Great Lakes Coastal Wetlands Monitoring Plan

Developed by the
Great Lakes Coastal Wetlands Consortium,
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Executive Summary

This document represents nearly seven years of work that has resulted in a long-term plan to monitor Great Lakes coastal wetlands using a scientifically validated sampling design and suite of indicators and metrics developed by many project partners. It includes a thorough cost analysis chapter that describes estimated costs associated with each element of the plan. The document should be of great value and benefit to agencies planning to incorporate coastal wetland monitoring into their overall monitoring strategy.

This document recommends multiple biological protocols and metrics for monitoring the condition of Great Lakes coastal wetlands – including those for plants, invertebrates, fish, amphibians, and birds. Also recommended is a design for sampling Great Lakes coastal wetlands that allows users to monitor condition of these wetlands on an annual basis. With a combination of repeated site visits and random sampling of other wetlands on an annual basis, users can establish status and trends (positive, negative, no change) of wetland condition for a given site, region, or for all Great Lakes coastal wetlands.

The objective of environmental monitoring is to establish the condition of ecosystems relative to reference conditions (the least impacted ecosystems in the area being monitored) and track changes in condition through time. Monitoring data are used to establish baseline conditions, temporal trends and compliance with regulatory requirements. Comprehensive monitoring is important to detect subtle changes to the environment that could have long-term negative consequences if not recognized and addressed.

The Great Lakes have benefited greatly from environmental monitoring. Decisions made by considering the results of effective monitoring programs have permitted the Great Lakes community to set fish consumption guidelines; better understand the health of Great Lakes fisheries; curb the loss of important wetlands; maintain safe air and drinking water; post public beach closings to avoid illness; control the introduction of invasive species through early detection; and maintain high water quality standards. These are just a few of the many benefits of maintaining a robust environmental monitoring regime in the Great Lakes basin (Great Lakes Commission, 2006).

In the 1990s, the need for environmental indicators measuring the integrity of Great Lakes coastal wetlands was identified, and many scientists and regulators around the Great Lakes began to work toward developing indicators that could be used to effectively monitor coastal wetland quantity and quality. In 1994, a seminal paper by The Nature Conservancy's Great Lakes Program titled *The Conservation of Biological Diversity in the Great Lakes Ecosystem: Issues and Opportunities*, called attention to Great Lakes coastal wetlands as "a system distinct to the Great Lakes." Further, the authors underlined the value of Great Lakes coastal wetlands to the Great Lakes as a whole in the following excerpts from the paper:

> *"They [Great Lakes coastal wetlands] are ecologically unique because they are dominated by large lake processes such as water level fluctuations, wave actions, and wind tides or "seiches." Spanning a diversity of types and the full geographic range, including freshwater estuaries, lagoons and deltas, Great Lakes coastal wetlands play a pivotal role in the aquatic ecosystem of the Great Lakes, storing and cycling nutrients and organic material from the land into the aquatic food web. They sustain large numbers of common or regionally rare bird, mammal, herptile and invertebrate species, including land-based species that feed from the highly productive wetlands. Most of the lakes' fish species depend upon them for some portion of their life cycles. Large populations of migratory birds rely on them for staging and feeding areas. Short- and long-term fluctuations in lake levels play a critical role in maintaining both wetland and shoreline systems. The processes of sediment inputs and longshore transport are important in maintaining bars and spits that shelter waters of many highly productive wetlands."*

Papers presented at the 1996 and 1998 State of the Lakes Ecosystem Conferences (SOLEC) reported on the status of Great Lakes coastal wetlands. Authors concluded that Great Lakes coastal wetlands were a valuable resource, but that no system was in place to determine their status or to track wetlands losses, degradation or improvements in condition. Furthermore, although many organizations focused resources on specific Great Lakes coastal wetlands and related issues, no one entity had responsibility for data collection and interpretation to determine basinwide status and trends and/or disseminate results.

To continue development of indicators and coordinate efforts leading to future Great Lakes coastal wetland monitoring, the U.S. Environmental Protection Agency Great Lakes National Program Office (U.S. EPA-GLNPO) sent out a request for proposals (RFP) in spring 2000 for consortia to design an implementable, long-term program to monitor Great Lakes coastal wetlands. The U.S. EPA-GLNPO considered the creation of a consortium, an approach that could meet these purposes and capitalize on the existing mandates and authorities of the organizations already working on Great Lakes coastal wetlands. The Great Lakes Commission submitted a proposal in response to the RFP and was awarded a grant to begin this work.

Thus, the Great Lakes Coastal Wetlands Consortium (Consortium) was formed in 2000 with the goal of producing a cohesive, long-term plan to monitor Great Lakes coastal wetlands. The Great Lakes Commission served as secretariat for the Consortium and, through the efforts of many partners, this plan has been completed. Since inception of the Consortium, more than 50 organizations have contributed to this plan from initial pilot studies, to development of a Great Lakes coastal wetlands inventory and classification system, drafting of final coastal wetlands monitoring protocols, to the design of a publicly accessible international database. The partners included scientific and policy experts drawn from key U.S. and Canadian federal, state and provincial agencies, nongovernmental organizations, academia, and members of other interest groups with responsibility for coastal wetlands monitoring.

The following are summaries of each aspect of the plan. The details of the plan have been included in the individual chapters that follow:

Statistical Design

The sampling design specifies how wetlands should be selected and the number, type and location (spatial and/or temporal) of wetland sampling units that are assessed. The paramount purpose of sampling designs within the context of the Consortium's recommendations for monitoring is to ensure that data collected are representative of an area and are of adequate scope to support defensible (statistical) inference. This permits one to draw logical conclusions about wetlands in federal, tribal, regional, state and provincial areas of responsibility while maintaining the standardized sampling protocols necessary to draw conclusions regarding wetlands at the entire basin level. Deciding how to sample is often difficult because one must consider trade-offs between costs and benefits of the amount and type of sampling undertaken. Thus, any sampling design represents a balance between the study objectives and the constraints of cost, time, logistics, safety and existing technology.

Many aspects of statistical design (in italics below) are addressed in this chapter, including those involving target populations and sampling frames (Figure 1-1), allocation and arrangement of samples (*membership design*), frequency of sampling occasions (*revisit design*), measurements to be taken at sampling locations (*response design*), and the number of samples required to meet stated objectives (*sample size*).

Chemical/Physical and Land Use/Cover Measurements

Basic chemical/physical parameters should be measured, and on-site observation of disturbance should be recorded at the same time that biological sampling is undertaken. These data will be used as covariates, helping to account for some of the statistical variability encountered during data analysis as well as providing the necessary information to develop additional metrics for quantifying ecosystem health. Sampling and analytical procedures should follow those recommended in Standard Methods for the Examination of Water and Wastewater (APHA 1998) or accepted U.S. EPA, U.S. Geological Survey, Environment Canada, or other operating procedures as dictated by local agencies. It is understood that logistic constraints may preclude the collection of some of these data, but it is essential that as many as possible are collected.

This chapter discusses several elements related to chemical/physical and land use/cover measurements that are important considerations for a coastal wetlands monitoring program. These elements include:

- Ensuring use of properly serviced and calibrated equipment and detailed check-box field data sheets;
- Which parameters should be considered and included in the sampling design if deemed relevant and budgets allow;
- Quality assurance/quality control procedures;
- Site assessment protocols; and
- General Interpretation of Covariates.

Vegetation Community Indicators

Emergent and submergent plants have been sampled in Great Lakes coastal wetlands for the purposes of classification, identification of wetlands important for protection or acquisition, and characterization of wetlands for management. Sampling has often been conducted along transects with the purpose of identifying physical gradients and corresponding biological gradients or zones. Relatively discrete vegetation zones occur at most coastal wetland sites due to differences in water depth, substrate, and exposure to wind and wave energy. Wave energy also affects wetland vegetation diversity. Plant sampling should be conducted in a way that insures that major plant zones are included at each site. Sites should also be subdivided by major coastal wetland type (riverine, drowned rivermouth, open embayment, closed embayment). A classification of coastal wetlands was developed by the Consortium (Appendix A at the end of this document) and is also available on the Consortium's web page at www.glc.org/wetlands.

Plant community attributes that correlated with marsh condition for all five of the Great Lakes were based on (1) identifying and quantifying the distribution and coverage of invasive plants for major plant zones and overall; (2) identifying significant changes to the submergent and floating-leaved vegetation of the emergent and submergent marsh zones; and (3) comparing regional Mean Conservatism Indices for Great Lakes coastal wetland types to a local site's Mean Conservatism Indices by plant zone and overall. These three attributes were incorporated into nine metrics by dividing plant zones into wet and dry portions of the plant zone. Protocols for collecting each set of data include a choice of using transects across the zones or using a sampling procedure with quadrats sampled by randomly selected locations within a randomly selected subset of grid elements.

Invertebrate Community Indicators

The invertebrate Index of Biotic Integrity (IBI) proposed and tested by Uzarski et al. (2004) appears to be the most appropriate and most broadly applicable means of assessing invertebrate community condition currently available for Great Lakes coastal wetlands. Other metrics are available for additional classes of wetlands, but they require data collected by field methods that differ slightly or substantially from those of Uzarski et al. (2004). These alternative methods are included where possible for comparison. Furthermore, because these alternative IBIs are either still in development or testing phase, or have not been quantitatively assessed against well-defined gradients of anthropogenic disturbance, it is premature to recommend their use. Thus, the Uzarski et al. protocol is recommended for sampling using the same protocol for all vegetation types and for all types of Great Lakes coastal wetlands. Metrics can be tested using data collected in the monitoring program and modified appropriately to extend to other wetland types not included in the Uzarski et al. publication. Alternative protocols can also be developed using procedures developed by others after they have been cross-tested against the Uzarski et al. protocol.

Fish Community Indicators

Great Lakes coastal wetlands provide critical habitat for more than 80 species of fish (Jude and Pappas 1992). More than 50 of these species depend upon wetlands while another 30+ migrate into and out of them during different periods in their life history (Jude and Pappas 1992, Wilcox 1995, Wei et al. 2004). An additional 30+ species of fish may be occasional visitors to coastal wetlands based on occurrence in adjacent habitats (Jude and Pappas 1992, Wei et al. 2004).

Fish have long been included as key indicators in assessment of biotic integrity in streams (e.g., Karr et al. 1986, Lyons and Wang 1996) and to a lesser degree in lakes (e.g., Fabrizio et al. 1995, Whittier 1998) and estuaries (e.g., Jordan et al.1991, Deegan et al. 1997). Fish had historically received little attention as indicators of wetland condition, but recognition of their ecological significance in Great Lakes coastal wetlands (Jude and Pappas 1992) generated considerable interest in using fish as indicators for these habitats (Wilcox et al. 2002, Timmermans and Craigie 2003, Environment Canada and Central Lake Ontario Conservation Authority 2004, Uzarski et al. 2005).

This chapter provides step-by-step detail of the Consortium-developed fish IBI, which is based on multiple metrics for *Typha* (cattail) & *Schoenoplectus* (bulrush)-dominated wetlands in relation to water quality and agricultural/urban land-use stresses (Uzarski et al. 2005). The chapter also compares the Consortium-developed monitoring protocols to alternative methods developed using fish as an indicator for coastal wetland health. The fish metrics have been tested for all five Great Lakes and can be utilized across the basin at present. These metrics can be modified and improved using data collected as the monitoring program is adopted basinwide.

Amphibian and Bird Community Indicators

Being directly associated with the Great Lakes hydrological influences, lacustrine or coastal wetlands are among the most important wetlands that occur within the Great Lakes basin. A high proportion of the Great Lakes basin's wildlife species inhabit wetlands during part of their life cycle, and numerous bird species federally listed as threatened or endangered in the United States or of conservation concern in Ontario are associated with wetlands. Although much is known about many landbird species of the Great Lakes, the ecology of most marsh-dependent birds has received much less attention, and relatively little is known about species such as rails and other secretive marsh birds.

Similarly, several frog and toad species are associated with wetlands of the Great Lakes basin. Amphibians rely heavily on aquatic environments for reproduction and other life sustaining purposes. Most amphibians inhabit wetland environments during most or part of their life cycle, and among the amphibian class, frogs and toads generally rely most heavily on wetland systems. Amphibians may also be the most sensitive vertebrates to aquatic and atmospheric pollution, and therefore may be deemed highly useful early warning indicators of wetland pollution and habitat degradation.

As recently as the 1990s, researchers began to realize that marsh bird and amphibian populations were declining in the Great Lakes basin. However, the magnitude and geographic extent of these declines was still uncertain. The uncertainty surrounding the nature of the declines was primarily due to lack of extensive, scientifically rigorous, consistently collected data, as well as a lack of detailed population information on localized metapopulations.

As a result of the loss and degradation of marsh habitats throughout the Great Lakes basin, there was increasing concern among citizens and scientists that continued stresses, including urban, industrial and agricultural development were negatively affecting marsh-dependent wildlife populations and other marsh functions such as water quality improvement. Consequently, Bird Studies Canada (BSC), in partnership with Environment Canada, developed the Marsh Monitoring Program (MMP) in Ontario in 1994. With substantial financial support from U.S.

EPA-GLNPO and the Great Lakes Protection Fund, the MMP was launched binationally throughout the Great Lakes basin in 1995 and has continued to operate annually since.

The methodological framework used to create coastal wetland indices of biotic integrity (IBI) relied on nine years of MMP data and was similar for both the bird and anuran communities. Within each community, attributes (e.g., species richness and abundance of marsh birds, species richness and presence/absence of anurans) that responded significantly to disturbance across sites were identified. The field-based values for responsive attributes (called metrics) were standardized. All metrics were then combined to give a quantitative measure of the condition of the community.

The marsh bird community IBI incorporated guilds that represent disturbance-sensitive marsh-nesting birds and general marsh-users. The metrics used were (1) abundance of non-aerial foragers, (2) abundance of marsh nesting obligates, and (3) species richness (number of species present in a sample) of area-sensitive marsh nesting obligates.

The amphibian community IBI also incorporated three metrics: (1) total species richness, (2) species richness of woodland species, and (3) probability of detecting a woodland species within the wetland.

The bird and amphibian IBIs were developed using sites in the Great Lakes basin within Ecoregion 8 (i.e., Southern lakes Huron and Michigan, all of lakes Ontario, Erie, St. Clair and connecting channels). Therefore, these IBIs should be limited to reporting on coastal wetland sites within this geographic area. Site size might also be a limiting factor for this approach, as there is evidence that suggests IBIs incorporating a guild approach might not provide accurate measures of marsh bird community condition in sites composed of less than 10 hectares of emergent marsh.

Landscape-Based Indicators

The Landscape chapter defines the role of landscape data in wetland monitoring, assesses landscape scale monitoring methods and data sources, and identifies an operational strategy for recurring assessment of the extent, composition and vigor of coastal wetland complexes and the surrounding landscape at a synoptic scale. The chapter provides background information on landscape methods to monitor coastal wetlands, and describes various remote sensing resources, tools and techniques. Because coastal wetland monitoring needs exist at the local, county, tribal, state, provincial and federal levels, the methods described are designed to provide flexibility in the sources of data used for landscape mapping and monitoring, as well as the ability to tailor them toward specific needs and budgets of each project. At the same time, it is important to provide some general protocols on classification schemes and landscape monitoring to keep the end products consistent enough for merging with adjacent maps created by other agencies, and for comparison to future maps.

The Landscape chapter describes the indicators and assessment and management programs that landscape metrics would inform. It also discusses details of landscape monitoring (e.g., sampling design, data sources and limitations, methodological innovations) and how they can be used to construct stressor gradients. Recommendations for a landscape monitoring protocol are provided. The chapter also describes and analyzes the Consortium's wetland inventory, which was assembled from various landscape data sources and is itself a spatial data set for intersecting with other landscape data layers.

To support Great Lakes coastal wetland monitoring, assessment and management into the future, a two-tier wetland mapping system is recommended, combining (1) a moderate (30 m) resolution satellite-based mapping of the entire basin every five years; and (2) a high resolution (< 1 m) airborne or satellite-based map of one lake basin per year on a rotating basis. This two-tier approach would provide a consistent baseline map from synoptic data sources using semi-automated techniques at the regional scale every five years, as well as a fine resolution map allowing more detailed discrimination of wetland boundaries and landscape land use and land cover. Using satellite data allows for multi-temporal and multi-spectral analysis to map wetlands that are dynamic throughout the seasons and allows automated change detection techniques to be used to update existing maps such as those of the National Wetlands Inventory (NWI). Note that highly sensitive areas (e.g. wetlands in high population areas or areas of rapid land cover/land use change and those with aggressive invasive species) will need to be mapped at high resolution with greater frequency.

Coastal wetlands are impacted by both local factors and stressors acting at the watershed scale; hence assessment and monitoring should quantify stressors operating at both spatial scales. The protocols described in this chapter are designed to monitor key landscape indicators that quantify watershed-scale changes relevant to coastal wetlands. The basic strategy is to (1) identify data sources that are updated regularly across the basin; (2) define watershed-scale spatial summary units appropriate for coastal wetlands; (3) enumerate key landscape metrics for these units; and (4) describe a monitoring process that allows identification of trends in key landscape stressor variables across the basin. The techniques and information in this chapter can be used in conjunction with field-based indicators described in other chapters to evaluate relationships among the broader landscape conditions and the condition and functions of coastal wetlands. The use of remote sensing data allows for a repeatable and comprehensive view of broad spatial characteristics across the Great Lakes basin (e.g., to produce landscape metrics and indicators), providing opportunities to capture the instances and magnitude of disturbances, which may, in turn, affect – or already have affected – coastal wetland condition and functions.

Cost Analysis for Sampling Great Lakes Coastal Wetlands

Great Lakes coastal wetland monitoring involves many possible costs including paying and training staff, buying equipment, travel expenses, and processing of samples. Funding availability often determines how much sampling is feasible; therefore it is important to evaluate cost as a factor in developing a wetland monitoring program.

During the course of this project detailed cost estimates were assembled and analyzed for the following indicators: water chemistry, plants, invertebrates, fish, amphibians, birds, and landscape attributes. Cost estimates for each indicator included:

- each item of equipment needed to sample each indicator and whether it is likely to already be owned, if it is shared by several indicators, and if it is consumable;
- salaries for technicians and professionals involved in sampling;
- the length of time it takes each person to sample each wetland for each indicator;
- time needed to train staff in the protocols for sampling each indicator;
- external lab processing of water chemistry and invertebrate samples; and
- automobile and boat travel (per mile/kilometer).

These cost estimates formed the basis for the development of a spreadsheet-based Wetland Sampling Cost Estimator Tool. This tool presents cost information in a format most useful for monitoring agencies since it allows them to test an almost unlimited variety of scenarios and evaluate the relative differences in cost. Members of the Consortium evaluated and verified the Cost Estimator Tool and its underlying assumptions and cost formulas.

Data Management System

Because of the breadth of potential users of the Consortium's coastal wetlands monitoring plan, there is clearly a need for a mechanism to facilitate communication and data sharing. In response, the Consortium's data management group developed a standardized approach that could be applied across the region, allowing data to be easily shared by researchers and sponsoring agencies. A centralized, online Data Management System (DMS) has been implemented. The DMS described in the Data Management chapter of this document is designed to allow data to be recorded in standardized formats and placed in a data archive housed within the Consortium website.

The Consortium DMS is considered a first generation system and will be fine-tuned as problems arise during its use by managers, regulators and others. It accepts data files prepared using a standardized data template compatible with Microsoft Excel and other spreadsheet software and stores the data on the Consortium web site and data server. From there, files can be downloaded and used as needed. The data template approach was chosen during the DMS design phase because it allowed system development to take place while scientific subcommittees finalized protocol content. Future versions of the DMS will include the capacity to upload raw data and to select and retrieve data based on more refined criteria.

The DMS is housed within an online database programmed using standard php/MySQL software. The user interface consists of background information about the Consortium and the DMS, a log-in page, and data submission and retrieval forms. As a means of protecting the integrity of the database, users are required to register before they can upload data. Active members of the Consortium's development committees were registered when the system was created. New users must submit a registration request via the DMS log-in page. Individuals retrieving data are asked to register as a means of tracking the distribution of the Consortium's products.

Partnerships for Implementation

In 2001 and 2002, initial stakeholder meetings of the Consortium were held in the U.S. and Canada to raise awareness of and receive input toward developing a science-based, binational coastal wetland monitoring plan for the Great Lakes. Presentations and discussion groups were used to begin partner engagement. Since then, the Consortium has been a significant presence at SOLEC, where representatives from agencies and organizations from around the basin meet to discuss indicators that assess environmental condition of the Great Lakes. The biennial SOLEC conferences have offered a venue for presentation of Consortium monitoring protocols and results from pilot investigations.

From the beginning, it was clear that agencies and organizations wishing to adopt Consortium protocols would need assistance in implementing this monitoring plan and forming partnerships to optimize use of staff, funding and equipment resources. Consequently, the Consortium Partnerships for Implementation Committee (PIC) was formed to promote awareness of and execution of this plan.

The PIC identified agencies and organizations that conduct coastal wetland monitoring or other wetland monitoring activities in the Great Lakes basin. It used the Great Lakes Commission's 2006 report *Environmental Monitoring Inventory of the Great Lakes Basin*, which assessed gaps and overlaps in observing systems and monitoring programs. The gap analysis summarized monitoring efforts for 21 resource areas, highlighted potential gaps in monitoring coverage, and provided recommendations to address the gaps.

The PIC surveyed agencies and organizations that might benefit from adoption of the Consortium's basinwide, standardized monitoring protocols and assessed whether these entities would have the capacity to conduct this monitoring. Survey questions addressed aspects of current or former coastal wetland monitoring activities, staff or volunteer expertise, available equipment, funding mechanisms, and protocol training requirements.

Finally, the PIC developed an implementation strategy for presentation to potential partner agencies, in order that the process of adopting (or adapting) this plan would be less daunting for those that already lack sufficient resources. This strategy includes adaptive management techniques to make adoption of the plan more seamless.

Although implementing new programs can be difficult for many agencies due to funding, equipment, and staff limitations, the PIC found that a number of agencies and organizations throughout the Great Lakes basin are already conducting monitoring programs that, if willing, could fully or partially adopt or adapt Consortium protocols. In addition, the PIC identified a number of partnership opportunities that could assist in the implementation of this plan.

Adoption or adaptation of the Consortium coastal wetland monitoring protocols can aid agencies in satisfying monitoring mandates and contribute to the goals set forth in SOLEC, the Great Lakes Regional Collaboration (GLRC), the Great Lakes Water Quality Agreement (GLWQA), and other important cooperative efforts. The recruitment of agencies and the formation of partnerships among those agencies will lead to greater success when implementing this plan. Accurate, standardized monitoring data, of which this plan will produce when implemented, is in the best interest of many Great Lakes stakeholders.

Final Summary Recommendations

In this chapter, we recommend an integrated sampling program for the entire basin that includes plant, invertebrate and fish metrics, with time of sampling periods recommended that allows a small crew of three trained individuals to gather, analyze and interpret the required data for parts of the Great Lakes shoreline in a particular jurisdiction with aid from several seasonal workers. For large states and provinces such as Michigan and Ontario with responsibility for multiple lakes and many miles/kilometers of lake shore, two or more such crews would be needed. These individuals would also work with trained volunteers using MMP protocols to generate the amphibian and bird data.

Chapter 1
Statistical Design

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Sampling design

Sampling design is a description of the sample collection plan that specifies the number, type, and location (spatial and/or temporal) of sampling units to be selected for assessment. The paramount purpose of sampling designs -- within the context of the Consortium's recommendations for monitoring -- is to ensure the collection of data that are representative of an area and of adequate scope to permit one to draw logical conclusions about a population of interest. But deciding how to sample is often difficult, because one must consider trade-offs between the costs and benefits of the amount and type of sampling undertaken. Thus, any sampling design represents a balance between the study objectives and the constraints of cost, time, logistics, safety and existing technology.

One must also make numerous practical and statistical decisions to be confident that a sampling design and indicator measurements provide the necessary "vital sign" information (Busch and Trexler 2003). The following questions can help make those decisions:

- What are the defining spatial boundaries of the ecological system?
- What is the appropriate temporal frame (time of year) for sampling?
- What is the appropriate time interval between samples?
- What sample size is necessary to estimate the value of the indicator?
- What survey design is most efficient (random, systematic, stratified random)?
- What is the appropriate unit of measure for the indicator variable?
- Is there an optimal sample unit size and shape for estimating the value of the indicator?
- What are the trade-offs between gains in precision and statistical power versus the additional costs per sample?
- How can the implementation plan be designed so that uncertainty about the true state of the ecological system is minimized?

Many of these questions are addressed in this chapter, including those involving target populations and sampling frames (Figure 1-1), allocation and arrangement of samples (*membership design*), frequency of sampling occasions (*revisit design*), measurements to be taken at sampling locations (*response design*), and the number of samples required to meet stated objectives (*sample size*). Italicized terms are described later in this chapter. Sampling designs, within the context of the Consortium's recommendations for the intended implementation plan, encapsulate the series of decisions that dictate where, when, and how to sample a "vital sign" indicator (e.g., the indicator nitrate as a measure of wetland water chemistry) (Elzinga et al. 2001). A sound sampling design requires clear and concise monitoring objectives and must be flexible.

Because the intent of this document is to propose a robust implementation plan that can meet the needs of the Great Lakes coastal wetland science community and policymakers well into the future, the designs must be able to accommodate changes in management and funding priorities, as well as environmental changes. Likewise, the description of a good sampling design should be appropriately concise, understandable and manageable. Overly complex designs can be confusing and may make an implementation plan less accessible to its key audience, few of whom are likely to be familiar with statistics and sampling design theory. Therefore, a description of an implementation plan should begin simply and add complexity conservatively and only when needed to explain how to achieve specific objectives. Of course, to monitor the health and integrity of a coastal wetland, some level of complexity cannot be avoided, particularly when the region of interest is large, remote, spatially complex and difficult to access (McDonald and Geissler 2004).

Since monitoring objectives call for estimating the *status* of wetlands in a region, *trends* in their condition, or both, these two terms are used explicitly in this chapter and follow definitions given by Urquhart et al. (1998) and McDonald(2003). **Status** is a measure of a current attribute, condition or state, and is typically summarized as a population mean. In the case of assessing wetland **status**, the population consists of all wetlands in the region of interest. So "wetland status" describes the average condition of all wetlands in an area at a specific time. **Trend** is a measure of change through time. This change can refer to a population parameter such as a mean (*net trend;* i.e., change in the average condition of wetlands through time), or of an individual member or unit of a population (*gross trend*; i.e., change in the condition of one specific wetland of interest through time). Status is typically estimated by sampling many different units (different wetlands) throughout the area of interest during a single time interval. In contrast, the study of trends requires repeated sampling, sometimes of the same wetlands, and sometimes of different wetlands. The question of whether the program goal is to estimate status, trends or both is one of the first and most important things that must be addressed.

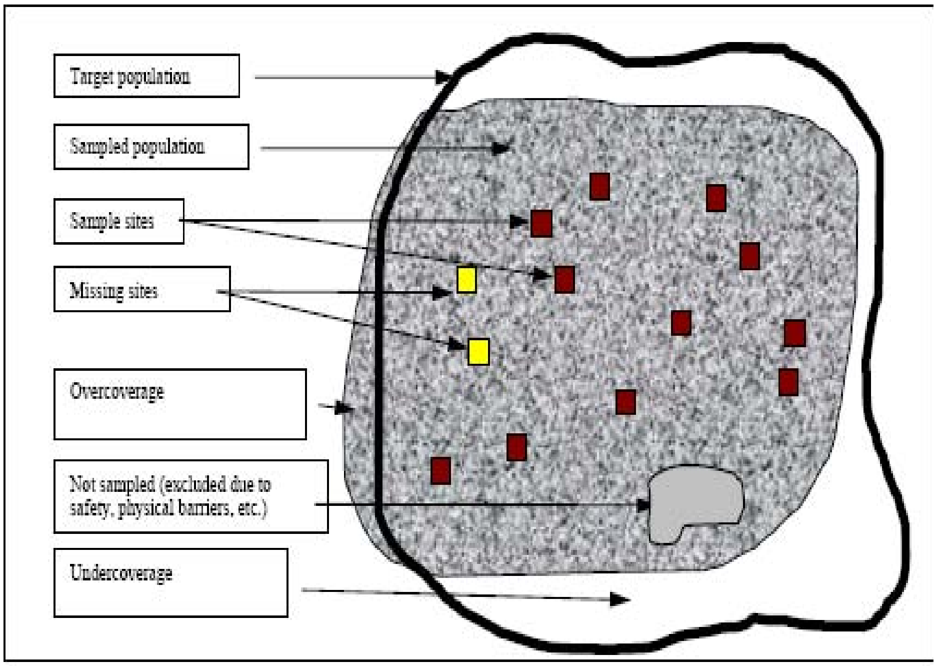

Figure 1-1. Conceptual illustration of terms used to describe various units associated with sampling a population of interest. Each square represents a different wetland within the sampling region of interest.

The first step in developing an implementation plan is to define the geographic bounds of the region of interest and perform an inventory of all of the study units (wetlands) within the region. The complete set of study units (study units = wetlands) in the region is the **target population** (Figure 1.1). Some portion of the region may be inaccessible or otherwise unsuitable for evaluation. Consequently, we compile a subset of units that can be sampled, and these together make up the **sample population.**

The next important step when developing a sampling design is to define the environmental units of interest within a specified study area (Figure 1-1). A population consists of **elements**, i.e., the objects on which a measurement is taken (Scheaffer et al. 1990). This is the basic "unit" of observation. In our case, the elements are the individual wetlands. The implementation plan becomes defined by selecting a sufficiently representative subset of units (wetlands) for sampling (indicated by squares in Figure 1-1).

Sampling unit refers to the place that is actually sampled. We quantify our target population by using a **sampling frame**, defined as the collection of sampling units. A **sample** is a subset of units chosen to evaluate the condition of each unit through counts, observation, or other form of measurement. If the sampling units are selected using some type of random draw, the sample is said to constitute a **probability-based sample** (because it is equally likely that any unit could have been chosen). Whenever possible, a probability-based sampling design should be used. This lets us argue that the "average" value calculated for the wetlands sampled truly represents the sample population as a whole.

If estimates of average condition are biased because the locations were not completely randomly chosen, they are subject to "nonsampling error" (Lessler and Kalsbeek 1992). Nonsampling error reduces the precision and accuracy of estimates. Lessler and Kalsbeek (1992) identified three components of nonsampling error, some of which may be unavoidable.

1. Frame error results when the sampled population is very different than the target population (Figure 1-1). The two types of frame error are overcoverage and undercoverage. Overcoverage occurs when the sampled population contains elements that were not part of the target population. Undercoverage occurs when elements of the target population are omitted from the sampled population.
2. Nonresponse error results from the failure to obtain measurements for all of the samples originally selected (yellow squares in Figure 1-1). When the missing measurements are very different from the values obtained from the wetlands that could be sampled, the estimates calculated from the available data may be biased.
3. Measurement error is defined as the difference between the measurements obtained during sampling and the true value of the measure. This can result from observers' detection errors or from using inaccurate instruments.

Once the target population and sampling frame have been determined, a strategy must be developed for determining how many samples should be collected, allocating the sampling effort appropriately across the sampling frame, determining (randomly) which specific wetlands in a subregion should be sampled, and timing the visits for sampling. Most sample designs selected for use with Consortium-developed metrics will involve rotating field sampling efforts through various sets of sample units over time. In this situation, it is useful to define a **panel** of sample units. A panel is a group of wetlands whose members are always sampled together according to a schedule of repeating "revisit" time periods (Urquhart and Kincaid 1999, McDonald 2003). See Figure 1-2 for a schematic representation of different revisit designs.

The rules by which units (wetlands) in the population become members of a panel are called the **membership design** (McDonald 2003). Membership design specifies the spatial allocation procedure. One familiar membership design strategy is simple random sampling. This procedure involves drawing units from a population at random (i.e., with equal probability). Unfortunately, this often fails to produce an ideal spatial pattern of samples across the study region because the habitat itself may be spatially uneven. In particular, simple-randomly selected samples can often be patchily distributed or clustered, leaving large areas of the frame unsampled. An alternative is to draw a spatially balanced random sample following the methods described by Stevens and Olsen (2004). This method involves splitting the sampling frame into a number of zones (strata) and randomly selecting the required number of sampling units from within each zone. This "stratified-random" approach allows for a spatially balanced, random draw of samples with variable inclusion probabilities. Often, a designer generates an ordered list of sample units for each stratum that can support additions and or omissions of sample collections while retaining spatial balance. These features provide considerable flexibility and efficiency to a sampling design.

Index sites – also known as *sentinel* or *intensive* sites – are sampling locations that are (i) visited repeatedly and regularly, (ii) sites where more detailed measures are made, or (iii) both. Conversely, a **survey** (or *extensive*) site is a sampling location that is visited once or on an irregular basis, or where less detailed measures are obtained. Generally, "always" visiting a sampling site provides data that are most useful for detecting temporal variation (trends). The data array from this type of design would look like Table 1-1 (from Urquhart et al. 1998), except that the rows would represent the selected set of wetlands, rather than all of the wetlands. This balanced data structure has substantial appeal, and is the design most monitoring personnel and ecologists seem to favor. In fact, even some statisticians (Skalski 1990) think this is by far the best temporal design for trend detection.

However, repeated sampling violates the equal-likelihood-of-sampling assumption of probability based designs and introduces bias into status estimates. A trend-detection design is most powerful for determining changes through time, if the same sites are sampled on every occasion and samples are collected at regular intervals. However, this design cannot be used to determine overall status because the sites are not randomly selected.

In contrast, the most statistically powerful design to summarize status in a region involves randomly selecting the complete set of sampling sites on every occasion. Some sites may be resampled, but only if they are selected by chance. This design is less powerful for illustrating trends.

What kind of sampling design should be used to monitor a spatially dispersed (regional) ecological resource of interest? Often, a monitoring program requires assessing both overall status and temporal trends in the region of interest. We want it to have good power for detecting temporal trends in a regional population while simultaneously providing precise estimates of that population's status. This is where compromise strategies such as panel sampling are most appropriate (Urquhart et al. 1998; see below). A mixed design incorporates some pattern of revisits to sites (wetlands), but that also involves collecting some new samples from the regional population for each "revisit."

Table 1-1. Tabular organization of response values, averages and slopes (Urquhart et al. 1998). Note that in the context of Consortium: sampling unit = wetland.

Sampling unit (= lake)	Time period (= Year)				Aver-ages	Slope (= trend)
	1	2	···	t		
1	Y_{11}	Y_{12}	···	Y_{1t}	$\bar{Y}_{1\cdot}$	β_1
2	Y_{21}	Y_{22}	···	Y_{2t}	$\bar{Y}_{2\cdot}$	β_2
···	···	···	···	···	···	···
l	Y_{l1}	Y_{l2}	···	Y_{lt}	$\bar{Y}_{l\cdot}$	β_l
Averages	$\bar{Y}_{\cdot 1}$	$\bar{Y}_{\cdot 2}$	···	$\bar{Y}_{\cdot t}$	$\bar{Y}_{\cdot\cdot}$	$\bar{\beta}_{\cdot}$

The Consortium adopted the notation of Urquhart et al. (1998) to describe revisit designs for brevity and consistency. Fig.1-2 schematically summarizes four designs for a monitoring program that assesses a study region over a period of 12 years. Figure 1-2 relates to Table 1-1 as follows:

PANEL	SIZE	1	2	3	4	5	6	7	8	9	10	11	12	...
		TIME PERIODS (=YEARS)												
DESIGN 1 = SAME SITES (= LAKES)														
1	60	X	X	X	X	X	X	X	X	X	X	X	X	...
DESIGN 2 = NEW SITES (= LAKES)														
1	60	X												
2	60		X											
3	60			X										
4	60				X									
5	60					X								
6	60						X							
7	60							X						
8	60								X					
9	60									X				
10	60										X			
11	60											X		
12	60												X	
...	...													...
DESIGN 3 = AUGMENTED SERIALLY ALTERNATING														
1	50	X				X				X				...
2	50		X				X				X			...
3	50			X				X				X		...
4	50				X				X				X	...
COMMON	10	X	X	X	X	X	X	X	X	X	X	X	X	...
DESIGN 4 = PARTIALLY AUGMENTED SERIALLY ALTERNATING														
1	35	X				X				X				...
2	35		X				X				X			...
3	35			X				X				X		...
4	40				X				X				X	...
1A	5	X	X			X				X				...
2A	5		X	X			X				X			...
...	...													...
1B	5	X				X	X			X				...
...	...													...
1C	5	X				X				X	X			...
...	...													...

Figure 1-2. Examples of four different revisit designs, beginning with the simplest, in which a single panel or set of sampling units are visited on every sampling occasion, and ending with a complex partially augmented serially alternating design (Urquhart et al. 1998).

Each panel in Fig.1-2 represents a selection of rows from Table 1-1, subject to the restriction that no wetland ('lake' reference from Urquhart et al. 1998) occurs in more than one panel; the columns in Fig.1-2, except for the first two, are the same as those in Table 1-1. The X's in Fig. 1-2 identify the year(s) in which wetlands from a particular panel will be visited. The first two columns identify the panels and give the numbers of wetlands in the respective panels. Each of the four designs was developed for the same number of wetland visits each year (60). The designs therefore operate under the same fixed budget for field work, except that Design 4 must have fewer wetlands (lakes) (55) during the first year of sampling in order to have 60 in subsequent years. Each of the designs continues for more years than are displayed in the table. The pattern of repetition (revisits) in the first three designs should be obvious, but the pattern in Design 4 deserves a bit more explanation. Fig 1-3 below (Urquhart, et al., 1999) illustrates a detailed form of Design 4.

Design 4 - Partially Augmented Serially Alternating
1-4 = Panels
A-J = Sub-Panels

	# OF SITES	YEAR 1	YEAR 2	YEAR 3	YEAR 4	YEAR 5	YEAR 6	YEAR 7	YEAR 8	YEAR 9	YEAR 10	YEAR 11	YEAR 12
1	35	X				X				X			
2	35		X				X				X		
3	35			X				X				X	
4	40				X				X				X
1A	5	X	X			X				X			
2A	5		X	X			X				X		
3A	5			X	X			X				X	
4A	5				X	X			X				X
1B	5	X				X	X			X			
2B	5		X				X	X			X		
3B	5			X				X	X			X	
4B	5				X				X	X			X
1C	5	X				X				X	X		
2C	5		X				X				X	X	
3C	5			X				X				X	X
4C	5				X				X				X
1D	5	X				X				X			
2D	5		X				X				X		
3D	5			X				X				X	

Figure 1-3. Partitioning of each panel into subpanels for Design 4 (Urquhart, N.S., and Kincaid, T.M. 1999).

Randomly select (without replacement) four panels of 55 wetlands each from the sample population of wetlands (lakes) (see Fig 1-3). Schedule each panel to be visited every four years, with a different panel starting in each of the first four years. Randomly divide each panel into 11 subpanels of five sites each (these are labeled A-K above, but only A-D are shown). Each time a panel is visited, randomly select a subpanel of five wetlands (lakes) to visit for two consecutive years - that year and the following one. The first four lines of Design 4 in Fig.1-3 collect the remaining subpanels that would not be visited in two consecutive years during the first 12 years representing 35, 35, 35, and 40 sites that will not be revisited respectively. The next two lines, labeled 1A and 2A, display the visit pattern of the first subpanels from the first two panels (panel 1 subpanel A and panel 2 subpanel A); the lines labeled 1B and 1C display the visit pattern of the second and third subpanels of panel 1.

As mentioned above the desired design must make a compromise between competing concerns of status and trend. Designs 1, 3, and 4 have similar power to detect trends because they include revisits to sites and incorporate augmentation to achieve connectedness. However, Designs 3 and 4 will give the most precise estimates of overall status because they include visits to the most sites (after 20 years Design 2 is superior for estimating status but still does not provide a good estimate of trend). There are two reasons why Design 4 is superior to Design 3. First, it provides a better estimate of the amount of “Wetland x Year” variation (i.e., to what extent does the estimate for a wetland depend on the year in which it was sampled); and second, it also causes less impact of physical sampling on the wetland due to repeat visits (i.e., taking the same samples from the same locations annually for 20 or more years; Urquhart et al. 1998).

Sample Size Considerations and Ability to Detect Change

Populations in the real world are dynamic; change over time is to be expected. However, what is important is whether or not there has been *meaningful* change (meaningful to the ecosystem, or public), what has caused the observed change, and whether or not the resource is expected to change further.

To understand what constitutes a meaningful and significant change, one must differentiate between statistical significance and biological significance. Statistical significance relies on probability and is influenced by sample size. Thus, even trivial changes (from a biological perspective) can be judged to be statistically significant if the sample size is large enough. So, regardless of statistical significance, one should consider something biologically significant if it represents a major shift in ecosystem structure or function (e.g., loss of one or more species, addition of non-native species, changes in ecosystem processes). The term "effect size" is operationally defined to be the smallest difference that represents a biologically meaningful change in a variable of interest. It is typically expressed as a percentage of the average existing value. Effect size is a value judgment that can be decided on the basis of prior scientific evidence, best professional judgment, public consensus, or legislated regulations. However, the effect size is also an attribute that must be defined as part of the implementation plan so that the sample design can be developed to maximize the power of detecting a change of that magnitude, should it occur. The power of a statistical comparison is the ability to detect a biologically meaningful change when it occurs. A statistical significant change is not always biologically significant, but a biologically significant change must also be statistically significant; if the latter is not true, then the power of the statistical comparison must be increased.

Thus, from a monitoring standpoint, one should be concerned with both statistical significance and the power to detect a biologically significant effect. To answer this, it must be decided what level of statistical significance to attain (i.e., what is our Type I error rate or α, discussed below), what level of change to consider biologically meaningful (what is the effect size), how certain one wishes to be to detect that change (what is the power), and how variable the indicator measure is that we are trying to estimate (what is the variance). The relationships among power, sample size, effect size and variation are summarized in equation 1 below.

$$\text{Power} \;\alpha\; \frac{(\text{sample size}) \times (\text{effect size})}{(\text{variance}) \times (\text{number of groups being compared})} \qquad (1)$$

In addition to implementation objectives, a **sampling objective** must be defined**.** Sampling objectives establish a desired level of statistical power, the capacity to detect a "real" change or trend, a minimum detectable change or effect size, and acceptable levels of both a false-change (α or the probability of a Type I error) and a missed-change (β or the probability of a Type II error) (Elzinga et al. 2001). Sample size affects each of these components. The larger the sample size, the lower error and the greater the power to detect a change (Eqn 1). Reducing sample size, which is desirable for cost-effectiveness, leads to reduced power and higher error rates. These tradeoffs are mitigated by reducing variance estimates (in the denominator of equation 1), either through modifications in response design, another component (e.g., revisit design), or by accepting a higher minimum effect size (in the numerator of equation 1) (Steidl et al. 1997).

In general, sample size should be large enough to give a high probability of detecting any changes that are of management, conservation or biological importance, but not unnecessarily large (Manly 2001). Scientists traditionally seek to reduce Type I errors, and accordingly prefer small alpha levels. In a regional implementation plan with a strong resource-conservation mandate, however, it is preferable to employ an early warning philosophy by tolerating a higher alpha, but consequently increasing the power to detect differences or trends (Sokal and Rohlf 1995, Mapstone 1995, Roback and Askins 2005).

Accordingly, the Consortium has initially set a very high target of an alpha of 0.10 and power of 0.80. The magnitudes of change that could be detected given these standards will depend on sampling effort, a given indicator, and on the wetland-to-wetland variability. Table 1-2 shows how sample size has to change to provide a given degree of power to detect various effect sizes of >20%, in agreement with other monitoring approaches. For some indicators and measures, it is possible to significantly increase power with acceptable increases in cost. For the initial set of protocols, *a priori* power analyses will be used to determine the approximate sample size needed to an effect size of 20%. Given the specification of alpha, desired power, and effect size, combined with information on the variance of the response variable in question (obtained from available data or comparable analogous data, where available), it is possible to calculate the sample size required to achieve these results. Statistical power analysis (Gerrodette 1993), is the typical approach to estimating sampling sizes for monitoring population trends.

From Table 1-2 below, Minimum sample size necessary to be 80% certain (i.e., power = 0.8) that a specified true difference (=effect size) between two groups will be found to be significant ($p<0.05$). **V** is the coefficient of variation of the 'reference' group (V= ([standard deviation/mean] x 100)). The variances of the two groups are assumed to be equal. The dotted line transecting the table indicates the minimum differences likely to be designated significant with triplicate sampling. The heavy line transecting the table indicates the minimum differences likely to be designated significant if 12 wetlands are sampled per group. Entries for which n>100 may be overestimated by approximately 2%. Three replicates are considered to be an absolute minimum sample size if outliers are to be identified. Entries were determined from power formulae given by Sokal and Rohlf (1981).

Table 1-2. Tabular organization of response values, averages and slopes (Sokal , et al. 1981).

V (%)	Effect Size (True difference between two means (%)									
	100	**90**	**80**	**70**	**60**	**50**	**40**	**30**	**20**	**10**
100	14	18	22	29	39	54	67	99	201	801
90	12	14	18	23	32	41	55	73	163	649
80	9	11	14	18	25	36	47	67	129	513
70	7	9	11	14	19	28	40	55	99	393
60	5	7	8	11	14	20	32	45	81	289
50	4	5	6	7	10	14	22	36	67	201
40	3	3	4	5	7	9	14	25	52	129
30	3	3	3	3	4	5	8	14	32	73
20	3	3	3	3	3	3	4	7	14	33
10	3	3	3	3	3	3	3	3	4	14

One may use existing software programs (e.g. Gerrodette 1993) and simple equations (Elzinga et al. 2001, Manly 2001) for approximating sample sizes. In the context of Consortium, the development of a monitoring and sampling program is best accomplished in a workshop setting involving key stakeholders and technical personnel and including the input of researchers and statisticians who can explain the theory and trade-offs to participants in straightforward terms. Such individuals could operate statistical software at the workshops to demonstrate the power and effectiveness of various sampling scenarios through simulations.

Recommendations

For now, the Consortium will recommend a target number of wetlands stratified by Great Lake and ecoregion. Ideally, a minimum of 12 wetlands from each ecoregion on each Great Lake should be randomly selected for study. The recommendation of 12 is simply a starting point until power analyses using means and variances of IBI scores from the GLCWC pilot studies can be performed. The number of sites may then be adjusted accordingly. Twelve sites were chosen based on best professional judgment and experience using the Burton et al. (1999) IBI and protocol on many Lake Huron and Lake Michigan wetlands over the past 10 years. If less than 12 sites are present within a given ecoregion, then all of the sites should be sampled. Whenever possible, more than 12 sites per ecoregion per Great Lake and connecting channel should be sampled.

Four panels of 12 wetlands were randomly selected (without replacement) from the population in each ecoregion. Each panel should be visited every four years, with a different panel starting in each of the first four years. From each panel is a randomly selected subset of three wetlands (subpanel) that will be visited two consecutive years. These subpanels were selected so they do not overlap, which effectively partitions each panel into four subpanels. Design 4 in Fig.1-3 above shows the pattern of sampling.

References

Busch, D. E., and D. T. Trexler, editors. 2003. Monitoring Ecosystems. Island Press, Washington.

Elzinga, C. L., D. W. Salzer, J. W. Willoughby, and J. P. Gibbs. 2001. Monitoring plant and animal populations. Blackwell Science, Inc.

Gerrodette, T. 1993. TRENDS: Software for a power analysis of linear regression. The Wildlife Society Bulletin **21**:515-516.

Lessler, J. T., and W. D. Kalsbeek. 1992. Nonsampling Errors in Surveys. John Wiley and Sons, Inc., New York.

Manly, B. F. J. 2001. Statistics for Environmental Science and Management. Chapman & Hall/CRC, Boca Raton, Florida.

Mapstone, B. 1995. Scalable decision rules for environmental impact studies: Effect size, type I & type II errors. Ecological Applications 5:401-410.

McDonald, T. L. 2003. Review of Environmental Monitoring Methods: Survey Designs. Environmental Monitoring and Assessment **85**:277-292.

McDonald, T. L., and P. H. Geissler. 2004. Systematic and stratified sampling designs in long-term ecological monitoring studies. http://science.nature.nps.gov/im/monitor/docs/SampleDesigns.doc.

Roback, P. J., and R. A. Askins. 2005. Judicious use of multiple hypothesis tests. Conservation Biology **19**:261-267.

Scheaffer, R. L., W. Mendenhall, and L. Ott. 1990. Elementary Survey Sampling, 4th edition. PWS-Kent, Boston.

Skalski, J. R. 1990. A design for long-term monitoring. Journal of Environmental Management **30**:139–144.

Sokal, R. R., and F. J. Rohlf. 1995. Biometry, 3rd edition. W.H. Freeman and Company, New York.

Sokal, R.R. and F.J. Rohlf. 1981. Biometry, 2nd Ed.. Freeman Publ., San Francisco, CA

Steidl, R. J., J. P. Hayes, and E. Schauber. 1997. Statistical power analysis in wildlife research. Journal of Wildlife Management **61**:270-279.

