Great Lakes Coastal Wetland Framework

Synthesis of Relevant Studies and Assessment of Lake Erie Current Conditions and Trends

prepared for:
U.S. Fish & Wildlife Service

Final Draft

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Rondeau Provincial Park, ON. Courtesy of the Coastal Wetland Monitoring Program

LimnoTech
Water | Environment | Scientists | Engineers

Great Lakes Coastal Wetland Framework

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prepared by:
LimnoTech

under contract to:
Kearns & West

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Executive Summary

Great Lakes coastal wetlands (GLCWs) are freshwater marshes containing herbaceous vegetation that exist along the shorelines of the Great Lakes and their connecting waterways[1]. Vegetation in coastal wetlands is strongly influenced by geomorphological configuration and water level fluctuations, and typical plant communities include deep marsh with submerged plants, emergent, and wet meadow zones. GLCWs provide habitat for many endangered and other species, support a high level of biodiversity, and provide a range of ecological functions and services (Uzarski et al. 2017). Wetland ecosystem services directly and indirectly affect human well-being through impacts on fish supply, water quality and availability, climate regulation and climate change mitigation, and an array of cultural services (MEA 2005). Unfortunately, significant loss of historical GLCWs has occurred throughout the Great Lakes due to anthropogenic impacts (e.g., drainage, urbanization, structural modifications).

Given the importance of GLCWs and the significant loss of historical wetland area and function, there is a need to establish the desired extent and condition of GLCWs and identify where to focus conservation actions to promote healthy Great Lakes ecosystems and communities. Over the past decade, significant monitoring, modeling, and data analysis work has been conducted for GLCWs. However, to date, the results of those efforts have not yet been integrated to develop a streamlined, systematic approach to drive targeted conservation actions. This includes a lack of specificity with respect to integrating GLCW-related human well-being needs that can support "healthy communities". To address this priority need, the Great Lakes Coastal Assembly convened a group of experts from more than 30 organizations to define three objectives towards developing a Great Lakes Coastal Wetland Conservation Framework (Framework):

- Objective One: Establish existing baseline extent and condition of Great Lakes coastal wetlands.
- Objective Two: Determine extent and condition of coastal wetland types needed to help achieve healthy Great Lakes and coastal communities.
- Objective Three: Identify where to focus coastal wetland efforts to achieve healthy Great Lakes and coastal communities.

This report creates a foundation for Objectives Two and Three by synthesizing a compilation of existing studies, planning efforts, available datasets, current conditions and trends, and other information relevant to coastal wetland conservation and restoration efforts. The particular focus in this document is on Lake Erie and the Lake Huron to Lake Erie corridor, which represents the pilot study area for the Framework. However, many of the concepts, findings, and themes discussed herein apply across the entire Great Lakes basin. In addition to discussing the core concepts for the Framework, this document summarizes key monitoring and

[1] All types of hydrogeomorphic wetlands (lacustrine, riverine, barrier protected) with current hydrologic connectivity (continuous or periodic) to, and directly influenced by, one of the Great Lakes (adapted from Pearsall et al 2013). This definition includes wetlands in the rivers connecting the Great Lakes but does not include historic wetland areas that are unlikely ever to be restored or reconnected to the Great Lakes. Factors that are common to multiple classification systems include 1) wetlands support the growth of hydrophytes (aquatic plants), and 2) consist of poorly drained or undrained soils.

modeling efforts related to GLCWs and identifies existing knowledge and data gaps that should be addressed under future studies.

The compilation, review, and synthesis effort involved review of more than 40 previous and ongoing studies relevant to GLCWs and especially studies addressing coastal wetlands in Lake Erie. Given that there has been minimal explicit engagement with, or monitoring and evaluation of, human well-being needs and benefits of coastal wetlands in the Great Lakes geography, the scope of review for well-being needs was extended to include studies from other regions (e.g., Puget Sound). The review process for these resources focused on the following concepts that will be incorporated into the Framework: 1) ecosystem services, 2) indicators of GLCW condition, 3) current and desired status of GLCWs, and 4) threats and stressors to GLCW health.

Ecosystem services as defined in this report include both ecological services/functions and human well-being needs associated with GLCWs. Key ecological services and functions identified for GLCWs include: 1) water quality improvement, 2) nutrient retention, 3) carbon sequestration, 4) fish and wildlife habitat, and 4) coastal protection. These services are supportive of a variety of human well-being needs, and this synthesis effort identified priority well-being categories as recreational opportunities, tourism, commercial fisheries, and cultural and spiritual activities.

Indicators relevant to GLCWs are related to ecological condition and the status of human well-being. Since 2010, significant monitoring and analysis has been conducted to assess ecological condition throughout the Great Lakes basin via USEPA's Great Lakes Coastal Wetland Monitoring Program (CWMP), ECCC's nearshore habitat and coastal wetland resilience studies, and various other federal and regional studies. Wetland areal extent is a key measure that relies on remote sensing methods and has been challenging to quantify; however, the Framework's Objective One products will provide significant advancements by estimating annual Lake Erie GLCW extent for 2000-2020. Ecological condition indicators are available for vegetation, fish, macroinvertebrates, birds, amphibians, and water quality for coastal wetlands in Lake Erie and the other Great Lakes for the 2011-2022 period. Additional measures that quantify the environmental conditions influencing coastal wetland health relate to water level, landscape context (e.g., land use, population), presence of barriers (dikes, dams, etc.) and aquatic habitat connectivity. Human well-being needs and status related to the Great Lakes and GLCWs have only been lightly studied, and more work will be needed to define a set of objective and subjective indicators that can be quantified in the near-term and the future through a combination of regional/state datasets (e.g., revenue, jobs) and surveys conducted for coastal communities. Based on the information currently available, it is anticipated that the GLCW Framework will: 1) adopt a set of ecological condition indicators that are well-supported by data, 2) define a set of "influencing variables" that affect wetlands (but do not quantify wetland condition), and 3) establish placeholder indicators related to human well-being.

Desired status defines the target condition(s) that coastal managers and partners will seek to achieve for Lake Erie (and other Great Lakes) through GLCW protection, enhancement, and restoration efforts. Efforts to synthesize indicator information (e.g., State of the Great Lakes reports) have typically converted indicator numeric results to a rating scale (e.g., Poor → Fair → Good) that can be used effectively by coastal managers and practitioners. However, previous studies have not clearly identified target conditions for GLCWs, including Lake Erie GLCWs. It is anticipated that the GLCW Framework will take into consideration the existing body of work related to indicator results and current/desired status and then establish specific desired status targets for GLCW areal extent and ecological condition in Lake Erie. This may include defining a specific timeframe in which the desired status would ideally be achieved via protection, enhancement, and restoration efforts, factoring in estimates of the time lag between the implementation of management actions and when benefits are realized in the wetlands.

Current conditions and trends for Lake Erie as a whole and its coastal wetlands are most succinctly summarized via the State of the Great Lakes 2022 report (USEPA and ECCC 2022a, 2022b), which is based on the CWMP monitoring datasets from the 2011-2019 period. Current conditions are rated "Fair" for amphibians, bird, and aquatic habitat connectivity and "Poor" for vegetation and fish (with macroinvertebrates "undetermined") sub-indicators. The 10-year trends are characterized as either "unchanging" or "undetermined" for most ecological sub-indicators, with only aquatic habitat connectivity "improving". These results highlight the overall degraded condition of Lake Erie coastal wetlands and the need for protection and restoration efforts to enhance and expand GLCW ecosystem services to support healthy ecosystems and communities along the U.S. and Canadian shorelines of the lake.

Threats and stressors affecting GLCWs are significant and include: 1) shoreline development and alterations, 2) dredged river mouth deltas, 3) invasive species, 4) habitat fragmentation due to dams/barriers, 5) non-point source pollution, 6) watershed hydrologic alterations, and 7) climate change. A recent landmark study conducted by ECCC specifically assessed the resiliency of GLCWs to these threats and stressors, with a particular focus on vulnerabilities to climate change and adaptive capacity components that could help mitigate present and future impacts. Findings and lessons learned from this assessment will be used to inform various aspects of the Framework.

The compilation and synthesis of information from existing GLCW resources in this report provides a solid foundation to support the development of the Great Lakes Coastal Wetland Conservation Framework. The ultimate selection of specific options to adopt for ecosystem services, indicators, and desired status is beyond the scope of this report, and this will be addressed through the remaining tasks associated with Framework Objectives Two and Three. This process will include ongoing work and collaboration between the Framework co-chairs, Project Team (Kearns & West and LimnoTech), and subject matter experts on the Technical Team and Steering Team to elucidate and prioritize ecosystem services, indicators, and desired status, and to design related mapping and decision support products to inform and support GLCW protection, enhancement, and restoration efforts.

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Acronyms and Abbreviations

CRSRA	Connecting River Systems Restoration Assessment (via GLCWRA)
CW	Coastal wetlands
CWMP	Coastal Wetland Monitoring Program
CWRM	Coastal Wetland Response Model
ECCC	Environment and Climate Change Canada
ESI	Environmental Sensitivity Index
Framework	Great Lakes Coastal Wetland Conservation Framework
GDP	Gross domestic product
GL	Great Lakes
GLAM	Great Lakes Adaptive Management Committee
GLCW	Great Lakes coastal wetlands
GLCWC	Great Lakes Coastal Wetland Consortium
GLCWRA	Great Lakes Coastal Wetland Restoration Assessment
GLFC	Great Lakes Fishery Commission
GLNPO	Great Lakes National Program Office
GLOS	Great Lakes Observing System
GLPI	Great Lakes Protection Initiative
GLRI	Great Lakes Research Initiative
GLWQA	Great Lakes Water Quality Agreement
ha	hectare
HAB	Harmful Algal Bloom
HEA	Habitat Equivalency Approach
HEC	Huron-Erie Corridor
IBI	Index of Biotic Integrity
IEC	Index of Ecological Condition
IJC	International Joint Commission
IPCC	Intergovernmental Panel on Climate Change
JV	Joint Venture
LAMP	Lakewide Action and Management Plan
LE	Lake Erie
LEARN	Lake Erie and Aquatic Research Network
LEBCS	Lake Erie Biological Conservation Study
LEC	Lake Erie Commission
LEQI	Lake Erie Quality Index
LETC	Lake Erie Technical Committee (of GLFC)
MDNR	Michigan Department of Natural Resources
MEA	Millennium Ecosystem Assessment
MNFI	Michigan Natural Features Inventory
N	Nitrogen
NCC	Nature Conservancy of Canada

NFWF	National Fish and Wildlife Foundation
NOAA-OCM	National Oceanic and Atmospheric Administration - Office of Coastal Management
NWI	National Wetland Inventory
NYDEC	New York Department of Environmental Conservation
NYDOS	New York Department of State
ODNR	Ohio Department of Natural Resources
OEPA	Ohio Environmental Protection Agency
OMECC	Ontario Ministry of the Environment and Climate Change
OMECP	Ontario Ministry of the Environment, Conservation and Parks
OMNRF	Ontario Ministry of Natural Resources and Forestry
ON	Ontario
OSU	Ohio State University
P	Phosphorus
QA/QC	Quality assurance / quality control
RCP	Representative Concentration Pathway
SAV	Submerged aquatic vegetation
SOGL	State of the Great Lakes
SWAP	State Wildlife Action Plan (Ohio)
TAP	Triennial Assessment of Progress (IJC report)
TN	Total Nitrogen
TNC	The Nature Conservancy
TP	Total Phosphorus
TRCA	Toronto and Region Conservation Authority
UNWTO	United Nations World Tourism Organization
USEPA	U.S. Environmental Protection Agency
USFWS	U.S. Fish and Wildlife Service
USGS	U.S. Geological Survey

1 INTRODUCTION

This section provides a brief introduction to this document, including the background and purpose of this report, the approach taken to review and synthesize information from past studies, and the organization of the remainder of this document.

1.1 Background & Purpose

Great Lakes coastal wetlands (GLCWs) are freshwater marshes containing herbaceous vegetation that exist along the shorelines of the Great Lakes and their connecting waterways (via **Michigan Natural Features Inventory**). Vegetation in coastal wetlands is strongly influenced by geomorphological configuration and water level fluctuations. Specific geomorphological types of GLCWs found in the Great Lakes include: lacustrine, barrier-protected, and riverine sites. Vegetation communities in these wetlands generally consist of deep marsh with submerged plants, emergent, and wet meadow zones. GLCWs provide habitat to a large number of endangered and other species, support a high level of biodiversity, and provide a range of ecological functions and services (Uzarski et al. 2017). Wetland ecosystem services directly and indirectly affect human well-being through impacts on fish supply, water quality and availability, climate regulation and climate change mitigation, and an array of cultural services (MEA 2005). Unfortunately, significant loss of historical GLCWs has occurred throughout the Great Lakes due to anthropogenic impacts (e.g., drainage, urbanization, structural modifications).

Given the importance of GLCWs and the significant loss of historical wetland area and function, there is a need to establish the desired extent and condition of GLCWs and identify where to focus conservation actions to help accelerate coastal wetland conservation efforts to promote healthy Great Lakes ecosystems and communities. Numerous plans and strategies throughout the Great Lakes, including the Great Lakes Water Quality Agreement and the Biodiversity Conservation Strategies, have recognized the overarching need to protect coastal wetlands, restore wetlands to increase extent, and enhance their condition and resilience. Over the past decade, significant monitoring, modeling, and data analysis work has been conducted for GLCWs. However, to date, the results of those efforts have not yet been integrated to develop a streamlined, systematic approach to drive targeted conservation actions. This includes a lack of specificity with respect to integrating GLCW-related human well-being needs that can support "healthy communities". To address this priority need, the Great Lakes Coastal Assembly convened experts from over 30 organizations to define three objectives towards developing a Great Lakes Coastal Wetland Conservation Framework (Framework):

- Objective One: Establish existing baseline extent and condition of Great Lakes coastal wetlands.
- Objective Two: Determine extent and condition of coastal wetland types needed to help achieve healthy Great Lakes and coastal communities.
- Objective Three: Identify where to focus coastal wetland efforts to achieve healthy Great Lakes and coastal communities.

A project team, which includes Kearns & West (facilitation focus) and LimnoTech (technical focus), was contracted by the U.S. Fish & Wildlife Service to address Objectives Two and Three in collaboration with the Framework project co-chairs and policy and subject matter experts who comprise the membership of a

Steering Team and a Technical Team. While the Framework is intended to be developed across the Great Lakes basin, Lake Erie, including the Lake Huron to Lake Erie corridor, has been selected as the pilot geography for testing, learning, and adapting the Framework under the current phase.

An important step in driving Objectives Two and Three is the compilation and synthesis of existing studies, planning efforts, available datasets, and other information relevant to coastal wetland conservation and restoration efforts, with a particular focus on Lake Erie. This report integrates the following products from Task 4 ("Compile Plans, Data, and Information") of the Phase I scope of work:

- Synthesis of prior work related to the Framework development effort (Task 4.1)
- Summary of current conditions and trends for coastal wetlands in Lake Erie (Task 4.3)

1.2 Review Approach

This compilation, review, and synthesis effort involved the review of many previous and current/ongoing studies related to GLCW and especially studies addressing coastal wetlands in Lake Erie. Given that there has been minimal explicit engagement with, or monitoring and evaluation of, human well-being needs and benefits of coastal wetlands in the Great Lakes geography, the scope of review for well-being needs was extended to include studies from other regions. Resources from past/current effort were generally grouped into the two categories described below:

- "Primary" resources include the studies and associated documents listed in the scope of work for Phase I. These resources were reviewed in the greatest depth to identify concepts, approaches, and outcomes that are relevant to the Framework.
- "Supplementary" resources include additional study documents, datasets, and other information relevant to GLCW as identified by Steering Team members and also by the LimnoTech technical team. These resources were generally reviewed at a higher level to draw out key aspects that are potentially relevant to the Framework.

The primary and supplemental resources reviewed for this effort are listed in Table 1 and Table 2, respectively. The review process for these resources focused on the following concepts that will be incorporated into the Framework:

- Ecosystem services, including ecological services/functions and human well-being needs, associated with GLCW;
- Indicators / metrics of coastal wetland health;
- Desired status of coastal wetlands;
- Threats/stressors;
- Resilience to climate change and other stressors; and
- Restoration and protection initiatives (progress and ongoing work).

In addition to the primary and supplemental resources, various other literature and study report sources are cited throughout this document to provide further support to the synthesis discussion.

Table 1. Primary resources reviewed in support of the GLCW Framework

Identifier	Title	Citation(s)
P-01a	Great Lakes Water Quality Agreement (GLWQA)	USEPA and ECCC 2012
P-01b	Canada-Ontario Agreement on Great Lakes Water Quality and Ecosystem Health	OMECP and ECCC 2021
P-02	GLRI - Action Plan III	USEPA et al. 2019
P-03	State of the Great Lakes 2022 Report	USEPA and ECCC 2022a, 2022b
P-04	Coastal Wetland Monitoring Program	Uzarski et al. 2017, 2019
P-05	Lake Erie Lakewide Action and Management Plan (LAMP)	USEPA and ECCC 2022c
P-06	Lake Erie Biodiversity Conservation Strategy	Pearsall et al. 2012
P-07	Canadian Assessment of the Resilience of Great Lakes Coastal Wetlands to a Changing Climate	ECCC 2022a-e
P-08	Great Lakes Coastal Wetland Restoration Assessment (GLCWRA)	USGS 2017
P-09	Blue Accounting coastal wetland metrics	GLC 2023
P-10	Canadian Lake Erie Coastal Baseline Habitat Survey	ECCC 2022f
P-11	Canadian Great Lakes Nearshore Assessment	ECCC 2021
P-12	Great Lakes Fishery Commission Lake Erie Technical Committee and Task Group documents	GLFC LETC 2023
P-13	*Strategies for Adapting Great Lakes Coastal Ecosystems to Climate Change*	Schmitt et al. 2022
P-14	Upper Mississippi/Great Lakes Joint Venture Plans and Strategies	Upper Mississippi/Great Lakes Joint Venture 2017
P-15	*Prioritizing coastal wetlands for marsh bird conservation in the U.S. Great Lakes*	Grand et al. 2020
P-16	*A review of selected ecosystem services provided by coastal wetlands of the Laurentian Great Lakes*	Sierszen et al. 2012
P-17	*Designing coastal conservation to deliver ecosystem and human well-being benefits*	Annis et al. 2017
P-18	Ohio State Wildlife Action Plan (SWAP)	Ohio Division of Wildlife 2015
P-19	Michigan State Wildlife Action Plan	Derosier et al. 2015
P-20	New York State Wildlife Action Plan	NYDEC 2015
P-21	Pennsylvania State Wildlife Action Plan	Pennsylvania Game Commission 2015
P-22	Ecosystems and human well-being: wetlands and water	MEA 2005

Identifier	Title	Citation(s)
P-23	Human Wellbeing Vital Signs and Indicators for Puget Sound Recovery	Puget Sound Partnership 2015
P-24	Saginaw Bay to Lake Erie Coastal Wetland Blueprint [1]	n/a

[1] This project is in progress, but it is not synthesized into this report as no products were available for review as of September, 2023.

Table 2. Supplemental resources reviewed in support of the GLCW Framework

Identifier	Title	Citations
S-01	H2Ohio Wetland Monitoring Program	H2Ohio Wetland Monitoring Program 2021
S-02	Lake Erie Protection & Restoration Plan	Ohio LEC 2023
S-03	Lake Erie Quality Index: 2022 Report	Ohio LEC 2022
S-04	Chatham-Kent Lake Erie Shoreline Study	Zuzek Inc. 2020
S-05	Wetland Conservation in Ontario: A Discussion Paper	Province of Ontario 2015
S-06	*Economic valuation of suspended sediment and phosphorus filtration services by four different wetland types*	Aziz and Van Cappellen 2021
S-07	*Turbidity and Estimated Phosphorus Retention in a Reconnected Lake Erie Coastal Wetland*	Carter et al. 2022
S-08	Western Lake Erie Report Card	University of Maryland Center for Environmental Science 2020a, 2020b
S-09	Lake Superior Manoomin Cultural and Ecosystem Characterization Study	Abt Associates and NOAA-OCM 2020
S-10	*Investigating groundwater-lake interactions in the Laurentian Great Lakes with a fully-integrated surface water-groundwater model*	Xu et al. 2021
S-11	Audubon Great Lakes Impact Report	Audubon 2022
S-12	Triennial Assessment of Progress	IJC 2020
S-13	Great Lakes Business Plan	NFWF 2015

1.3 Report Organization

This report integrates the closely related deliverables from Task 4 of the Great Lakes Coastal Wetland Framework pilot project for Lake Erie, which were developed based on the review of the resources described above. The remaining sections of this document are organized as follows:

- Section 2: Synthesis of Relevant Coastal Wetland Studies (Task 4.1 deliverable).
- Section 3: Assessment of Current Conditions and Trends (Task 4.3 deliverable).
- Appendix A: Measles charts summarizing overlap between the primary/supplemental resources and key concepts and components of the Framework.
- Appendix B: Capsule summaries of the primary and supplemental documents reviewed to support the synthesis and discussion of current conditions and trends in Sections 2 and 3.

