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MEMORANDUM

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To: Liz Berg
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Project: Great Lakes Coastal Wetland Conservation Framework
CC: Steering Team

SUBJECT: **Proposed Ecosystem Services and Indicators for the Great Lakes Coastal Wetland Conservation Framework**

Introduction

The Great Lakes Coastal Assembly (GLCA) is a binational, voluntary partnership of researchers and organizations committed to large-scale conservation of coastal wetlands in the Great Lakes region. The GLCA collaborated with over 30 organizations to develop a framework to advance Great Lakes coastal wetland conservation in the U.S. and Canada. Three objectives were defined to develop this framework:

1. Establish existing baseline extent and condition of Great Lakes coastal wetlands;
2. Determine extent and condition of coastal wetland types needed to help achieve healthy Great Lakes and coastal communities; and
3. Identify where to focus coastal wetland efforts to achieve healthy Great Lakes and coastal communities.

The GLCW Framework is intended to provide information on the current state of various ecosystem services, and to allow users to plan improvements to, or preservation of, those services through targeted conservation practices, which may include protection, enhancement, and/or restoration activities. Monitoring the response of coastal wetlands following the implementation of conservation measures is an integral part of the overall GLCW Framework, to assess the realized benefits of protection, enhancement, and restoration activities.

The Technical Team, led by LimnoTech, was tasked with developing a Lake Erie pilot of the GLCW Framework to address Objectives Two and Three, while drawing on information produced by NOAA and its contractor in support of Objective One. This technical memorandum documents the development of a set of ecosystem services and indicators of coastal wetland health and human well-being that provide the basis for addressing Objectives Two and Three. The assessment of *current status* and a proposed approach for defining the *desired status* of the indicators are addressed in a separate technical memorandum (LimnoTech 2026).

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/functions* and the "direct" ecosystem services are referred to as *human well-being needs*. The ecological services/functions of GLCWs are more easily quantifiable than human well-being needs; however, a core purpose of these indirect services is to support the human well-being needs of communities in the region.

The following sections outline the draft recommendations for both ecological services/functions and human well-being needs. In parallel with the development of the GLCW Framework, the Saginaw Bay-Western Lake Erie Wetland Conservation Blueprint ("Blueprint") project team has developed and vetted a set of ecosystem services with regional conservation partners. Because there is a desire to establish a consistent approach for defining ecosystem services across the two projects, some additions or changes to the draft ecosystem services described here may be made based on ongoing coordination with the Blueprint team.

Ecological Services and Functions

Coastal wetlands play a crucial role in supporting the ecology of the Great Lakes, providing a range of important benefits. The primary ecological services/functions that GLCWs provide to the Great Lakes include:

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

Each of these services/functions are briefly described below. Additional discussion and documentation of relevant source material is available in the GLCW Framework synthesis report (LimnoTech 2023).

Water Quality Improvement

Coastal wetlands act as natural filters, trapping sediment and pollutants to enhance the water quality of the Great Lakes. They break down organic pollutants, providing a buffering effect against runoff. The improved nearshore water quality can benefit local communities by purifying drinking water, supporting fish habitats, and enhancing nearshore aesthetics.

Wetland plants absorb and store nutrients, while organic and suspended materials trap nutrients through absorption and adsorption, promoting retention. Decomposition and microbial activity further contribute to nutrient cycling, including nitrogen removal via denitrification. This ecological service is closely tied to water quality, helping counter the impacts of eutrophication. The positive effects of retaining sediments and nutrients benefit local communities by purifying water, preventing siltation in crucial fish habitats, and enhancing the aesthetic appeal of nearshore areas.

Carbon Sequestration

Coastal wetlands may act as carbon sinks through plant biomass growth, soil organic matter accumulation, peat formation, sedimentation, and methane oxidation. These effects can mitigate greenhouse gas emissions, and potentially help address climate change impacts affecting Great Lakes communities. However, few studies have quantified the role of coastal wetlands in carbon sequestration, and uncertainty remains regarding the magnitude of carbon uptake relative to greenhouse gas production from the decomposition of organic matter in coastal wetlands.