Stevens Jr., D. L., and A. R. Olsen. 2004. Spatially balanced sampling of natural resources. Journal of American Statistical Association **99**:262-278.

Urquhart, N. S., and T. M. Kincaid. 1999. Trend detection in repeated surveys of ecological responses. Journal of Agricultural, Biological, and Environmental Statistics **4**:404-414.

Urquhart, N. S., S. G. Paulsen, and D. P. Larsen. 1998. Monitoring for policy relevant regional trends over time. Ecological Applications **8**:246-257.

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Chapter 2

Chemical/Physical and Land Use/Cover Measurements

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Basic chemical/physical parameters should be measured at the same time that biological sampling is undertaken. These data will be used as covariates, helping to account for some of the statistical variability encountered during data analysis. The colleting and analytical procedures should follow those recommended in Standard Methods for the Examination of Water and Wastewater (APHA 1998) or accepted U.S. EPA, USGS or other operating procedures as dictated by local agencies.

Properly serviced and calibrated meters provide excellent quality data in the field. Multimeters permit reliable field measurements of parameters such as dissolved oxygen, temperature, turbidity, specific conductance and pH, but back-up water sampling containers should be taken along in case of equipment failure. The use of detailed check-box field data sheets can help ensure that all required measurements are taken and that samples are properly handled and stored during the trip. GPS coordinates for each sampling point should be recorded at the time of collection site by the field crew.

Other water chemistry parameters routinely require that water samples be collected, preserved and properly stored until they can be sent to a lab for analysis. Measurements such as soluble reactive phosphorus, ammonium-N, nitrite/nitrate-N, chloride, dissolved oxygen, temperature, turbidity, specific conductance, pH and total alkalinity should be considered and included in the sampling design if deemed relevant and budgets allow. They can provide essential information that can help determine the nutrient status of a wetland, possible sources of degradation and even which of several possible indices of biotic integrity (IBI) formulations may be most appropriate for biological assessment.

Additional measurements of chlorophyll a, total phosphorus, sulfate, redox potential (in the water column), vegetation type and stem density, and organic sediment depth (simply measured by forcing a meter stick into the organic sediments until more resistance indicates a change in consistency) should also be considered and are highly recommended. Sediment samples can also be collected and assessed in the laboratory for particle size and organic content analysis. Quality assurance/quality control procedures should follow standard operating protocols recommended by U.S. EPA, USGS, Environment Canada, or those that have been routinely used by the sponsoring agency if there is a historical record to which the surveys contribute.

Some IBIs exist in several formulations that are tied to the dominant landscape type of the wetland being sampled. In other cases, on-site assessment of land use, local disturbances, aquatic vegetation distribution and growth forms, and other local habitat features provide important complementary diagnostic information. The Great Lakes Environmental Indicator (GLEI) field teams investigating fish and invertebrate condition in wetlands developed detailed site assessment protocols using simple classification systems to assess these variables in various classes of coastal wetlands. More detailed habitat assessment protocols have been developed by the Ohio EPA for both coastal and inland wetlands. Notes on possible point sources of pollution and land cover including plant zonation should be recorded in the field note book. A good sketch, as well as on-site photos of the area, should be made as well.

General Interpretation of Covariates

Turbidity, specific conductance, and chloride should be considered to be linear, with greater values indicating disturbance. However, specific conductance values should not be interpreted as being related to anthropogenic disturbance until reaching values near 600 µS. Extreme values, either very high or very low for nitrate-N, ammonium-N, and soluble reactive phosphorus concentrations, as well as percent saturation of dissolved oxygen and pH, should be considered indicators of disturbance. With respect to inorganic dissolved nutrients, we tended to find moderate concentrations at relatively pristine sites.

Impacted sites often have either nondetectable values, because these systems are very productive and the nutrients are tied up in organic matter and sediments, or nutrient concentrations that are so high that the communities do not assimilate them as quickly as they enter the system. Also, in a system experiencing cultural eutrophication, dissolved oxygen may be as high as 180% saturated during the day when samples are collected. In this case, percent saturation likely plummets at night when only respiration is taking place in the absence of photosynthesis. Likewise, a system with organic pollutants may have very low percent saturation (e.g., 50%) of dissolved oxygen due to decomposition of excess organic matter in the absence of photosynthesis. This can be caused by siltation, cloud cover, coverage of duckweed (*Lemna* or *Spirodela* spp.) and/or turbidity. Often, pH measurements follow this relationship to some degree; a very high daytime pH may be indicative of extreme productivity, while very low daytime pH may be indicative of organic pollution.

Basic chemical/physical parameters should be measured and personal observations of disturbance should be recorded in conjunction with biotic sample collection. These data will be used as covariates, helping to account for some of the statistical variability encountered during data analysis. It is understood that logistics may preclude the collections of some of these data, but ask that as many as possible are collected.

References

APHA 1998. Standard Methods for the Examination of Water and Wastewater, 20th edition. American Public Health Association, Washington, DC.

Chapter 3
Vegetation Community Indicators

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Michigan Natural Features Inventory

Introduction

Vegetation sampling has been conducted in Great Lakes coastal wetlands for the purposes of classification, identification of important wetlands for protection or acquisition, and characterization of wetlands for management. Sampling has often been conducted along transects with the purpose of identifying physical gradients and corresponding biological gradients or zones. It is recognized that relatively discrete vegetation zones occur at most coastal wetland sites due to differences in water depth and substrate, and that wave energy also effects wetland vegetation diversity. A classification of coastal wetlands, developed by the Great Lakes Wetland Consortium, is present on the Consortium's web page.

In the initial phases of this project, data were collected across four regional areas of lakes Erie, Ontario and Huron, in an attempt to develop a Great Lakes-wide plant index of biotic integrity (IBI). Studies were being conducted in other parts of the Great Lakes as well in attempts to create a multimetric plant index. These attempts have not been clearly successful for several reasons, including extreme water level fluctuations, as well as the complex array of disturbance factors that occur at different spatial scales and in different spatial configurations around the Great Lakes. Differences in prevailing wind direction, shoreline configuration and wetland size all combine to make direct comparisons of neighboring wetlands nonproductive.

Because of the limited success at developing a Great Lakes-wide IBI with plants, this study suggests a more limited approach to evaluating coastal wetland degradation, one focusing on those factors agreed on by the plant ecologists studying Great Lakes coastal wetlands and participating in the Great Lakes Coastal Wetlands Consortium. These factors include 1) the coverage and distribution of invasive plants, 2) the coverage and diversity of submergent and floating plants, and 3) computing the Floristic Quality Index (FQI) and comparing it to regional FQI scores.

In the Great Lakes, the expansion of invasive plants into wetlands is the result of disturbances that alter the upper, seasonally wet edge of the wetland or disturbances that alter the permanently flooded portion of the wetland. The wet meadow and inner emergent marsh zones are typically degraded by alterations of the hydrology caused by ditching or the physical disturbance of sediments, resulting in the introduction of invasives. In contrast, changes to the outer emergent marsh and the submergent marsh zones are the result of disturbances to the flooded portion of the marsh by dredging, the addition of nutrients in the form of fertilizer or animal waste, or the addition of fine sediment as the result of intensive agriculture. It is recommended that these zones be monitored separately to identify sources of degradation, and thus allow solutions to be identified for each zone.

Alterations of the wet meadow or upper emergent zone result in drier conditions and bare exposed sediments, allowing small-seeded invasive species to establish and rapidly expand by rhizomes or stolons. Many invasives are tall perennials that shade out native plants. A list of invasive species is provided.

The submergent and flooded emergent marsh zones are degraded by fine sediments and organic nutrients from either agriculture or urban areas, resulting in high turbidity and resultant reduced photosynthesis and regeneration by seed for many submergent plants. Added nutrients and sediments provide habitat for Eurasian carp – large, aggressive bottom feeders which uproot many aquatic plants. Some of the species most tolerant of high nutrient and turbidity levels are invasive species that form dense weed beds of reduced habitat value to fish and other aquatic fauna.

A successful approach to evaluating the intactness of plant communities is the computation of a floristic quality index, which utilizes all plant species present at a site to estimate the intactness of the plant community. Conservatism index scores, discussed below, are developed and applied regionally with upper and lower limits of 10 and zero. A mean conservatism score evaluates the intactness of the wetland habitat, based on all of the plant species at a site. The use of the mean conservatism index is recommended for monitoring changes to Great Lakes coastal wetland vegetation.

In summary, this monitoring protocol focuses on 1) identifying and quantifying those invasive plants that are considered indicators of degraded habitat, 2) identifying significant changes to the submergent and floating-leaved vegetation of emergent and submergent marsh zones, and 3) comparing regional Mean Conservatism Indices for Great Lakes coastal wetland types to the local site's Mean Conservatism Indices.

Vegetation Sampling

Extensive vegetation sampling has been conducted in Great Lakes coastal wetlands for the purpose of classification, identification of important wetlands for protection or acquisition, and characterization of wetlands for management. Much of the sampling has been conducted along transects placed perpendicular to the shoreline with the purpose of identifying physical gradients and corresponding biological gradients or zones. In general, it is recognized that relatively discrete zones of shrub, wet meadow, emergent and sometimes submergent vegetation occur at most coastal wetland sites, and that these zones are related to differences in water depth, as well as associated differences in substrate. Frequency of inundation and wave energy increase with water depth in coastal wetlands directly connected to the Great Lakes. As wave energy increases, the amount of aquatic vegetation decreases; along high energy areas of the shoreline, the only coastal wetlands present are sheltered behind a barrier dune or beach ridge. See the classification of coastal wetlands on the Great Lakes Wetland Consortium web site for a more detailed description of coastal wetland types (Albert et al. 2003, Albert et al. 2005).

Evaluation of Great Lakes coastal wetlands quality and health

In the initial phases of this project, data were collected in more than 40 wetlands across four regional areas of lakes Erie, Ontario and Huron in an attempt to develop a Great Lakes-wide plant Index of Biotic Integrity (IBI), which would allow the ranking of all Great Lakes wetlands sites (Minc and Albert 2004). This attempt was not conducted in isolation, as other studies were being conducted as well, typically on a smaller scale (Albert and Minc 2004, Albert et al. 2006, Mack et al. in press, Simon and Rothrock 2006, Stewart et al. 2003, 1999, Wilcox et al. 2002). Attempts to create a multimetric plant index have not been clearly successful, for several reasons. Probably the greatest source of variability in Great Lakes wetland plant community composition is the extreme water level fluctuations that characterize the Great Lakes (Wilcox et al. 2002, Albert and Minc 2004, Albert et al. 2006, Hudon et al. 2006). Comparing the health of several wetlands of a single type or lake is complicated by the fact that each wetland is altered by a complex array of disturbance factors that occur at different spatial scales and in different spatial configurations. For example, winds along Saginaw Bay result in nutrient-rich organic sediments from the Saginaw River accumulating in a single wetland, contributing to the formation of dense algal mats nearly a meter thick at times. While other wetlands may receive similar amounts of organic sediments, they are not regularly concentrated to such a degree by the wind. Prevailing wind direction, shoreline configuration and wetland size all combine to make direct comparisons of neighboring wetlands nonproductive.

Because of the limited success in developing a Great Lakes-wide IBI for plants, we are suggesting a more limited approach to evaluating coastal wetland degradation, one focusing on those factors agreed on by the plant ecologists studying Great Lakes coastal wetlands and participating in the Great Lakes Coastal Wetlands Consortium. These wetland ecologists agreed that the most effective factors or approaches for evaluating wetland degradation were measuring 1) the coverage and distribution of invasive plants, 2) the coverage and diversity of submergent and floating plants, and 3) computing the Floristic Quality Index (FQI) and comparing it to regional FQI scores. A fourth and extremely important approach, determining the amount of wetland already lost or altered by comparing historic and recent aerial photos, is not the focus of the vegetation group.

In the Great Lakes, the expansion of invasive plants into wetlands is the result of two distinct types of disturbance: disturbances that alter the upper, seasonally wet edge of the wetland or disturbances that alter the permanently flooded portion of the wetland. The wet meadow and inner emergent marsh zones are only occasionally flooded and are typically degraded as the result of alterations of the hydrology caused by ditching or the physical disturbance of sediments. Major introductions of invasives into the wet meadow are often the result of such physical disturbances. In contrast, changes to the outer emergent marsh and the submergent marsh zones are the result of disturbances to the flooded portion of the marsh, either by dredging, the addition of nutrients in the form of fertilizer or animal waste, or the addition of fine sediment as the result of intensive agriculture. For this reason, we have separated the recommended monitoring into tracking these zones separately for the purpose of identifying the sources of the degradation, and thus potentially allowing solutions to be identified for each zone.

Alteration of the wet meadow or upper emergent zone often results in both drier conditions and exposed sediments with no vegetation, a combination that allows small-seeded invasive species to become established in large numbers. Once established, many of the invasive plants in this zone are able to rapidly expand by rhizomes or stolons. Many of these invasives are also tall perennials that rapidly shade out and replace shorter native plants. A list of these invasive species is provided in the footnotes of Table 3.1 below.

The submergent marsh zone and the flooded portion of the emergent marsh zone are often degraded by the addition of fine sediments and organic nutrients from either agriculture or urban areas, resulting in high turbidity. High turbidity levels reduce the ability of many submergent plants to photosynthesize effectively. In addition, the deposition of suspended particulates on submergent plants may affect gas exchange with the environment. The combination of high turbidity and deposition of fine sediments on the bottom also reduces the ability of many submergent and floating plants to reproduce from seed, resulting in reduced plant reproduction. These additions of nutrients and sediments also provide excellent habitat for Eurasian carp (*Cyprinus carpio*), which are large, aggressive bottom feeders. Carp disturb the sediment, resulting in the resuspension of sediments and the uprooting of many aquatic plants. While minor levels of nutrient enrichment result in increased growth of many submergent and floating plants, further increases in nutrient enrichment are followed by rapid loss of plant coverage and/or diversity as turbidity increases beyond a critical point. Some of the species most tolerant of high nutrient and turbidity levels are invasive species. These invasives typically form dense weed beds that are of reduced habitat value to fish and other aquatic fauna and may create localized nocturnal anoxia.

An approach that has been used successfully to evaluate the intactness of plant communities is computation of a floristic quality index using a floristic quality assessment (FQA) program, which utilizes all plant species present at a site to estimate the intactness of the plant community and the site. FQAs are used to develop several indices, including the widely used *conservatism index* (*C*) and the *floristic quality index*. Each species is assigned a conservatism index based upon the specificity of a plant to a specific habitat. Species that can occupy a broad range of habitats are assigned low conservatism index scores, while those that are very restricted in their habitat are assigned high scores. Conservatism index scores are assigned through consensus by groups of plant ecologists with expert knowledge of plant species habitat fidelity. Conservatism index scores are developed and applied regionally and have upper and lower limits of 10 and zero. A mean conservatism score evaluates the conservatism of all of the species at a site. The floristic quality index is based on the square of the number of species times the conservatism index and is therefore influenced more by the number of species collected at a site than is the mean conservatism index. Floristic quality index scores are overly sensitive to sample size and water-level fluctuation, thus resulting in potentially large year-to-year score changes that do not reflect real changes in wetland quality. For that reason, the use of the mean conservatism (Mean C) is recommended for monitoring changes to Great Lakes coastal wetland vegetation.

Use of the Michigan Floristic Quality Assessment program (Herman et al. 2001) is recommended for the Great Lakes basin, as it was designed for use in Michigan, which encompasses most of the latitudinal gradient encountered in the Great Lakes. Alternative FQIs for Ohio, Indiana, Wisconsin, and southern Ontario do not adequately reflect the diverse flora found in Great Lakes wetlands. The FQA software is available through the Conservation Research Institute (Conservation Design Forum: cdf@cdfinc.com). Table 3-1 shows the standard output from FQA analyses for Mackinac Bay, a northern Lake Huron protected embayment. Standard indices computed with the software include FQI score, Mean C score, and Wetland Index (W). Each of these are computed for native species and for the total flora at a site, including adventive species. For this study, the Mean C for native species and total flora are being used. For Mackinac Bay, there are 44 native species and only one adventive species. As a result, the Mean C for native species (6.1) and total species (6.0) are very similar. For more disturbed sites, the difference between native and total Mean C scores can be much greater (Table 3-2).

In summary, this monitoring protocol focuses on 1) identifying and quantifying those invasive plants that are considered indicators of degraded habitat, 2) identifying significant changes to the submergent and floating-leaved vegetation of the emergent and submergent marsh zones, and 3) comparing regional mean conservatism indices for Great Lakes coastal wetland types to the local site's mean conservatism indices.

Table 3-1. Floristic Quality Assessment output for Mackinac Bay, Lake Huron.

Site:	Mackinac Bay 1999			By: D. Albert			
FLORISTIC QUALITY DATA		Native	44	97.80%	Adventive	1	2.20%
44	NATIVE SPECIES	Tree	0	0.00%	Tree	0	0.00%
45	Total Species	Shrub	3	6.70%	Shrub	0	0.00%
6.1	NATIVE MEAN C	W-Vine	0	0.00%	W-Vine	0	0.00%
6	W/Adventives	H-Vine	0	0.00%	H-Vine	0	0.00%
40.7	NATIVE FQI	P-Forb	28	62.20%	P-Forb	1	2.20%
40.2	W/Adventives	B-Forb	0	0.00%	B-Forb	0	0.00%
-4.7	NATIVE MEAN W	A-Forb	2	4.40%	A-Forb	0	0.00%
-4.7	W/Adventives	P-Grass	2	4.40%	P-Grass	0	0.00%
AVG:	Obl. Wetland	A-Grass	1	2.20%	A-Grass	0	0.00%
		P-Sedge	7	15.60%	P-Sedge	0	0.00%
		A-Sedge	0	0.00%	A-Sedge	0	0.00%
		Fern	1	2.20%			

ACRONYM	C	SCIENTIFIC NAME	W	WETNESS	PHYSIOGNOMY	COMMON NAME
AGRHYE	4	Agrostis hyemalis	1	FAC-	Nt P-Grass	TICKLEGRASS
ASTPUN	5	Aster puniceus	-5	OBL	Nt P-Forb	SWAMP ASTER
BIDCER	3	Bidens cernuus	-5	OBL	Nt A-Forb	NODDING BUR MARIGOLD
CALCAN	3	Calamagrostis canadensis	-5	OBL	Nt P-Grass	BLUE JOINT GRASS
CAMAPR	7	Campanula aparinoides	-5	OBL	Nt P-Forb	MARSH BELLFLOWER
CXAQUA	7	Carex aquatilis	-5	OBL	Nt P-Sedge	SEDGE
CXLASI	8	Carex lasiocarpa	-5	OBL	Nt P-Sedge	SEDGE
CXSTRI	4	Carex stricta	-5	OBL	Nt P-Sedge	SEDGE
ELEACI	7	Eleocharis acicularis	-5	OBL	Nt P-Sedge	SPIKE RU.S.H
ELESMA	5	Eleocharis smallii	-5	OBL	Nt P-Sedge	SPIKE RU.S.H
EQUFLU	7	Equisetum fluviatile	-5	OBL	Nt Fern Ally	WATER HORSETAIL
GALTRD	6	Galium trifidum	-4	FACW+	Nt P-Forb	SMALL BEDSTRAW
HETDUB	6	Heteranthera dubia	-5	OBL	Nt P-Forb	WATER STAR GRASS
HIPVUL	10	Hippuris vulgaris	-5	OBL	Nt P-Forb	MARE'S TAIL
IRIVER	5	Iris versicolor	-5	OBL	Nt P-Forb	WILD BLUE FLAG
LATPAL	7	Lathyrus palustris	-3	FACW	Nt P-Forb	MARSH PEA
LYCUNI	2	Lycopus uniflorus	-5	OBL	Nt P-Forb	NORTHERN BUGLE WEED
LYSTHY	6	Lysimachia thyrsiflora	-5	OBL	Nt P-Forb	TUFTED LOOSESTRIFE
MYRGAL	6	Myrica gale	-5	OBL	Nt Shrub	SWEET GALE
MYREXA	10	Myriophyllum exalbescens	-5	OBL	Nt P-Forb	SPIKED WATER MILFOIL
MYRHET	6	Myriophyllum heterophyllum	-5	OBL	Nt P-Forb	VARIOU.S. LEAVED WATER MILFOIL
NAJFLE	5	Najas flexilis	-5	OBL	Nt A-Forb	SLENDER NAIAD
NUPVAR	7	Nuphar variegata	-5	OBL	Nt P-Forb	YELLOW POND LILY
POLAMP	6	Polygonum amphibium	-5	OBL	Nt P-Forb	WATER SMARTWEED
PONCOR	8	Pontederia cordata	-5	OBL	Nt P-Forb	PICKEREL WEED
POTAMP	6	Potamogeton amplifolius	-5	OBL	Nt P-Forb	LARGE LEAVED PONDWEED
POTGRM	5	Potamogeton gramineus	-5	OBL	Nt P-Forb	PONDWEED
POTNAT	5	Potamogeton natans	-5	OBL	Nt P-Forb	PONDWEED
POTPAL	7	Potentilla palustris	-5	OBL	Nt P-Forb	MARSH CINQUEFOIL

Table 3-1. Floristic Quality Assessment output for Mackinac Bay, Lake Huron, Continued.

Site: Mackinac Bay 1999 By: D. Albert

SAGLAT	1	Sagittaria latifolia	-5	OBL	Nt P-Forb	COMMON ARROWHEAD
SALCAN	9	Salix candida	-5	OBL	Nt Shrub	HOARY WILLOW
SCHACU	5	Schoenoplectus acutus	-5	OBL	Nt P-Sedge	HARDSTEM BULRU.S.H
SCHSUB	8	Schoenoplectus subterminalis	-5	OBL	Nt P-Sedge	BULRU.S.H
SCUGAL	5	Scutellaria galericulata	-5	OBL	Nt P-Forb	COMMON SKULLCAP
SIU.S.UA	5	Sium suave	-5	OBL	Nt P-Forb	WATER PARSNIP
SPAMIN	8	Sparganium minimum	-5	OBL	Nt P-Forb	SMALL BUR REED
SPIALB	4	Spiraea alba	-4	FACW+	Nt Shrub	MEADOWSWEET
TEUCAN	4	Teucrium canadense	-2	FACW-	Nt P-Forb	WOOD SAGE
TRIFRA	6	Triadenum fraseri	-5	OBL	Nt P-Forb	MARSH ST. JOHN'S WORT
TYPANG	0	TYPHA ANGU.S.TIFOLIA	-5	OBL	Ad P-Forb	NARROW LEAVED CATTAIL
UTRINT	10	Utricularia intermedia	-5	OBL	Nt P-Forb	FLAT LEAVED BLADDERWORT
UTRMIN	10	Utricularia minor	-5	OBL	Nt P-Forb	SMALL BLADDERWORT
UTRVUL	6	Utricularia vulgaris	-5	OBL	Nt P-Forb	GREAT BLADDERWORT
VALAME	7	Vallisneria americana	-5	OBL	Nt P-Forb	EEL GRASS
ZIZAQU	9	Zizania aquatica var. aquatica	-5	OBL	Nt A-Grass	WILD RICE

Table 3-2. Comparison of Native Mean C and Total Mean C scores for three Great Lakes Marshes on lakes Huron and Erie.

Marsh Name	Mean C Score	
	Native	Total (Native + Adventive)
Mackinac Bay, Lake Huron	6.1	6.0
Presque Isle Bay, Lake Erie	4.8	4.4
Bradleyville, Saginaw Bay, Lake Huron	3.9	3.3

Materials and Methods

Protocol for Great Lakes Marsh Aquatic Macrophyte Sampling

Mapping to identify sampling transects or random sampling points:

1. Using aerial photos, map wetland to be sampled, identifying major zones: wet meadow, emergent, and possibly submergent (Figures 3-1 and 3-2). Flooded portions of the emergent marsh zone typically contain abundant submergent and floating species, and these submergent plants can be analyzed rather than collecting data for the deeper submergent zone.
2. Overlay a random grid or identify three potential sampling transects that will cross typical zones.
3. If there are obvious monoculture (uniform) patches on the photos, these should be sampled, as these uniform areas are often areas of invasive plants. Large, dense areas of invasive plants should be mapped with GPS units or identified on aerial photos or satellite imagery to track the long-term expansion of these invasive patches.

Field Sampling:

1. In each zone, place 15 sample quadrats along transects or randomly, each quadrat with an area of 1.0 m^2. Limit sampling to two zones; 1) the wet meadow zone and dry portion of the emergent zone, and 2) the

flooded portion of the emergent zone and the submergent zone (Figures 3-1 and 3-2). Sampling points can be located along three transects (Figure 3-1) or randomly located using a GIS mapping program (Figure 3-2). Establishing points along transects requires less time than sampling random points and may be preferred for monitoring programs that have small budgets. For wetlands with narrow zones, sampling points may need to be located along a transect that is not perpendicular to the drainage gradient of the wetland (see Insert B on Figure 3.1). In some wetlands there is a submergent marsh zone that contains only floating or submergent plants. Typically, it is not necessary to sample this zone, as the flooded portion of the emergent zone will contain most of the plants in the deeper submergent zone and the emergent zone can be sampled much more rapidly.

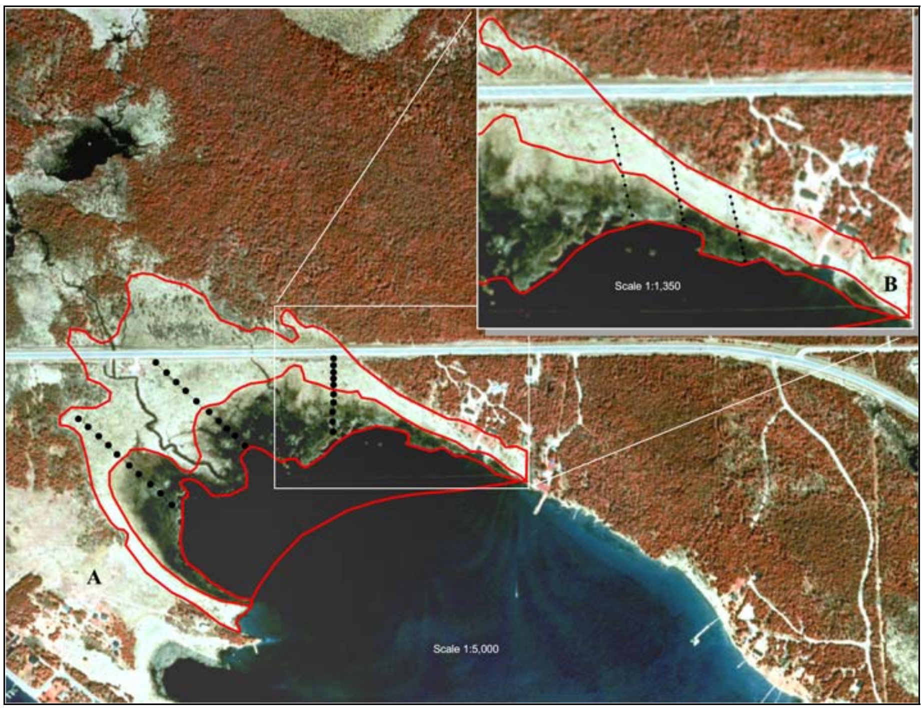

Figure 3-1. This aerial photo view of a wetland along northern Lake Huron shows the location of three transects, each beginning at the upland edge of the wetland and continuing south across the meadow zone (white) and the emergent/submergent zone (dark). The transects end at the edge of the emergent zone, even though there may be continued vegetation in a more open submergent zone. This open vegetation cannot typically be seen easily on aerial photos. Photo A shows 15 sampling points in each of the two zones. Photo insert B shows that if a narrow portion of this wetland, or a wetland that was narrow along its entire length, were being sampled, that the transects would need to be configured at an angle to the wetland's slope to allow for all 30 points to be placed. Locating the points along transects allows for more rapid sampling than the random sampling shown in Figure 3-2.

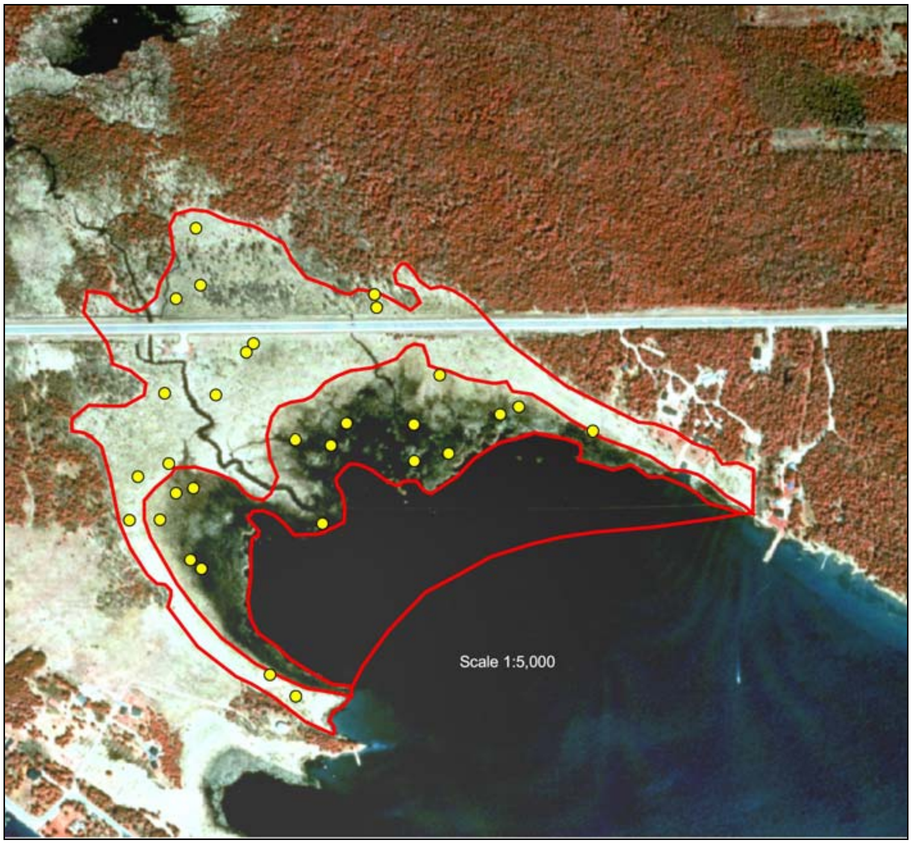

Figure 3-2. Random sampling of the wetland shown in figure 1. Random sampling can be configured utilizing GIS software, or by physically (or electronically) placing a grid over the photo and randomly choosing sampling points.

2. If transects are used, the starting point for each transect is randomly placed within 25 meters of the upland edge of the wet meadow zone, with sampling points established 25 meters apart. The location of each sampling quadrat around a sampling point is selected randomly using compass bearings and distances from one to nine meters. Percent cover is estimated for each plant species in the sample quadrat; coverage is estimated for all emergent, floating and submergent species. Substrate, organic depth, water depth and water clarity (using Secchi disk) are recorded. Depths of shallow organic soils can be measured with forcing a sharpened 4' x 3" (1.2 m x 8 cm) clear Plexiglas tube into the substrate until mineral soils are encountered and then forcing a rubber stopper into the top of the tube to create a vacuum, and then extracting the tube and reading the depth of the organic material in it. For deeper organic materials, as often encountered in barrier-enclosed or riverine wetlands, a 10-foot (3 m) length of ¾ inch (1.8 cm) aluminum conduit provides an inexpensive measuring pole. In each sample plot, list the species present along with approximate coverage value. Use values of 1%, 3%, 5%, 10% and so on, increasing by increments of 5% for higher coverage values. Note that cumulative areal coverage of all species can exceed 100% because more than one species can occupy the same space in a 2-dimensional plane. In addition, if it is not possible to place the quadrat close to the ground (i.e., in dense *Typha*), surveyors should be mindful of parallax and not include areas outside of the quadrat frame in their areal coverage estimates.

Although only vascular macrophytes are used in the mean conservatism indices, surveyors should record all aquatic macrophytes (e.g., *Chara*, *Nitella*, *Riccia*, *Ricciocarpos*). This may allow for further analyses in the future, including potential development of FQI indices for nonvascular plants. We are suggesting that plant taxonomic nomenclature be based on that found in the Michigan Flora (Voss 1972, 1985, 1996 and Herman et al. 2001). This will allow easy utilization of the FQA program, which contains almost all of the Great Lakes wetland flora. Another web-based flora of North America has been recommended (http://www.itis.gov), because it covers the entire flora of the continent, but taxonomic differences between this program and the FQA program are significant and will require the development of a crosswalk between ITIS and the FQA nomenclature.

Data are recorded on a standardized plant sampling form (Figure 3-3). This form provides the scientific names of the most commonly occurring aquatic macrophytes, with spaces provided for unknown species or species not listed on the form. For some genera with many species, such as *Carex* or *Potamogeton*, spaces are provided to fill in additional species within the genus. Since there are more than 600 species of aquatic macrophyte within Great Lakes coastal wetlands, only the most common are listed on the form. A more complete list of species is provided in Appendix 1. While this is a more complete list, no wetland tree species are included, although they might establish briefly during low-water conditions or they may be present at the edges of the open coastal wetland.

Worksheets

The worksheets utilized for the plant protocols include **Table 3-3:** Wetland quality based on aquatic macrophyte sampling; **Table 3-5:** Flow chart for determining quality rating of submergent marsh zone or submergent component of an emergent marsh zone; **Table 3-6:** Species tolerant of nutrient enrichment, sedimentation, or increased turbidity; and **Table 3-7:** Combined standardized score from Table 3-3, Rows A-I. Tables 3-1, 3-2, 3-4, and 3-8 provide additional examples and information, but are not required for computer marsh quality scores. **Figure 3-3:** Great Lakes Marsh Sampling Form, is utilized for collecting plant data in the wetland.

Checklists

One checklist is included: **Appendix 3-1**, a list of the most common wetland plants encountered in Great Lakes coastal wetlands.

Site selection/number of sites/stratification

Project-wide site selection, number of sites, and stratification is based on recommendations in the Statistical Design chapter of the report by Otieno and Uzarski. Overall statistical analysis selects and stratifies sites on the basis of ecoregions (Omernik 2000) and lake. For individual administrative units (state or province), it is recommended that hydrogeomorphic type (Albert and Simonson 2004) be noted, as the hydrogeomorphic types are important for understanding floristic differences.

As noted above, 15 sampling points are located in each zone of the wetlands chosen for sampling. Species areas curves leveled off after 12 to 15 sampling points in each marsh zone for most of the U.S. and Canadian wetlands studied, demonstrating that overall plant diversity was adequately sampled.

Analysis of quadrat data (use Table 3.3):

1. Compute overall INVASIVE COVER for the **entire site** by summing the coverage values for all invasive plants and dividing by the number of quadrats. This is the INVASIVE COVER score for the entire site and can be used to estimate the site quality; see Table 3-3-A for quality classes (High, Medium, Low, Very Low) and the equivalent numeric scores (5, 3, 1, 0).

2. Compute overall INVASIVE FREQUENCY for the **entire site** by summing the number of quadrats containing invasive species and dividing by the total number of quadrats. See Table 3-3-B for quality classes based on INVASIVE FREQUENCY.

3. Compute the MEAN CONSERVATISM INDEX for the **entire site** by totaling the conservatism score for each species and dividing by the number of species. This can be rapidly computed using the Michigan FQA software (Herman et al. 2001). The mean conservatism index for all species (total) is divided by the mean conservatism index for native species (native) and the ratio is compared (See Table 3-3, Row C for quality scores). Low scores (0.79 or lower) reflect large numbers of exotic species and degraded conditions. Table 3-4 provides average regional mean conservatism index scores for each of the Great Lakes and for each of the hydrogeomorphic types. The scores in Table 3.4 are not used in computing the quality of the wetland, but provide a regional perspective to wetland quality in different lakes and hydrogeomorphic types.

4. Compute overall INVASIVE COVER for the **wet meadow and dry emergent zone** by summing the coverage values for all INVASIVE plants in these zones and dividing by the number of quadrats in these zones. This is the INVASIVE COVER score for the wet meadow and dry emergent zone and can be used to estimate the zone quality; see Table 3-3, Row D for quality classes.

5. Compute overall INVASIVE FREQUENCY for the **wet meadow and dry emergent zone** by summing the number of quadrats (in these zones) containing INVASIVE species and dividing by the total number of quadrats in the wet meadow and dry emergent zones. See Table 3-3, Row E for quality classes of the wet meadow and dry emergent zone based on INVASIVE FREQUENCY.

6. Compute the MEAN CONSERVATISM INDEX for the **wet meadow and dry emergent zone** by totaling the conservatism score for each species in these zones and dividing by the number of species. This can be rapidly computed using the Michigan FQA software (Herman et al. 2001). The mean conservatism index for all species (total) in the **wet meadow and dry emergent zone** is divided by the mean conservatism index for native species (native) and the ratio is compared (See Table 3-3, Row F for quality scores). Table 3-4 provides average regional mean conservatism index scores **by zone** for most of the Great Lakes and hydrogeomorphic types.

7. Compute overall INVASIVE COVER for the **flooded emergent and submergent zone** by summing the coverage values for all invasive plants in these zones and dividing by the number of quadrats in these zones. This is the INVASIVE COVER score for the **flooded emergent and submergent zone** and can be used to estimate the zone quality; see Table 3-3, Row G for quality classes.

8. Compute overall INVASIVE FREQUENCY for the **flooded emergent and submergent zone** by dividing the number of quadrats (in these zones) containing invasive species and dividing by the total number of quadrats in the **flooded emergent and submergent zone**. See Table 3-3, Row H for quality classes of the wet meadow and dry emergent zone based on INVASIVE FREQUENCY.

9. Compute the MEAN CONSERVATISM INDEX for the **flooded emergent and submergent zone** by totaling the conservatism score for each species in these zones and dividing by the number of species. This can be rapidly computed using the Michigan FQA software (Herman et al. 2001). The mean conservatism index for all species (total) in the **flooded emergent and submergent zone** is divided by the conservatism index for native species (native) and the ratio is compared (See Table 3-3, Row I for quality scores). Table 3-4 provides average regional mean conservatism index scores by zone for most of the Great Lakes and hydrogeomorphic types.

Table 3-3. Wetland quality based on aquatic macrophyte sampling.

VARIABLE	QUALITY			
	HIGH (5)	MEDIUM (3)	LOW (1)	VERY LOW (0)
A: INVASIVE COVER (entire site)[1]	Absent	<25 %	25-50%	>50%
B: INVASIVE FREQ. (entire site)	Absent	<25 %	25-50%	>50%
C: Mean conservatism of entire site (native/total)	>0.95	0.8 -0.94	0.6-0.79	< 0.6
D: INVASIVE COVER (wet meadow and dry emergent zones)[2]	Absent	<25 %	25-50%	>50%
E: INVASIVE FREQ. (wet meadow and dry emergent zones)	Absent	<25 %	25-50%	>50%
F: Mean conservatism score of wet meadow and dry portion of emergent zones (native/total)	>0.95	0.8 -0.94	0.6-0.79	< 0.6
G: INVASIVE COVER (flooded emergent and submergent zone)[3]	Absent	<25 %	25-50%	>50%
H: INVASIVE FREQUENCY (flooded emergent and submergent zone)	Absent	<25 %	25-50%	>50%
I: Mean conservatism of flooded emergent and submergent zones (native/total)	>0.95	0.8 -0.94	0.6-0.79	< 0.6

[1]Invasive species of entire site to include in analysis: *Butomus umbellatus* (flowering rush), *Cirsium arvense* (Canadian thistle), *Cirsium palustre* (marsh thistle), *Cirsium vulgare* (bull thistle), *Glyceria maxima* (tall manna grass), *Hydrocharis morsus-ranae* (European frog's-bit), *Impatiens glandulifera* (touch-me-not), *Iris pseudacorus* (yellow flag), *Lythrum salicaria* (purple loosestrife), *Myriophyllum spicatum* (Eurasian water milfoil), *Phalaris* arundinacea (reed canary grass), *Phragmites australis* (tall reed), *Polygonum lapathifolium* (nodding smartweed), *Potamogeton crispus* (curly pondweed), *Rorippa amphibia* (yellow cress), *Rumex crispus* (curly dock), *Typha angustifolia* (narrow-leaved cattail), *Typha* X *glauca* (hybrid cattail).

[2]Invasive species of wet meadow and dry emergent marsh: *Cirsium arvense*, *Cirsium palustre*, *Cirsium vulgare*, *Impatiens glandulifera, Iris pseudoacorus*, *Lythrum salicaria*, *Phalaris arundinacea*, *Phragmites australis*, *Polygonum lapathifolium*, *Rorippa amphibian, Rumex crispus*, *Typha angustifolia*, *Typha X glauca*.

[3]Invasive species of flooded emergent and submergent zone to include in analysis: *Butomus umbellatus*, *Hydrocharis morsus-ranae*, *Lythrum salicaria*, *Myriophyllum spicatum*, *Phalaris arundinacea*, *Phragmites australis*, *Potamogeton crispus*, *Typha angustifolia*, *Typha X glauca*.

Reference conditions for Regional Wetland Types

Several regional wetland types were identified through cluster analysis and Twinspan ordinations (Hill 1973, 1979) of vegetation data collected across the Great Lakes, including the connecting rivers (Minc 1997). Mean conservatism indices were computed for each of the regional wetland types (Table 3.2). For most of the wetland types, the indices were computed from the list of species that were present in more than 1% of the sampling points during inventories conducted in 1987, 1988, 1989, 1994, and 1995 (Albert et al. 1987, 1988, 1989; Minc 1997). For Georgian Bay protected embayments and Lake Erie sandspit embayments, the indices were computed from unpublished data collected in 2003 and 2004 (D. Albert). For the Lake Huron, Lake Michigan and Lake Superior swale complexes (barrier enclosed), scores were summarized from studies of swale complexes in Michigan (Comer et al. 1991, 1993). The Lake Ontario protected embayment and drowned river mouth sites are summarized from data collected by the Canadian Wildlife Service of Environment Canada in 2002 and 2003.

Table 3-4. Mean Conservatism Scores for each regional marsh type.

LAKE or REGIONAL MARSH TYPE	MEAN CONSERVATISM SCORE BY ZONE		
	MEADOW ZONE	EMERGENT ZONE	TOTAL MARSH
Lake Erie Open Embayments**	3.1 (4.6)	3.8 (5.3)	3.7 (5.3)
Lake Erie Sand-spit Embayments	4.3 (4.5)	4.4 (6.1)	4.5 (4.8)
Georgian Bay Protected Embayments *	5.1 (6.5)	6.4 (7.2)	5.8 (6.8)
Lake Huron (northern) protected Embayments	5.1	5.6	5.6
Lake Huron (northern) Open Embayments (Rich Fens)	5.5	4.5	5.1
Lake Huron's Saginaw Bay Open Embayment	3.2	4.5	3.9
Lake Huron Swale Complex (Barrier Enclosed)	-	-	4.9 (6.4)
Lake Michigan Drowned River Mouths	4.0	4.9	4.5
Lakes Michigan (northern) Open Embayments (Rich Fens)	5.5	4.5	5.1
Lake Michigan (northern) Protected Embayments	5.1	5.6	5.6
Lake Michigan Swale Complex (Barrier Enclosed)	-	-	5.3 (6.3)
Lake Ontario Barrier Beach Lagoons	5.0	5.7	5.3
Lake Ontario Drowned River Mouths	4.2	4.3	4.2
Lake Ontario Protected Embayments*	4.7 (6.4)	3.9 (5.8)	4.5 (6.3)
Lake St. Clair Open Embayments**	3.1	3.8	3.7
Lake Superior Barrier Beach Lagoons & Riverine Wetlands	6.3	6.7	6.4
Lake Superior Swale Complex (Barrier Enclosed)	-	-	5.9 (6.9)
St. Clair River Delta	4.2	5.5	4.7
St. Lawrence River Drowned River Mouths	4.4	5.5	5.0
St. Marys River Connecting Channel	5.1	5.6	5.6

* For Lake Ontario and Georgian Bay protected wetlands the mean scores for each zone are based on the scores of several wetlands rather than on a mean coverage value for all of the marshes studies. The maximum score of a single wetland for each zone is shown in parenthesis when the data is available ( ).
** For Lake Erie, mean C scores from historic data collected in high quality wetland at Perry's Victory Monument (Stuckey 1975) is shown in parenthesis ().

Evaluating wetland quality using submergent and floating plant species

Evaluating the quality of the portion of a wetland dominated by submergent or floating plants requires a multi-step process (Table 3-5), as several factors can influence the presence and density of these plants. Table 3.5 summarizes the ranks proposed for submergent or emergent zones using submergent and floating plants. It is common for submergent plants to cover only a portion of the bottom substrate in a marsh, so sparse submergent or floating vegetation does not necessarily indicate degraded conditions. High coverage (>75%) of submergent or floating vegetation, with a predominance (>50%) of nutrient-enrichment or sediment-and-increased-turbidity tolerant species (Table 3-6) typically indicates that either agriculture or urban development has resulted in increased nutrient, sediment, or turbidity in the lake waters (Index score = 1), but not to a level that would result in complete elimination of submergent or floating vegetation (Index score = 0). Under such conditions, other submergent and floating plants can be more common, in which case the wetland is considered less degraded (Index score = 3). Submergent and floating vegetation cover ranging from 25-75% is the typical condition for most emergent and submergent wetlands, and Index scores of 3 or 5 indicate this increased quality. Coverage values of less than 25% indicate degraded conditions if **only** nutrient-enrichment or sediment-and-increased-turbidity tolerant species are present, but are typical for other submergent or floating plant coverage values in many marshes (Index score = 5).

If submergent or floating plants are completely absent, it can indicate several conditions. In lower stream reaches (drowned river mouths, connecting rivers, or deltas), it can indicate that the stream velocity is too high for these plants to persist. Emergent plants may, however, be able to persist in these higher velocity regions of a stream. However, in protected bays or in slow-flowing lower reaches of streams, lack of submergent and floating vegetation typically indicates that sedimentation or turbidity is preventing plant establishment or persistence. When conditions are windy or when turbidity is the result of fine mineral or organic sediments, turbidity is often evident and can be directly linked to lack of wetland vegetation. However, when conditions are calm, surface waters can be clear, but thick, loose sediments will often be evident and easily stirred up during plant sampling. Another complication can be that strong winds may stir up sediment even though conditions are adequate for submergent and floating plants to occupy the wetland. In this case, the wetland would be judged on the basis of the vegetation present, **not** on the basis of the short-term turbidity.

Combined standardized score

A combined standardized score can be calculated by adding the wetland quality scores from Table 3-3 (Rows A-I) and Table 3-5. Each of these ten numeric scores ranges from zero to five, with a maximum total score of 50 and a minimum score of zero. The Combined numeric quality scores and their equivalent descriptive quality scores are shown in Table 3-7. Table 3-8 provides example scores for six riverine wetlands resulting from totaling the metrics in Table 3-3 and 3-5.

Table 3-5. Flow chart for determining quality rating of submergent marsh zone or submergent component of an emergent marsh zone.

	Plant Coverage	Type of submergent plants present	Index Score
Submergent or Floating Vascular Plant Species Present	>75%	>50% nutrient-enrichment tolerant species or sediment-and-increased-turbidity tolerant species	1 LOW
		<50% nutrient-enrichment tolerant species or sediment-and-increased-turbidity tolerant species	3 MODERATE
	25-75%	>50% nutrient-enrichment tolerant species or sediment-and-increased-turbidity tolerant species	3 MODERATE
		<50% nutrient-enrichment tolerant species or sediment-and-increased-turbidity tolerant species	5 HIGH
	<25%	>75% nutrient-enrichment tolerant species or sediment-and-increased-turbidity tolerant species	1 LOW
		<75% nutrient-enrichment tolerant species or sediment-and-increased-turbidity tolerant species	5 HIGH
Submergent or Floating Plant Species Absent	0%	Clear water in rapidly flowing streams or where bottom consists of cobbles or rock	? REQUIRES FURTHER ANALYSIS
		Highly turbid at time of survey, loose bottom sediments	0 VERY LOW
		Clear water, but thick, loose bottom sediments	0 VERY LOW
Only Algae Present			0 VERY LOW

Mapping of invasive species

If there are areas where invasive species have greater than 50% cover, these should be mapped. Boundaries of polygons should be identified on recent aerial photos and or mapped with a GPS unit. Mapping allows the agency managing the marsh to either initiate restoration activities or document the spread of invasive species in future monitoring periods. Further detailed sampling can be conducted in polygons dominated by invasives to meet the needs of the sampling agency. For example, five randomly located 1 m2 quadrats could be sampled in one or several large patches of invasive plants to document the species composition and relative coverage values (estimated to 5%) for long-term monitoring of change within the patches, either due to natural wetland changes or to active management. If there are several patches of invasive species, at least one polygon of each invasive-species type could be sampled.

Table 3-6. Species tolerant of nutrient enrichment, sedimentation, or increased turbidity.

