectivity. Collaborate across governments, Indigenous communities, and non-governmental organizations to identify priority connections between protected and conserved areas. Example: New England Governors and Eastern Canadian Premiers Resolution 40-3 on Ecological Connectivity, Adaptation to Climate Change, and Biodiversity Conservation (in Climate Adaptation Committee of the Association of Fish and Wildlife Agencies (2021). See Strategy 5-A and Option 6-8.

8	Adopt an integrated coastal zone management approach with equal attention paid to ecosystem health and function, habitat connectivity, natural coastal processes, impacts of shoreline hardening, natural hazards, and ecosystem services (See Strategy 2).
9	Avoid wetland loss (extent, function, and features) and fragmentation during new land development. Where avoidance is not possible, adapt infrastructure to avoid bisecting wetlands, reduce disturbance to adjacent habitats, and counteract fragmentation by protecting and establishing additional green spaces within and surrounding the development to compensate and achieve a net habitat gain (Luell et al., 2003).
10	Advance the science of landscape connectivity and climate adaptation by validating and measuring success of the functional connectivity of new corridors and habitat mosaics (Environment Canada, 2005; Correa Ayram et al., 2016).

5.3 Strategy #2: Protect Littoral Cell Geodiversity and Restore Barrier Landforms

Many barrier-protected coastal wetlands and the native species they support are sheltered from the energy of the Great Lakes by sand and gravel spits, barrs, and beaches. These landforms represent significant geological features that protect coastal wetland complexes under threat from extreme lake level fluctuations, severe storms, shoreline erosion, and anthropogenic disruption of coastal processes. Geodiversity is defined as the variety of sediments, rock, and soils and the natural processes (erosion, sediment transport, and deposition) that operate within littoral cells and create ecologically significant Great Lakes shoreline landforms. This strategy consists of four measures and associated options related to policies and regulations, integrated littoral cell management, restoring sediment supply, and restoration of barrier systems.

Littoral sediment supply is essential to the creation and long-term maintenance of sand spit features that shelter large wetland complexes. Protected lacustrine (e.g., sand spit embayments), barred drowned river mouth, and barrier-enclosed coastal wetlands (e.g., barrier beach lagoons) are sensitive to disruptions in sediment supply (Maynard and Wilcox, 1997; Wilcox and Whillans, 1999, Albert et al. 2005). With the decline in annual average ice cover (Mason et al., 2016), the wave energy is projected to increase by as much as 120% by late century in parts of the north shore of Lake Erie (Zuzek, 2020c).

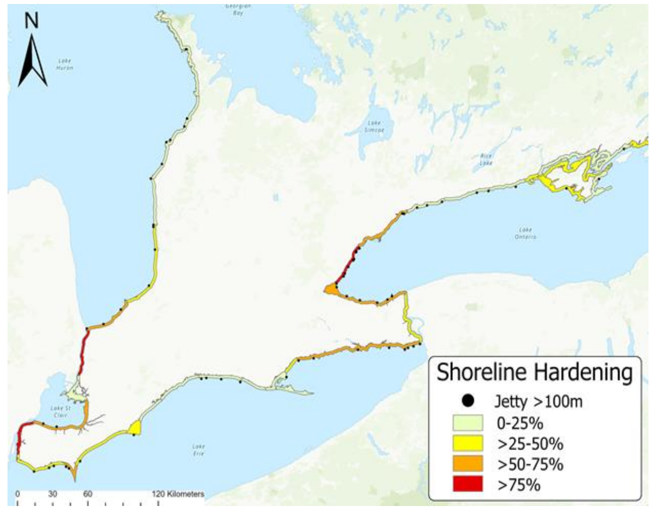


Figure 28. *Degree of shoreline hardening (Canadian Baseline Coastal Habitat Survey, ECCC, 2021).*

When threatened by coastal hazards, the typical response by property owners is to protect the shoreline from erosion and flooding using engineered steel and concrete structures (**Figure 28**). Large scale shoreline hardening disrupts natural sediment dynamics, increases erosion at adjacent shoreline reaches, impacts the overall sediment budget, degrades wetland habitat, results in fewer species of benthic fauna and fishes (Mackey, 2009; Hartig and Bennion, 2017; Zuzek, 2021), and restricts wetlands from dynamically migrating laterally and to upland habitat.

Collectively, the depositional landforms at Point Pelee, Rondeau, and Long Point protect roughly 90% of the coastal wetlands found on the north shore of Lake Erie (ECCC, 2020). Other areas protected by depositional landforms in the lower lakes include Hillman Marsh on Lake Erie, the barrier lagoon wetlands of Oshawa Second Marsh, and barred drowned river mouth wetlands at Lynde Creek, and the swale wetlands at Presquile on Lake Ontario. The vulnerability of these sediment-starved landforms was apparent during storms and recent high lake levels from 2017 to 2020. Major breach events and severe erosion occurred at barriers and sand spits that shelter coastal wetlands along the shore of Lakes Erie and Ontario (Zuzek, 2021). For example:

- The barrier beach at the northeast corner of Point Pelee National Park has retreated inland 300 m into the marsh since 1931. Erosion along the entire eastern shore of the park since 1931 resulted in the direct loss of 80 hectares of coastal wetlands (Zuzek Inc., 2021a).
- In 2018, the Hillman Marsh barrier beach breached and eroded completely. The system has undergone a regime change from a barrier beach lagoon to an open muddy embayment (Zuzek Inc., 2021a).
- The Big Creek Marsh barrier beach at Long Point breached in 2020. The barrier beach protecting the Hahn Marsh has retreated more than 110 m since 1964, resulting in a net loss of coastal wetlands. Since 1964, the beach fronting the wetlands of the Long Point Company has retreated 348 m resulting in the loss of 200 hectares of wetland habitat.

- The Rondeau Bay barrier beach has eroded inland 650 m over the last 150 years due to the impact of the harbour jetties trapping sand, resulting in the loss of more than 240 ha of coastal wetlands (**Figure 29;** Zuzek Inc., 2020d).
- In 2019, the high-water levels on Lake Ontario inundated the barrier beach at the Cranberry Marsh, Lynde Shores Conservation Area, exposing the emergent and submergent aquatic vegetation to lake waves and sedimentation (Zuzek Inc., 2020c).
- The barrier beach protecting the Oshawa Second Marsh and McLaughlin Bay Marsh downdrift of the Port of Oshawa has been eroding since 1954 at an average annual rate of 0.4 m/yr., with a maximum rate of 2.4 m/yr.

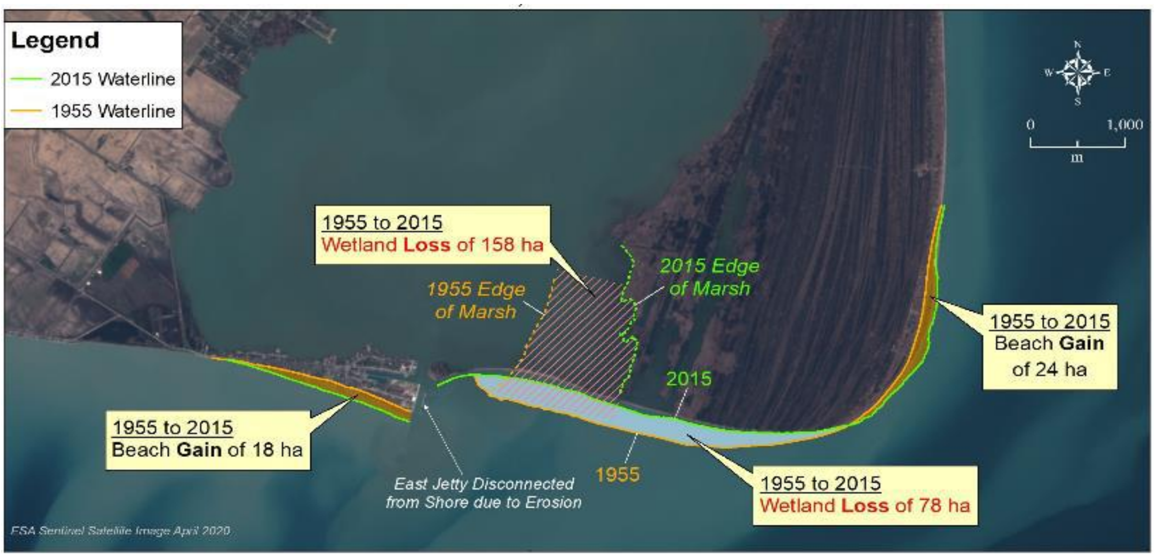


Figure 29. *Graphic illustrating wetland loss due to sediment trapped on the west side of the west jetty protecting the navigation channel at Rondeau Bay (Zuzek, 2021).*

The key threats and causative factors that impact geological landforms that protect barrier-protected coastal wetlands are:

- Climate change, high lake levels, and the absence of cumulative impact assessments for shoreline development in policies and regulations.
- Fragmented shoreline management, and plans that do not consider all resource management agency mandates (e.g., fisheries, wildlife, harbours, and recreation).
- Lack of legislation that requires owners to mitigate the impacts of harbour structures that trap littoral sediment.
- Absence of regional sediment management plans that utilize strategic and innovative strategies for littoral and riverine sediment for projects that restore and create new habitat, reduce coastal hazards for communities, and increase coastal resilience.
- Insufficient baseline data collection and monitoring of shoreline alterations, erosion and sedimentation, and related impacts and loss of coastal wetland habitat.

Integrated coastal management is required at the scale of the littoral cell to address these threats (**Figure 30**). Proper assessment, research, and monitoring are essential to define environmental issues, establish cause-and-effect relationships, evaluate habitat rehabilitation options, select preferred enhancement techniques, and document effectiveness. Globally and nationally, resource managers are taking bold actions to deal with sea level rise and protecting coastal ecosystems with nature-based solution. Opportunities exist for transformational, multijurisdictional, and multidisciplinary approaches across littoral cell boundaries that can restore sediment dynamics, enhance and restore barrier-protected wetlands and other coastal habitat, reduce coastal hazards, and increase resilience. The measures and options associated with this strategy are summarized from a report entitled "Recommendations for Long-term Conservation of Barrier-Protected Coastal Wetlands" prepared for ECCC by Zuzek Inc. (2021a).

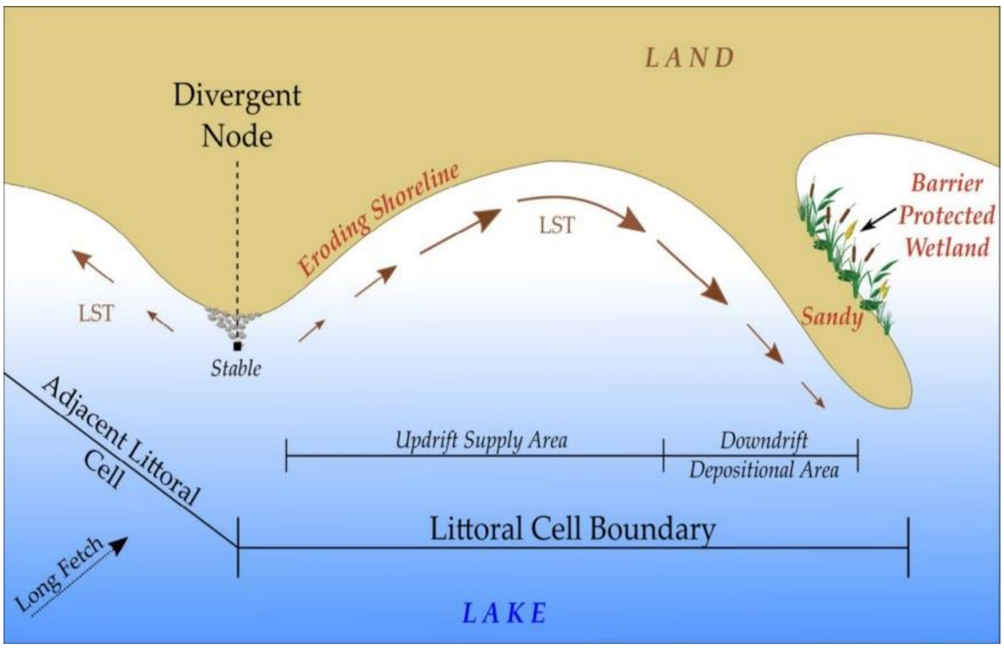


Figure 30. *Littoral cell conceptual diagram (Zuzek, 2021a).*

5.3.1 Measure 2A: Update Land Use Policies and Regulations that Impact Coastal Processes

This measure outlines the essential changes to transform existing land use policies and regulations for the Canadian Great Lakes shoreline and to restore geodiversity in littoral cells crucial for the creation and maintenance of landforms that protect barrier-protected wetlands and landforms. Rather than protecting the physical processes responsible for the formation and stability of barrier systems, existing official plans have sometimes zoned eroding shorelines for residential development. Zoning for residential developments allow permits to be issued for shoreline protection structures that negatively impact littoral cell sediment budgets. There is no legislation or policy that deals with the impacts of barriers that trap sediment (e.g., harbours) and deprive the downdrift shoreline of sediment supply. These development approaches, and the subsequent shoreline armouring that follows building on eroding shorelines, have resulted in negative near- and far-field impacts to landforms at Point Pelee, Long Point, and Rondeau (Baird, 2007; Baird, 2008; Baird, 2010; Zuzek Inc., 2021a).