Fish and Wildlife Habitat

Coastal wetlands serve as vital habitats for diverse plant and animal species, offering breeding, nesting, and foraging grounds for fish, birds, amphibians, reptiles, and mammals. The plant communities of wetlands, including submerged vegetation, provide shelter and sustenance for fish during crucial early life stages. Many commercially and recreationally important fish species depend on wetlands for spawning and rearing. Dense marsh vegetation, such as cattails and bulrush, provides protection from predators and extreme weather. Wetlands are also crucial for wetland birds, including migratory species, with specific areas prioritized for conservation efforts. Fish and wildlife habitat services contribute to human well-being by supporting commercial fisheries, offering recreational opportunities, preserving cultural practices, and boosting tourism and the local economy.

Coastal Protection

Coastal wetlands play a crucial role in stabilizing shorelines and safeguarding adjacent land from erosion. Their vegetation and root systems stabilize the soil structure, preventing washout by waves and currents. During storms, wetlands function as natural buffers, attenuating wave energy and reducing flooding impacts. This protection benefits communities by minimizing property flooding and preserving beaches for recreational and tourist activities.

Human Well-Being Needs

Ecosystem services, categorized into provisioning (e.g., food, water), regulating (e.g., climate control), supporting (e.g., nutrient cycling), and cultural (e.g., recreational and spiritual) services, contribute to human well-being. All categories of ecological services can support human well-being (e.g., water quality improvements for human health); however, provisioning, regulating, and supporting services tend to relate most closely to the physical and material aspects of human well-being. Cultural ecosystem services encompass the intangible, nonmaterial, and relational pathways through which people derive life-enriching and life-affirming benefits from interactions with nature, uniquely contributing to the social, psychological, and cultural aspects of human well-being.

Coastal wetlands in the Great Lakes region provide a range of cultural ecosystem 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 as being highly relevant to coastal wetland ecosystems fall under the following categories:

- Recreational Opportunities
- Tourism
- Commercial Fisheries
- Cultural and Spiritual Practices
- Sense of Place

While each of these human well-being needs categories is discussed further below, this list and the services under each category are considered draft and subject to change. Revisions should be expected as the Framework is further developed and applied. Additional discussion and documentation of relevant source material is available in the GLCW Framework synthesis report (LimnoTech 2023).

Recreational Opportunities

Coastal wetlands offer diverse, nature-based recreational opportunities, including fishing, hunting, birdwatching, boating, kayaking, hiking, and nature photography. Engaging in these activities promotes physical, psychological, and social well-being, providing exercise, relaxation, connection with nature, and social experiences. The economic impact is also notable, with the Lake Erie recreational fishery alone generating over $1.4 billion annually (Annis et al. 2017).

Tourism

Coastal wetlands attract outdoor and nature-based tourism and contribute significantly to the economies of the Great Lakes region. Lake Erie supports an $11.5 billion tourism industry in seven Ohio coastal counties alone, providing over 100,000 jobs. Northwestern Ohio's "Biggest Week" in birding, the largest spring birding festival in the U.S., generated $37 million in 2014 (Annis et al.

2017). This tourism not only benefits local communities and service providers but also offers recreational opportunities for individual visitors. Additionally, coastal wetlands support environmental education and interpretation programs.

Commercial Fisheries

Great Lakes coastal wetlands serve as critical habitats for key life stages of commercially important fish species, including yellow perch and walleye. The commercial fishing industry provides a sustainable food source, supporting local economies by offering income, employment, and livelihoods for fishers. The Lake Erie commercial fishery alone generates approximately $190 million annually in Ontario, while the combined commercial and recreational fishery in Ohio exceeds $800 million. Coastal wetlands not only support key life stages of several commercially important fish species but also provide habitat for the forage species crucial for their survival, such as rainbow smelt, emerald shiner, and gizzard shad.

Cultural and Spiritual Practices

Great Lakes coastal wetlands hold cultural and spiritual significance, with cultural practices involving the intergenerational transfer of knowledge and customs related to identifying, harvesting, and processing natural resources. Engaging in these practices supports well-being by connecting individuals to their heritage and identity. Spiritual practices, encompassing beliefs and ceremonies related to nature, are integral to various religions and individual experiences. While coastal wetlands may be important for all, their specific significance to the cultural and spiritual activities of Indigenous peoples is acknowledged. The substantial loss and degradation of these wetlands due to European settlement disproportionately impacted Indigenous peoples and diminished their opportunities to engage in cultural and spiritual practices, which have not historically been prioritized in restoration efforts. An example is the historical loss of *manoomin* (wild rice), a culturally significant species for Indigenous communities.