Stress	Species
Nutrient Enrichment	*Ceratophyllum demersum*
	Elodea canadensis
	Lemna minor
	Myriophyllum spicatum
	Potamogeton crispus
	Potamogeton pectinatus
	Algae
Sedimentation and Increased Turbidity	*Butomus umbellatus*
	Ceratophyllum demersum
	Elodea Canadensis
	Heteranthera dubia
	Myriophyllum spicatum
	Potamogeton crispus
	P. foliosus
	P. pectinatus
	P. pusillus
	Ranunculus longirostris

Table 3-7. Combined standardized score from Table 3.3, Rows A-I and Table 3.5.

Combined Numeric Score	Combined Descriptive Scores
0-5	VERY LOW
6-20	LOW
21-40	MEDIUM
41-50	HIGH

Table 3-8. Examples of Combined Standardized Scores for five riverine wetlands

METRICS	SITES				
	Au Train, Mich.	Kalamazoo, Mich.	Kewaunee, Wis.	Fox, Wis.	Lineville, Wis.
Table 3A	5	3	3	0	1
Table 3B	5	0	3	0	0
Table 3C	5	3	3	0	3
Table 3D	5	3	3	0	0
Table 3E	5	3	1	0	0
Table 3F	5	3	3	0	3
Table 3G	5	5	3	0	1
Table 3H	5	3	3	0	0
Table 3I	5	3	3	0	3
Table 5	5	1	0	0	1
TOTAL SCORE	50 HIGH	27 MODERATE	25 MODERATE	0 VERY LOW	12 LOW

Interpretation of results

In the vegetation section, an attempt was made to incorporate interpretations of the results into a discussion of the protocols. For example, Table 3-4 (Mean conservatism scores for each regional marsh type) provides the scores derived from previous sampling of coastal wetlands that will allow state and provincial wetland monitors to compare their wetlands to the conditions encountered in each lake and hydrogeomorphic wetland type. Similarly, Table 3-8 (Examples of combined standardized scores for five riverine wetlands), shows the range of quality scores found for a given wetland type, in this case riverine wetlands along lakes Michigan and Superior. It is common for riverine wetlands in the northern portions of the Great Lakes to be of higher quality than those in the southern portion of the lakes, but it can be seen that even northern riverine wetlands (Kewaunee, Fox and a small stream at Lineville near the town of Green Bay) can be degraded by urban and agricultural land use.

The effectiveness of vegetation data to detect wetland degradation was discussed in the introduction. Probably the greatest challenge in evaluating wetland degradation is presented by the response of wetland plant composition to water-level fluctuations. The use of a simplified set of metrics and indices was an acknowledgement that the number of effective plant metrics is greatly limited by natural plant response to water level fluctuation.

Data handling and storage

A data-handling protocol has been developed by the Great Lakes Commission, which will maintain long-term storage of the data collected for this project. The plant analyses have been simplified to utilize only the metrics (invasive species and species tolerant of nutrient enrichment and turbidity) and indices (mean conservatism, part of floristic quality assessment) agreed upon by the group of wetland plant ecologists meeting in Duluth, Minn. during the spring of 2007. As a result, the statistical analysis of the vegetation data is not complex. However, the data collected provides an opportunity to conduct future analyses as the long-term database is developed. These future analyses may well provide us with adequate data to further test metrics and indices developed for wetlands in other parts of the Great Lakes basin, and to develop a more robust set of Great-Lakes based plant metrics and indices.

References

Albert, D.A., Minc, L.D., 2004. Plants as Regional Indicators of Great Lakes Coastal Wetland Health. Aquatic Ecosystem Health and Management 7(2): 233-247

Albert, D.A., Reese, G., Crispin, S., Wilsmann, L.A., Ouwinga, S.J., 1987. A survey of Great Lakes marshes in Michigan's Upper Peninsula. Michigan Natural Features Inventory, Lansing, Mich.

Albert, D.A., Reese, G., Crispin, S., Penskar, M.R., Wilsmann, L.A., Ouwinga, S.J., 1988. A survey of Great Lakes marshes in the southern half of Michigan's Lower Peninsula. Michigan Natural Features Inventory, Lansing, Mich.

Albert, D.A., Reese, G., Penskar, M.R., Wilsmann, L.A., Ouwinga, S.J., 1989. A survey of Great Lakes marshes in the northern half of Michigan's Lower Peninsula and throughout Michigan's Upper Peninsula. Michigan Natural Features Inventory, Lansing, Mich.

Albert, D. A., and L. Simonson. (2004) *Coastal wetland inventory of the Great Lakes basin* (GIS coverage of the entire U.S. Great Lakes: www.glc.org/wetlands/inventory.html), Great Lakes Coastal Wetlands Consortium, Great Lakes Commission, Ann Arbor, M ich.

Albert, D. A., Tepley, A. J., and L. D. Minc. 2006. *Plants as indicators for Lake Michigan's Great Lakes coastal drowned river wetland health.* Pages 238-258 in Thomas P. Simon and Paul M. Stewart (Eds.), *Coastal Wetlands of the Laurentian Great Lakes: Heath, Habitat, and Indicators*, Authorhouse Press, Bloomington, Ind.

Albert, D. A., J. W. Ingram, T. A. Thompson, and D. A. Wilcox. 2003. Hydrogeomorphic classification for Great Lakes coastal wetlands (Great Lakes Consortium web site).

Albert, Dennis A., Douglas A. Wilcox, Joel W. Ingram, and Todd A. Thompson. 2005. Hydrogeomorphic classification for Great Lakes coastal wetlands. Journal of Great Lakes Research 31(Supplement 1): 129-146.

Bourdagns, M., C. A. Johnston, and R. R. Regal. 2006. Properties and performance of the floristic quality index in Great Lakes coastal wetlands. Wetlands 26 (3): 718-735.

Comer, P.J. and D.A. Albert. 1993. *A Survey of Wooded Dune and Swale Complexes in Michigan*. MNFI report to Michigan Department of Natural Resources, Land and Water Management Division, Coastal Zone Management Program. 159 pp.

Comer, P.J. and D.A. Albert. 1991. *A Survey of Wooded Dune and Swale Complexes in The Northern Lower and Eastern Upper Peninsulas of Michigan*. MNFI report to the Michigan DNR, Coastal Zone Management Program. 99 pp.

Environment Canada. 2004. Durham Region Coastal Wetland Monitoring Project: Year 2 Technical Report. Environment Canada, Ontario.

Herman, K. D., L. A. Masters, M. R. Penskar, A. A. Reznicek, G. S. Wilhelm, W. W. Brodovich, and K. P. Gardiner. 2001. Floristic Quality Assessment with Weltna Categories and Examples of Computer Applications for the State of Michigan.

Hill, M. O. 1973. Reciprocal averaging: an eigenvector method of ordination. Journal of Ecology 61: 237-249.

Hill, M. O. 1979 TWINSPAN: A FORTRAN Program for Arranging Multivariate Data in an Ordered Two-Way Table by Classification of the Individuals and Attributes. Cornell Ecology Program 41. Section of Ecology and Systematics, Cornell University, Ithaca, MY. 90 pp.

Hudon, C., D. Wilcox, and J. Ingram. 2006. Modeling wetland plant community response to assess water-level regulation scenarios in the Lake Ontario-St. Lawrence River basin. Environmental Monitoring and Assessment 113(1-3): 303-328.

Mack, J. J., N. H. Avdis, E. C. Braig IV, and D. L. Johnson. Accepted. Application of a Vegetation-based Index of Biotic Integrity for Lake Erie coastal marshes in Ohio. Journal of Aquatic Ecosystem Health and Management.

Omernik 2000. http://mercury.ornl.gov/metadata/ornldaac/html/rgd/daac.ornl.gov_data_bluangel_harvest_RGED_QC_basic_vegetation_omernik_ecosystems.html.

Simon, P.T., and P. E. Rothrock. 2006. Plant Index of Biotic Integrity for Drowned River Mouth Coastal Wetlands of Lake Michigan. Pages 228-237 in Thomas P. Simon and Paul M.Stewart (Eds.), Coastal Wetlands of the Laurentian Great Lakes: Heath, Habitat, and Indicators, Authorhouse Press, Bloomington, Ind.

Stewart, P.M., Butcher, J.T., Simon, T.P., 2003. Response Signatures of Four Biological Indicators to an Iron and Steel Industrial Landfill. In: T.P. Simon (E.) Biological Response Signatures, pp. 419-444. CRC Press, New York, NY.

Stewart, P.M., Scribailo, R.W., Simon, T.P., 1999. The use of aquatic macrophytes in monitoring and in assessment of biological integrity. In: A. Gerhardt (Ed.).

Biomonitoring of Polluted Water, pp. 275-302. Environmental Research Forum vol. 9. Trans Tech Publications, Zurich, Switzerland.

Stuckey, R. L. 1975. A floristic analysis of the vascular plants of a marsh at Perry's Victory Monument, Lake Erie. Michigan Botanist 14: 144-166.

Swink, F., and G. Wilhelm. 1994. Plants of the Chicago Region. Fourth Edition. Indiana Academy of Science, Indianapolis, IN. 921 pp.

Voss, E. G. 1972. Michigan Flora. Part I Gymnosperms and Monocots. Cranbrook Inst. Sci. Bull. 55 & Univ. Mich Herb. 488 pp.

Voss, E. G. 1985. Michigan Flora. Part II Dicots (Saururaceae-Cornaceae). Cranbrook Inst. Sci. Bull. 59 & Univ. Mich Herb. 724 pp.

Voss, E. G. 1996. Michigan Flora. Part III Dicots (Pyrolaceae-Compositae). Cranbrook Inst. Sci. Bull. 61 & Univ. Mich Herb. 622 pp.

Wilcox, D. A. 2005. Lake Michigan wetlands: classification, concerns, and management opportunities. Pages 421-437 in Edsall, T. and M. Munawar, eds. State of Lake Michigan: Ecology, Health, and Management. Ecovision World Monograph Series. Aquatic Ecosystem Health and Management Society, New Delhi.

Wilcox, D. A. 2004. Implications of hydrologic variability on the succession of plants in Great Lakes wetlands. *Aquatic Ecosystem Health & Management* 7(2): 223-231.

Wilcox, D. A., J. E. Meeker, P. L. Hudson, B. J. Armitage, M. G. Black, and D. G. Uzarski. 2002. Hydrologic variability and the application of Index of Biotic Integrity metrics to wetlands: a Great Lakes evaluation. *Wetlands* 22(3): 588-615.

Wilhelm, G., and L. A. Masters. 1995. Floristic quality assessment in the Chicago Region and application computer programs. Morton Arboretum, Lisle, IL. 17 pp.

Appendix 3-1. Great Lakes Marsh Sampling Form

Marsh name:	Location:	Local Jurisdiction:	Date
GPS:N E		Samplers:	
GPS Pt - begin transect 1:		End 1:	
GPS Pt - begin transect 2:		End 2:	
GPS Pt - begin transect 3:		End 3:	
Lake:	Hydrogeomorphic Type:	Substrate (circle): sand silt clay gravel	
Marsh zone: 1=meadow 2=emergent 3=submergent		Secchi Disk Reading:	

SUBSTRATE TYPE															
ORGANIC DEPTH															
WATER DEPTH															
MARSH ZONE															
SAMPLING POINT															
SPECIES															
Agrostis hyemalis															
Algae sp.															
Alisma plantago-aquatica															
Alnus rugosa															
Aster puniceus															
Aster umbellatus															
Aster															
Bidens cernuus															
Bidens															
Boehmeria cylindrical															
Bolboschoenus fluviatilis															
Brasenia schreberi															
Butomus umbellatus															
Calamagrostis Canadensis															
Calla palustris															
Caltha palustris															
Campanula aparinoides															
Carex aquatilis															
Carex lacustris															
Carex stricta															
Carex															
Carex															
Cephalanthus occidentalis															
Ceratophyllum demersum															
Chara spp.															
Cicuta bulbifera															
Cirsium															
Cladium mariscoides															
Cornus stolonifera															
Cornus															
Cyperus															
Decodon verticillatus															
Drosera															
Dulichium arundinaceum															
Echinocloe walteri															
Eleocharis smallii															
Eleocharis															

Page 2, Marsh Name:	Samplers:								Date:						
SAMPLING POINT															
SPECIES															
Elodea Canadensis															
Epilobium															
Equisetum fluviatile															
Erechtites hieracifolia															
Erigeron philadelphicus															
Eriophorum															
Eupatorium maculatum															
Eupatorium perfoliatum															
Euthamia graminifolia															
Galium															
Galium trifidum															
Glyceria															
Heteranthera dubia															
Hippuris vulgaris															
Hydrocharis morsus-ranae															
Hypericum															
Ilex verticillata															
Impatiens capensis															
Iris															
Juncus															
Juncus alpinus															
Juncus balticus															
Juncus canadensis															
Juncus dudleyi															
Juncus nodosus															
Lathyrus palustris															
Leersia oryzoides															
Lemna minor															
Lemna trisulca															
Lobelia															
Ludwegia palustris															
Lycopus americanus															
Lycopus uniflorus															
Lysimachia															
Lysimachis terrestris															
Lysimachis thyrsiflora															
Lythrum salicaria															
Megalodonta beckii															
Mentha															
Menyanthes trifoliata															
Mimulus ringens															
Muhlenbergia glomerata															
Myosotis															
Myriophyllum exalbescens															
Myriophyllum spicatum															
Myriophyllum															

Page 3, Marsh Name:	Samplers:								Date:						
SAMPLING POINT															
SPECIES															
Najas flexilis															
Nitella spp.															
Nuphar advena															
Nuphar variegata															
Nymphaea odorata															
Onoclea sensibilis															
Osmunda															
Panicum															
Peltandra virginica															
Phalaris arundinacea															
Phragmites australis															
Poa															
Polygonum amphibium															
Polygonum lapathifolium															
Polygonum															
Pontederia cordata															
Potamogeton crispus															
Potamogeton gramineus															
Potamogeton illinoensis															
Potamogeton natans															
Potamogeton pectinatus															
Potamogeton richardsonii															
Potamogeton zosteriformis															
Potamogeton															
Potamogeton															
Potentilla palustris															
Ranunculus longirostris															
Ranunculus															
Rhamnus															
Rhynchospora															
Rorippa palustris															
Rosa palustris															
Rubus															
Rumex crispus															
Rumex orbiculatus															
Sagittaria latifolia															
Sagittaria															
Salix candida															
Salix exigua															
Salix															
Sarracenia purpurea															
Saururus cernuus															
Scheuchzeria palustris															
Schoenoplectus acutus															
Schoenoplectus pungens															
Schoenoplectus subterminalis															
Schoenoplectus tabernaemontani															

Page 4, Marsh Name:	Samplers:								Date:						
SAMPLING POINT															
SPECIES															
Scirpus															
Scutellaria galericulata															
Sium suave															
Solanum dulcamara															
Solidago															
Sparganium															
Sparganium chlorocarpum															
Sparganium eurycarpum															
Sparganium minimum															
Sphagnum spp.															
Spiraea alba															
Spirodela polyrhiza															
Teucrium canadense															
Thelypteris palustris															
Tofieldia glutinosa															
Triadenum															
Triglochin															
Typha angustifolia															
Typha latifolia															
Typha x glauca															
Urtica dioica															
Utricularia vulgaris															
Utricularia intermedia															
Utricularia															
Vaccinium															
Vallisneria americana															
Verbena hastata															
Veronica															
Viburnum lentago															
Viola cucullata															
Vitis riparia															
Wolffia columbiana															
Zannichellia palustris															
Zizania aquatica															

NOTES:

Appendix 3-2. Wetland plant species most commonly encountered in Great Lakes coastal wetlands.

Acorus calamus
Agrostis hyemalis
Algae sp.
Alisma plantago-aquatica
Alnus rugosa
Andromeda glaucophylla
Anemone canadensis
Apocynum sibiricum
Aronia melanocarpa
Asclepias incarnata
Aster borealis
Aster dumosus
Aster lanceolatus
Aster lateriflorus
Aster longifolius
Aster novae-angliae
Aster puniceus
Aster umbellatus
Betula pumila
Bidens cernuus
Bidens connatus
Bidens coronatus
Bidens frondosus
Boehmeria cylindrica
Bolboschoenus fluviatilis
Brasenia schreberi
Bromus ciliatus
Butomus umbellatus
Calamagrostis canadensis
Calamagrostis inexpansa
Calla palustris
Callitriche hermaphroditica
Calopogon tuberosus
Caltha palustris
Campanula aparinoides
Cardamine pensylvanica
Carex alata
Carex aquatilis
Carex atherodes
Carex bebbii
Carex bromoides
Carex buxbaumii
Carex canescens
Carex chordorrhiza
Carex comosa
Carex crinita
Carex cryptolepis
Carex diandra
Carex exilis
Carex flava
Carex hystericina
Carex interior
Carex intumescens
Carex lacustris
Carex lanuginosa
Carex lasiocarpa
Carex leptalea
Carex limosa
Carex livida
Carex michauxiana
Carex oligosperma
Carex pauciflora
Carex paupercula
Carex prairea
Carex pseudo-cyperus
Carex retrorsa
Carex rostrata
Carex sartwellii
Carex scoparia
Carex sterilis
Carex stipata
Carex stricta
Carex tenera
Carex vesicaria
Carex viridula
Carex vulpinoidea
Cephalanthus occidentalis
Ceratophyllum demersum
Chamaedaphne
calyculata
Chara spp.
Chelone glabra
Cicuta bulbifera
Cinna arundinacea
Cirsium arvense
Cirsium muticum
Cladium mariscoides
Clematis virginiana
Cornus amomum
Cornus drummondii
Cornus foemina
Cornus racemosa
Cornus rugosa
Cornus stolonifera
Crataegus spp.
Cuscuta gronovii
Cyperus diandrus
Cyperus strigosus
Cypripedium calceolus
Cypripedium spp.
Cystopteris bulbifera
Decodon verticillatus
Deschampsia cespitosa
Drosera intermedia
Drosera rotundifolia
Dryopteris cristata
Dulichium arundinaceum
Echinocloe walteri
Eleocharis acicularis
Eleocharis elliptica
Eleocharis erythropoda
Eleocharis obtusa
Eleocharis rostellata
Eleocharis smallii
Elodea canadensis
Elodea nuttallii
Elymus virginicus
Epilobium ciliatum
Epilobium coloratum
Epilobium hirsutum
Epilobium leptophyllum
Equisetum fluviatile
Equisetum hyemale
Equisetum palustre
Equisetum variegatum
Erechtites hieracifolia
Erigeron philadelphicus
Eriocaulon septangulare
Eriophorum angustifolium
Eriophorum spissum
Eriophorum tenellum
Eriophorum virginiana
Eupatorium maculatum
Eupatorium perfoliatum
Euthamia graminifolia
Galium asprellum
Galium labradoricum
Galium palustre
Galium tinctorium
Galium trifidum
Gaylussacia baccata
Geum aleppicum
Geum canadense
Geum rivale
Glyceria borealis
Glyceria canadensis
Glyceria striata
Heteranthera dubia
Hibiscus palustris
Hippuris vulgaris
Hydrocharis morsus-ranae
Hydrocotyle americana
Hypericum boreale
Hypericum kalmianum
Hypericum majus
Ilex verticillata

Impatiens capensis
Iris versicolor
Iris virginica
Juncus alpinus
Juncus balticus
Juncus brevicaudatus
Juncus bufonius
Juncus canadensis
Juncus dudleyi
Juncus effusus
Juncus greenei
Juncus nodosus
Juncus pelocarpus
Juncus tenuis
Kalmia polifolia
Lathyrus palustris
Ledum groenlandicum
Leersia oryzoides
Lemna minor
Lemna trisulca
Liatris spicata
Lobelia dortmanna
Lobelia kalmii
Lobelia siphilitica
Lobelia spicata
Ludwegia palustris
Lycopus americanus
Lycopus uniflorus
Lysimachia ciliata
Lysimachia nummularia
Lysimachia quadriflora
Lysimachis terrestris
Lysimachis thyrsiflora
Lythrum alatum
Lythrum salicaria
Matteuccia struthiopteris
Megalodonta beckii
Mentha arvensis
Mentha piperita
Menyanthes trifoliata
Mimulus ringens
Muhlenbergia glomerata
Muhlenbergia unifloris
Myosotis laxa
Myosotis scorpioides
Myosoton aquaticum
Myrica gale
Myrica pensylvanica
Myriophyllum alterniflorum
Myriophyllum exalbescens
Myriophyllum heterophyllum
Myriophyllum spicatum
Myriophyllum tenellum
Myriophyllum verticillatum
Najas flexilis
Najas minor
Nelumbo lutea
Nemopanthus mucronata
Nitella spp.
Nuphar advena
Nuphar variegata
Nymphaea odorata
Onoclea sensibilis
Osmunda cinnamomea
Osmunda regalis
Panicum lindheimeri
Panicum virgatum
Parnassia glauca
Peltandra virginica
Penthorum sedoides
Phalaris arundinacea
Phragmites australis
Physostegia virginiana
Pilea fontana
Pilea pumila
Platanthera clavellata
Poa palustris
Pogonia ophioglossoides
Polygonum amphibium
Polygonum hydropiperoides
Polygonum lapathifolium
Polygonum pensylvanicum
Polygonum persicaria
Polygonum punctatum
Polygonum sagittatum
Pontederia cordata
Potamogeton alpinus
Potamogeton amplilfolius
Potamogeton berchtoldii
Potamogeton crispus
Potamogeton epihydrus
Potamogeton filiformis
Potamogeton foliosus
Potamogeton friesii
Potamogeton gramineus
Potamogeton illinoensis
Potamogeton natans
Potamogeton nodosus
Potamogeton obtusifolius
Potamogeton pectinatus
Potamogeton perfoliatus
Potamogeton praelongus
Potamogeton pusillus
Potamogeton richardsonii
Potamogeton robbinsii
Potamogeton spirillus
Potamogeton strictifolius
Potamogeton zosteriformis
Potentilla anserina
Potentilla fruticosa
Potentilla palustris
Prenanthes racemosa
Proserpinaca palustris
Pycnanthemum virginianum
Ranunculus abortivus
Ranunculus longirostris
Ranunculus pensylvanicus
Ranunculus recurvatus
Ranunculus sceleratus
Rhamnus alnifolia
Rhamnus frangula
Rhynchospora alba
Rhynchospora capillacea
Rorippa palustris
Rosa palustris
Rubus hispidus
Rubus pubescens
Rubus strigosus
Rumex crispus
Rumex maritimus
Rumex orbiculatus
Sagittaria graminea
Sagittaria latifolia
Sagittaria montevidensis
Sagittaria rigida
Sagittaris cuneata
Salix amygdaloides
Salix bebbiana
Salix candida
Salix cordata
Salix discolor
Salix eriocephala
Salix exigua
Salix lucida
Salix myricoides
Salix pedicellaris
Salix petiolaris
Salix pyrifloia
Salix sericea
Salix serissima
Sarracenia purpurea
Saururus cernuus
Scheuchzeria palustris
Schoenoplectus acutus
Schoenoplectus pungens
Schoenoplectus subterminalis
Schoenoplectus tabernaemontani
Scirpus atrovirens
Scirpus cespitosus
Scirpus cyperinus
Scutellaria galericulata
Scutellaria lateriflora
Sium suave
Solanum dulcamara
Solidago gigantea
Solidago ohioensis

Solidago patula
Solidago rugosa
Solidago uliginosa
Sparganium americanum
Sparganium chlorocarpum
Sparganium eurycarpum
Sparganium fluctuans
Sparganium minimum
Spartina pectinata
Sphagnum spp.
Spiraea alba
Spiraea tomentosa
Spiranthes cernua
Spiranthes romanzoffiana
Spirodela polyrhiza
Stachys palustris
Stachys tenuifolia
Symplocarpus foetidus
Teucrium canadense
Thalictrum dasycarpum
Thelypteris palustris
Tofieldia glutinosa
Triadenum fraseri
Triadenum virginicum
Triglochin maritimum
Triglochin palustre
Typha angustifolia
Typha latifolia
Typha x glauca
Urtica dioica
Utricularia cornuta
Utricularia intermedia
Utricularia resupinatua
Utricularia vulgaris
Vaccinium corymbosum
Vaccinium macrocarpon
Vaccinium oxycoccos
Vallisneria americana
Verbena hastata
Veronica anagalis-aquatica
Veronica officinalis
Viburnum lentago
Viola cucullata
Vitis riparia
Wolffia columbiana
Wolffia punctata
Xyris montana
Zannichellia palustris
Zanthoxylum americanum
Zizania aquatica
Zizania aquatica var. aquatica

Chapter 4
Invertebrate Community Indicators

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Introduction

Great Lakes coastal wetlands are subject to multiple anthropogenic disturbances. They are categorized into geomorphologic classes reflecting their location in the landscape and exposure to waves, storm surges and lake level changes (Albert and Minc 2001). The anthropogenic disturbances to Great Lakes coastal wetlands are superimposed on natural stress resulting from a highly variable hydrologic regime (Burton et al. 1999, 2002; Keough et al. 1999).

Fringing wetlands were the focus of the invertebrate studies reported here. They make up more than one-quarter of the 2.17×10^5 hectares of Great Lakes coastal wetlands. They include protected and open embayment wetlands which form along bays and coves leeward of islands or peninsulas. They occur along all five Great Lakes, and are especially common on the southern and northern shores of lakes Michigan and Huron and in the St. Mary's river-island complex. The location of the shoreline with respect to long-shore currents and wind fetch determines the type of wetland found along the shoreline (Burton et al. 2002). The greater the effective fetch (e.g., Burton et al. 2004), the more the wetland is exposed to waves and storm surges until a threshold is reached where wetlands no longer persist. The separation of variation due to anthropogenic disturbance from variation due to natural stressors related to water level changes and to biogeographic and ecoregional differences (Brazner et al. 2007) is central to predicting community composition and in turn, developing indices of biotic integrity (IBI) for these systems.

The development of indicators of ecosystem health for the Great Lakes was recognized as a major need at the State of the Lakes Ecosystem Conference (SOLEC) in 1998 in Buffalo, N. Y., and progress in developing indicators was the emphasis of SOLEC following that time. Among the indicators listed as high priority needs at SOLEC 1998 were indices of biotic integrity (IBIs) for coastal wetlands based on fish, plants and invertebrates.

Several initiatives have been undertaken to develop IBIs for specific aquatic guilds of invertebrates in wetlands of single Great Lakes, but their applicability to the entire basin has not been tested. Krieger (1992), Thoma et al. (1999), and de Szalay et al. (2004) evaluated various sampling methods for assessing zoobenthos at Lake Erie drowned rivermouths. These studies were somewhat limited because few, if any, undegraded reference wetlands remain in Lake Erie (de Szalay et al. 2004). Wilcox et al. (2002) attempted to develop wetland IBIs for the upper Great Lakes using fish, macrophytes, and invertebrates entering activity traps. While they found attributes that showed promise, they concluded that natural water level changes were likely to alter communities and invalidate metrics. Burton et al. (1999) developed a preliminary macroinvertebrate-based bioassessment procedure for coastal wetlands of Lake Huron. This system could be used across wide ranges of lake levels since it included invertebrate metrics for as many as four deep- and shallow-water plant zones, using a scoring system based on the number of inundated zones present. That procedure has since been tested and modified (Uzarski et al. 2004). The methods presented in Uzarski et al. (2004) are recommended herein.

While Great Lakes-wide studies of aquatic macrophytes indicate that similar geomorphic wetland types support very different plant assemblages in geographically distinct ecoregions (Minc 1997, Minc and Albert 1998, Chow-Fraser and Albert 1998, Albert and Minc 2001), several plant zones are common to many of these systems. In preliminary invertebrate-based IBI development studies, Burton et al. (1999) used dip nets to collect invertebrates from four plant zones that characteristically develop in inundated shorelines of fringing lacustrine wetlands during high water years. The invertebrate metrics from each of those zones were used in the IBI of Uzarski et al. (2004), where it was argued that developing separate metrics for each wetland plant zone across a water level gradient from wet meadow to the zone of deep-water emergents could compensate for absence of higher elevation zones (e.g., wet meadow) during low lake level years by placing more emphasis on metrics from zones that remained inundated. With the exception of Lake Ontario, which is regulated, lake levels fell sharply between 1998 and 2002, permitting Uzarski et al. (2004) to test this assumption, and the IBI performed well. Based on this verification, we recommend the collection procedures and metrics described by Uzarski et al. (2004) as the primary means of assessing macroinvertebrate community health in Great Lakes coastal wetlands.

Other sampling methods and metrics have been proposed and/or implemented that pertain to other classes of wetlands or areas that have may have lost their vegetative cover. Although still in development or under refinement, these approaches can be considered where the recommended Uzarski et al. (2004) IBI procedure is unsuitable (see limitations (below).

Materials and Methods

Macroinvertebrates sampling

Macroinvertebrate samples should be collected with standard 0.5-mm mesh, D-frame dip nets from late July through August. July-August is the interval during which emergent plant communities generally achieve maximum annual biomass and are mature, in flower and hence easier to identify than earlier in the season. Late instars of most aquatic insects are present in Great Lakes coastal wetlands from early July until mid-August.

Three replicate dip net samples should be collected in each plant zone that is inundated to provide a measure of variance associated with sampling. Each replicate should be collected from a random/haphazardly chosen location ideally at least 20 meters from any other station. Each dip net replicate collection should be a composite of sweeps taken at the surface, mid-depth and just above the sediments while brushing vegetation with the base of the net to incorporate all microhabitat at a given replicate location.

Net contents should be emptied into white pans that are approximately 25 cm wide, 30 cm long and 5 cm deep (size of the pan can vary). Drawing a grid of 5x5 cm squares on the inside bottom of the pan helps collectors systematically examine the contents. One hundred fifty macroinvertebrates should be collected using forceps and/or a pipette, working systematically from one end of the pan to the other, attempting to pick all specimens from each grid before moving on to the next. Specimens should be immediately placed into labeled (date, site, plant zone, rep number) 30-mL or larger vials containing 70% ethanol. Special efforts should be made to ensure that smaller, cryptic and/or sessile organisms (those resting on or attached to vegetation or debris) are not overlooked. Multiple sweep net collections may be necessary to achieve the 150-specimen count.

For the majority of cases, obtaining 150 organisms per replicate is a relatively easy task. However, in some cases invertebrates are extremely scarce. Therefore, it is suggested to limit picking-time for each replicate; the following is a means of semi-quantification or catch per unit effort. Individual replicates should be picked for one-half-person-hour (i.e. two people for 15 minutes). Organisms should then be tallied; if 150 organisms have not been obtained, then picking should continue to the next multiple of 50. Therefore, each replicate sample should contain 50, 100, or 150 organisms. The number of organisms remaining in each of the picked grids of the pan should nearly always be exhausted to the point where finding just a few more organisms will require a substantial effort. If this occurs for the entire pan before the target number of specimens is reached, then timing should stop while dip nets are used to refill the pan.

In the laboratory, specimens should be identified to lowest operational taxonomic unit -- usually genus or species for most insects, crustaceans and gastropods – and then tallied. Identifications should be made with the aid of a dissecting microscope capable of at least 40x magnification. Difficult-to-identify insect taxa such as *Chironomidae* should be identified to tribe or family, and some other invertebrate groups including *Oligochaeta, Hirudinea, Turbellaria, Hydracarina* and *Sphaeriidae* should be identified to family level or, where this is not possible, to order. Taxonomic keys such as those of Thorp and Covich (1991), or Merritt and Cummins (1996) should be used for identification.

Accuracy should be confirmed by sending voucher specimens to expert taxonomists. Sample vials may occasionally contain small parasitic invertebrates that have been released from their host upon submersion in ethanol. Such organisms never occur by themselves in nature, and consequently they have not been considered in the creation of invertebrate IBIs. Therefore, they should not be included in taxonomic lists used for richness counts or metric calculations for the sample.

Deviations from Protocol

The sampling protocols of Burton et al. (1999) and Uzarski et al. (2004) were developed for sampling macroinvertebrates, and field crews were instructed to only pick macroinvertebrates. However, microinvertebrates (typically <1 mm long) such as *Copepoda* and *Cladocera* were commonly included in picked samples (D. Uzarski, personal communication). These microinvertebrates were identified to order level and included in the databases from which the IBIs of Burton et al. (1999) and Uzarski et al. (2004) were derived. Inclusion of such specimens by the original sampling crews suggests that this might also occur when others use the IBI, but it is not recommended. Nevertheless, to ensure that the IBI was robust to this common error, Uzarski et al. (2004) used those data in calculations of metrics such as percent Crustacea+Mollusca and the total richness and diversity metrics. Inclusion of the microinvertebrates had little effect on the IBI (D. Uzarski, unpublished data).

Limitations and Applicability of the IBI

Sensitivity to Interannual Fluctuation in Water Levels

Wilcox et al. (2002) argued that the IBI approach would not work for coastal wetlands because natural water level fluctuations of the Great Lakes would likely alter communities and invalidate metrics. However, by sampling only defined and inundated vegetation zones, this protocol removes enough variation associated with water level fluctuation to maintain metric consistency from year to year. During development, the IBI of Uzarski et al. (2004) was tested during times of above average annual lake levels and during times nearing record lows.

Although other collection methods may yield additional taxa and individuals, the purpose of the Consortium field methodology and data analysis is to give an indication of invertebrate community condition – not a full taxonomic inventory. Thus, consideration of the benefit using more exhaustive sampling protocols should be based on the potential diagnostic value of alternative or additional collecting methods.

Plant Zone Applicability

This IBI was developed specifically for only three plant zones commonly found in fringing Great Lakes coastal wetlands. It performed well in lakes Huron and Michigan for the Scirpus (Schoenoplectus) and wet meadow plant zones (Uzarski et al. 2004). However, Uzarski et al. (2004) recommended that the Typha IBI not be used without further modification. The Typha IBI has since been adapted for use in Lake Ontario (see below).

Many wetland types, such as drowned river mouth wetlands and dune and swale complexes, can contain very different plant and animal communities. Therefore, the Burton et al. (1999) and Uzarski et al. (2004) IBI scores will not apply. However, these data should still be collected using the standard protocol above so that IBIs specific to these systems can be developed (see below).

Modifications made for Lake Ontario

Coastal wetland macroinvertebrates have been sampled as part of the Durham Region Coastal Wetland Monitoring Project (DRCWMP) for five years, using methodology consistent with Uzarski et al. (2004) except for the vegetation zones sampled.

Sweep net data collected from Typha zones in Lake Ontario did not yield suitable metrics for Burton et al. (1999) and Uzarski et al. (2004). However, the Typha zone is the only vegetation zone consistently found within Lake Ontario coastal wetlands. Inner and outer Scirpus zones are not common, and meadow marsh (when present) is seldom inundated in July and August. In support of the Consortium process, the DRCWMP developed a separate Lake Ontario-based Typha community aquatic macroinvertebrate IBI (Environment Canada and the Central Lake Ontario Conservation Authority (EC and CLOCA) 2004a, EC and CLOCA 2004b).

A modified IBI was developed using data collected from a suite of Durham Region and other Lake Ontario sites that represented a range in disturbances and hydrogeomorphic types. Data were collected according to Uzarski et al. (2004) and assessed for suitability to report on Lake Ontario Typha zones using metrics identified in Burton et al. (1999). Environment Canada has successfully applied the DRCWMP IBI to report on the condition of coastal wetlands across Lake Ontario and to contribute to the Remedial Action Plan for the Bay of Quinte Area of Concern (EC-Canadian Wildlife Service 2007).

This IBI developed by EC and CLOCA (2004) is recommended for assessment of Lake Ontario coastal wetlands. However, because it is lake-specific, additional work will be required to compare and calibrate the results of this IBI to allow them to be interpreted in a Great Lakes basin-wide context.

Alternative Methods and Associated Research Needs

The Great Lakes cover a huge area, traversing a broad latitudinal gradient. Consequently, geological and biogeographic variation has major influences on the physical structure and ecological character of the wetlands (see Landscape chapter). These differences are reflected strongly in the composition of aquatic invertebrate communities. A detailed analysis of the sources of variation affecting aquatic invertebrate indicators (Brazner et al. 2007a) found that zoobenthic community composition strongly reflects local vegetation conditions, which varies among lakes and ecoregions. Anthropogenic stress accounted for only 20% or less of the variation in 10 invertebrate metrics assessed across five wetland hydrogeomorphic types, five Great Lakes, and six ecoregions (Brazner et al. 2007a,b). Although meaningful stress-response trends could be determined, the strength and direction of responses varied complexly by wetland type within each lake (Brazner et al. 2007a). Similar results have been reported by others (Brady et al. 2006, Kostuk and Chow Fraser 2006). This makes it unlikely that a single invertebrate IBI will be developed that can be used for all wetlands in the Great Lakes. The IBI of Uzarski et al. (2004), which are calibrated to dominant emergent vegetation types, are currently the most broadly applicable across the Great Lakes. However, even this IBI needs modification to account for regional differences (e.g., Lake Ontario Typha wetlands - see below).

Table 4-1. Summary of the status of invertebrate assessment metrics developed or in development for Great Lakes coastal wetlands by some key research groups. (Definitions provided on next page.)

	RESEARCH GROUP				
	Consortium	REMAP	GLEI	Chow Fraser	OH EPA
Wetland Type					
Fringing wetlands	All (vegetation)		*S,M,H,E,O*	*H,O*	E
Drowned river mouth		M,C,E	*S,M,H,E,O*	*H,O,E*	E
Barrier protected			*S,M,H,E,O*	*H,O*	E
Unvegetated/High energy			*S,M,H,E,O*		
Sampling Type					
D-net	X	X	X		*x*
Activity trap		X		X	X
Core sampling			X		
Grab sampling			X		
Artificial substrate	*x*				*x*
Light trap	*x*				*x*
Wetland condition criterion					
Best professional judgment	X		x		X
Scores of other IBIs		X (fish, plant)		X water qual.)	
Land cover (Ag/urban)	X	X	X		
Water chemistry	X	X	X	X	X
Multiple GIS-based stresses			X		
Sites stratified along gradient(s)	X		X	X	X
Sites randomly selected		X			
IBI cross-validated	Yes	No	*Yes*	No	No
Covariates					
Date			X		
Lake	X	X	X	X	
Ecoregion			X	X	
Wetland type	X	X	X	X	X
Vegetation type	X		X		
Adjacent vegetation/Land use			X	X	
Substrate texture			X		
Substrate org. content			X		
Water depth			X		
pH, DO, Conductivity			X	X	
Turbidity			X	X	
Nutrient concentration (P,N)				X	
Chl *a*				X	
Weather conditions			X		

Research Group designations:
Consortium - Great Lakes Coastal Wetlands Consortium - Burton & Uzarski (2003); de Szalay et al. (2004), Uzarski et al. (2004), EC & COCA (2003);
REMAP – Regional Environmental Monitoring and Assessment Program - Simon & Stewart (2006)
GLEI – Great Lakes Environmental Indicators Project - Brady et al. (2006), Brazner et al. (2007a,b), Ciborowski et al. (2007)
Chow Fraser - Kostuk & Chow Fraser (2006)
OH EPA - Ohio EPA (1998),Mack (2003), Ohio EPA (2007)

Letters listed for each wetland type summarize the Great Lake for which a proposed (italic face) or existing (normal face) metric pertains. Superior (S), Michigan (M), Huron (H), St. Clair (C), Erie (E), Ontario (O).

Sampling types assessed by each research group are indicated by a letter X. Samples considered that were assessed and not recommended are indicated with a small italic *x;* those for which an IBI has been proposed or is in development are indicated with a large X.

Condition Criterion represents the means by which the degree of anthropogenic disturbance exists at a sampled site and was assessed during IBI development by each group. Use of a criterion is indicated for a group with a large X. Criteria evaluated and deemed unsuitable are indicated with a small italic *x.*
Sites Stratified: Site selection was based on predefining disturbance gradients and selecting wetlands to reflect the different degrees and classes of disturbance.
Sites Randomly Selected: Site selection was random or stratified-random, but selection was based on criteria other than predefined disturbance gradients.
IBI Cross-validated: Were the sites assessed for IBI effectiveness different from those used to develop the IBI?

Covariates represent variables measured for a sample site that can help determine the specific metric to be used among several alternative formulations developed by a research group.

Lake-specific invertebrate IBIs have been proposed for particular wetland classes by several consortia and individual workers (Table 4-1). Their metrics may be suitable for monitoring once they have been adequately evaluated across quantitatively determined stressor gradients and cross-validated with independent data. Other invertebrate IBIs currently in development (Kostuk and Chow Fraser 2006, Ciborowski et al. 2007) may ultimately apply within ecoregions that cross individual Great Lakes boundaries. Because aquatic invertebrates are small and relatively immobile, communities also vary greatly along relatively fine-grained environmental gradients. Therefore, complementary physical and chemical environmental data should be collected at the same time as the invertebrate samples to help categorize the type of invertebrate reference community that should be expected at the sampling area. The IBIs proposed by different workers can use different classification variables to guide selection of the most appropriate IBI metric. Table 4-1 summarizes the covariates deemed important by each of several groups proposing invertebrate metrics for Great Lakes coastal wetlands, as well as the associated invertebrate collection methods on which the metrics are based.

IBIs Proposed for Drowned River Mouth Wetlands from REMAP Assessments

In 1998, a coastal wetland regional monitoring and assessment program (REMAP) was designed to establish reference conditions and undertake an inventory and classification of Laurentian Great Lakes coastal wetlands (Simon and Stewart 2006). Wetlands in Lake Michigan were sampled during pilot studies in 1999, and other lakes were sampled in 2000 using a stratified-randomly selected subset of all inventoried wetlands (Moffett et al. 2006). Macroinvertebrate comparative sampling involved using both activity trap (Wilcox et al. 1999) and sweep net sampling (Burton et al. 1999) protocols (Stewart and Simon 2006). Pairs of activity traps were placed in each dominant habitat type for 24 hours. Up to 20 D-net sweep samples werre collected within the 500-m sampling zones of the same major habitat types as identified by Burton et al. (1999) and preserved for sorting and identification in the laboratory.

Although wetlands selected on the basis of stratified-random sampling provide an unbiased indication of average condition, such sampling is unlikely to include wetlands that reflect the full range or diversity of anthropogenic stress (ranging from undisturbed to heavily degraded). Consequently, attempts to derive IBIs from such a dataset can best be regarded as provisional and to require validation before their reliability and effectiveness can be assessed. Nevertheless, an activity trap-based IBI has been proposed for macroinvertebrates collected in activity traps (Stewart et al. 2006a). Macroinvertebrate IBIs have been proposed based on D-net sampling in drowned river mouths of lakes Michigan (Stewart et al. 2006b), St. Clair (Stewart et al. 2006c), and Erie (Stewart et al. 2006d). Variations in ecological conditions among wetlands in these studies was based on best professional judgment and on patterns suggested by simultaneously derived IBIs for fishes and aquatic plants.

Activity Trap Sampling and Comparisons with Dip net ("D-net) Sampling:

Activity traps, which consist of a jar or cylinder into which one or two inverted funnels are nested, have been evaluated and used by several investigators (Murkin et al. (1983), Wilcox et al. (1999; 2002), de Szalay et al. (2004), Kurtash and Chow Fraser (2004), Stewart and Simon (2006), Ohio EPA (2007)). Because the traps tend to collect different relative abundances of aquatic invertebrates than sweep nets or other samplers, metrics developed for sweep samples are probably not amenable to use with trap-caught data. Cross-validation of the reliability of sweep net vs. activity trap data when used with a complementary IBI is a significant research need.

De Szalay et al. (2004) compared the catches of 24-hour activity trap samples with samples collected by live-picking up to 150 sweep-netted aquatic invertebrates in the field or with equivalent samples that were preserved and sorted and enumerated in the laboratory. They found that activity traps collected only about half the total number of taxa as the sweep net procedures.

In contrast, Ohio EPA (2007) found that banks of 10 activity traps collected as many or more taxa than sweep net samples. In inland Ohio wetlands, funnel traps consistently collected an average of 10 more macroinvertebrate taxa than qualitative sampling using dip nets (Mack 2003). Mack (2003) also reported that qualitative dipnet sampling of all available habitats in a wetland collected somewhat more Mollusca and Chironomidae taxa than did funnel traps. Consequently, Ohio EPA (2007) developed a density-based invertebrate community index (DICI) on those data. Stewart and Simon (2006) found that subsamples of 300 invertebrates collected from composite D-net sweep samples were richer than subsamples of 300 invertebrates taken from composite activity trap samples.

De Szalay et al. (2004) found that mean taxa richness of live-picked samples was not significantly different than richness of laboratory-processed samples, although there was a trend for more taxa to be found in lab-processed samples. Lab-processed samples contained 5-15 times as many specimens and required 3 times as long to process as did field-picked samples. These assessments were limited in that no composition-specific comparisons were made. Nor were certain taxa identified below nominal levels (Oligochaeta, Chironomidae, Hydracarina). The major drawback associated with laboratory sorting is the investment of time

Grab and core sampling:

Grab and core samples (including stove-pipe samples) have the desirable property of quantitatively collecting benthic invertebrates from a fixed area. Furthermore, some of these samplers can be deployed from a boat to sample at depths greater than can be reached by wading. Grabs and cores become less effective than sweep netting in vegetated areas because coarse debris impedes the closing mechanism and the ability of the sampler to penetrate the substrate. Thoma (Ohio EPA 1998) developed a nearshore benthic IBI for organisms found in Ponar grab samples collected from Ohio drowned rivermouths. A multivariate zoobenthic index based on Ponar grabs is also being developed by GLEI researchers (Ciborowski et al. in prep).

Artificial substrates:

Benoit et al. (1997) and Thoma (Ohio EPA 1998) assessed artificial substrates to assess zoobenthic colonization in coastal wetlands. Thoma studied colonization of Hester-Dendy multiplate samplers tied to concrete blocks in drowned river mouths (which he termed 'lacustuaries') for 6-week periods. Lewis et al. (2001) also used Hester-Dendy samplers to evaluate the feasibility of invertebrate IBI development for New England lakes. Although the technique was suitable for development of 12 proposed metrics by Lewis et al. (2001), Mack (2003) concluded that "Hester-Dendy artificial substrate samplers were ineffective for sampling most wetland macroinvertebrates, except oligochaetes, Chironomidae, and Mollusca".

Benoit et al. (1997) constructed artificial substrates from ceramic tile, to which they glued commercially made "aquarium" plants designed to mimic Myriophyllum. They concluded that tiles left in place for 8 days collected a representative suite of macroinvertebrates whose density became stable over this time. Leonhardt (2003) found that such tiles were as effective as D-net sampling in assessing the macroinvertebrate communities of constructed wetlands but required only a fraction of the processing time. To our knowledge, these types of samplers have not been used in Great Lakes coastal wetlands.

Discussion

Reliability of the Invertebrate IBI in a Basinwide Context: Summary of Invertebrate Site Scores Plotted Along the GLEI "Sum-Rel" Gradient

An overall assessment of human land-use disturbance in the watersheds associated with coastal wetland sites sampled by all Consortium groups across the Great Lakes basin was calculated as a sum of the relativized measures of several different classes of disturbance, "Sum-Rel" (Figure 4-1). The Sum-Rel scores were derived from data provided by the Great Lakes Environmental Indicators (GLEI) project Danz et al. 2005) using a method outlined by Host et al. (2005). The method is outlined in detail in the Landscape chapter of this document. The boundaries of each second-order or higher watershed in the Great Lakes was delineated using a GIS approach (Hollenhorst et al. 2007). The relative amount of each of three classes of human disturbance was then determined for each watershed, scaled from 0.0 (least disturbed watershed in the Great Lakes basin) to 1.0 (most disturbed watershed). The Sum-Rel score for a wetland site was the sum of the 3 relative disturbance scores pertaining to the watershed in which that site occurred. The Sum-Rel scores were based on integrated landcover, road density and population density information from 1990s digital land cover data sets (Hollenhorst et al. 2007).

The Sum-Rel scores of wetlands sampled by Consortium researchers ranged from a low of 0.0880 to a high of 2.667. Only the wetland suite sampled by the Marsh Monitoring Program (MMP) covered this full range of values. The overall range sampled by MMP researchers was considerably broader than the range observed for the sites that were sampled for invertebrates. The Sum-Rel scores at invertebrate sites ranged from a minimum value of 0.696 at a Lake Erie site (Thorofare) on Long Point to a maximum of 2.444 at a Lake Ontario fringing site (Frenchman's Bay).