A relevant example is found in the western basin of Lake Erie. From the mouth of the Detroit River to the western shores of Point Pelee National Park, historical bank erosion and longshore currents naturally delivered 60,000 m^3/yr of sand to the park shoreline. As of 2008, 87% of the natural supply of sand and gravel was eliminated by shoreline armouring and the remaining supply is trapped by the Leamington and Kingsville Harbours (Baird, 2008). The sand and gravel supply to the National Park has been reduced to almost zero (Baird, 2008).

Other jurisdictions have prioritized the protection of ecological sensitive coastal systems and beaches over shoreline armouring. For example, in 1982, the United States Congress passed the Coastal Barriers Resources Act (CBRA) to protect biologically rich coastal barriers by restricting federal funding that encourages development issues (https://www.fws.gov/cbra/). New and existing development on barrier systems are not eligible for federal flood insurance, which reduces the occurrence of at-risk development on eroding and hurricane exposed barrier systems. In North Carolina and Oregon, the construction of shoreline protection structures is no longer permitted on beaches. The options below can help restore physical processes that deliver sediment to the Canadian Great Lakes barrier systems. In some cases, policy-related options required to achieve integrated coastal zone management are relevant to Measures 2B and 2C.

Table 9. *Measure 2A Adaptation Options.*

1	Ensure that land use planning and development decisions in Ontario are consistent with the Provincial Policy Statement and enforced, including Section 3.1.7 that pertains to development and site alteration: c) New hazards are not created, and existing hazards are not aggravated; and d) No adverse environmental impacts will result.
2	Develop a universal definition for the “Conservation of Land” for shoreline-related policies and provide guidance for its application when evaluating shoreline development applications. Rationale: If properly defined, the Conservation of Land could be used to control lot by lot shoreline armouring applications. Example: The definition from the Mining and Lands Commission, “to include all aspects of the physical environment and considering incremental and cumulative loss” (Russell vs TRCA, 2009).
3	Strengthen land use planning to protect geodiversity and downdrift sediment supply to barrier-protected wetlands in littoral cells with eroding shorelines and sandy barrier systems that protect coastal wetlands.

4	Develop a Task Force that collaborates with all levels of government to create approaches to limit the construction of shoreline protection structures along the Great Lakes coast. Example: Jurisdictions in North America have banned the construction of new shoreline protection structures, such as North Carolina and Oregon (https://deq.nc.gov/about/divisions/coastal-management/coastal-management-oceanfront-shorelines/protecting-oceanfront-property-from-erosion) and https://www.oregon.gov/lcd/OP/Pages/Goals.aspx). See Measure 2B.
5	Explore the use of incentives to promote managed retreat over shoreline armouring. Example: Puget Sound, Washington tax-based incentives to encourage residential landowners to avoid or remove shoreline protection structures (Faghin and Mateo, 2014).
6	Where shoreline armouring is unavoidable, explore mechanisms that encourage or require landowners to mitigate the annual sediment deficit attributed to their shoreline structures. Example: Beach nourishment projects to restore landforms, barrier-wetland restoration, or support other nature-based solutions to increase resilience (Zuzek, 2021a).
7	Better integrate climate change impacts into land use planning decisions when depicting the future 100-year erosion setback and 100-year flood hazard limit. For example, refer to the 50- and 100-year future top of bluff mapping below (Zuzek Inc., 2021c).
8	Expand the planning horizon for erosion hazard setback from 100 to 200 years (i.e., the theoretical amount of time before new development is threatened by erosion) where appropriate, and include climate change impacts when establishing appropriate setbacks to delay the time before new shore protection causes negative impacts to the littoral cell (Zuzek, 2021a).
9	Explore mechanisms (e.g., policy, regulations) that encourage or require owners of new and existing littoral barriers to mitigate downdrift impacts associated with trapping sand and gravel. Examples: The US Army Corps of Engineers mitigates the impacts of harbours including a 388,000 cubic yard beach nourishment at Town Neck Beach, Sandwich, Massachusetts; Fixed bypassing plants on the updrift side of harbours to bypass sediment to downdrift beaches; Indian River Inlet on the Delaware coast bypassing plant mitigates erosion for 1,500 m downdrift (Boswood and Murray, 2001; Keshtpoor, M, et al, 2013).

10	Protect (or establish designated areas) where maintenance of geodivesity is fundamental to protecting landforms that shelter and sustain coastal wetlands. Develop integrated management plans at appropriate scales for these areas. Example: The Coastal Barrier Resource Act (U.S. Fish and Wildlife Service, 2021) for barrier beaches in the USA.

5.3.2 Measure 2B: Employ Integrated Coastal Zone Management Principles to Develop Littoral Cell Management Plans

This measure proposes the use of Integrated Coastal Zone Management (ICZM) as a continuous process for decision making to ensure the sustainable use, development, and protection of coastal areas and resources. It is a dynamic, multidisciplinary, and iterative process including data collection, planning, decision-making, management, and monitoring. The ICZM process is a global decision-making framework designed to overcome the fragmentation inherent in the sectoral management approach of the coast and the division of jurisdictions across the Ontario government. The ICZM process provides a framework to make decisions across different sectors of the coastal system and levels of government that are consistent with coastal policies and planning documents. Another key aspect is the design of institutional agreements to accomplish harmonization and execution of ICZM (Cicin-Sain and Knecht, 1998).

While there is a strong legislative framework for the Canadian coastal zone of the Great Lakes, the current approach to coastal management is not integrated. The physical-social-ecological system is decoupled into compartments with different mandates given to individual ministries and departments (e.g., water quality, fisheries, migratory birds, endangered species, navigation, contaminants, and protected areas). Local governments are responsible for land use planning, and Conservation Authorities regulate new development on hazardous lands. The primary approach under this measure is the development of integrated littoral cell management plans for the Canadian shores of the Great Lakes. The Long Point littoral cell stretches from Port Glasgow to the tip of the Long Point lighthouse, would be a location to pilot Option #1. Options 2 to 9 outline a series of tasks and approaches that would support littoral cell management plans. These actions embrace ICZM processes and principles, and help to achieve the GLWQA Habitat and Species Annex goal of net habitat gain.

Table 10. *Measure 2B Adaptation Options.*

1	Develop a governance structure and utilize ICMM principles to develop new integrated littoral cell management plans where necessary. Consult with the community to co-develop the plan, solutions, adaptations, and implementation actions. Key partners include: Federal Departments and Provincial Ministries with mandates along the Canadian Great Lakes coast in partnership with local Conservation Authorities, Municipal Governments, and ENGOs.

Sub-Components of Options #1	
2	Establish balanced goals and objectives for management plans that respect the interconnected components of the physical-social-ecological systems in littoral cells and reduce unintended consequences and maladaptation.
3	Give equal consideration to the protection of geodiversity (sediment, landforms, and physical processes that form and alter them), as biodiversity (habitat and species protection) in the integrated littoral cell management plans.
4	Develop littoral cell sediment budgets (e.g., quantify sediment sources, transport pathways, and sinks) to highlight the interrelationships between erosion and beach stability and negative impacts of littoral barriers and armouring (Cappucci et al, 2020).
5	Measure changes in coastal wetland habitat within littoral cells and investigate causation to identify drivers. Use the findings to prioritize action plans to restore wetlands and achieve a net habitat gain (GLWQA, Canada and USA, 2012). Example: Beach and wetland loss at the Long Point Company, Long Point sand spit.
6	Implement robust monitoring plans to quantify rates of change within the littoral cell (shoreline and in the nearshore). Assess risk and threats to the plan goals and modify/update the management strategy within an adaptive management framework.
7	Anticipate the impacts of climate change on physical processes, habitat, and species. Modify the management strategies accordingly to achieve the plan objectives. For example, a warming atmosphere and lakes will eventually result in ice-free winters.
8	Co-develop adaptation strategies with communities to re-align hazardous lands with transformative adaptation concepts that reduce risk and create co-benefits. Example: Rondeau Bay Advisory Committee co-development of a nature-based restoration plan (Zuzek, 2020d).
9	Leverage the littoral cell management plan and collaborative partnerships to implement strategic and restoration projects to increase the resilience of barrier systems and restore coastal wetland habitat within littoral cells to meet the GLWQA target of net

	habitat gain. Include transformative thinking such as the feasibility of modifying jetties to permit natural sediment transport within littoral cells.

5.3.3 Measure 2C: Re-establish Sediment Supply and Alongshore Sediment Transport in Littoral Cells

Re-establishing the historical supply and alongshore transport of sand and gravel in littoral cells is the focus of this Measure. Shoreline and harbour structures trap sediment and deprive beaches and barrier-protected wetlands of nourishing sand. Shoreline armouring and harbour construction are the primary reasons for the disruption of natural coastal processes, which in turn negatively impacts barrier landforms that protect coastal wetlands. For example, harbours structures at Port Stanley, Port Bruce, and Port Burwell have trapped 18 million m^3 of sand and gravel that entered the littoral cell from bluff erosion, and are preventing the downdrift deposition of this sediment to the Long Point sand spit (Zuzek Inc, 2020b).. Options under this measure include sediment bypassing, nature-based solutions, sand nourishment projects, sediment backpassing plans, and strategic land acquisition in the eroding portion of littoral cells. Placement and remobilization of dredged sand can result in habitat creation, enhancement, and protection of native species, beach nourishment, recreational and aesthetics improvements, and cost savings.

Table 11. *Measure 2C Adaptation Options.*

1	Develop sediment bypassing plans at ports and harbours that trap sand and gravel in fillet beaches. These initiatives require partnership between harbour owners (e.g., Transport Canada, Small Craft Harbours, and private entities) and coastal managers in the littoral cell. Example: Wheatley Harbour has been bypassing sediment from its navigation channel since ~2000 (Baird, 2007) to keep the sediment that accumulated in the navigation channel in the littoral cell.
2	Implement bypassing programs and innovative nature-based bypassing solutions, such as the Dutch Sand Engine (**Figure 14**; Stive, M.F.J. et al., 2013). For the Great Lakes, mobilize sediment trapped in harbour fillet beaches for alongshore sediment transport in the littoral cell. A Canadian version of the Dutch innovation, known as the Port Burwell Sand Engine, was conceptualized in a White Paper on Nature-based Solutions (Zuzek Inc., 2021b) to bypass sediment trapped at Port Burwell and nourish Long Point.
3	Nourish littoral cells with sand from upland sources or lake bottom deposits to target barrier beaches with a deficit in sand supply. Example: The State of Pennsylvania and

	U.S. Army Corps of Engineers have been nourishing Presque Isle State Park for decades to protect the interior wetlands and support beach tourism.
4	Mechanically move (sediment backpass) sediment from depositional features/zones in littoral cells to barrier beaches and sand spits that require artificial nourishment by hydraulic dredging or trucking. Example: In 2019, the community of Avalon in Cape May County, New Jersey on Seven Mile Island completed its fifth sand backpassing project since 2012 (https://avalonboro.net/projects/2019-sand-back-passing-project/). North Wildwood, New Jersey, recently moved 375,000 cubic yards of sand from a depositional area to a portion of the town with an eroding beach (picture below, https://pressofatlanticcity.com/news/local/north-wildwood-builds-a-beach-one-truckload-at-a-time/article_aeb3c36f-e425-5f7c-92cb-915ab3263a26.html).
5	Purchase undeveloped shorelines in eroding portions of littoral cells to allow natural erosion processes to nourish the littoral cell. Example: In Ohio, a track of coastal land was purchased by the Ohio State Government to allow natural bluff erosion processes to continue and nourish downdrift beaches (Livchak and Mackey, 2007).