2 SYNTHESIS OF RELEVANT STUDIES

This section provides a synthesis of information and data relevant to the *Great Lakes Coastal Wetland Conservation Framework* (Framework) from the resources described and listed in Section 1. The discussion in this section is organized into subsections that map to key topical areas and concepts that will be evaluated as part of the Framework development process, including:

- Ecosystem Services
- Indicators and Metrics
- Desired Status
- Evaluation and Current Understanding of Wetland Dynamics

The first three sub-sections map directly to key tasks and products envisioned to support Objectives Two and Three of the Framework development process, including identifying: priority ecosystem services, including ecological services/functions and human well-being needs (Task 5); specific indicators (Task 6); and desired status/outcomes for coastal wetlands (Task 7). The "Assessment of Coastal Wetland Processes and Response" section addresses various topics that are also highly relevant to the Framework, both in terms of providing the scientific foundation for the approach and in supporting geospatial analyses of condition and the development of mapping products and decision support tools to make the Framework accessible. The topics covered in that subsection include relevant monitoring programs, key datasets, modeling efforts, and decision support tools.

The general approach taken in the following sections is to: 1) provide an overview of the general topic/concept, 2) identify key elements (e.g., a specific ecological service/function) under the topic that are highlighted in multiple studies, and 3) summarize the relevance/importance and supporting information for each key element. Section 2 concludes with a high-level summary of perceived knowledge and data gaps based on an assessment of the available studies and information (Section 2.5).

Matrices provided in Appendix A (hereafter referred to as measles-style charts) highlight the overlap between specific content identified in the resources (listed in rows) and concepts and elements that are relevant for the Framework (organized in columns). In addition, capsule summaries of the various studies that were reviewed and integrated into the synthesis are provided in Appendix B, roughly following the organization in Tables 1 and 2.

2.1 Ecosystem Services

Ecosystem Services have been defined as the "direct and indirect contributions of ecosystems to human well-being" (Bratt and de Groot 2012). For the purposes of the GLCW Framework, the so-called "indirect" ecosystem services are referred to as *ecological services and functions* and the "direct" ecosystem services are referred to as *human well-being needs*. These two components of GLCW ecosystem services are discussed individually in Sections 2.1.1 and 2.1.2, with specific points of connection highlighted. Valuation of ecosystem services is an important topic that is beyond the scope of this synthesis report. However, it should be noted that there has been a recent study conducted for the Saginaw Bay to Western Lake Erie corridor that estimated economic value for individual ecosystem services, many of which overlap with those discussed below (Eastern Research Group 2020). The methodologies established for that study and other valuation studies may be used to inform any future valuation efforts for GLCWs.

2.1.1 Ecological Services and Functions

Coastal wetlands play a crucial role in supporting the ecology of the Great Lakes, providing a range of important benefits. Ecological benefits that coastal wetlands provide to the Great Lakes include:

- Water Quality Improvement
- Nutrient Retention
- Carbon Sequestration
- Fish and Wildlife Habitat
- Coastal Protection

Table 3 (a summary of Table A.2 in Appendix A) below shows the relative frequency that each service/function was discussed in the resources reviewed, with fish and wildlife habitat being the most common ecological services/functions referenced. It should be noted that many of the sources indirectly referenced many of the ecological services/functions, but the table below is an accounting of studies that included explicit focus and extended discussion of those topics.

Table 3. Frequency of Reporting on Ecological Services & Functions in Great Lakes Coastal Wetlands

Ecological Services & Functions	Count of References
Water Quality Improvement	10
Nutrient Retention	11
Carbon Sequestration	1
Fish and Wildlife Habitat	19
Coastal Protection	8

The subsections below provide further context and examples of each ecological service/function. Table A.2 in Appendix A provides a measles-style summary of the ecological services and functions that are discussed in each of the studies.

2.1.1.a Water Quality Improvement

Coastal wetlands act as natural filters, trapping sediment and pollutants that would otherwise flow into the open waters of the Great Lakes. They help improve the water quality of nearshore waters as plants and microorganisms can also break down or metabolize certain organic pollutants, such as pesticides and petroleum compounds, converting them into less harmful substances within the wetlands. Coastal wetlands also provide a buffering effect against runoff, allowing excess flow to infiltrate before moving offshore. The water quality improvement service provided by GLCWs positively impact local communities by purifying water withdrawn from the Great Lakes for drinking and other purposes, improving habitat conditions for key fish species, and improving the overall aesthetic of nearshore areas.

In addition to nearshore water quality in the coastal wetlands themselves, many of the datasets and studies discuss the importance of coastal wetlands relative to offshore water quality. Studies conducted by Sierszen et al. (2012), Aziz and Van Cappellen (2021), and Carter et al. (2022) emphasize the importance of coastal wetlands in retaining nutrients and sediments to improve offshore water quality indirectly. The Lake Erie Quality Index (Ohio LEC 2022) also noted the link between degraded coastal wetlands and water quality issues, such as harmful algal blooms.

2.1.1.b Nutrient and Sediment Retention

Coastal wetlands can provide significant sediment and nutrient retention and promote nutrient cycling within the wetland habitat. Wetland plants, including emergent and submerged vegetation, have the capability to take up and store nutrients from the water column. Nutrients can also be trapped in wetlands via absorption to organic and suspended solid materials and subsequent sedimentation. Decomposition and microbial activity can also promote nutrient cycling within the wetland itself, including the cycling of nitrogen via denitrification processes.

This ecological service is highly correlated with general water quality influences, as retaining nutrients will help mitigate some effects of eutrophication. Several studies mentioned the capability of coastal wetlands to mitigate the effects of excess nutrients through plant uptake, filtration, and sedimentation (e.g., Sierszen et al. 2012, Aziz and Van Cappellen 2021, Carter et al. 2022). The retention of sediments and nutrients by GLCWs positively impacts local communities by purifying water withdrawn from the Great Lakes for drinking and other purposes, reducing siltation of key habitat areas for recreational and commercial fish species, and improving the overall aesthetic of nearshore areas.

2.1.1.c Carbon Sequestration

Wetlands may be effective at storing and sequestering carbon dioxide. The organic material that accumulates in wetland soils, known as peat, contains large amounts of carbon. The combination of plant biomass, soil organic matter, peat formation, sedimentation, and methane oxidation allows coastal wetlands to act as significant carbon sinks, helping to mitigate the impacts of greenhouse gas emissions and climate change, which contribute to extreme weather patterns and events that impact communities around the Great Lakes, as well as throughout Northern America and the world.

Carbon sequestration was not discussed in significant detail in the reference studies, with only one primary source explicitly discussing its importance. Sierszen et al. (2012) attempted to quantify the impact of coastal wetlands on carbon sequestration and found minimal discussion in peer-reviewed literature. That publication identified carbon sequestration as a knowledge gap that may or may not be an important ecological service. A more recent study conducted for southern Ontario by Byun et al. (2018) suggested that temperate wetlands may have functioned as significant sinks of carbon in the pre-industrial carbon cycle. In addition, Braun et al. (2019) provide some perspective on how coastal processes can affect carbon sequestration and processing in wetlands, noting that erosion of the shoreline along a coastal wetland will remove carbon and significant deposition (e.g., due to longshore sand transport) will tend to reduce the capacity of a wetland to sequester carbon. This study highlights that the role of erosion and deposition processes would need to be considered to appropriately evaluate wetland carbon sequestration at the regional or site scale.

2.1.1.d Fish and Wildlife Habitat

Coastal wetlands provide diverse and productive habitats for a wide variety of plant and animal species. They serve as important breeding, nesting, and foraging grounds for numerous fish, birds, amphibians, reptiles, and mammals. The complex structure of wetlands, which often includes an abundance of submerged vegetation, provides shelter, food, and protection for fish eggs, larvae, and young fish. Wetlands often have abundant food sources, such as insects, small invertebrates, and detritus, that support the growth and survival of fish during critical early life stages. Many commercially and recreationally important fish species, including various types of bass, pike, perch, and panfish, rely on coastal wetlands for spawning and rearing. The dense vegetation, including cattails, bulrushes, and marsh grasses, also offers protection and cover from predators and extreme weather conditions and provides habitat for fish that are foraged on by predator species (e.g., walleye) outside of the wetlands. The Great Lakes Fishery Commission (GLFC) Lake Erie technical Committee (LETC) Habitat Task Group has paid special attention to wetlands in the lake and has concluded that "*[o]ver 40% of Lake Erie's fish species are classified as wetland dependent or facultative wetland dependent*". Specific wetlands mentioned in the GLFC reports include those in the St. Clair Delta, Western Basin (Michigan and Ohio, including Sandusky Bay), Niagara River, Long Point Area, and in the lower reaches of major tributaries (e.g., Thames, Maumee, and Grand) (GLFC LETC 2023).

The importance of coastal wetland habitat for supporting wetland birds, including migratory species, and waterfowl has also been well-documented. A recent study conducted by Grand et al. (2020) focused on prioritizing specific coastal wetlands across the Great Lakes basin for marsh bird conservation. This analysis, which was based on the CWMP wetland bird dataset, concluded that 45% of the Lake Erie CW habitat is "high priority" for bird habitat and roughly only 50% of that area currently has protection status. The Upper Mississippi River & Great Lakes Joint Venture (2018) has also developed detailed assignments of high-priority waterbird and waterfowl habitat areas in Lake Erie and throughout the Great Lakes basin.

Fish and wildlife habitat services support human well-being needs in a variety of ways, including: 1) supporting a strong and sustainable commercial fishery; 2) providing recreational fishing, hunting, and birding opportunities; 3) supporting and restoring cultural and spiritual practices; and 4) supporting tourism and the local economy. The importance of fish and wildlife habitat was discussed in many of the primary and secondary resources, as described further in Appendices A and B and Section 3.

2.1.1.e Coastal Protection

Coastal wetlands help to stabilize shorelines and protect adjacent land areas from erosion. Their vegetation and complex root systems bind soil particles together, preventing them from being washed away by waves and currents. Additionally, wetlands act as natural buffers during storm events, absorbing excess water and reducing the impacts of flooding. The benefits of coastal protection to human communities include reduced flooding of property and the maintenance of beaches and other nearshore areas that support recreational and tourist activities.

Coastal protection was mentioned in many of the reference studies for this effort. The Chatham-Kent Lake Erie Shoreline Study (Zuzek Inc. 2020), in particular, investigated many strategies for improving coastline protection through nature-based solutions. The study outlined the impacts of changing water levels and degradation of the capability of coastal wetlands to continue to provide adequate protection against erosion.

2.1.2 Human Well-Being Needs

As recognized by the Millennium Ecosystem Assessment, people derive benefits from nature through four primary categories of ecosystem services (MEA 2005):

- Provisioning services (e.g., food and water),
- Regulating services (e.g., climate and flood regulation),
- Supporting services (e.g., nutrient cycling), and
- Cultural services (e.g., recreational, spiritual, and other non-material benefits).

All categories of ecological services/functions can support human well-being (e.g., water quality improvement benefits for human health); however, provisioning, regulating, and supporting services tend to relate most closely to physical and material aspects of human well-being. Cultural services account for the intangible, nonmaterial, and relational pathways by which people derive life-enriching and life-affirming benefits through interactions with nature, uniquely contributing to social, psychological, and cultural aspects of human well-being (Fish et al. 2016, Leong et al. 2019).

Coastal wetlands in the Great Lakes region provide a range of cultural services that support various socio-economic activities and can contribute to overall quality of human life and well-being. Services explicitly related to human well-being identified during the review generally fell under the following categories:

- Recreational Opportunities
- Tourism
- Commercial Fisheries
- Cultural and Spiritual Activities

As shown in Table 4 (a subset of Table A.2 in Appendix A) below, "recreational opportunities" was the most frequent human well-being need that was referenced in the primary and secondary resources, followed by cultural and spiritual activities and tourism. A smaller number of studies identified "sense of place" and overall "economic vitality" as additional human well-being needs. The frequency results in Table 4 should not be used to infer the relative importance of the human well-being needs, as some of the needs are much more difficult to measure than others (e.g., sense of place). In contrast, the ecological services/functions (Table 3) are more straightforward to quantify.

Table 4. Frequency of Reporting on Human Well-being Needs in Great Lakes Coastal Wetlands

Human Well-Being Needs	Count of References
Recreational Opportunities	16
Tourism	9
Commercial Fisheries	6
Cultural and Spiritual Practices	9
Economic Vitality (general)	6
Sense of Place	3

The subsections below provide further context and examples of each human well-being need. Table A.2 in Appendix A provides a measles-style summary of the human well-being needs that are discussed in each of the studies.

2.1.2.a *Recreational Opportunities*

Coastal wetlands offer opportunities for nature-based recreational activities for personal enjoyment in one's leisure time, such as recreational and subsistence fishing and hunting, birdwatching, boating, kayaking, hiking, and nature photography. Recreational activities in coastal wetlands can promote physical, psychological, and social aspects of well-being by providing opportunities for exercise, relaxation and psychological restoration, connection with nature, and social experiences. Outdoor recreation can also provide local economic benefits; for example, the Lake Erie recreational fishery generates more than $1.4 billion annually (Annis et al. 2017).

The importance of coastal wetlands to recreational activities was discussed in many of the reviewed studies and reports for the Great Lakes, as well as a Puget Sound Partnership (2015) report detailing human well-being needs for Puget Sound.

2.1.2.b *Tourism*

The recreational opportunities and scenic landscapes afforded by coastal wetlands are also an attraction for outdoor and nature-based tourism to the area. Distinguishing from individual recreational opportunities, we consider tourism as the *activities of persons traveling to and staying in places outside their usual environment for leisure, business, and other purposes* (UNTWO 2013), in the specific content of activities that are tied to Lake Erie. The Lake Erie tourism industry has a significant impact on the economies of coastal communities in Ohio, Ontario, Michigan, New York, and Pennsylvania as evidenced by the following statistics:

- In the seven coastal counties in Ohio alone, Lake Erie helps support an $11.5 billion tourism industry including providing over 100,000 jobs.
- Northwestern Ohio's "Biggest Week" in birding is the largest spring birding festival in the United States and generated $37 million in revenues in 2014 (Annis et al. 2017).

Along with the economic and livelihood benefits to local communities and outdoor tourism service providers, nature-based tourism related to coastal wetlands also confers recreational opportunity benefits to individual visitors. Finally, in addition to the recreational activities outlined above, coastal wetlands provide opportunities for environmental education and interpretation programs.

2.1.2.c *Commercial Fisheries*

Great Lakes coastal wetlands provide critical habitats for various commercially important fish species, including yellow perch, walleye, and smallmouth bass. The commercial fishing industry in and around coastal wetlands provides consumers with a healthy and sustainable food source and supports local economies, through providing income, employment, and livelihoods for commercial fishers. The Lake Erie commercial fishery generates roughly $190 million annually in Ontario (Ontario Commercial Fisheries' Association 2015) and the combined commercial and recreational sport fishery in Ohio exceeds $800 million (Ohio Division of Wildlife 2015).

The GLFC LETC oversees several task groups that evaluate the status and management strategies for Lake Erie overall habitat and the populations of coldwater species, walleye, and yellow perch. In addition to providing habitat for key life stages of these species, coastal wetlands provide habitat for the forage species that these predator species rely on for survival (e.g., rainbow smelt, emerald shiner, gizzard shad).

2.1.2.d *Cultural and Spiritual Practices*

Great Lakes coastal wetlands hold cultural and spiritual value for many people. Cultural practices are shared through intergenerational transfer of knowledge, experience, and customs and may encompass a wide array of activities such as identifying, locating, harvesting and/or processing natural resources as well as the values and ethics about which resources, and what quantities, to harvest (Breslow et al., 2018; Leong et al. 2019). The ability to engage in one's cultural practices supports well-being through maintaining connections to heritage and ancestors as well as supporting a person's current sense of self and identity.

Spiritual practices are those that perpetuate spiritual and religious beliefs and practices, and they may or may not relate to cultural practices. In various forms, experiences in and relationships with nature play an important role across major religions and individual spiritual experiences (Cooper et al., 2016). Spiritual practices may include formal and informal ceremonies and customs related to the presence and recognition of, as well as the relationships with and responsibilities towards, plants, animals, and natural places (Leong et al., 2019).

While Great Lakes coastal wetlands may be part of any person or group of people's cultural and spiritual activities, we recognize the specific importance of coastal wetlands in relation to the cultural and spiritual activities of Indigenous peoples of the Great Lakes. The substantial loss (> 90%; Mitsch 2017) and degradation of Great Lakes coastal wetlands due to European settlement and associated development activities (e.g., logging, draining) has had a disproportionate impact on the practices and vitality of Indigenous peoples in the region. This impact has translated to diminished community and individual opportunities and systemic lack of prioritization for addressing restoration work that would address these losses and inequities.

Manoomin (wild rice) provides a good example of the historical loss experienced by Indigenous peoples of the Great Lakes. Healthy coastal wetlands can provide ideal growing conditions for manoomin and other species that hold significant cultural and subsistence importance for indigenous communities in many regions of the Great Lakes (Abt Associates and NOAA-OCM 2020). Historically, the Anishinaabek people who lived in southeastern Michigan also harvested manoomin from Lake Erie (Barton 2018). However, the draining of coastal wetlands, urbanization, and degradation of water quality in Lake Erie resulted in the elimination of wild rice from the lake. Although manoomin may not be a realistic desired condition or metric for present-day Lake Erie, the approach undertaken by the Lake Superior Manoomin study, including the engagement with multiple tribal groups, and the metrics identified could be considered when developing the GLCW Framework.

2.1.2.e *Sense of Place*

While a variety of conceptualizations exist, we consider "sense of place" to broadly encompass people's connections to and relationships with places, based primarily on the meanings people hold for a place (e.g., beautiful scenery, home, source of inspiration) and the strength of attachment (i.e., an emotional and identity-based bond) that results (Masterson et al. 2017; Rajala, Sorice, and Thomas, 2020). Sense of place is a holistic cultural ecosystem service that emerges from the interaction of characteristics of a person, the ecosystem or 'place' in question, and a person's experiences there. For example, the meanings for which a person may feel attached to a place can encompass descriptions of biophysical attributes of the place (characteristic meanings), actual or desired uses for a place (functional meanings), individually oriented experiences (experiential meanings) and socially oriented experiences or interactions (interpersonal meanings). Sense of place and associated relational values can enhance meaning and satisfaction in life and enrich human well-being through multiple pathways based on place meanings and place attachment (Chan et al., 2016; Rajala and Sorice, 2021).

"Sense of Place" is identified as a human well-being need in the Puget Sound Partnership (2015) study, and this theme was also implicitly addressed in the various Great Lakes studies that were reviewed. Specific attributes associated with "Sense of Place" include positive connections to a person's region, a sense of pride and also stewardship, inspiration, stress reduction, and overall life satisfaction.

2.2 Indicators

Several past and ongoing studies have developed indicators of coastal wetland condition for Lake Erie and, in some cases, across the entire Great Lakes basin. The specific term associated with the concept of "indicators" varies across the studies and the terms *ecological attributes* and *metrics* (e.g.) have been used with equivalent meaning. Indicators are intended to be used to assess wetland condition for a specific spatial and temporal extent; therefore, it is critical that the indicators selected for a particular study (in this case, the GLCW Framework) meet the following conditions: 1) directly map to a desired status/condition for a site or spatial region of interest, and 2) be quantifiable through the use of available ecological and/or physical data or results from simulation models. As the GLCW Framework is developed, it will be important to both identify quantifiable indicators and track any "potential" indicators that are excluded due to current data/information limitations, as well as document the associated data gaps.

An ecological indicator that is specifically designed to quantify the condition of a particular taxa group (e.g., fish) is commonly referred to as an *Index of Biotic Integrity* (IBI) or an *Index of Ecological Condition* (IEC). However, various other coastal wetland ecological and contextual indicators have also been developed. As discussed below, *adaptive capacity* has become an important concept when assessing the resilience of coastal wetlands to climate change, and recent studies have made progress in defining indicators to evaluate future resiliency in addition to assessing present-day condition.