Sense of Place

"Sense of place" refers to people's connections and relationships with locations, shaped by the meanings they attribute to a place and the emotional attachment that results. It is a holistic cultural ecosystem service influenced by individual characteristics, the ecosystem or place, and personal experiences. Meanings for attachment can include biophysical attributes, uses, individual experiences, and social interactions. Sense of place enhances life satisfaction and well-being through various pathways. Attributes associated with "sense of place" include positive regional connections, pride, stewardship, inspiration, stress reduction, and overall life satisfaction.

Indicators of Coastal Wetland Health

With respect to Great Lakes coastal wetland health, the term “indicator” relates to a specific component that can be quantified for the purpose of assessing some aspect of coastal wetland

health for a specific spatial extent and temporal period. The following criteria were established and applied to determine which indicators should be included in the GLCW Framework:

1. Indicators must have the potential to be **influenced by conservation actions** taken on the wetland area(s) that they represent (i.e., they are expected to be responsive to protection, restoration, and enhancement actions over some time scale).

2. Indicators must be **quantifiable** now and in the future through the use of available ecological, physical, or socioeconomic data, or results from simulation models.

3. Indicator data must be **directly mappable to a specific** site or spatial region of interest. Ecological indicators of condition or health will map directly to an individual wetland or wetland region, whereas human well-being indicators may not spatially correspond to a wetland. (In the latter case, the spatial relationship to a wetland or wetland region must be supported by evidence.)

4. Indicator data must be collected on a **basin-wide scale** to ensure consistency as the GLCW Framework is implemented in future Great Lakes.

Criterion 1 was established to focus indicator selection on ecological components that should theoretically be affected by protection, enhancement, and restoration activities in the coastal wetland areas they represent (e.g., specific sites). The term "influencing variables" is used to describe wetland ecological components that meet criteria 2 and 3 but not criterion 1. Influencing variables represent potential threats and stressors to coastal wetlands but are not expected to be notably affected by restoration actions on the wetlands themselves. Those variables are further discussed in the "Influencing Variables" section below.

As part of the Task 4 existing data synthesis report (LimnoTech 2023), various coastal wetland indicators were identified from previous studies and organized into two broad (and linked) dimensions corresponding to the ecosystem service areas described in the previous section. Figure 1 displays a draft diagram linking indicator types to specific ecosystem services, grouped into the ecological services/functions and human well-being needs dimensions. Within the ecological services/functions dimension (right side of figure), indicators generally fall into either "wetland condition" or "wetland extent" categories and are directly connected to specific ecological services/functions. Wetland condition indicators directly relate to the health of specific floral or faunal communities in the wetland, while extent indicators are related to the areal coverage of wetlands (either total area or specific vegetation communities). Wetland condition and wetland extent indicators are discussed separately in the following sub-sections. All proposed indicators currently meet all three indicator selection criteria established above.

Indicators of human well-being are driven by ecological services/functions, as well as the dynamics of social systems, but they are intended to assess the realized benefits of wetland conservation actions for specific human well-being needs. While human well-being indicators will be an important component of the overall GLCW Framework, additional work is needed to identify which specific

indicators are 1) best suited to assess human well-being, and 2) will meet the appropriate selection criteria. At this time, the human well-being indicators have not been fully defined, and therefore are indicated as "to be determined" on the left side of Figure 1. Potential human well-being indicators are further discussed in a separate section below. As potential human well-being indicators are further developed, it may be necessary to revisit the three indicator criteria outlined above or develop alternative criteria specific to human well-being needs.