5.3.4 Measure 2D: Implement Local Projects to Protect and Restore Barrier Landforms

Changing policies and regulations that negatively impact barrier-protected wetlands, adopting new ICZM principles for littoral cell management plans, and re-establishing alongshore sediment transport processes take time to plan and implement. Acquiring permits for use of dredge material can be difficult to secure. However, many barrier systems that protect coastal wetlands require immediate attention. For example, the barrier beach protecting the Cranberry Marsh at the Lynde Shores Conservation Area, and the barrier beach at Hillman Marsh was completed eroded in 2019 and 2020, exposing these wetlands to erosive lake waves (Zuzek Inc., 2020c). In some cases, five to ten years will be too long to save barrier systems and coastal wetlands under current high lake levels and frequent storm events. This measure highlights local options to restore barrier beaches and sand spits that protect coastal wetlands in the short-term.

Table 12. *Measure 2D Adaptation Options.*

1	Design and implement beach nourishment projects to stabilize eroding barrier beaches and sand spits with sediment trucked from inland sources or in-lake deposits.

2	Study, design, and implement wave attenuation structures, such as shoals, islands, and breakwaters to protect sand barrier systems, which in turn shelter coastal wetlands. Example: Braddock Bay restoration by the USACE on Lake Ontario (USACE, 2018).
3	Design and implement hybrid green-grey solutions to restored eroded barrier beaches and sand spits which previously sheltered coastal wetlands. Example: A conceptual design was recently prepared to replace the eroded Hillman Marsh barrier beach with a series of rocky habitat islands and shoals (Zuzek Inc., 2021a).
4	Restore dune ecosystems on barrier systems that trap wind-blown sediment, increase the volume of sand stored in the beach/dune system, and reduce the threat of coastal erosion and flooding which improves resilience to periods of high lake levels. Example: Refer to dune grass planting below, Lighthouse Beach, Pictou, NS
5	Strategically use and recycle dredged sediment to create islands and/or shoals for wildlife, to prevent erosion, and to recreate wetland protective features (Baird, 2019, Hanley et al. 2020; Carmo, 2018; SAGE 2019). Example: U.S. Army Corps of Engineers Regional Sediment Management Program and Engineering with Nature (Rosatti et al., 2001; Banks and Smith, 2014); Consider effective use of Detroit and St. Clair River dredge materials for wetland habitat restoration if acceptable contaminant levels.

5.4 Strategy #3: Maintain and Restore Biodiversity and Functional Redundancy

This strategy addresses the need to maintain or restore biodiversity and functional redundancy of coastal wetlands; both of which are foundational to resilience and adaptation (see **Table 2**). Biodiversity includes the variety, balance and disparity among ecosystem components including genes, species, populations, functional groups and communities, as well as their spatial and temporal configuration (Naeem, et al., 2009). Functional redundancy, or the replication of multiple ecosystem components or taxonomic groups, share similar roles in ecosystem function and can provide 'insurance' within a system by allowing some components to compensate for the loss or failure of others (Rosenfield, 2002).

The maintenance and restoration of biodiversity and functional redundancy can enhance the resilience of wetland ecosystem services by providing options for responding to change (Briggs et al., 2012). Most ecosystem services are produced by multiple ecosystem components (e.g., habitats and species), and diversity allows some components to persist through a disturbance and continue to deliver on a particular ecosystem service (Elmqvist et al., 2003; Folke et al., 2004). Redundancy provides insurance for wetland ecosystem service by allowing some ecosystem components to compensate for the loss of others (Briggs et al., 2012).

The measures and options associated with this strategy focus on 1) enhancing community structure and habitat required by wetland wildlife, 2) controlling invasive plant species, and 3) conserving populations and communities of native plants. Several options can be classified as active wetland restoration or creation, (Simenstad et al., 2006; Zhao et al., 2016), which require the intervention of local government and non-governmental organizations, and the support of private and public landowners who will oversee the stewardship and long-term conservation of wetlands on their property.

5.4.1 Measure 3A: Enhance Community Structure and Native Species Populations

When coastal wetlands can no longer support diverse populations and communities of native wildlife, or when existing, anthropogenic stressors are compounded by climate change (see Strategy 1), active restoration may be required. Three restoration techniques are recommended: (i) dredging to restore vegetation community structure; (ii) inducing microtopographic heterogeneity in created or restored wetlands; and (iii) the restoration or enhancement of degraded breeding habitats. Active restoration seeks the best recovery outcomes practicable to compensate for past damage and to increase wetland extent and functionality.

The interspersion of open water with emergent vegetation (1:1 ratio) is a structural component of coastal wetlands associated with increased biodiversity (Kaminski & Prince, 1981; Murkin & Clark, 2000; Rehm & Baldassarre, 2007). Interspersion has been associated with high dabbling duck density (Murkin et al, 1982); high survivourship in juvenile mallards (*Anas platyrhynchos*; Stafford et al., 2002); and, greater marsh bird and macroinvertebrate abundance, as well as plant species richness (Hohman et al., 2021; Schummer et al., 2012). The invasion of non-native cattail and *Phragmites* have resulted in a loss of wetland interspersion, and lake-level variability associated with climate change may favour their continued expansion (Lishawa et al., 2010; Mazur et al., 2014; Mortsch, 1998). A loss of interspersion has been linked to black tern (*Chlidonias niger*) colony abandonment (Wyman et al. 2017), and wetlands with low interspersion, such as those dominated by non-native cattail and invasive Phragmites appear to be avoided by fish (Jude and Pappas, 1992; Keough et al., 1999; Croft and Chow-Fraser, 2007), anurans (frogs and toads; Stevens et al., 2002), and waterbirds (Poole et al. 2009; Meyer et al. 2010).

Inducing microtopography heterogeneity (e.g., raised, flat, and lowered sediment surfaces) in the emergent, meadow, and upland communities of created or restored wetlands affects radiation, reflection, and hydrological processes, thereby forming different microhabitats, and promoting plant biodiversity and species niche differentiation (Bruland & Richardson, 2005; Vivian-Smith, 1997; Watt, 1947; Werner & Zedler, 2002). Small-scale heterogeneity can promote the coexistence of species by creating a variety of locations and environmental conditions for seedling establishment, refuge for non-dominant taxa, and greater habitat surface area (Peach & Zedler, 2006; Tessier et al., 2002; Werner and Zedler 2002, Varty & Zedler, 2008). The restoration or enhancement of degraded breeding habitat can improve recruitment of wetland dependent wildlife, enhance wildlife persistence, and ensure the continued delivery of ecosystem and cultural services (Briggs et al., 2012; Elmqvist et al., 2003, Rosenfield, 2002).

Table 13. *Measure 3A Adaptation Options.*

1	Restore interspersion by managing non-native cattail and Phragmites in lower Great Lakes wetlands for the benefit of marsh-nesting birds and habitat for fish and wildlife (Schummer et al. 2012). Examples: Swan Lake Marsh, Walpole Island First Nation, Lake St. Clair, ON (Government of Canada, 2017); Long Point Crown Marsh and Long Point Provincial Park, (Meyer et al., 2010; Schummer et al., 2012); Clark Island, Lake Ontario, ON (DUC, 2019).
2	Increase microtopography in created and restored wetlands to promote vegetation diversity and prevent the dominance of habitat generalists (Moser et al., 2007) achieved mechanically (e.g., through disking) or biogenically. Biogenic methods include the restoration of tussock sedge meadows (Lawrence & Zedler, 2011) and enhancing muskrat activity by emulating lake-level variability in managed systems Example: Carpenters Branch, French Creek, St. Lawrence River, NY (Kua et al., 2020).
3	Create vernal pools and palustrine wetlands where they have become isolated, degraded, or lost with attention paid to hydroperiod, substrate, drainage, volume, depth and slope, native vegetative, canopy cover, amount of existing breeding habitat, and connections with the surrounding landscape (Calhoun et al.2014). Example: Jacobsburg State Park, PA; Merrill Creek Reservoir Environmental Preserve, NJ; and, the Lee and Virginia Graver Arboretum, PA (Rothenberger et al., 2019).
4	Rehabilitate degraded turtle nesting habitat by installing artificial nesting mounds in areas of high road mortality to entice gravid females to nest closer to aquatic habitats. Examples: Algonquin Provincial Park (Paterson et al. 2013). Within created or restore wetlands, include basking/ sunning features (e.g., logs), grade banks to ease access, and plant native emergent, submerged aquatic and floating-leaved vegetation (Hartwig & Kiviat, 2007; Long Point Basin Land Trust, 2017). Example: Weston Pond, Canadian Domain, Toronto Zoo, ON.
5	Install nest boxes and floating or raised platforms where recruitment of cavity-nesting waterfowl and other wetland-dependent bird species is a concern (USDA-NRCS, 2008). For additional habitat considerations on wood duck (*Aix sponsa*) nest boxes, floating

	platforms for terns and osprey (*Pandion haliaetus*) nesting platforms within the Great Lakes Region, see Dyson et al. (2018), Shealer et al., (2006) and Martin et al. (2005).
6	Research, design, and implement restoration projects that utilize native plants and wildlife that play a functional role in wetland structure and function. Example: Positive species interactions (where at least one partner benefits and none are adversely impacted) help wetlands recovery after disturbance through trophic facilitation, stress reduction and associational defenses (Renzi et al., 2019).

5.4.2 Measure 3B: Control Invasive Plant Species

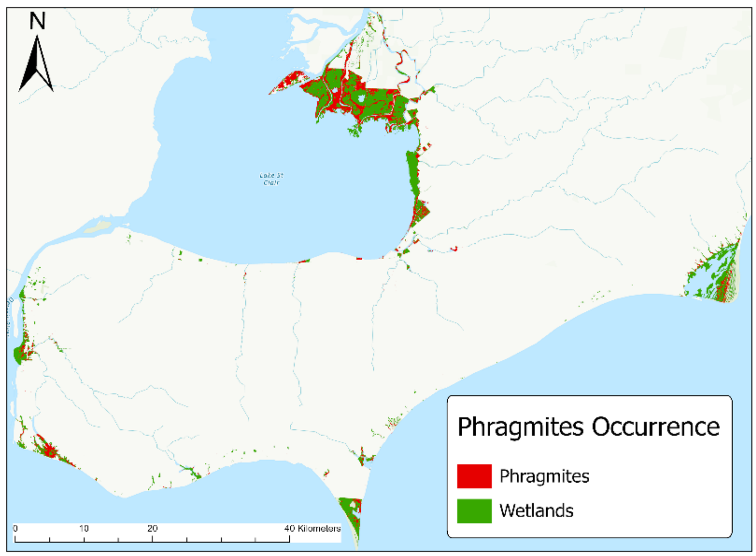


Figure 31. *Phragmites occurrence in Lakes Eire and St. Clair (ECCC, 2021).*

Invasive plant species are found outside of their natural range and which threaten the environment, economy, or society (Government of Canada, 2004). Common characteristics of non-native invasive plants species include rapid reproduction and growth, high dispersal ability, physiological adaptations to new conditions, and the ability to survive in a wide range of environmental conditions (Convention on Biological Diversity, 2011). Non-native invasive species can alter habitats and essential ecosystem functions, including hydrology, nutrient cycling and energy flows and cycles (Government of Canada, 2004). After habitat loss, non-native invasive species are considered the most significant threat to Great Lakes biodiversity (Pearsall et al., 2012). Actions targeting the invasive common reed, Phragmites, and non-native cattails are the focus of this measure.

Phragmites, is a perennial grass species native to Eurasia and Africa introduced to North American in the 1800s. It occurs primarily in the lower Great Lakes at densities as high as 37% of total coastal wetland area (**Figure 31**). It also occurs in along the shores of Georgian Bay, the North Channel, and Lake Superior (Nichols, 2020). As an opportunistic species, *Phragmites* can expand into new habitats faster than native flora and take advantage of disturbance events including lake-level variability and nutrient enrichment under a warming climate (Hines et al., 2013; Johnston, et al., 2008; King et al., 2007; Pengra et al., 2007). Once established, dense monocultures can displace native plant species thereby degrading habitat and reducing populations and diversity of wetland wildlife (Carlson Mazur et al., 2014; Greenberg & Green, 2013; Markle & Chow-Fraser, 2018; Perez et al., 2013; Tozer & Beck, 2018).