Based on the review of primary and supplementary resources, the following studies were identified as providing substantial development and/or analysis of indicators of coastal wetland condition and resiliency in Lake Erie (as well as the broader Great Lakes):

- Lake Erie Biological Conservation Study (LEBCS; Pearsall et al. 2012) [resource P-06, see section B-6 in Appendix B]
- Coastal Wetland Monitoring Program (CWMP; Uzarski et al. 2017, 2019) [resource P-04, section B-4]
- State of the Great Lakes (SOGL) Report (USEPA and ECCC 2022a,b) [resource P-03, section B-3]
- Assessment of the Resilience of Great Lakes Coastal Wetlands to a Changing Climate (ECCC 2022a,b,c) [resource P-07, section B-7]
- Canadian Great Lake Nearshore Assessment (ECCC 2021) [resource P-11, section B-11]

The 2022 Lake Erie Lakewide Management Plan (LAMP) also addresses indicators, but the discussion in that plan is based on the SOGL (and CWMP) indicators and it does not provide any new or different indicator information relative to the source material. Other supplemental resources that include an expanded discussion of indicators include: the Lake Erie Quality Index, the Chatham-Kent Lake Erie Shoreline Study, and the Lake Superior Manoomin Cultural and Ecosystem Characterization Study.

The LEBCS was published in 2012, shortly after the CWMP sampling efforts were initiated in 2011. While the LEBCS includes similar indicators to those developed later based on CWMP data, the LEBCS indicators were based on lower intensity coastal wetland datasets collected prior to the 2011-12 timeframe. The CWMP has since generated unique, long-term (2011-2022) datasets for coastal wetland vegetation, fish, macroinvertebrates, amphibians, birds, and water quality that have been used to develop a suite of indicators that quantify taxa group (and water quality) conditions at the wetland site scale. The CWMP indicators are integrated into the SOGL report and the Lake Erie LAMP report. Recently, ECCC completed its "Assessment of Resilience of Great Lakes Coastal Wetlands to a Change Climate" study under its Great Lakes Protection Initiative (GLPI). That 5-year effort included the application of a two-dimensional *Coastal Wetland Response Model* (CWRM) that was calibrated and applied to calculate ecological attributes for 20 sites along the Canadian shorelines of the Great Lakes (including five sites in Lake Erie) based on simulations of vegetation community dynamics in response to changing water levels and other drivers. Those ecological indicators were ultimately used in concert with adaptive capacity indicators to support a vulnerability assessment for the focal wetland sites. The Canadian Great Lakes Nearshore Assessment was completed in 2021 (ECCC 2021) and also describes a number of status indicators related to coastal processes, water quality, and human use.

The indicators developed and presented for the various studies can be roughly categorized as follows:

- Hydrological (i.e., related to water level dynamics)
- Adaptive capacity (including landscape context)
- Wetland quantity/size
- Aquatic habitat connectivity
- Ecological indicators specific to a taxa group (e.g., fish, macroinvertebrates, plants)
- Vegetation community-specific indicators (e.g., meadow marsh, *Phragmites*)
- Water quality indices

Specific indicators (or types of indicators) within each of these categories are discussed in the following sections. Section 2.2.8 also discusses other indicators that are relevant to, or could be affected by, coastal wetland function.

2.2.1 Hydrological Indicators

Water level conditions and fluctuations over seasonal to interannual timeframes are an important driver affecting wetland vegetation and faunal communities. Interannual variations in water level have been well-documented as an important factor in maintaining high quality, diverse vegetation communities and habitat. In particular, periodic natural high and low water level conditions and transitional periods have been documented to promote the growth of wet meadow communities and promote the expansion of native species while limiting the spread of invasive species such as *Phragmites* (common reed) and *Typha* (cattail) (Wilcox and Xie 2007).

Because water level is an important driver of coastal wetland extent and can influence condition, water level indicators have been developed to serve as proxies for coastal wetland condition. For example, the LEBCS defined the following indicators, which were assessed along a categorical scale of “Poor”, “Fair”, “Good”, or “Very Good” based on specific criteria and thresholds for Lake Erie (Pearsall et al. 2012):

- Mean growing season (Mar-Oct) water level (applied within a 5-year window)
- Variance in mean growing season (Mar-Oct) water levels for 30-year rolling period (“Good” rating associated > 0.045 m variance)

Similar hydrological indicators were developed by various working groups to support the International Joint Commission (IJC) water level studies for Lake Ontario and the upper Great Lakes in the 2000-2012 timeframe (IJC 2006). While these indicators do not directly measure coastal wetland condition, they can provide valuable information about the water level regime and dynamics that have a significant influence on wetland condition and trends in upslope or downslope migration.

2.2.2 Adaptive Capacity & Landscape Context Indicators

Adaptive Capacity (AC) is an important concept for GLCWs, and the recent ECCC study regarding coastal wetland resilience to climate change developed a specific set of indicators for AC. The term “adaptive capacity” has been defined by the Intergovernmental Panel on Climate Change (IPCC) as “*the ability of a system to adjust to climate change to moderate potential damages, to take advantage of opportunities, or to cope with the consequences.”* (ECCC 2022b). Adaptive capacity indicators may represent either specific habitat characteristics of a wetland (e.g., invasive species coverage) or contextual information or statistics related to the landscape surrounding a wetland or its tributary watershed(s). As indicated by the above definition, these indicators are specifically focused on how well a wetland can adapt to environmental and anthropogenic stressors (especially climate change effects), rather than strictly assessing the present-day ecological condition of the wetland. For example, in its recent study on GLCW resilience to climate change, ECCC adopted the following indicators of adaptive capacity:

- Related to habitat characteristics: vegetation richness, quantity of *Phragmites* (note: these overlap with indicators discussed under Section 2.2.5 and 2.2.6).
- Landscape context: plant community upslope/downslope migration potential, and level of mandate protection by federal or other entities.

Other examples of landscape context indicators described in the LEBCS report (Pearsall et al. 2012) include:

- Percent natural land cover in the watershed (of the coastal wetland)
- Percent natural land cover within 500 m of mapped wetlands

The Canadian Great Lakes Nearshore Assessment include similar landscape context indicators such as:

- Percent of shoreline that is hardened
- Number of barriers preventing littoral drift

"Natural cover" for these and similar indicators refers to any areas that have not undergone any development (e.g., conversion to agricultural or urban area). Calculation of these indicators typically requires identifying an appropriate land cover dataset (e.g., National Land Cover Dataset in the U.S.) and conducting a series of geoprocessing operations (e.g., buffering, zonal summaries) to produce the desired statistical results. A complementary approach to evaluating land cover is quantifying shoreline hardening, which represents the percentage of shoreline length (e.g., in the vicinity of a wetland) where infrastructure exists.

In addition to the direct representation of landscape context in indicators, landscape context has been incorporated as a component within other indicators. One example is the *Water Quality and Land Use Index* developed based on the CWMP water quality datasets (Harrison et al. 2020). This indicator combines information for the land cover surrounding each surveyed wetland site with nutrient, chlorophyll *a*, and other constituent observations to calculate a relative index that can be used to rank sites (see Section 2.2.5 for further discussion).

2.2.3 Wetland Areal Extent Indicators

As discussed above, the impact of water level regime on wetland dynamics is well-documented and inter-annual fluctuations can cause wetlands to migrate upslope or downslope as vegetation communities respond to changes in wetting/drying cycles and water depth at various elevations. Extended periods of high-water levels will promote upslope migration of the wetland as upland trees/shrubs are replaced by meadow and emergent species. Conversely, extended periods of low water level will promote downslope migration of a wetland, with submerged aquatic vegetation (SAV) and emergent communities shifting towards the lake, and trees/shrubs replacing meadow and emergent species at the landward edge. Both the upslope and downslope migration of a wetland complex can potentially be limited by barriers to vegetation and therefore habitat expansion. Limitations imposed on migration include land development (urbanization or agricultural) on the landward edge of the wetland and infrastructure (e.g., dikes or other barriers) that may exist along the edges or within the wetland complex.

Indicators that express total wetland area have been used in various contexts to quantify and track wetland quantity/extent. Both the LEBCS and ECCC's recent evaluation of coastal wetlands resilience to climate change identified 'wetland area' indicators (Pearsall et al. 2012, ECCC 2022c). While the LECBCS indicator was presumably intended to be calculated based on remote sensing data, the ECCC indicator (referred to as an "ecological attribute") was derived from two-dimensional modeling results. The GLRI Action Plan III, as well as earlier versions of that plan, includes a measure of progress for Focus Area 4 (Habitat and Species) defined as "*acres of coastal wetland, nearshore, and other habitats restored, protected, or enhanced*" and identifies specific acreage targets for Fiscal Year (FY) 2020-2024 (ranging from 394,000 – 442,000 acres). The Coastal Assembly has been tracking progress towards these targets via the **Blue Accounting website** which provides a snapshot of coastal wetland restoration progress across the Great Lakes basin based on an inventory and aggregation of acreage affected by CW protection and restoration projects.

The measurement and tracking of GLCW areal extent are challenging endeavors for a variety of reasons, including significant year-to-year shifts in wetland extent and composition (i.e., due to water levels), and the complexities of training remote sensing methods to accurately identify wetland areas/types (Ryerson 2018). The *First Triennial Assessment of Progress on Great Lakes Water Quality* (IJC 2017) noted the inability of the U.S. and Canada to accurately report on extent. However, some promising initiatives have been undertaken recently to address this data gap. ECCC is currently leveraging the results of its Canadian Baseline Coastal

Habitat Survey (ECCC 2020, 2022f) to develop estimates of wetland areal extent along the Ontario shoreline of Lake Erie. “Objective One” of the GLCW Framework project is specifically designed to address the question of coastal wetland extent, and it will provide draft and final geospatial products for Lake Erie coastal wetland coverage in July 2023 and December 2023, respectively. The new datasets generated by this effort will provide comprehensive wetland spatial coverage for the lake for each year within the 2010-2020 timeframe. Those datasets are expected to provide some important new insights into the relationship between water level regime and wetland extent.

2.2.4 Aquatic Habitat Connectivity Indicators

Aquatic habitat connectivity and continuity between GLCWs and adjacent aquatic and terrestrial habitats encompasses the following:

- GLCW connections to tributaries (i.e., drowned river mouth wetlands), which can be affected by the presence of dams and other barriers present in rivers.
- GLCW connections to open lake/bay waters, which can be affected and limited by dike structures.
- GLCW connections to upland terrestrial habitats, which can be affected by development.

Habitat connectivity is a critical aspect of a high-functioning coastal wetland environment, and there is a great need and opportunity to improve connectivity between GLCWs and surrounding habitats to maintain or improve their ecological integrity and environmental resilience to climate change.

Aquatic habitat connectivity and associated indicators are addressed in the LEBCS and the SOGL 2022 Report, as well as the Canadian Great Lakes Nearshore Assessment. Under its “Habitat and Species” top-level indicator, the SOGL report includes an “aquatic habitat connectivity” sub-indicator for coastal wetlands. The purpose of this sub-indicator, which is calculated based on publicly available Great Lakes connectivity data, is to quantify the degree to which the tributaries that serve as conduits between the watersheds and the Great Lakes have an “open” connection to the lake that supports passage for migratory fish. The SOGL report indicates that roughly 33% of originally connected tributaries to Lake Erie are currently accessible to migratory fish. While the intent of increasing tributary connectivity is to promote the migration of native fish species, a recognized challenge is that increased access may also benefit invasive fish species (e.g., sea lamprey in the upper Great Lakes).

Specific indicators have not been developed to assess GLCW habitat connectivity to adjacent lake aquatic and terrestrial habitats. However, contextual information regarding the presence of dikes and developed areas around the wetlands have been quantified and used to assess GLCW environments on a site-specific basis.

2.2.5 Ecological Indicators by Taxa Group

Many of the ecological indicators developed for coastal wetlands are specific to a particular group of taxa and are typically referred to as IBIs or IECs. The purpose of such indicators is to quantify the wetland site-specific condition of a particular taxa group (e.g., fish or birds) that is strongly connected to wetland habitat quantity and quality condition. Typically, the algorithms for calculating the IBI/IEC scores integrate information regarding the abundance and diversity of native species, and many also factor in the prevalence and impact of invasive species (i.e., as a degrading factor).

In addition to evaluating the condition of a specific taxa group, the results of these indicators can be used collectively to assess the overall quality of a wetland site. However, it must be recognized that the unique characteristics of individual sites may be more favorable for certain taxa groups (e.g., birds may favor sites that are located along a migratory route), and so these evaluations must be done cautiously and incorporate site-specific context as necessary. Results for specific taxa groups can also be evaluated across multiple sites within Lake Erie (or sub-regions) or other Great Lakes to provide an aggregate assessment of coastal wetland health across the lake or sub-region.

Existing studies that document taxa group-specific indicators include the LEBCS, the CWMP, the SOGL 2022 Report, and the Lake Erie LAMP. The LEBCS identified the following taxa group-level indicators that quantify condition by taxa group:

- Amphibian: community-based coastal wetland IBI
- Bird: marsh bird IBI (for abundance and diversity of wetland-dependent bird species)
- Macroinvertebrate: invertebrate IBI
- Fish: spawning/recruitment success of representative coastal wetland spawners, and Wetland Fish Index (WFI)

At the time the LEBCS was published, data were generally available to support the amphibian and bird indicators but not the macroinvertebrate and fish indicators. The CWMP has since addressed those data gaps by sampling roughly 200 coastal wetland sites per year (~1,000 every five years) across the Great Lakes basin, including annual monitoring of anurans (frogs and toads), birds, fish, macroinvertebrates, and vegetation. A suite of taxa group-level indicators has been developed and refined over time based on the raw monitoring datasets, including IBI scores for vegetation, macroinvertebrates, and fish and IEC scores for anurans and birds (Table 5). These indicators are extended by the CWMP each spring to integrate the dataset from the prior monitoring year and any other refinements made to earlier datasets. Because the CWMP has been consistently monitoring ecological and water quality condition through the past 12 years, the raw datasets and indicators generated by the CWMP capture both lower and higher water level conditions and transitional periods. This is a unique feature of this dataset that affords the opportunity to assess changes in site-level conditions through time in response to water level trends and other changes and stressors. The potential to evaluate temporal trends should be considered in the context of the GLCW Framework development effort.

Table 5. Coastal wetland taxa group indicators developed by the CWMP

Metric Name	Years Available	Relevant Publication(s)
Vegetation IBI	2011-2022	Dybiec et al. (2020) [1]
Macroinvertebrate IBI	2011-2022	Uzarski et al. (2004, 2017)
Fish IBI	2011-2022	Cooper et al. (2018)
Anuran IEC	2011-2022	n/a
Bird IEC	2011-2022	n/a

[1] The original version of the vegetation IBI, which was used through 2021 and is presented in the SOGL 2022 Report, was based on Albert and Minc (2004).

The SOGL 2022 Report defines a "Habitat and Species" indicator, which is linked to GLWQA Objective 5 (USEPA and ECCC 2012) and represents the indicator that is most strongly associated with coastal wetland condition, restoration, and protection. Within this top-level indicator, six sub-indicators are defined for "coastal wetlands and aquatic habitat connectivity." The status and trends for five of the coastal wetland sub-indicators (excluding aquatic habitat connectivity) are directly based on the CWMP indicators listed in Table 5, with the most recent SOGL 2022 Report incorporating scores reported through the 2019-2020 monitoring years. The Lake Erie LAMP also provides coverage of indicators, which is based on the indicator results presented in the SOGL report. It is important to note that the SOGL reporting lags CWMP monitoring activities and indicator calculations, and IBI/IEC results are now available from the CWMP for the entire 2011-2022 period.

Finally, the recent assessment of coastal wetland resilience to climate change conducted by ECCC included modeling of two site-scale vegetation attributes based on application of the Coastal Wetland Response Model developed under that effort (ECCC 2022c):

- Vegetation community diversity (based on the Shannon Diversity Index)
- Wetland interspersion (ratio of wetland vegetation to open water)

The implementation of these indicators was unique because they were derived from gridded wetland model simulation results that provided an explicit spatial representation of the focal sites for a multi-decadal period and included consideration of potential future climate scenarios. The five sites assessed for Lake Erie were: Fox / Dolson's Creek, Grand River mouth, Long Point, Rondeau Bay, and Selkirk Provincial Park.

2.2.6 Vegetation Community-Specific Indicators

The vegetation indicators discussed in the prior section provide an assessment of the overall condition of the vegetation community within a specific wetland site. In addition to those group-level assessments, indicators have been developed to evaluate specific components *within* the overall vegetation community. Examples of community-specific indicators include:

- Wetland macrophyte index (LEBCS)
- Submerged aquatic vegetation extent/volume (LECBS, ECCC climate resilience study)
- Floating leaf vegetation volume (ECCC climate resilience study)
- Meadow marsh area (ECCC climate resilience study; IJC water levels studies for Lake Ontario and the upper Great Lakes (e.g., IJC 2006))
- Relative cover of invasive species - e.g., *Phragmites* or *Typha* spp. (ECCC climate resilience study, LEBCS)

Similar to the broader vegetation IBI indicators, the community-specific indicators typically require either taxa-level data collected via transect sampling (e.g., as implemented by the CWMP) or two-dimensional modeling results (e.g., via the CWRM). Another potential approach for quantifying the extent (areal coverage) of a specific plant community is via remote sensing, including photo interpretation based on machine learning (or manual) techniques and ground-truthing. Such efforts are critical to supporting the calibration of spatially resolved models such as the CWRM (ECCC 2022c).

2.2.7 Water Quality Indices

While many coastal wetland indicators are focused on specific ecological components, water quality conditions have also been assessed. Examples of water quality indicators developed for GLCW include:

- Mean annual TP concentration (LEBCS)
- Water Quality Index (WQI) for wetland quality (LEBCS, via Chow-Fraser 2006)
- Water Quality and Land Use Index (Harrison et al. 2020, via CWMP datasets)

Calculation of water quality indicators is predicated on having a specific algorithm to integrate one or multiple constituents and sufficient data available to support its application. The *Water Quality and Land Use Index* has been developed based on the robust CWMP dataset, and results are available for hundreds of wetland sites across the Great Lakes for the 2011-2022 period. This indicator integrates surrounding land use and observed concentrations of nutrients, chlorophyll *a*, and other constituents into a unified index that is used to provide a relative ranking of sites. For Lake Erie, results are available for roughly 75 coastal wetland sites.

2.2.8 Other Relevant Indicators

The SOGL 2022 Report and the Canadian Great Lakes Nearshore Assessment (as well as other resources) describe indicators that quantify the condition of the broader Lake Erie environment, including nearshore and offshore areas. Although these indicators are not explicitly connected to coastal wetland environments, it is recognized that properly functioning wetlands can provide ecosystem services that influence the health of the broader lake. Specifically, wetlands can help filter and retain sediment and nutrients (Carter et al. 2022, Aziz and Van Cappellen 2021), thereby reducing the turbidity and nutrient levels in Lake Erie. Examples of SOGL sub-indicators that have the potential to be impacted by coastal wetland protection and restoration include:

- Nutrients in lakes
- Harmful algal blooms (nearshore & embayments)
- *Cladophora*
- Various sub-indicators under the "Aquatic Food Web" component of the "Habitat and Species" indicator (e.g., phytoplankton, native prey fish diversity)

Current conditions and trends associated with these indicators are discussed in Section 3.1.2.

2.3 Desired Status

The primary and secondary resources were reviewed to determine how often and at what level of detail desired statuses or goals for coastal wetland health were prescribed. Six of the primary resources and two of the secondary resources explicitly discussed a desired endpoint for coastal wetland status. A meaningful evaluation of desired status requires that the status evaluation be tied to a specific indicator (see Section 2.2) that can be used to quantify the condition of a particular wetland ecological component or other attribute (e.g., landscape context variable). In addition to being quantifiable, application of an indicator to assess past status and progress towards a desired status requires that:

- Appropriate and sufficient input data (via monitoring or models) be available to assess status for the spatial and temporal scales of interest.
- If necessary, a rating scale is developed, vetted, and applied to convert raw indicator scores to a meaningful output for progress tracking and decision-making purposes. In most cases, both current conditions and desired status are conveyed along a relative, categorical scale (e.g., "Poor" → "Good") based on rating thresholds identified for the indicators that the status is in reference to. However, in some cases raw numeric targets may be appropriate (e.g., acreage of wetlands).

Particular attention needs to be paid to the temporal and spatial scale of the indicators and their supporting data, including maintaining consistency in how, where, and when data are collected (or results simulated by a model). For example, if the desired status for a particular wetland site is defined as a site-scale vegetation IBI rating of "Excellent" relative to a current "Fair" condition based on a particular dataset, then it is important that future assessments of progress towards that desired status be evaluated via comparable future datasets for the site that are based on similar monitoring protocols and spatial coverage for the (future) time period of interest. This is why long-term monitoring programs such as the CWMP that follow consistent protocols and maintain a predictable pattern of resampling sites are essential to supporting status evaluations over a period of time.

Some references described the desired status in terms of levels of stress for particular indicators. For example, the Canadian Great Lakes Nearshore Assessment (ECCC 2021) prescribes a "low stress" status for shoreline hardening, representing < 25% of the total shoreline length as hardened. Most references to desired status indicate a goal of positive trends in costal wetland health. For example, as discussed in Section 2.2, the SOGL report identifies several sub-indicators for Lake Erie (and other GL) coastal wetland health, including composition of fish communities, composition and occurrence of wetland bird communities, and the composition and occurrence of wetland amphibians. The current status for each sub-indicator and top-level indicator in each lake is rated categorically as either "Poor", "Fair", or "Good"; and indicator trends are categorized as "Deteriorating", "Unchanging", or "Improving". The desired status is "Good" or to demonstrate a positive trend (i.e., "Improving") for sub-indicators that are rated as "Poor" or "Fair".