It was counterintuitive to find that the wetlands with the two lowest Sum-Rel scores (i.e., the 'least disturbed' locations) were located in Lake Erie and were not Lake Superior sites, given our general knowledge of landscape conditions and relative human disturbance in these regions. However, the two low scoring sites on Lake Erie were both associated with small, undeveloped and protected watersheds on Long Point, Ontario. So, despite the relatively coarse nature of the summary that was done for "Sum-Rel" calculations, the scores do seem to reflect relative disturbance levels accurately. The values observed for the Long Point, Lake Erie sites demonstrate some of the limitations of landscape analysis in that small watersheds with associated wetlands immersed in a "sea" of highly polluted/disturbed waters (L. Erie proper) may reflect disturbed biology even though the watersheds are relatively intact (e.g. Uzarski et al. 2005). Bhagat (2005) observed a similar phenomenon in her attempts to develop fish IBIs for Great Lakes coastal margins sampled as part of the GLEI project. She found that fish IBI and community composition better reflected the condition of entire "segment sheds" than the condition of the landscape immediately surrounding the sampling site. Obviously, the accuracy of an IBI score will depend on a number of factors (wetland type, level and type of disturbance etc), but the plant and animal communities at these kinds of sites seem unlikely to overcome the broad-scale stress of a highly disturbed system in which they lie, even if the bordering uplands are in good condition.

The wetlands in Lake Superior and northern Lake Huron and Lake Michigan that that had Sum-Rel scores at the low end of the disturbance scale were most likely to have invertebrate IBI values reflecting the highest ecological integrity because of the overall health of the lakes/regions in which they occur. However, the lowest of these Lake Superior and northern lake Huron-Michigan scores (1.274; Fig. 4-1) was from a Lake Superior site in Tahquamenon Bay, which is only near the midpoint of all Consortium sites that were scored (see Fig. 4-1, bottom row of points). If most "Sum-Rel" scores accurately reflect the relative human disturbance in their watersheds, these "Sum-Rel" scores suggest that the breadth of the overall gradient sampled for the invertebrate IBI-development study was fairly limited, and the suite of samples reported by Uzarski et al. (2004) primarily reflects conditions at the more disturbed end of the human disturbance scale in the Great Lakes. The alternative and perhaps more likely explanation for the

Taquamenon site is that local pollution, including leachates from the campsite toilets and showers from the state campground at that site, may have resulted in lower invertebrate IBI scores than indicated for Sum-Rel scores based on watershed landscape analyses. This indicates that local sources of pollution should be recorded by field crews and considered when a site is an outlier in subsequent analyses.

Synopsis – Current recommendations and future work

The invertebrate IBIs proposed and tested by Uzarski et al. (2004) seem to be the best developed and most broadly applicable means of assessing invertebrate community condition currently available for Great Lakes coastal wetlands. They appear to reflect conditions and effects of anthropogenic stresses in the Scirpus (Schoenoplectus) and wet meadow zones of Great Lakes fringing wetlands. A modified version of the Typha IBI has been applied to Lake Ontario fringing wetlands. Other metrics are available for additional classes of wetlands, but require data collected by field methods that differ slightly (D-net sampling with laboratory-based sorting) or substantially (activity traps; Ponar grab; coring) from those of Uzarski et al. (2004). Furthermore, because these alternative IBIs are either still in development or the testing phase, or have not been quantitatively assessed against well-defined gradients of anthropogenic disturbance, it is premature to recommend their use. Nevertheless, the alternative methodologies could be used to collect data that can be archived until the alternative metrics have been better evaluated.

The research required to expand the value of using invertebrates to assess coastal wetland condition includes:

1. comparison of the relative diagnostic value of activity traps vs. D-net sampling methods across the full gradient of diverse anthropogenic disturbances, as exemplified by the GLEI basinwide GIS-derived stressor scores; crosswalking derived values to permit equivalencies to be determined between the methods
2. true cross-validation of IBIs to assess their predictive value with samples independent of those used to derive indices. In some cases, this could be accomplished through the exchange of existing data. In others, it would required coordinated, contemporaneous wetlands sampling by each method.
3. Analysis of existing or new data to provide IBIs algorithms that apply to each wetland hydorgeomorphic class across the five Great Lakes.

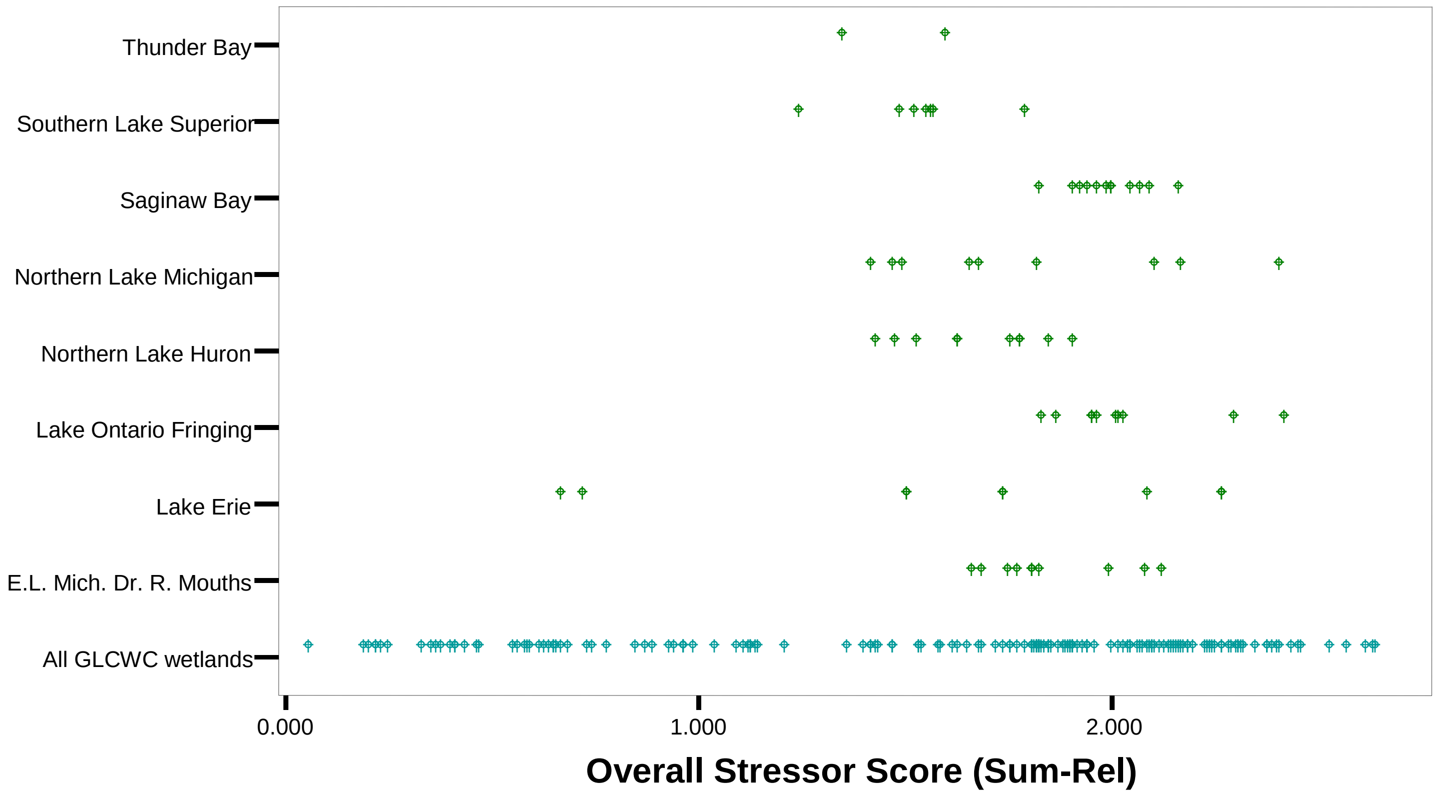

Figure 4-1. Consortium invertebrate sampling locations relative to the "Sum_Rel" overall landscape stressor scores.

Worksheet for Calculating IBI Scores

IBI use and interpretation of results

An index of biotic integrity (IBI) for fringing Great Lakes Coastal Wetlands. **All values should be based on the median of at least three replicates taken from each zone.** When all vegetation zones are present, wetlands are scored as follows: A total score of 31 to 53 (0% to 15% of possible score) = "Extremely Degraded.", or "in comparison to other Lake Huron wetlands, this wetland is amongst the most impacted"; total score of >53 to 76 (>15% to 30% of possible score) = "Degraded" or "the wetland shows obvious signs of anthropogenic disturbance"; total score of >76 to 106 (>30% to 50% of possible score) = "Moderately Degraded" or "the wetland shows many obvious signs indicative of anthropogenic disturbance;" total score of >106 to 136 (>50% to 70% of possible score) = "Moderately Impacted" or "the wetland shows few, but obvious, signs of anthropogenic disturbance;" total score of >136 to 159 (>70% to 85% of possible score) = "Mildly Impacted" or "the wetland is beginning to show signs indicative of anthropogenic disturbance"; total score of > 159 to 182 (>85% to 100% of possible score) = "Reference Conditions" or "the wetland is among the most pristine of Lake Huron." **When only a subset of vegetation zones are present, wetland category scores are adjusted as follows:** Wet Meadow Only = 9 to 14; >14 to 19; >19 to 27; >27 to 34; >34 to 39; >39 to 45; Inner Scirpus only = 11 to 19; >19 to 29; >29 to 41; >41 to 53; >53 to 62; >62 to 72; Outer Scirpus only = 11 to 18; >18 to 26; >26 to 37; >37 to 48; >48 to 56; >56 to 65; Wet Meadow and Inner Scirpus = 20 to 33; >33 to 47; >47 to 66; >66 to 84; >84 to 99; >99 to 113; Wet Meadow and Outer Scirpus = 20 to 32; >32 to 46; >46 to 64; >64 to 82; >82 to 96; >96 to 110; Inner and Outer Scirpus = 22 to 38; >38 to 55; >55 to 79; >79 to 102; >102 to 119; >119 to 137;

Table 4-2. Wet Meadow Zone: Dominated by Carex and Calamagrostis

Metric	Score 1	Score 3	Score 5
Odonata taxa richness (Genera):	0 score= 1	>0 to 3 score= 3	>3 score= 5
Relative abundance Odonata (%):	0 to <1 score= 1	>1 to 5 score= 3	>5 score= 5
Crustacea plus Mollusca taxa richness (Genera):	<2 score= 1	>2 to 6 score= 3	>6 score= 5
Total Genera richness:	<10 score= 1	>10 to 18 score= 3	>18 score= 5
Relative abundance Gastropoda (%):	0 to 1 score= 1	>1 to 25 score= 3	>25 score= 5
Relative abundance Sphaeriidae (%):	0 score= 1	>0 to 3 score= 3	>3 score= 5
Evenness:	0 to 0.4 score= 1	>0.4 to 0.7 score= 3	>0.7 score= 5
Shannon diversity index:	0 to 0.4 score= 1	>0.4 to 0.9 score= 3	>0.9 score= 5
Simpson index:	>0.3 score= 1	>0.15 to 0.3 score= 3	0 to 0.15 score= 5

Table 4-3. Inner Scirpus Zone: Often dense Scirpus mixed with Pontedaria and submergents, protected from wave action.

Metric	Score 0	Score 1	Score 3	Score 5	Score 7
Odonata taxa richness (Genera):		0 score= 1	>0 to <1 score= 3	1 to 2 score= 5	>2 score= 7
Relative abundance Odonata (%):		0 score= 1	>0 to <2 score= 3	<2 to 7 score= 5	>7 score 7
Crustacea plus Mollusca taxa richness (Genera):		0 to 2 score= 1	>2 to 4 score= 3	>4 to 6 score= 5	>6 score= 7

Total Genera richness:		<10 score= 1	<10 to 14 score= 3	>14 to 18 score= 5	>18 score= 7
Relative abundance Gastropoda (%):		0 score= 1	>0 to 2 score= 3	>2 to 4 score= 5	>4 score= 7
Relative abundance Sphaeriidae (%):		0 score= 1	>0 to 0.05 score= 3	>0.05 score= 5	
Ephemeroptera plus Trichoptera Taxa richness (Genera)		0 score= 1	>0 to 3 score= 3	>3 score= 5	
Relative abundance Crustacea plus Mollusca (%):		<8 score= 1	<8 to 30 score= 3	>30 score= 5	
Relative abundance Isopoda (%):	0 score= 0	0 to 1 score= 1	>1 to 10 score= 3	>10 to 20 score= 5	>20 score= 7.
Evenness:		0 to 0.4 score= 1	>0.4 to 0.7 score= 3	>0.7 score= 5	
Shannon diversity index:		0 to 0.4 score= 1	>0.4 to 0.9 score= 3	>0.9 score= 5	
Simpson index:		>0.3 score= 1	>0.15 to 0.3 score= 3	0 to 0.15 score= 5	

Relative abundance Amphipoda (%):
If 40 to 60 _____and total score from Innner Scirpus Zone (metrics 1 through 12) is greater than 41, then subtract 5;
If 40 to 60 _____and total score from Innner Scirpus Zone (metrics 1 through 12) is less than 41, then add 5.

Table 4-4. Outer Scirpus Zone: Sometimes relatively sparse, usually monodominant stands, subject to direct wave action.

Metric	Score 1	Score 3	Score 5	Score 7
Odonata taxa richness (Genera):	0 score= 1	>0 to <1 score= 3	>1 to 2 score= 5	>2 score= 7
Relative abundance Odonata (%):	0 score= 1	>0 to <1 score= 3	>1 to 2 score= 5	>2 score= 7
Crustacea plus Mollusca taxa richness (Genera):	0 to 2 score= 1	>2 to 4 score= 3	>4 to 5 score= 5	>5 score= 7
Total Genera richness:	<8 score= 1	>8 to 13 score= 3	>13 to 17 score= 5	>17 score= 7
Relative abundance Gastropoda (%):	0 score= 1	>0 to 3 score= 3	>3 to 5 score= 5	>5 score= 7
Relative abundance Sphaeriidae (%):	0 score= 1	>0 to 0.05 score= 3	>0.05 score= 5	
Total number of families:	0 to 7 score= 1	>7 to 12 score= 3	>12 score= 5	
Relative abundance Crustacea plus Mollusca (%):	<8 score= 1	>8 to 30 score= 3	>30 score= 5	
Evenness:	0 to 0.4 score= 1	>0.4 to 0.7 score= 3	>0.7 score= 5	
Shannon diversity index:	0 to 0.4 score= 1	>0.4 to 0.9 score= 3	>0.9 score= 5	
Simpson index:	>0.3 score= 1	>0.15 to 0.3 score= 3	0 to 0.15 score= 5	

For further reference, see Appendix B (Uzarski et al. 2004) at the end of this document.

References

Albert, D.A. and L.D. Minc. 2001. Abiotic and floristic characterization of Laurentian Great Lakes coastal wetlands Verh. International *Verein. Limnol.* 27:3413-3419.

Armitage, B.J., P.L. Hudson, and D.A. Wilcox. 2000. Caddisflies (Insecta: Trichoptera) of fringing wetlands of the Laurentian Great Lakes. Verh. International Verein. Limnol. 27:3420-3424.

Bhagat, Y. 2005. Fish indicators of anthropogenic stress at Great Lakes coastal margins: multimetric and multivariate approaches. M.Sci. Thesis. University of Windsor, Windsor, Ontario, Canada.

Brady V., L.B. Johnson, J.J.H. Ciborowski, D. Breneman, T. Hollenhorst, T. Brown, and J.P. Gathman. 2006. Macroinvertebrate responses to disturbance at local and watershed scales. Proceedings of the 49th Annual Conference of the International Association for Great Lakes Research, Windsor, Ontario. May 2006.

Brazner, J.C., N.P. Danz, G.J. Niemi, R.R. Regal, A.S. Trebitz, R.W. Howe, J.M. Hanowski, L.B. Johnson, J.J.H. Ciborowski, C.A. Johnston, E.D. Reavie, V.J. Brady, G.V. Sgro. 2007. Evaluation of geographic, geomorphic and human influences on Great Lakes wetland indicators: a multiassemblage approach. Ecological Indicators 7:610-635.

Brazner, J.C., N.P. Danz, G.J. Niemi, R.R. Regal, T. Hollenhorst, G. Host, T. Brown, A.S. Trebitz, C.A. Johnston, E. Reavie, R.Howe, J. Hanowski, L. Johnson, J.J.H. Ciborowski, and G. V. Sgro. 2007. Responsiveness of Great Lakes wetland indicators to human disturbances at multiple spatial scales: a multiassemblage assessment. Journal of Great Lakes Research 33: In press.

Burton, T.M., D.G. Uzarski, J.P. Gathman. J.A. Genet, B.E. Keas, and C.A. Stricker. 1999. Development of a preliminary invertebrate index of biotic integrity for Lake Huron coastal wetlands. Wetlands 19:869-882.

Burton, T.M. C.A. Stricker, and D.G. Uzarski. 2002. Effects of plant community composition and exposure to wave action on habitat use of invertebrate communities of Lake Huron coastal wetlands. Lakes and Reservoirs: Resource Management 7:255-269.

Burton, T.M. and D.G. Uzarski. 2003. Michigan: Bioassessment procedures and baseline reference data for great lakes coastal marshes and inland forested wetlands in Michigan. U.S. EPA. 2003. Methods for Evaluating Wetland Condition: Wetland Biological Assessment Case Studies. Pp. 32-36. T.J. Danielson and D.G. Hoskins (Editors). Office of Water, U.S. Environmental Protection Agency, Washington, D.C. EPA-822-R-03-013.

Chow Fraser, P. and D.A. Albert. 1998. Biodiversity Investment Areas: Coastal wetland Ecosystems. Identification of "Eco-Reaches" of Great Lakes coastal wetlands that have high biodiversity value. Background paper for State of the Lake Ecosystem Conference. 1998. U.S. Environmental Protection Agency, Great Lakes National Program Office, Chicago, Ill., and Environment Canada, Burlington, Ontario. 106 p.

Ciborowski, J.J.H., L.B. Johnson, V. Brady, G.E. Host, J. Schuldt and J.P. Gathman. 2007. Developing Multivariate Zoobenthic Indicators Using a priori Classification of Reference Condition and Degraded Condition Sites. Proceedings of the 50th Annual Conference of the International Association for Great Lakes Research, State College, Pa. May 2007.

Danz, N., R. Regal, G.J. Niemi, V.J. Brady, T. Hollenhorst, L.B. Johnson, G.E. Host, J. M. Hanowski, C.A. Johnston, T. Brown, J. Kingston, J.R. Kelly. 2005. Environmentally stratified sampling design for the development of Great Lakes environmental indicators. Environmental Monitoring and Assessment, 102:41-65.

Danz, N.P., G.J. Niemi, R.R. Regal, T. Hollenhorst, L.B. Johnson, J.M. Hanowski, R. Axler, J.J.H. Ciborowski, T. Hrabik, V.J. Brady, J.R. Kelly, J.C. Brazner, R.W. Howe, C.A. Johnston, G.E. Host. 2007. Integrated gradients of anthropogenic stress in the U.S. Great Lakes basin. Environmental Management, 39:631-647.

DeShon, J. D. (1995). "Development and application of the invertebrate community index (ICI)." Biological Assessment and Criteria: Tools for Water Resource Planning and Decision Making. W.S. Davis and T. Simon (eds.). Boca Raton, Fla, Lewis Publishers: 217-243.

De Szalay, F.A., J. Kieper, M.W. Kirshner and K.A. Krieger. 2004. Final Report: testing flora and fauna indicators of coastal wetland health in Lake Erie. Project code: GL-97547301-0, subcontract #6. Prepared for U.S. EPA.

Environment Canada and Central Lake Ontario Conservation Authority. 2004a. Durham Region Coastal Wetland Monitoring Project: Year 2 Technical Report. Downsview, Ontario: ECB-OR. 177 pp. + appendices

Environment Canada and Central Lake Ontario Conservation Authority. 2004b. Baseline Conditions of Durham Region Coastal Wetlands: Preliminary Findings 2002- 2003. Downsview, Ontario: ECB-OR. May 2004. 36 pp.

Environment Canada – Canada Wildlife Service 2007. Bay of Quinte Area of Concern: Coastal Wetland Status and Remedial Action Plan Delisting Target Recommendations. June 2007. Toronto, Ontario: EC-CWS 95 pp.

Fennessy, M.S., M.A. Gray, and R.D. Lopez (1998). An ecological assessment of wetlands using reference sites Volume 1: Final Report, Volume 2: Appendices. Final Report to U.S. Environmental Protection Agency. Wetlands Unit, Division of Surface Water. Grant CD995761-01.

Garono, R.J. and J.G. Kooser. 1994. Ordination of wetland insect populations: evaluation of a potential mitigation monitoring tool. W.J. Mitsch (ed.) Global Wetlands: Old World and New. Pp. 509-516. Elsevier Science, New York.

Hollenhorst, T., T.N. Brown, L.B. Johnson, J.J.H.Ciborowski and G.E. Host. 2007. A multiscale watershed delineation approach for developing ecological indicators of Great Lakes coastal ecosystems. Submitted to Journal of Great Lakes Research 33: in press.

Host, G. E., Schuldt, J., Ciborowski, J. J. H., Johnson, L. B., Hollenhorst, T., and Richards, C. 2005. Use of GIS and remotely sensed data for a priori identification of reference areas for Great Lakes coastal ecosystems. International Journal of Remote Sensing, 26:5325-5342.

Innis, S.A., R.J. Naimen, and S.R. Elliot. 2000. Indicators and assessment methods for measuring the ecological integrity of semiaquatic terrestrial environments. Hydrobiologia, 422/423:111-131.

Kashian, D.R. and T.M. Burton. 2000. A comparison of macroinvertebrates of two Great Lakes coastal wetlands: testing potential metrics for and Index of Biotic Integrity. J. Great Lakes Res. 26: 460-481.

Keough, J. R., Thompson, T. A., Guntenspergen, G. R., and Wilcox D.A. 1999. Hydrogeomorphic factors and ecosystem responses in coastal wetlands of the Great Lakes. Wetlands, 19:821-834.

King, R.S. and J.C. Brazner. 1999. Coastal wetland insect communities along a trophic gradient in Green Bay, Lake Michigan. Wetlands, 19: 426-437.

Kostuk, K. and P. Chow Fraser 2006. Proceedings of the 49th Annual Conference of the International Association for Great Lakes Research, Windsor, Ontario. May 2006.

Krieger, K.A. 1992. The ecology of invertebrates in Great Lakes coastal marshes: current knowledge and research needs. J. Great Lakes Res. 18:634-650.

Krieger, K.A. 1995a. Spatial and seasonal distributions of nonplanktonic aquatic invertebrates in the Old Woman Creek National Estuarine Research Reserve. Final report, Ohio DNR Div. Of Natural Areas and Preserves. 47 pp. + app.

Lewis, P.A., D.J. Klemm, and W.T. Thoeny. 2001. Perspectives on use of a multimetric lake bioassessment integrity index using benthic macroinvertebrates. Northeastern Naturalist, 8:233-246.

Lougheed, V.L. and P. Chow-Fraser. 2002. Development and use of a zooplankton index of wetland quality in the Laurentian Great Lakes basin. Ecological Applications, 12: 474–486.

Lougheed, V. L., Crosbie, B., Chow-Fraser, P. 2001. Primary determinants of macrophyte community structure in 62 marshes across the Great Lakes basin: Latitude, land use, and water quality effects. Canadian Journal of Fisheries and Aquatic Sciences. 58: 1603-1612.

Mack, J.J. 2003. Ohio: Developing IBI Assessment methods for water quality standards and regulatory decisions. U.S. EPA. 2003. Methods for Evaluating Wetland Condition: Wetland Biological Assessment Case Studies. Pp 63-71. T.J. Danielson and D.G. Hoskins (Editors). Office of Water, U.S. Environmental Protection Agency, Washington, D.C. EPA-822-R-03-013.

Murkin, H.R., P.G. Abbott, and J.A. Kadlec. 1983. A comparison of activity traps and sweep nets for sampling nektonic invertebrates in wetlands. Freshwater Invertebrate Biology. 2:99-106

Merritt, R.W. and K.W. Cummins (editors). 1996. An introduction to the aquatic insects of North America. Kendall/Hunt Publ. Co., Dubuque, Iowa. 862 pp.

Minc, L.D. 1997. Great Lakes coastal wetlands: an overview of controlling abiotic factors, regional distribution and species composition. Michigan Natural Features Inventory. Lansing, Mich.

Minc, L.D. and D.A. Alberta. 1998. Great Lakes coastal wetlands: abiotic and floristic characterization. A summary of reports. Michigan Natural Features Inventory, Report 1998-05. Lansing, Mich.. 13 pp. + appendices.

Moffett, M.F., R.L. Dufour, and T.P. Simon. 2006. An inventory and classification of coastal wetlands of the Laurentian Great Lakes. T.P. Simon and P.M. Stewart (editors). Coastal Wetlands of the Laurentian Great Lakes: Health, Habitat, and Indicators. Pp. 17-99. AuthorHouse Publishing, Bloomington, Ind. 523 p.

Ohio EPA. 1998. Development of biological indices using macroinvertebrates in Ohio nearshore waters, harbors, and lucustuaries of Lake Erie in order to evaluate water quality. Ecological Assessment Unit, Division of Surface Water, Columbus, Ohio.

Ohio EPA. 2007. Density based invertebrate community index (DICI) of Ohio wetlands. Final index report to: Integrated wetland assessment program Part 8: Initial development of wetland invertebrate community index for Ohio and investigations of invertebrate communities of wetlands in the Huron/Erie Lake Plains Ecoregion (2003) and mitigation banks (2004). Ohio EPA Technical Report WET/2007-5

Rankin, E. T. (1989). The Habitat Evaluation Index (QHEI): Rationale, Methods, and Application, Ohio EPA.

Simon, T.P. and P.M. Stewart (editors). 2006. Coastal Wetlands of the Laurentian Great Lakes: Health, Habitat, and Indicators. AuthorHouse Publishing, Bloomington, Ind. 523 p.

Stewart, P.M., M.M. Pilstvzyk and T.P. Simon. 2006a. Development of an activity trap macroinvertebrate index of biotic integrity for Lake Michigan coastal wetlands T.P. Simon and P.M. Stewart (editors). Coastal Wetlands of the Laurentian Great Lakes: Health, Habitat, and Indicators. Pp. 321-332. AuthorHouse Publishing, Bloomington, Ind.

Stewart, P.M., M.M. Pilstvzyk and T.P. Simon. 2006b. Development of a D-net macroinvertebrate index of biotic integrity for Lake Michigan drowned river mouth wetlands. T.P. Simon and P.m. Stewart (editors). Coastal Wetlands of the Laurentian Great Lakes: Health, Habitat, and Indicators. Pp. 333-346. AuthorHouse Publishing, Bloomington, Ind.

Stewart, P.M., M.M. Pilstvzyk and T.P. Simon. 2006c. Development of a D-net macroinvertebrate index of biotic integrity for wetlands of Lake St. Clair and the connecting channels. T.P. Simon and P.m. Stewart (editors). Coastal Wetlands of the Laurentian Great Lakes: Health, Habitat, and Indicators. Pp. 347-362. AuthorHouse Publishing, Bloomington, Ind.

Stewart, P.M., M.M. Pilstvzyk, R.F. Thoma and T.P. Simon. 2006d. Development of a preliminary D-net macroinvertebrate index of biotic integrity for Lake Erie drowned river mouth coastal wetlands. T.P. Simon and P.m. Stewart (editors). Coastal Wetlands of the Laurentian Great Lakes: Health, Habitat, and Indicators. Pp. 363-374. AuthorHouse Publishing, Bloomington, Ind.

Stewart, P.M. and T.P. Simon. 2006. Comparison of ecoregional discriminative ability and collection efficicy of D-net versus activity trap sampling of macroinvertebrate assemblages in Great Lake coastal wetlands. T.P. Simon and P.m. Stewart (editors). Coastal Wetlands of the Laurentian Great Lakes: Health, Habitat, and Indicators. Pp. 227-237. AuthorHouse Publishing, Bloomington, Ind..

Thoma, R.F. 1999. Biological monitoring and an index of biotic integrity for Lake Erie=s nearshore waters. T.P. Simon (ed). Assessing the Sustainability and Biological Integrity of Water Resources Using Fish Communities. Pp. 417-461. CRC Press, Boca Raton, Fla.

Thorp, J.H. and A.P. Covich 1991. Ecology and classification of North American freshwater invertebrates. Academic Press Inc., San Diego, Calif.

Uzarski, D.G., Burton, T.M., Cooper, M.J., Ingram, J.W., and Timmermans, S. 2005. Fish habitat use within and across wetland classes in coastal wetlands of the five Great Lakes: development of a fish-based Index of Biotic Integrity. Jouranl of Great Lakes Research 31(Suppl. 1):171-187.

Uzarski, D.G., T.M. Burton and J.A. Genet. 2004. Validation and performance of an invertebrate index of biotic integrity for Lakes Huron and Michigan fringing wetlands during a period of lake level decline. Aquatic Health and Management 7:269-288.

Wilcox, D.A., J.E. Meeker, P.L. Hudson, B.J. Armitage, M.G. Black, and D.G. Uzarki. 1999. Development of evaluation criteria to assess and protect the biological integrity of Great Lakes wetlands. Unpublished report, U.S. Geological Survey, Ann Arbor, Mich.

Wilcox, D. A., Meeker, J. E., Hudson, P. L., Armitage, B. J., Black, M. G., and Uzarski, D. G. 2002. Hydrologic variability and the application of index of biotic integrity metrics to wetlands: a Great Lakes evaluation. Wetlands 22:588-615.

Appendix 4-1.

Field Equipment Checklist
For invertebrate and accompanying chemical/physical (covariates) sampling

Presampling checklist:

______Conductivity meter	______ Turbidimeter
______DO meter/Probe/Repair kit	______1 L water sample bottles (at least 3 per site)
______Tape	______Mechanical pencils
______Field notebooks	______Meter stick
______2 dip nets	______White enamel pans
______Fine-tipped forceps/eyedroppers	______Alcohol (95%) in 1 L bottles and 1 squirt bottle
______Invertebrate sample vials (Ethanol-filled) and labels+pencil (9 per site)	______Permanent marker
______Cooler and ice (depending on temp)	______Waders or boots
______ Insect repellent	______Cell phone
______Filter apparatus	______Filters/forceps
______Metal hand pump/tubing bottles	______250 mL sample (at least 3 per site)

In field:

Water samples → Surface 1 L (1 sample per station)

Invertebrate samples → 3 per station

Chapter 5
Fish Community Indicators

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Introduction

Great Lakes coastal wetlands provide critical habitat for more than 80 species of fish (Jude and Pappas 1992). More than 50 of these species are dependent upon wetlands while another 30+ migrate into and out of them during different periods in their life history (Jude and Pappas 1992, Wilcox 1995, Wei et al. 2004). An additional 30+ species of fish may be occasional visitors to coastal wetlands based on occurrence in adjacent habitats (Jude and Pappas 1992, Wei et al. 2004).

As transitional systems between land and water, coastal wetlands are among the first habitats impacted by disturbances from adjacent uplands and/or pollutants from upstream (Mayer et al. 2004). Activities and pollutants that degrade wetland habitat may also pose threats to other near-shore and deepwater habitats if allowed to continue unabated. Since many pollutants accumulate in coastal wetlands and land-use changes in adjacent areas tend to affect them first, coastal wetlands can provide "early warning" of potential threats to the Great Lakes ecosystem. The governments of Canada and the United States recognized this potential and initiated a process to identify and/or develop indicators of "ecosystem health" for wetlands and other Great Lakes habitats at the State of the Lakes Ecosystem Conference (SOLEC) held in Buffalo, N. Y. in 1998. Progress was reviewed and potential indicators were identified by working group members at SOLEC 2000 in Hamilton, Ontario. Potential indicators listed by the wetlands indicators working group included indices of biotic integrity (IBIs) based on invertebrates, fish, and plants, even though no broadly accepted protocol was available at the time for any of these biotic groups.

Great Lakes coastal wetlands occupy a relatively small percentage of the Great Lakes shoreline (e.g., about 11 % of the shoreline of the U.S. side of Lake Huron (Prince and Flegel 1995). Conversion of wetlands over the last 100 years has reduced the area of Great Lakes coastal wetlands by more than 50%, with losses greater than 95% in some areas such as western Lake Erie (Krieger *et al.* 1992). Sustainable management of the remaining wetlands and efforts to restore the large number of wetlands that have been converted to other land uses are critical to the long-term viability of the Great Lakes ecosystem. An important tool needed for the management and restoration of coastal wetlands is a system of assessment that will allow managers to monitor the health of these and adjacent coastal systems on a routine basis so that trends in wetland condition can be established and used to identify threats to these ecosystems.

Fish have long been included as key indicators in assessments of biotic integrity in streams (e.g., Karr et al. 1986, Lyons and Wang 1996) and to a lesser degree in lakes (e.g., Fabrizio et al. 1995, Whittier 1998) and estuaries (e.g., Jordan et al.1991, Deegan et al. 1997). Fish have received little attention as indicators of wetland conditions, but recognition of their ecological significance in Great Lakes coastal wetlands (Jude and Pappas 1992) has recently generated considerable interest in using fish as indicators for these habitats (Wilcox et al. 2002, Timmermans and Craigie 2003, Environment Canada and Central Lake Ontario Conservation Authority 2004, Uzarski et al. 2005).

Minns *et al.* (1994) developed a fish-based IBI for shallow areas of Great Lakes Areas of Concern that includes metrics sensitive to impacts by exotic fishes, water quality changes, physical habitat alterations and changes in piscivore abundance related to fishing pressure and stocking. This system has not been extended outside of the limited and often highly impacted Areas of Concern. The work of Brazner (1997), Brazner and Beals (1997), and Minns *et al.* (1994) demonstrated relationships between fish populations and wetland and/or near-shore habitats that suggested that development of a fish-based IBI for coastal wetlands was possible. Recently, Randall and Minns (2002) used an IBI to assess habitat productivity of nearshore areas (including coastal wetlands) of lakes Erie and Ontario and compared results to those obtained using their Habitat Productivity Index. Thoma (1999) developed a fish-based IBI for near-shore waters of Lake Erie. More recently, Seilheimer and Chow Fraser (2006) proposed a fish-based IBI that reflected degradation of the water quality of Great Lakes coastal wetlands. Despite promising results, Wilcox *et al.* (2002) concluded that development of wetland IBIs for the upper Great Lakes using macrophytes, fish and microinvertebrates was impractical. Even though some of their metrics showed potential, they concluded that natural water level changes from those that existed during data collection were likely to alter communities enough to invalidate metrics in subsequent years.

This problem was overcome when developing an integrity index using invertebrate assemblages in fringing coastal wetlands in Lake Huron by developing a method based on sampling any or all of four emergent plant zones, depending on the number of zones inundated (Burton *et al.* 1999, Uzarski *et al.* 2004). The IBI scores for a particular year were calculated by summing scores from each zone that were inundated when sampling occurred. As water levels decreased and zones were no longer inundated, the IBI scores changed, but metrics for even a single inundated zone proved to be effective in describing the condition of fringing wetlands of lakes Huron and Michigan between 1997 and 2002 – a period during which water levels decreased by more than 1 meter (Uzarski *et al.*, 2004). Based on these results, we hypothesized that fish-based IBI metrics developed using samples from each inundated plant zone, rather than using combined samples to develop one set of metrics for the entire wetland, would provide the flexibility needed to make the IBI useful over a wide range of lake levels. This makes our approach different from other recent efforts, including the approach used by the REMAP project of U.S.EPA, where multiple samples collected across the entire wetland were combined to produce one integrated sample per wetland.

Materials and Methods

Various methods exist for sampling fish from coastal margins. The most commonly used techniques are various forms of trap nets (especially fyke nets), seines and electrofishing. Each method has its strengths and biases, which vary depending on time of day, season, duration and intensity of sampling, and habitat. Comparative studies of the effectiveness of these techniques at describing the fish community and condition of Great Lakes wetlands have been conducted by Thoma (1999), Chow Fraser et al. (2006) and Ruetz et al. (2007). Given that agencies may have longstanding traditions and databases compiled using a particular type of gear, it would be desirable to develop metrics for each sampling class. Chow Fraser et al. (2006) observed that, although electrofishing and fyke netting each caught 60%-75% of the species present in a wetland, particular species and dominant functional groups tended to be gear specific. Metric responses to stress could be developed but patterns of response to particular anthropogenic pressures were unique to gear type. Thoma (2002) argued that nocturnal electrofishing was most effective at summarizing biodiversity in Lake Erie coastal wetlands and drowned river mouths. However, Chow Fraser et al. (2006) developed an effective fish index from daytime electrofishing only. The most recent sampling efforts of several groups have emphasized fyke net methodology (Brazner and Beals 1997; Consortium – Uzarski et al. 2005; GLEI – Bhagat 2005; REMAP – Simons et al. 2006) but since both electrofishing and fyke netting have been used effectively to characterize fish assemblages from Great Lakes coastal wetlands, details associated with each approach have been included in this report. However, the IBI metrics reported here have only been calibrated with catches obtained with fyke nets and additional calibration would no doubt be needed if there is a desire to use electrofishing data to score the metrics and compute an IBI.

Fish Sampling (Fyke Netting)

Fish sampling should be conducted using a minimum of three replicate fyke nets with 4.8-mm mesh in each dominant vegetation zone for one net-night (Uzarski et al. 2005, Brady et al. 2007). Sampling should correspond to the maturity of the vegetation in each system. The need to be able to identify plant zones will determine the earliest date at which sampling can be conducted (typically no earlier than mid-June). Sampling should not be conducted after the end of August as seasonal movements of fish to winter locations may bias estimates of community composition. Only dominant plant zones that can be definitively assigned to a dominant plant species or morphotype (i.e. visually more than 75% composition by one species or morphotype) (*Sparganium, Schoenoplectus, Nuphar/Nymphaea, Pontederia/Sagittaria/Peltandra, Typha, Zizania,* or *Eleocharis*) should be sampled to partition variation due to structure or habitat type. It is rare to encounter vegetation zones without an obvious dominant. If a zone without an obvious dominant is encountered, it should be avoided. Uzarski et al.'s (2005) IBI relied primarily on bulrush-

(*Schoenoplectus*), water lily (*Nuphar/Nymphaea)* and cattail-(*Typha*) dominated zones, and these zones should be sampled if present. Scoenoplectus zones can be divided into outer and inner zones in areas where this zone is more than 50-100m wide, since the outer edge of this plant zone may only support low stem density while inland zones may be sheltered enough from wave action by higher stem density to support different fish species than the outer zone. In high lake level years, inundated wet meadow zones may also be added as a different habitat.

Two sizes of fyke nets can be used, 0.5-m x 1-m openings and 1-m x 1-m openings. Smaller nets should be set in water approximately 0.25-0.5 m deep; larger nets are set in water depths > 0.50 m. Leads should be 7.3 m long and wings should be 1.8 m long. The depth of water in each plant zone will dictate net size used since the only difference between large and small nets is height. The nets should be set so that the top of the cod end is far enough above the water surface to prevent turtles and other air breathing vertebrates from drowning. The location for each net should be determined randomly/ haphazardly within each vegetation zone and should be set with at least 20 m between nets if possible. Nets should be placed perpendicular to the vegetation zone of interest, with leads extending from the center of the mouth of the net into the vegetation. Therefore, fishes in the plant zone or moving along the edge of plant zone are likely to be caught. Wings should be set at 45° angles to the lead and connected to the outer opening on each side of the net. When a defined boundary or edge of the vegetation type of interest is not found or difficult to reach, the nets can be fished lead to lead rather than just individually.

Fish Sampling (Electrofishing)

Although electrofishing data has not been used extensively to generate IBI scores for coastal wetlands (however, see Environment Canada and Central Lake Ontario Conservation Authority, 2004 for one exception), the methods described here are intended to provide a representative sample of the fish assemblage present at a Great Lakes coastal wetland and allow relationships among the assemblage or particular fish species, in-wetland habitat and human disturbance to be established at a number of spatial scales. The data will be suitable for calculating indices of biotic integrity, their individual metrics, and function- or species-based indicators of condition, assuming proper calibration has been completed for the sampling region and wetland type. These methods have been tested and found to be feasible and effective across the Great Lakes basin (Brazner et al. 2007, Trebitz et al. *in press*) in all of the main Great Lakes coastal wetland types (e.g., fringing, protected, drowned river mouth; see Keough et al. 1999 and Albert et al. 2005 for details on types).

Selection of Great Lakes coastal wetland study sites for electrofishing will depend on specific study goals but will be limited to locations where boat access is feasible, since boat-mounted gear is required to effectively sample most Great Lakes coastal wetlands. Access is not a trivial problem for electrofishing coastal wetlands because boat launches have not been developed for many sites, and many wetlands along high-energy shorelines develop partial or complete barrier beaches across their mouths, preventing access from the open lake. In addition, the distance from existing launches is often prohibitive due to safety concerns associated with travel across the open Great Lakes in small, flat-bottomed boats.

It is recommended that all fish sampling be conducted within a two-month period during July and August. This corresponds with the peak growing season for aquatic vegetation and is the season of highest fish diversity and abundance in Great Lakes coastal wetlands (Brazner 1997, Brazner and Beals 1997). It is also a time of year when abiotic conditions (water temperature, lake level, stream discharge) are relatively stable and when fish occupying Great Lakes coastal wetlands are primarily resident species rather than spring or fall migrants. Karr et al. (1986) suggested that capture of primarily resident species was essential when data were intended to be used in metric calculations for indices of biotic integrity.

Assuming sites have been selected by an acceptable methodology and field access is deemed feasible, the first step once in the field is to select sampling transects. Since wetland habitat structure appears to be organized by fluvial zones (channel areas, back-bay areas, lacustrine areas - Trebitz et al. 2005) and habitat structure appears to structure Great Lakes coastal wetlands fish assemblages (Brazner and Beals 1997; Uzarski et al. 2005), transect selection and fish sampling are recommended at the fluvial zone scale. Measures can later be scaled up to the whole wetland scale if desired for comparisons with whole wetland habitat measures.

Samples within fluvial zones should be made along 100-m reaches of shoreline (Trebitz et al. in press). In general, transects can be treated as replicates to examine differences in fish assemblages within or among fluvial zones or other within-wetland factors such as vegetation type, or aggregated to the wetland scale by area-weighting or simple summation.

It is also recommended to use seven sampling transects based on field trials (Trebitz et al., in press). Shocking and processing the fish at seven transects typically requires about 4-5 hours in the field, an amount of time that typically allows the field crew to complete a number of other sampling activities at the same wetland within one day, or alternatively to sample fish at two different wetlands on the same day. The amount of sampling that can be completed in a day will depend on a number of factors, including difficulty of access to and movement within the wetland, size of the wetland, distance between sampling locations and number of fish captured. However, this method has been tested and utilized at more than 60 Great Lakes coastal wetlands and the 4-5 hour time to completion estimate was rarely exceeded.

Approximate transect locations can be identified before going out in the field using geographic analysis of digital orthophotoquads for each site. On the orthophotoquads, the perimeter of the standing water portion of the wetland is divided into seven equal length segments. Sampling locations can be initially set to correspond with segment boundaries on the orthophotoquad. In the field, the actual sampling locations should be adjusted as necessary so that each 100-m transect falls entirely within one fluvial zone, to accommodate altered water levels or wetland morphology, and to provide the best representation of the habitat types and fluvial zones that are present. This procedure (approximately equally spaced transects, with some adjustments in the field) ensures good spatial coverage of the wetland inundated area (i.e., crews not just sampling the closest or most accessible parts), while allowing field crews to deal with the various contingencies that may arise.

Once transects have been identified and adjusted for habitat representativeness, they should be clearly marked along the shoreline so they can be easily located by all field crews during any revisits to the sites. Recording GPS coordinates and other nearby landmarks are also recommended so that transects can be relocated even if shoreline markers have been removed or are not desired by landowners. Covariate data (dominant vegetation, depth, substrate characteristics, other forms of disturbance, basic water chemistry, turbidity) should be measured at each transect as time and resources permit. This information is often important in selecting the appropriate metric to apply to a particular wetland or reach (Table 5-1).

Electrofishing in Great Lakes coastal wetlands is most effectively accomplished from smaller, lighter-weight boats than are typically used in larger lake and river environments. Smaller boats provide more ready access to the very shallow waters that predominate in coastal wetland habitats (they can be pushed with an on-board pole in shallow and densely vegetated areas where using the motor is impractical) and are easier to launch at the less-developed boat landings typical of these sites. A 5-m long, flat-bottomed boat with a shallow v-shaped bow will optimize flat working space within the boat while minimizing draft and providing some protection from waves if travel across the open Great Lakes is required to access a site. Additionally, a removable front railing on the boat is useful for getting under low bridges that would otherwise limit access to substantial portions of some wetlands. It is recommended that the boat be equipped with a 1.0-m Wisconsin ring anode fitted with stainless steel droppers mounted on a 3.0-m boom, but boom length will need to be adjusted to boat size so that the Wisconsin ring is centered approximately 1.5m in front of the bow. A ring-shaped anode is recommended because it is less likely to become entangled in emergent vegetation than other electrode configurations.

A 3-m stainless steel cable suspended from the boat rail is recommended as a cathode. This has been found to be a more effective cathode design for coastal wetland sampling than the more typical use of the boat-bottom surface; but using the boat bottom surface or a metal plate mounted on nonmetallic hulls would be an acceptable approach as well. Current should be generated with at least a 5.000`watt generator and voltage adjusted to produce current (in-water amperage) at a level that will be effective in stunning fish while minimizing potential harmful effects. This level varies among lakes and between locations within a lake depending on conductivity, depth, substrates and other factors, but is often in the 5 to 6 amp range. This level is considerably higher than what we have found to be effective in most stream habitats (≈ 2 amps), but is necessary to be effective in many Great Lakes coastal wetland habitats, particularly those with highly organic or sandy substrates. Minimizing potential harmful effects should always be paramount, so assessment of minimum effective current will need to be completed at each site immediately before sampling begins. An output setting of 60-120 pulses per second of direct current is recommended to achieve these results. Output setting and effective current delivered to the water should be maintained consistently across all sites.

Each transect should be fished an equal time across all wetlands. A total of 10-15 minutes of continuous shocking is recommended per transect parallel to shore. Although it is not necessary and meaningful data can be obtained without it, it is recommended that one weights the time spent fishing in different vegetation zones (e.g., emergent, submergent and open water, other) at each transect by the predominance of each of these habitats at a particular transect. Estimating the areal coverage of the different vegetation zones can be done quickly by visual estimation adjacent to the transect immediately before beginning fishing. Habitat crews can provide a more precise estimate of this coverage after fishing has been completed if deemed necessary. The weighting of vegetation zones is particularly important if certain metrics or indicators are based on fishes associated with particular plant zones (e.g., Uzarski et al. 2005). For example, if 10 minutes has been selected as the total time for each transect, and 25% of the aquatic portion of the site is estimated to be occupied by emergent plants, 50% by submergent plants and 25% of the site is open water habitat (macrophytes not present or rare), five minutes should be allotted to sampling in the submergent zone and 2.5 minutes in both the emergent and open water zones. All effort should be spread evenly across the 100 m transect in each designated zone. If weighting time fished by vegetation zones is not incorporated into the design, then all areas within the transect should be fished as exhaustively as possible within the time frame allotted.

Fish from each of the vegetation zones should be placed in separate coolers as they are captured and worked up separately if data stratification by vegetation zone is desired. Data can be aggregated later if analyses are being conducted at the scale of transects within wetlands or at the scale of entire wetlands. Since it is likely that fish data will be analyzed relative to other biotic or abiotic data, some thought should be given to matching the scales at which abiotic data are sampled to the scale of fish sampling. For example, vegetation cover and composition are readily surveyed at spatial scales matching the fish transects (Trebitz et al. 2005), and water quality data can be collected from the midpoint of each transect.

At each transect, vegetation zones should be fished to the middle of the wetland at each transect not to exceed a maximum distance of 100 m from shore. The 100-m limit is recommended because greater distances create a sampling transect that is impractical for most field crews to effectively sample, particularly if all seven locations to be sampled in a wetland are configured in a similar manner. When large open water areas are present, the width of open water zone fished should be limited to the greater of the two widths from the emergent and submergent zones. For example, if the emergent zone was 20 m wide and the submergent zone was 40 m wide, only 40 m of the open water zone would be fished even if there was a much larger area of open water present. Similarly, if there was 10 m of emergent zone and 20 m of submergent zone only 20 m of open water would be fished. In channel or backwater areas that are less than 25 m wide, emergent and submergent zones on both sides of the channel/backwater should be fished if necessary to meet the calculated fishing times for each area.

Fish Enumeration and Identification

Regardless of the capture method, fishes greater than 25 mm should be identified to species and enumerated so that diversity indices can be calculated. Catch per net per night or per minute of electrofishing should be recorded for each species caught. Ten to 20 specimens of each species and approximate life stage based on regional size-at-age relationships (YOY, yearling, adult), should be chosen randomly for measurement (total length, evidence of deformities, ectoparasites, lesions or tumors, etc.); these data are not needed here but should be obtained for future use. Depending on study objectives, all fish or a representative subsample may need to be weighed and measured for total length before release. If a fish cannot be identified in the field, specimens should be collected for later identification in the lab. Whenever possible, auxiliary (covariate) physicochemical data (water chemistry, depth, temperature, etc.) should be recorded before and/or after sampling. This information can later be used to explain variability or anomalies in catch data. Recommended covariate measurements are summarized in Table 5-1.