Non-native cattails can form dense, homogenous stands or mats that displace diverse wetland vegetation communities, degrade the foraging and breeding habitat of wetland wildlife, and alter biogeochemical cycling and hydrology (Bansal, et al., 2019; Farrer & Goldberg, 2009; Tuchman, et al., 2009). Broadleaf cattail (*T. latifolia*) is native to the Great Lakes; however, narrowleaf cattail (*T. angustifolia)* and the invasive hybrid of broad and narrowleaf cattails (*Typha* x *glauca*) are considered non-native (Bansal et al., 2019). Since 1960, regulation of the outflows from Lake Ontario has been associated with expansion of non-native cattails and a loss in wetland vegetation community diversity (Wilcox et al., 2005; Wilcox & Bateman, 2018; Smith et al., 2020). By reducing vegetation diversity, non-native cattails are expected to reduce the resilience of wetlands and ecosystem services (Folke, et al., 2004; McNaughton, 1977).

Management practices for other wetland invasive species including reed canary grass (*Phalaris arundinacea*) and European frog-bit (*Hydrocharis morsus-ranae*) are provided by the Ontario Invasive Plant Council. Local conservation authority, provincial, or federal authorizations may be required (e.g., Species at Risk Act or Fisheries Act permit).

Table 14. *Measure 3B Adaptation Options.*

Options for Invasive Plant Species	
1	Create regional, coordinated invasive plant management strategies that includes: (i) initial site assessment, including wetland and landscape mapping (Bourgeau-Chavez et al., 2012; White et al., 2020); (ii) the development of management goals and priorities; iii) planning management and monitoring actions; (iv) site restoration, (v) awareness, collaboration and knowledge transfer. The site prioritization tool for controlling invasive *Phragmites* can aid management strategy development (Ontario Phragmites Working Group et al., 2016). Example: A Strategic Framework for Coordinated Management in Ontario prepared by the Invasive Species Centre and the Nature Conservancy of Canada (In press).
2	Apply an ecosystem approach to invasive plant management. Develop a strategy for the integrated management of land, water, and living resources that promote conservation, sustainable use, and the fair and equitable sharing of ecosystem benefits among coastal wetland users (CBD, 2021; Nichols, 2020).

3	Develop an integrated pest management program that is proactive and preventive, incorporates a combination of treatment options (e.g., chemical, biological, manual, etc.), and is species and placed-based. Coastal wetlands should be monitored regularly to determine whether action is warranted and evaluate the efficacy of the program. Preventive actions include protecting and attracting native species or reducing human activities that cause disturbance (Nichols, 2020).
4	Conduct habitat assessments before and after invasive species management to: (i) detect species at risk; (ii) avoid conducting management during sensitive life-cycle events (e.g., breeding, nesting and spawning); and (iii) evaluate the efficacy of management (Ducks Unlimited Canada, 2013; Nichols, 2020).
5	Report observations of any invasive plant species (new or existing) to the Invading Species Hotline, 1-800-563-7711 or https://www.eddmaps.org/ontario/.
Options for the Invasive Common Reed, Phragmites	
1	Control of invasive *Phragmites* along Ontario's roads to ensure it does not invade coastal wetlands (Alexander et al., 2015).
2	For dry-land management (uplands and meadow), employ the use of herbicide (glyphosate, imazapyr) via foliage spray, and undertake selective cutting and spading (Nichols, 2020). Examples: Spading on the south shore of Manitoulin Island, Lake Huron (Jones, 2019) and Wymbolwood Beach, Nottawasaga Bay, Lake Huron (Short, 2017).
3	For wet-area management, use a registered herbicide and consult the Ontario Ministry of Environment, Conservation, and Parks. Example: Health Canada's Pest Management Regulatory Agency granted registration for the sale and use of Imazapyr Technical Herbicide and Habitat Aqua to control certain invasive plants that grow in and around aquatic sites consistent with the Proposed Registration Decision PRD2020-17, *Imazapyr and Habitat Aqua*
4	For wet-area management where the use of herbicides is not preferred, perform selective cutting using a raspberry crane, brush cutter, or an amphibious cutting vehicle. Permits and authorizations may be needed. Examples: Stokes Bay, Bruce Peninsula, Lake Huron (Rodgers, 2019); Brucedale Conservation Area, Port Elgin, Lake Huron (LHCCC, 2017);

	and, Wood Drive Marsh, Lambton Shores, Lake Huron (Gilbert & Vilder, 2013; Vidler & MacDonald, 2017).
5	Assess the utility of biological control agents when developing an integrated pest management program for invasive *Phragmites* (Blossey et al., 2020; Kiviat et al., 2019). The import and release of biological control agents into Canada is regulated by the Canadian Food Inspection Agency. Example: Agriculture Agri-Food Canada and the University of Toronto is identifying candidate sites for the release of stem-boring noctuid moths (*Lenisa geminipuncta* and *Archanara neurica*) to manage populations of invasive *Phragmites* (McTavish et al., 2020).
6	In combination with other management techniques (e.g., herbicide application), implement prescribed burns to remove biomass suppressing the growth of native vegetation and to ease the vigor of subsequent herbicide applications (Nichols, 2020). Example: Coastal wetlands within the St. Clair Area of Concern (e.g., Bay Lodge, Rex Club 14 and Mud Creek Club), Lake St. Clair (Lozon, 2015).
7	Dispose *Phragmites* biomass based on management goals, available resources, and local disposal processes and bylaws. Common disposal techniques include bagging, burning, drying, and leaving on site. Less common techniques include bioenergy production, burying and composting (Nichols, 2020). If burying, lay at least one metre of overburden on top of *Phragmites* biomass (Howell, 2017). Contact municipal landfills in advance of disposal to determine if *Phragmites* biomass is accepted.
8	Plant or seed restoration sites after 85% or more of the *Phragmites* has been removed (Michigan Department of Environmental Quality [MDEQ], 2014). Native plants shown to outcompete *Phragmites* include wood shrubs (e.g., dogwoods, *Cornus* spp.), tall grasses and sedges (e.g., prairie cordgrass, *Spartina pectinata*, fox sedge, *Carex vulpinoidea*) and flowering forbs (e.g., swamp milkweed, *Asclepias incarnata*). Avoid planting native *Phragmites* to prevent hybridization (Nichols, 2020). Example: Mentor Marsh State Nature Reserve, Ohio (Cleveland Museum of Natural History, 2017).
9	Practice proactive, landscape-level management by collecting information on the spatial distribution of invasive plants, identify and map areas suitable for future colonization under climate change scenarios, and target for control (Carlson Mazur et al., 2014).

Options for Non-Native Cattail	
1	In diked/impounded wetlands, manipulate lake levels to control non-native cattails by flooding or dewatering. Cattail vigor can be impeded when sustained water depths of one metre are reached (Grace, 1989; van der Valk, 1994; van der Valk & Davis, 1980). Water level management should be coupled with other techniques, such as burning and/or cutting (Ball, 1990; Bansal et al., 2019; Malik & Wein, 1986; Svedarsky, et al., 2016). Examples: Delta Marsh, MB (van der Valk, 1994), St. Clair National Wildlife Area, Lake St. Clair, ON (Ball, 1990), and Shiawassee National Wildlife Refuge, Saginaw County, Lake Huron, MI (Lishawa, et al., 2020).
2	For dry-land management (upland and meadow), employ herbicides (glyphosate, imazapyr) through foliar treatments on foot (Bansal et al., 2019; Wilcox et al., 2018) and in late summer when cattails are actively growing and transporting carbohydrates to their rhizomes (Linz & Homan, 2011). Example: Kents Creek, NY (Wilcox et al., 2018).
3	Use mechanical treatments, including grazing, mowing, disking, shearing, crushing, and scraping to control non-native cattails when used in combination with other control methods (e.g., herbicide application, water-level manipulation; Ball. 1990; Bansal et al., 2019; Lishawa, et al., 2017; Murkin & Ward, 1980; Schultz, 1987; Wilcox et al., 2018). Example: Sand Island, St. Marys River, MI (Lishawa et al. 2017).
4	Harvest cattail biomass and associated litter to increase native biodiversity and habitat complexity over the short-term under a range of environmental conditions (Bansal et al., 2019). Harvested biomass can be used in bioenergy production. Example: Cheboygan Marsh, Lake Huron, MI (Lishawa et al., 2015).
5	Inoculate restored sites with native, competitive species via plug planting or seeding to supplement recovery and to compensate for seedbank deficiencies (Bansal et al., 2019; van der Valk & Baalman, 2018).

5.4.3 Measure 3C: Conserve and Restore Native Plant Species and Communities

In response to a changing climate, plant species will alter their phenology or physiology, and adapt through selection or migration to a more suitable condition (Davis & Shaw, 2001). However, within the Great Lakes Basin, climate change may shift species' preferred environmental ranges to thresholds where human intervention may be required to ensure their long-term conservation (McDermid et al., 2015). In areas of high wetland loss or fragmentation, transformative actions such as assisted migration may be necessary, particularly for species unable to adapt and those of cultural significance (Seddon, 2010; Vitt el al. 2010).

Increasingly, restoration practitioners are shifting from traditional, local seed sourcing to admixture, or climate-adjusted sourcing that involves supplementing local seed sources with collections across a species' natural distribution. Climate-adjusted sourcing is defined as supplementing local seed sources with targeted non-local sources collected along a gradient reflecting potential future climate conditions based on projections (Breed et al., 2018). Seedbank resilience is critical and should be assessed to ensure that the species diversity can persist through multiple disturbances, and that species no longer present in remnant vegetation communities are preserved (Kirkman & Sharitz, 1994; Chow-Fraser, 1998). If seedbank resilience has been reduced by anthropogenic stressors, coastal wetlands may be more vulnerable to climate disturbances. Lake-level variations might expose seedbanks lacking diversity, and provide an opportunity for invasive species to expand (Frieswyk & Zedler, 2006).

Table 15. *Measure 3C Adaptation Options.*

1	Re-establish natural hydrology for improved regeneration of wetland emergent vegetation, improve water quality (See Strategy 1), and to facilitate wetland migration (See Strategy 5).
2	Develop a seed sourcing and planting strategy that: (i) increases the adaptive potential of plants within restoration sites by increasing genetic diversity (e.g., admixture sourcing); and (ii) matches sources with projected, future climatic conditions (e.g., climate-adjusted sourcing; Breed, et al., 2018). Maximize the number of native species, and the diversity of phenotypes and functional traits present in seed mixes or plantings to increase the probability that native vegetation will dominate under variable environmental conditions.
3	Work with local Indigenous communities to integrate knowledge about culturally significant wetland species and traditional ranges. Include planting and seeding strategies for manoomin (wild rice, *Zizania* spp.), ratroot (sweetflag, *Acrous clamus*), native cattail (*Typha latifolia*) and wisqoq (black ash, *Fraxinus nigra*). Example: Lake Superior Manoomin Cultural and Ecosystem Characterization Study (Great Lakes Wild Rice Initiative, 2020).

4	Research wetland plant vulnerability to climate change and trial human-assisted movement of wetland plant species in response to climate change (Hoegh-Guldberg, et al., 2008; Seddon, 2010; Vitt et al., 2010; 2016). Example: Forestry practices in BC and Ontario have extended seed transfer zones 200 m higher in elevation, and selected species and seed sources from the lower U.S. for use in trials (NRCAN, 2020); Assisted migration of confers in Canada and Mexico (Sáenz -Romeror et al., 2021).
5	Collect soil samples and assess seed bank attributes (e.g., seed density, species richness, species composition, species types) to validate the wetland resilience to climate and anthropogenic stressors. Example: Atkinson, Peter's, Long Tail, Little Suamico and Oconto River marshes, Green Bay, Lake Michigan, MI (Frieswyk and Zedler, 2006).
6	Conserve and restore native plant populations that support the recolonization and succession of wetland vegetation communities. Positive species interactions (where at least one partner benefits and none are adversely impacted) help wetlands recovery after disturbance through trophic facilitation, stress reduction, and associational defenses (Renzi et al., 2019).

5.5 Strategy #4: Enhance Capacity to Cope with Altered Hydrology

Planning for expected changes in Great Lakes water levels is essential for successful climate change adaptation. However, this is a challenge given the natural variability of lake levels and influences of precipitation, drainage basin runoff, inflows and outflows, lake surface evaporation, and water level regulation (Clamen & Macfarlane, 2018; Heinrich & Penning-Rowsell, 2020; Mortsch et al., 2006a; Bartolai et al., 2014; Wilcox & Whillans, 1999). During 2019 and 2020, each of the five Great Lakes were at or near all-time record high water levels in the recorded history dating back to 1918. However, record low lake levels were also recorded for Lakes Michigan and Huron in 2013 following a long-term decline that began in 1999. Other lakes were also well below average at this time due to lower-than-normal rainfall and higher air temperatures that lead to more evaporation. Coastal wetlands of Lakes Ontario and Superior have been subjected to different water level regimes relative to other lakes. The International Joint Commission Supplementary Orders of Approval include requirements to reduce the range of water levels in these lakes to protect coastal communities, provide flow for hydropower, adequate navigation depths, and other interests. However, regulation dampens the seasonal and inter-annual water level fluctuations essential for maintaining wetland plant structure, diversity, and ecological functions (Keddy and Reznicek, 1986; Mortsch et al., 2006a; Midwood & Chow-Fraser, 2012; Perry et al., 2015; Didiano et al., 2018; Weller and Chow-Fraser, 2019; Smith et al., 2020).