The Lake Erie Biodiversity Conservation Strategy (Pearsall et al. 2012) outlines specific quantitative goals for coastal wetland health. These desired statuses include:

- By 2030, the average wetland macrophyte index for Coastal Wetlands around the lake will reflect a "Good" condition.
- By 2030, coastal wetland area around the lake will have increased by 10% compared to the 2011 wetland area.

The Lake Erie Lakewide Action and Management Plan highlights specific actions from partnerships with other agencies to help improve coastal wetland condition, including:

- Implement Sandusky Bay Initiative projects in priority Lake Erie coastal areas, through partnership with Ohio Department of Natural Resources and Ohio EPA.
- Continue to implement shoreline softening and coastal wetland restoration projects in connecting channels and embayments, through funding and partnerships with EPA, USGS, USFWS, ECCC and others.
- Increase hydrologic connectivity between coastal wetlands and Lake Erie.

- Implement St. Clair – Detroit River System Initiative projects identified to achieve the coastal wetland-related priority objectives of the Initiative.
- Assess coastal wetland health and vulnerability to climate change.
- Restore/enhance 110 acres of coastal wetland within the Western Lake Erie/Lake St. Clair Focus Area as part of USFWS Midwest Coastal Program Strategic Work Plan.

A tabular accounting of the GLCW Framework concepts addressed by each source is provided in Appendix A, and more detailed summaries of each primary and secondary resource are provided in Appendix B.

2.4 Assessment of Coastal Wetland Processes and Response

The eventual selection of priority ecosystem services (including ecological services/functions and human well-being needs), indicators, and desired status for the GLCW Framework will be based on the "state of the science" understanding of coastal wetland dynamics, as well as practical and logistical considerations related to the availability and continuity of key supporting datasets and models. Several of the resources reviewed for this effort describe specific past and ongoing efforts to monitor or model coastal wetlands to generate raw data/results that can be leveraged by coastal managers for decision-making. This section describes key monitoring programs, datasets, and modeling efforts that are directly relevant to the assessment of Lake Erie coastal wetland dynamics and response, and it concludes with a brief discussion of decision support tools that have been developed to support coastal wetland assessment.

2.4.1 Monitoring Programs and Datasets

Efforts to monitor ecological and physical conditions for coastal wetlands and adjacent nearshore areas are critically important both in terms of continuing to build on existing knowledge of coastal wetland processes and response and for providing raw data that can be refined into products to support decision-making for restoration and protection initiatives. This section briefly summarizes two key active monitoring programs for Lake Erie, as well as additional supporting datasets generated by prior efforts. Each of these datasets merit consideration within the GLCW Framework development effort. Note that this discussion is intended to highlight some specific resources and is not intended to provide a comprehensive review of Lake Erie coastal wetland monitoring or datasets.

In addition to the datasets described below, there are two current efforts that will eventually be integrated into the Framework:

- "Objective One" of the Framework development effort will provide wetland coverage (polygon) datasets for Lake Erie for each year within the 2010-2020 timeframe. The products from this effort will provide a unique, long-term dataset of wetland extent that will roughly mirror the timeframe of data and indicator availability from the CWMP.
- The *Saginaw Bay to Lake Erie Coastal Wetland Blueprint* project is being conducted in parallel with the GLCW Framework pilot project for Lake Erie. While no products were available from this project as of spring 2023, it is anticipated that findings from this effort will eventually be integrated into this synthesis and potentially the Framework itself.

2.4.1.a Coastal Wetland Monitoring Program

The **Coastal Wetland Monitoring Program** (CWMP) is a GLRI-funded program that was initiated in 2010 to meet a primary objective of implementing a standardized basin-wide coastal wetland monitoring program (Uzarski et al. 2017, 2019). The initial five years of sampling (2011-2015) set the baseline for future sampling years and demonstrated the value of ecological datasets that can be used to inform decision-makers on coastal wetland conservation and restoration priorities throughout the Great Lakes basin.

The first five years of the program (2011-15) involved establishing and fully implementing a standardized sample design with rotating panels of wetland sites to be sampled across years, accompanied by sampling protocols, QAPPs, and other methods documents. In addition to the planning and implementing field activities, a database management system (DMS) was developed, and the approaches for calculating coastal wetland indicators based on the raw monitoring data were developed and documented. The CWMP is now in its third 5-year monitoring cycle, and it has sampled approximately 1,000 wetland sites across the Great Lakes (roughly 200 sites per year), with many of those sites sampled at least once every five years. Monitoring data have been generated for each year in the 2011-2022 timeframe for the following taxa groups: vegetation, fish, macroinvertebrates, anurans, and birds. Fish/invertebrate crews also sample a suite of water quality parameters within each monotypic vegetation zone, including nutrients, chlorophyll *a*, chloride, color, turbidity, and other parameters. The CWMP relies on rough polygon representations of wetland sites originally developed by the Great Lakes Coastal Wetland Consortium (GLCWC) in 2010 for the purpose of identifying routes and sampling locations, and then specific coordinates for sampling points and zones are collected during the monitoring surveys.

Further detail regarding CWMP monitoring protocols are described in Appendix B and on the **sampling protocols page** of the program's website. A monitoring report and the raw monitoring data are delivered to USEPA (GLNPO) on a semi-annual basis (spring and fall) of each year, with the spring database deliverable incorporating the prior year's monitoring dataset, with primary QA/QC review completed. In addition, customized data deliverables are provided to external users based on an established data request and fulfillment protocol.

2.4.1.b H2Ohio Monitoring Program

The objective of the H2Ohio Wetland Monitoring Program is to evaluate the nutrient removal accomplished by wetland restoration and enhancement projects implemented by the Ohio Department of Natural Resources (ODNR) as part of the H2Ohio Initiative. The program is focused on assessing both the phosphorus (P) and nitrogen (N) removal capacity of coastal wetlands. A suite of H2Ohio wetland projects have been implemented and are currently in progress, including 26 projects under Phase I and 31 additional projects planned for Phase II. This monitoring program plan provides the scientific rationale and overall programmatic guidance to support site-specific wetland monitoring. However, because many wetland systems are characterized by complex hydrology and multiple inflow/outflow points, site-specific plans are being developed and tailored to local conditions to ensure that monitoring objectives are met. A small number (4-5) of "focal" projects are being monitored intensively, with less intensive monitoring being conducted for "non-focal" projects. Specific datasets that are collected by the H2Ohio Wetland Monitoring Program include:

- Physical Datasets: bathymetric and topographic surveys

- Hydrology/Hydrodynamics: Water levels and inflow/outflow at tributary and lake connection points and groundwater well monitoring (hydrodynamic models will be developed for focal wetlands)
- Soil Characteristics: nutrient content, texture, etc.
- Water Quality: surface water nutrient concentrations
- Process Data: water-sediment nutrient exchange rates and denitrification rates

2.4.1.c Canadian Lake Erie Coastal Baseline Habitat Survey

The 2020 Lake Erie Canadian Baseline Coastal Habitat Survey assessed key habitat types, biodiversity, and ecological conditions of coastal wetland habitats within Lake Erie and the Huron-Erie Connecting Waterways. This survey delineated coastal ecosystem types, assessed wetland and upland species richness and biodiversity, and examined the effectiveness of protection and restoration efforts.

The study indicates that the current wetland ecosystem contains 63 different wetland habitat types (unique marsh, shrub swamp, and swamp ecosites) and supports 344 species of conservation concern, including 126 species at risk. Wetlands in the survey area cover 29,944 hectares, with 75% being coastal wetlands and 25% being inland wetlands. Forty-three percent of coastal wetlands are lacustrine, 46% are riverine, and 11% are barrier-protected. *Phragmites* is estimated to negatively impact at least 25% of Ontario's species at risk.

2.4.1.d Canadian Great Lakes Nearshore Assessment and Related Datasets

As part of the Canadian Great Lakes Nearshore Assessment, ECCC and the Government of Ontario provides several online datasets related to coastal wetlands in the Great Lakes region. Relevant datasets include the **Aquatic Landscape Inventory System**, the **Great Lakes Shoreline Ecosystem Inventory**, and the **Aquatic Ecosystems Classification: Great Lakes Basin - Coast, Streams, Lakes and Wetlands**. These datasets provide geospatial information related to habitat type and land features along the shores of the Great Lakes, within Ontario's boundaries.

2.4.1.e Human Well-Being Survey for Puget Sound

While it is not a Great Lakes monitoring program, the human well-being survey described for Puget Sound is relevant to potential evaluations of human well-being in the Great Lakes basin. The study describes a human well-being survey introduced circa 2015 that is designed to capture data to inform 13 indicators of well-being (Puget Sound Partnership 2015). The study report notes that important aspects of the survey include sampling a large population and stratifying the results across key demographics, including urban and rural households, tribal and non-tribal households, and across countries/region. The content and logistical approaches used for this survey should be reviewed in detail if/when new studies of human well-being are designed and implemented for the Great Lakes region.

2.4.2 Modeling Efforts

Only two primary and two secondary studies that were reviewed explicitly discussed coastal wetland modeling efforts, although several resources indirectly discussed the benefits and needs for improved model capabilities. The IJC funded multi-year, multi-agency modeling efforts to assess the impact of water level regulation on coastal wetlands in the Great Lakes. The first study (IJC 2006) focused on Lake Ontario and the St. Lawrence River (LOSLR), investigating water regulations at the Moses Saunders dam in the St. Lawrence

River. This effort heavily relied on a coastal wetland model developed by Doug Wilcox (Wilcox and Xie 2007), which simulated up- and down-slope migration of plant communities in Lake Ontario coastal wetlands as water levels fluctuated and specifically estimated the annual area of meadow marsh communities in the lake. This model was used to assess the overall performance of candidate water level regulation regimes and helped guide the implementation of the flow release plan at the Moses Saunders dam. The model attempted to determine ideal water level fluctuations to promote meadow and emergent marsh plant communities. In addition to fluctuating water levels, the modeled wetland response was also a function of wetland site-specific bathymetry/topography and geomorphic type. Other status indicators were related to the response of the plant community distributions from the wetland model, such as migratory bird, fish, herptile and species-at-risk native to Great Lakes coastal wetlands. Subsequently, the IJC funded a follow up study of water levels in the upper Great Lakes (IUGLS), which was also heavily based on the Wilcox and Xie (2007) coastal wetland model. The IJC Great Lakes Adaptive Management Committee (GLAM) is currently updating the LOSLR ecological performance indicators as part of its expedited review of Plan 2014.

ECCC developed a Coastal Wetland Response Model (ECCC 2022c) for the Great Lakes, which simulated the response of coastal wetlands to a number of hydroclimate variables. The CWRM is a habitat response model that integrates hydroclimate variables that regulate the spatiotemporal distribution of wetland classes and their succession. It is used to create projections for the recent past and the future, and thus simulate the evolution of ecosystems in the event of continued greenhouse gas emissions. The CWRM predicts the distribution of broad wetland classes, and it can be used to develop specific measures dedicated to a given wetland class. The CWRM was used to simulate five key indicators of wetland health, at 20 wetland sites across the Great Lakes region and simulated both past and future climatic conditions. Those ecological attributes included:

- Total wetland area,
- Volume of the submerged and floating aquatic vegetation,
- Wetland interspersion,
- Wetland vegetation community diversity, and
- Meadow marsh area.

By integrating the five metrics into an overall wetland metric for sensitivity to climate change, the CWRM results were used to determine that 5 of the 20 wetland sites were critically-at-risk, 14 were at-risk, and only 1 was low risk. All three sites in the Huron-Erie Corridor were considered “critically at risk” in the upper-bound lake level simulation. Four of five Lake Erie sites were considered “at risk” in the upper-bound simulation, and Long Point was considered to be “critically at risk”.

Based on analysis from the CWRM, ECCC recommends several strategies to mitigate the vulnerability and sensitivity of coastal wetlands to climate change. These strategies are outlined in detail in the CWRM documentation and can be briefly summarized as follows:

- Strategy 1. Reduce Non-Climatic Stressors and Enhance Adaptive Capacity
- Strategy 2. Protect Littoral Cell Geodiversity and Restore Barrier Landforms
- Strategy 3. Maintain and Restore Biodiversity and Functional Redundancy
- Strategy 4. Enhance Wetland Capacity to Cope with Altered Hydrology

- Strategy 5. Identify, Manage, and Protect Climate Change Refugia
- Strategy 6. Improve Great Lakes Coastal Wetland Conservation and Protection

Tracking changes in Great Lakes coastal wetland vegetation, particularly the meadow marsh community, is critical to validate existing GLCW vegetation models and to assess how changes in water level regulation plans may be impacting vegetation response. Remote sensing techniques, which are based on statistical interpretation of imagery data, provide essential tools for estimating overall wetland area and vegetation community extent. However, developing accurate estimates of wetland extent is challenging, and ongoing refinement of the methods is needed (Ryerson 2018).

Other potentially important modeling studies point to knowledge gaps in the current understanding of coastal wetland dynamics. For example, Xu et al. (2021) discussed the role of groundwater in supplying water and nutrients to coastal waters in the Great Lakes and acknowledge that this is currently not well quantified and may be significant.

2.4.3 Decision Support Tools

Several decision support tools have been developed to synthesize data and information for the purpose of supporting the assessment and prioritization of Great Lakes coastal wetlands for restoration and protection efforts. Examples of CW decision support tools include, but are not limited to:

- The **Great Lakes Coastal Wetland Restoration Assessment** (GLCWRA) provides a planning and assessment tool to identify historic coastal wetland areas that should receive priority for restoration/reconnection efforts.
- The **Coastal Wetland Decision Support Tool** (CWDST) serves as a complementary tool to the GLCWRA and allows user to rank the prioritization of coastal wetland sites for restoration based CWMP monitoring data, indicator scores (e.g., for fish), and landscape context attributes.
- The Upper Mississippi River & Great Lakes Joint Venture (JV) (2018) developed a decision support tool that generated maps for prioritizing landscapes for waterfowl and waterbird restoration. GIS datasets for **waterfowl** and **waterbirds** include: breeding and non-breeding water bird/fowl distribution, conservation opportunities, decision support models (biological, social, mixed), and occurrence and predicted breeding habitat for key species.

2.5 Knowledge and Data Gaps

This section briefly identifies and summarizes knowledge and data gaps based on the project team's review and assessment of the resources reviewed for the synthesis effort. This discussion is intended to provide a preliminary, high-level assessment, and it is not intended to be comprehensive or to provide any specific recommendations.

2.5.1 Significance of carbon sequestration

Coastal wetlands are often associated with the capability to capture carbon dioxide from the atmosphere through plant uptake and storage into biomass and sediments. However, only one reference study explicitly discussed this mechanism (Sierszen et al. 2012), and this publication acknowledged that the magnitude of this ecological benefit is not well quantified and may not be as significant as expected. If carbon sequestration is envisioned as a potentially important ecosystem service of coastal wetlands, further study will be needed to quantify its significance.

The Province of Ontario has recently taken steps toward addressing the carbon sequestration data gap via a collaborative research agreement with the University of Toronto aimed at improving foundational data and spatial information of carbon dynamics in southern Ontario wetlands. The goal of this effort is to support provincial climate mitigation goals by improving inventorying and characterization of diverse wetland types, and by refining the understanding and modeling of wetland carbon.

2.5.2 Role of groundwater

An analysis by Xu et al. (2021) coupled surface water and ground water models to investigate the role that ground water can play in the overall water budget of the Great Lakes. This study found that groundwater intrusion into the lakes coastal region varies spatially and temporally across the Great Lakes basin, but this source may represent approximately 1% of the water budget for the Great Lakes. This analysis did not provide a quantification of nutrients associated with groundwater, but it indicated that this may be an important nutrient source that is not well understood. Quantifying the role of groundwater in the overall hydrologic and nutrient budget of a particular wetland site is likely to be extremely challenging given the complex dynamics of wetland hydrology and the variability reported in this publication.

2.5.3 Status of Connection to the Great Lakes

Physical and hydrological processes that occur along the Great Lakes shoreline are highly complex. While some coastal wetlands are located immediately adjacent to a lake, others are located upstream along tributary water bodies or adjacent water bodies at varying distances from the lake. Furthermore, even wetlands located adjacent to a lake may be temporarily or semi-permanently isolated from the lake due to longshore sediment dynamics that reconfigure or block previous points of connection. Therefore, the "connectedness" of a wetland can be a challenging evaluation, as the degree of connection may depend on nearshore transport processes and seasonal or inter-annual fluctuations in water levels, seiches, wave action, and other factors. The protocols for the CWMP program restrict monitoring to only "connected" wetlands and a rough accounting of connection status is maintained by the program. However, the degree of connection to the lake must sometimes be reassessed during the actual monitoring surveys - e.g., if a wetland is found to be 'perched' or otherwise cut off from the lake. The topic of connectivity will require continued discussion as consideration is given to how to integrate the temporally-varying geospatial data generated by Objective One into the overall GLCW Conservation Framework.

2.5.4 Limitations of Ecological Monitoring, Modeling, and Indicators

Sections 2.4.1 and 2.4.2 discussed specific monitoring and modeling efforts, respectively, that have been developed to evaluate coastal wetland processes and condition in Lake Erie (and other Great Lakes). While these efforts have collectively generated a large quantity of information on coastal wetlands, it is important to recognize that the spatial and temporal scope of each of the efforts are necessarily limited by their specific purpose (scope) and available resources. Some examples of limitations are briefly discussed below.

- The CWMP monitors approximately 100 wetlands in Lake Erie on a 5-year program cycle. However, the monitoring effort only includes sites that had an extent larger than 4 hectares (~10 acres) circa 2010 and that are "connected" to the lake (e.g., diked wetlands are not monitored). Recent high water levels have likely increased the extent of many of these wetlands and may also have affected connectivity to the lake. Also, while the intent of the program is to monitor the selected sites at least once every five years, limitations imposed by site access restrictions or high water levels can prevent sampling of some sites and affect monitoring frequency.

- The macroinvertebrate and fish indicators (IBIs) developed based on the CWMP datasets are based on scoring of specific vegetation/habitat zones that the indicator was developed based on. Therefore, the indicators cannot be calculated for sites where the vegetation zones in a particular year do not overlap with the protocols of the algorithms. The fish IBI is based on Bulrush, *Typha*, Lily, and SAV zones, while the macroinvertebrate IBI is based on 'Sparse Bulrush', 'Dense Bulrush', and 'Wet Meadow' zones.
- The CWRM (ECCC 2022c), which was calibrated and applied under the ECCC project to evaluate coastal wetland resilience to climate change, provides a robust simulation model of site-specific coastal wetland response. However, because there are intense data and resource requirements for applying the model, to date the CWRM has only been applied to five Canadian sites in Lake Erie, and 20 sites overall for the Great Lakes.
- The H2Ohio Monitoring Program is collecting some highly valuable datasets for coastal wetlands in Lake Erie. However, only 4-5 "focal" sites are being intensively monitored to evaluate nutrient dynamics and mass budgets.
- Existing coastal decision support tools typically address only sub-regions of specific interest or wetland sites for which monitoring data have been collected for. Extrapolation of the results provided in these tools and in the supporting datasets may be needed to cover unmonitored areas.

Finally, it should be noted that this synthesis and many of the supporting resources reviewed for this effort are primarily focused on Lake Erie coastal wetlands. Lake Erie has received considerable attention and funding that have driven a large variety of studies, both for coastal wetlands and the broader lake, but some of the other Great Lakes will have a lower level of study coverage. Fortunately, several of the monitoring, modeling, and assessment efforts (e.g., SOGL, CWMP, CWRM applications) have been designed to assess the broader Great Lakes basin and can potentially be used to support the GLCW Framework as the effort expands to the other Great Lakes. In addition, some of the existing efforts reviewed for this effort are currently expanding to other Great Lakes or have plans to do so (e.g., the Canadian Baseline Habitat Survey).

2.5.5 Limitations of Human Well-Being Monitoring and Indicators

As discussed in Section 2.1 (Ecosystem Services), coastal wetlands support a variety of human well-being needs. The suite of ecological services and functions described in Section 2.1.1 provides the connection from the physical, chemical, and biological conditions in GLCWs to human well-being. Although limitations and uncertainties remain, significant progress has been made in monitoring and developing indicators to quantify ecological services and functions, as discussed above. However, monitoring and indicator development specifically related to human well-being needs has been generally lacking for coastal wetlands, Lake Erie, and the Great Lakes as whole. The evidence for this includes the general lack of Great Lakes specific human well-being literature and studies, and the need for reviewing resources from outside the Great Lakes basin to support this synthesis effort.