Worksheet for Calculating IBI Scores

IBI use and interpretation of results

The recommended fish-based index of biotic integrity metrics for Great Lakes coastal wetlands are those of Uzarski et al. (2005). It is important to recognize that the metrics reported here are based on fyke net catches only and will need to be adapted for other fish capture methods. Scoring for each metric is calculated from mean values per net-night (Figure 5-1) in *Schoenoplectus* and *Typha* zones when a mean of at least 10 fish are captured per net per vegetation zone. If fewer than 10 fish are captured or a sample is suspected to be atypical, an additional net-night is recommended. Additional sampling increases sample sizes without altering community composition (Brady et al. 2007).

***Schoenoplectus* Zone:**

1. Mean catch per net-night:
<10 score = 0 | 10-30 score = 3 | >30 score = 5

2. Total richness:
<5 score = 0 | 5 to <10 score = 3 | 10 to 14 score = 5 | >14 score = 7

3. Percent non-native richness:
>12% score = 0 | 7% to 12% score = 3 | <7% score = 5

4. Percent omnivore abundance:
>70% score = 0 | 50% to 70% score = 3 | <50% score = 5

5. Percent piscivore richness:
<15% score = 0 | 15% to 25% score = 3 | >25% score = 5

6. Percent insectivore abundance:
<20% score = 0 | 20%-30% score = 3 | >30% score = 5

7. Percent insectivorous Cyprinidae abundance:
<1% score = 0 | 1%-2% score = 3 | >2% score = 5

8. Percent carnivore (insectivore+piscivore+zooplanktivore) richness:
<60% score = 0 | 60%-70% score = 3 | >70% score = 5

9. White sucker (*Catostomus commersoni*) mean abundance per net-night:
0 score = 0 | >0 to 0.4 score = 3 | >0.4 score = 5

10. Black bullhead (*Ictalurus melas*) mean catch per net-night:
0 score = 0 | >0 to 3 score = 3 | >3 score = 5

11. Rock bass (*Ambloplites rupestris*) mean catch per net-night:
0 score = 0 | >0 to 4 score = 3 | >4 score = 5

12. Alewife (*Alosa psuedoharengus*) mean catch per net-night:
>11 score = 0 | 1 to 11 score = 3 | <1 score = 5

13. Smallmouth bass (*Micropterus dolomieu*) mean catch per net-night:
0 score = 0 | >0 to 5 score = 3 | >5 score = 5

14. Pugnose shiner (*Notropis anogenus*) mean catch per net-night:
0 score = 0 | >0 to 5 score = 3 | >5 score = 5

Figure 5-1. Mean values per net-night for Schoenoplectus zones. For further reference, see Appendix C (Uzarski, et al. 2003) at the end of this document.

Typha Zone:

1. Percent insectivore catch:
<40% Score = 0 40% to 80% score = 3 >80% score = 5

2. Insectivorous Cyprinidae richness:
0 to 1 Score = 0 >1to 3 score = 3 >3 score = 5

3. Percent Centrarchidae abundance:
0-30 score = 0 >30 to 60 score = 3 >60 to 80 score 5 >80 score = 7

4. Centrarchidae richness:
0 to 1 score = 0 >1 to 3 score = 3 >3 score = 5

5. Mean Shannon Diversity Index:
<0.2 score = 0 0.2 to 0.7 score = 3 >0.7 score = 5

6. Mean evenness:
<0.2 score = 0 0.2 to 0.6 score = 3 >0.6 score = 5

7. Longnose gar (*Lepisosteus osseus*) catch per net-night:
0 score = 0 >0 to 0.5 score = 3 >0.5 to 2 score = 5 >2 score = 7

8. Largemouth bass (*Micropterus salmoides*) abundance per net-night:
0 to 2 score = 0 >2 to 30 score = 3 >30 score = 5

9. Rock Bass (*Ambloplites rupestris*) catch per net-night:
0 to 1 score = 0 >1 to 5 score = 3 >5 score = 5

10. Bluegill (*Lepomis macrochirus*) abundance per net-night:
0 to 3 score = 0 >3 to 20 score = 3 >20 to 30 score = 5 >30 score = 7

11. Lepomis catch per net-night:
0 to 5 score = 0 >5 to 20 score = 3 >20 to 50 = 5 >50 score = 7

Figure 5-2. The IBI of Uzarski et al. 2005 recommend by the GLCWC. Data are collected using fyke nets. For further reference, see Appendix C (Uzarski, et al. 2003) at the end of this document.

Table 5-1. Recommended Landscape and Water Quality Parameters to Record During Field Surveys

Parameter	Instrument	Consortium	GLEI	FQI (WQI)
TP	Water sample	X		X
TN	Water sample	X		X
TSS	Filtered sample	X	X	X
Chl *a*	Filtered sample	X		X
SRP	Water sample			X
TNN	Water sample			X
TAN	Water sample			X
Temperature	Multimeter	X	X	X
Conductivity	Multimeter	X	X	X
PH	Multimeter		X	X
DO	Multimeter	X	X	X
Inorganic SS	Filtered sample			X
Tubidity	Turbidimeter/Secchi disk	X	X	X
Water depth	Meter stick		X	X
Net distance from shore	Range finder/tape measure		X	
Substrate texture	Visual estimate		X	
Organic content	Sediment Sample for LOI		X	
Substrate particle size	Sediment sample (composite)		X	
Emergent plants (species, % cover, distrib.)			X	
Floating plants (species, % cover, distrib.)			X	
Submerged plants (species, % cover, distrib.)			X	
Shoreline features (land use at closest shoreline)			X	
Wetland hydrogeomorphic type		X	X	X
Adjacent land use				X
Set time (start)			X	X
Strike time (end)			X	X
Wave & wind conditions			X	X
Air temperature				X
Ecoregion				X
Relative water level		X	X	X

Limitations and alternate analyses

The recommended IBI is specific to only two plant zones. However, data should be collected from any/all plant zones encountered. IBIs will be developed for additional plant zones as data permits. The plant species that dominate in a particular area are determined by the habitat and physico-chemical features of the wetland and adjacent landscape. *Schoenoplectus* zones are typical of coastal wetlands that have sandy substrates, clear water and relatively low levels of nutrients. *Typha* zones tend to have more organic sediments and higher nutrient content. Ordination of fish IBI scores for the two plant zones indicate that the IBIs are not universal indicators of generalized anthropogenic stress. The *Typha* IBI varies in response to pressures related to increasing population pressure and associated loss of forest cover and increased residential and commercial use of adjacent land. In contrast, the *Schoenoplectus* IBI is responsive to increasing intensity of agricultural land use and point source discharges (Bhagat et al. 2007). Therefore, sampling both vegetation classes is important for interpreting what types of land use activity may be most responsible for altered fish community health where both zones occur.

If sampling is conducted in areas or habitats that lack vegetation entirely or have different dominant vegetation – such as a mixture of floating leafed vegetation including water lilies – alternate fyke net-based metrics are theoretically available if the appropriate covariates have been collected at the time of sampling. The fish quality index (FQI; Seilheimer and Chow Fraser 2006) relates community composition to a nutrient-dominated water quality index (WQI). As mentioned above, the Consortium-developed indices of biotic integrity (Fish-IBI) are based on multiple metrics for Typha & Schoenoplectus-dominated wetlands in relation to water quality and agricultural/urban land-use stresses (Uzarski et al. 2005). The Great Lakes Environmental Indicator (GLEI) metrics are derived from multivariate analyses of fish species relative abundances ordinated against agricultural and urban development stress gradients (Bhagat 2005; Bhagat et al., in prep).

Bhagat (2005; in prep) used a multivariate approach of fish community assessment to develop indicators of coastal margin condition based on relative abundances of species captured in fyke nets. Cluster analysis was used to distinguish unique groupings of reference sites based on relative abundances of fish species. A discriminant function analysis model distinguished the clusters on the basis of ecoregion and seven other environmental variables. Bray-Curtis ordination was then used to assess changes in fish community across 143 sites sampled with respect to two classes of human activity: agriculture and population density. Population density related stress was observed to have stronger effects than agriculture-related stress. Her assessment included nonvegetated locations (high energy coastlines and embayments), as well as coastal wetlands. It was especially noteworthy that species considered to be indicators of degraded conditions in cold, nutrient-poor northern ecoregions were found to be indicators of reference conditions in warmer, more mesotrophic southern ecoregions. This emphasizes the importance of collecting habitat and physicochemical data at the time of sampling, as it provides important information on the reference community that should be expected in a particular wetland.

Each fyke net-based index still needs validation using data external to that employed in model creation. However, the GLEI-derived land-use based stressor scores offer a basinwide, common suite of stressor measures against which to assess each index because scores exist for the entire U.S. Great Lakes coast. Scores for Canada are partially complete.

References

Albert, D.A., Wilcox, D.A., Ingram, J.W., and Thompson, T.A. 2005. Hydrogeomorphic classification for Great Lakes coastal wetlands. Journal of Great Lakes Research 31(Suppl. 1):129-146.

Bhagat, Y. 2005. Fish indicators of anthropogenic stress at Great Lakes coastal margins: multimetric and multivariate approaches. M.Sc. thesis. University of Windsor, Windsor, Ontario, Canada.

Bhagat, Y. J.J.H. Ciborowski, L.B. Johnson, T.M. Burton, D.G. Uzarski, S. A. Timmermans and M. Cooper. 2007. Testing a fish index of biotic integrity for Great Lakes coastal wetlands: stratification by plant zones. Journal of Great Lakes Research 33: In press.

Brady,V.J., J.J.H. Ciborowski, J. Holland, N. Danz, L. Johnson, D. Breneman, N.P. Danz, J.D. Holland, and J. Gathman. 2007. Optimizing fishing time: One vs. two night fyke net sets in Great Lakes coastal systems. Journal of Great Lakes Research 33: In press

Brazner, J.C., N. P. Danz, G. J. Niemi, R.R. Regal, J.M. Hanowski, C.A. Johnston, E.D. Reavie, A.S. Trebitz, R.W. Howe, L.B. Johnson, V.J. Brady, J.J.H. Ciborowski, and G.V. Sgro. 2007. Evaluating geographic, geomorphic and human influences on Great Lakes wetland indicators: multi assemblage variance partitioning. Ecological Indicators. 7:610-635.

Brazner, J.C. and E.W. Beals. 1997. Patterns in fish assemblages from coastal wetland and beach habitats in Green Bay, Lake Michigan: a multivariate analysis of abiotic and biotic forcing factors. Canadian Journal of Fish and Aquatic Science. 54:1743-1761.

Brazner, J.C. 1997. Regional, habitat, and human development influences on coastal wetland and beach fish assemblages in Green Bay, Lake Michigan. Journal of Great Lakes Research 23:36-52.

Chow-Fraser, P., K. Kostuk, T. Seilheimer, M. Weimer, T. MacDougall, and T. Theÿsmeÿer. 2006. Effect of wetland quality on sampling bias associated with two fish survey methods for coastal wetlands of the lower Great Lakes. Simon, T.P. and Stewart, P.M. (Eds). Coastal wetlands of the Laurentian Great Lakes: health, habitat and indicators. Pp. 239-262. AuthorHouse, Bloomington, Ind.

Chow-Fraser, P. 2006. Development of the Wetland Water Quality Index (WQI) to assess effects of basinwide land-use alteration on coastal marshes of the Laurentian Great Lakes. Simon, T.P and Stewart, P.M. (eds.) Coastal wetlands of the Laurentian Great Lakes: health, habitat and indicators. Pp. 137-166. AuthorHouse, Bloomington, Ind.

Deegan, L.A., Finn, J.T., Ayvasian, S.G., and Ryder-Kieffer, C.A., and Buonaccorsi, J. 1997. Development and validation of an estuarine biotic integrity index. Estuaries 20:601-617.

Environment Canada and Central Lake Ontario Conservation Authority. 2004. Durham Region Coastal Wetland Monitoring Project: Year 2 Technical Report. Downsview, Ontario: Environmental Conservation Branch – Ontario Region.

Fabrizio, M.C., Ferreri, C.P., and Hanson, M.J. 1995. Prey fish communities as indicators of ecosystem health in Lake Michigan. National Biological Service, Project Completion Report, Great Lakes Science Center, Ann Arbor, Mich.

Jordan, S.J., Vaas, P.A., and Uphoff, J. 1991. Fish assemblages as indicators of environmental quality in Chesapeake Bay. Proceedings of Biological Criteria: Research and Regulation Symposium. EPA-440/5-91-005. U.S. Environmental Protection Agency, Washington, D.C.

Jude, D.J., Pappas, J. 1992. Fish utilization of Great Lakes coastal wetlands. Journal of Great Lakes Research 18:651-672.

Karr, J.R, Fausch, K.D., Angermeier, P.L., Yant, P.R., and Schlosser, I.J. 1986. Assessment of biological integrity in running waters. A method and its rationale. Illinois Natural History Survey Special Publication No. 5. Chicago, Ill.

Keough, J.R., Thompson, T.A. Guntenspergen, G.R., and Wilcox, D.A. 1999.
Hydrogeomorphic factors and ecosystem response of wetlands of the Great Lakes. Wetlands 19:821-834.

Krieger, K.A. et al. 1992. The Ecology of Invertebrates in Great Lakes Coastal Wetlands: Current Knowledge and Research Needs. Journal of Great Lakes Research Vol. 18, No. 4, p 634-650.

LaPointe, N.R.,.D. Corkum and N.E. Mandrak. 2006. A Comparison of Methods for Sampling Fish Diversity in Shallow Offshore Waters of Large Rivers. North American Journal of Fisheries Management 26:503–513.

Lyons, J., and Wang, L. 1996. Development and validation of an index of biotic integrity for coldwater streams in Wisconsin. North American Journal of Fisheries Management 16:241-256.

Mayer, T. Edsal and M. Munawar. 2004. Evolution of coastal Great Lakes wetlands.

Minns, C.K., V.W. Cairns, R.G. Randall, and J.E. Moore. 1994. An Index of Biotic Integrity (IBI) for Fish Assemblages in the Littoral Zone of Great Lakes' Areas of Concern. Can. J. Fish. Aquat. Sci. 51: 1804-1822.

Morrison H. A.; Minns C. K.; Koonce J. F. 2001. A methodology for identifying and classifying aquatic biodiversity investment areas: Application in the Great Lakes basin. Aquatic Ecosystem Health & Management 4: 1-12

Seilheimer,T.S. and P. Chow-Fraser. 2006. Development and use of the Wetland Fish Index to assess the quality of coastal wetlands in the Laurentian Great Lakes. Canadian Journal of Fisheries and Aquatic Science 63: 354–366

Seilheimer, T. and Chow-Fraser, P. 2007 Application of the Wetland Fish Index to northern Great Lakes marshes with an emphasis on Georgian Bay coastal wetlands. Journal of Great Lakes Research 33: In press.

Ruetz III C.R., D.G. Uzarski, D.M. Krueger, and E.S. Rutherford. 2007. Sampling a littoral fish assemblage: Comparing small-mesh fyke netting and boat electrofishing. North American Journal of Fisheries Management 27:825-831.

State of the Great Lakes Ecosystem Conference, 1998. U.S. Environmental Protection Agency and Environment Canada, Buffalo, N.Y.

Thoma, R.F. 1999. Biological monitoring and an index of biotic integrity for Lake Erie's nearshore waters: Assessing the sustainability and biological integrity of water resources using fish communities*,* T. P. Simon, (ed.) pp. 417-461. CRC Press, Boca Raton, Fla.

Thoma, R.F. 2002. Correlation between nutrient stimulation and presence of omnivorous fish along the Lake Erie nearshore. Biological Response Signatures: Indicator Patterns Using Aquatic Communities, T. P. Simon (ed.) pp. 187-199. CRC Press. Boca Raton, Fla.

Thoma, R.F. 2004. Methods of Assessing Habitat in Lake Erie Shoreline Waters Using the Qualitative Habitat Evaluation Index (QHEI) Approach. Ohio Environmental Protection Agency, Division of Surface Water, 401 Section, Columbus, Ohio.

Timmermans, S.T.A, and Craigie, G.E. 2003. The Great Lakes Coastal Wetlands Consortium Year-One Pilot Project Research Indicator Activities: A Technical Report by Bird Studies Canada. Marsh Monitoring Program, Bird Studies Canada.

Trebitz, A.S., Brazner, J.C., Tanner, D.K., Brady, V.J. and Axler, R. *In press*. Turbidity tolerances of Great Lakes coastal wetland fishes. North American Journal of Fisheries Management 27.

Trebitz A.S., Morrice, J.A., Taylor, D.L., Anderson, R.L., West, C.W. and Kelly, J.R. 2005. Hydromorphic determinants of aquatic habitat variability in Lake Superior coastal wetlands. Wetlands 25:505-519.

Uzarski, D.G., Burton, T.M., Cooper, M.J., Ingram, J.W., and Timmermans, S. 2005. Fish habitat use within and across wetland classes in coastal wetlands of the five Great Lakes: development of a fish-based Index of Biotic Integrity. Journal of Great Lakes Research 31 (Suppl. 1):171-187.

Whittier, T.H. 1999. Development of IBI metrics for lakes in southern New England. In: Simon, T.P. (ed.), Assessing the sustainability and biological integrity of water resources using fish communities. Lewis Publishers, Boca Raton, Fla, pp. 563-582.

Wilcox, D.A., Meeker, J.E., Hudson, P.L., Armitage, B.J., Black, M.G., and Uzarski, D.G. 2002. Hydrologic variability and the application of Index of Biotic Integrity metrics to wetlands: a Great Lakes evaluation. Wetlands 22:588-615.

Appendix 5-1. GREAT LAKES COASTAL WETLANDS DATA SHEET - Electrofishing

Page___of _____

Date_____________ Wetland______________________ Type: Riverine Protected

Fluvial Zone: Channel Back Bay Lacustrine Mouth

Lake_______________ Transect#______ Lat_________________ Lon_________________ Gear: Boat Tote Barge

Voltage_________ Amps_________ # GPP Seconds Fished________ Total Time Fished (min)_______ Veg. Zone: Emergent Submergent Open Mixed

Distance Fished - Length (m)______ Width (m)_______

L=length(cm), W=weight(g), C=condition

Species/Age		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	Comments
	L																
	W																
	C																
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Anomalies: A=anchor worm, B=black spot, C=leeches, D=deformities, E=eroded fins, F=fungus, I=ich, L=lesions, N=blind, P=other parasites, Y=popeye, S=emaciated, W=swirled scales, T=tumor, Z=other (H-heavy =>20%, L-light=<20%)

Appendix 5-2.

Field Equipment Checklist
For fish and accompanying chemical/physical (covariates) sampling

<u>Pre-sampling checklist</u>:

______Conductivity meter

______DO meter/probe/repair kit

______Tape

______Field notebooks

______6 Fyke nets

______Permanent marker

______Cooler and ice (depending on temp)

______ Insect repellent

______Filter apparatus

______Metal hand pump/tubing bottles

______Buckets

______ Turbidimeter

______1 L water sample bottles (at least 3/site)

______Mechanicalpencils

______Meter stick

______Fish processing boards

______Metal conduit (42 pcs.)

______Waders or boots

______Cell phone

______Filters/forceps

______250 mL sample (at least 3 per site)

<u>In field</u>:

Water samples → surface 1 L (1 sample per station)

Fish samples (nets) → 3 per station

Chapter 6

Amphibian Community Indicators

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Introduction

Amphibians rely heavily on aquatic environments for reproduction and other life sustaining purposes. Most amphibians inhabit wetland environments during most or part of their life cycle, and among the amphibian class, anurans generally rely most heavily on wetland aquatic systems. Amphibians also are perhaps the most sensitive vertebrates to aquatic and atmospheric pollution (Blaustein and Wake 1995), and therefore may be deemed highly useful early warning indicators of wetland pollution and habitat degradation (Crewe and Timmermans 2005, *but see* Price et al. *In Review*). Directly associated with Great Lakes hydrological influences, lacustrine or coastal wetlands are among the most important wetlands that occur within the Great Lakes basin. Numerous anuran species are associated with wetlands of the Great Lakes basin (Mitsch and Gosselink 1993, Hecnar 2004).

Many anuran species have experienced population declines, likely due to historical and current sources of anthropogenic environmental pollution, and habitat loss and degradation. As recently as the 1990s, researchers began to realize that declining amphibian populations was a global phenomenon, although the magnitude and geographic extent of these declines was still uncertain (Alford et al. 1999, Carey 2000, Houlahan et al. 2000). Because the uncertainty surrounding the nature of these declines was primarily due to lack of extensive, scientifically rigorous, consistently collected data, as well as a lack of detailed population information on localized metapopulations, researchers and conservationists in Canada and the United States began to consolidate efforts to report and determine the sources of these declines (Pechmann et al. 1991, Green 1997, Kiesecker et al. 2001).

There were increasing concerns that continued stresses by urban, industrial and agricultural development were negatively affecting marsh-dependent wildlife populations and other marsh functions, such as water quality improvement. As a result, Bird Studies Canada (BSC) partnered with Environment Canada to develop the Marsh Monitoring Program (MMP) in Ontario in 1994. With substantial financial support from the United States Environmental Protection Agency's Great Lakes National Program Office and the Great Lakes Protection Fund, the MMP was launched binationally throughout the Great Lakes basin in 1995 and the program has been growing ever since.

Concern over the status of anuran communities in the Great Lakes basin was also raised at the State of the Lakes Ecosystem Conference (SOLEC) in 1998, which provided the impetus for a team of experts and the public to identify and begin developing a suite of ecological indicators based on amphibian communities. SOLEC indicators were designed to incorporate all major aquatic and terrestrial habitats of the Great Lakes basin that were deemed important to human health and society. Coastal wetlands were one of these habitats and certain characteristics of the amphibian community were adopted as a means to assess their overall integrity through SOLEC indicator #4504: *Species composition and relative abundance of calling frogs and toads, based on evening surveys using protocol developed for the Marsh Monitoring Program (MMP) or modification of MMP protocol.*

In 2002, the Great Lakes Coastal Wetlands Consortium began to develop indicators based on the condition of Great Lakes coastal wetland amphibian communities, relying on MMP data and protocols to design these studies. The MMP had an established methodology, a network of skilled volunteer surveyors and several years of supporting data. The next five years were dedicated to collecting data and developing and testing indicators for reporting on the condition of marsh-dependent amphibian communities in coastal wetlands across the Great Lakes basin.

During this time there was also considerable interest in assessing and monitoring the condition of amphibian communities at a regional scale within the Great Lakes basin, particularly within Great Lakes Areas of Concern (AOC). For example, when Beneficial Use Impairment # 3 (i.e., degraded fish and wildlife populations) has been listed as part of a Remedial Action Plan (RAP), wetland amphibian communities have often been a key factor in the listings for Canadian AOCs (e.g., Bay of Quinte, Niagara River), United States AOCs (e.g., Clinton River, Cuyahoga

River), and all binational AOCs (Timmermans et al. 2004; Archer et al. 2006; Environment Canada – Canadian Wildlife Service [EC-CWS] 2007); see http://www.ijc.org/en/activities/raps.htm.

Another example where amphibians have been used as part of regional monitoring efforts is the Durham Region Coastal Wetland Monitoring Project (DRCWMP), which focused on 15 wetlands located just east of Toronto. For the past six years, marsh-dependent amphibian data have been collected for the DRCWMP through a combination of paid staff and citizen volunteers participating in the MMP. These data have been reported in technical documents and fact books in an effort to further Great Lakes coastal wetland science, promote regional coastal wetland conservation, and influence environmental policy in Durham Region (Environment Canada [EC] and the Central Lake Ontario Conservation Authority [CLOCA] 2004a, EC and CLOCA 2004b).

Bird Studies Canada personnel who coordinate the MMP have been primary investigators for the Consortium, and have worked with EC partners and others to develop marsh-dependent amphibian monitoring protocols and associated amphibian community indicators specific to Great Lakes coastal wetland ecological indicator (EI) biomonitoring. These investigators established monitoring protocols that adequately met all the required criteria established by the Consortium, and also developed associated amphibian indices of biotic integrity (IBI) derived from resulting monitoring data. During the five-year Consortium data collection and indicator development process, the main collaborators for the amphibian community indicators were BSC and EC-CWS (EC and CLOCA 2004a; Crewe and Timmermans 2005).

During this same period, a similar research project, the Great Lakes Environmental Indicators (GLEI) project (http://glei.nrri.umn.edu/default/), concurrently examined use of another method to report on Great Lakes coastal wetland amphibian communities with data collected based on the GLEI's amphibian survey methods (Niemi et al. 2006). In the final year of the Consortium work plan, there were efforts to collaborate with the GLEI scientists to develop an integrated amphibian community condition indicator, recognizing the inherent differences in both anuran survey field data collection methods and data analytical procedures used between Consortium and GLEI investigators. Consortium wetland amphibian indicator investigators worked with GLEI investigators to examine the possibility of integrating certain data analytical procedures, called the Index of Ecological Condition (IEC), that were being developed by GLEI for estimating coastal wetland condition based on amphibians. Unfortunately, time was short and the benefits of a more timely and thorough collaboration were not fully realized. The methods and indicators presented in this section are a result of the Consortium indicator development process. We hope to continue our collaboration with GLEI investigators to evaluate the potential of integrating IEC data analytical methods for future Great Lakes coastal wetland amphibian indicator calculations.

Materials and Methods

Field Protocols

MMP data collection is coordinated through Bird Studies Canada. To participate, surveyors must have received and be familiar with the current MMP training kit and instructions. The package contains training audio tapes or compact discs, station identification tags, an instruction manual and data sheets, and is available from:

Bird Studies Canada
Marsh Monitoring Program
115 Front Street
P.O. Box 160
Port Rowan, Ontario N0E 1M0 Canada
Toll free: 1-888-448-2473
Fax: 519-586-3532
Email: aqsurvey@bsc-eoc.org

The full protocols are available in Appendix 6-1. A summary of the methodology is below.

MMP amphibian surveys use an unlimited distance point count method to collect data on amphibian species. These point counts entail a surveyor standing at a focal point (or survey point) and listening for breeding calls of various frog and toad (anuran) species that are heard in a standardized period of time in the defined survey area. MMP amphibian survey protocol consists of a semicircular (180 degree radius) survey station with an unlimited distance. However, surveyors are asked to indicate whether individuals or groups of amphibians are heard calling within or beyond a100-meter survey radius. Survey stations are separated by at least 500 meters to ensure independence between stations (i.e., reduce double counting of breeding calls between adjacent stations).

A route consists of one to eight survey stations established within a site; a site can contain a number of routes. Routes are established based on the following protocol:

- Routes occur only in marsh habitat (i.e., greater than 50 percent nonwoody emergent plants interspersed with shallow open water);
- Route survey stations are established along the shoreline (e.g., marsh edge) and/or within the interior of a marsh;
- Survey stations are selected by program coordinators following a scientifically robust stratified-random sample station selection scheme adapted from Meyer et al. (2006) to best represent the wetland habitats;
- Edge survey station direction is positioned to maximize marsh area surveyed; interior survey station direction is selected via random bearing selection;
- Each station is visited three times during the breeding season (i.e., peak vocalization time) and,
- Landmarks are established so that distances within the survey area can be accurately estimated.

Amphibian surveys are standardized to occur during a specific survey window (three visits, each timed appropriately for latitudinal region), time of day (sunset to 24:00 hrs [midnight] EST), duration (3 minutes per station), date (region- and visit-specific), specific weather conditions (visit-specific minimum ambient temperatures), low drizzle or no precipitation, and gentle wind (less than 19 kilometers per hour). In addition, at least 15 days must fall between survey visits.

Birds Studies Canada also coordinates MMP recruitment sessions during late winter and early spring, and training sessions during spring. Special training sessions will be given in regions with abundant or specialized (i.e., implementation of Consortium work plan) interest.

Worksheets

Standardized data collection forms are available from BSC in the MMP package.

Table 6-1. Checklist of supplies needed for the MMP amphibian monitoring protocols.

Required	MMP training and instruction package
	Material to stake survey stations (e.g., electrical conduit)
	Watch or timer
	Standardized data collection forms
	Pens/pencils
	Flashlight
Recommended	GPS and/or compass
	Canoe, boat or chest waders/boots depending on survey route
	Clipboard
	Insect Repellent
	Thermometer
	Spare batteries
	Reflector tape to mark station stakes

Site Selection

Sites should be selected in reference to Chapter 1 of this document on Statistical Design and represent a range of the four main coastal wetland hydrogeomorphic types (See Albert et al. 2005) present in the area of interest.

Data used for all analyses included all amphibian observations recorded within the 100-m radius MMP survey area. Using multiple years of MMP data (1995-2003) from 73 sites within Ecoregion 8 of the Great Lakes basin, a power analysis was performed for a paired t-test using Statistica (StatSoft, Inc. 2005; power=0.8, alpha=0.05). The power analysis helped estimate the number of sites required to detect a statistically significant difference within an area of interest (i.e., Great Lakes basin, lake basin, state, region, etc.) between two sampling times. Sampling frequency can occur over any time frame (e.g., annual, biennial; for SOLEC years) and will likely depend on available resources. With a paired design, the sampling must be done at the same sites throughout each sampling period. The power analysis predicted the number of sites required to detect a statistical difference within the area of interest with various mean differences between paired sites (Figure 1-2).

Table 6-2. The approximate number of sites required to detect a difference in IBIs within an area of interest (e.g., Great Lakes basin, lake basin, state, region). IBIs are expressed out of 100 with higher scores indicating amphibian communities in better condition.

Number of sites required	Mean difference in IBI between paired sites
10	30
20	20
30	15
40	12

For example, if an agency wanted to detect a mean difference of 20 IBI points in a suite of sites sampled in a particular region, at least 20 sampling sites (wetlands) are recommended.

Interpretation of Results

Amphibian Groups and Response Variables

Amphibians were categorized into four species guilds: woodland species, disturbance tolerant species, disturbance intolerant species, basinwide species and total species richness. These categories were based on, but refined from, Crewe and Timmermans (2005) and EC and CLOCA (2004) and using expert opinion (Table 6-3). For each station, maximum species richness across visits and presence/absence of each amphibian guild were summarized. To calculate the amphibian community coastal wetland IBI, mean richness and probability of detection (proportion of stations with guild "present") of each guild were calculated for each wetland site.

Table 6-3. Classification of Great Lakes amphibian species into community guilds.

Species Code	Common Name	Woodland	Disturbance Tolerant	Disturbance Intolerant	Basinwide
AMTO	American toad		X		X
BCFR	Blanchard's cricket frog				
BULL	Bullfrog			X	
CHFR	Chorus frog	X	X		
FOTO	Fowler's toad				
GRFR	Green frog		X		X
GRTR	Gray treefrog	X	X		
MIFR	Mink frog				
NLFR	Northern leopard frog			X	X
PIFR	Pickerel frog			X	
SPPE	Spring peeper	X	X		X
WOFR	Wood frog	X		X	X

Using data collected south of the Canadian Shield (i.e., within Ecoregion 8), total species richness (rTOT) responded consistently and significantly ($p < 0.20$) to the amount of landscape disturbance within 1 kilometer surrounding a wetland during three of four high water level years (1995-1998), and the response of woodland species richness (rWOOD) and presence/absence of woodland species (pWOOD) responded significantly to disturbance ($p < 0.08$) during all high and low water level years (1995-2003). All three metrics were combined to create an amphibian-based Great Lakes coastal wetland IBI, suitable for wetlands sampled within Ecoregion 8. Methods for development were based on a combination of metric suitability, data treatment and calculation techniques used in Crewe and Timmermans (2005) and EC and CLOCA (2004).

Table 6-4. A description of metric codes used in the amphibian-based coastal wetland IBI.

Metric Code	Description
rTOT	Mean total species richness across survey stations in a wetland.
rWOOD	Mean species richness of woodland associated amphibian species across survey stations in a wetland.
pWOOD	Probability of detection of woodland-associated amphibian species across survey stations in a wetland.

Description of amphibian-based coastal wetland IBI calculation

To calculate the amphibian community IBI, data must first be summarized as a mean per station for each of the three species guilds (rTOT, rWOOD, pWOOD). The total possible richness of rTOT and rWOOD species guilds must also be determined for your site by consulting species range maps. A corrected rTOT and rWOOD score is then calculated by dividing station richness by the total possible richness at your site.

Station data is then summarized as a mean value across stations at a wetland for each of the three species guilds (rTOT, rWOOD, pWOOD). The IBI is then calculated as follows:

Step 1: Standardize species richness and probability of detection metrics to scores out of 10, where 10 indicates the highest integrity of the amphibian community.

Metric Code	Calculation
rTOT	If rTOT ≥ 0.41, then the metric automatically scores a 10 If rTOT < 0.41, then multiply the percentage by 24.4
rWOOD	If rWOOD ≥ 0.5, then the metric automatically scores a 10 If rWOOD < 0.5, then multiply the percentage by 20
pWOOD	If pWOOD = 1, then the metric automatically scores a 10 If pWOOD < 1, then multiply the proportion by 10

Step 2: Combine standardized metrics into an IBI score ranging from 0-100. For each wetland, this is accomplished by adding standardized metric scores and multiplying the sum by 3.3333.

Example: For Bainsville Bay Wetland in 1995, the station values for rTOT and rWOOD were divided by the total possible richness (rTOTpossible = 11 species; rWOODpossible = 4 species). The mean across stations of all three amphibian community metrics was then calculated. Mean metric scores were as follows: rTOT = 0.102, rWOOD = 0.0625, pWOOD = 0.25.

According to Step 1 above:

- rTOT = 0.102, which is less than 0.41, so the standardized metric is 0.102 * 24.4 = 2.5.
- rWOOD = 0.0625, which is less than 0.5, so the standardized metric is 0.0625 * 20 = 1.25.
- pWOOD = 0.25, which is less than 0.1, so the standardized metric is 0.25 * 10 = 2.5.

According to Step 2 above:

- IBI = (2.5 + 1.2 + 2.5) * 3.3333= 20.8 (out of 100)

Table 6-5. Amphibian community based coastal wetland IBIs (out of 100) for a subset of sites sampled south of the Canadian Shield by MMP surveyors from 1995-2003. Higher scores indicate amphibian communities in better biotic condition.

Wetland Name	Province/ State	1995	1996	1997	1998	1999	2000	2001	2002	2003	Mean IBI
Hay Bay Marsh	Ontario								100		100
Long Point Wetland 7	Ontario								100		100
Presquille Bay Marsh 4	Ontario	100									100
South Bay Marsh	Ontario								100		100
West Saginaw Bay Wetland	Michigan								100		100
Wilmot Rivermouth Wetland	Ontario								100		100
Button Bay	Ontario								100.0		100
Big Island Marsh	Ontario	100	76.4	100	100	96.7	94.8	100	100	100	96.4
Bayfield Bay Wetland	Ontario								94.4		94.4
Presquille Bay Marsh 3	Ontario	92.6									92.6
Wye Marsh	Ontario	100.0	95.1	98.8	88.3	96.3	93.5	79.0	95.1	64.8	90.1
Mentor Marsh	Ohio		90.4	93.3	90.5	85.0					89.8
Turkey Point Wetland	Ontario			93.3	83.3						88.3
Hillman Marsh	Ontario					99.5	81.2	100	82.0	77.5	88.0
Upper Canada Migratory Bird Sanctuary	Ontario		87.0								87.0
Indiana Dunes Wetland	Indiana			89.3	89.3	90.7	85.3	85.7	90.4	72.8	86.2
White River Wetland	Michigan		75.9	95.0							85.4
Grand River Mouth Wetlands	Ontario	100		72.2	80.5	88.9					85.4
Long Point Wetland 5	Ontario								83.3		83.3
Long Pond Wetland 1	Pennsylvania		93.2	100	78.4	75.3	82.4	75.3	72.8		82.5
Wildfowl Bay Wetland	Michigan	92.7	95.9	82.6	69.6	87.7	81.2	74.7	73.0		82.2
Empire Beach Backshore Basin Forest	Ontario	51.9	96.3	61.1	96.3	81.5	81.5	88.9	88.9	81.5	80.9
East Bay Wetland	New York		80.6								80.6
Braddock Bay Wetland	New York					79.9	79.9		79.9		79.9
East Lake Marsh	Ontario							51.9	88.9	96.3	79.0
Matchedash Bay	Ontario	92.6						84.3	61.1	76.9	78.7
Rondeau Bay Wetland 3	Ontario		94.4			61.9					78.2
East Saginaw Bay Coastal Wetland	Michigan								76.8		76.8
Tuscarora Bay Wetland	New York		82.8	78.5		62.2	66.3	70.4	78.7	95.2	76.3
Port Britain Wetland	Ontario								75.9		75.9
Charlottenburgh Marsh	Ontario	100.0	61.6		76.2	76.5	67.9	72.2			75.7

Wetland Name	Province/ State	1995	1996	1997	1998	1999	2000	2001	2002	2003	Mean IBI
Rondeau Provincial Park 1	Ontario	48.7	100	77.7	74.7	61.5	74.8	67.9	98.8		75.5
Seagull Bar Area Wetland	Wisconsin			71.5	99.3			55.2			75.3
Big Creek Marsh	Ontario					68.5	79.2	77.8			75.2
Braddock Bay-Cranberry Pond Wetland	New York								72.7		72.7
Tobico Marsh Wetland	Michigan	83.0	87.0	78.7	66.3	45.6					72.1
Little Cataraqui Creek Complex	Ontario		67.6			88.9	34.6		85.9	73.1	70.0
Waukegan Area Wetland	Illinois		68.5								68.5
Point Pelee Marsh	Ontario	69.8				68.0	48.6	72.7			64.8
Long Point Wetland 3	Ontario		38.0						83.3		60.6
Suamico River Area Wetland	Wisconsin			35.9			33.1		78.6	92.5	60.0
Long Point Wetland 1	Ontario	45.8	49.0	48.9	70.8	51.9	58.3	80.1	78.3	55.6	59.9
Rondeau Provincial Park 2	Ontario		56.9								56.9
Buckthorn Island Wetland	New York	51.5	38.1	61.4		64.2					53.8
Illinois Beach State Park Wetland	Illinois		51.1	59.4	72.6	58.4	41.5	34.3		45.8	51.9
Belleville Marsh	Ontario	53.1	59.0	43.5							51.9
Port McNicholl Marsh	Ontario		74.8	95.4	74.3	57.9	19.6	12.4	13.8		49.7
Cootes Paradise	Ontario	11.4	14.7	41.2	46.1	38.4	79.3	61.1	57.8	76.0	47.3
Long Point Wetland 4	Ontario								46.3		46.3
Sawguin Creek Marsh	Ontario					29.2	59.7				44.4
Harsens Island Area Wetland	Michigan		12.2					34.9	76.4		41.2
Ottawa National Wildlife Refuge Wetland	Ohio				18.6	16.7	12.0	39.4	100	57.5	40.7
Cedar Point National Wildlife Refuge	Ohio		7.4			7.4	32.9	58.2	89.4	47.2	40.4
Cranberry Marsh	Ontario	44.8	41.9						9.9	58.6	38.8
Ottawa Wildlife Refuge Wetland	Ohio					32.2	24.5	39.3		53.7	37.4
Lake St. Clair Marshes	Ontario	40.0	32.3	37.6	40.5	34.4	22.7	65.2	30.8	33.2	37.4
Magee Marsh	Ohio		36.3								36.3
RBG- Hendrie Valley (LHW)	Ontario	25.8	17.5	49.5	38.0	49.4	22.4	16.3	34.4	59.3	34.7
Penetang Marsh	Ontario	32.4									32.4
Metzger Marsh	Ohio			9.3	22.6	38.0	55.1				31.2
Long Point Wetland 2	Ontario	22.2	28.1			29.6			39.4		29.8
Bainsville Bay	Ontario	20.8	24.4	46.7	17.9	37.2					29.4
Hydro Marsh	Ontario	9.3	0.0	72.2					29.6		27.8
Oshawa Second Marsh	Ontario	24.4	35.5	35.6	25.3	17.4	21.1	17.0	23.4	23.1	24.8
Corbett Creek Mouth Marsh	Ontario								24.1		24.1

Wetland Name	Province/ State	1995	1996	1997	1998	1999	2000	2001	2002	2003	Mean IBI
Ruscom Shores Marsh	Ontario								21.6		21.6
Rouge River Marsh	Ontario	7.4	0.0	32.4		7.4					11.8
Bronte Creek Marsh	Ontario	14.8	7.4								11.1
Port Darlington Marsh	Ontario								19.1	2.5	10.8
Humber River Marshes	Ontario		9.9	4.9	14.8				2.5	4.9	7.4
Van Wagners Marsh	Ontario		11.6	0.0							5.8
Lynde Creek Marsh	Ontario								5.9	2.5	4.2
Monroe City Area Wetland	Michigan		0.0								0.0

Data Handling and Storage

Data sheets should be returned to Bird Studies Canada as directed in the training and instruction package by July 31 of the survey year.

Limitations

Geographic

The IBI developed for the Consortium was developed using sites in the Great Lakes basin south of the Canadian Shield (Ecoregion 8, i.e., southern lakes Huron and Michigan, all of lakes Ontario, Erie, St. Clair and connecting channels). Therefore, the IBI described above is applicable only to wetlands within the same geographic area.

Water Levels

Craigie et al. (2003), DesGranges et al. (2005), and Steen et al. (2006) describe how Great Lakes water levels can influence attributes of coastal wetland marsh bird communities. Given this, we considered the possibility that water levels might also influence coastal wetland amphibian community attributes, and examined amphibian attribute response to disturbance to both high water (1995-1998) and low water (1999-2003) periods in a similar manner done for marsh birds. For amphibians, two of the community metrics used to develop the coastal wetland IBI (rWOOD, pWOOD) responded significantly to disturbance during all years surveyed (1995-2003). Alternatively, rTOT responded significantly to wetland disturbance during only one of five low water level years (1999-2003) but responded significantly during all high water level years (1995-1998). When metric scores were averaged across all years, however, all three metrics responded significantly to disturbance. Thus, the IBI described here should be considered appropriate for all water levels, though amphibian response to disturbance, and therefore the response of the amphibian IBI to disturbance, will be stronger during high water levels. Additional analysis is recommended to quantify the effect of changing water levels on the coastal wetland amphibian community IBI.

References

Albert, D.A., Wilcox, D.A., Ingram, J.W. and Thompson, T.A.. 2005. Hydrogeomorphic classification for Great Lakes coastal wetlands. Journal of Great Lakes Research 31(Supplement 1): 129-146.

Alford, Ross A. and Richards, Stephen J. 1999. Global Amphibian Declines: A Problem in Applied Ecology. Annual Review of Ecology and Systematics 30: 133-65.

Archer, R.W., Timmermans, S.T.A. and Robinson, C.L.. Monitoring and Assessing Marsh habitats in Great Lakes Areas of Concern; Final Project Report. Bird Studies Canada, Port Rowan, Ontario. 302pp.

Blaustein, A.R., and Wake, D.B. 1995. The puzzle of declining amphibians. Scientific American 272(4): 52-57.

Carey, Cynthia, 2000. Infectious Disease and Worldwide Declines of Amphibian Populations, with Comments on Emerging Diseases in Coral Reef Organisms and in Humans. Environmental Health Perspectives. 108 (Supp. 1): 143-150.

Craigie, G.E., Timmermans, S.T.A. and Ingram, J.W. 2003. Interactions Between Marsh Bird Population Indices and Great Lakes Water Levels: A Case Study of Lake Ontario Hydrology. February 2003. Bird Studies Canada and Environment Canada. Port Rowan, Ontario. 40pp.

Crewe, T.L. and Timmermans, S.T.A. 2005. Assessing Biological Integrity of Great Lakes Coastal Wetlands Using Marsh Bird and Amphibian Communities. March 2005. Bird Studies Canada, Port Rowan, Ontario. 89pp.

DesGranges, J.-L., Ingram, J., Drolet, B., Savage, C., Morin, J., and Borcard, D. 2005. Wetland bird response to water level changes in the Lake Ontario - St. Lawrence River hydrosystem. Final report to the International Joint Commission in support of the International Lake Ontario – St. Lawrence River Water Regulation Review Study. Canadian Wildlife Service, Québec and Ontario Regions. Environment Canada. Unpublished report xiv + 132 pp. (including 4 enclosures and 14 appendices).

Environment Canada and Central Lake Ontario Conservation Authority. 2004a. Durham Region Coastal Wetland Monitoring Project: Year 2 Technical Report. Downsview, Ontario, Environmental Conservation Branch – Ontario Region.

Environment Canada and Central Lake Ontario Conservation Authority. 2004b. Baseline Conditions of Durham Region Coastal Wetlands: Preliminary Findings 2002- 2003. Downsview, Ontario. Environmental Conservation Branch – Ontario Region. May 2004.

Environment Canada – Canada Wildlife Service. 2007. Bay of Quinte Area of Concern: Coastal Wetland Status and Remedial Action Plan Delisting Target Recommendations. June 2007. Toronto, Ontario: Environment Canada –Canadian Wildlife Service. 95pp.

Hecnar, S.J. 2004. Great Lakes wetlands as amphibian habitats: a review. Aquatic Ecosystem Health and Management. 7(2): 289-303.

Houlahan, Jeff E., Findlay, C. Scott, Schmidt, Benedikt R., Meyers, Andrea H. and Kuzmin, Sergius L.. 2000. Quantitative evidence for global amphibian population declines. Nature. 404: 752-755.

Kiesecker, Joseph M., Blaustein, Andrew R. and Belden, Lisa K. 2001. Complex causes of amphibian populations. Nature 410: 681-684.

Meyer, S.W., Ingram, J.W. and Grabas, G.P. 2006. The Marsh Monitoring Program: Evaluating Marsh Bird Survey Protocol Modifications to Assess Lake Ontario Coastal Wetlands at a Site-level. Technical Report Series 465. Canadian Wildlife Service, Ontario Region, Ontario.

Mitsch, W.J. and Gosselink, J.G. 1993. Wetlands. Van Nostrand Reinhold, New York.

Niemi, G.J., Axler, R., Brady, V., Brazner, J., Brown, T., Ciborowski, J.H., Danz, N., Hanowski, J.M., Hollenhorst, T., Howe, R., Johnson, L.B., Johnston, C.A., Reavie, E., Simcik, D., Swackhamer, D. 2006. Environmental indicators of the U.S. Great Lakes coastal region. Report NRRI/TR-2006/11 to the U.S.Environmental Protection Agency STAR Program, ver.1. Agreement R82-8675, Washington DC. Prepared by Great Lakes Environmental Indicators Collaboration, Natural Resources Research Institute, University of Minnesota Duluth, 121 pp + attachments (CD).

Pechmann, Joseph H. K., Scott, David E., Semlitsch, Raymond D., Caldwell, Janalee P., Vitt, Laurie J. Gibbons, J. Whitfield. 1991. Declining Amphibian Populations: The Problem of Separating Human Impacts from Natural Fluctuations. Science 253: 892-895.

Price, S. J., Howe, R. W., Hanowski, J., Regal, R. R., Niemi, G. J. and Smith, C. R. Are anurans of Great Lakes coastal wetlands reliable ecological indicators of environmental condition? Journal of Great Lakes Research. In Review.

Steen, D.A., J.P. Gibbs, and Timmermans, S.T.A. 2006. Assessing the sensitivity of wetland bird communities to hydrological change in the Eastern Great Lakes basin. Wetlands 26: 605-611.

Timmermans, S.T.A., Craigie, G. E. and Jones,. K. 2004. Marsh Monitoring Program: Areas of Concern Summary Reports 1995 – 2002. Bird Studies Canada, Port Rowan, Ontario.

Weeber, R.C., and Vallianatos, M. (eds.). 2000. The Marsh Monitoring Program 1995 – 1999: Monitoring Great Lakes Wetlands and Their Amphibian Inhabitants. Bird Studies Canada, in cooperation with Environment Canada and the U.S. Environmental Protection Agency.

Appendix 6-1.

MMP Amphibian Survey Protocol

The protocol for the amphibian surveys is largely based upon earlier work conducted in Wisconsin and Ontario and is now being used throughout North America. Read these instructions carefully and listen to the amphibian training tape prior to doing your first survey.

Amphibians in the Great Lakes Basin

The amphibian surveys are limited to easily detected species (i.e. frogs and toads). Male frogs and toads defend territories and advertise their presence to females by singing. Each species has a distinctive call that can be used in species identification. In the Great Lakes basin, there are 13 species of frogs and toads, several of which are widely distributed. Depending on your location, you will encounter some of the following species:

Common Name	Species Code	Latin Name
American toad	AMTO	*Bufo americanus*
Fowler's toad	FOTO	*Bufo woodhousei fowleri*
Gray (tetraploid) treefrog	GRTR	*Hyla versicolor*
Cope's (diploid) gray treefrog	CGTR	*Hyla chrysoscelis*
Spring peeper	SPPE	*Pseudacris crucifer*
Chorus frog	CHFR	*P. triseriata & P. maculata*
Blanchard's cricket frog	BCFR	*Acris crepitans blanchardi*
Wood frog	WOFR	*Rana sylvatica*
Northern leopard frog	NLFR	*Rana pipiens*
Pickerel frog	PIFR	*Rana palustris*
Green frog	GRFR	*Rana clamitans melanota*
Mink frog	MIFR	*Rana septentrionalis*
Bullfrog	BULL	*Rana catesbeiana*

American Toad
The American toad is common throughout the Great Lakes basin in a variety of habitats. Call description: Long, drawn-out, high-pitched, musical trill lasting up to 30 seconds.