Results from a recent modeling study by ECCC indicate that lake level projections for unregulated lakes (i.e., Lakes Michigan-Huron, Erie, and St. Clair) will have a greater degree of deviation from long-term averages, as well as more frequent and extreme highs and lows (ECCC, 2022a). Projections for Lake Ontario also indicate a high degree of variation (described in section 3; **Figure 9**). This highlights the need to plan for both higher and lower lake levels than experienced in the past and to design and implement adaptation approaches that accommodate both scenarios.

There are detrimental impacts associated with frequent, extreme, or sustained periods of lake level change. As levels rise above historic highs, wetland area and aquatic habitat could decrease because of inundation, or become lost if shoreline structures, land use, or topography impede landward migration of wetland vegetation. Conversely, under an extreme and prolonged low lake level scenario, wetlands can dry up, become disconnected from the lake, and decrease in size, and transition to drier meadow and shrub plant communities (Midwood & Chow-Fraser, 2012). Dampened seasonal and interannual lake levels on Lakes Superior and Ontario can result in loss of diversity and structure of the wetland vegetation (Wilcox et al., 2005; Smith et al., 2020).

The measures and options for this strategy are primarily at the local level, acknowledging that international water level management is a complex, multi-jurisdictional endeavor and requires considerable input and cooperation beyond wetland managers. Potential adaptive measures and actions focus on managing many possible hydrologic shifts, including sustained, rapid, alternating and prolonged water level changes. Managers can enhance wetland resilience by working to maintain, conserve, and enhance natural processes and desirable wetland structure and functions. This includes preparing for higher highs and lower lows, by anticipating both extensive flooding interspersed with drought (Tu et al., 2017). All hydrogeomorphic wetland types are addressed in this strategy, including impounded/diked wetlands.

5.5.1 Measure 4A: Manage Wetlands to Cope with Periods of High Lake Levels

The options associated with this measure will help to enhance wetland resilience under extreme high and/or prolonged high lake level regimes. Significant shoreline erosion in southern Lake Huron, and much of Lakes Erie and Ontario is expected because of the relatively soft glacial till, outwash sediments, and sandy beaches formed on spits and baymouth barriers with their associated wetland systems (Zuzek, 2021a, 2021b).

High lake levels and changes to wave climate is likely to have the greatest impact, due mostly to the warming water temperatures, which will reduce the duration and extent of ice cover and increase shoreline exposure to storm events. Lacustrine and barrier-protected wetlands are likely to be the most directly impacted where potential exists for overwash and breaching of dikes, barriers that shelter wetlands, and barriers at proximal end of spits (e.g., Long Point, Point Pelee; ELPC, 2019). Extreme and/or prolonged high lake levels can also compress submerged aquatic plants into a narrow margin on the landward side and cause die-off of emergent plants, and changes in vegetation communities, particularly due to inland flooding affecting drier, higher elevation vegetation communities like meadow marshes, shrubs, and upland vegetation, and the expansion of *Typha* up slope into the meadow marsh zone (Smith et al., 2020).

There is a need and opportunity for innovation, particularly related to the design and implementation of approaches where natural and built infrastructure are combined (hybrid approaches, Sutton-Grier et al., 2015) to provide maximum coastal protection benefits while providing social and ecological services. For example, the Don Mouth Naturalization Project (Waterfront Toronto, City of Toronto, and the Toronto Region Conservation Authority) addresses high water levels and recurrent flooding and erosion issues while creating and restoring coastal wetlands, river valley habitat, and providing recreation opportunities.

Table 16. *Measure 4A Adaptation Options.*

1	Plant native wetland plants that are adapted to high lake levels when undertaking wetland restoration (Mortsch et al., 2006).
2	Ensure existing and future proposed solutions for invasive aquatic species (e.g., carp barriers) are designed to function under higher lake levels (Wilcox & Whillans, 1999; Asian Carp Canada, n.d.; Heer et al., 2019).
3	Control undesirable species that respond to higher lake levels, like non-native cattails (e.g., *Typha angustifolia*), and *Phragmites australis subsp. australis* (Wilcox et al., 2007; Wilcox & Nichols, 2008). (See Strategy 3B)
4	Where high water flow enters a wetland through a culvert or a storm sewer outfall, install energy dissipating features to limit impacts of extreme runoff from the drainage basin on wetlands (Minnesota Stormwater Steering Committee, 2018).
5	Assess the wave energy environment and identify the extent to which living shorelines and nature-based solutions are feasible under high water conditions (Gallagher et al., 2020; Stewardship Centre for British Columbia, 2020)
6	Restore protective barrier beaches (‘beach ridges’) and sand spits that historically protected coastal wetlands (Wilcox & Whillans 1999) (See Strategy 2).

7	Move shoreline hardening and breakwalls back from the shoreline where feasible (e.g., management realignment) and allow natural infrastructure like wetland vegetation to recruit between the lake and breakwalls (Sutton-Grier et al., 2015).
8	Install offshore reef and breakwater structures (SAGE 2019), or install underwater barriers for diffraction against storm wave energy (Tamara 2018) and flows. In Strategies and Approaches for Adapting Great Lakes Coastal Ecosystems to Climate Change by Schmitt et al., 2020). Example: Building underwater reefs in in the Detroit River near Belle Isle and Fighting Island that serve as fish spawning habitat can be built to protect aquatic habitat (Michigan Sea Grant, 2021).
9	Prevent sedimentation of drowned-river mouth wetland vegetation by installing upstream sediment management areas that slow flood water velocity and allow sediment deposition and dredging. Example: Rattray Marsh Conservation Area, Credit Valley Conservation; Don River Naturalization a Project (Waterfront Toronto, City of Toronto, and the Toronto Region Conservation Authority).
10	Identify, conserve, and enhance wetland retreat areas to facilitate the landward migration of plant communities during prolonged high lake levels (See Adaptive Measure 5A).
11	Support monitoring, modelling, and assessment of the Lake Superior outflow to the St. Marys River for improved aquatic habitat function, and the Lake Ontario water level regulation approach that replicate, as near as possible, natural water level fluctuations (AECOM, 2016; Clamen & Macfarlane, 2018).
12	Research, design, and test combinations of natural and built infrastructure (hybrid approaches) to enhance resilience to storms and flooding protection. Example: "Designing with Water" (Boston, U.S.), "Living with Water" (Netherlands) (Sutton-Grier et al. 2015), Don River Naturalization Project (City of Toronto, Toronto Region Conservation Authority).

5.5.2 Measure 4B: Manage Wetlands to Cope with Periods of Low Lake Levels

Wetland conservation practitioners should also anticipate periods of extreme and/or sustained low lake levels. Dry conditions are of particular concern during the growing season with the potential for large-scale die-off of submerged and emergent aquatic vegetation when optimal water temperature, depth, and duration of wetting conditions do not occur and lakeward migration of wetlands is not possible (Mortsch et al., 2006b). While periodic water-level drawdowns can have benefits on wetland biodiversity such as the regrowth of meadow and emergent species from an exposed seedbank (Keddy & Reznicek, 1986), drawdowns may also benefit invasive species which out compete native species (Wilcox, 2012). Prolonged low lake levels can result in wetland stranding if they get cut off from the lake, or meadow vegetation can dominate at the expense of aquatic habitat (Quinlan and Mulamoottil, 1987; Midwood and Chow-Fraser, 2012). A loss of wetland fish habitat can occur as shallow water wetland habitat decreases under low water level conditions (Fracz and Chow-Fraser (2013). Parts of the shoreline of the Canadian Shield do not have gentle slopes for wetland migration and have a more abrupt drop-off to extreme low lake levels that prevents wetland vegetation from migrating towards or away from the shoreline (Midwood & Chow-Fraser, 2012). During periods of sustained low lake levels, there tends to be an increasingly homogeneous habitat and an overall net loss of aquatic vegetation (drier vegetation community dominates, less interspersion), which provides habitat for many fish species (Midwood & Chow-Fraser, 2012). Options associated with this measure include wetland vegetation management techniques, controlling anthropogenic stressors, and restoration.

Table 17. *Measure 4B Adaptation Options.*

1	Protect and manage the original wetland area and riparian buffer from development or alteration during periods of prolonged low water levels.
2	Inter-seed with plant species tolerant to lower lake levels, and specifically in sites with open wetlands that are drying, inter-seed with wet meadow species (Meyer et al., 2006).
3	Control invasive species that favour low lake levels, like Typha X glauca that may expand and become more dominant behind barrier beach ridges (Lishawa et al., 2010).
4	Where diverse, open wetland communities are desired, manage the encroachment of woody plant species that can dominate meadows.
5	Address upstream pressures impacting wetland water quality, hydrological flow, and landscape connectivity (See Adaptive Measure 1A, 1C and 1D for possible actions).
6	Maintain and restore suitable wetland water table levels during drought by filling in ditches or blocking ditches at their outlets (Wilcox & Whillans, 1999)
7	Limit or restrict shoreline hardening that does not permit landward or lakeward wetland migration, including migration towards more suitable moisture and substrate conditions (Mortsch et al., 2006a). See Adaptive Measure 4C.

8	Remove infrastructure that restrict/impede flow to and through wetlands, and instead utilize/adopt nature-based solutions where possible (Shannon et al., 2019). See Adaptive Measure 1C and 4C.
9	Restore degraded floodplain and riparian zone habitat to increase water retention and water flow connections to reduce impacts of flooding, erosion, and sedimentation (Junk et al., 1989). See Strategy 1C-7.
10	Improve aquatic habitat connectivity between the lakes and vulnerable wetland sites through strategic rock placement and modifying bedrock elevation. Example: Eastern Georgian Bay Stewardship Council – Shebeshekong River channel modification using Dexpan, a nonexplosive demolition agent.

5.5.3 Measure 4C: Remove, Realign and Relocate Wetland-Constraining Infrastructure and Integrate Living Shorelines

Lake level trends and future projections reveal the necessity to adopt new, innovative, and sustainable development practices and actions. This may include the removal and/or realignment of built infrastructure that impedes wetland capacity to adapt to changing climate conditions (Glick et al., 2011; Shannon et al., 2019) and implementing green infrastructure and nature-based solutions (ICF for Canadian Council of Ministers of the Environment, 2018; Gallagher et al., 2020).

The design and placement of shoreline protection structures (e.g., revetments, groins, jetties, and other shoreline stabilization structures) based only on historical climate trends, ignores the risks posed by current and future climate change (See Strategy 2). Accordingly, climate projections should be incorporated into the planning, operations, retrofitting, and development of existing and proposed infrastructure. The first priority is to avoid placing new buildings, roads, trails or shoreline hardening where they can impair wetland function and the provision of wetland services (US Army Corps of Engineers, 2003). A re-examination of hard infrastructure and its life cycle represents an opportunity to make forward-looking decisions on replacement, removal, and repair to facilitate natural processes (Federation of Canadian Municipalities, 2018).

Options under this measure also support larger-scale social-ecological transformation as discussed in Section 5.1. This includes incorporating climate change into community and land use planning, creating or modifying development approaches (e.g., removing shoreline hardening where feasible, encouraging low impact development), and developing disaster preparedness plans and policies. Wetlands must also be valued for their ability to provide services such as shoreline erosion control in urban and rural environments (Moudrak et al., 2017).

Living shorelines, green infrastructure, and natural and nature-based climate solutions are effective in reducing ecological impacts, improving water quality, recoupling shorelines with open water systems, and enhancing overall ecosystem resilience (ICF for Canadian Council of Ministers of the Environment, 2018; Gallagher et al., 2020). These solutions represent an opportunity to utilize wetlands to increase human, ecosystem, and infrastructure resilience to climate impacts, reduce damage from natural hazards and the negative impacts from traditional engineered projects, often at less cost (ICF for Canadian Council of Ministers of the Environment, 2018; Eyzaguirre, 2020). The geographic scope of adaptation options below are best defined by the end-user of this document depending on local or regional needs within a particular lake basin.