The existing measures of human well-being tied to Great Lakes ecosystem services are limited and appear to be focused on *objective* indicators of well-being, including statistics related to the economy, tourism, and other data-based factors. Existing studies (e.g., Puget Sound Partnership 2015) note the importance of also quantifying *subjective* indicators of well-being based on the analysis of data collected via carefully planned and executed public opinion surveys (i.e., for the affected communities). For example, a "sense of place" index would need to be based on a survey of individuals in Lake Erie communities along the U.S. and Ontario shorelines. Additional studies and supporting funding will be required to close the gap in human well-being monitoring and indicators, including collecting data for both objective and subjective indicators. The designed survey(s) should be conducted at a regular interval (e.g., every 2-3 years) so that time trends can be evaluated for the indicators and progress towards desired statutes can be tracked. Refinements to the survey(s) will likely be needed over time to improve the capability of the instruments to capture the desired data regarding human well-being.

One ongoing challenge related to current and future work on human well-being is the specific role of coastal wetlands as a driver in fulfilling well-being needs and the ability to measure the impact. Because GLCWs are tightly integrated into the broader environment of Lake Erie (and each Great Lake), it will likely be difficult to isolate the role of wetlands in affecting change in indicators related to revenue, jobs, or subjective indices. For example, improvements in reducing harmful algal blooms in Lake Erie could drive gains in human well-being even if no enhancements are made to coastal wetlands in the lake. This challenge should be kept in mind when designing and implementing future studies and survey instruments related to human well-being.

2.6 Summary of Key Framework Considerations

The development of the GLCW Framework will expand the existing knowledge base that is summarized in this report as well as other ongoing studies and the Steering Team's expertise. Some important aspects of the Framework's developmental timeline include:

- "Objective One" of the overall GLCW Framework project is scheduled to provide draft and final geospatial products for Lake Erie coastal wetland coverage in July 2023 and December 2023, respectively. These datasets will update the current state and trends in coastal wetland extent.
- The Saginaw Bay to Western Lake Erie Coastal Wetland Blueprint project is being conducted in parallel with the GLCW Framework pilot project for Lake Erie.
- While Lake Erie and Lake Erie-Huron Corridor is intended to serve as a pilot region for the Framework, many of the ongoing monitoring and modeling efforts are focused on other regions of the Great Lakes Basin. These datasets can potentially be incorporated into the Framework as it expands.
- The Framework will collaboratively develop priority ecosystem services (including ecological services/functions and human well-being needs), indicators, desired status, and detailed information on wetland extent as the project progresses.

3 ASSESSMENT OF CURRENT CONDITIONS AND TRENDS

The purpose of this section is to build on the synthesis and findings from Section 2 by summarizing the current conditions and trends for coastal wetland systems in Lake Erie. Section 3.1 summarizes the overall current condition and trend of Lake Erie, with a focus on indicators of coastal wetland health and integration of relevant information for the broader nearshore and offshore areas of Lake Erie. Section 3.2 discusses how well Lake Erie wetlands currently support ecosystem services that were identified in Section 2.1 and related trends. Section 3.3 summarizes the key threats and stressors affecting Lake Erie coastal wetlands at present and anticipated trends in which stressors are likely to become more or less important in the future. Section 3.4 provides some focused discussion on current assessments and future projections of GLCW resilience to climate change. Finally, Section 3.5 provides an overview of progress and expanding plans for Lake Erie restoration initiatives.

3.1 Lake Erie Current Conditions and Trends

One of the most recent and comprehensive assessments of overall conditions and trends in Lake Erie, as well as the other Great Lakes, is provided in the State of the Great Lakes 2022 Report (USEPA and ECCC 2022a, 2022b). The overall status of each Great Lake, as well as all indicators and sub-indicators, is rated as “Poor”, “Fair”, or “Good”. Overall trends and trends in indicators are characterized as either “Improving”, “Unchanging”, or “Deteriorating”. The SOGL 2022 Report assesses the overall condition of Lake Erie as “Poor” with a trend of “Unchanging”. Elevated nutrient concentrations and harmful algal blooms (HABs) are noted as persistent problems in the lake, but a key positive for the lake is the strong and improving productivity of the Walleye fishery.

3.1.1 Coastal Wetland Conditions

One of the key questions that the SOGL Report addresses is: “*are the lakes supporting healthy wetlands and populations of native species?”* Per the SOGL report and various other resources, coastal wetlands in the Great Lakes and Lake Erie specifically are currently facing various challenges due to human activities and environmental stressors. Over half of all historic Great Lakes coastal wetlands have been lost or changed by human activities, and many remaining coastal wetlands suffer from anthropogenic stressors such as nutrient and sediment loading, fragmentation, invasive species, shoreline alteration, and water-level control.

As discussed in Section 2.2, the SOGL 2022 Report provides a suite of six sub-indicators related to coastal wetland condition under its top-level “Habitat and Species” indicator (Table 6). Overall, the “Habitat and Species” indicator is assessed across the Great Lakes as in “Fair” condition, with the trend classified as “Unchanging”. The current status and the 10-year trend (or rough equivalent) are also assessed for each individual sub-indicator. As shown in Table 6, the statuses of amphibians, birds, and aquatic habitat connectivity are rated as “Fair”, while fish and plants are rated as “Poor”. It is noteworthy that Lake Erie is the only Great Lake where the condition of fish is rated as “Poor”.

The trends for amphibians, birds, and plants are assessed as “Unchanging”, while fish and invertebrate trends are “Undetermined”. The trend for the aquatic habitat connectivity is classified as “Improving”. Only roughly

33% of tributaries that were historically connected to Lake Erie are connected at the present time, but restoration actions are underway for reestablishing watershed-to-lake connections for additional tributaries.

Table 6. Status and Trends for "Coastal Wetland and Aquatic Habitat Connectivity" Sub-indicators.

Sub-Indicator	Status	Trend (10-year period)
Coastal Wetland Invertebrates	Undetermined	Undetermined
Coastal Wetland Fish	Poor	Undetermined
Coastal Wetland Amphibians	Fair	Unchanging
Coastal Wetland Birds	Fair	Unchanging
Coastal Wetland Plants	Poor	Unchanging
Aquatic Habitat Connectivity	Fair	Improving

Various other resources also describe and quantify contemporary conditions in Lake Erie coastal wetlands. While the findings are generally similar to those documented in the SOGL 2022 Report, the approaches and assessment outcome do differ somewhat. For example, the Lake Erie Quality Index 2022 Report provides an assessment of coastal wetlands in Ohio's Lake Erie watershed. The overall trend in coastal wetland health is mixed, with small high-quality wetlands decreasing in quality and large low-quality wetlands improving in quality. The overall metric for coastal wetlands is rated as "Fair".

3.1.2 Lake-Scale Conditions

In addition to assessing coastal wetlands, the SOGL 2022 Report provides sub-indicators to assess broader-scale conditions in the nearshore and offshore of Lake Erie. These sub-indicators fall under the "Aquatic Food Web" category of the "Habitat and Species" indicator, the "Nutrients and Algae" indicator, and the "Invasive Species" indicator. Table 7 provides a matrix summarizing the statuses and trends assigned for the Lake Erie sub-indicators that fall under those categories.

Table 7. SOGL Status and Trends for Lake Erie Aquatic Food Web, Nutrients, Algae, and Invasive Species Sub-indicators

Current Status	Trend (e.g., over 10-year period)			
	Improving	**Unchanging**	**Deteriorating**	**Undetermined**
Good	Walleye, Sea lamprey	--	--	--
Fair	Lake Trout	Zooplankton, Dreissenids	Native prey fish diversity	Rate of new invasive species
Poor	HABS, Lake sturgeon	Phytoplankton, Benthos	Nutrients, *Cladophora*	Harmful algal blooms

As discussed in the SOGL 2022 Report and many other resources, Lake Erie faces persistent problems with elevated nutrient concentrations and harmful algal blooms, especially in its western and central basins. These issues are influenced by factors such as agricultural and urban runoff, invasive species, and climate change. The high nutrient levels contribute to the growth of harmful algal blooms and hypoxia, which negatively impact water quality, aquatic life, and human health. Likewise, nuisance *Cladophora* growth continues to be a significant issue in some areas of the Eastern Basin of Lake Erie, with growth of that benthic alga likely promoted by a combination of excessive nutrient concentrations and increased light penetration resulting from water column filtering by dreissenid mussels. Efforts to reduce nutrient inputs and improve water quality in Lake Erie are ongoing, but the current statuses for both nutrients and HABs indicate that much more work is needed to address the nutrient-related challenges in the lake.

Other resources also provide similar lake- and basin-scale condition assessments for Lake Erie, including the Lake Erie LAMP. The *Western Lake Erie Report Card* developed by the University of Maryland provides an overall grade of "C" for the watershed and "C+" for the lake (Western Basin only). While wetlands were not a focus of that report, it did contain the following statement: "*Its wetland systems [Sandusky Bay] support a productive fishery, and the bay provides opportunities for recreation and tourism.*"

3.2 Ecosystem Services

The overall "Poor" to "Fair" condition of Lake Erie coastal wetland indicators and the lack of significant improvement suggests that existing wetlands have been significantly impacted and degraded relative to their natural (reference) state. This assessment only reflects present-day wetlands and does not consider the substantial loss of coastal wetlands from the Lake Erie ecosystem due to logging and draining activities prior to the 1900s that converted historic wetlands for agricultural, industrial and residential purposes. For Western Lake Erie, which previously included the "Great Black Swamp", it is estimated that roughly only 5% of the original historical extent of 400,000 ha of wetlands still exists today (Mitsch 2017).

The diminished and degraded status documented for Lake Erie wetlands suggests that the capabilities of these wetlands to meet ecological services/functions and human well-being needs are significantly reduced relative to their original state. Examples of how ecological services/functions and human well-being needs are impacted by the loss and degradation of LE coastal wetlands are outlined below:

- <u>Water Quality Improvement / Nutrient Reduction</u>: As discussed in Section 2.1, an important function of well-functioning coastal wetlands is to filter nutrients and sediments originating from the watershed landscape to reduce delivery to the lake. The loss and degradation of coastal wetlands has undoubtedly significantly reduced the overall filtering capacity for Lake Erie. The lack of filtering in the nearshore combined with high nutrients loadings from the predominantly agricultural watershed result in significant winter/spring nutrient loadings to the lake, and especially the Western Basin, in many years.
- <u>Habitat & Coastal Protection</u>: The substantial loss of historic wetland area and the diking of remaining wetlands has negatively impacted habitat availability for fish and wildlife and has also reduced the level of protection wetlands provide to the impact of storm events, etc. The impact of degraded habitat is reflected in the various indicator scores for Lake Erie, based on CWMP monitoring data and documented in the SOGL 2022 Report.
- <u>Recreational Opportunities and Tourism</u>: Harmful agal blooms and nuisance *Cladophora* growth in nearshore areas limit access to, and interest in, recreational opportunities and tourism along the

Lake Erie shoreline. This impact likely varies year-to-year depending on the severity of eutrophication responses to changing phosphorus loading and climate conditions.

- Commercial Fisheries: For Lake Erie, the status of Walleye, a highly-valued species in commercial fisheries, is assessed as "Good", with a 10-Year Trend of Improving (Table 7). In the last 10 years, the estimated Walleye abundance in Lake Erie has nearly tripled from 33.5 million fish in 2011 to 95.5 million fish in 2020. Despite the success of Walleye production, the degraded condition of Lake Erie water quality conditions, including the proliferation of HABs and hypoxia events in the Central Basin, certainly has the potential to impact both commercial and recreational fishing. As discussed above, the degradation of coastal wetland directly affects species that rely on wetlands for parts of their life cycle.

3.3 Threats and Stressors

The threats and stressors impacting coastal wetlands in Lake Erie and the Great Lakes at large are discussed in many of the resources reviewed for this effort. Specific threats and stressors for Lake Erie coastal wetlands and the broader lake environment include:

- Shoreline development and alterations: Shoreline development disrupts physical processes such as littoral flow and sediment transport, which can degrade coastal wetlands and nearshore habitats. Shoreline armoring and lakebed modifications can also make it easier for invasive species to replace native species.
- Degraded river mouth deltas: River mouth deltas are important habitats for various species, but human activities like dredging, construction of jetties and marinas, and shipping infrastructure have led to their destruction or degradation.
- Invasive species: Invasive species like Zebra and Quagga Mussels, Sea Lamprey, Round Goby, and Common Reed can decrease native biodiversity by outcompeting native species and altering physical and chemical habitat parameters.
- Habitat fragmentation due to dams and barriers: Dams and barriers in tributaries can disconnect habitats, limiting access to spawning grounds and reducing genetic exchange among migratory fish populations. The SOGL 2022 Report notes that only approximately 33% of tributaries to Lake Erie are fully connected to the lake, although there is a trend of restoring connections.
- Non-point source pollution: Pollution from sources like agricultural runoff, urban stormwater, and residential activities can degrade water quality and negatively impact coastal wetland habitats, as well as the broader lake environment. Non-point source pollution in Lake Erie results in nutrient enrichment and sedimentation, which can impact wetlands and is also recognized as a significant driver of nearshore HABs in the Western Basin.
- Watershed Hydrologic Alterations: Development activities, including urbanization of land and stream channel alterations (e.g., via channelization and infrastructure additions), in the upstream watershed can significantly increase the flashiness of streams, disrupting the natural hydrologic response and increasing the hydraulic, sediment, and nutrient loading to coastal wetlands.

- <u>Climate change</u>: Extreme fluctuations in water levels (or compression of the interannual water level range) and other climate change-related impacts can influence the extent and composition of coastal wetlands, further stressing these ecosystems.

While it is easiest to consider these stressors individually (as done above), the reality is that Lake Erie coastal wetlands, as well as adjacent nearshore and offshore environments, are often subjected to the *combined* impact of multiple stressors acting in concert. As discussed in several of the resources, the impact of multiple stressors may potentially be additive or even multiplicative depending on the circumstances. The prevalence of these stressors in the Lake Erie ecosystem underscore the need for cost-effective strategies to promote the restoration and protection of existing wetlands and to consider restoration of historic wetland areas where opportunities exist.

3.4 Resiliency to Climate Change

ECCC developed a comprehensive assessment of the sensitivity, adaptive capacity, and overall vulnerability of 20 Canadian Great Lakes coastal wetlands, with respect to climate change (ECCC 2022a-e). This study frames the resilience of coastal wetlands as a function of climate exposure, sensitivity to climate change, adaptive capacity, and vulnerability. The study examined overall vulnerability as determined by exposure to lake level changes, wetland sensitivity, and wetland adaptive capacity. The assessment used eight variables to evaluate the adaptive capacity of coastal wetlands: natural land cover surrounding the wetland, vegetation biodiversity, invasive *Phragmites* within the wetland, invasive *Phragmites* surrounding the wetland, capacity to migrate lakeward (downslope migration potential), capacity to migrate landward (upslope migration potential), level of protection (within the wetland), and level of protection (surrounding the wetland). These variables were grouped into four sub-indicator categories:

- Landscape Condition
- Biological Condition
- Migration Potential
- Protection (level of designated federal or local protection).

A composite indicator was used to aggregate these variables and sub-indicators to provide a qualitative assessment of the adaptive capacity of the selected coastal wetlands. Overall, 20 sites were assessed under the study, including five sites in Lake Erie: Fox / Dolson's Creek, Grand River mouth, Long Point, Rondeau Bay, and Selkirk Provincial Park.

The *Landscape Condition* sub-indicator results showed that coastal wetlands along the shores of Lake Huron and the St. Lawrence River had higher relative scores compared to wetlands along the Huron-Erie Corridor, Lake Erie, and Lake Ontario. The lowest-scoring site was the Lake St. Clair Marshes (13LSC) on the eastern shoreline of Lake St. Clair.

The *Biological Condition* sub-indicator was composed of invasive *Phragmites* within and surrounding the wetlands, as well as vegetation species richness. With respect to Lake Erie, the results showed that the lowest-scoring site was Johnston Bay Wetland (12SAM) at the mouth of the St. Clair River (Huron-Erie Corridor). All seven of the wetland sites found on Lake Huron, along with two sites from Lake Ontario (2ACM 47 and 1HIE), and one site from Lake Erie (8SPP) scored within the top 50% of sites. Three of the four lowest-scoring sites were concentrated along the Huron-Erie Corridor.

The *Migration Potential* sub-indicator was composed of upslope and downslope migration potential. Of note for Lake Erie was that the highest Wetland Migration Capacity Score was estimated for Johnston Bay (12SAM) at the mouth of the St. Clair River (Huron-Erie Corridor). Wetlands along Lake Erie and the Huron-Erie Corridor had the highest Migration Potential due to their shallow bathymetry and fine-grained sediments. In contrast, wetlands along Lake Huron and the St. Lawrence River received poor Migration Potential scores, often due to being in protected embayments, having bedrock, or having till-derived sediments, which would impact their ability to migrate. With respect to Lake Erie, Rondeau Bay (10 RBY) received the highest relative protection score of all wetlands assessed.

The overall adaptive capacity scores from this study found that six of the 20 wetland sites had high, eight had moderate and six had low adaptive capacity. The majority of the low adaptive capacity sites were in Lake Erie and the Huron-Erie Corridor.

Combining the adaptive capacity with vulnerability and climate sensitivity under this study provided an assessment of overall resilience to climate change. Figure 1 (adopted from Figure 21 in ECCC 2022b) demonstrates that the most vulnerable wetlands generally coincide with the lowest adaptive capacity scores, indicating limited resiliency. Orange and red colors in the figure show the most vulnerable and least resilient coastal wetland sites. The ECCC climate resilience study highlights the importance of evaluating not only the current condition of a wetland but also the characteristics of a wetland site and its surrounding landscape that will aid or limit the resilience of the wetland to climate change and related stressors.

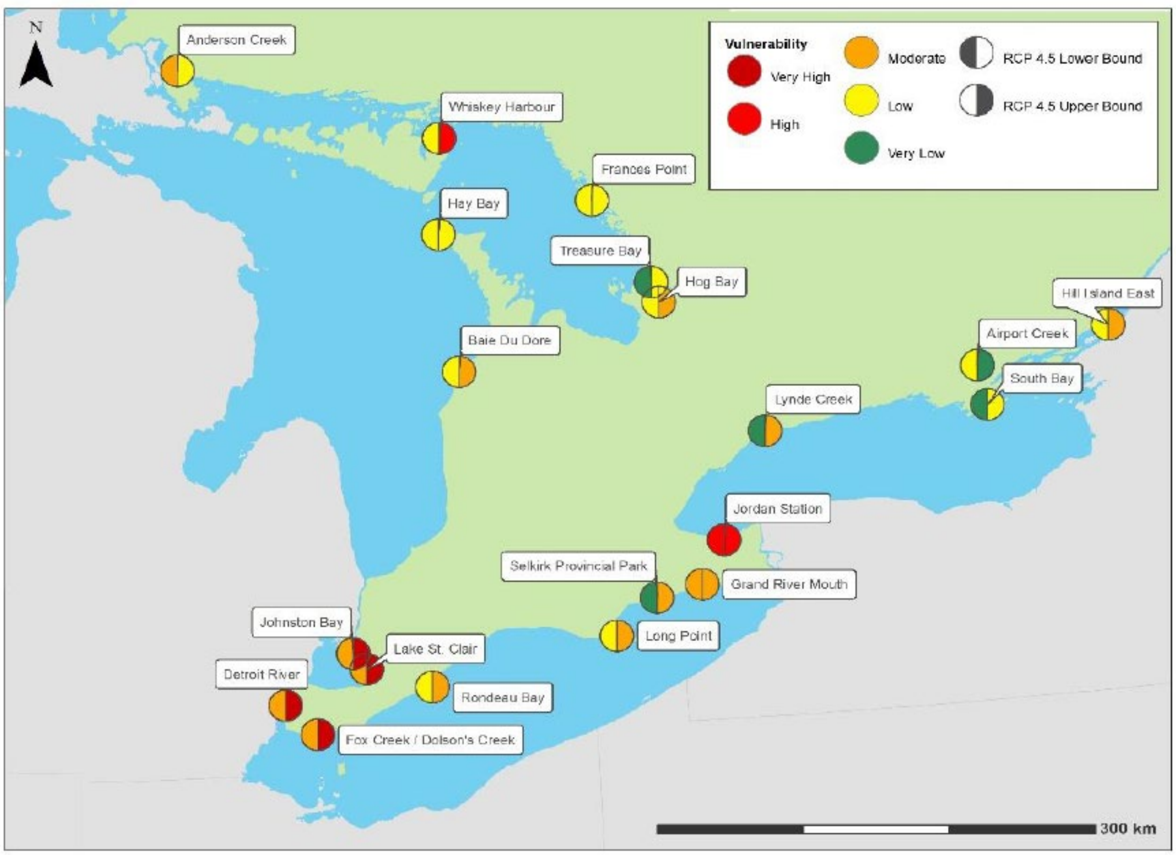

Figure 1. Vulnerability categorizations for all coastal wetlands assessed. The left- and right-hand sides of each point represent vulnerability categorizations for the RCP 4.5 lower-bound and upper-bound cases, respectively.