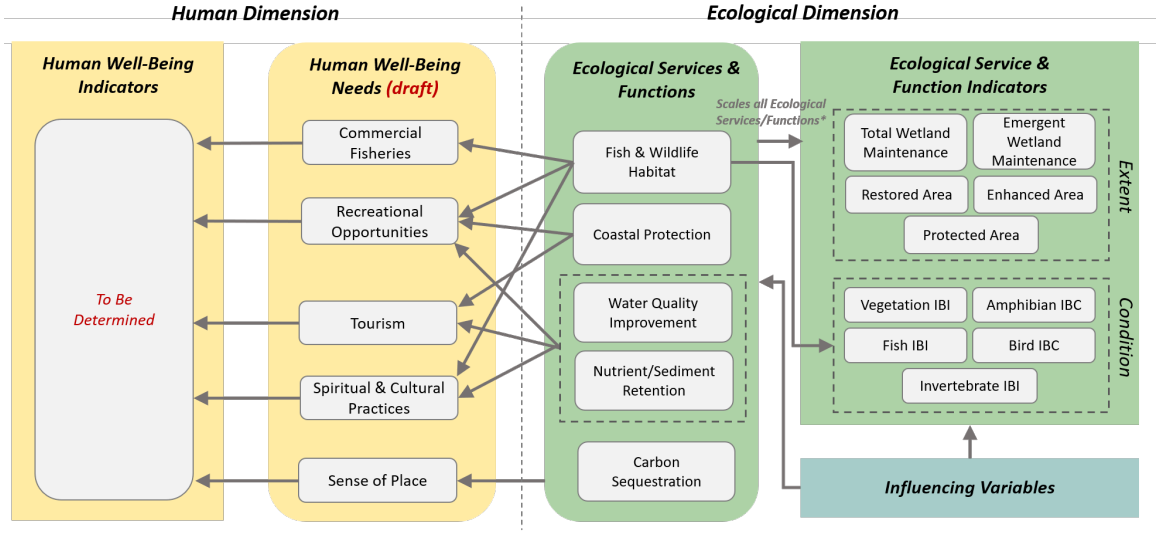

Figure 1. Diagram depicting relationships between the proposed Ecosystem Services and Indicators.

Wetland Condition Indicators

Wetland condition indicators are intended to represent the state of ecological health, typically at the wetland site level. An ecological indicator specifically designed to quantify the condition of a particular taxon group (e.g., fish) is commonly referred to as an *Index of Biotic Integrity* (IBI) or an *Index of Biotic Condition (IBC)*. However, various other coastal wetland ecological and contextual indicators have also been developed. As an example, *adaptive capacity* has become an important concept for assessing the resilience of coastal wetlands to climate change, and recent studies have made progress in defining indicators and other influencing factors to evaluate future resilience in addition to assessing present-day conditions.

The wetland condition indicators proposed for inclusion in the GLCW Framework are generally based on the Coastal Wetland Monitoring Program (CWMP), which has compiled data to quantify these indicators for 2011-2025 (Table 1). Note that the temporal and spatial coverage of monitoring data is not consistent across metrics, as some IBIs and IBCs are measured and quantified more frequently than others. As a result, data availability varies by indicator across Lake Erie.

Table 1. Coastal wetland taxa group indicators developed by the CWMP.

Metric Name	Years Available	Sites Assessed in Lake Erie (#)
Vegetation IBI	2011-2025	81
Macroinvertebrate IBI	2011-2025	8
Fish IBI	2011-2025	63
Amphibian IBC	2011-2025	92
Bird IBC	2011-2025	95

Wetland Extent Indicators

Wetland plant community dynamics are a function of the local water level regime, as inter-annual fluctuations can cause wetlands to migrate upslope or downslope in response to changes in wetting/drying cycles and water depth at various elevations. Extended high-water periods can promote upslope migration of the wetland, with trees and shrubs replaced by marsh plant species. Conversely, extended low-water periods tend to promote downslope plant migration, with submerged aquatic vegetation (SAV) and emergent communities shifting towards the lake, and trees/shrubs replacing marsh plants further downslope. Both the upslope and downslope migration of a wetland complex can be limited by barriers (e.g., urbanization or agricultural land development) that impede vegetation and habitat expansion.

Five wetland extent indicators have been identified for the GLCW Framework. Two maintenance indicators assess whether observed wetland extent meets or exceeds an expected water-level-adjusted baseline (the *Minimum Expected Area*, or MEA): (1) Total Wetland Maintenance and (2) Emergent Wetland Maintenance. These indicators use annual wetland extent data from Objective One products, combined with water-level regression models, to evaluate whether observed extent meets or exceeds the MEA in at least 80% of years over a rolling 10-year window. Three project activity-based indicators track cumulative conservation outcomes: (3) Restored Area, (4) Enhanced Area, and (5) Protected Area. Each tracks the cumulative area (in acres) of coastal wetland restored, enhanced/improved, and protected through conservation activities conducted under the Great Lakes Restoration Initiative and complementary ecological restoration efforts. See Appendix A of the "Current and Desired Status" technical memorandum (LimnoTech, 2026) for additional detail on the regression methodology underlying the maintenance indicators.