Table 18. *Measure 4C Adaptation Options.*

1	Spatially identify and map optimum locations for living shorelines (e.g., prevailing winds, wave direction and energy, erosion/recession rates, soil type, and elevation) and support their permitting, construction, and long-term maintenance (ELI, 2016). See Measure 2B.
2	Use asset management strategies at the design, planning, operational, maintenance, and decommissioning stages to define climate impacts on infrastructure (Federation of Canadian Municipalities, 2018). Assess the feasibility, cost, and benefits of removing hard infrastructure and construction of green infrastructure. See Measure 2B.
3	Facilitate managed retreat and relocate facilities and other infrastructure with high flood risk and low access using a long-term plan that ensures future management supports wetland conservation (US Army Corps of Engineers, 2003; Strauch et al., 2015).
4	Decommission deteriorated trails and/or access roads, and re-establish native plants where appropriate (Strauch et al., 2015; Parks Canada, 2018; Shannon et al., 2019).
5	Remove structures that restrict surface and sub-surface flow such as undersized and improperly sited culverts, dams, or weirs (Shannon et al., 2019; Yochum & Reynolds, 2020). See Strategy 1C.
6	Consider environmental issues occurring at larger scales (e.g., watershed development and sediment transport disruption within littoral cells that cross jurisdictions) during infrastructure restoration and replacements to prevent downstream impacts, and to

	identify opportunities to replace impervious surfaces upstream with pervious or naturalized systems (Glick et al., 2011).
7	Design infrastructure to minimize hydrologic disruption (surface, instream and groundwater) within and between wetlands caused by crossings (roads and earthen berms) by installing properly sited culverts, large culverts, spaced culverts, or continuous conduits to allow water flow, sediment transport, and species movement under maximum flow events (Nason et al., 2019; Ducks Unlimited Canada, 2014). See Strategy 1C.

5.5.4 Measure 4D: Manage and Enhance the Resiliency of Diked Wetlands

Impounded, or diked, coastal wetlands necessitate special attention to reduce the adverse impacts of prolonged high and low lake levels and provide ecosystem services. At least 31% of the remaining wetlands in Lake Erie (Robb & Mitsch, 1990), and almost half of all wetlands in Lake St. Clair are diked (McCullough, 1985). Some of these dikes are close to the end of their lifecycle and consist of an earth-filled core with a grass cover as surface protection. In the face of projected storm frequency and severity, and higher water level projections, diked wetlands are particularly vulnerable to erosion from water level fluctuations and storm-driven waves. Given the variety, locations and climate vulnerabilities of diked wetlands, it is prudent to take a site-based evaluation and prioritization approach when considering adaptation options. Ultimately, management requires striking a balance between fisheries, waterfowl, adjacent land use, overall wetland biodiversity goals, and the cost of long-term dike maintenance.

Diked wetlands can reduce Great Lakes biodiversity and integrity because of lost physical, chemical and biological connections with the open waters, reduce sediment and nutrient trapping and cycling, and loss of fish access to feeding, cover, spawning and nursery habitat (Pearsall et al., 2012; Kowalski et al., 2014). Diked wetlands can also contain greater abundance of vegetation and seed banks of invasive plants such as *Lythrum salicaria* (purple loosestrife), *Phalaris arundinacea* (reed canary grass) and *Typha spp.* (cattail) (Herrick & Wolf, 2005; Herrick et al., 2007). The technical and financial resources required for long-term maintenance, water control structures, pumps and intakes, and non-native plant management are also expected to increase under climate change (Wilcox & Meeker, 1995; Doka et al., 2006; Galloway et al., 2006).

In cases where diked wetlands may no longer be viable or desirable, adaptation actions may need to occur along with appropriate science-based risk assessments and public consultation. With prolonged high lake levels, these dikes could be under water for a prolonged period. Once fully saturated, dikes with an earthen core can deteriorate. In other cases, dikes may be so degraded that wetland managers are unable to do a complete drawdown during high lake levels or mimic high-water level, because the differential in hydrostatic pressure would damage the dike infrastructure. In these cases, a feasible option is to work with nature, re-establish a hydrological connection with the lake or channel system, and invest the cost savings to create more open water, channels, and potholes. Hydrological re-connection of diked wetlands has been successful, however, there are ecological risks involved including, increased nutrient loading, turbidity, reduced SAV coverage in connected coastal marshes, and increased invasive plants (Kowalski et al., 2014). In cases where diking is necessary, they can be managed and enhanced by restoring and creating habitat, increasing plant diversity, improving wildlife habitat, and providing social values (Galloway et al., 2006; Kowalski et al., 2009).

Table 19. *Measure 4D Adaptation Options.*

1	Where diked wetlands must be preserved, maintain high plant and structural diversity by creating interspersed vegetation communities (Doka et al., 2006) and re-establishing annual and seasonal water level variation (Wilcox and Whillans, 1999) (See Strategy 3).
2	Manage for the full suite of biodiversity by designing and installing selective fish passage structures for most shapes and sizes (Wilcox and Whillans, 1999; Kowalski et al., 2014) while allowing for the exclusion of invasive fishes.
3	Enhance the ecological, social, and structural values of dike systems by (1) planting foreshore vegetation, (2) increase width and reduce slope on lakeward side, (3) integrated soil-filled, vegetated revetments, (4) provide exterior texture and water retaining features and engineered dikes (Scheres and Schüttrumpf, 2019).
4	Remove and reduce invasive fish (e.g., carp) and non-native plants like *Phalaris arundinacea* (reed canary grass) and *Typha spp.* (cattail) that are more prominent in diked wetlands (Herrick & Wolf, 2005; ECCC, 2018). (See Strategy 3).
5	Create and maintain mid- to deep-water areas and channels within wetlands to establish refuge for fish and wildlife during winter drawdowns and extended periods of ice cover and low oxygen (Environment and Climate Change Canada, 2018).
6	Where temporary isolation of wetlands from lakes is required (e.g., for restoration), consider the use of aquadams (Wilcox & Whillans, 1999).
7	Limit inflow and divert water flow around diked wetlands to prevent sediment deposition and nutrient loading (Doka et al., 2006).

8	In dikes and shorelines with a steep side slope, supplement wave-reducing measures by installing substrate support agents such as biodegradable geotextiles to waterproof the dike (Abrahams, 2008). Example: The reconstruction of the dike and water level control structure of the Digue-aux-Aigrettes marsh, Lake Saint-François National Wildlife Area.
9	Where dikes are highly vulnerable to erosion, degraded, or too costly to repair, realign existing dike, or strategically breach (partial or full) dikes to match with relict channels and drainage basins. Example: Truro-Onslow Dike Realignment Nova Scotia.
10	Discourage the construction of new permanent dikes unless replicating/reproducing the protective function of a lost barrier beach. Do not build new dikes on shorelines that are eroding or vulnerable to future erosion. Include a water control structure to allow for hydrological connection similar to the original wetland (Wilcox & Whillans, 1999).

5.6 Strategy #5: Identify, Manage, Protect, and Create Climate Refugia

Agriculture, development, and shoreline development, combine with climate-induced drying and inundation to reduce the quality and availability of habitat for wetland flora and fauna. Establishing climate-change refugia is a promising adaptation measure that enhances wetland resilience and safeguards the ecosystem services they provide (Keppel *et al*., 2015; Beavers et al., 2016; Morelli *et al*., 2016; 2020; Selwood and Zimmer, 2020). Refugia are areas in which a population of organisms and habitats can survive through a period of unfavourable conditions (Morelli *et al*., 2020). A strategic approach is to identify refugia at broad coastal scales that: (1) are projected to experience less severe climate and development changes; (2) contain a diversity of physical and topographic features; and (3) are projected to retain or remain within suitable climatic conditions (Michalak et al., 2020). Climate change refugia science (Ashcroft, 2010; Michalak et al., 2020; Morelli et al., 2016; 2020) advances adaptation planning by:

- Protecting land where components of biodiversity can persist in, retreat to, and potentially expand from under changing environmental conditions (Keppel *et al*., 2012).
- Protecting land that is relatively buffered from climate change over time (e.g., low exposure to thermal change at coastal fens) and water level extremes (Krawchuk *et al*., 2016; Morelli et al., 2020).
- Acquiring and protecting lands where soil and hydrology can support wetland rehabilitation, restoration, and creation.
- Enabling wetland migration landward or waterward (Prahalad et al., 2019; McLaughlin et al., 2017).

Adaptation approaches that identify, protect, create, and manage climate change refugia should consider ecological processes, diversity of species, topography and climate vulnerabilities (Hagerman and Chan, 2009; Morelli, 2016; Michalak et al., 2020). Spatial scale is also important when identifying refugia, including microrefugia (e.g., groundwater seeps), from areas within wetlands that can buffer changing conditions (e.g., varied bathymetry and topography), to large wetland complexes that enable changes in species behaviour, response, and movement (Beever et al., 2017). As described in Strategy 1, long-term management of wetlands is required to ensure that water quality, hydrologic connections, and coastal processes operate at scales within and outside of wetlands. Conserving refugia must also resolve 1) misaligned management objectives between the institutions that manage land, water, and aquatic resources, 2) logistical constraints imposed by land ownership, and 3) valuation of trade-offs. Asking the question "refugia for what?" and incorporating species-specific information into planning can also advance refugia identification (Michalak et al., 2020).

5.6.1 Measure 5A: Identify and Manage Refugia Retreat Areas

Ensuring the availability of land for migration into upslope areas and protecting nearshore physical and biological conditions for downslope migration are important adaptive measures. Lake level fluctuations will continue to occur, and wetland plant communities can transition, provided that land is available for wetlands to form during sustained high and low lake levels (**Figure 32**). An assessment of the potential for wetland migration at 26 Canadian wetland sites found that, aside from constraints including geomorphic conditions (bluffs, cliffs, rock barrens), land use (agriculture and development), and landscape connectivity, the main impediments to landward wetland migration under prolonged high lake levels are shoreline development, roads, and infrastructure (Zuzek, 2020d). Approximately 39% of the Lake Erie shoreline and 37% of the Lake Ontario shoreline is hardened (ECCC, 2021). Future lake levels are projected to be variable with periods of high and low water levels. The physical environment - wave energy, bottom substrate type, water depth, and slope of the lake bottom in the waters adjacent to wetlands - influences the potential for downslope migration and wetland expansion.

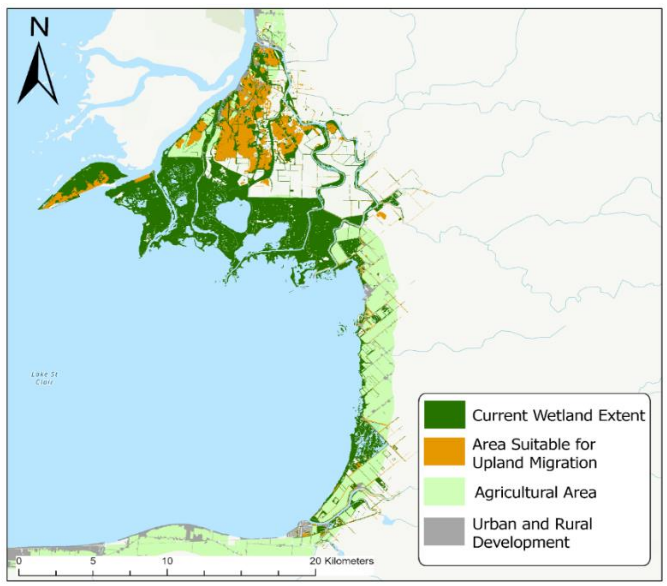


Figure 32. *Potential landward wetland migration in Lake St. Clair and the Walpole Delta (ECCC, 2021).*

Management practices and regulatory guidance that promote natural vegetation buffers adjacent to coastal wetlands will result in higher upslope migration potential and greater resilience. Mapping potential climate change refugia has advanced (Enwright et al., 2016; Carroll et al. 2017; Stralberg et al., 2018: Morelli and Ramirez, 2019; Thorne et al., 2020); however, challenges remain in identifying refugia at finer scales relevant to local land management (Selwood and Zimmer, 2020), ground-truthing, and mobilizing resources to ensure refugia are protected over time (Barrows et al., 2020). After potential refugia have been identified, managers need to prioritize refugia features for management actions to ensure functionality and resilience (Morelli et al., 2016, 2020).