3.5 Restoration and Protection Initiatives

Studies related to coastal wetlands in Lake Erie universally recommend ongoing and expanding restoration and protection efforts to maintain and enhance existing coastal wetland areas throughout the lake. The advent of the GLRI and the associated Action Plans circa 2010 spurred a significant expansion of restoration and protection efforts in Lake Erie and the other Great Lakes; however, recent studies agree that there is much work left to accomplish by federal and state agencies and non-governmental organizations. Some key studies and documents that address specific restoration progress, planning efforts, and objectives include:

- Lake Erie LAMP (USEPA and ECCC 2022c)
- Lake Erie Protection & Restoration Plan – 2023 Draft (Ohio LEC 2023)
- Great Lakes Fishery Commission (GLFC) Lake Erie Technical Committee (LETC) and Task Group documents (e.g., GLFC-LETC 2023)
- Ohio Statewide Action Plan (SWAP) (Ohio Division of Wildlife 2015)
- Michigan State Wildlife Action Plan (Derosier et al. 2015)
- Upper Mississippi & Great Lakes JV (2018)

Examples of continuing or planned restoration and protection initiatives for Lake Erie coastal wetlands include, but are not limited to:

- Sandusky Bay Initiative, which is being led by the Ohio Department of Natural Resources (ODNR), is addressing various projects to restore wetlands and aquatic ecosystems in the Sandusky Bay region. This effort includes reuse of dredged sediments to create new wetland areas to expand fish habitat, retain nutrients, and improve water clarity.
- The *Lake Erie Protection & Restoration Plan (2023 Draft)* developed by the Ohio LEC identifies 2023 restoration priorities that map on to the Focus Areas established by the GLRI Action Plan III (and prior action plans). The Plan cites the following progress: 1) 140 projects and ~15,000 acres of coastal wetland restoration completed under the H2Ohio Initiative to reduce nutrient delivery to Lake Erie; 2) increases in bald eagle, piping plover, trumpeter swan, and other key species populations; and 3) increased state and federal funding directed towards habitat restoration and protection. Goals for 2023-25 include the restoration of up to an additional 500 acres of CW, increased nature-based solutions (in place of "hard" infrastructure), and identifying critical habitats through mapping and monitoring.
- The **St. Clair – Detroit River System (SCDRS) Initiative** seeks to enhance and expand fish habitat in the Huron-Erie Corridor through the construction of artificial reefs.
- Restoration/enhancement 110 acres of coastal wetland within the Western Lake Erie/Lake St. Clair Focus Area (Great Lakes Coastal Program 5-year Target).
- The Ohio SWAP outlines specific conservation opportunity areas for wetlands, such as the Lake Erie Marsh Conservation Opportunity Area.
- The 2023 GLFC LETF habitat report (2023) highlights the Ontario – Rondeau Bay- McLean coastal wetland restoration project, as well as various other restoration projects aimed at maintaining and enhancing populations of priority fish species.

- The Upper Mississippi River & Great Lakes JV identifies wetland restoration and retention objectives for growing and sustaining waterfowl and waterbirds. The JV plans include specific acreage targets for restoration of emergent, aquatic bed, and unconsolidated (open water and shore) habitats by state. The JV's efforts have included the development of a decision support tool that generated maps for prioritizing landscapes for waterfowl and waterbird restoration.
- The USACE's Engineering with Nature (EWN) Initiative is encouraging more sustainable delivery of economic, social, and environmental benefits associated with water resources infrastructure through innovation.

Assessing progress towards restoration and protection objectives requires that activities and affected coastal wetland areas be consistently tracked and reported. Restoration planning, tracking, and reporting efforts for Lake Erie wetlands are being supported by the following programs and decision support tools:

- The **Great Lakes Coastal Wetland Restoration Assessment** (GLCWRA) provides a planning and assessment tool to identify historic coastal wetland areas that should receive priority for restoration/reconnection efforts.
- The CWMP conducts "benchmark" (supplemental) monitoring to characterize pre- and post-restoration condition of wetland sites.
- The **Blue Accounting coastal wetland acreage page** tracks and reports progress of coastal wetland restoration and protection for Lake Erie and the rest of the Great Lakes basin by identifying project locations and associated acreage and aggregating acreage by district, state, and lake levels.
- The **Coastal Wetland Decision Support Tool** (CWDST) serves as a complementary tool to the GLCWRA and allows user to rank the prioritization of coastal wetland sites for restoration based CWMP monitoring data, indicator scores (e.g., for fish), and landscape context attributes.

It is anticipated that the GLWC Framework being developed under the current project will build on and extend beyond the existing decision support tools by incorporating collaboratively developed priority ecosystem services, indicators, desired status, and detailed information on wetland extent for each year within the 2010-2020 timeframe.

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APPENDIX A
Measles Chart Summaries of Relevant Studies

Appendix A provides a series of “measles” charts that were developed to identify the links between the resources reviewed for relevant past/current studies and key components envisioned for the Great Lakes Coastal Wetland Framework. This appendix is provided as a Microsoft Excel spreadsheet which is organized into the following tables (as separate sheet tabs):

- Figure A.1: Measles Chart for High-Level Topics Addressed in the Synthesis and Summary of Current Conditions / Trends
- Figure A.2: Measles Chart for Specific Ecological Services/Functions and Human Well-Being Needs
- Figure A.3: Measles Chart for Specific Indicators
- Figure A.4: Measles Chart for Specific Stressors and Threats

The measles charts are intended to capture which resources have an explicit focus and expanded discussion on specific topics.

APPENDIX B
Capsule Summaries of Relevant Studies

This appendix provides capsule summaries of the key resources that were reviewed and integrated into the synthesis (Section 2) and the summary of current conditions and trends (Section 3) included in this report. Most resources are addressed in individual sub-sections below, although some secondary resources are addressed in aggregate under the "Supplemental Resources" sub-section (B.21).

B.1 Great Lakes Water Quality Agreement (2012) and the Canada-Ontario Agreement on Great Lakes Water Quality and Ecosystem Health (2021)

The *Great Lakes Water Quality Agreement* (GLWQA) is a foundational binational agreement that acknowledges:

> *"the vital importance of the Great Lakes to the social and economic well-being of both countries, the close connection between quality of the Waters of the Great Lakes and the environment and human health, as well as the need to address the risks to human health posed by environmental degradation*" (USEPA and ECCC 2012)

Article 3 of the GLWQA outlines general and specific objectives of the agreement. General objectives include (but are not limited to) ensuring the Waters of the Great Lakes provide high-quality drinking water, allow for recreational use, allow for (unrestricted) human consumption of fish and wildlife, be free from pollutants, support healthy and productive wetlands and other habitats to "sustain resilient populations of native species", and be free from the introduction and spread of aquatic (and also terrestrial) invasive species. GLRI Action Plan III and many other Great Lakes initiatives are specifically designed to address the objectives outlined in the GLWQA.

The *Canada-Ontario Agreement on Great Lakes Water Quality and Ecosystem Health* (ECCC 2021) documents Canada's approach to address its obligations under the GLWQA. Annex 8 (Habitat and Species) of this agreement including the following steps related to coastal wetlands:

- Complete a science-based assessment of coastal wetland vulnerability to climate-related impacts.
- Identify adaptive measures and develop guidance to enhance wetland resilience.
- Undertake and support studies that investigate the functions and ecosystem services of wetlands including hydrology, water quality and quantity, phosphorus reduction capabilities, carbon sequestration, and fish and wildlife habitat.
- Build consensus and promote implementation of actions with the Great Lakes community on priorities and strategies for enhancing coastal wetlands resilience.

B.2 Great Lakes Restoration Initiative - Action Plan III

The Great Lakes Restoration Initiative (GLRI) is a non-regulatory program that was initiated in 2010 to expand and accelerate efforts to protect and restore the Great Lakes, which represents the largest system of surface freshwater in the world. GLRI seeks to accomplish this goal by providing resources to enhance progress towards achieving critical long-term goals through the Great Lakes basin. The GLRI Action Plan III (USEPA et al. 2019) outlines the current phase of work to address Great Lakes environmental issues, which seeks to continue moving the Great Lakes ecosystem closer to the long-term goals outlined in the 2012 Great Lakes Water Quality Agreement (GLWQA) (USEPA and ECCC 2012). Similar to previous versions of the action plan, Action Plan III outlines the following five Focus Areas, along with associated objectives and measures of progress:

1. Toxic Substances and Areas of Concern
2. Invasive Species
3. Nonpoint Source Pollution Impacts on Nearshore Health
4. Habitats and Species
5. Foundations for Future Restoration Actions

Of these focus areas, "Habitat and Species" (Focus Area 4) is the most strongly connected to coastal wetland restoration and protection efforts, with "Invasive Species" (Focus Area 2) also being highly relevant. In addition, Focus Areas 1 (toxic substances) and 3 (nonpoint source pollution) address specific stressors that may affect coastal wetland and broader nearshore habitat conditions, as well as species populations.

The "Habitat and Species" (Focus Area 4) discussion in the Action Plan describes some specific accomplishments realized during the Fiscal Year (FY) 2015 through FY 2018 timeframe, including piping plover and lake sturgeon population recoveries and the restoration/protection of more than 52,000 acres of coastal wetlands. The specific GLRI goals outlined for habitat and species during the FY 2020 – FY 2024 timeframe include: restoration of river wetlands where barriers have been removed, reconnection of aquatic/terrestrial habitat, coordination on invasive species control, reduction of human impacts, and maximizing habitat improvements for key breeding marsh bird species (e.g., bitterns, terns, grebes). Specific quantitative measures of progress and targets are summarized in Table B.1 below.

Table B.1. Quantitative Measures of Progress and Targets for "Habitats and Species" (Focus Area 4).[1]

Measure of Progress	Baseline	Universe	Targets for FY 2020 – FY 2024
4.1.1. Acres of coastal wetland, nearshore, and other habitats restore, protected, or enhanced	370,488 acres	1,550,000 acres	394,000 – 442,000 acres
4.1.2. Miles of connectivity established for aquatic species	5,289 miles	n/a	5,700 – 6,500 miles

[1] Information adapted from Focus Area 4 table in GLRI Action Plan III

B.3 State of the Great Lakes 2022 Report

The State of the Great Lakes (SOGL) is a binational report, including summary and technical volumes, that is collaboratively developed by the USEPA and Environment and Climate Change Canada (ECCC) every two years, with the 2022 edition representing the most recent version (USEPA and ECCC 2022a, 2022b;

https://stateofgreatlakes.net/). The SOGL report provides an overview of the status and trends of the Great Lakes based on nine (9) indicators and supported by 40 sub-indicators that are linked to objectives of the Great Lakes Water Quality Agreement (GLWQA 2012). Status and trends are identified for each sub-indicator and rolled up to main indicator level and an overall assessment of each Great Lake. The overall status of Lake Erie is reported as "Poor" with an "Unchanging" trend. The SOGL report notes that the Lake Erie walleye fishery continues to be productive, but excessive nutrient loading and in-lake concentrations and harmful algal blooms continue to be major issues.

Mirroring GLRI Action Plan III, the SOGL "Habitat and Species" indicator, which is linked to GLWQA Objective 5, represents the indicator that is most strongly associated with coastal wetland condition, restoration, and protection. This overall indicator is assessed by evaluating sub-indicators that fall within two sub-categories: 1) coastal wetlands and aquatic habitat connectivity (6 sub-indicators), and 2) aquatic food web (8 sub-indicators). The aquatic food web sub-category of "Habitat and Species" and the separate "Nutrients and Algae" indicator assess the overall condition of Lake Erie waters, while the six sub-indicators for "coastal wetlands and aquatic habitat connectivity" directly address coastal wetland status and trends (as summarized in Table B.2).

The status and trends for the five (5) coastal wetland sub-indicators are developed based on the Index of Biological Integrity (IBI) and Index of Ecological Condition (IEC) metrics and scores developed by the Coastal Wetland Monitoring Program (CWMP) based on plant, fish, invertebrate, amphibian, and bird data collected at roughly 1,000 wetland sites in the Great Lakes every 5 years. See the CWMP sub-section for additional discussion and references.

Table B.2. Status and Trends for "Coastal Wetland and Aquatic Habitat Connectivity" Sub-indicators.

Sub-Indicator	Status [1]	Trend (10-year period)
Coastal Wetland Invertebrates	Undetermined	Undetermined
Coastal Wetland Fish	Poor	Undetermined
Coastal Wetland Amphibians	Fair	Unchanging
Coastal Wetland Birds	Fair	Unchanging
Coastal Wetland Plants	Poor	Unchanging
Aquatic Habitat Connectivity	Fair	Improving

[1] In the SOGL 2022 report, "Status" is based on data collected and metrics calculated through 2019 for fish, invertebrates, and plants, for data/metrics through 2020 for amphibians and birds.

Coastal wetland extent is not directly addressed in the SOGL 2022 report. However, the SOGL 2007 report published 15 years prior identified *"coastal wetland area by type"* as indicator #4510 (USEPA and ECCC 2007). The IJC's *First Triennial Assessment of Progress (TAP) Report* later noted that this indicator was based on GLCWC data generated in 2004 and that *"the current areal extent and composition of coastal wetlands… cannot be accurately reported"* (IJC 2017). Although quantifying GLCW extent continues to be a challenging and complex endeavor, the GLCW Framework "Objective One" task and ECCC's work based on the Canadian Baseline Habitat Survey should help to identify standardized methodologies for quantifying past (e.g., 2010-20) and future GLCW extent.

B.4 Coastal Wetland Monitoring Program

The **Coastal Wetland Monitoring Program** (CWMP) is a GLRI-funded program that was initiated in 2010 to meet a primary objective of implementing a standardized basin-wide coastal wetland monitoring program (Uzarski et al. 2016, 2019). The initial five years of sampling (2011-2015) set the baseline for future sampling years and demonstrated the value of ecological datasets that can be used to inform decision-makers on coastal wetland conservation and restoration priorities throughout the Great Lakes basin.

The first five years of the program (2011-15) involved establishing and fully implementing a standardized sample design with rotating panels of wetland sites to be sampled across years, accompanied by sampling protocols, QAPPs, and other methods documents. In addition to the planning and implementing field activities, a database management system (DMS) was developed and the approaches for calculating coastal wetland indicators based on the raw monitoring data were developed and documented. The CWMP is now in its third 5-year monitoring cycle, and it has sampled approximately 1,000 wetland sites across the Great Lakes (roughly 200 sites per year), with many of those sites sampled at least once every five years. Monitoring data have been generated for each year in the 2011-2022 timeframe for the following taxa types:

- Vegetation: sampled five (5) quadrats for the wet meadow, emergent, and submergent zones, as available (maximum of 15 quadrats), for three distinct transects per survey. For each quadrat, summary information is collected on soils and overall vegetative cover, and percent cover is estimated and recorded for individual species.
- Fish and Macroinvertebrates: Three replicates are taken for each vegetation monotype (zone) identified during a site survey. Fish counts and lengths are observed in the field based on the deployment of fyke nets. Macroinvertebrate specimens are collected via net sweeps in the field, and taxa are identified and counted via laboratory analysis.
- Anurans and birds: Data are collected at specific points within each wetland site across multiple samples within a monitoring season (typically early through late spring).

Fish/invertebrate crews also sample a suite of water quality parameters within each monotypic vegetation zone, including nutrients, chlorophyll a, chloride, color, turbidity, and other parameters. Further detail regarding CWMP monitoring protocols can be found on the **sampling protocols page** of the program's website. A monitoring report and the raw monitoring data are delivered to USEPA (GLNPO) on a semi-annual basis (spring and fall) of each year, with the spring database deliverable incorporating the prior year's monitoring dataset (with primary QA/QC review completed). In addition, customized data deliverables are provided to external users based on an established data request and fulfillment protocol.

The raw ecological and water quality datasets collected by the CWMP are leveraged to compute a series of metrics designed to provide a snapshot of coastal wetland health for each site-year where monitoring data are available (Table B.3). With the exception of the "Water Quality & Land Use Index", all of the CWMP metrics have been adopted as sub-indicators by the State of the Great Lakes reporting effort, and the metric results available through 2019-2020 are presented and discussed in the 2022 SOGL report. As noted in Table B.3, indicator results are now available from the CWMP for the entire 2011-2022 period.

Because the CWMP has been consistently monitoring ecological and water quality condition through the past 12 years, the raw datasets and metrics generated by the CWMP capture both lower and higher water level conditions and transitional periods. This is a unique feature of this dataset that affords the opportunity to assess changes in site-level conditions through time in response to water level trends and other changes and stressors. The potential to evaluate temporal trends should be considered in the context of the GLCW Framework development effort.

Table B.3. Coastal wetland indicators developed by the Coastal Wetland Monitoring Program

Metric Name	Years Available	Relevant Publication(s)
Vegetation IBI	2011-2022	Dybiec et al. (2020) [1]
Macroinvertebrate IBI	2011-2022	Uzarski et al. (2004)
Fish IBI	2011-2022	Cooper et al. (2018)
Water Quality & Land Use Index	2011-2022	Harrison et al. (2020)
Anuran IEC	2011-2022	n/a
Bird IEC	2011-2022	n/a

[1] The original version of the vegetation IBI, which was used through 2021, was based on Albert and Minc (2004).

B.5 Lake Erie Lakewide Action and Management Plan

The Lake Erie Lakewide Action and Management Plan (LAMP) highlights the current state of ecosystem services in Lake Erie, Lake St. Clair and connecting channels. The 2021 annual report highlights the persistence of harmful and nuisance algal blooms, decline of prey fish diversity and the proportion of native prey fish species, and human stressors that can contribute to these issues. With regards to coastal wetlands, the LAMP 2021 report notes the crucial role that wetlands play in maintaining water quality, providing habitat for wildlife, and supporting overall ecosystem health. Based on assessment of conditions from 2019-2023, coastal wetland conditions in Lake Erie range from “Fair” to “Poor”.

Historically, coastal wetlands in the Lake Erie region have experienced significant loss and degradation due to human activities such as urbanization, agriculture, and shoreline development. The Lake Erie LAMP recognizes several important and inter-related vulnerabilities with regard to coastal wetland health, including climate change, urbanization and shoreline development, invasive species, nutrient loading and water level fluctuations.

The resiliency of the wetlands to mitigate these vulnerabilities varies by location and wetland type, however, overall coastal wetlands are considered moderately resilient. They have a natural ability to adjust to fluctuations in water levels and capture and cycle nutrients. The stressors outlined above that represent vulnerabilities to the wetlands may exceed their resilience and lead to degradation or loss of habitat.

To enhance the resilience of coastal wetlands, the Lake Erie LAMP emphasizes the importance of shoreline softening, enhancing wetland connectivity, controlling invasive species, managing nutrient inputs, and considering adaptive management approaches. Additionally, the plan underscores the significance of collaborative efforts involving government agencies, non-profit organizations, researchers, and local communities to promote the resilience of coastal wetlands.

B.6 Lake Erie Biodiversity Conservation Strategy

The Lake Erie Biodiversity Conservation Strategy (LEBCS) report recognizes coastal wetlands as valuable ecosystems that support numerous ecological services/functions, including habitat provision, water quality improvement, flood mitigation, shoreline stabilization, carbon sequestration, and nutrient cycling.

Stressors affecting coastal wetlands include habitat loss, altered hydrology, nutrient enrichment, invasive species, climate change impacts, and human disturbance. These stressors pose challenges to the health and functioning of coastal wetlands and underscore the importance of protective measures, restoration efforts, and sustainable land-use practices.

Key ecological indicators for coastal wetlands include vegetation composition and diversity, water quality, fish and wildlife populations, wetland bird abundance and diversity, hydrological conditions, and invasive species presence. Threats to these indicators include habitat fragmentation, altered hydrology, eutrophication, invasive species, climate change, and anthropogenic disturbances.

The report assesses the overall viability of coastal wetland regions in Lake Erie as ranging from "Good" (St. Clair River and southern shore of Central Basin) to "Fair" (all other coastal wetland areas), resulting in an overall score of "Fair."

The Lake Erie Biodiversity Conservation Strategy suggests the following for short-term goals to be achieved by 2030:

- The average wetland macrophyte index for Coastal Wetlands around the lake will reflect good condition;
- Coastal Wetland area around the lake will have increased by 10% compared to the 2011 wetland area.