Human Well-being Indicators

Existing assessments of human well-being tied to Great Lakes ecosystem services are limited and appear to focus on objective, quantitative measures, including statistics related to the economy, tourism, and recreational activities. These indicators can, in principle, be observed in the public

domain and tend to be uniformly interpreted. Potential objective, quantifiable indicators related to human well-being could include revenue from commercial fishing, tourist counts, employment statistics, proximity to coastal wetland recreation areas, or wild rice production.

Previous research has emphasized the importance of including subjective well-being indicators alongside objective indicators to capture human well-being. Subjective indicators are not publicly observable, as they describe a person's subjective evaluations of their experiences, circumstances, and the reality in which they live. An example of a recreational opportunity is a person's satisfaction with opportunities for outdoor recreation in coastal wetlands in their community. To address the gap in human well-being monitoring and indicators, further research and funding are essential, including collecting data on both objective and subjective indicators to provide a more complete representation of human well-being. A persistent challenge is determining the role of coastal wetlands themselves in fulfilling well-being needs and quantifying their impact. Due to the direct coupling of GLCWs with the broader Lake Erie ecosystem, isolating the role of wetlands in influencing changes in revenue, employment, or subjective indices is likely to be difficult. For example, even without improvements to coastal wetlands, advances in reducing harmful algal blooms could still improve human well-being as it relates to Lake Erie.

Summary of Indicators

The previous sections describe the preliminary recommendations for ecosystem service indicators associated with the wetland condition, wetland extent, and human well-being categories. The indicators recommended for the GLCW Framework have been selected based on 1) their adherence to the three criteria outlined at the beginning of this section (i.e., influenced by conservation actions, quantifiable, and mappable to current/desired condition), and 2) the current and likely future availability of supporting data. Wetland *condition* indicators generally relate to taxa group indices that describe the state of wetland health, while wetland *extent* indicators include two maintenance indicators (Total Wetland Maintenance and Emergent Wetland Maintenance) that assess whether observed extent meets an expected water-level-adjusted baseline, and three project-based indicators (Restored Area, Enhanced Area, and Protected Area) that track the cumulative areas of impact for conservation activities. Future human well-being indicators could include measures such as tourism and commercial fishing revenue, wild rice production, and sense-of-place indices (e.g., based on surveys), among others, and will be defined in subsequent phases of work. Table 2 summarizes the coastal wetland indicators developed to date for the pilot study and recommended for inclusion in the GLCW Framework.

The indicator selection process to support Objectives Two and Three of the GLCW Framework has focused on identifying a foundational set of indicators that will support not only the Lake Erie pilot but also the application of the Framework across the Great Lakes basin. Supporting data for each indicator described in Table 2 are either currently available or will be available in the near future to support basin-wide application.

Table 2. Coastal wetland indicators recommended for the GLCW Framework.

Indicator Group	Indicator Name	Description
Wetland Condition	Vegetation IBI	Wetland plant presence, abundance, and diversity at the site scale. (Dybiec et al. 2020)
	Invertebrate IBI	Diversity of macroinvertebrate community quantified at the site scale; used to infer water quality, habitat suitability, and biological integrity. (Uzarski et al. 2004)
	Fish IBI	Composition and diversity of fish community quantified at the site scale; used to infer suitability of habitat and water quality. (Cooper et al. 2018)
	Amphibian IBC	Composition and occurrence of wetland breeding amphibians quantified at the site scale (Howe et al. 2023)
	Bird IBC	Composition and occurrence of wetland birds quantified at the site scale (Howe et al. 2023)
Wetland Extent	Total Wetland Maintenance	Determination of whether annual *total* wetland extent meets or exceeds the Minimum Expected Area (MEA) in at least 80% of years within a rolling 10-year window (based on Objective One datasets and water-level regression models)
	Emergent Wetland Maintenance	Determination of whether annual *emergent* wetland extent meets or exceeds the MEA in at least 80% of years within a rolling 10-year window (based on Objective One datasets and water-level regression models)
	Restored Area	Cumulative area (acres) of coastal wetland restored through conservation actions supported by the GLCW Framework, tracked from the Framework baseline year.
	Enhanced Area	Cumulative area (acres) of coastal wetland enhanced through conservation actions supported by the GLCW Framework, tracked from the Framework baseline year.
	Protected Area	Cumulative area (acres) of coastal wetland protected through conservation actions supported by the GLCW Framework, tracked from the Framework baseline year.