Fowler's Toad
While similar to the American toad in appearance, the Fowler's toad is restricted to sandy shoreline areas along Lake Erie and Lake Michigan. Call Description: High-pitched, nasal, nonmusical trill ("wh-a-a-a-ah") lasting two to five seconds.

Gray Treefrog
The gray treefrog is most easily distinguished from Cope's gray treefrog by its call. The gray treefrog occurs throughout the Great Lakes basin and is more common than Cope's gray treefrog. Call Description: Musical, slow, bird-like trill, lasting up to 30 seconds. The call is slower and more musical than Cope's gray treefrog.

Cope's Gray Treefrog
Although identical in appearance to the gray treefrog, Cope's gray treefrog is found only in the southern and western regions of the basin in the United States. In Ontario, it is found only in the Lake-of-the-Woods area. Call Description: Faster, shorter, and higher-pitched trill than the gray treefrog's call, lasting up to 30 seconds.

Spring Peeper

The spring peeper is common and widespread throughout the basin. Call Description: Advertisement call is a short, loud, high-pitched peep, repeated every second. The peeper's aggressive call is a short, trill “purrreeek,” usually rising in pitch at the end. This call can be confused with the call of the chorus frog, but can be distinguished as it is more of a trill.

Chorus Frog
Due to their similar calls, the boreal chorus frog (*Pseudacris maculata*) and the western chorus frog (*P. triseriata*) will be considered as a single species (chorus frog) for the purposes of this study. Chorus frogs are commonly found throughout the basin except for parts of northern lakes Huron, Michigan and Superior. Call Description: Short, ascending trill-like “cr-r-e-e-e,” resembling a thumb drawn along the teeth of a comb, repeated every couple of seconds.

Blanchard's Cricket Frog
Blanchard's cricket frog is a highly localized species, found at the southwestern end of Lake Erie and the southern half of Lake Michigan in the United States. In Canada, it is found only on Pelee Island in Lake Erie. Call Description: A fast, repeated clicking, like two pebbles being struck together, increasing in speed then decreasing, over a few seconds.

Wood Frog
The wood frog is common throughout the basin but can only be heard for a short time very early in spring calling in forested swamps. Call Description: Short, subtle chuckle, like ducks quacking in the distance.

Northern Leopard Frog
The leopard frog is common and widespread throughout the basin. Call Description: Short, rattling ”snore” followed by guttural chuckling (“chuck-chuck-chuck”), sounding like wet hands rubbing a balloon. Although shorter in length, its snore can be mistaken for that of a pickerel frog.

Pickerel Frog
Similar to leopard frogs in appearance, pickerel frogs have a smaller range around the Great Lakes. Though widespread throughout most of the basin, they are quite localized, and are often found in association with cold-water streams. Call Description: Low-pitched, drawn-out snore, increasing in loudness over a couple of seconds.

Green Frog

The green frog is common throughout the Great Lakes. Call Description: The advertisement and territorial call is a short, throaty "gunk" or "boink," like the pluck of a loose banjo string, usually given as a single note. It may also give several stuttering, guttural calls, "ru-u-u-ng," followed by a single staccato "gunk!" The stuttering call can be mistaken for that of a bullfrog, although the green frog's call is shorter and not as rhythmic nor as deep.

Mink Frog

The mink frog is primarily a northern species found around Lake Superior and the northern parts of lakes Michigan and Huron, although its range does extend east to the St. Lawrence River. Call Description: Rapid, muffled "cut-cut-cut," like a hammer striking wood; the chorus sounds like horses' hooves running over cobblestone.

Bullfrog

The bullfrog is common and widespread in the basin except for northern Lake Superior. Call Description: Deep bass, two syllable "rrr-uum" or "jug-o-rum."

When Should I Do My Amphibian Surveys?

In order to be assured that frogs and toads are actually going to be calling, you need to pay close attention to weather conditions and choose an appropriate time to survey. If it is too cold, dry or windy, calling activity will be greatly suppressed. Collection of the data under the proper conditions is quite important to ensure a measure of standardization between surveys.

- Each route is to be surveyed for calling amphibians **three times** during the spring and early summer. Surveys should be conducted **at least 15 days apart**. By conducting three surveys, you should be able to detect all species present. The first survey is timed to monitor species that breed very early (e.g. chorus frog, wood frog and spring peeper). The second survey should coincide with "optimum" breeding for spring peeper, American toad, northern leopard frog, pickerel frog and, where they occur, Fowler's toad and Blanchard's cricket frog. The third survey will monitor gray treefrog, Cope's gray treefrog, mink frog, green frog and bullfrog (see charts below).

- An amphibian's body temperature changes as the temperature of its environment (e.g. air and water) changes. Frogs and toads always require an **air temperature greater than 5°C (41°F)** to elicit calling activity. "Late-season" frogs (e.g. bullfrogs and green frogs) don't begin their calling activity until the temperature is even higher. Therefore, **night-time air temperature should be greater than 5°C (41°F) for the first survey, 10°C (50°F) for the second survey and 17°C (63°F) for the third survey.**

- **Each station is surveyed for 3 minutes.** Routes are to be surveyed in their entirety, in the same station sequence, starting at about the same time, on all visits.

- In **southern and central regions** of the Great Lakes basin, surveys can begin **one half hour after sunset and end before midnight.** Because of "longer days" during the summer months in the northern regions of the basin, surveys that begin one half hour after sunset could continue beyond midnight! Therefore, in **northern regions**, surveys can start at **2200 h (10 p.m.)** in the summer even if it isn't dark then.

- Because dry air or strong wind dries out an amphibian's skin, frogs will stay under water in such conditions, thereby reducing calling activity. Strong winds also interfere with our ability to hear. **Do your**

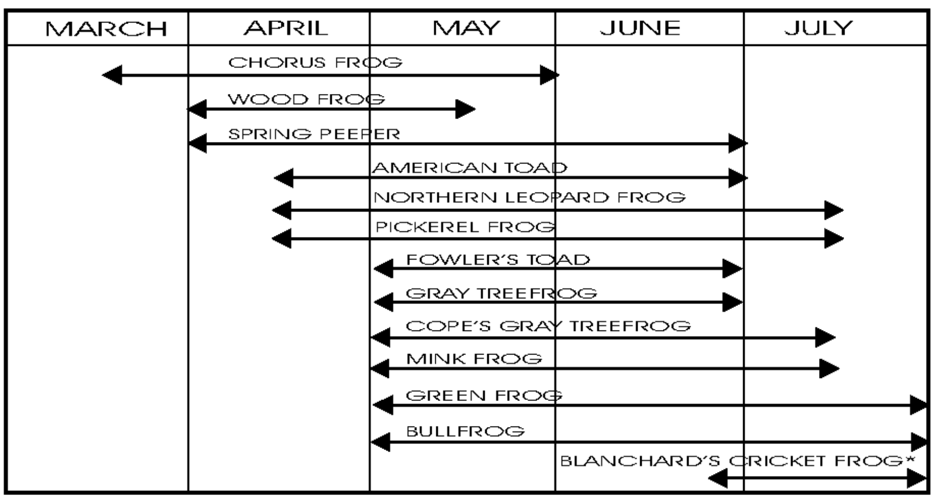
survey only when the wind strength is Code 0, 1, 2, or 3 on the Beaufort Scale. If the wind is strong enough to raise dust or loose paper and move small tree branches, then you should wait for a calmer evening. Ideally, there should be no wind.

- You may conduct your survey before or after the dates given below if weather conditions are right. These dates are provided **only** as a **guideline**. Remember, **air temperature and lack of wind are the most important factors** to pay attention to when deciding when to conduct your surveys.

Amphibian Survey Guidelines

	Survey #1	Survey #2	Survey #3
South (south of the 43rd parallel)	1 - 15 April	1 - 15 May	1 - 15 June
Central (between the 43rd and 47th parallels)	15 - 30 April	15 - 30 May	15 - 30 June
North (north of the 47th parallel)	1 - 15 May	1 - 15 June	1 - 15 July

General Breeding Periods for Frogs and Toads in the Great Lakes Basin.



*Historic calling dates for Pelee Island, Ontario

Other Considerations

- **Nights that are damp, foggy or have light rain falling are ideal, especially for your first survey**. Avoid persistent or heavy rainfall. Early in the season, it is best to survey shortly after the first or second warm spring shower. Later, choose a night with a warm temperature. Watch the local news or weather channel, or phone your local airport weather office to get weather forecasts. Ideally, you should be prepared to go out on any evening that is suitable. Plan ahead!

- Early in the season, weather conditions are unpredictable. Nights can cool off quickly to temperatures below optimal for calling frogs. If conditions deteriorate during your survey, cancel the survey and repeat it on the next suitable night.

- **"Explosive" breeders!** Amphibians take their cues from the environment as to when to start migrating to breeding sites and when to initiate breeding. Some species (e.g. wood frog) are known as "explosive" breeders. In these species, most males are apt to migrate all on one night to breeding ponds as soon as conditions are right. Males may call for only a few nights and most breeding is done in one evening. It is best to survey on one of the first few suitable evenings during the allotted time, since frog and toad activity begins as soon as the weather permits. If you delay too long, you could miss some species.

Conducting the Survey

Getting Started

Check to make sure that you have your Amphibian Data Form; a small "mouth size" flashlight or headlamp (to keep your hands free); a pen or pencil; watch or timer (preferably one with an alarm); clipboard (if desired), and mosquito repellent. If you have already filled in Habitat Description Forms, bring along a copy to help you relocate your stations. A thermometer, compass, spare pens, and this instruction booklet are other useful items. It's best to be prepared! See the Spring Refresher on the inside back cover for a checklist.

Since you will be conducting these surveys in the dark, you may wish to bring an assistant along for company and to share in the experience! This person can help you find the stations, document some kinds of information (such as weather conditions) and hold your flashlight. However, your assistant is not to help you identify or tally amphibians! More than one observer will bias the results.

Before you start the survey, fill in the information required in the top section of the Amphibian Data Form. Please use the format specified in the sample form as it will minimize data entry errors. Each survey route should be given a unique route name that describes the marsh name (or names if a series of marshes are being sampled) and the location of the route in the marsh (e.g. "Maumee Marsh- South"). If the marsh does not already have a name, choose one. If you are conducting marsh bird surveys on the same route, the route name should be consistent for both. Stations should be labelled in order of sequential coverage from A to H. Record the observer name, date, visit number (#1, 2 or 3), and the time you start your route. Please use the 24-hour (military) clock. For example, 5:00 a.m. is written as 0500 h, whereas 5:00 p.m. is written as 1700 h (i.e. 12 plus 5). Similarly, 6:57 p.m. is written as 1857 h.

All weather information can be easily estimated. Determine the wind speed according to the Beaufort scale. Cloud cover is estimated as covering so many 10ths of the sky (e.g. if it's completely starry with no cloud cover, 0/10 of the sky will be covered). If possible, carry a thermometer and record the air temperature at the start of your survey. Because this program spans two different countries with two different scales of measure, be sure to specify whether you are recording the temperature in degrees Fahrenheit or Celsius. If you don't have a thermometer, record the air temperature from a reliable source (e.g. the local weather station or an outdoor thermometer at your home). Use the Remarks section to record any assistants' names, problems encountered (e.g. "I heard a call I couldn't identify"), and other comments you might think useful (e.g. "Lots of activity tonight!"). Use additional pages if necessary. All remarks and comments are welcome.

Please fill in all of the blanks at the top of the form – without this information your data may be unusable!

Counting Amphibian Calls

Before going into the field, it is important that you are familiar with the calls of all species of amphibians found in the Great Lakes basin, not just the ones normally found in your region. The distribution of some amphibians is still not very well known. The Amphibian Training Tape describes how to identify each species' call and instructs you on how to measure the intensity and number of individuals calling using the call level code and abundance count.

Call Level Code and Abundance Count

The amphibian survey uses three Call Level Codes to categorize the intensity of calling activity. For two of these categories, we also ask that you count or estimate the number of calling amphibians — this is an abundance count. Use the following Call Level Codes for each species detected during your surveys (see sample Amphibian Data Form):

1. **Individuals can be counted; calls not simultaneous.** Assign this number when individual males can be counted, and when the calls of individuals of the same species do not start **at the same time**. For the abundance count, record the number **of individual frogs** of each species calling beside the code.

2. **Calls distinguishable; some simultaneous calling**. This code is assigned when there are a few males of the same species calling **simultaneously**. However, with a little work, individual males can still be distinguished. In this case, an exact abundance count can't be tallied, but you are able to **reliably estimate** the number of individuals present, based on their locations and/or by the differences in their voices.

3. **Full chorus; calls continuous and overlapping**. This value is assigned when you encounter a full chorus. When there are so many males of one species calling that all the calls sound like they are overlapping and continuous (like a blur of sound), then you are hearing a full chorus! There are too many overlapping calls to allow for any reasonable count or estimate. Hence, there is no need to record an abundance count.

Mapping and Recording Amphibians

Amphibian surveyors use their best judgement to distinguish whether each species detected is calling from inside the 100 meter (110 yard) sample area, from outside the sample area, or from both inside and outside. We recognize that the 100 meter (110 yard) radius sample area cannot be accurately determined at night. Don't worry about not knowing exactly where the station boundary is – make the best estimate you can.

A separate Amphibian Data Form is used for each visit to your route. The data form contains an outline of the semicircular sample area, with a midpoint arc drawn inside for your reference. Record what direction you are facing in the small box on the map of the sample area (e.g. "23° NNE," or just "NNE" if you can't take a compass bearing).

At each station, once you have everything ready, wait quietly for at least one minute to allow the frogs to start calling again after being disturbed by your presence. After this initial settle-down period, set your timer, and survey for three minutes. Record on the map all species heard calling within the semicircle in front of you.

Using the appropriate four-letter species code, map the relative position of each individual or chorus on the Amphibian Data Form (see the sample data form). Under each species code, record the call level code. For codes 1 and 2, also record the number of individuals that you count or estimate are calling, using a dash to separate the two measures of abundance (e.g. "NLFR/2-7" indicates a Call Level Code of 2 and that you heard seven different frogs calling). Recall that you do not need to record an abundance count beside Code 3 since this code means that there are too many individuals calling to accurately estimate numbers. Using the table to the left of the station diagram on the data form, enter a checkmark in the In column if a species is calling from *inside* the station boundary. If a species is calling from *outside* the station boundary, check the Out column. If a species is calling from inside and outside the station boundary, check both In and Out columns for that species. Be sure to record the time you finish your route (in 24-hour clock) after you last station is surveyed.

The remainder of the Summary Sheet is devoted to your amphibian data from each of the three visits. For each station and visit, study your mapped observations and determine the highest Call Level Code for each species. Enter this code beside the species name in the column labelled CC. Next, add up all the individuals counted (*inside* + *outside*) for each species and enter this information into the adjacent column labelled Count. For example, if you heard two groups of wood frogs (1-1 and 2-8), you would enter a code of 2 and a count of 9. Don't forget, if you enter a Code 3 then there is no count to record since there are too many to count. If a species was only calling from inside the station boundary, or if a species was calling from inside and outside the station boundary, check the In column. If a species was only calling from outside the boundary, leave the In column empty.

You'll find it very useful to tick off the mapped observations on your Amphibian Data Forms as you transfer them to your Route Summary Sheet. This helps ensure that you haven't counted the same observation twice or forgotten to transcribe a record. Since we will be key-punching your data directly from your Route Summary Sheet, it is important that you double-check to be sure that your sheets are complete and correct!

Marsh Monitoring Program - Amphibian Route Summary Form

Route #	Observer #	Observer Name	Year
0N098	18203	KATHY JONES	2002

*Please print with BLOCK CAPITALS, remain within the boxes and mark each individual choice by filling in the corresponding circle. Please use pen (not felt tip).

**Has the habitat on your route changed from previous years? ○ Yes ○ No ○ N/A

Visit Information:	Day	Month	Start Time (24hr)	End Time (24hr)	Wind Scale	Cloud Cover (10ths)	Temp		Precipitation (fill in one per visit)
Visit 1	15	04	2005	2245	1	.7	15	● C ○ F	○ None/Dry ● Damp/Haze/Fog ○ Drizzle ○ Rain
Visit 2	07	05	2100	2315	2	1.6	16	● C ○ F	○ None/Dry ○ Damp/Haze/Fog ● Drizzle ○ Rain
Visit 3	10	06	2145	2300	2	.0	20	● C ○ F	● None/Dry ○ Damp/Haze/Fog ○ Drizzle ○ Rain

Notes: Please fill the **"Yes"** circle for each station surveyed during the visit, please leave blank for any station not surveyed.
At each station surveyed, please fill in the information for each species heard, if a species was not heard please leave blank.
In column **"CC"** please print the Calling Code (1-3).
If the Calling Code (**CC**) was 1 or 2, please print the total combined number of individuals heard both inside and outside of the station boundary under **"Count"**.
If individuals were calling inside or inside and outside the station boundary (100m), please fill the "In" circle.

Visit 1

Station Letter	A			B			C			D			E			F			G			H		
Station Surveyed	● Yes			● Yes			● Yes			○ Yes			○ Yes			○ Yes			○ Yes			○ Yes		
Species Name	CC	Count	In	CC	Count	In	CC	Count	In	CC	Count	In	CC	Count	In	CC	Count	In	CC	Count	In	CC	Count	In
American Toad			○			○			○			○			○			○			○			○
Blanchard's Cricket Frog			○			○			○			○			○			○			○			○
Bullfrog			○			○			○			○			○			○			○			○
Chorus Frog	3		●	2	6	●	3		○			○			○			○			○			○
Cope's Gray Tree Frog			○			○			○			○			○			○			○			○
Fowler's Toad			○			○			○			○			○			○			○			○
Gray Treefrog			○			○			○			○			○			○			○			○
Green Frog			○			○			○			○			○			○			○			○
Mink Frog			○			○			○			○			○			○			○			○
Northern Leopard Frog	2	7	○			○			○			○			○			○			○			○
Pickerel Frog			○			○			○			○			○			○			○			○
Spring Peeper	3		●	2	10	○	3		●			○			○			○			○			○
Wood Frog	2	9	●	2	7	●	1	3	○			○			○			○			○			○

**Please complete the habitat forms annually

3528571719

Visit 2

Marsh Monitoring Program - Amphibian Route Summary Form

Station Letter	A			B			C			D			E			F			G			H		
Station Surveyed	● Yes			● Yes			● Yes			○ Yes			○ Yes			○ Yes			○ Yes			○ Yes		
Species Name	CC	Count	In	CC	Count	In	CC	Count	In	CC	Count	In	CC	Count	In	CC	Count	In	CC	Count	In	CC	Count	In
American Toad	2	8	○	3		●	1	3	●			○			○			○			○			○
Blanchard's Cricket Frog			○			○			○			○			○			○			○			○
Bullfrog			○			○			○			○			○			○			○			○
Chorus Frog			○			○			○			○			○			○			○			○
Cope's Gray Tree Frog			○			○			○			○			○			○			○			○
Fowler's Toad	3		●			○	3		○			○			○			○			○			○
Gray Treefrog	1	1	○	2	6	●	3		○			○			○			○			○			○
Green Frog			○			○			○			○			○			○			○			○
Mink Frog			○			○			○			○			○			○			○			○
Northern Leopard Frog	1	2	●	2	5	●	2	6	●			○			○			○			○			○
Pickerel Frog			○			○			○			○			○			○			○			○
Spring Peeper			○			○			○			○			○			○			○			○
Wood Frog			○			○			○			○			○			○			○			○

Visit 3

Station Letter	A			B			C			D			E			F			G			H		
Station Surveyed	● Yes			● Yes			● Yes			○ Yes			○ Yes			○ Yes			○ Yes			○ Yes		
Species Name	CC	Count	In	CC	Count	In	CC	Count	In	CC	Count	In	CC	Count	In	CC	Count	In	CC	Count	In	CC	Count	In
American Toad			○			○			○			○			○			○			○			○
Blanchard's Cricket Frog			○			○			○			○			○			○			○			○
Bullfrog	2	7	●	3		●	1	4	○			○			○			○			○			○
Chorus Frog			○			○			○			○			○			○			○			○
Cope's Gray Tree Frog			○			○			○			○			○			○			○			○
Fowler's Toad			○			○			○			○			○			○			○			○
Gray Treefrog			○			○			○			○			○			○			○			○
Green Frog	3		●	3		●	3		○			○			○			○			○			○
Mink Frog	2	9	●	3		○	2	8	●			○			○			○			○			○
Northern Leopard Frog			○			○			○			○			○			○			○			○
Pickerel Frog			○			○			○			○			○			○			○			○
Spring Peeper			○			○			○			○			○			○			○			○
Wood Frog			○			○			○			○			○			○			○			○

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Amphibian Data Form

Return by 31 July to Aquatic Surveys Officer, Bird Studies Canada, P.O. Box 160, Port Rowan, Ontario, Canada, N0E 1M0

Please write legibly (in pen).

Observer: Kathy Jones

Route name: Mud Lake Marsh

Date (dd-mm-yr): 15 04 01	Visit No.: 1	
Start time (24 hr clock): 2005 h	Finish time (24 hr clock): 22 45 h	
Beaufort Wind Scale No.: 1	Cloud Cover (10ths): 7/10	Air Temp (°C or °F): 15°C

Precipitation (check one): None/dry: Damp/Haze/Fog: __ Drizzle: ✓ Rain: ____

Has the habitat on your route changed from previous years: Yes: ____ No: ✓ Not applicable: _

Remarks: Flashlight died halfway through survey. Glad I brought fresh batteries

CALL LEVEL CODES

Code 1: Calls not simultaneous, number of individuals can be accurately counted

Code 2: Some calls simultaneous, number of individuals can be reliably estimated

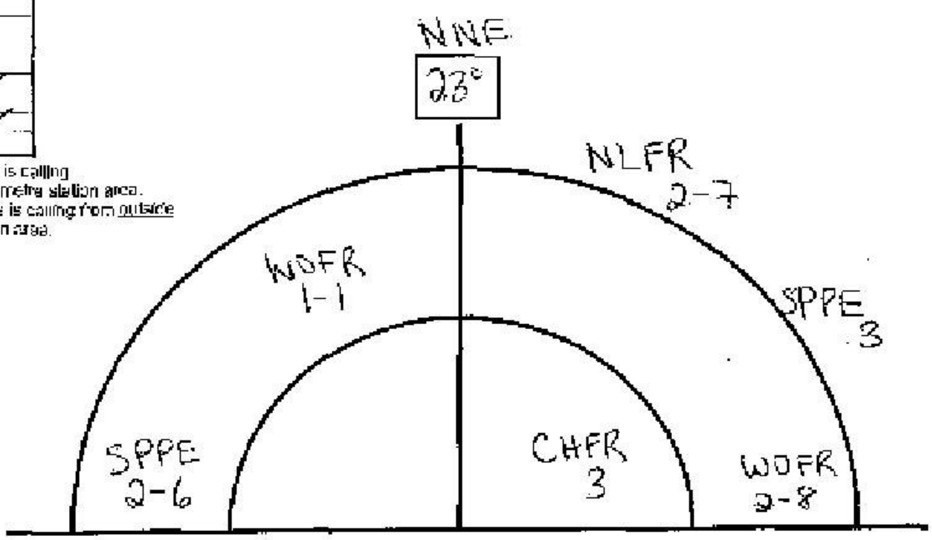
Code 3: Full chorus, calls continuous and overlapping, number of individuals cannot be reliably estimated

Species	In*	Out**
AMTO		
BCFR		
BULL		
CHFR	✓	
CGTR		
FOTO		
GRTR		
GRFR		
MIFR		
NLFR		✓
PIFR		
SPPE	✓	✓
WOFR	✓	

* Check if species is calling from inside 100-metre station area.

** check if species is calling from outside 100-metre station area.

Station A



100m Focal Point 100m

Summarizing Amphibian Data

Transcribe your data from the Amphibian Data Form to the Amphibian Route Summary Sheet as soon as possible after completing your survey. Don't let this additional paperwork wait too long; it is best done while everything is fresh in your mind.

The sample Route Summary Sheet shows how the data from the sample data form would be recorded. Please study both of these sample sheets. Call us if you have any questions!

One Route Summary Sheet is used to summarize the information from all three visits to your route. First, fill in the top part of the sheet with your name and address. Each survey route should be given a unique route name that describes the marsh name (or names if a series of marshes are being sampled) and the location of the route in the marsh (e.g. "Maumee Marsh-South" versus "Maumee Marsh-North"). Your amphibian route name should be consistent with that of your bird survey, if you have conducted one on the same route. Record the nearest town to your route (pick one that's on a road map so that we will be able to locate it) and county. Fill in the year and the number of stations on your route.

For each visit, record the date it was conducted, the time you started and finished your route, wind scale number, your estimate of cloud cover and air temperature. Fill in the circle below the station letter of each station you surveyed during that visit, even if you did not observe any frogs or toads. If this circle is not filled in, the scanner will not read the data in that station's column.

Chapter 7
Bird Community Indicators

Chapter Authors
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Introduction

A high proportion of the Great Lakes basin's wildlife species inhabit wetlands during part of their life cycle, and many species at risk that occur in the basin are associated with wetlands. Being directly associated with the Great Lakes hydrological influences, lacustrine or coastal wetlands are among the most important wetlands that occur within the Great Lakes basin. Numerous bird species federally listed as threatened or endangered in the United States or of conservation concern in Ontario are associated with wetlands (Mitsch and Gosselink 1993, Austen et al. 1994). Although much is known about many landbird species of the Great Lakes, the ecology of most marsh-dependent birds has received much less attention and relatively little is known about rails and other secretive marsh birds (Gibbs et al. 1992; Conway 1995; Melvin and Gibbs 1996). As a group, marsh birds have experienced population declines, believed partly to result from historical and current habitat loss and degradation. As recently as the 1990s, the magnitude and geographic extent of these declines was still unclear (Gibbs et al. 1992; Conway 1995; Melvin and Gibbs 1996). The uncertainty surrounding the nature of these declines was primarily due to lack of extensive, scientifically rigorous, consistently collected data.

As a result of the loss and degradation of marsh habitats throughout the Great Lakes basin, there was increasing concern among citizens and scientists that continued stresses, including urban, industrial and agricultural development were negatively affecting marsh-dependent wildlife populations and other marsh functions such as water quality improvement. Consequently, Bird Studies Canada (BSC), in partnership with Environment Canada, developed the Marsh Monitoring Program (MMP) in Ontario in 1994. With substantial financial support from the United States Environmental Protection Agency's Great Lakes National Program Office and the Great Lakes Protection Fund, the MMP was launched bi-nationally throughout the Great Lakes basin in 1995 and has continued to operate annually.

The importance of marsh bird communities in the Great Lakes basin was further recognized by State of the Lakes Ecosystem Conference (SOLEC) in 1998, when a team of experts and the public identified and began to develop a suite of ecological indicators (See Executive Summary). SOLEC indicators were designed to incorporate all major aquatic and terrestrial elements of the Great Lakes basin important to human health and society. One of these elements was coastal wetlands and characteristics of the marsh bird community were adopted as SOLEC indicator #4507:

> *Species composition and relative abundance of wetland-dependent birds, based on evening surveys using protocol developed for the Marsh Monitoring Program (MMP) or modification of the MMP protocol.*

In 2002, the Great Lakes Coastal Wetlands Consortium (Consortium) began to develop indicators based on the condition of Great Lakes coastal wetland bird communities, relying on MMP data and protocol to design the studies. The MMP had an established methodology, a network of skilled volunteer surveyors, and several years of supporting data. The next five years were dedicated to collecting data and developing and testing indicators to report on the condition of marsh bird communities in coastal wetlands across the Great Lakes basin.

During this time there was also considerable interest in assessing and monitoring the condition of marsh bird communities at a regional scale within the Great Lakes basin, particularly within Great Lakes Areas of Concern (AOCs). For example, when Beneficial Use Impairment # 3 (i.e., degraded fish and wildlife populations) has been listed as part of a Remedial Action Plan (RAP), wetland bird communities have often been a key factor in the listings for Canadian AOCs (e.g., Bay of Quinte, Hamilton Harbour), United States AOCs (e.g., Clinton River, Cuyahoga River), and all binational AOCs (Timmermans et al. 2004; Archer et al. 2006; Environment Canada – Canadian Wildlife Service [herein EC-CWS] 2007; also see: http://www.ijc.org/rel/boards/annex2/aoc_php/bui_targets.php). Another example where birds have been used as part of regional monitoring efforts is the Durham Region Coastal Wetland Monitoring Project (DRCWMP), which focused on 15 wetlands located just east of Toronto. For the past six years, marsh bird data have been collected for the DRCWMP through a combination of paid staff and citizen volunteers participating in the MMP. These data have been reported in technical documents and fact books in an effort to further Great Lakes coastal wetland science, promote regional coastal wetland conservation, and influence environmental policy in Durham Region (Environment Canada and the Central Lake Ontario Conservation Authority [herein EC and CLOCA] 2004a, EC and CLOCA 2004b).

Bird Studies Canada personnel who coordinate the MMP have been primary investigators for the Consortium, and have worked with EC partners and others to develop wetland bird monitoring protocols and associated wetland bird community indicators specific to Great Lakes coastal wetland ecological indicator (EI) biomonitoring. These investigators established monitoring protocols that adequately met all the required criteria established by the Consortium, and also developed associated wetland bird Indices of Biotic Integrity (IBIs) derived from the resulting monitoring data. During the five-year Consortium data collection and indicator development process, the main collaborators for the bird community indicators were BSC and EC-CWS (See EC and CLOCA 2004a; Crewe and Timmermans 2005).

During this same period, a similar research project, the Great Lakes Environmental Indicators (GLEI) project (http://glei.nrri.umn.edu/default/), concurrently examined use of another method to report on Great Lakes coastal wetland bird communities with data collected based on the GLEI's bird survey protocols (Howe et al. 2007). In the final year of the Consortium work plan, there were efforts to collaborate with the GLEI scientists to develop an integrated bird community condition indicator, recognizing the inherent differences in both bird survey field protocols and data analytical procedures used between Consortium and GLEI investigators. Consortium wetland bird indicator investigators worked with GLEI investigators to examine the possibility of integrating data analytical procedures being developed by GLEI for estimating coastal wetland condition based on birds, called the Index of Ecological Condition (ICI). Unfortunately, time was short and the benefits of a more timely and thorough collaboration were not fully realized. The methods and indicators presented in this section are a result of the Consortium indicator development process. We hope to continue our collaboration with GLEI investigator to evaluate the potential of integrating ICI data analytical methods for future Great Lakes coastal wetland bird indicator calculations.

Materials and Methods

Protocols

Field

MMP data collection is coordinated through Bird Studies Canada. To participate, surveyors must have received and be familiar with the current MMP training kit and instructions. The package contains training and broadcast audio tapes or compact discs, station location identification tags, an instruction manual, and data sheets available from:

Bird Studies Canada
Marsh Monitoring Program
115 Front Street
P.O. Box 160
Port Rowan, Ontario N0E 1M0 Canada
Toll free: 1 888 448 2473
Fax: 519 586 3532
Email: aqsurvey@bsc-eoc.org

The full protocols are available in Appendix 7-1. A summary of the methodology is below.

MMP bird surveys use a fixed-distance point count method to collect data on bird species. Fixed-distance point counts entail a surveyor standing at a focal point (or survey point) and counting birds seen or heard in a standardized period of time in a defined survey area. MMP marsh bird survey protocol consists of a semi-circular survey station with a 100-meter survey radius. Survey stations are separated by at least 300 meters to ensure independence between stations (i.e., reduce double counting of birds during a visit due to bird movement).

A route consists of one to eight survey stations established within a site; a site can contain a number of routes. Routes are established based on the following protocol:

- Routes occur only in marsh habitat (i.e., greater than 50 percent non-woody emergent plants interspersed with shallow open water);
- Route survey stations are established along the shoreline (e.g., marsh edge) and/or within the interior of a marsh;
- Survey stations are selected by program coordinators following a scientifically robust stratified-random sample station selection scheme adapted from Meyer et al. (2006) to best represent the wetland and to maximize detectability of birds in the survey area;
- Edge survey station direction is positioned to maximize marsh area surveyed; interior survey station direction is selected via random bearing selection;
- Each station is visited at least two times during the breeding season (i.e., peak vocalization time) and,
- Landmarks are established so that distances within the survey area can be accurately estimated.

Marsh bird surveys are standardized to occur during a specific survey window (two visits timed appropriately for latitudinal region), time of day (for any given route, either sunrise to end at or before 9:00 hrs EST, or 18:00 hrs EST to sunset), duration (15 minutes per station), and during specific weather conditions (good visibility, warm temperatures [greater than 16 °C], no precipitation, and gentle wind [less than 19 kilometers per hour]). In addition, at least 10 days must fall between survey visits.

Finally, bird surveys consist of five minutes of passive visual and auditory observation, followed by five minutes of song broadcasting (for secretive species [Virginia Rail, Sora, Least Bittern, Common Moorhen / American Coot, and Pied-billed Grebe]) and visual and auditory observation to elicit responses and increase species detectability, followed by five minutes of post-broadcast passive visual and auditory observation (see Appendix 7-2 for more information about these standardized MMP marsh bird survey protocols).

Birds Studies Canada also coordinates MMP recruitment sessions during late winter and early spring, and training sessions during spring. Special training sessions will be given in regions with abundant or specialized (i.e., implementation of Consortium work plan) interest.

Worksheets

Standardized data collection forms are available from BSC in the MMP package.

Table 7-1. Checklists.

Required	MMP training and instruction package
	Material to stake survey stations (e.g., electrical conduit)
	Audio broadcast unit (e.g., cassette, CD, MP3 player) calibrated to 80-90dB at a distance of one meter
	Binoculars
	Watch or timer
	Standardized data collection forms
	Pens/pencils
Recommended	GPS and/or compass
	Canoe, boat or chest waders/boots depending on survey route
	Clipboard
	Insect Repellent
	Thermometer
	Spare batteries
	Flashlight

Site Selection

Sites should be selected in reference to protocols outlined in Chapter 1 – Statistical Design – and represent a range of the four main coastal wetland hydrogeomorphic types (See Albert et al. 2005) present in the area of interest. Sites should preferably support more than 10 hectares of emergent marsh (see Limitations below).

Using multiple years of MMP data (1995-2003) from 64 sites within Ecoregion 8 of the Great Lakes basin, a power analysis was performed for a paired t-test (power=0.8, alpha=0.05). The power analysis helped estimate the number of sites required to detect a statistically significant difference within an area of interest (i.e., Great Lakes basin, lake basin, State, Region, etc.) between two sampling times. Sampling times could be any time frame (e.g., annual, biennial; for SOLEC years). Sampling frequency will likely depend on available resources, but with a paired design the sampling must be done at the same sites throughout each sampling period. The power analysis predicted the number of sites required to detect a statistical difference within the area of interest with various mean differences between paired sites (Table 7-2).

Table 7-2. The approximate number of sites required to detect a difference in IBIs within an area of interest (e.g., Great Lakes basin, lake basin, State, Region). IBIs are expressed out of 100 with higher scores indicating marsh bird communities in better condition.

Number of sites required	Mean difference in IBI between paired sites
10	20
15	17
20	13
30	10
40	8
80	4

For example, if an agency wanted to detect a mean difference of 20 IBI points in a suite of sites sampled in a particular region, at least 10 sampling sites (wetlands) are recommended. For a regional coastal wetland project such as the DRCWMP, that samples 15 sites, a mean difference of 17 IBI points could be detected regionally among sampling periods.

Interpretation of Results

Using marsh bird data collected through the MMP, a suite of marsh bird indicator guilds was combined to create a Great Lakes coastal wetland marsh bird community IBI. Methods for development were based on a combination of metric suitability, data treatment and calculation techniques used in Crewe and Timmermans (2005) and EC and CLOCA (2004). Several bird guilds (Figure 7-1) were evaluated for their response to wetland disturbance. The recommended IBI incorporates guilds that represent disturbance-sensitive marsh-nesting birds and general marsh users (Table 7-3).

Table 7-3. A description of metric codes used in the marsh bird IBI.

Metric Code	Description
aNAF	Mean relative **a**bundance (i.e., proportion) of **N**on-**A**rial **F**oragers for the survey route
aMNO	Mean relative **a**bundance (i.e., proportion) of **M**arsh **N**esting **O**bligates for the survey route
rAMNO	Mean species **r**ichness of **A**rea-sensitive **M**arsh **N**esting **O**bligates for the survey route

Avian Groups and Response Variables

Surveyed birds, or Marsh Users, are categorized into one of two guilds based on marsh use identified from published literature and expert opinion (Brown and Dinsmore 1986, Naugle et al. 2001, Riffell et al. 2001, Poole and Gill [ongoing]; Figure 7-1). Marsh Nesting Birds include birds that nest within marsh habitat (e.g., meadow marsh, emergent vegetation or hemi-marsh habitat). This guild was further divided based on species' nesting dependency on this habitat. Marsh Nesting Obligates include bird species that depend exclusively on emergent or hemi-marsh habitat for nesting. Marsh Nesting Obligates are divided into Area and Non-Area Sensitive species. Area Sensitive species are those species that are known to prefer larger wetland areas, and less likely to be found nesting in smaller wetland sites, whereas Non-Area Sensitive species are found in similar frequencies among all marsh sizes and therefore tend not to be area sensitive in nest site selection. Marsh Nesting Generalists include birds that primarily nest within marsh habitat but can also nest elsewhere. Marsh Foragers comprise the second guild, and are divided into Water, Aerial, and Non-Aerial Foragers based upon species-specific foraging behavior.

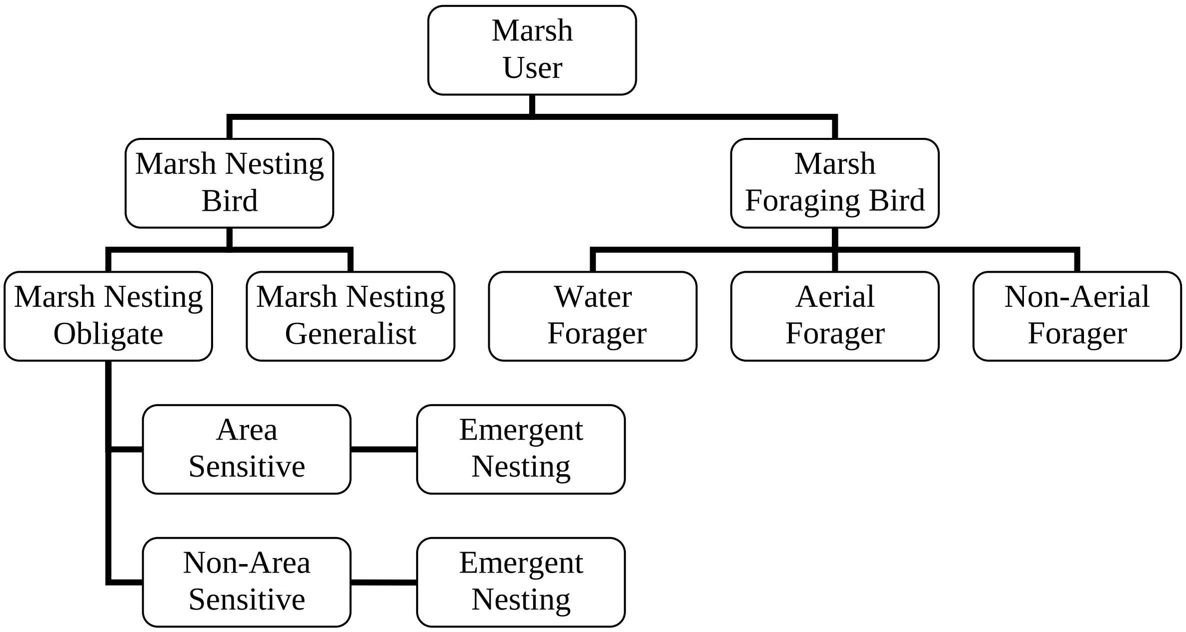


Figure 7-1. Illustration of marsh user categories for bird species based on marsh use.

Each bird observation was summarized as either a mapped observation or an aerial forager. Mapped observations include birds that contacted the vegetation or water during the point count inside the survey radius. Aerial foragers include birds actively foraging overhead inside the survey radius and no higher than 100 meters. The maximum number of individuals for each species guild was calculated for each survey station. Because point counts provide only a crude estimate of individual numbers due to differing detection probabilities among days, habitats, weather, etc., station counts were divided by total abundance at a station to obtain a percent of total (relative) abundance for each guild (Ralph et al. 1995). For analysis, mean values of abundance and species richness across survey stations in a route/wetland were used for each site.

Once data are summarized as a mean per site, the IBI is calculated as follows:

Step 1: Standardize the relative abundance and species richness metric scores to values out of 10. (Higher scores out of 10 indicate better marsh bird community attribute).

Metric Code	Calculation
aNAF	If aNAF≥76.2%, then the metric automatically scores a 10 If aNAF<76.2%, then multiply the percentage by 0.13
aMNO	If aMNO≥33.5%, then the metric automatically scores a 10 If aMNO<33.5%, then multiply the percentage by 0.30
rAMNO	If rAMNO≥0.57, then the metric automatically scores a 10 If rAMNO<0.57, then multiply the percentage by 17.5

Step 2: Combine the standardized metrics and calculate an IBI out of 100.

For the site, add the standardized metrics and multiply the sum by 3.33.

Example: For Point Pelee Marsh #2 in Lake Erie in 2001 the mean marsh bird community attributes were aNA = 77.8%, aMNO = 18.9%, rAMNO = 0.42.

According to Step 1 above:
aNAF = 77.8% which is greater than 76.2% so the standardized metric is 10.
aMNO = 18.9% which is less than 33.5%, therefore multiply 18.9 by 0.30 = 5.7
rAMNO = 0.42, which is less than 0.57, therefore multiply 0.42 by 17.5 = 7.4

According to Step 2 above:
IBI = (10 + 5.7 + 7.4) · 3.33
= 77.0 (out of 100)

Table 7-4. Coastal wetland marsh bird IBIs (out of 100) for a subset of sites sampled in Ecoregion 8 by MMP surveyors from 1995-2003. Higher scores indicate marsh bird communities in better biotic condition.

Wetland Name	Lake	1995	1996	1997	1998	1999	2000	2001	2002	2003
Canard River Mouth Marsh	Detroit R.	11.4	15.4	9.3	41.5	17.9				
Algonac Wetland	Erie	44.7								
Big Creek Marsh	Erie						31.2	18.8	21.3	39.9
Black Creek Area Wetland	Erie	93.2								
Bouvier Bay Wetland	Erie		29.8							
Cedar Point National Wildlife Refuge Wetland	Erie		78.3				23.8	15.9		
Grand River Mouth Wetlands	Erie	69.9	58.9							
Hillman Marsh	Erie					28.7	38.8	42.2	47.2	54.5
Long Point Wetland 1	Erie	95.2	91.5	97.0	87.4	60.0	40.9	81.2	72.1	40.0
Long Point Wetland 2	Erie	37.1	69.8	79.7	87.2	67.8			84.7	48.4
Long Point Wetland 3	Erie		45.9	57.5	63.4	53.3	56.4	22.9	53.1	
Long Point Wetland 4	Erie								47.0	
Long Point Wetland 5	Erie		59.7	74.1	61.5	41.1	73.5	65.7	67.3	
Mentor Marsh	Erie		23.8	35.2	30.1	24.6				
Metzger Marsh	Erie		21.7			78.5				
Monroe City Area Wetland	Erie		23.8							
Ottawa National Wildlife Refuge Wetland	Erie					34.4	58.9	39.3	52.1	
Ottawa Wildlife Refuge Wetland	Erie					56.0	62.5	42.2		63.5
Point Pelee Marsh 2	Erie	69.6	89.0	82.3	84.6	83.4	85.1	77.0		
Rondeau Provincial Park Wetland 1	Erie	83.5	78.4	90.9	91.1	64.0	61.4	43.6	48.4	52.7
Tremblay Beach Marsh	Erie						47.2			
Collingwood Shores Wetland 4	Huron					31.4	33.3	22.8		
Wye Marsh	Huron	83.0	93.4	85.6	61.5	64.3	89.3	88.3	87.1	54.6
Illinois Beach State Park Wetland #1	Michigan				26.3	31.7	33.3			
Muskegon River Wetland	Michigan	43.0	54.8	51.0	58.9	58.5	40.7	47.0		67.3
Suamico River Area Wetland	Michigan	93.1		82.1	88.3	77.8	77.8	63.6	47.2	76.9
White River Wetland	Michigan			68.6						
Belleville Marsh 2	Ontario	33.3	36.1	38.2						
Big Island Marsh	Ontario		54.5	77.0	75.6	47.3	49.8	46.9	62.7	45.3
Blessington Creek Marsh 2	Ontario	61.9								
Braddock Bay Wetland	Ontario					88.4	84.8		41.7	
Buck Pond	Ontario	64.1	96.0	98.1	84.2	64.6	58.7	61.9	60.3	54.6
Carrs Marsh (Peters Rock Marsh)	Ontario		32.0	55.1	65.1	65.0	66.7	66.7	66.7	
Cootes Paradise 1	Ontario	36.5	47.6	42.0	56.5	47.4	53.4	31.2	36.0	36.8

Corbett Creek Mouth Marsh	Ontario								41.4	
Cranberry Marsh	Ontario	37.9							64.4	85.4
Duffins Creek Lakeshore Marsh	Ontario	43.2	47.2	21.6	33.9					27.1
East Bay Wetland	Ontario		48.1							
Frenchman's Bay Marsh	Ontario	23.0	63.6	7.8	30.4	27.9			18.9	24.7
Hay Bay Marsh 7	Ontario								48.0	
Hucyks Bay 1	Ontario								77.0	
Humber River Marshes	Ontario	14.4	21.0	9.5	20.8					23.3
Hydro Marsh	Ontario	32.5	30.2						17.2	
Irondequoit Bay Wetland	Ontario		59.9	41.6	41.7	57.2	63.3	62.8	57.6	42.6
Little Cataraqui Creek Complex	Ontario		42.3			17.9	45.0		78.9	38.0
Lynde Creek Marsh	Ontario								49.5	47.4
Oshawa Second Marsh	Ontario	89.4	90.6	73.3	87.0	60.7	62.5	54.8	50.7	61.9
Parrott Bay Wetland 2	Ontario								53.8	
Port Darlington Marsh	Ontario								45.8	38.8
Rattray Marsh	Ontario	44.3	41.8	47.2	54.3	46.9				
RBG- Hendrie Valley	Ontario	28.1	50.0	50.3	35.4	27.4	30.6	22.4	38.3	31.7
Robinson Cove Marsh	Ontario								50.3	33.3
Round Pond	Ontario	60.0	57.4	44.3	81.2	54.3	54.6	46.1	86.7	53.0
Sawguin Creek Marsh 1	Ontario	66.7								
Sawguin Creek Marsh 7	Ontario	57.6								
Snake Creek Marsh	Ontario		44.7	54.5						
Sodus Bay Wetland	Ontario		52.5							
South Bay Marsh 1	Ontario								29.2	
Tuscarora Bay Wetland	Ontario	28.9	33.3	30.0						
Van Wagners Marsh	Ontario		38.0	31.9						29.9
Westside Beach Marsh	Ontario	13.4	34.5	24.4			54.4	29.9	48.2	55.4
Lake St. Clair Marshes	St. Clair	89.0	94.5	94.3	79.2	66.7	70.8			
Ruscom Shores Marsh	St. Clair	31.5	30.1	39.8	32.8	35.9	32.0	30.9	48.3	17.9

Data Handling and Storage

Data sheets should be returned to Bird Studies Canada as directed in the training and instruction package by July 31st of the survey year. Once the data are entered into the BSC database and checked by BSC personnel, the data can be used in support of the Consortium implementation plan (e.g., data transferred to Consortium database, metrics/IBI calculations completed).

Limitations

Geographic

The IBI developed for the Consortium was developed using sites in the Great Lakes basin within Ecoregion 8 (i.e., Southern lakes Huron and Michigan, all of lakes Ontario, Erie, St. Clair and connecting channels). Therefore, this IBI should only be used to report on sites within this geographic area.

Site Size

Environment Canada (2007) suggests that IBIs incorporating a guild approach as recommended in this document might not provide accurate measures of marsh bird community condition in small sites (<10 hectares of emergent marsh). IBI estimates from small sites should be interpreted with caution.