Table 20. *Measure 5A Adaptation Options.*

1	Use GIS and other tools to map potential wetland migration refugia/retreat areas. Example: Quantifying potential for landward migration and coastal squeeze for 39 estuaries along the wetland-rich USA Gulf of Mexico coast under sea level scenarios (Borchert et al., 2018; Prahalad et al., 2019).
2	Integrate spatial planning overlays of refugia/retreat area at early land-use planning stages to identify and protect areas that are naturally resilient to climate change to serve as refugia and provide opportunities for range shifts. Where possible, secure, preserve, conserve, and restore these areas as wetland refugia under future lake level scenarios (ELI, 2016). Example: Derwent Estuary Program planning tool and "natural coastal processes' for tidal wetlands & saltmarshes (Whitehead, 2011).
3	Maximize the ecological conditions of refugia-retreat areas by reducing non-climatic stressors (Strategy 1), and by removing roads, culverts, trails, right of ways, and infrastructure, bulkheads that could alter hydrology, connectivity, erosion and introduce invasive species (Morelli et al., 2016; Selwood and Zimmer, 2020).
4	Remove (where feasible), shoreline armouring, riprap or other obstructions that prevent upslope wetland migration to suitable retreat areas. See Measure 2b and 4C.
5	Preserve and/or enhance topographic (e.g., shallow depressions to larger ridge and swale complexes) and bathymetric (shallow and deep-water pools and potholes) heterogeneity and complexity within coastal wetlands to provide high- and low-water refugia and diversity of water regimes (Beller et al., 2019).
6	Reduce habitat fragmentation, and identify, protect, enhance, or rehabilitate migration routes and retreat areas to ensure access to wetland habitats (e.g., access to refuges, spawning, and nursery areas; Dove-Thompson et al., 2011).

7	Create new refugia wetland habitat by transplanting intact wetland soil and/or vegetation to wetland restoration or creation sites (In Moomaw et al., 2018).
8	Identify, map, and manage adjacent aquatic habitats that support wetland function and resilience, such as vernal pools, pool networks, and their drainage connections that serve as travel corridors (Calhoun and deMaynadier, 2008; Wenning, 2015).
9	Identify, map and protect low-marsh areas that maintain aquatic habitat volume under fluctuating water level scenarios. Example: Simulated changes in extent of Georgian Bay low-marsh habitat under multiple lake levels (Weller and Chow-Fraser, 2019).
10	Advance refugia science by validating refugia functionality with independent data and incorporate the need for climate change refugia into management decision-making (Barrows et al., 2020).

5.6.2 Measure 5B: Protect Groundwater Sources, Processes and Refugia

Adaptation approaches that identify and protect groundwater sources, (recharge and discharge areas) as climate refugia sites can maintain wetland climate resilience (Morelli et al., 2016; McLaughlin et al., 2017; Cartwright et al., 2020). Groundwater enters a wetland directly from a spring, by lateral movement from an adjacent aquifer (seepage) or by upward movement from an underlying aquifer (discharge). Groundwater is controlled by (1) the physiography of the land adjacent to the wetland, (2) the relative elevations of the wetland and the lake as they fluctuate over time, and (3) the amount of infiltration that occurs (Crowe and Shikaze, 2004).

The protection of groundwater sources to provide refugia is important for coastal fens. Kraus and White (2009) identified coastal fens as the main groundwater-dependent coastal wetland on flat glacial lake plains. They are sedge- and rush-dominated wetlands with a limestone substrate. Groundwater structures and processes that link recharge zones to surface discharge springs help maintain cooler water temperatures within and around fens. The flow of groundwater stabilizes the seasonal variation of water levels within coastal fens (Godwin et al., 2002) and helps to buffer the influence of lake level fluctuations (Mortsch, 2006). Discharge of groundwater promotes cool wetland soil temperatures during the growing season (Rentch et al., 2008) and plays an important role in maintaining cooler water temperatures in streams and supporting coldwater refugia during summer (Mortsch et al., 2003) and warm water refugia in winter (Meisner et al., 1988). Groundwater rich in calcium and magnesium carbonate provides a stable influx of water and nutrients that also supports distinct plant communities from those fed by surface waters. Fens occurring in Lake Huron and Georgian Bay are globally at-risk communities containing over 40 species of provincially significant plants (Ontario Natural Heritage Information Centre, 1995).

Sensitive groundwater-fed fens are under threat from road development, drainage, erosion, and pollution. Off-road vehicles and parking on fens and beaches cause rutting, soil compaction, and damage to seedbeds. The creation of drainage ditches, channels, and temporary roads can also change the surrounding hydrologic regime and water quality, as well as shift the plant community from native sedges to bulrushes, cattails and invasive Phragmites.

Table 21. *Measure 5B Adaptation Options.*

1	Use GIS or other tools to map fens and mineral-rich groundwater sources for fens. Example: Conservation Authority ecologically significant groundwater recharge area mapping.
2	Protect fens from pollution, drainage, or other alterations in hydrology to maintain chemical characteristics. Example: Conservation Authority ecologically significant groundwater recharge area mapping. See Strategy 1.
3	Restore groundwater micro-refugia at coastal fens that have undergone partial drainage from ditching and near surface drain tiling. This can be accomplished by blocking drainage ditches and canals to achieve rewetting (Raney, 2014; Lamers et al., 2014).
4	Prevent increased surface flow and reduction in groundwater recharge by establishing no-cut buffers in stands immediately adjacent to fens.
5	Avoid road construction through fens to prevent hydrologic alterations and changes in species composition and structure.
6	Prevent vehicle parking and access to sensitive coastal fens and associated beaches to prevent soil compaction, rutting, altered surface flows and species composition, and the spread of invasive plants (Peach and Donnelly, 2010).

5.7 Strategy #6: Improve Great Lakes Coastal Wetland Conservation and Protection

Coastal wetland resilience cannot be achieved without effective conservation measures that include: (1) protecting existing wetland area and riparian corridors (Moomaw et al., 2018); (2) minimizing further damage; (3) restoring, enhancing, or re-establishing wetland area and function (OMNRF, 2017), and (4) maintaining and re-establishing ecological connectivity (See Strategy 1, Measures C and D). Protected areas wi coastal wetlands play a critical role in Canada (ECCC, 2016) and elsewhere to conserve biodiversity (Chape et al., 2005; Le Saout et al., 2013), enhance climate resilience (Stein et al., 2014, Beller et al., 2015 and 2019, Beavers et al., 2016; Chambers et al., 2019) and maintain ecological functions that generate ecosystem services (ECCC, 2016). Wetland conservation supports provincial, regional, continental, and international objectives established through a variety of mechanisms (e.g., RAMSAR, North American Waterfowl Management Plan; Ontario Eastern Habitat Joint Venture).

Coastal wetlands receive direct protection through national and provincial parks, and indirect protection through a variety of policies that include over 20 different pieces of legislation administered and/or implemented by five provincial Ministries, two federal departments, a provincial agency (the Niagara Escarpment Commission), 36 Conservation Authorities, 444 municipalities (OMNRF, 2017), and through the natural heritage protection measures of Ontario's Planning Act and Provincial Policy Statement (2020). The Provincial Policy Statement prohibits “development” and “site alteration” in significant wetlands in southern Ontario and significant Great Lakes coastal wetlands across the province. Wetlands are identified as “significant” using provincial evaluation procedures’ however, the definitions of these terms do not include other land uses such as infrastructure projects and drainage works.

Canada has domestic and international biodiversity goals that include conserving a quarter of Canada’s lands by 2025, creating healthier habitats for species at risk, and improving Canada’s natural environment, as part of a commitment to nature-based climate solutions that encompass wetlands and urban forests (The Minister of the Environment and Climate Change Mandate Letter, 2019). As a member of the High Ambition Coalition for Nature and People, Canada is also setting the stage to protect and conserve 30% of land and sea by 2030[2]. To track progress, the Canadian Protected and Conserved Areas Database provides updated spatial data[3].

Many candidate sites for expanding Canada’s protected areas network have already been identified through Parks Canada’s system plan, Key Biodiversity Areas, Indigenous and community-conserved areas, and land-trust acquisition plans (MaKinnin et al., 2016; Coristine et al., 2018). However, only a small proportion of the Great Lakes region was identified for protection relative to other Canadian regions. For example, Ontario’s Mixedwood Plains Ecozone of the Lower Great Lakes has the least protection (1.8%) relative to other eco zones (ECCC, 2016).

The existing network of protected areas may not be sufficient to allow wetlands and wetland-dependent organisms to adapt, transition, or be resilient to changing climatic conditions. This is based on the amount of surrounding land cover and water quality (Harrison et al., 2020), the maintenance and restoration of natural processes (e.g., sedimentology, hydrology) that operate

[2] https://www.campaignfornature.org/high-ambition-coalition

[3] https://www.canada.ca/en/environment-climate-change/services/national-wildlife-areas/protected-conserved-areas-database.html

at a landscape or littoral cell scale (See Strategy 2), and factors that influence the effectiveness of protected areas including size and configuration, proper management and funding, invasive species control, integrated management of water resources, monitoring and research, and other factors summarized by Acreman (2020). Even within protected areas, adaptation actions are required to address climate impacts (Barr, 2021). A re-envisioning of coastal wetlands and other habitat as an interconnected ecosystem would improve wetland resilience and conservation.

There is no unequivocal value for the percentage of land and water that should be protected. However, a review of the scientific evidence for large-scale percentage area conservation targets indicate that at least 30 per cent, or even higher, of land and sea should be protected (Woodley et al., 2019). Land protection in the coastal margin of the Great Lakes falls well below this value (**Table 2**).

The science to identify and map resilient terrestrial and freshwater aquatic habitat exists, as does the capacity for tool development to support assessment and management. For example, The Nature Conservancy created a spatial mapping tool that identifies climate-resilient and connected lands in the U.S. and Canada (Anderson et al. 2016). Weller and Chow-Fraser (2019) developed a multi-scale resilience index to identify important Georgian Bay wetland refugia for muskellunge (*Esox masquinongy*). Coastal wetlands in the U.S. Great Lakes have been prioritized for wetland bird conservation (Grand et al., 2020). Vulnerable Lake Erie coastal reaches are identified for improved integrated sediment management (Zuzek, 2021b). In the first direct study of extinction debt for the Great Lakes, seventeen (17) high priority Lake Erie coastal wetlands are identified for restoration, with an estimated 178 km^2 of additional wetland habitat required across 29 unprotected wetlands required to reduce the risk of future biodiversity loss of freshwater fishes (Montgomery et al., 2020).These studies and others contribute to a better understanding of coastal wetland management and conservation needs.

Wetlands should be conserved in strong partnership with federal, provincial and local levels of government, Indigenous communities, local public sector agencies, private landowners, the agricultural community, industry, non-governmental organizations and others involved in wetland conservation. Everyone can help protect coastal wetlands, including wetlands in urban and semi-urban areas, as these wetlands help moderate temperature extremes, conserve biodiversity, and provide aesthetic and recreation benefits (OMNRF, 2017). Protecting and conserving additional coastal wetland habitat reduces the urban heat island effect, adds to refugia for native species, increases carbon sequestration, and enhances adaptive capacity and coastal resilience, while also ensuring deliver of ecosystem goods and services.

Table 22. *Strategy 6 Adaptation Options.*

1	Develop a standardized methodology to map and report on coastal wetland area by hydrogeomorphic type and composition, and regularly track change over time.

2	Identify opportunities to improve and modernize coastal and inland wetland conservation and management policies to help prevent the net loss of remaining wetlands.
3	Strengthen urban wetland protection and enhancement as an integral component of land use planning, restoration, resilience, and nature-based climate solutions to mitigate urban climate impacts (e.g., heat island effect) (Jain and Carpay, 2020)
4	Protect additional coastal wetlands, adjacent habitat, and riparian corridors through conservation easements, land acquisitions, conservation partnerships (e.g. Eastern Habitat Joint Venture) and/or other means, including but not limited to federal, provincial, municipal, private lands, and Indigenous-led land protection efforts.
5	Increase the number of protected areas (or other effective area-based conservation measures) by modifying the size, placement, and number of protected areas, altering the shape of protected areas, creating linkages between protected areas, and enhancing land management (MacKinnon et al., 2020). (See Strategy 1D)
6	Identify and protect undeveloped shoreline properties with intact natural coastal processes and sediment dynamics that help to maintain wetland structure and functionality (Livchak & Mackey 2007, Zuzek, 2021a) (See Strategy 2).
7	Designate newly selected public wetlands for protection as climate change refugia (i.e., for its resistance to climate change) via enabling legislation, by other legal or regulatory instruments, or as a “climate change refugia emphasis area” in management plans (Morelli et al., 2016) (See Strategy 5)
8	Establish a protected coastal corridor to improve connectivity and facilitate adaptation through protection of wetlands and other areas to allow for wetland migration and natural sediment transport processes. Include concepts such as zones of core natural areas, buffer zones, and coastal transition zones (Mortsch et al., 2006). Also see Adaptive Measure 1D for a coastal subwatershed corridor.
9	Develop multi-scale prioritization and resilience indices to identify and map areas in need of restoration or protection as part of an overall strategy to manage native fish and wildlife populations (Grand et al., 2020; Weller and Chow-Fraser, 2019).