Note that due to its Great Lakes basin-scale focus, the GLCW Framework is not intended to comprehensively represent indicators that may be useful at a more regional planning scale. However, the "Site Evaluation" mode of the GLCW-DSS (DSS) will incorporate additional attributes relevant at a regional planning scale. In addition, it is anticipated that the Blueprint project will incorporate additional indicators that add value when prioritizing coastal wetland enhancement and restoration activities in the Saginaw Bay to Western Lake Erie region.

Influencing Variables

In addition to the wetland condition and extent indicators discussed previously, various external factors influence the overall health of coastal wetland habitats but are not directly affected by

conservation and restoration activities within wetland areas (and therefore do not meet "criterion 1"). These *influencing variables* provide context for the overall health of coastal wetlands, and therefore can help define baseline conditions and the resiliency of Great Lakes coastal wetlands to counteract various threats and stressors. Categories of influencing variables discussed as part of the GLCW Framework development effort include:

- Hydrological (i.e., related to water level dynamics)
- Adaptive capacity (including landscape context)
- Aquatic habitat connectivity
- Protection status
- Social system factors

Each of these categories is further discussed below. At this time, a definitive set of influencing factors has not yet been developed to support the GLCW Framework. It is anticipated that discussion regarding influencing factors will extend into future phases of the GLCW Framework development effort. In the meantime, the objective of this discussion is to establish that influencing factors affect coastal wetland health and should be considered alongside the proposed indicators of coastal wetland condition and extent when prioritizing wetland conservation actions and evaluating the realized benefits of those actions.

Hydrological

Water-level fluctuations over seasonal to interannual timescales are an important driver of 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 habitats. 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 the expansion of native species while limiting the spread of invasive species such as *Phragmites* (common reed) and *Typha* (cattail). It is anticipated that water-level data will be incorporated into the GLCW Framework Decision Support Tool to support analysis of coastal wetland indicators and of current and desired statuses.

Adaptive Capacity

Adaptive capacity may represent either specific habitat characteristics of a wetland (e.g., invasive species coverage) or contextual information about the surrounding landscape or watershed. Such variables focus on how well a wetland can adapt to environmental and anthropogenic stressors, rather than strictly assessing the wetland's present-day ecological condition. For example, the *Water Quality and Land Use Index* ("WQLU Index"), which has been developed based on the robust CWMP

water quality dataset (Harrison et al. 2020) and geospatial analyses, is an influencing factor that quantifies land use conditions within the adjacent/contributing watersheds and the resulting water quality conditions within coastal wetlands. Specifically, the WQLU Index generates a relative ranking of sites based on observed concentrations of nutrients, chlorophyll *a*, and other constituents integrated with land cover data available from the North American Land Change Monitoring System (NALCMS). WQLU Index results are available for approximately 75 coastal wetland sites in Lake Erie and hundreds of other sites across the Great Lakes basin for the 2011-2025 period.

Aquatic Habitat Connectivity

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. It is anticipated that the GLCW Framework Decision Support Tool will eventually incorporate information quantifying habitat connectivity across different regions of the Great Lakes.

Protection Status

The level of federal or local government protection of coastal wetlands and surrounding lands can determine where and how restoration activities may occur. This information provides important context for where planning efforts should be focused. It is anticipated that information on protection status across different regions, or even at more local scales, will eventually be incorporated into the GLCW Framework Decision Support Tool.

Social System Factors

In addition to the potential indicators of human well-being needs discussed above, several social system factors can influence these indicators but may not be directly affected by conservation efforts in coastal wetlands. For example, access to services that GLCWs provide to enrich human lives (e.g., provisioning, tourism, and sense of place) can be affected by social constructs such as economic status, proximity to coastal wetlands, and the presence of infrastructure to facilitate access. Additionally, a lack of education and awareness about the historical importance and present-day benefits of these services may limit their use by some communities.

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