Water Levels

Craigie et al. (2003), DesGranges et al. (2005), Steen et al. (2006), and Meyer et al. (2006b) describe how Great Lakes water levels can influence attributes of coastal wetland marsh bird communities. Great Lakes water levels during the breeding season might influence the IBI recommended in this document. Crewe and Timmermans (2005) considered these potential hydrologic influences and examined their marsh bird IBIs during both low and high water periods. The metrics used to develop the marsh bird IBI in this chapter responded significantly ($p<0.20$) to the amount of disturbance within one kilometer of a coastal wetland during at least three of four high water level years (1995-1998), and when scores were averaged across both high water level period and low water level periods. Although the strength of metric response to disturbance is more limited during low-water levels, we believe that the marsh bird IBI described here is appropriate for both higher and lower Great Lakes water levels because the patterns of metric response, albeit weaker, are similar during both low water level and high water level periods. Additional analysis is recommended to improve understanding of the effect that different hydrologic conditions have on the coastal wetland bird community IBI.

References

Albert, D.A., Wilcox, D.A., Ingram, J.W., and Thompson, T.A. accepted 2005. Hydrogeomorphic classification for Great Lakes coastal wetlands. Journal of Great Lakes Research.

Archer, R.W., S.T.A. Timmermans, and C.L. Robinson. Monitoring and Assessing Marsh habitats in Great Lakes Areas of Concern; Final Project Report. Bird Studies Canada, Port Rowan, Ontario. 302 pp.

Austen, M.J.W., M.D. Cadman, and R.D. James. 1994. Ontario Birds at Risk: Status and Conservation Needs. Federation of Ontario Naturalists and Long Point Bird Observatory. 165 pp.

Brown, M. and J.J. Dinsmore. 1986. Implications of marsh size and isolation for marsh bird management. Journal of Wildlife Management 50: 392-397.

Conway, C.J. 1995. Virginia Rail (Rallus limicola). In The Birds of North America. No. 173 (A. Poole and F. Gill, eds). The Academy of Natural Sciences, Philadelphia, and The American Ornithologists' Union, Washington, D.C. 20 pp.

Craigie, G.E., S.T.A. Timmermans, and J.W. Ingram. 2003. Interactions Between Marsh Bird Population Indices and Great Lakes Water Levels: A Case Study of Lake Ontario Hydrology. February 2003. Bird Studies Canada and Environment Canada. Port Rowan, Ontario. 40 pp.

Crewe, T.L. and S.T.A. Timmermans, 2005. Assessing Biological Integrity of Great Lakes Coastal Wetlands Using Marsh Bird and Amphibian Communities. March 2005. Bird Studies Canada, Port Rowan, Ontario. 89 pp.

DesGranges, J.-L., J. Ingram, B. Drolet, C. Savage, J. Morin, and D. Borcard. 2005. Wetland bird response to water level changes in the Lake Ontario - St. Lawrence River hydrosystem. Final report to the International Joint Commission in support of the International Lake Ontario – St. Lawrence River Water Regulation Review Study. Canadian Wildlife Service, Québec and Ontario Regions. Environment Canada. Unpublished report xiv + 132 pp. (including 4 enclosures and 14 appendices).

Environment Canada and Central Lake Ontario Conservation Authority. 2004a. Durham Region Coastal Wetland Monitoring Project: Year 2 Technical Report. Downsview, ON: Environmental Conservation Branch – Ontario Region. 177 pp. + appendices

Environment Canada and Central Lake Ontario Conservation Authority. 2004b. Baseline Conditions of Durham Region Coastal Wetlands: Preliminary Findings 2002- 2003. Downsview, ON: Environmental Conservation Branch – Ontario Region. May 2004. 36 pp.

Environment Canada – Canada Wildlife Service. 2007. Bay of Quinte Area of Concern: Coastal Wetland Status and Remedial Action Plan Delisting Target Recommendations. June 2007. Toronto, Ontario: Environmental Conservation Branch – Ontario Region. 95 pp.

Gibbs J.P., Reid, F.A. and S.M. Melvin. 1992. Least Bittern (Ixobrychus exilis). In The Birds of North America, No. 17 (A. Poole and F. Gill, eds.). The Academy of Natural Sciences, Philadelphia, and The American Ornithologists' Union, Washington, D.C. 12pp.

Howe, R.W., R.R. Regal, J.M. Hanowski, G.J. Niemi, N.P. Danz, C.R. Smith. 2007. A new approach to the development of ecological indicators for coastal wetlands of the Laurentian Great Lakes. Journal of Great Lakes Research. In review.

Melvin S.M. and J.P. Gibbs. 1996. Sora (Porzana carolina). In: The Birds of North America, No. 250 (A. Poole and F. Gill, eds.). The Academy of Natural Sciences, Philadelphia, and The American Ornithologists' Union, Washington, D.C. 19pp.

Meyer, S.W., J.W. Ingram and G.P. Grabas. 2006a. The Marsh Monitoring Program: Evaluating Marsh Bird Survey Protocol Modifications to Assess Lake Ontario Coastal Wetlands at a Site-level. Technical Report Series 465. Canadian Wildlife Service, Ontario Region, Ontario. 25pp.

Meyer, S., J. Ingram, and K. Holmes. 2006b. Chapter 5. Vulnerability of Marsh Birds in Great Lakes Coastal Wetlands to Climate-Induced Hydrological Change. In L. Mortsch, J. Ingram, A. Hebb, and S. Doka (eds.), Great Lakes Coastal Wetland Communities: Vulnerability to Climate Change and Response to Adaptation Strategies, Environment Canada and the Department of Fisheries and Oceans, Toronto, Ontario, pp. 79-100.

Mitsch, W.J. and J.G. Gosselink. 1993. Wetlands. Van Nostrand Reinhold, New York.

Naugle, D.E., R.R. Johnson, M.E. Estey, and K.F. Higgins. 2001. A landscape approach to conserving wetland bird habitat in the prairie pothole region of eastern South Dakota. Wetlands 21: 1-17.

Poole, A. and F. Gill (eds.). Ongoing. The Birds of North America. The Academy of Natural Sciences, Philadelphia, PA, and The American Ornithologists' Union, Washington, D.C.

Ralph, C.J., J.R. Sauer, and S. Droege (eds.). 1995. Monitoring bird populations by point count. Gen. Tech. Rep. PSW-GTR-149. Albany, CA: Pacific Southwest Research Station, Forest Service, U.S. Department of Agriculture.

Riffell, S.K., B.E. Keas, and T.M. Burton. 2001. Area and habitat relationships of birds in Great Lakes coastal wet meadow. Wetlands 21: 492-507.

StatSoft, Inc. 2005. STATISTICA (data analysis software system), version 7.1. www.statsoft.com.

Steen D.A., J.P. Gibbs, and S.T.A. Timmermans. 2006. Assessing the sensitivity of wetland bird communities to hydrologic change in the eastern Great Lakes basin. Wetlands 26 (2): 605-611.

Timmermans, S.T.A., G. E. Craigie and K. Jones. 2004. Marsh Monitoring Program: Areas Of Concern Summary Reports 1995 – 2002. Bird Studies Canada, Port Rowan, Ontario.

Appendix 7-1. Members of each guild used in the IBI. This list was developed from bird species identified during MMP surveys from 1995-2005.

Guild	CODE	Common Name	Genus species
Non-aerial foragers			
	AMCR	American Crow	*Corvus brachyrhynchos*
	AMGO	American Goldfinch	*Carduelis tristis*
	AMRE	American Redstart	*Setophaga ruticilla*
	AMRO	American Robin	*Turdus migratorius*
	AMWO	American Woodcock	*Scolopax minor*
	ATSP	American Tree Sparrow	*Spizella arborea*
	BAOR	Baltimore Oriole	*Icterus galbula*
	BAWW	Black-and-white Warbler	*Mniotilta varia*
	BBCU	Black-billed Cuckoo	*Coccyzus erythropthalmus*
	BCCH	Black-capped Chickadee	*Parus atricapillus*
	BGGN	Blue-gray Gnatcatcher	*Polioptila caerulea*
	BHCO	Brown-headed Cowbird	*Molothrus ater*
	BLCK	Unknown Blackbird	---
	BLJA	Blue Jay	*Cyanocitta cristata*
	BOBO	Bobolink	*Dolichonyx oryzivorus*
	BRBL	Brewer's Blackbird	*Euphagus cyanocephalus*
	BRTH	Brown Thrasher	*Toxostoma rufum*
	BTNW	Black-throated Green Warbler	*Dendroica virens*
	BWWA	Blue-winged Warbler	*Vermivora pinus*
	CARW	Carolina Wren	*Thryothorus ludovicianus*
	CAWA	Canada Warbler	*Wilsonia canadensis*
	CCSP	Clay-colored Sparrow	*Spizella pallida*
	CEDW	Cedar Waxwing	*Bombycilla cedrorum*
	CHSP	Chipping Sparrow	*Spizella passerina*
	CMWA	Cape May Warbler	*Dendroica tigrina*
	COGR	Common Grackle	*Quiscalus quiscula*
	CORA	Common Raven	*Corvus corax*
	COSN	Common Snipe	*Gallinago gallinago*
	COYE	Common Yellowthroat	*Geothlypis trichas*
	CSWA	Chestnut-sided Warbler	*Dendroica pensylvanica*
	DOWO	Downy Woodpecker	*Picoides pubescens*
	DUNL	Dunlin	*Calidris alpina*
	EABL	Eastern Bluebird	*Sialia sialis*
	EAME	Eastern Meadowlark	*Sturnella magna*
	EATO	Eastern Towhee	*Pipilo erythrophthalmus*
	FISP	Field Sparrow	*Spizella pusilla*
	GRSP	Grasshopper Sparrow	*Ammodramus savannarum*
	GRYE	Greater Yellowlegs	*Tringa melanoleuca*
	HAWO	Hairy Woodpecker	*Picoides villosus*
	HETH	Hermit Thrush	*Catharus guttatus*
	HOFI	House Finch	*Carpodacus mexicanus*
	HOWR	House Wren	*Troglodytes aedon*
	INBU	Indigo Bunting	*Passerina cyanea*
	KILL	Killdeer	*Charadrius vociferus*
	LCSP	Le Conte's Sparrow	*Ammodramus leconteii*

LESA	Least Sandpiper	*Calidris minutilla*
LEYE	Lesser Yellowlegs	*Tringa flavipes*
LISP	Lincoln's Sparrow	*Melospiza lincolnii*
LOWA	Louisiana Waterthrush	*Seiurus motacilla*
MAWA	Magnolia Warbler	*Dendroica magnolia*
MAWR	Marsh Wren	*Cistothorus palustris*
MODO	Mourning Dove	*Zenaida macroura*
MOWA	Mourning Warbler	*Oporornis philadelphia*
NAWA	Nashville Warbler	*Vermivora ruficapilla*
NOCA	Northern Cardinal	*Cardinalis cardinalis*
NOFL	Northern Flicker	*Colaptes auratus*
NOMO	Northern Mockingbird	*Mimus polyglottos*
NOPA	Northern Parula	*Parula americana*
NOWA	Northern Waterthrush	*Seiurus noveboracensis*
NSTS	Nelson's Sharp-tailed Sparrow	*Ammodramus nelsoni*
OROR	Orchard Oriole	*Icterus spurius*
OVEN	Ovenbird	*Seiurus aurocapillus*
PAWA	Palm Warbler	*Dendroica palmarum*
PISI	Pine Siskin	*Carduelis pinus*
PIWA	Pine Warbler	*Dendroica pinus*
PIWO	Pileated Woodpecker	*Dryocopus pileatus*
PROW	Prothonotary Warbler	*Protonotaria citrea*
PUFI	Purple Finch	*Carpodacus purpureus*
RBGR	Rose-breasted Grosbeak	*Pheucticus ludovicianus*
RBNU	Red-breasted Nuthatch	*Sitta canadensis*
RBWO	Red-bellied Woodpecker	*Melanerpes carolinus*
RCKI	Ruby-crowned Kinglet	*Regulus calendula*
REVI	Red-eyed Vireo	*Vireo olivaceus*
RHWO	Red-headed Woodpecker	*Melanerpes erythrocephalus*
RNPH	Ring-necked Pheasant	*Phasianus colchicus*
RTHU	Ruby-throated Hummingbird	*Archilochus colubris*
RUBL	Rusty Blackbird	*Euphagus carolinus*
RUGR	Ruffed Grouse	*Bonasa umbellus*
RUTU	Ruddy Turnstone	*Arenaria interpres*
RWBL	Red-winged Blackbird	*Agelaius phoeniceus*
SAVS	Savannah Sparrow	*Passerculus sandwichensis*
SBDO	Short-billed Dowitcher	*Limnodromus griseus*
SCTA	Scarlet Tanager	*Piranga olivacea*
SEPL	Semipalmated Plover	*Charadrius semipalmatus*
SEWR	Sedge Wren	*Cistothorus platensis*
SORA	Sora	*Porzana carolina*
SOSA	Solitary Sandpiper	*Tringa solitaria*
SOSP	Song Sparrow	*Melospiza melodia*
SPAR	Unknown Sparrow	---
SPSA	Spotted Sandpiper	*Actitis macularia*
SWSP	Swamp Sparrow	*Melospiza georgiana*
SWTH	Swainson's Thrush	*Catharus ustulatus*
TEWA	Tennessee Warbler	*Vermivora peregrina*
TUTI	Tufted Titmouse	*Parus bicolor*
VEER	Veery	*Catharus fuscescens*
VIRA	Virginia Rail	*Rallus limicola*

WAVI	Warbling Vireo	*Vireo gilvus*
WBNU	White-breasted Nuthatch	*Sitta carolinensis*
WEVI	White-eyed Vireo	*Vireo griseus*
WIPH	Wilson's Phalarope	*Phalaropus tricolor*
WIWR	Winter Wren	*Troglodytes troglodytes*
WOTH	Wood Thrush	*Hylocichla mustelina*
WTSP	White-throated Sparrow	*Zonotrichia albicollis*
YBCH	Yellow-breasted Chat	*Icteria virens*
YBCU	Yellow-billed Cuckoo	*Coccyzus americanus*
YBSA	Yellow-bellied Sapsucker	*Sphyrapicus varius*
YERA	Yellow Rail	*Coturnicops noveboracensis*
YHBL	Yellow-headed Blackbird	*Xanthocephalus xanthocephalus*
YTVI	Yellow-throated Vireo	*Vireo flavifrons*
YWAR	Yellow Warbler	*Dendroica petechia*

Marsh Nesting Obligate

AMBI	American Bittern	*Botaurus lentiginosus*
AMCO	American Coot	*Fulica americana*
BLTE	Black Tern	*Chlidonias niger*
COMO	Common Moorhen	*Gallinula chloropus*
COSN	Common Snipe	*Gallinago gallinago*
FOTE	Forster's Tern	*Sterna forsteri*
HOGR	Horned Grebe	*Podiceps auritus*
KIRA	King Rail	*Rallus elegans*
LEBI	Least Bittern	*Ixobrychus exilis*
LIGU	Little Gull	*Larus minutus*
MAWR	Marsh Wren	*Cistothorus palustris*
MOOT	Am. Coot/C. Moorhen	*Fulica americana/Galinula chloropus*
PBGR	Pied-billed Grebe	*Podilymbus podiceps*
REDH	Redhead	*Aythya americana*
RNDU	Ring-necked Duck	*Aythya collaris*
RNGR	Red-necked Grebe	*Podiceps grisegena*
SACR	Sandhill Crane	*Grus canadensis*
SORA	Sora	*Porzana carolina*
SWSP	Swamp Sparrow	*Melospiza georgiana*
TRU.S.	Trumpeter Swan	*Cygnus buccinator*
VIRA	Virginia Rail	*Rallus limicola*
YERA	Yellow Rail	*Coturnicops noveboracensis*
YHBL	Yellow-headed Blackbird	*Xanthocephalus xanthocephalus*

Area-sensitive Marsh Nesting Obligate

AMBI	American Bittern	*Botaurus lentiginosus*
AMCO	American Coot	*Fulica americana*
BLTE	Black Tern	*Chlidonias niger*
FOTE	Forster's Tern	*Sterna forsteri*
KIRA	King Rail	*Rallus elegans*
LEBI	Least Bittern	*Ixobrychus exilis*
REDH	Redhead	*Aythya americana*
RNGR	Red-necked Grebe	*Podiceps grisegena*
SACR	Sandhill Crane	*Grus canadensis*
YERA	Yellow Rail	*Coturnicops noveboracensis*

Appendix 7-2. MMP Marsh Bird Survey Protocol

This marsh bird survey protocol has been designed to conform to North America-wide marsh bird monitoring standards. Please read these instructions carefully and listen to the Training CD prior to conducting your first survey.

When Should I Do My Surveys?

- Each route is to be surveyed for marsh birds two times each year between May 20 and July 5. Surveys must be at least 10 days apart.

- Surveys at a particular route may be conducted during the morning or the evening, but not both. Once you begin morning or evening surveys at a route, that route must always be surveyed during that time period for each subsequent survey visit annually. Morning surveys begin at or following sunrise and end at or before 9:00 h (9:00 a.m.). Evening surveys begin at or following 18:00 h (6:00 p.m.) and must end at or before sunset. Routes are to be surveyed in their entirety, in the same station sequence during both visits, starting at about the same time of day.

- Each station is surveyed for 15 minutes. Hence, a typical route of four stations will take you no more than about 2 hours to survey, including the time that it takes you to travel between stations.

- Surveys should be undertaken in weather that is conducive to surveying birds: good visibility, warm temperatures (at least 60°F or 16°C), no precipitation and little or no wind. If the weather should exceed these limitations during the survey, you should cancel the survey and redo it later.

- Strong wind not only suppresses bird calling activity, it interferes with your ability to hear. Do your survey only when the wind strength is Code 0, 1, 2 or 3 on the Beaufort Scale. If the wind is strong enough to raise dust or loose paper and move small tree branches, then wait for a calmer morning or evening.

- All but the lightest drizzle suppresses bird activity and interferes with your ability to hear, not to mention soaking you and your forms, and generally making you miserable! We want you to find these surveys interesting and pleasant, not a burden. Pick a nice morning or evening!

Conducting the Survey

Getting Started

Check to make sure that you have your Marsh Bird Data Form; a pen or pencil; watch or timer (preferably one with an alarm); clipboard (if desired); portable CD player with speakers and fresh batteries; the marsh bird broadcast CD; binoculars; and mosquito repellent. If you have already completed your Habitat Description Forms, you can bring along a copy to help you relocate the stations and their sample areas. A compass, thermometer, spare batteries, spare pen or pencil, and this instruction booklet are other useful items. It's best to be prepared! See the Spring Refresher on the inside back cover for a checklist of survey items.

You might want to bring an assistant along for company and to share in the experience. This person can help you find the stations, hold your CD player and speakers, and document information such as the weather conditions. Your assistant may even be able to take over for you in future years. However, you must find, identify, and count all the birds unaided. More than one observer will bias the results.

Before starting the survey, fill in the information required in the top section of the Marsh Bird Data Form (see example on page 14). Each survey route should be given a unique route name that describes the marsh name (or names if a series of marshes are being sampled) and the location of the route in the marsh (e.g. "Maumee Marsh-South"). If the marsh does not already have a name, choose one. If you are conducting an amphibian survey on the same route, the route name should be consistent for both. Stations should be labeled in sequential order of coverage from A to H. Record the observer name, date, and visit number (e.g., #1, #2).

All weather information can be easily estimated. Determine the wind speed according to the Beaufort Scale. Cloud cover is estimated as covering so many 10ths of the sky (e.g. if it's sunny with no cloud cover, 0/10 of the sky will be covered). If possible, carry a thermometer and record the air temperature at the start of the survey. Because this program spans two countries with two different scales of measure, be sure to specify whether you are recording the temperature in degrees Fahrenheit or Celsius. If you don't have a thermometer, record the air temperature from a reliable source (e.g. the local weather station or an outdoor thermometer at your home).

If you have surveyed your route for more than one year, and the habitat characteristics within any of your stations has changed in that time, please indicate this on the Data Form. For example, the marsh area in Station D of your route is partially dried-up in Survey Year Two, compared to its condition in Survey Year One. If you have questions about station locations, please contact Kathy Jones through the contact information provided in this manual.

Use the Remarks section to record the names of any assistants, notes on any other wildlife detected (e.g. "2 Bullfrogs calling"), problems encountered (e.g. "started to rain"), and other comments (e.g. "10 million mosquitoes; glad I remembered my repellent!"). Use additional pages if necessary. All remarks and comments are welcome.

Prior to surveying each station, record the survey start time. Please use the 24-hour ("military") clock. For example, 5:00 a.m. is written as 05:00 h, whereas 5:00 p.m. is written as 17:00 h (i.e. 12 plus 5). Similarly, 6:57 p.m. would be written as 18:57 h. Also, please note the level of background noise present at each of your survey stations. Background noise categories and codes are provided on the reverse-side of the Station A Data Form. Do your best to estimate the appropriate noise code.

Please fill in the data form completely – without this information we may not be able to use your data!

Marsh Bird Broadcast CD

Although several species of marsh birds are secretive, they can often be coaxed into responding to a recorded broadcast of their call. In order to ensure data are collected for some important but secretive marsh birds, you have been provided with a broadcast CD that contains a 5-minute sequence of call recordings of the following species: Virginia Rail, Sora, Least Bittern, a combination of Common Moorhen/American Coot and Pied-billed Grebe. The CD player that you use should broadcast loud enough to be heard well at a distance of 100 m (110 yards). Many of the small, low-cost players can produce enough volume, but the speakers must also be capable of attaining the appropriate loudness. You should test the effective broadcast distance beforehand. Recruit a friend to help you establish that you can in fact hear the calls at the appropriate distance. If you can't, you should upgrade your equipment. In some jurisdictions, marsh bird call broadcast units (portable CD players and speakers) are available to borrow from partnering organizations and MMP volunteer coordinators. Please contact Kathy Jones for further information.

Caution: Please don't play the broadcast CD any more than necessary. Repeated and excessive broadcasting can affect the natural response and detectability of many marsh birds, and might deter them from their established territories.

Marsh Bird Data Form

The primary objective of this survey is to track observations of "focal" marsh bird species; those species that rely on marsh habitats for one or more stages of their life cycles (see the Marsh Bird Data Form for a list of focal species). However, "secondary" or non-focal species are also recorded through this protocol. Focal and secondary marsh bird species are tracked and recorded differently on the Marsh Bird Data Form. Focal bird species individuals are tracked separately and individually throughout the entire 15-minute survey. Each observed focal species individual is entered as a separate record (row) in the main data table of the Data Form. For example, you hear two different Sora individuals calling at Station A. You then write "SORA" twice in two separate rows under the "Focal Species" column. Throughout the 15-minute survey, you will indicate in which response period(s) you saw or heard each of these individuals. See below for further information about recording observations during each of the response periods.

Focal species are tracked at unlimited distances. For each focal species individual tracked throughout the entire 15 minutes of the survey period, we ask that you estimate whether that individual occurs either within (distance category '1') or beyond (distance category '2') a 100-m semi-circular distance of where you are standing. Distance category codes are provided on the reverse-side of the Station A Data Form for your reference.

Secondary species are recorded only during the final 10 minutes of the survey. Secondary species are recorded by mapping species' locations within the survey station area on the Secondary Species Map, located on the Data Form. See below for information on mapping bird observations. Unlike for focal marsh bird species, only secondary species observed within 100 m of where you are standing are recorded during this survey. The exceptions to this are secondary species that fly through the sample area (see "Fly-Throughs" section below).

The 15-minute MMP marsh bird survey consists of a 5-minute silent (passive) listening period, a 5-minute call playback period (using the marsh bird broadcast CD), and a final 5-minute passive listening period, in that order. Press play on your CD player once you arrive at your sampling station. A double-tone will mark the start of the 15-minute survey. The first 5 minutes of the broadcast CD features silence, during which you will record your observations of focal species as part of the first (pre-broadcast) passive observation period. The pre-broadcast passive period is divided into two sub-periods of 2 minutes and 3 minutes, respectively. When recording observations, treat these two sub-periods independently. For example, if you observe a Pied-billed Grebe in your station at Minute 1, record it under the "1st Passive (min. 1-2)" column on the Data Form. If you observe that same individual again at Minute 3, record it again under the "1st Passive (min. 3-5)" column within the same PBGR row. A single tone will mark the beginning of the second (min. 3-5) time interval of the 5-minute pre-broadcast passive period. Because secondary species observations do not begin until the 5-minute pre-broadcast focal species passive observation period is completed, it is important to remain still and quiet during the pre-broadcast passive period to minimize effects of your presence on activity of secondary species (or any species for that matter). Only focal species are recorded during this entire first 5-minute period.

Following completion of the 5-minute pre-broadcast passive period, the 5-minute call broadcast period will begin with the call broadcast of the Virginia Rail. The CD is to be played at full volume (or no more than 90 decibels, measured 1 m in front of the speaker), held at chest height and aimed so that it broadcasts in front of you. Each of the five calls plays for 30 seconds, followed by 30 seconds of silence, thereby subdividing the 5-minute call broadcast period into five 1-minute time intervals. Treat each 1-minute time interval independently when recording observations. For example, after having broadcast the Virginia Rail call, you hear an immediate response from a nearby Virginia Rail during Minute 6 of the survey. Record your observation for this individual under the "VIRA (min. 6)" column on the Data Form. Two minutes later, following the Least Bittern call broadcast, you hear the same Virginia Rail individual call again. Record your observation for this individual (in the same VIRA row) again under the "LEBI (min. 8)" column. Record observations for all species seen and/or heard during the call broadcast period, not just observations for those species whose calls are being broadcast. Both focal and secondary species are recorded during this period. Following the 30-second silent period after the Pied-billed Grebe call broadcast (the last species call), a single tone will mark the end of the 5-minute call broadcast period and the beginning of the 5-minute post-broadcast passive observation period.

Because secretive marsh birds may take several minutes to respond to the call broadcasts, a second (post-broadcast) 5-minute silent listening (passive) period has been deemed necessary to track these responses. During this period, you will continue to track and record all bird species observations. However, the post-broadcast passive period is not subdivided into sub-periods as are the previous two 5-minute periods. During the post-broadcast passive period, for focal species you will continue to record observations for each separate individual. If you see or hear any focal species individual any time during the five minute period, you check the box for that individual under the "2nd Pass. (min. 11-15)" column. For new focal species individuals not recorded during previous observation periods, assign each individual to a new row on the table and remember to assign each individual a distance category code. For secondary species, continue to record observations of individuals on the station map, then when the survey is completed count the total number of individuals observed for each secondary species in the table next to the station map. Both focal and secondary species are recorded during this final 5-minute observation period. A double-tone will mark the end of the 15-minute survey.

Prior to the official start of the 15-minute marsh bird survey there is an observation and recording period called the "Flush Period". This period allows surveyors to record observations of focal species that fly away, or "flush", from the station area upon the surveyor's arrival, and would otherwise not be counted during the formal survey period. For example, herons frequently flush once humans approach them. The Flush Period is a non-standardized period of time, consisting of the time it takes you to reach your survey station focal point until the point at which you begin your formal timed 15-minute survey at each station. Each focal species individual flushing from approximately within a 100-m semi-circular distance of your upcoming station focal point during that time is recorded separately in the main data table of the Data Form (as is done for focal species during the formal 15-minute survey). Secondary species are not recorded during the Flush Period.

Recording Bird Observations

Focal species individuals that are observed at an unlimited distance from the focal point are recorded in the main data table of the Marsh Bird Data Form. Individuals are recorded separately in this table by creating a row for each individual using the species name or four-letter code and placing a "✓" or an "x" under each response period during which that individual was detected.

Secondary species, which are tracked only during the last 10 minutes of the survey, are recorded initially by "mapping" species' locations within the survey station area on the Secondary Species Map. The map is a representation of the semi-circular sample station area, showing an outline of the 100-m distance from the focal point. As secondary species are only recorded within 100 m of the focal point, the 100-m arc on the map represents an outer station boundary for secondary species observation records. You can also use the station map to record locations of focal species, especially in the case where multiple individuals of any given focal species are detected. In such cases, it might be helpful to track each focal species individual by labeling each individual with numeric superscript identifiers (e.g., VIRA^1, VIRA^2). Record what direction you are facing in the small box on the map of each sample area (e.g. "23° NNE," or just "NNE" if you can't take a compass bearing). Species locations within the sample station area are mapped by writing the appropriate species codes in the corresponding locations on the map. The four-letter codes for the species most likely to be encountered are provided on the Marsh Bird Route Summary Sheet. You should familiarize yourself with these codes before your first survey. For secondary species, please count the number of individuals observed and recorded on the map and record these numbers for each species on the associated Secondary Species Count table. In the frenzy of surveying, it's difficult to be neat, but please try to write legibly. Your Data Forms will be proofed by us when we receive them, so we need to be able to read your writing! Young of the year are not to be counted, even if independent. We are interested in adults only.

Aerial foragers are birds seen actively foraging in the air within the survey station area, and not otherwise using the station area. Examples of aerial foragers include insect-eaters such as swallows and flycatchers, and fish-eaters such as Common Tern. Some aerial forager species, such as Black Tern, Green Heron and Belted Kingfisher are focal species, and as such, observations of these species are recorded in the main data table instead of the Aerial Forager Box.

Actively foraging birds are usually seen flying slowly over the station, occasionally diving to the water's surface or picking insects from the air, as opposed to birds simply flying through the area (see Fly-Throughs below). Record each aerial forager species using the appropriate species code within the Aerial Forager Box to the right of the Secondary Species Map. Because there are often many aerial foragers (swallows in particular), it helps if you tally them separately and then produce a summary count at the end of the survey. Both focal (e.g., Black Tern) and secondary (e.g., Tree Swallow) aerial forager species are recorded the same way. However, if an aerial forager species individual lands within the survey station area, record it within the main data table on the Marsh Bird Data Form or map it within the Secondary Species Map, depending on whether that individual is a focal or secondary species, respectively.

Fly-Throughs are secondary species birds that fly through the survey station area without landing or foraging during the 15-minute survey. Examples of Fly-Throughs include gulls, crows and hawks. Simply list each Fly-Through species within the Fly-Throughs Box to the right of the Secondary Species Map. Information about these species will help determine simple presence/absence information for the birds occurring in the marsh complex.

Be sure that you record each individual bird in only one of the three categories — Focal Species Response Period table/Secondary Species Map observations, Aerial Foragers or Fly-Throughs. In descending order, our priorities are focal species birds actually breeding in or visiting the marsh survey station area (recorded in the main data table of the form), followed by secondary species birds actually breeding in or visiting the marsh survey station area (recorded in the Secondary Species Map), Aerial Foragers, and then Fly-Throughs. Always choose the highest priority level!

One Marsh Bird Data Form is used for each survey station on your route. Therefore, if your route contains 4 stations, then you will require 8 Data Forms to complete two survey visits.

Please try to ensure that there are no species identification errors. While the Training CD will help you overcome most identification problems, many calls are difficult to distinguish. Those of the Common Moorhen and American Coot can be particularly difficult. If you can't positively identify either species, then use the generic code "MOOT."

Please ensure that you do not double-count bird individuals between stations. This is especially true for focal species. For example, the call of the American Bittern can travel great distances and could potentially be heard at multiple sampling stations. You would only record that American Bittern once as part of the observation data collected at one of the stations where you heard its call. However, if one of your later stations ends up occurring closer to the calling individual (thereby giving you a better estimate of its distance from the station focal point), record it as part of that station's data and draw a line through that individual's record on the earlier station's data form.

Birders like to coax birds into view by "pishing" or making a variety of other noises. Birds are not to be coaxed in any way other than using the broadcast CD when you are completing your survey! If you have trouble identifying a bird, you can take time between stations to identify it.

The only two species for which you will not record birds of both sexes are Red-winged Blackbird and Yellow-headed Blackbird. Record male blackbirds of both species only. Both species are polygamous (one male forms pair bonds with several different females) and experience has shown there are often too many females to track.

Sample Survey

In order to help you understand how to map and record your observations, a sample survey has been provided. The sample Marsh Bird Data Form demonstrates how the following examples would be recorded and you should refer to it as you read through the examples given below. Now, sit back and imagine that you're approaching Station A on your route . . .

Just before you arrive at Station A, you notice two Great Blue Herons fly up from the sample station area and out of sight. Under the "Focal Species" column of the Data Form's main data table, you write "GBHE" on two separate rows, indicating that two individuals were detected. Within each row, you mark a checkmark under the column "Flush Period". As it appeared that each heron occurred within 100 m of your upcoming station focal point, you assign each a distance category code of "1".

Upon arriving at Station A, you fill in the information on the top of your Data Form. After taking a moment to listen to the level of background noise, you decide to assign a Background Noise Category code of "1" for this station. Ready to begin, you record the station start time on your form and press "play" on your CD player to begin the 15-minute survey. A double-tone from the CD player marks the beginning of the survey

As the 5-minute pre-broadcast passive period begins, you keep your eyes and ears open for focal marsh bird species. You are quickly rewarded as a Pied-billed Grebe swims into view during Minute 1 of your survey. You proceed to write "PBGR" on a new line on the data table, and place a checkmark under the "1st. Passive (min. 1-2)" column. As this individual is less that 100 m from you, you assign it a distance category code of "1".

Soon after, you hear the tone from the CD to mark the beginning of the 3-minute subperiod of the 5-minute pre-broadcast passive period. Still seeing the same Pied-billed Grebe at Minute 3, you place another checkmark within that individual's row, this time under the "1st. Passive (min. 3-5)" column.

At Minute 4 you hear a Sandhill Crane call in the distance. You write "SACR" on a new row, place a checkmark under the column "1st Passive (min. 3-5)", and assign it a distance category code of "2" since it is quite distant.

The broadcasted call of the Virginia Rail marks the end of the 5-minute pre-broadcast passive period and the beginning of the 5-minute call broadcast period. Following the Virginia Rail call broadcast, you immediately hear a response from a Virginia Rail only a few meters away from you. You write "VIRA" on a new row under the "Focal Species" column, place a checkmark under the column "VIRA (min. 6)" and assign it a distance category code of "1".

The Pied-billed Grebe that you recorded earlier is still visible. You place a third checkmark within that individual's row under "VIRA (min. 6)".

Now that you are free to record secondary species observations, you map two Red-winged Blackbird males that are calling within 50 m to your right by writing and encircling the four-letter species code (RWBL) for each in their approximate station locations within the station on the Secondary Species Map.

You map a Swamp Sparrow (SWSP) calling about 40 m to your left.

Following the call broadcast of the Least Bittern at Minute 8, you hear the Virginia Rail heard earlier call again. Within that individual's row on the data table, you mark a checkmark under the "LEBI (min. 8)" column.

At Minute 9, you see a pair of Common Yellowthroats to your right. The male calls, and then flies away, landing somewhere in the middle of the sample area. You map and tally the pair (COYE) and note the male's change in position on the Secondary Species Map.

After the 30 seconds of silence following the final (Pied-billed Grebe) call broadcast, you hear a tone from the CD player to mark the end of the 5-minute broadcast period and the beginning of the 5-minute post-broadcast passive period.

You notice a male Red-winged Blackbird singing to your left, near a group of 3 female Red-winged Blackbirds. You map the male (RWBL) on your data form but you do not map the females.

Five young coots, accompanied by two adults, emerge from the vegetation. You record the two adults within separate rows of the main data table and place a checkmark under the "2nd Pass. (min. 11-15)" column for each. After estimating their distance to be within 100 m, you assign them each a distance category code of "1". You then decide to note in the Remarks section that the entire family group was seen.

As you scan the sample area with your binoculars, you spot a Canada Goose sitting on a nest. You map the CAGO using the symbol to indicate that a nest was located.

Two Black Terns are seen circling over an area of the marsh to your left, beyond 100 meters of you. You record both individuals on the main data table, and place a checkmark under the "2nd Pass. (min. 11-15)" column and assign a distance category code of 2 for each individual.

You see a Mallard fly overhead high over the marsh. You record MALL as an additional species in the Fly-Throughs box. Just then, the same Mallard circles around, flies in, and lands in the sample area. You strike out your previous record of MALL from the Fly-Through box and map this individual on the Secondary Species Map. You place a checkmark under the "2nd Pass. (min. 11-15)" column and assign a distance category code of "2".

A Wood Duck flushes from within the sample area and flies away. You map one WODU.

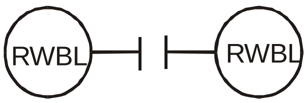
Three Tree Swallows appear in your sample area. You watch their aerial acrobatics as they circle and catch insects out of the air and then tally these three in the Aerial Foragers box. After tallying, you notice that there are now 13 Tree Swallows. You add an additional 10 to your tally.

You hear a double-tone from the CD player, signaling the end of your survey at this station. As you take a moment to count and record the total number of secondary species individuals seen in the Secondary Species Tally table next to the Secondary Species Map, a Least Bittern calls in the distance. You note the presence of this species in the Remarks section. After making sure you haven't left anything behind, you head out to survey your next station. t

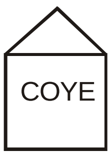
The mapping symbols that you will use on the Data Form's Secondary Species Map are as follows:

Mapping Symbols for MMP Bird Surveys

Singing/calling bird.
Count as 1 on summary sheet.



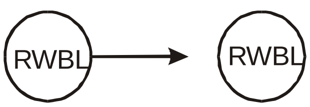
Simultaneous song/different individuals of same species.
Count as 2.



Pair together (assumed mated).
If RWBL or YHBL, count 1 (male only).
All other species count as 2.

Family group.
Count number of adults only.

Observed, not singing/calling (e.g., feeding, loafing, landing, flushing).
Count as 1.



Change in position.

Nest location.

Note: For Red-winged Blackbirds (RWBL) and Yellow-headed Blackbirds (YHBL), count males only

Example Data Sheet – Next Page

Marsh Monitoring Program - Marsh Bird Data Form

Observer:		Route name:
Date (dd-mm-yr):		Visit No.:
Beaufort Wind Scale No.:	Cloud Cover (10ths):	Air Temperature (C or F):
Has the habitat on your route changed from previous years? Yes: No: Not applicable:		
Remarks:		

STATION A

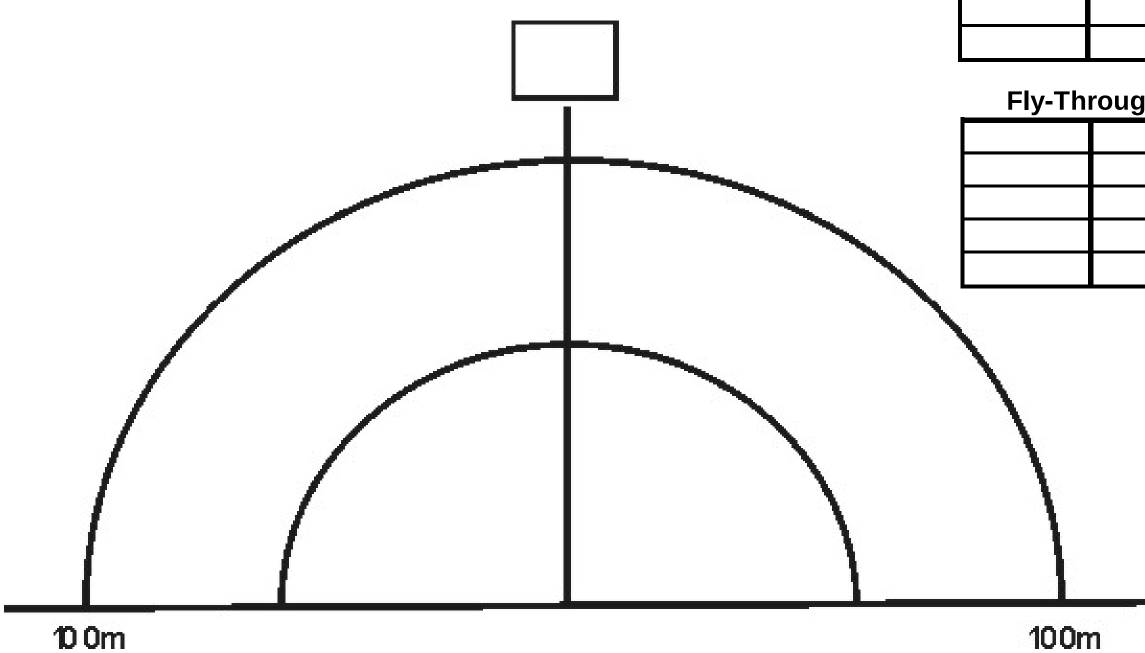
Station Start Time: ____________ **Background Noise Category: ________**

Focal Species	Response Period									
	Flush Period	1st Passive (min. 1-2)	1st Passive (min. 3-5)	VIRA (min. 6)	SORA (min. 7)	LEBI (min. 8)	MOOT (min. 9)	PBGR (min. 10)	2nd Pass. (min. 11-15)	Distance Category

Secondary Species Tally

Species	Tally

Secondary Species Map



Aerial Foragers

Species	Tally

Fly-Throughs

Marsh Monitoring Program - Marsh Bird Data Form

Return by 31 July to Aquatic Surveys Officer, Bird Studies Canada, PO Box 160
Port Rowan, Ontario, Canada, N0E 1M0

Mapping Symbols

RWBL (circled)	**Singing/calling bird.**
RWBL ─┤├─ RWBL (circled)	**Simultaneous song/different birds of the same species.**
SWSP (in house shape)	**Pair together** (assumed mated).
CAGO (in hexagon)	**Family group** seen. Include number of observed accompanying adults only beside the symbol. Do not record number of young.
● GTBH	**Observed** but not calling or singing. Bird may be simply feeding, loafing, landing or flushing from the sample area.
RWBL → RWBL (circled)	**Known change in position.**
✶ TRES	**Nest**

24-Hour Time

12-Hour	24-Hour
1:00 pm	13:00
2:00 pm	14:00
3:00 pm	15:00
4:00 pm	16:00
5:00 pm	17:00
6:00 pm	18:00
7:00 pm	19:00
8:00 pm	20:00
9:00 pm	21:00
10:00 pm	22:00
11:00 pm	23:00
12:00 am	24:00

Focal Marsh Bird Species

American Bittern (AMBI)
American Coot (AMCO)
Belted Kingfisher (BEKI)
Black-crowned Night Heron (BCNH)
Black Rail (BLRA)
Black Tern (BLTE)
Common Moorhen (COMO)
Forster's Tern (FOTE)
Great Blue Heron (GBHE)
Great Egret (GREG)
Green Heron (GRHE)
King Rail (KIRA)
Least Bittern (LEBI)
Pied-billed Grebe (PBGR)
Sandhill Crane (SACR)
Sora (SORA)
Virginia Rail (VIRA)
Yellow Rail (YERA)

Background Noise Categories

Category	Definition	Code
No Noise		0
Faint Noise		1
Moderate Noise	Can't hear some birds beyond 100 m	2
Loud Noise	Can't hear some birds beyond 50 m	3

Distance Categories

Description	Code
Within 100 m of focal point	1
Beyond 100 m of focal point	2

Marsh Monitoring Program - Marsh Bird Data Form

Observer: Ryan Archer		Route name: Mud Lake Marsh	
Date (dd-mm-yr): 25-05-07		Visit No.: 1	
Beaufort Wind Scale No.: 1	Cloud Cover (10ths): 1/10		Air Temperature (C or F): 20°C
Has the habitat on your route changed from previous years? Yes: No: Not applicable: ✓			
Remarks: 5 young AMCOs seen with 2 adults; LEBI heard calling after survey ended			

STATION A

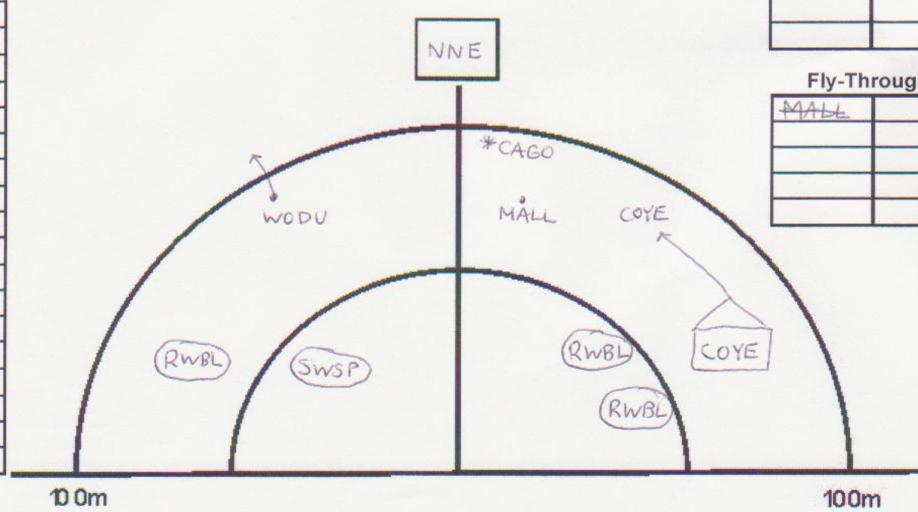
Station Start Time: 19:15 **Background Noise Category:** 1

Focal Species	Response Period									
	Flush Period	1st Passive (min. 1-2)	1st Passive (min. 3-5)	VIRA (min. 6)	SORA (min. 7)	LEBI (min. 8)	MOOT (min. 9)	PBGR (min. 10)	2nd Pass. (min. 11-15)	Distance Category
GBHE	✓									1
GBHE	✓									1
PBGR		✓	✓	✓						1
SACR			✓							2
VIRA				✓		✓				1
AMCO									✓	1
AMCO									✓	1
BLTE									✓	2
BLTE									✓	2

Secondary Species Tally

Species	Tally
RWBL	3
COYE	2
SWSP	1
CAGO	1
MALL	1
WODU	1

Secondary Species Map



Aerial Foragers

Species	Tally
TRES	III + 10

Fly-Throughs

~~MALL~~	

Chapter 8
Landscape-Based Indicators

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Introduction

The objectives of this chapter are to define the role of landscape data in wetland monitoring, assess landscape-scale monitoring methods and identify an operational strategy for making recurring assessments of the extent, composition and vigor of coastal wetland complexes at a synoptic scale. The landscape metrics used are quantifiable measurements of these wetland attributes, based on data that are spatially explicit and geographically referenced (i.e., geospatial). In the context of coastal wetland assessment and management, there are several areas where landscape metrics are useful; these are briefly presented in this introduction and described in greater detail later in this chapter. It is important that landscape data be linked to field data for both validation and scaling. Integration of landscape-scale metrics with ground-level wetland functional assessments is critical to managing these resources across the Great Lakes coastal zone.

A) ***Wetland Inventory*****:** A comprehensive assessment of the location and extent of wetland area that exists over the landscape is typically expressed in a geospatial context as a census of a particular time period (e.g., one year). A comprehensive wetland inventory provides a sampling "frame" from which particular sites can be selected for ground-based assessment and monitoring. It also can provide estimates of various types of wetlands and how they may change over time. A wetland inventory that consists of maps and statistics can also provide a reference to assist local, state, tribal and federal agencies in evaluating projects for which they have permitting and oversight responsibilities. A census of wetland identification from ground-based surveys over the entire Great Lakes coastal zone is impractical and has never been attempted; instead, aerial photography and satellite sensors have been used to generate wetland inventories in the past.

B) ***Wetland Condition*****:** Many measurements aimed at assessing wetlands conditions are obtained from ground-based sampling (e.g. water quality, biotic assemblages) and are described in other chapters of this report. However, some aspects of wetland conditions can only be assessed using remote sensing. For example, changes in spectral reflectivity that indicate vegetative stress can only be assessed synoptically using remote sensing. In addition, the prevalence of some invasive or opportunistic plant taxa can best be assessed comprehensively using remote sensing, which also provides ideal tools for looking at spread over time. Recurring remote sensing assessments can also provide a means to monitor wetland loss, hydrologic alterations, changes to physical habitat condition and other types of wetland change.

C) ***Wetland Setting*****:** Natural aspects of the landscape in which wetlands exist (e.g., hydrology, climate, surface geology) significantly affect their physical and biotic characteristics. Responses to anthropogenic activities in the landscape (e.g., agriculture and development) are a major cause of wetland loss and degradation. Anthropogenic stressors are frequently physically removed from wetlands, with influences exerted over relatively large areas. Information on climate (e.g., temperature, precipitation), surface geology (e.g., soils) and watershed characteristics (flow direction, volume, duration) are often available as geospatial data themes. Landscape data on anthropogenic stressors are widely available and can be used to assess both the intensity and types of impacts and spatial variability. Adjacent land cover may also be relevant to wetland conditions, as natural lands surrounding wetlands can buffer their vulnerability to anthropogenic impacts.

D) ***Wetland and landscape spatial configuration*****:** The spatial configuration of coastal wetlands (i.e., size, shape, and interspersion within the larger landscape) can be important in regulating their function and conditions. Some questions require the consideration of wetlands as an interconnected suite rather than in isolation. For example, wetlands collectively support biodiversity over large areas, a function that is dependent on wetlands' connectivity and diversity in size, type and composition. Landscape metrics that lend themselves to remote sensing include those describing connectivity or spacing among wetlands, fragmentation or heterogeneity of land-cover categories, and patch size, patch shape, and patch interspersion.