B.7 Assessment of the Resilience of Great Lakes Coastal Wetlands to a Changing Climate

Environment and Climate Change Canada (ECCC) assessed coastal wetland health by evaluating the vulnerability, sensitivity, and adaptive capacity of Great Lakes coastal wetlands to climate change. The assessment involved a combination of climate change projections, lake-level projections, wetland survey data, remote sensing data, integrated ecosystem response modeling, and geographic information systems. The study focused on the resiliency of wetlands based on the following ecosystem metrics:

- Vulnerability: A novel index was constructed using multiple quantitative indicators to describe the vulnerability of 20 coastal wetland sites. The index considered factors such as landscape condition, biological condition, wetland migration potential, and protection.
- Sensitivity: The sensitivity assessment estimated the negative ecological effects of climate change on Great Lakes coastal wetlands. It focused on adverse effects by comparing hindcast years (1981-2008) to forecast years (2071-2098) using a Coastal Wetland Response Model (CWRM). The assessment used predicted wetland vegetation community maps for 20 wetland sites under different climate change scenarios.
- Adaptive Capacity: The adaptive capacity of wetlands was assessed based on current biological and physical factors, such as the proportion of natural land cover, invasive Phragmites cover, plant

species richness, and the potential for upland and lakeward migration during high and low water-level periods.

To enhance the resiliency of Great Lakes coastal wetlands in the face of climate change and other stressors, the study recommends the following management strategies:

- Restoring hydrology: Match pre- and post-development surface and groundwater balance to coastal wetlands, restore groundwater micro-refugia at coastal fens, and employ dam-regulation best practices to control excessive sediment and nutrient outputs.
- Conservation and protection: Protect existing wetland areas and riparian corridors, minimize further damage, restore or enhance wetland area and function, and maintain or re-establish ecological connectivity.
- Agricultural practices: Implement best management practices, such as buffer strips, cover crops, and reduced fertilizer and pesticide usage, to minimize nutrient runoff and sedimentation in coastal wetlands.
- Urban settings: Install and maintain green infrastructure or low-impact development to promote stormwater retention and infiltration in urban areas adjacent to coastal wetlands.
- Shoreline management: Protect and restore natural shorelines, minimize shoreline armoring, and explore mechanisms to mitigate sediment deficit and downdrift impacts associated with shoreline structures.
- Climate change adaptation: Integrate climate change impacts into land-use planning decisions, expand planning horizons for erosion hazard setbacks, and protect areas where geodiversity is fundamental to sustaining coastal wetlands.
- Invasive species management: Implement targeted control and management strategies to reduce the spread and impact of invasive species on coastal wetlands.
- Monitoring and research: Conduct regular monitoring and research to assess the effectiveness of implemented measures and adapt management strategies accordingly.

B.8 Great Lakes Coastal Wetland Restoration Assessment (GLCWRA)

The **Great Lakes Coastal Wetland Restoration Assessment** (GLCWRA) is a web-based decision support tool that provides six landscape-scale geospatial data models that support the assessment of the restorability of wetland areas in the coastal zones. The landscapes included in the tool that are relevant to the Lake Erie pilot for the GLCW Framework include the *Western Lake Erie Restoration Assessment* (WLERA) and the *Connecting River Systems Restoration Assessment* (CRSRA). For each landscape, the GLCWRA provides an overview of the study area and a "Restoration Index" that symbolizes areas along a relative scale of "least restorable" (yellow) to "most restorable" (dark green). Information documented in the GLCWRA for the WLERA and CRSRA study areas is summarized below:

- WLERA: This study area covers nearly half a million acres. Western Lake Erie was formerly the home of the Great Black Swamp and it was characterized by expansive coastal wetland areas. However, logging and draining activities largely replaced wetlands with agricultural, industrial, and residential development prior to the 1900s. The present-day coverage of coastal wetlands is only ~5% of the original historical extent of 400,000 hectares, and most remaining wetlands are highly degraded. Several areas within this assessment zone were considered to have a high restorability, including the North Maumee Bay Bottomlands area, Howard Marsh, and inner Sandusky Bay.

- CRSRA: The majority of the wetlands in the CSRSA that are scored as most likely to be restored are located near the city of Algonac, near the mouth of the St. Clair River. Most of these areas are currently diked agricultural land.

B.9 Blue Accounting coastal wetland metrics

The **Blue Accounting website** includes a "Coastal wetland acreage" metric that provides a snapshot of coastal wetland restoration progress across the Great Lakes basin. A mapping tool provides specific locations and "heat maps" depicting the distribution of restored wetland acreage. The specific purpose of this tool is to track progress towards the coastal wetland acreage targets values established in GLRI – Action Plan III (as well as Action Plan II) by inventorying acreage that has been "protected, enhanced, or restored by GLRI projects." Wetland acreage can be summarized by Great Lake, state/province, congressional district, project and funding types, and project award end year. As of May 31, 2023, the following progress was reported:

- Total Protected, Restored & Enhanced: 96,830 acres
- 2017 GLRI Protected, Restored & Enhanced: 24,306 acres (GLRI 2017 target was: 30,000 acres)

B.10 Canadian Lake Erie Coastal Baseline Habitat Survey

The 2020 Lake Erie Canadian Baseline Coastal Habitat Survey assessed key habitat types, biodiversity, and ecological conditions of coastal wetland habitats within Lake Erie and the Huron-Erie Connecting Waterways. This survey delineated coastal ecosystem types, assessed wetland and upland species richness and biodiversity, and examined the effectiveness of protection and restoration efforts.

The study indicates that the current wetland ecosystem contains 63 different wetland habitat types and supports 344 species of conservation concern, including 126 species at risk. Wetlands in the survey area cover 29,944 hectares, with 75% being coastal wetlands and 25% being inland wetlands. Forty-three percent of coastal wetlands are lacustrine, 46% are riverine, and 11% are barrier-protected. Phragmites is estimated to negatively impact at least 25% of Ontario's species at risk.

The stressors to coastal wetlands outlined in this study included land use and conversion of natural areas to urban and agricultural land, invasive species, shoreline hardening, and loss and degradation of wetland area.

The survey also highlights the importance of conserving and protecting coastal wetlands to maintain their ecological and human services. These key services include soil and water conservation, shoreline protection, biodiversity support, fish spawning and nursery habitats, migratory and nesting bird habitats, and recreational services.

B.11 Canadian Great Lakes Nearshore Assessment

ECCC has developed a comprehensive assessment of the Canadian nearshore region of the Great Lakes as part of its Nearshore Framework. The purpose of the Nearshore Framework is to address ongoing and emerging challenges to the nearshore waters of the Great Lakes, where restoration, protection and prevention activities are critical to improving and sustaining the ecological health of Great Lakes coastal areas and supporting attendant social, cultural, recreational and economic benefits.

The Nearshore Assessment highlights the importance of coastal wetlands in maintaining the health of the Great Lakes ecosystem. Coastal wetlands, along with other nearshore components like river mouths, beaches, dunes, and sediment supply, are maintained by the interaction of nearshore coastal processes with the landscape. The assessment notes that increasing shoreline development and physical alteration of the land-water interface is a significant factor stressing nearshore coastal processes and can lead to the degradation of coastal wetlands. In particular, coastal wetlands at Point Pelee National Park, Rondeau Bay, and Long Point in Lake Erie are threatened by the lack of sand supply caused by shoreline hardening and littoral barriers, as well as the impact from climate change. The protective barrier beach at Rondeau Bay was breached in 2018, leaving the coastal wetland exposed and vulnerable to Lake Erie wave action.

The Nearshore Assessment provides a number of potential ecological indicators, including:

- percent of shoreline hardening
- amount of tributary connectivity
- water, benthic, and sediment quality
- fish consumption advisories
- beach closings
- water treatment facility adverse incidents.

These indicators are rated based on their stress level, with a desired status of each indicator to be at low stress, according to various metrics outlined in the report, such as less than 25% of shoreline as hardened material and no littoral barriers. Not all of the indicators listed above are directly attributed to coastal wetlands, but they can be indicators of overall health of the Great Lakes.

ECCC and the Government of Ontario also provides several online geospatial datasets related to coastal wetlands in the Great Lakes region that were used during development of the Nearshore Assessment. Relevant datasets include the **Aquatic Landscape Inventory System**, the **Great Lakes Shoreline Ecosystem Inventory**, and the **Aquatic Ecosystems Classification: Great Lakes Basin - Coast, Streams, Lakes and Wetlands**. These datasets provide geospatial information related to habitat type and land features along the shores of the Great Lakes, within Ontario's boundaries.

B.12 Great Lakes Fishery Commission Lake Erie Technical Committee and Task Group documents

The Great Lakes Fishery Commission (GLFC) operates a **Lake Erie Technical Committee** that oversees multiple task groups that focus on specific components of the overall Lake Erie fishery. Full reports and separate executive summaries were published in 2023 by the following task groups:

- Lake Erie Coldwater Task Group
- Forage Task Group
- Walleye Task Group

- Yellow Perch Task Group
- Habitat Task Group

In addition to the recent task group reports, the GLFC has recently published a yellow perch management plan and a lake trout rehabilitation plan for Lake Erie. The Habitat Task Group has paid special attention to wetlands in the lake and has concluded that "[o]ver 40% of Lake Erie's fish species are classified as wetland dependent or facultative wetland dependent". Nearshore fish communities are especially dependent on coastal wetlands for spawning and habitat. Northern pike spawn in wetlands in early spring, swimming against the flow of water moving from wetlands into the lake. Specific wetlands mentioned in reports include those in the St. Clair Delta, Western Basin (Michigan and Ohio, including Sandusky Bay), Niagara River, Long Point Area, and in the lower reaches of major tributaries (e.g., Thames, Maumee, and Grand).

B.13 Strategies for Adapting Great Lakes Coastal Ecosystems to Climate Change

The document provides a menu of adaptation strategies and approaches for coastal ecosystems, including maintaining and enhancing hydrologic processes, sediment dynamics, water quality, and coastal vegetation. It also emphasizes the importance of community engagement, planning, and policy in coastal management decisions. The menu is designed to be used with the Adaptation Workbook, a structured process for integrating climate change considerations into planning, decision-making, and implementation. The collection also includes references to various studies and resources related to climate change impacts on Great Lakes ecosystems and coastal management projects.

The menu discusses several stressors affecting coastal wetlands due to climate change, including changing water level regimes, increased storm frequency and intensity, increased surface water temperatures, and direct and indirect human influences.

Several strategies are recommended for adapting coastal wetlands to climate change, including:

- Maintain and enhance hydrologic processes.
- Maintain and enhance sediment dynamics.
- Maintain and restore water quality.
- Maintain, restore, and manage coastal vegetation.
- Facilitate transformation of coastal ecosystems.
- Manage surface water runoff.
- Engage communities and develop policies.

B.14 Upper Mississippi/Great Lakes Joint Venture Plans and Strategies

The **Upper Mississippi River / Great Lakes Joint Venture** (JV) is a U.S.-based regional bird-habitat partnership implementing the North American Waterfowl Management Plan and the North American Waterbird Conservation Plan. The most recently updated plans that are part of the JV cover waterbirds (2018), waterfowl (2017), and shorebirds (2007). The JV sets goals for species recovery and habitat restoration or protection, including coastal wetlands. The mission of the JV is "to deliver the full spectrum of bird conservation through regionally based, biologically driven, landscape-oriented partnerships". The group of partners that make up the JV functions under the leadership of the U.S. Fish & Wildlife Service, with substantial funding coming from the Great Lakes Restoration Initiative and programs covered by the Great Lakes Fish and Wildlife Restoration Act.

B.15 Prioritizing coastal wetlands for marsh bird conservation in the U.S. Great Lakes (Grand et al. 2020)

A study conducted and published by Grand et al. (2020) focused on prioritizing specific coastal wetlands across the Great Lakes basin for marsh bird conservation. This evaluation was based on bird species occurrence and relative abundance data available from the CWMP for 2011-2017, focusing on 14 marsh bird species (American Bittern, Black-crowned Night Heron, Black Tern, Blue-winged Teal, Common Gallinule, Least Bittern, Marsh Wren, Osprey, Pied-billed Grebe, Sandhill Crane, Sedge Wren, Sora, Swamp Sparrow, and Virginia Rail). The prioritization evaluation followed five steps:

- Step 1: Marsh bird survey data collection (accomplished by the CWMP)
- Step 2: Detection offset estimation
- Step 3: Environmental covariate data collection
- Step 4: Species-habitat modeling
- Step 5: Coastal wetland prioritization

Under step 5, Zonation conservation planning software was used to rank every 100-m coastal wetland cell in the landscape based on probability of occurrence or relative abundance of the 14 species listed above. In addition to the CWMP datasets (including GPS-referenced point locations), other key inputs were the USEPA potential wetlands and National Wetland Inventory (NWI) emergent wetlands layers. Weights were assigned to individual bird species to reflect relative climate vulnerability across the focal species. The quantity of impervious surface in the landscape surrounding wetland area and the availability of open water and herbaceous vegetation were key predictors across all species (with other factors affecting a subset of the species).

The results of the prioritization analysis were reported on a lake-specific basis. Overall, Lake Erie and Lake Ontario were scored with the highest priority ranking, followed by Lake Huron, Lake Michigan, and Lake Superior. “Priority ranking” in the context of this study is an indication of the importance of the wetland cells analyzed to the focal species. The combined results for Lake Erie and Lake St. Clair identified 45% (37,029 ha) of the total coastal wetland area as being “high priority” and noted that only 50% of those areas are currently protected habitat.

A significant outcome of this study is the identification of a “spatial mismatch” between ecological value and protection status. A significant fraction of the highest priority coastal wetland area (i.e., scoring in the top 20% in terms of supporting the focal species) was located outside of areas that are currently protected. The results of the analysis can be used to cost-effectively prioritize additional areas where coastal wetland protection should be considered.

B.16 A Review of Selected Ecosystem Services Provided by Coastal Wetlands of the Laurentian Great Lakes (Sierszen et al. 2012)

This article by **Sierszen et al. (2012)** outlines several significant ecosystem services provided by coastal wetlands in the Great Lakes, including wildlife habitat, fisheries support, water quality improvement, carbon sequestration, and cultural services such as wild rice production. The report also notes declines in wildlife and fishery services as a result of anthropogenic disturbances. Specific stressors to coastal wetlands health mentioned in the study include channel dredging, suppression of natural water level fluctuations, nutrient and sediment loading, land-cover and land-use changes, invasive species, and changes in fish composition.

The study notes several important ecosystem indicators to represent coastal wetland health, as summarized in Table B.4 below.

Table B.4. Summary of ecosystem indicators from Sierszen et al. (2012)

Ecosystem Service Endpoint/Indicators	Importance	Information
Wildlife Habitat		
birds: presence/absence, habitat	high	high
amphibians & reptiles: presence/absence, habitat	high	moderate
mammals (muskrats): presence/absence	limited	limited
Fisheries Support		
fish: presence/absence, habitat	very high	high
Water Quality Improvement		
nutrient retention: indicators lacking	high but variable	locally high
sediment retention: indicators lacking	variable	limited
Plant Crops		
wild rice: presence/absence, area	localized/rare	limited
Climate Regulation		
carbon sequestration: indicators lacking	unknown	lacking
Coastal Protection		
lacustrine wetland extent	localized	limited

B.17 Designing Coastal Conservation to Deliver Ecosystem and Human Well-Being Benefits (Annis et al. 2017)

Annis et al. (2017) discuss a conservation plan for the coastal and nearshore areas of the western Lake Erie basin that would identify the most efficient locations for conservation actions to meet ecological goals while sustaining or enhancing human well-being values. The project used an optimization analysis with 26 features representing ecological and human well-being priorities and included seven cost layers. The results showed that the most important areas for conservation to achieve multiple goals are clustered along the coast, reflecting a concentration of existing or potentially restorable coastal wetlands, coastal landbird stopover habitat and terrestrial biodiversity, as well as important recreational activities. Inland important areas tended to cluster around trails and high-quality inland landbird stopover habitat. Most concentrated areas of importance also are centered on lands that are already conserved, reflecting the lower costs and higher benefits of enlarging these conserved areas rather than conserving isolated, dispersed areas.

The results of this study formed the basis of a decision support tool titled the Western Lake Erie Coastal Conservation Vision (WLECCV). The WLECCV is intended to highlight areas important for achieving regional ecological goals as well as contributing to important human well-being values. This effort accounted for several ecological services/functions for both inland and coastal waters. Coastal services were primarily related to fish and wildlife habitat (e.g., nearshore fish habitat, fish spawning sites, land and shorebird habitats, waterfowl habitat). Human well-being needs that were represented in the study include recreational opportunities (e.g., birding, fishing, hunting, hiking, swimming) and various spiritual and cultural activities.

B.18 Ohio State Wildlife Action Plan (SWAP)

Ohio's State Wildlife Action Plan (2015) provides information on the status and conservation of various habitats in Ohio, including coastal wetlands. The document notes that Ohio's wetlands have experienced significant losses, with estimates suggesting that less than 25% of the original wetland habitat remains today. Wetlands are threatened by habitat loss, fragmentation, and aquatic invasive species. The document outlines specific conservation actions to address these threats, including wetland restoration and maintenance, assessment of wetland quality, and monitoring of wetland wildlife populations.

The action plan outlines several goals for improving the quality of coastal wetlands in Ohio, including:

- Protecting and restoring wetland habitat to maintain and enhance the ecological functions of wetlands.
- Assessing the quality of wetland habitat to identify areas in need of restoration and to monitor the effectiveness of restoration efforts.
- Monitoring wetland wildlife populations to assess the health of wetland ecosystems and to identify areas in need of conservation action.
- Developing and implementing management plans for wetland conservation opportunity areas, including Lake Erie Marsh, Killbuck Marsh, and Grand River/Mosquito Creek.
- Controlling and preventing the spread of aquatic invasive species in wetlands.
- Promoting public awareness and understanding of the importance of wetlands and their role in supporting healthy ecosystems.

B.19 Michigan Wildlife Action Plan

The 2015 Michigan wildlife action plan (Derosier et al. 2015) provides information about species in need of conservation and outlines priorities for the next 10 years. The plan includes details about priority habitats and focal species, status of species and habitats, critical threats, needed conservation actions, places for partnerships, monitoring needs, and goals.

The stressors discussed in this document are related to threats to the health of fens and their associated wildlife. These include invasive and problematic species, natural systems modifications, agriculture and aquaculture, human intrusions and disturbance, and pollution. Additionally, climate change and severe weather are identified as a significant threat to fen ecosystems and their associated species. The document also provides information on the focal species of fens and their conservation actions.

Specific goals discussed in this plan are to increase or maintain the quality of fen habitats, complete groundwater watershed mapping for fens in southern Lower Peninsula, and to protect and conserve associated rare plants such as Prairie Indian-plantain, White lady slipper, Mat muhly, Rosinweed, Prairie dropseed, and Edible valerian. The plan also outlines specific actions to achieve these goals, such as conducting habitat management to mimic natural disturbance regimes, controlling invasive species, and implementing timber harvest best management practices.

B.20 New York State Wildlife Action Plan

The New York State Wildlife Action Plan (SWAP) outlines the New York State's approach to conserving its diverse wildlife and the habitats they depend on. The plan includes measures for monitoring the effectiveness of conservation actions, such as the number of acres of habitat restored or the number of species monitored for contaminants. It also provides templates for reporting the results of these actions and methods to incorporate this information into grant reporting and adaptive management.

The SWAP does not directly discuss actions, threats or desired status for coastal wetland services, but it does outline overall plans for ecological health in the state, particularly related to Species of Greatest Conservation Need (SGCN). The threats related to SGCN include climate change, human disturbances, landscape development, pollution and invasive species. The specific goals mentioned in the SWAP include protecting viable habitats for SGCN, restore and manage vulnerable habitats, restore self-sustaining populations of SGCN, and develop and maintain monitoring efforts to improve habitat and populations of SGCN.

B.21 Pennsylvania 2015-2025 Wildlife Action Plan

The 2015-2025 Pennsylvania Wildlife Action Plan outlines the plans for conserving Pennsylvania's native wildlife and their habitats. The plan identifies Species of Greatest Conservation Need (SGCN) and outlines the threats they face, such as residential and commercial development, energy production and mining, pollution, and invasive species. The plan also includes conservation actions, including planning, direct management of natural resources, law and policy, technical assistance, and data collection and analysis. The action plan does not explicitly discuss coastal wetlands, but it focuses on actions that can improve the ecological health of many species in the state.

B.22 Ecosystems and Human Well-Being: Wetlands and Water (Millennium Ecosystem Assessment)

The Millennium Ecosystem Assessment (MEA) is focused on wetland ecosystem services, including ecological services and human well-being needs (MEA 2005). The scope of this study includes the full range of wetlands defined by the Ramsar Convention on Wetlands, but many of the core ecosystem service concepts and linkages identified in the report are consistent with those identified in other resources that describe ecosystem services specific to the Great Lakes. The study identifies four ecosystem service domains:

- Provisioning services (e.g., food and water),
- Regulating services (e.g., climate and flood regulation),
- Supporting services (e.g., nutrient cycling), and
- Cultural services (e.g., recreational, spiritual, and other non-material benefits).