10	Restore wetlands and their functions to support healthy, resilient habitat and native communities (OMNRF, 2017).
11	Improve knowledge mobilization and communication within and between organizations in the protected areas community regarding monitoring and adaptation approaches (Barr, 2020).
12	Develop climate-envelope models (Pearson & Dawson, 2003) to assess the ability for protected areas and associated networks to support habitat for species under different climate-change scenarios (Scott et al., 1996; Burns et al., 2003; Araújo et al., 2004; Hannah, 2008).
13	Maintain species diversity by considering habitat heterogeneity under multiple climatic scenarios when establishing new protected areas in order to provide diverse topographic/ bathymetric, edaphic and hydrologic conditions (Anderson & Feree, 2020; Beier & Brost, 2010; Halpin, 1997; Hunter, 1988; Wessels et al., 1999). See Strategy 5
14	Quantify and value coastal wetland natural assets, goods, and services for the purpose of policy and management, and as a strategy for protection and restoration (Moudrak et al., 2018).
15	Develop municipal or regional biodiversity conservation strategies and natural heritage system plans in partnership with other levels of government, Indigenous communities, and the public that include priorities for coastal wetland restoration and protection. Example: Bruce Peninsula Conservation and Stewardship Plan (Liipere, S. 2014), A Biodiversity Strategy for Toronto (City of Toronto and the Toronto Region Conservation Authority, 2019; Coastal Action Plan for the Southeastern Shores of Lake Huron (Lake Huron Centre for Coastal Conservation, 2019).
16	Improve overall governance, collaboration, coordination and further develop partnerships to advance and align coastal wetland conservation goals similar to the Great Lakes Coastal Wetland Conservation Action Plan approach (http://glwcap.ca/GLWCAPfiles/GLWCAP_HighlightsReport_2005-2010.pdf).

6.0 Summary of Management and Policy Gaps

Identifying and addressing management and policy gaps that influence coastal wetland vulnerability and achieving climate resilience is essential to developing a robust Great Lakes adaptation approach. Literature reviews, interviews, workshops, and focus group discussion with wetland managers and conservation practitioners (OCC, 2019; 2020; Mortsch, 2020) were used to identify challenges, gaps, and needs. Six elements emerged that are discussed below:

governance; policy; science and predictive modelling; inventories, assessment and monitoring; data harmonization and visualization; and the design, implementation and assessment of adaptation actions.

6.1 Governance

As the rate and magnitude of the climate changes across the Great Lakes Basin, one of the greatest challenges ahead is developing the capacity, knowledge, and governance structure to advance beyond ad-hoc, opportunistic, and incremental adaptation responses, to proactive or even transformational changes (see **Figure 11**). Governance in this context is an inclusive approach and means by which the wetland conservation community merges different disciplines, determines and acts on adaptation goals, and develops priorities to enhance coastal wetland resilience, including:

- High level leadership that recognizes the urgency of climate change adaptation, enable policy frameworks, and foster multi-agency, multi-stakeholder coordination and collaboration to enhance coastal wetland resilience.
- Improved engagement, collaboration, coordination, and partnership development to advance coastal wetland adaptation science, planning, and implementation.
- A Great Lakes coastal wetland climate adaptation and resilience network to build on the work of the many scientific, regulatory, and regional activities already addressing aspects of climate adaptation and resilience.
- Mechanisms, protocols, and agreements to share data and transfer knowledge across the coastal wetland conservation community.
- Develop shared visions, goals, objectives, and methodologies to improve coastal wetland conservation outcomes across the Great Lakes Basin.

6.2 Policy

As our knowledge and understanding of climate change and coastal wetland conservation improves, new issues will emerge requiring forward-thinking adaptation strategies and policy tools (e.g., laws, regulations, procedures, incentives) to conserve wetland function and area, including:

- How objectives and targets for wetland conservation and management could be set in the light of climate change.
- Adaptation policy grounded on a sound understanding of natural coastal processes, wetland dynamics, and evolving wetland conditions under a changing climate.
- Best-available climate change adaptation science and case studies to inform evidence-based policy.
- Innovative policies that integrate coastal wetlands as natural or nature-based features and solutions to achieve climate risk reduction and resilience in coastal areas.

- Policies to identify, conserve, restore, and enhance lands to allow for wetland migration landward or waterward under future water level regimes.
- Integrated coastal zone management strategic approaches with attention paid to coastal health and function, connectivity of habitats, natural physical processes, natural hazards, and ecosystem services.
- Collaborative regional sediment management initiatives that safeguard vulnerable and geodiverse features (Point Pelee, Rondeau, and Long Point) and barrier-protected wetlands.
- Consideration of climate change impacts into regulatory decisions for an accurate depiction of future 100-year erosion setbacks and 100-year flood hazard limits, to direct development away from marginal lands and reduce the amount of future shoreline armouring.
- Updated natural hazard technical guidelines that incorporate nature-based/living shoreline options as alternatives to traditional hardened shoreline protection measures.
- Updated land use policy and regulatory instruments that protect natural coastal processes and sediment management.
- Land exchange programs where owners can exchange property in a flood and erosion risk areas for land inland or in lower risk coastal areas, allowing ecosystems to adapt to changes.
- Conservation approaches and policy tools in the design of natural heritage systems to improve connectivity of natural features and prevent the net loss of coastal wetlands.
- Support to Indigenous-led conservation efforts and the integration of Traditional Ecological Knowledge (TEK) into coastal wetland conservation, adaptive management, policy, and stewardship programs.

6.3 Science and Predictive Modeling

A key to advancing adaptation practice is through science, predictive modelling, and spatial analysis that explores a range of climate change scenarios and wetland responses. Guidance and tools in support of the coastal wetland conservation include:

- Predictive and integrated wetland response modelling of non-climatic stressors such as land use, land cover, sediment transport, invasive species, and wetland thresholds to explore management questions and inform priorities.
  - Collection and integration of bathy-topographical elevation data to produce high resolution wetland digital elevation models for modelling purposes.
  - Characterization of important wetland attributes, functions, and processes through remote-sensing and the collection of georeferenced field data.
- Vulnerability/impact assessments that address the effects of climate, lake levels, hydrologic connectivity, sedimentation, and geochemistry for impounded/dike wetlands and barrier-protected wetlands to improve adaptation decision making.
- Technical best practices and specifications for the spatial identification of critical areas that contribute to wetland resilience, such as:

- Existing wetlands that serve climate risk reduction and resilience purposes, and identification of opportunities to conserve and restore these areas.
    - Future wetland areas, wetland migration pathways, and identification of opportunities to conserve these areas and conduct activities to facilitate wetland migration.
    - Optimum locations for living shorelines, and support for their permitting application, construction and maintenance where warranted. .
- Research to improve the understanding of how changes in wetland habitat structure (e.g., size and composition) influence populations and communities of wetland wildlife (e.g., habitat suitability modelling, climate-envelop or climate-niche modelling, etc.).

6.4 Monitoring, Inventories, Mapping, and Assessment

The changing Great Lakes Basin landscape and land use practices require updated information about the area, location, and quality of existing coastal wetland habitat. A standardized methodology and regular five-year updates are a requisite for a baseline survey, to track change over time, and to facilitate priority-setting actions for acquisition and restoration. Site level monitoring can provide insights into the health and function of wetlands, the effects of climate change, and direct management and policy decisions, such as securement, restoration, and implementation of adaptation actions. A Great Lakes coastal wetland inventory could be developed by implementing a series of activities that includes:

- Standardized protocols for coastal wetland inventories and mapping (by hydrogeomorphic type and extent) at resolutions that can track change over time and inform local and regional planning to improve decisions on land use and development.
- Assessment and monitoring to track wetland health, function, and change over time to support the identification of priority areas for restoration, protection, and adaptation.
- Data visualization to advance the understanding of wetland distribution, extent, composition, climate vulnerability, and the implementation of adaptation strategies. Data visualization can be used for public communication and outreach, and effectively communicate spatially explicit decisions to government agencies, local officials, and others responsible for developing priorities or considering new policies.
- A web-based platform to house and visualize data and map products: (i) accessible to the public; (ii) managed by the government; and (iii) allows local wetland stakeholders to assess the ecological, economic and human-health related risks of climate change.

6.5 Prioritization, Design, and Implementation of Adaptation Options

Once climate change risks and vulnerabilities have been assessed and the preferred adaptation options have been identified, a framework for implementation (e.g., strategy and action plan) should be established. The framework should consider climate vulnerabilities, the design of the appropriate adaptation strategy, and discussions with relevant stakeholders and partners to garner support. Adaptation should be integrated with existing policy frameworks, municipal planning, and risk management to raise the profile of adaptation, save on resources, and identify synergies with development, as well as climate mitigation efforts. Data sets, models, and spatial analysis can be used to support the process and priority setting. Performance indicators and assessments are important components to assess the outcome of adaptation projects and to make adjustments, including determining new data needs, monitoring outcomes, and updating or adjusting models. Communication of strategies, methods and results is a fundamental component of adaptation to ensure understanding of objectives, outcomes, and continuous learning.

- Identify priority areas for wetland adaptation in the Great Lakes Basin for long-term, collaborative, funded research.
- Establish indicators and monitoring protocols to assess effectiveness of adaptation projects.
- Co-create and implement climate adaptation solutions for enhanced coastal wetland resilience.
- Ensure adaptation actions do not limit opportunities for future action as conditions change.
- Regularly monitor and report on progress to decision-makers and relevant stakeholders.
- Update, revise and readjust adaptation strategy and/or action plan according to the findings of the project.
- Evaluate the effectiveness of implementation of adaptation strategies, measures, and actions using performance indicators and an adaptive management framework.
- Build a portfolio of wetland adaptation case examples to illustrate cost/benefits and begin the learning process with partners and stakeholders to drive action.

7.0 Coastal Wetlands Resilience: An Optimistic Look to the Future

Climate change presents a multitude of risks, opportunities, and trade-offs for Great Lakes coastal wetland conservation and the people that rely on them. Changes in climate will likely persist and, in many cases, will intensify over the coming decades. Large gaps remain in our preparedness for climate change, and research indicates that current efforts to adapt are insufficient in the face of the accumulating ecological, social, and economic losses.

As governments, policy makers, and the conservation community plan for climate change impacts, it is crucial to ensure that coastal wetlands maintain biodiversity and function to provide indispensable ecosystem services. Much of the Great Lakes Basin population live and recreate in close proximity to the shoreline. This means that coastal communities and shoreline residents must coexist with coastal wetlands and the native species they support. Urgent action, supported by strong investments, is needed to increase resilience to climate change through adaptation. Informed decisions, drawing from the best science and knowledge are imperative.

Fortunately, there is a greater acknowledgement that climate change, biodiversity, and human well-being are interconnected. The social, ecological, and economic values of coastal wetlands have gained widespread recognition and there is strong public support for wetland protection. Science and monitoring have come a long way, and there is an extraordinary collection of complementary conservation strategies and human and technical resources to draw upon. Federal and provincial policies, agreements, and programs are contributing significantly to coastal wetland assessment and restoration. Lessons on good practices are continuing to emerge and are helping to guide successful adaptation. Coastal wetland managers across multiple jurisdictions are mobilized and willing to advance climate adaptation. Additionally, unprecedented funding is available to protect biodiversity through protected and conserved areas, species at risk conservation, and nature-based climate solutions that involve restoring degraded ecosystems, improving land management practices, and conserving carbon-rich ecosystems.

This white paper sets out an adaptation framework as an entry point to provide wetland managers with information and resources essential to understand, design, and implement climate adaptation approaches. Six overarching adaptation strategies provide the initial, broad outcomes to design climate change adaptation approaches. The 17 associated adaptive measures are more detailed formulations of options and targets. The more than 150 options provide specific alternatives to incorporate into plans. Collectively, they can be used to support a common goal of improved coastal wetland conservation and climate resilience.

The next step is to apply this knowledge through the design, implementation, and evaluation of adaptation actions for continuous learning. Coordination, cooperation, and collaboration across governments, Indigenous communities, non-government environmental organizations, and local landowners, will be required to leverage the breadth of knowledge, technical capacity, and financial support across jurisdictions. Together, collective action can support and safeguard the many wetland functions, values, and services upon which the Great Lakes community and biodiversity depend.

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