Specific wetland services and functions that are identified as having a strong linkage to human well-being include: 1) water purification and detoxification of wastes, 2) climate regulation, 3) mitigation of climate change, and 4) cultural services. The report also describes wetland status and trends and the causes of wetland loss and degradation from a global perspective.

B.23 Human Wellbeing Vital Signs and Indicators for Puget Sound Recovery

The Puget Sound Partnership (2015) describes a suite of human well-being needs associated with Puget Sound (WA) in its *Human Wellbeing Vital Signs and Indicators for Puget Sound Recovery* report. While the scope of the project and report are outside of the Great Lakes basin, it is useful to compare/contrast the "vital signs" documented in this report against human well-being needs identified in coastal wetland and other studies that are specific to the Great Lakes. The study identified two overarching goals, human health and human quality of life, as well as "vital signs" and associated indicators that fall under each goal:

- Goal: Human Health
    - Outdoor Activity (indicators: swimming beaches, nature-based recreation, nature-based work)
    - Drinking water (no indicators provided)
- Goal: Human Quality of Life
    - Economic vitality (natural resource industry GDP, fraction of natural resource to total GDP)
    - Cultural wellbeing (participation in cultural practices)
    - Good governance (trust in government agencies, opportunity to influence decisions)
    - Sense of place (positive connections, sense of stewardship)
    - Sound behavior (engagement in stewardship activities)

The Puget Sound report also describes the development of a human well-being needs survey and key aspects of using that survey instrument to collect the necessary data to inform the well-being indicators selected through the study.

B.24 Saginaw Bay to Lake Erie Coastal Wetland Blueprint

This project is underway, but no specific products have been developed and made available as of the writing of this document. Relevant aspects of the Blueprint project may be reviewed and incorporated into a future version of this document.

B.21 Selected Supplemental Resources

This section provides brief capsule summaries for the supplemental resources listed in Table 2, as well as some additional resources.

H2Ohio Wetland Monitoring Program Plan

The objective of the H2Ohio Wetland Monitoring Program is to evaluate the nutrient removal accomplished by wetland restoration and enhancement projects implemented by the Ohio Department of Natural Resources (ODNR) as part of the H2Ohio Initiative. The program is focused on assessing both the phosphorus (P) and nitrogen (N) removal capacity of coastal wetlands. A suite of H2Ohio wetland projects have been implemented and are currently in progress, including 26 projects under Phase I and 31 additional projects planned for Phase II. This monitoring program plan provides the scientific rationale and overall programmatic guidance to support site-specific wetland monitoring. However, because many wetland systems are characterized by complex hydrology and multiple inflow/outflow points, site-specific plans are being developed and tailored to local conditions to ensure that monitoring objectives are met. The monitoring program has outlined a tiered approach for the monitoring effort consisting of:

- Focal Projects: A relatively small number (4-5) of sites/projects will be monitored intensively (through space and time) to support the detailed estimation of nutrient budgets for each site. Process-based measurements that will be conducted for focal projects will include intact cores to measure denitrification rates and water-sediment exchange of dissolved P and N.
- Non-Focal Projects: A larger number of sites/projects will be monitored less intensively, with fewer samples collected through space and time. The objective of data collection for non-focal projects will be to demonstrate directional change in nutrient removal, but the data will not be sufficient to directly quantify nutrient mass budgets and removal efficiencies.

Specific datasets that are collected by the H2Ohio Wetland Monitoring Program include:

- Physical Datasets: bathymetric and topographic surveys
- Hydrology/Hydrodynamics: Water levels and inflow/outflow at tributary and lake connection points and groundwater well monitoring (Hydrodynamic models will be developed for focal wetlands.)
- Soil Characteristics : nutrient content, texture, etc.
- Water Quality: surface water nutrient concentrations
- Process Data: water-sediment nutrient exchange rates and denitrification rates

Lake Erie Protection & Restoration Plan

The *Lake Erie Protection & Restoration Plan – 2023 Draft* (Ohio LEC 2023) reports progress on restoration and protection initiatives in the lake and outlines 2023 priorities that map on to the Focus Areas identified in GLRI Action Plan III (and prior action plans). Reported progress toward nutrient pollution reduction goals includes 140+ projects and roughly 15,000 acres of coastal wetlands to help filter nutrients and reduce delivery to the lake. Progress under "Habitat and Species" includes increased populations for bald eagles, piping plovers, trumpeter swans, river otters, and other key species.

New goals identified by the Plan for the 2023-25 timeframe include:

- Restoring up to 500 acres of coastal wetlands;
- Increasing nature-based solutions (in place of "hard" infrastructure);
- Defining critical habitats through monitoring and mapping; and
- Continuing investments in ecosystem scale habitat restorations for embayments, islands, and other focal areas.

Lake Erie Commission 2022 Lake Erie Quality Index

The Lake Erie Quality Index 2022 Report provides an assessment of coastal wetlands in Ohio's Lake Erie watershed. The overall trend in coastal wetland health is mixed, with small high-quality wetlands decreasing in quality and large low-quality wetlands improving in quality. The overall metric for coastal wetlands is rated as "Fair".

Ohio EPA and The Ohio State University developed the Vegetation Index of Biological Integrity specific to coastal wetlands (VIBI-C), which showed a decline in scores for small, historically persistent coastal wetlands. This index, which is a composite of three different plant community (emergent, forest, and shrub) indices, was developed specifically from data from Lake Erie's coastal marshes, but may be useful as an indicator in other areas. The average VIBI-C score dropped from 56.2 (Excellent) in 2000-2004 to 41.8 (Good) in 2014, primarily due to the increase in dominance of invasive plant species.

The coastal wetlands in Ohio's Lake Erie watershed face challenges such as invasive plant species and loss of acreage, but efforts are being made to restore and improve their health. The overall condition of these wetlands is rated as "Fair", with mixed trends in quality.

Chatham-Kent Lake Erie Shoreline Study

The Chatham-Kent Lake Erie Shoreline Study is a comprehensive vulnerability and risk assessment of the Lake Erie shoreline of Chatham-Kent, Ontario, Canada. The study was conducted to assess the impacts of climate change on future lake levels, ice cover, storm surge, and the nearshore wave climate. The study also evaluated potential economic damages to coastal development from flooding and erosion, threatened road infrastructure, and the coastal ecosystem. The study found that the coastal wetlands along the Lake Erie shoreline of Chatham-Kent occur primarily in the sheltered waters of Rondeau Bay and are vulnerable to damage from erosion and recession. The study also identified several ecological stressors, including erosion impacts on coastal wetlands, terrestrial nutrient loading to the nearshore, sedimentation in the navigation channel, changes to wave exposure in Rondeau Bay, and wetland impacts. The study recommended several adaptation options to increase community resilience to coastal hazards, including beach nourishment, low crested offshore breakwaters, and the relocation of dredged sediment to mitigate ongoing shore erosion.

Lake Superior Manoomin Cultural and Ecosystem Characterization Study

The **Lake Superior Manoomin Cultural and Ecosystem Characterization Study** (NOAA-OCM, 2020) was conducted as part of the broader Great Lakes Wild Rice Initiative. The study successfully engaged with a large community of stakeholders, including federal and state agencies and several different tribal entities, to develop methodologies for characterizing the cultural and ecological importance of manoomin (wild rice) and its associated habitat. Ultimately, a *Habitat Equivalency Approach* (HEA) was selected to serve as the basis for "scaling" the habitat restoration needed to counter-balance losses in cultural and ecological functionality over time. The HEA factors in not only total surface area of habitat, but also the relative functionality of habitat. For example, restoring 20 acres of manoomin that only has 50% habitat functionality would be required to restore a lost area of 10 acres.

This study identifies a total of 12 cultural and ecological metrics to support the HEA analysis:

- **Cultural Metrics (5)**: Anishinaabe (original people), Community relationships, Spirit relationships, *Manoominikewin* (the Anishinaabe communal practice of harvesting, preparing, and sharing wild rice), Food sovereignty and health.

- **Ecological Metrics (4)**: Biodiversity, Integrity, Water quality, Water level
- **Cultural and Ecological Education Metrics (3)**: Knowledge generation, Knowledge sharing, Educational opportunities.

A suite of case studies is presented and used to highlight the application of the HEA approach and metrics for Lake Superior Manoomin sites. Although Manoomin itself is likely not a realistic desired condition or metric for Lake Erie, the approach undertaken by this study, including the engagement with multiple tribal groups, and the metrics identified can be considered when developing the GLCW Framework.

Investigating groundwater-lake interactions in the Laurentian Great Lakes with a fully-integrated surface water-groundwater model (Xu et al. 2021)

The study by **Xu et al. (2021)** investigated groundwater-lake interactions in the Laurentian Great Lakes using a fully-integrated surface water-groundwater model. The model was developed using HydroGeoSphere and was applied towards a water balance analysis of the Great Lakes Basin. The study found that the groundwater discharge into the Great Lakes varied spatially and temporally, and the results provide new information to help better understand how spatial and temporal variability in direct groundwater discharge could influence the thermal regime, ecological conditions, and nutrient loading along shoreline regions within the lakes.

This study did not focus on coastal wetlands and did not discuss ecological services/functions or human well-being needs provided by coastal wetlands. This study also did not provide a quantification of nutrient loading from ground water sources.

Sediment and Nutrient Retention Studies (Carter et al. 2020; Aziz and Van Cappellen (2021))

Multiple studies have been conducted to evaluate the effectiveness of Lake Erie coastal wetlands in removing sediment and nutrient (especially phosphorus) mass from the water column and quantifying the ecological benefits/services associated with this removal. The following relevant publications were reviewed and summarized to support this synthesis effort:

- ***Turbidity and estimated phosphorus retention in a reconnected Lake Erie coastal wetland***

  Carter et al. (2020) conducted a study for Crane Creek (located in northwest OH) during 2013-14 to assess fluxes of suspended sediment and phosphorus in and out of this wetland site. Data collected included concurrent observations of velocity/flow and suspended sediment and total phosphorus concentrations. This study estimated that, on an annual basis, Crane Creek retained an estimated 8-10% of total phosphorus (TP) that entered the wetland complex. Seasonal variations suggested that TP retention was higher in the summer and winter relative to the spring and fall seasons when the largest storms and seiche events tend to cause increased turbidity. Ultimately, this study demonstrated that restoring connections between coastal wetlands and the main lake has the potential to help reduce loading and alter delivery of TP to Lake Erie.

- ***Economic valuation of suspended sediment and phosphorus filtration services by four different wetland types.***

  Aziz and Van Cappellen (2021) conducted a valuation study for the four major wetland types found in Southern Ontario: bogs, fens, marshes, and swamps. The scope of this study was much broader than

Great Lakes coastal wetlands, but the findings for marshes are generally relevant for both Lake Erie and Lake Ontario. The methodology followed for this study combined estimated sediment accretion rates in each wetland type with mean soil P concentrations to estimate the P retention rate. Of the four types, marshes were estimated to have the highest retention of both sediment and P. The following parameters were estimated for marshes:

- Sediment accretion rate (mean): 0.36 cm/yr
- Sediment retention rate: 36 (± 20) m^3/ha/year
- Sediment retention value: 6120 (± 4410) $/ha/year
- P retention rate: 57.9 (± 42) kg/ha/year
- P retention value: 1100 (± 1105) $/ha/year

Both publications underscore that trapping and retention of sediments and nutrients is an important ecosystem service provided by GLCW.

Ecosystem services in the Great Lakes (Steinman, et al. 2017)

Steinman et al. (2017) make the case for the importance of evaluating ecosystem services when making decisions about habitat restoration in the Great Lakes to determine the ecological and human returns on such investments. The article explicitly recognizes the existence of ecological production function hotspots in the Great Lakes like coastal wetlands/river mouths. The authors further distinguish the concept of common spatial offsets between areas where ecosystem services are produced, and "delivery hot spots" where ecosystem services are consumed. This is an important aspect of the fish spawning and nursery role of coastal wetlands, for example, which is often separate from the location of harvest.

Western Lake Erie report card

Researchers from the University of Maryland Center for Environmental Science and their partners in the Lake Erie region produced a report card in 2020 covering the health of the western part of the lake and its watershed based on 2018 data (**https://ecoreportcard.org/report-cards/lake-erie/**). The overall grade was a "C" for the watershed and a "C+" for the lake. While wetlands were not a focus of the report, it did contain the following statement: "[Lake Erie] wetland systems [Sandusky Bay] support a productive fishery, and the bay provides opportunities for recreation and tourism."

Triennial Assessment of Progress (International Joint Commission [IJC])

The IJC's Triennial Assessment of Progress report was first released in 2017, as required by **Section 7.1(k) of the 2012 GLWQA**, with the most recent edition in 2020 and a 2023 volume in preparation (**IJC 2020**). After the Progress Report of the Parties (PROP) to the GLWQA (Canada and U.S.) is published, the IJC—in consultation with its advisory boards (Water Quality Board, Science Advisory Board, and Health Professionals Advisory Board) and the public—prepares a Triennial Assessment of Progress (TAP) Report. The report reviews the PROP, provides a summary of the public input received on the PROP, assesses how well government programs are achieving the objectives of the GLQWA, and offers advice and recommendations to the governments of Canada and the United States. In the 2020 TAP Report, key stressors identified for Great Lakes habitats, including coastal wetlands, were invasive species and climate change. The nine general objectives of the GLWQA include: "Support healthy and productive wetlands and other habitats to sustain resilient populations of native species".

National Fish & Wildlife Foundation (NFWF) Great Lakes Business Plan, 2015-2025

The NFWF **Great Lakes Business Plan** outlines quantitative outcomes over ten years for NFWF grantmaking programs in the Great Lakes (NFWF 2015). The specific goals for coastal wetlands are stated as follows:

> *"NFWF programs will: restore 13,000 acres, representing 11% of the projected 2025 GLRI Action Plan target; provide habitat to support more than 10% of the additional birds needed to achieve priority shorebird and waterfowl regional objectives; and restore access by northern pike and other marsh-spawning fish to 25 coastal wetlands, representing 5% of monitored coastal wetlands identified as impaired for fish."*

Audubon Great Lakes Impact Report

The **2022 Audubon Great Lakes Impact Report** summarizes progress toward Audubon's goal, established in 2020, of improving or restoring almost 300,000 acres of priority coastal habitat in the region, including wetlands. In the Lake Erie area, priority wetlands highlighted on a map in the report include the St. Clair Delta, southeast Michigan, and the area of Ohio between Toledo and Sandusky Bay. Highlighted species included the Black Tern and the Least Bittern, a secretive marsh bird.

State Coastal Zone Management program documents

The Great Lakes states maintain NOAA-supported programs to manage their coastal resources with regard to erosion, habitat, and other aspects. These programs were established by planning documents, which are listed in Table B.5. Ohio's latest plan revision contains over 400 references to wetlands (ODNR 2007). Michigan's original plan (1978) references wetlands 80 times and describes them as "ecologically sensitive areas". In 2015, the state released a ***Wetland Monitoring and Assessment Strategy***, which cites the Great Lakes Coastal Wetland Consortium protocols extensively.

Table B.5. State Coastal Zone Management Program Documents

State	CZM Document
Illinois	**State of Illinois Coastal Management Program (2011)**
Indiana	**Evaluation Findings: Indiana Lake Michigan Coastal Management Program, September 2014 to April 2021 (2021)**
Michigan	**State of Michigan Coastal Management Program and Final Environmental Impact Statement (1978)**
Minnesota	**Final Evaluation Findings: Minnesota Coastal Management Program, August 2008 to May 2018 (2020)**
Ohio	**Combined Coastal Management Program and Final Environment Impact Statement for the State of Ohio (2007)**
New York	**Coastal Management Program and Final Environment Impact Statement (2023)**
Pennsylvania	**Commonwealth of Pennsylvania Coastal Resources Management Program (2008)**

State	CZM Document
Wisconsin	**Wisconsin Coastal Management Program: Needs Assessment and Strategy, 2021-2025 (2020)**

NOAA Environmental Sensitivity Index maps

NOAA's **Environmental Sensitivity Index (ESI) maps** provide summaries of coastal resources that are at risk if an oil or chemical spill occurs nearby. Examples of at-risk resources include biological resources (such as waterbird nesting areas), sensitive shorelines (such as coastal wetlands), and human-use resources (such as public beaches and parks).

When a spill occurs, ESI maps can help responders reduce the environmental consequences of the spill and guide cleanup efforts. Additionally, ESI maps can be used by planners in advance of spills, especially in spill-prone areas, to identify vulnerable locations, establish protection priorities, and identify cleanup strategies. The ESI maps are updated periodically for each Great Lake, and the most recent update for Lake Erie was completed in 2022.

MI-EGLE AOC ecosystem services tool (GLEVER)

Although not released to the public, the Michigan Office of the Great Lakes (now part of the Department of Environment, Great Lakes, and Energy) commissioned a study by Earth Economics and ECT, Inc. to develop a decision-support tool that could quantify ecosystem service returns on restoration investments. The tool especially targeted actions in Michigan Areas of Concern. Among the outcomes of the study was a table of herbaceous wetland ecosystem services values that considered carbon sequestration, birds, fish, flood regulation, and drinking water benefits, along with several others, to arrive at an annual value per acre ranging from $1,845 to $3,531.

The influence of extreme water levels on coastal wetland extent across the Laurentian Great Lakes (Anderson et al. 2023)

Anderson et al. (2023) showed that, overall, there was a landward migration from 2011 to 2019 (although 38% of wetlands had lakeward migration of the wetland-upland border). Wetland length and inundation length decreased with increased water levels, as mediated by the presence of certain vegetation zones. This decrease in wetland extent is of concern because it likely relates to a decrease in wetland function and habitat. A better understanding of how GLCW migrate with shifts in water levels enables decision makers to better predict where Great Lakes coastal wetlands are at risk of being lost and thus where to prioritize management efforts. The findings from this publication are summarized in Figure B.1 (adapted from Anderson et al. (2023)).

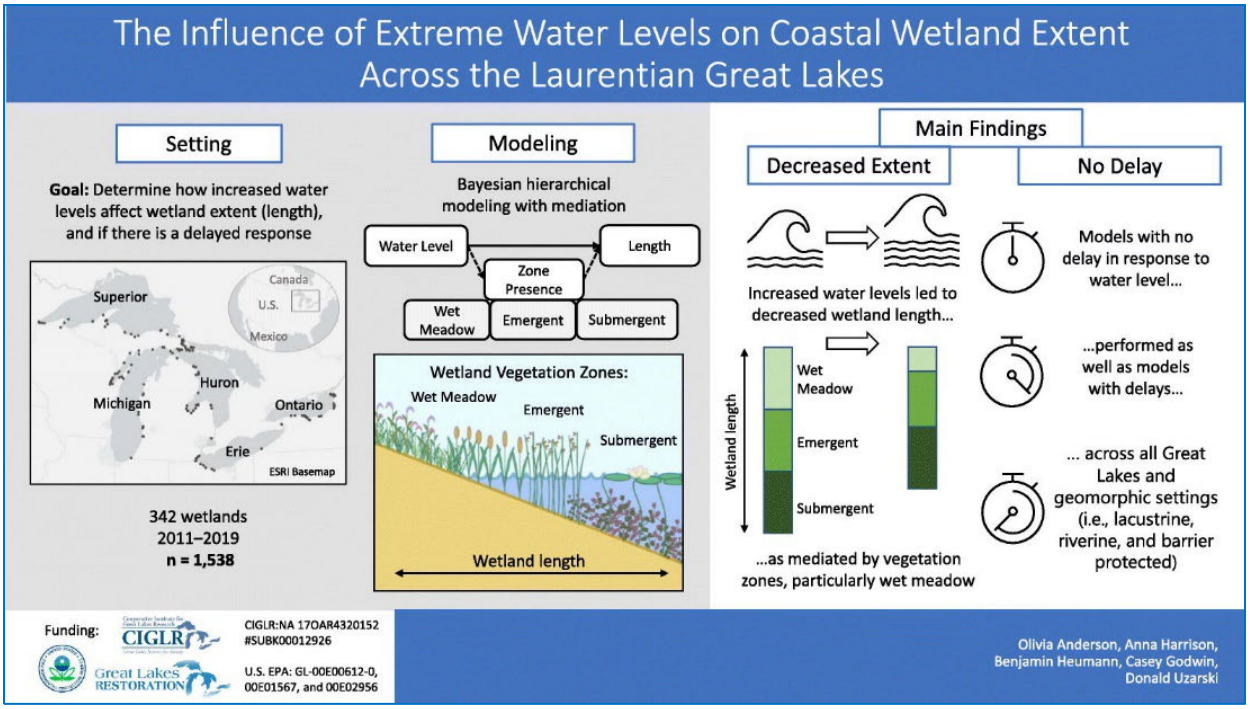

Figure B.1. Graphical abstract from the Anderson et al. (2023) paper