Data needed to compute these types of landscape metrics are either obtained directly from remote sensing (e.g., land use/land cover maps based on interpretation of aerial photographs or classification of satellite imagery), or assembled via spatial interpolation of ground-based surveys (e.g., census maps, soil surveys, bathymetry). For individual wetlands or over a small area, these data might be collected by a specific group using limited resources and techniques. On a broader scale, the cost, effort and technical expertise needed to collect, analyze, and maintain such spatial datasets are typically beyond the resources of individual organizations. Consistent, repeatable and broadly applicable data sets are needed to facilitate assessment of wetland conditions across the Great Lakes coastal zone. Even if local-scale assessments could be universally conducted across the region, a common protocol for landscape data would be needed to ensure that such data could be merged to create regional inventories and assess status and trends. Reliance on geospatial data and airborne/satellite imagery obtained and processed by collaborating government entities or commercial enterprises is often the only means for assessing landscape changes across the region. This chapter summarizes the types of landscape data available from such sources, the frequency with which they are updated and reassessed, and the constraints on the type of landscape metrics that can be generated.

The techniques and information in this chapter should be used in conjunction with the field-based indicators documented elsewhere in this report to determine causal relationships that exist between the broader landscape-level forcing functions, such as those associated with water/soil quality, habitat characteristics, or wetland ecological processes. Broader landscape conditions include disturbance factors, which may be particularly difficult to measure and characterize in field surveys for numerous reasons. Remote sensing can provide a repeatable and comprehensive view of broad spatial characteristics across the Great Lakes coastal zone.

Existing Landscape Indicators

This section reviews existing landscape indicators developed for monitoring wetland conditions across the region. Since these indicators rely on regularly updating landscape data, which all too often does not occur, comments are provided on how monitoring shortfalls affect indicator reporting.

SOLEC Indicators

The State-of-the-Lake Ecosystem Conferences (SOLEC) report on the condition of the Great Lakes on a biennial basis. Several SOLEC indicators (most recently summarized in the 2005 report by Environment Canada and U.S. EPA) are intended to address landscape condition and trends. Although generally useful as an aggregation of a multitude of methods and results, several of the SOLEC landscape indicators cannot be consistently assessed, because the necessary landscape datasets are lacking, incomplete, inconsistent or not updated frequently enough at the basin-wide scale. Several SOLEC landscape indicators have not advanced beyond the proposed stage due in part to a paucity of suitable data on adjacent land uses; the extent and quality of nearshore natural land cover; and the quality and protection of special lakeshore habitats (islands, cobble beaches, sand dunes and alvars). The Land Cover/Land Conversion SOLEC indicator was not assessed in the most recent biennial assessment due to lack of a consistent, updated basin-wide dataset at a sufficient spatial resolution. The Wetland Area by Type indicator was assessed in the 2005 report, but could not be addressed in any standardized way. The authors of that indicator report noted that available inventories were static, outdated and lacked accurate area information. They called for the development of consistent, improved, accessible and affordable remote sensing data to complete these assessments on a regular basis. The Extent of Hardened Shoreline indicator has not been reported on since 2001, due largely from a lack of updated basin-wide digital shoreline detail since the early 1990s. The report suggests a 10-year basin-wide cycle with five-year assessments in areas where shoreline hardening is of particular concern.

GLEI Indicators

The Great Lakes Environmental Indicators Initiative (GLEI) was a comprehensive effort to develop indicators across a range of biotic and landscape variables, with a particular focus on hydrogeomorphically defined coastal wetlands, as well as high-energy shorelines and embayments (Niemi *et al.* 2007). One of the important classes of landscape indicators was the type and degree of land use/land cover (LULC) change, which is an indicator of changing human demographics, natural resource uses, agricultural technologies, economic priorities, and land tenure systems. Different land uses impose different environmental stresses on natural plant and animal communities, with consequent implications for water quality, climate, ecosystem goods and services, economic welfare, and human health (Gutman *et al.* 2004).

Both raw Landsat sensor data (1992 & 2001) and existing, Landsat-based, thematic data from various state and federal sources were used to assemble and quantify LULC data for the U.S. portion of the Great Lakes watershed. Because of some incompatibilities among different temporal images of Landsat, a variety of adjustments were essential to achieve consistent imagery between the 1992 and 2001 data (Wolter *et al.* 2006). Wolter et al. (2006) found that approximately 2.5% of the U.S. Great Lakes watershed underwent LULC transitions, with a 33% increase in low-intensity development, a 7% increase in road density, and a 2.3% decrease in mature forest area. New development was concentrated in coastal areas – over one-third of wetland losses occurred within 10 km of the coast, with much of that in the nearest kilometer.

The GLEI landscape study also used multivariate analysis to synthesize a set of 86 spatially delineated variables into five categories of anthropogenic stress: agriculture (21 variables), atmospheric deposition (11 variables), human population (five variables), land cover (23 variables), and point source pollutants (26 variables; Danz et al. 2007). Products of this work include a cumulative index of anthropogenic stress defined for 762 watershed-based units across the U.S. side of the Great Lakes basin, and for subsequent higher resolution watershed delineations also across the basin. These demonstrate the strong spatial patterning in landscape-scale stressors; these are currently being related to variation in fish, amphibian, bird, water quality and other indicators to build landscape-based stress-response models. Subsequent watershed delineations have a higher resolution, with 3,591 watersheds covering the U.S. side of the Great Lakes. Recently, an integrated U.S./CA watershed delineation was completed for the basin, describing 5,890 watersheds across the entire basin. More details about the stressor summaries associated with these watersheds are provided in the "GLEI Stressor Gradient" section of this report.

Landscape Metrics as Indicators of Coastal Wetland Condition

Interconnected wetland patches function as a network (e.g., within a watershed or migratory bird flyway), and have the cumulative functional capability of all the individual wetlands. A collection of wetlands in the landscape may be particularly important for providing a vital ecological unit for some animals, while other animals may require a mixture of wetland and upland areas for different portions of their life cycle or their daily activities (e.g., reproduction, resting, and foraging). The absence of such wetland complexes or integrated upland and wetland conditions may completely interrupt or degrade the reproduction rates, survival rates and overall fitness of some plant and animal species. Fragmentation of the landscape may result in the isolation of coastal wetlands, with the remnants of the formerly larger interconnected wetland complexes being replaced by less heterogeneous landscapes that are dominated by agriculture, urban or rural human habitations, or industrial land. Such conversions of wetland to other land-cover types may reduce the functional capability of coastal wetlands and also increase the likelihood that remaining wetlands are further affected by new land-use types (Tiner *et al.*, 2002). The capability of coastal wetlands to continue to function and provide ecological benefits to the residents of the Great Lakes (e.g., improving and maintaining clean water; providing critical habitat for plants and animals; and shoreline stabilization and protection) is dependent upon their surrounding landscape.

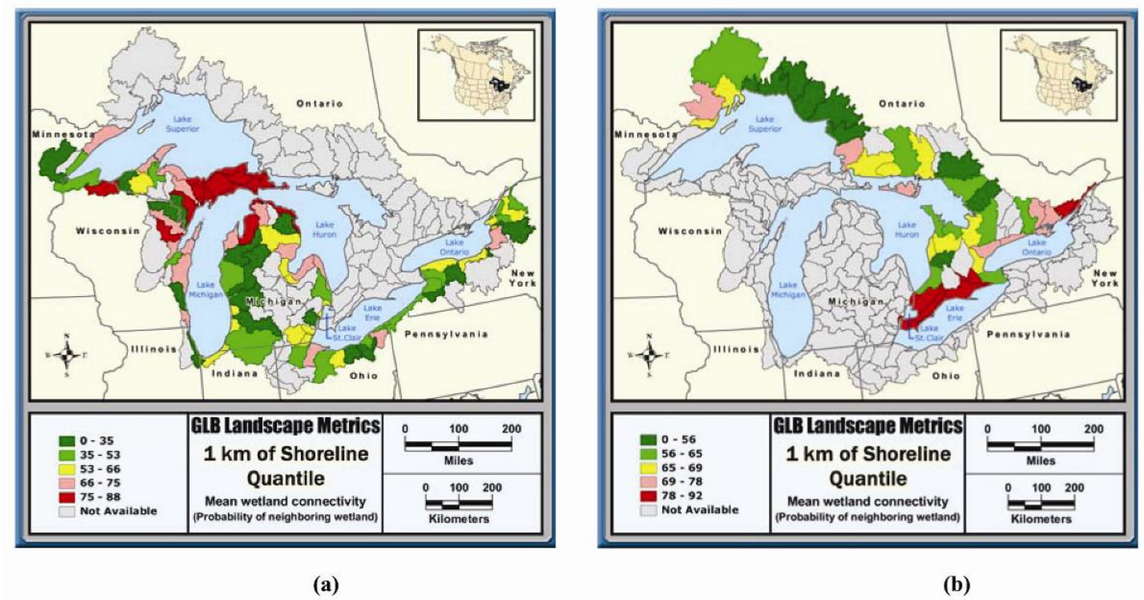
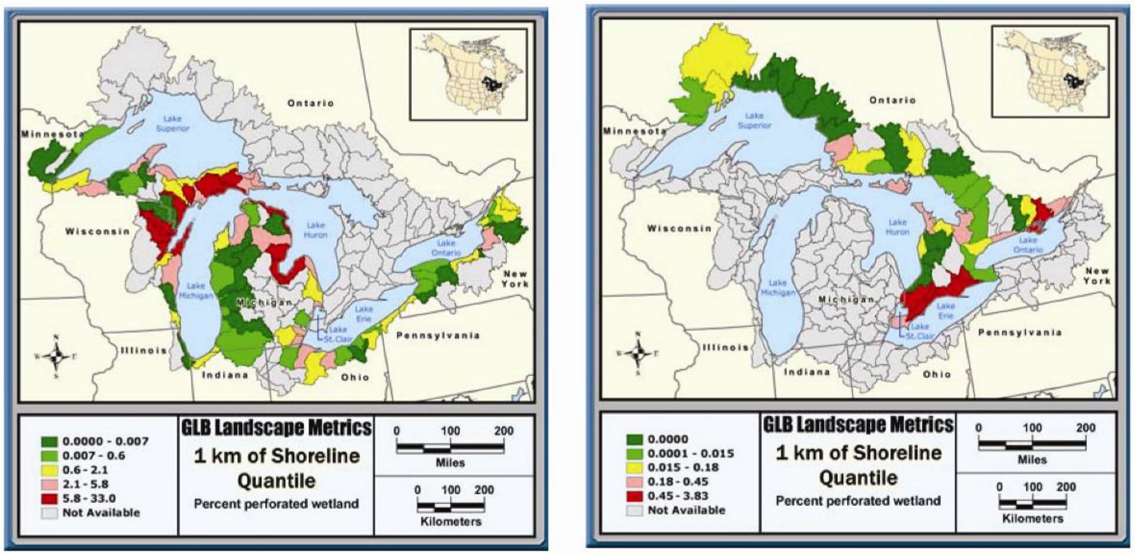


Figure 8-1. Mean wetland connectivity, a measure of landscape fragmentation, in a one-kilometer coastal region of the entire Great Lakes basin. Because these analyses use two differing land cover data sets, results for (a) U.S. and (b) Canada may not be directly comparable (from Lopez et al., 2005).

Wetland interconnectivity (Figure 8-1) is one way of measuring the fragmentation of coastal wetlands in Great Lakes coastal regions (Lopez *et al.* 2005). Figure 8-1 and figures 8-2 to 8-5 are based on U.S. NOAA C-CAP data land cover (30m spatial resolution ETM+ Landsat based) and Canadian OMNR land cover (30m spatial resolution Landsat TM-based).A standard and uniform method for measuring wetland interconnectivity in coastal regions (e.g., within one km of the shoreline) is to determine the probability of a wetland area cell having a neighboring wetland, using a "moving window" over a GIS data set (e.g., a 9 pixel x 9 pixel area) to examine the boundaries between all pixel pairs. Interconnectivity is measured as the number of boundaries where both pixels are wetland, divided by the total number of wetland boundaries (regardless of neighbor land-cover type), with high values being better connected than low values.

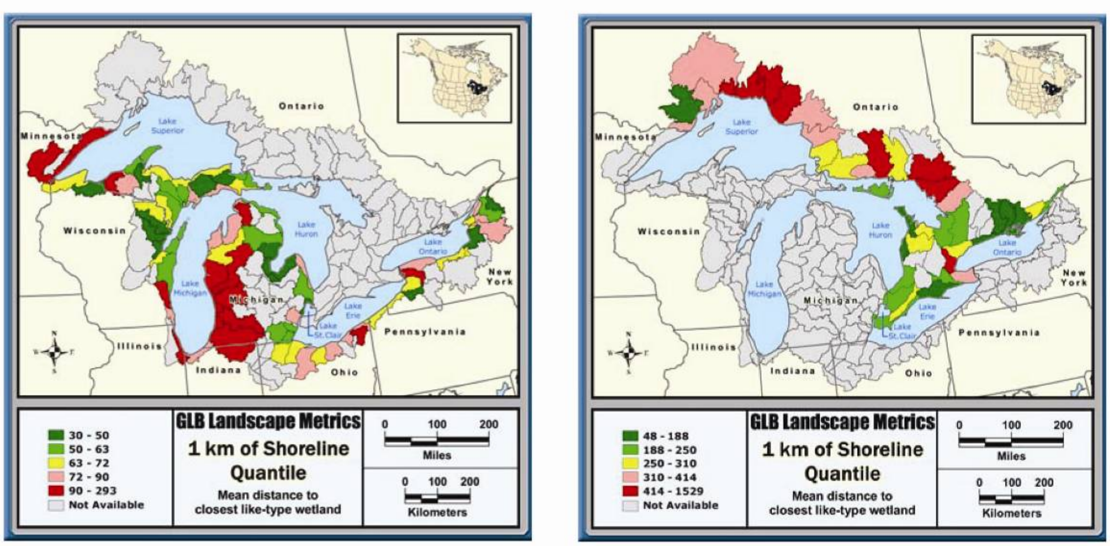
The relative percentage of "perforated" wetlands (Figure 8-2) is another measurement of ecosystem fragmentation (Turner et al., 2001), and is also calculated by using a moving window across the GIS land-cover data set. When the percent wetland in the window exceeds some threshold (60% in a 9 X 9 pixel square in this example), and is greater than the window's mean wetland connectivity value, the wetland cell in the center of the window is categorized as perforated. The number of perforated wetland cells is then divided by the total land area (i.e., excluding cells classified as water) to derive the percentage of perforated wetland. Perforated wetland generally consists of a patch of wetland with center upland areas, such as would occur if small clearings were made within the wetland, or if an area of wetland contained an interior upland region (Lopez et al., 2005). Perforated wetlands may not provide suitable interior habitat for some wetland species, but may provide suitable habitat for plants and animals that require fluctuating wetland conditions and isolated upland areas. High perforation values may be detrimental for some ecological functions and species but advantageous for others.



(a) (b)

Figure 8-2. Percentage of perforated wetland, a measure of wetland connectivity, in a one-kilometer coastal region of the Great Lakes basin. Because these analyses use two differing land cover data sets, results for (a) U.S. and (b) Canada may not be directly comparable (from Lopez et al., 2005).

Fragmentation of coastal wetlands may lead to increased interwetland distances as other land-use types develop in the intervening spaces (e.g., farm land or human habitations). Mean distance to the closest like-type wetland (Figure 8-3) can be used to describe proximity of similar wetland habitat (Lopez et al., 2002); for example, neighboring emergent wetlands for waterfowl resting and foraging, or forest wetlands for migratory song bird resting and foraging. The mean distance from each wetland patch to its nearest neighboring wetland patch should be measured from one patch edge to another patch edge, and may consist of multiple measures, such as the mean distance of three nearest patches (Lopez et al., 2006). This metric is useful in determining relative wetland habitat suitability at scales that are ecologically meaningful for specific plants and animals; because these are taxa specific, the ecological endpoint(s) of interest must be established in advance.



(a) (b)

Figure 8-3. Mean minimum distance to closest like-type wetland patch (i.e., emergent-to-emergent, forested-to-forested, and scrub/shrub-to-scrub/shrub) within each hydrologic unit. Because these analyses use two differing land-cover data sets, results for (a) U.S. and (b) Canada may not be directly comparable (from Lopez et al., 2005).

The Shannon-Wiener index and Simpson's Index are two different ways of measuring the diversity and distribution – and by proxy the interspersion – of land-cover types in the vicinity of Great Lakes coastal wetlands. The Shannon-Wiener Index (H) of land cover type diversity is calculated as:

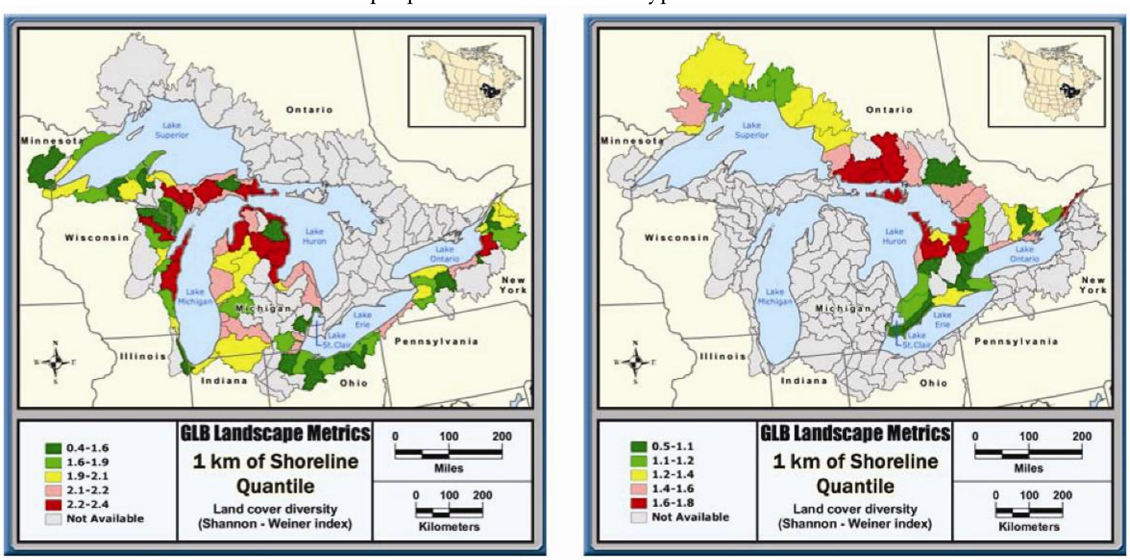
$$H = -\sum_{i=1}^{m} P_i * \ln P_i$$

where Pi = the proportion of land-cover type i.

Shannon-Wiener Index values increase as the number of land-cover/ land-use types within the reporting unit increases, with higher index values having more diverse land cover, often as the result of anthropogenic conversions of the original land cover types. Because higher Shannon-Wiener diversity in coastal areas (Figure 8-4) does not always indicate greater opportunities for species variety (i.e., land-cover diversity includes agriculture and urban), Simpson's Index can be used to better describe the distribution of the land cover in a coastal region (Figure 8-5). Simpson's Index is a quantitative measure of the evenness of the distribution of land-cover classes and is most sensitive to the presence of common land-cover types within a reporting unit. Simpson's Index values range from 0 to 1, with 1 representing perfect evenness of all land-cover types within a reporting unit. Simpson's Index (C) is calculated as:

$$C = 1 - \sum_{i=1}^{m} P_i^2$$

where Pi = the proportion of land-cover type i.



(a) (b)

Figure 8-4. The Shannon-Wiener Index is one of several ways to measure the diversity of land-cover types within a specific area of the landscape. The Shannon-Wiener values increase as the number of land-cover/land-use types within the reporting unit increases. Because these analyses use differing land-cover data sets, results for the U.S. and Canada are not directly comparable (from Lopez et al., 2005).

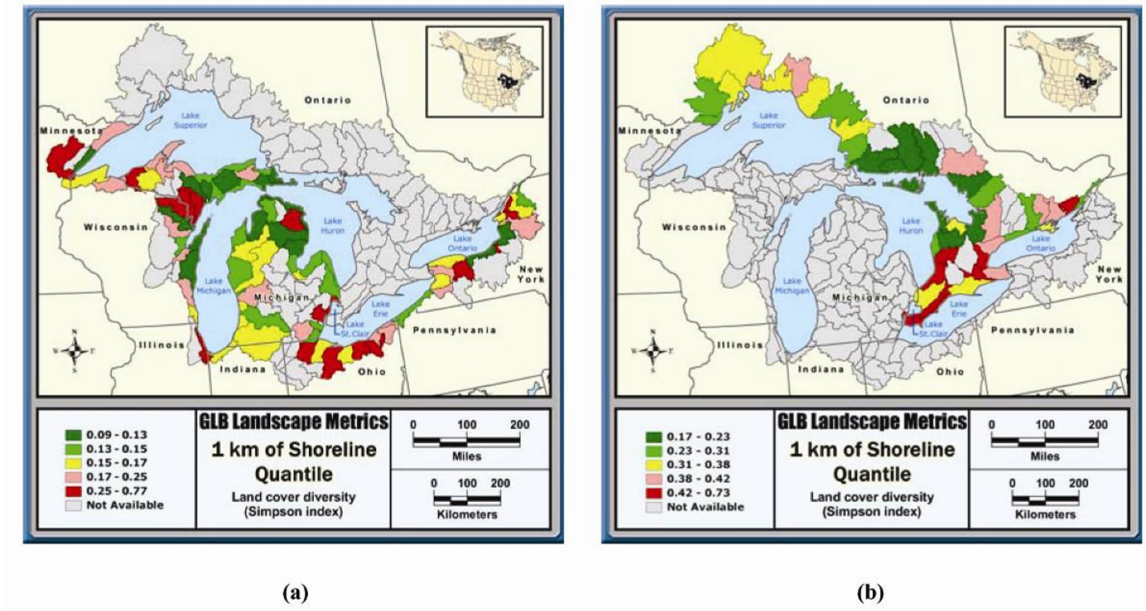


Figure 8-5. Simpson's Index is a measure of the evenness of the distribution of land-cover classes within a specific area of the landscape. Because these analyses use differing land-cover data sets, results for the U.S. and Canada are not directly comparable (from Lopez et al., 2005).

Other Applications of Coastal Wetlands Landscape Monitoring Protocols

Lake-wide Management Plans

A lake-wide management plan, or LaMP, is a plan of action to assess, restore, protect and monitor the ecosystem health of a Great Lake, produced by states and coordinated by the U.S. Environmental Protection Agency's Great Lakes National Program Office and Region 5. A LaMP is used to coordinate the work of all the government, tribal and nongovernmental partners working to improve the lake ecosystem. A public consultation process is used to ensure that the LaMP is addressing the public's concerns. Because LaMP reports are biennially updated, they are especially dependent upon current landscape metric and indicator maps, specifically to guide action plans for Great Lakes wetlands assessment, restoration, protection and monitoring. Current and past LaMP reports are available at www.epa.gov/glnpo/gl2000/lamps/index.html.

Great Lakes Interagency Task Force

The Wetlands subcommittee of the Great Lakes Interagency Task Force is mandated to coordinate activities among U.S. federal agencies towards the accomplishment of: 1) developing, implementing and tracking the restoration or protection of 200,000 hectares of wetlands in the basin (both coastal and inland); 2) streamlining and coordinating federal wetland management and permitting programs; and 3) updating the National Wetland Inventory. Existence of consistent, basin-wide wetland and land-use/land-cover datasets is integral to accomplishing these goals.

Consortium Wetlands Inventory

The 2004 Great Lakes Coastal Wetland Inventory was developed as a binational initiative to create a single classified inventory of all coastal wetlands of all five Great Lakes and their connecting channels in both the U.S. and Canada.

Coastal wetlands in the inventory were classified and attributed based on a hierarchical hydrogeomorphic scheme (detailed in Albert et al. 2005). Wetlands were first divided into three broad hydrogeomorphic types (lacustrine, riverine, and barrier-protected), and then further subdivided based on physical features and shoreline processes. Each wetland type is expected to have associated floral and faunal communities and specific physical attributes related to sediment type, wave energy, water quality and hydrology. The classification scheme addresses a longstanding interest in organizing wetland information in order to better understand wetland processes and biologic composition (e.g., Herdendorf 1988, Bowes 1989, Minc 1997, Keough et al. 1999), consistent with a hydrogeomorphic (HGM) framework proposed for describing wetlands over a broad range of geographic and geologic conditions (Smith et al. 1995).

The inventory reports the name, coordinates, spatial extent, hydrogeomorphic designation and area of coastal wetlands. The inventory includes both a point and polygon coverage, with associated attributes (available as GIS shapefiles at http://www.glc.org/wetlands). The inventory provides a standard reference for the Great Lakes coastal wetland community, a sampling frame for future assessments and a temporal snapshot from which to estimate wetland area by type.

The inventory was built upon the most comprehensive coastal wetlands data available at the time. Although the final product is seamlessly integrated across datasets, it represents a mosaic of a number of different products that use different mapping and protocol standards across a range of time periods. The U.S. dataset was assembled from the National Wetlands Inventory, Wisconsin Wetland Inventory, Ohio Wetland Inventory, and U.S. Fish and Wildlife Service reports and hard copy maps describing coastal wetlands across the Great Lakes basin (Herdendorf et al. 1981). The Canadian dataset was built from "The Ontario Great Lakes Coastal Wetland Atlas" (March 2003), with spatial extents obtained from the Ontario Ministry of Natural Resources (OMNR) digital Evaluated Wetlands polygon data. Data gaps were filled using air photo interpretation following National Biological Service guidelines (Owens and Hop 1995) or hydrogeomorphically based digitization/delineation following guidelines described in the Great Lake Commission's Great Lakes Coastal Wetlands Classification First Revision (July 2003).

The Consortium inventory attempted to include all known coastal wetlands of the Great Lakes and represents the most spatially complete and comprehensive binational digital database for the basin. Nevertheless, the inventory has some shortcomings, including the omission of wetlands where data were not available and insufficiently resolved classification of large, multifaceted wetland complexes. Many of the omissions and misclassifications reflect the nature and age of the baseline data sets used; for example, the U.S. National Wetlands Inventory dates from the 1970s, and existing inventories are known to be incomplete for the Canadian sides of Lake Superior and Lake Huron (Ingram et al. 2004, Wei and Chow-Fraser 2006). Other omissions arise due to designating U.S. wetlands as coastal based on a distance-from-lake rather than elevation-above-lake criteria (Moffett et al. 2007). If the wetlands inventory is to serve as the sampling "frame" for future assessments in the Great Lakes, errors of omission or inadequate classification would preclude some wetlands from consideration and would bias estimations of wetland area or condition by type. A secondary inventory classification attempts to address representation of large wetland complexes, but a better eventual solution would be to subdivide these polygons into smaller units that appear as separate entities.

Such issues are to be expected with any large data-assembly project, and in no way detract from what the inventory has accomplished. However, they do highlight the need to make the database expandable and updatable in the future. Rather than being static, the Consortium Inventory should capture the dynamic nature of wetlands themselves and our knowledge about them. A mechanism for correcting omissions and misclassifications and expanding attribute data based on new information acquired by researchers and managers needs to be developed. Wetland inventory efforts conducted by others (e.g., Chow-Fraser 2002, Wei and Chow-Fraser 2007, Moffett et al. 2007) should be incorporated where appropriate. The addition of attributes describing ecological function or biological composition, as well as those describing geological origins, would serve a wider range of applications. We recommend that an entity, mechanism and financial support to manage, update and host the database into the future be identified. We also recommend finding a way to serve the inventory to the public in some more accessible formats in addition to the current GIS shapefiles.

Wetlands and Landscape Mapping Programs

Several completed or ongoing landscape mapping programs in the Great Lakes serve as sources of landscape data. These programs are described and compared in tabular format below (Table 8-1).

Table 0-1. Listing of available landscape maps from historical and ongoing mapping programs.

Historical Wetland Map	Resolution	Agency	Era	Extent	Base data
U.S. National Wetlands Inventory (NWI) www.fws.gov/nwi/	.01-1m	U.S.FWS	1970s-present	U.S. Nationwide	Aerial Photos
National Land Cover Database (NLCD) landcover.usgs.gov/natllandcover.php	30 m	U.S. EPA	2001	U.S. Nationwide	Landsat
Coastal Change Assessment Program (C-CAP) www.csc.noaa.gov/crs/lca/ccap.html	30 m	NOAA	2001	U.S. Coastal Basins - Lower 48	Landsat
Canadian Wetland Inventory www.cwi-icth.ca/	30 m	Environment Canada	2000	Canada Nationwide	Landsat/Radarsat
Minnesota CWAMMS www.pca.state.mn.us/water/wetlands/cwamms.html	.01-1m	Minn. DNR & Pollution Control Agency	2006-present	Minnesota	Aerial Photos and Satellites
Wisconsin WWI www.dnr.state.wi.us/org/water/fhp/wetlands/mapping.shtm	.01-1m	Wis. DNR	1978-present	Wisconsin	Aerial Photos
Wisconsin – WISCLAND dnr.wi.gov/maps/gis/datalandcover.html	30m	Wis. DNR	1992	Wisconsin	Landsat
Michigan Resource Information System - Current Use Inventory (MIRIS-CUI) www.mcgi.state.mi.us/mgdl/?rel=thext&action=thmname&cid=5&cat=Land+Cover%2FUse+MIRIS+1978	.01-1m	Mich. DNR	1978	Michigan	Aerial Photos

Spatial and Temporal Monitoring Considerations

Comprehensive Inventories versus Sampling Approaches

Almost all field-based monitoring efforts implemented across large regions require a sample design that allows for some level of statistical inference. Since the entire population cannot be sampled on the ground, the problem of selecting "representative" samples to detect trends in the larger population arises, which raises several questions:

- What is the true target population? (a seemingly obvious question that becomes less obvious as the population is defined –"what is a lake?" is a good example)
- What level of change should the program be able to detect? (e.g. 10% change in 10 years – what degree ("effect size") is biologically or ecologically relevant?)

- What is the desired power of the design (i.e. what is the probability of detecting a trend as large as the "effect size" when one occurs?)
- What is the appropriate balance of statistical power, alpha level, and effect size, and how many samples are required to achieve this?

Fortunately, landscape metrics derived from remotely sensed data permit "wall-to-wall" coverage across the entire basin population, thus providing a basis for identifying target sample populations for field-based monitoring. Landscape metrics derived from categorized imagery can be calculated across a range of spatial scales or summary units, from fine-scale watershed delineations to eight-digit hydrologic unit codes (HUCS). This provides a means of integrating landscape data with other types of monitoring data. In addition, analysis of temporal sequences of images provides a whole-basin view of landscape change, making this an important covariate dataset for accounting for trends in biotic data. The comprehensive inventories currently available have moderate-to-coarse resolution. Fine-scale remote-sensing data, such as aerial photography, Quickbird or LIDAR type imagery, have small spatial extents and are subject to the sampling design constraints noted above.

Spatial scale: stratification and hierarchical designs for landscape analyses

Identifying the basic sampling units and the degree to which these units represent a larger population is a fundamental and problematic issue in monitoring. Different biotic condition variables – e.g., birds, fish, herptiles – respond to environmental stress at different scales, and the extent to which an indicator "represents" some area of land is also variable (Brazner, et al. 2007*;* Brazner, et al. *in press*). In addition, a landscape such as the Great Lakes basin can be partitioned into different types of land units, at scales ranging from ecological region classifications with varying delineation criteria (e.g., Omernik 1987, Bailey 1987) to watersheds, which also can be defined at varying sizes. These spatial stratifications are important parts of the monitoring design, because much of the variation in biotic communities across of a region of this size can be attributed to biogeographic factors (climate, regional landform), and any landscape stress-biotic response models need to account for this scale of variation.

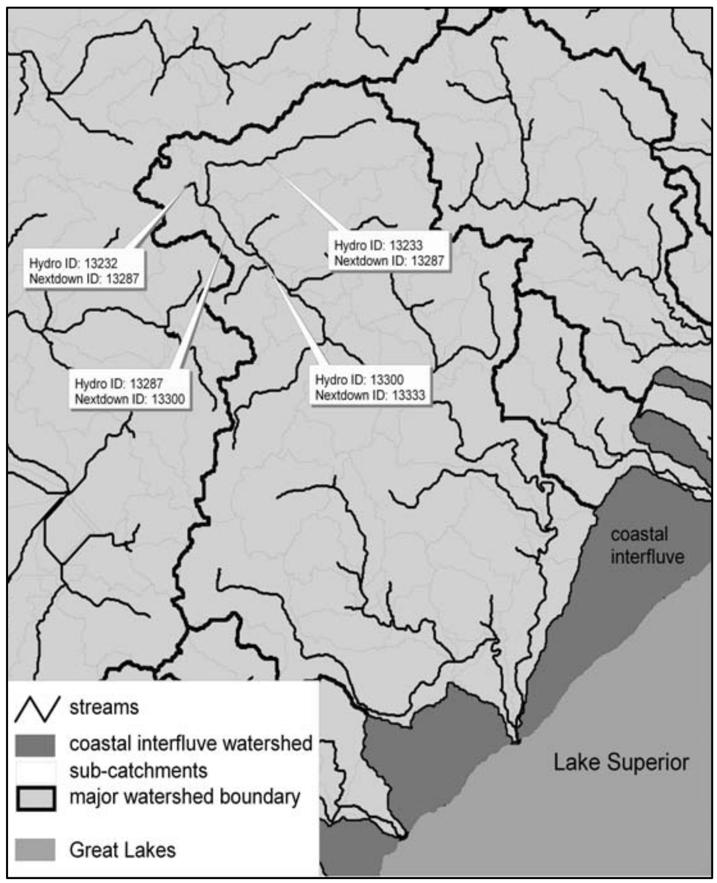


Figure 8-6. Network connectivity of ArcHydro catchments. Each stream segment is identified by its unique numerical label (Hydro ID) and by the identity of the "next downstream" segment. Figure also shows coastal interfluve areas (areas of direct overland flow to the lake).

Within broad-scale ecological regions, many stressors to coastal and aquatic ecosystems are delivered via hydrologic processes. Nested watersheds provide an important spatial framework for interpreting data and allow landscape metrics to be summarized at multiple scales as appropriate for the various biotic response variables. The different scales at which species respond to landscapes has been a confounding issue in developing monitoring programs, and has contributed to the lack of concordance among agencies implementing these programs. To date, there have been few attempts to develop a scalable framework that is applicable across different environmental indicators. The U.S. EPA Science to Achieve Results (STAR) program's Great Lakes Environmental Initiative (GLEI) project tested several watershed delineation methods that provide a common sampling framework for investigative teams operating at a range of spatial scales – from point samples of contaminants in sediments to sequences of 100 m. radius plots for breeding bird surveys (Hollenhorst, et al., 2007). These variable size sample areas were integrated to define sampling complexes encompassing the total area sampled by all teams visiting a site. These complexes became a basis for summarizing anthropogenic stressors within complex-specific watersheds. This allowed the development of stressor-response models in which the dependent and independent variables were at optimal scales for the indicator of interest.

Recent advances in watershed delineations have led to the development of hierarchical and scalable watershed classifications. One of these approaches (ArcHydro model) uses standard digital elevation models (DEMs) to delineate individual watersheds for each stream segment (reach) between stream confluences (Maidment et al. 2002). Stream reaches are numbered in sequence so that each is characterized both by its own unique identification label and by the "next-down" reach into which it flows (Figure 8-6). Maintaining this network identity allows watersheds to be scaled by concatenating stream reaches, consequently providing a platform on which to summarize environmental stressors at multiple spatial scales. This system also allows the identification of coastal interfluves (Figure 8-6), which are land areas between stream mouths that drain directly to the lake. Typically neglected in watershed analyses, coastal interfluves account for most of the shoreline length, and are thus important contributors to nearshore environments of the Great Lakes.

Temporal Scale: Providing consistent measurements across the Great Lakes basin

In general, major landscape metrics change slowly, compared with other types of response variables. The average return intervals for forest harvests, for example, are about 100 years, which translates to 1% of the landscape harvested on an annual basis. Rates of forest change due to natural disturbances are even lower. Typical historic stand replacing fire return intervals range from 200-400 years (0.50-0.25% annualized landscape change; White and Host *in review*). Human-caused changes to the landscape such as wetland loss or development occur at greater rates, but still involve relatively low percentages when landscape area is calculated on a basinwide or regional basis. As a result, regional landscapes can be effectively monitored over multiyear time scales – a five-year revisit interval is common for several agencies conducting integrated monitoring approaches (e.g. Route and Elias 2006). Unlike natural disturbances, however, human modification of the landscape tends to be spatially concentrated. The interface between urban/agriculture or urban/forest regions is one example of locations exhibiting rapid rates of land use change; the Great Lakes coasts and inland lakes are another. In areas of great human activity, both the spatial resolution of the source data and the temporal resolution of sampling frequency should be increased to more precisely track these changes; in these cases, a biennial revisit schedule may be appropriate.

Remote Sensing and Ancillary Data Sources

Remote sensors work in many regions of the electromagnetic spectrum from optical and ultraviolet to near infrared to thermal and radar. Similarly, the resolutions vary widely among sensors from kilometers (AVHRR and MODIS) to a few meters (IKONOS). Some of the data sources are free to users (MODIS) or relatively inexpensive (JERS and PALSAR-$25 and $125 per scene), but generally speaking, the finer the resolution the higher the cost. The sensor choice depends on the study area, availability of ancillary data, cost, the resolution desired and what features need to be observed or monitored. To routinely monitor a large regional area such as the Great Lakes basin, moderate resolution (e.g., 30-meter grid cells or ¼-hectare) would be the best choice. High risk areas should be reviewed more closely with higher resolution imagery or air photos and field truth. Sometimes, there are advantages to using coarser resolution data with a frequent (1-2 day) repeat, especially when looking for large-scale features (e.g. algal blooms can be seen in 1 km. MODIS and AVHRR data) or more general regional changes due to climate (e.g. Leaf Area Index and FPAR with MODIS products). Using repeat pass satellite imagery allows the advantage of multi-temporal data analysis. In many cases, however, finer-scale but less frequently generated data are necessary. A monitoring plan using both high and moderate resolution sensors will provide the greatest amount of information.

Traditionally, optical and IR data have been used for land-cover mapping, including wetlands. However, wetlands are difficult to map and monitor using this type of data alone, due to the high variability in wetland morphology and the inability of optical sensors to detect flooding beneath closed tree canopies. There are additional problems associated with cloud-cover and obtaining data with optical systems during timely conditions. Some of the most promising "new" sensors for mapping and monitoring wetlands include those operating in the thermal and microwave spectra. Additionally, unlike optical, thermal or IR data, radar data can be collected during day or night and penetrate clouds so that timely data may be collected. Systems using LiDAR, synthetic aperture radar (SAR) and thermal infrared provide information complementary to optical sensors and will be invaluable in future mapping and monitoring programs.

Types and sources of remotely-sensed data are summarized in Table 2, below. We comment specifically on Landsat imagery because of its widespread use and concerns about its availability in the future.

Landsat Data and the expected future data gap

The Landsat series of optical/IR sensors has been widely used to study land-cover processes. However there is much concern in the scientific community regarding the quality of the current information and availability of future Landsat data, because of problems with Landsat-7, the age of Landsat-5, and the distant proposed launch of the successor satellite (2011 at the earliest). The first Landsat sensor was launched in 1972, while the latest sensor, Landsat-7, was launched in 1999. While Landsat-7 and Landsat-5 are currently operational, Landsat-7 operates with a flawed scan-line corrector (SLC) assembly, causing gaps in the imagery that can be problematic for many applications (25% missing pixels). Despite this data flaw, Landsat-7 will continue to produce a high-quality data product providing global coverage at a 30-m resolution several times annually for the life of the sensor. Currently, the USGS provides a gap-filled image product that is useful for many applications, and researchers are working on methods to provide improved products from the acquired data using advanced image processing methods. However, Landsat-5 (long past its expected lifetime) is currently used extensively due to the diminished capability of Landsat-7.

Scientists and engineers from NASA and NOAA are planning a successor to the Landsat 7 satellite mission (http://ldcm.usgs.gov/LDCMHome.php), with an expected launch in 2011. The inadequacies of Landsat-7 and the expected failure of Landsat-5 by 2010 due to age and fuel depletion means there will likely be a 1-5 year gap in Landsat coverage. The U.S. government has initiated a program to provide alternative non-U.S. earth satellite imagery to current government and nongovernmental U.S.-based Landsat users. Alternate data sources for this gap include the Indian ResourceSat-1, which carries 23-m and 55-m ground resolution sensors, the Chinese/Brazilian CBERS-2, with several sensors on board ranging from 20- to 80-m resolution, France's SPOT sensors, and the Japanese ASTER sensor, whose data are comparable to Landsat-TM but at 15-m resolution, and with a smaller spatial extent. The anticipated gap in coverage by Landsat will cause difficulties, but this effort is meant to provide data sharing agreements and access to imagery that would otherwise be difficult for many users to obtain. The U.S.DA has already begun purchasing AWiFS imagery for their crop mapping activities over the United States. These data and others like it will likely be more available once the Landsat gap actually arrives.

Table 8-2, below, provides a comparison of current resources available, but it is not exhaustive. Mention of trade names or commercial products does not constitute endorsement or recommendation for use. Reference: www.asprs.org/news/satellites/

Improving Wetland Classification Approaches through Ancillary Data and Processing

Several types of geographic ancillary datasets are useful for wetland mapping, including elevation data and soils maps, especially in combination with remote sensing data. Some new processing approaches (described below) can also be used to improve wetland mapping accuracy.

Elevation Data
There are typically one or more Digital Elevation Model (DEM) datasets available for Great Lakes coastal wetlands. Canada DEMS are available from http://www.geobase.ca/geobase/en/data/cded/cded1.html. DEM utility depends on the resolution of the model, both in elevation and on the ground. Generally, the 30-m DEM available from the USGS is too coarse for the fine-scale microrelief that often results in wetland development. Interferometric SAR and LiDAR are two sources of remote sensing that can produce higher resolution DEMs.

Soils
The NRCS has created soils maps with classification of hydric soils that can be a useful ancillary dataset in mapping wetlands. There are two U.S. soils maps sources: U.S. General Soil Map STATSGO available for every state but at coarser scale (www.ncgc.nrcs.usda.gov/products/datasets/statsgo/) and Soil Survey Geographic SSURGO available for all states but Alaska (www.ncgc.nrcs.usda.gov/products/datasets/ssurgo/index.html). Canada Soils Maps are available from: http://res.agr.ca/cansis/systems/online_maps.html.

Processing Approaches
Object-based classification methods, such as those available in the eCognition image processing software, may be useful for wetland mapping. This type of classification involves two steps: 1) spatial objects are formed using a region-growing segmentation algorithm to merge pixels of homogeneous type; then 2) image classification techniques are applied using traditional statistical methods, a fuzzy logic rule base, or a combination of both methods. The segmentation phase provides additional attributes describing the spatial context and morphology of features that can be used to inform the classification beyond spectral values alone. Moreover, the segmentation phase can be reiterated at various scales to capture the range of features contained in the image. This also allows heterogeneous wetland types (e.g., wetlands containing some open water pixels mixed with denser canopy) to be grouped or not depending on the scale of the segmentation. The operator makes the decision. Grenier et al. (2007) have applied this processing approach to Landsat/Radarsat mapping in Quebec (Canada) and describe the process and results in detail.

Table 8-2. List of current and historical sensor data available, the spectral regions in which they work, spatial resolution, swath size and revisit time, period of operation, approximate cost and a link to further information on each sensor and where the data can be obtained.

Sensor	Frequency	# Spectral Bands	Spatial Resolution	Size/ revisit time	Operation period	Cost	Source
AVHRR	MS	4-6	1.1 km	2400 x 6400 km single swath, other options	1978-present	Free (single scene) - $190 stitched geo-registered segments	http://edc.usgs.gov/products/satellite/avhrr.html#description
MODIS	MS	36 0.4 - 14.5 µm	250-1000m	2,300km 1-2 day revisit	2000 - present	Free	LPDAAC http://modis.gsfc.nasa.gov/
Landsat ETM+ Landsat TM Landsat MSS	Pan/MS	8 bands 0.4 – 12.5 µm 7 bands 0.4–12.5 µm 5 bands	15m pan 30m 60m thermal 30m 120m thermal 60m	18 km 5-16 day revisit	1999 – present 1982-present 1973 – 1983†	$425 TM $700 ETM+	EROS http://landsat.gsfc.nasa.gov/
AWiFS	MS	4 bands 0.52-1.7µm	56m at nadir 70m at field edges	5 day revisit 737km swath	2003-present	$700/quad 4quads/scene	www.euromap.de/docs/doc_005.html http://directory.eoportal.org/pres_IRSP6IndianRemoteSensingSatellite.html
LISS-III	MS	4 bands 0.52-1.7µm	23.5m	24 days 140km swath	2003-present		www.euromap.de/docs/doc_005.html http://directory.eoportal.org/pres_IRSP6IndianRemoteSensingSatellite.html
ASTER	MS	15 bands 0.5 - 12 µm	15m VNIR 30m SWIR 90m TIR	4-16 day revisit, 60km	2000 - present	Free-$170+	http://asterweb.jpl.nasa.gov/ Free (already existing Level 1B data over the U.S. and territories, available through the LPDAAC Data Pool
SPOT	Pan/MS	4	10m Pan / 20m MS	20 x 20 -60 x 60km	1986-present	$1000-$14,000	www.spotimage.fr/html/_167_.php (already existing Level 1B 20 x 20 km, which is 1/8 scene, is 1,020 euro or about $1,400), No per km price found

Sensor	Frequency	# Spectral Bands	Spatial Resolution	Size/ revisit time	Operation period	Cost	Source
IRS	Pan/MS	4-6	6m Pan / 23m MS	148km	1988 – present	$375/ 10x10km map sheet	Photosat, http://rst.gsfc.nasa.gov/Intro/Part2_23.html, http://ccrs.nrcan.gc.ca/resource/tutor/fundam/chapter2/12_e.php
Quickbird/ IKONOS	Pan/MS	5 bands 0.45-0.9 µm	0.6m pan 2.4m	3-7 day revisit 16.5km	2001 - present	$8/km (IKONOS) $16/km (Quickbird)	www.digitalglobe.com/
Aerial Imagery e.g. CAESAR™	MS	12 bands VIS	0.5 – 4m	Weather and flight logistics		High	CAESAR was a NATO project that ended in 2005, to be replaced by MAJIIC http://edcsns17.cr.usgs.gov/airborne/
Air Photos	Pan / Color/ Color-IR		0.1-1.0m	Small spatial area/ varies/ as tasked	1909-present airplane	High	
OrbView 3™	Pan/MS	4 bands VIS/NIR	1m pan 4m	< 3 days	2003	$10-50/ km	www.orbimage.com/corp/orbimage_system/ov3/, www.geoeye.com/whitepapers_pdfs/OV-3_Catalog.pdf
HyMAP Imaging Spectrometer™		128 VIS NIR SWIR	3.5 – 10m	Weather and flight logistics		$6,000 per 2.3 x 20km scene; proprietary data $12,000 per scene	www.hyvista.com
Fugro Earthdata LiDAR	Light (350 – 800 nm)		35cm vertical 3m horizontal	As tasked			http://www.earthdata.com/servicessubcat.php?subcat=lidar
RADARSAT-1	C-band SAR	1, 5.7 cm C-HH Multiple modes and incidence angles	10m (fine beam mode), 30m, and 100m (wideswath mode)	45-500km Approx. 6 day revisit 50 - 500km	1995-present	$0-$2,750	ASF www.asf.alaska.edu/ or MDA Corporation http://gs.mdacorporation.com/

Sensor	Frequency	# Spectral Bands	Spatial Resolution	Size/ revisit time	Operation period	Cost	Source
RADARSAT-2	C-band SAR	4 5.7 cm C-HH, C-HV, C-VH, C-VV	3 to 100m	500 km, daily to 3 days	2007 launch		http://gs.mdacorporation.com/, www.radarsat2.info/, www.space.gc.ca/asc/eng/satellites/radarsat2/innovations.asp
ERS-1 and 2	C-band SAR	1, 5.7cm, C-VV 23° incidence angle	30m	100km 35 day revisit	1991-present	$85-$450+	http://earth.esa.int/ers/ Eurimage and ESA http://eopi.esa.int/esa/esa?cmd=aodetail&aoname=cat1 http://eods.nrcan.gc.ca/ers_e.php
Envisat	C-band SAR	2, 5.7cm Any 2 : C-VV ,C-HH, C-VH, C-HV Multiple incidence angles	10, 30m, and 100 m (wideswath mode)	100 –400km 35 day revisit	2002-present	$480 (archive)* $720 (new)* $125 (ESA CAT-1 data grant)	Eurimage* and ESA http://earth.esa.int/ers http://eopi.esa.int/esa/esa?cmd=aodetail&aoname=cat1
JERS	L-band SAR	1, 23cm L-HH 37° incidence angle	30m	70km	1992-1998	$25	JAXA's CROSS https://cross.restec.or.jp/cross/CfcLogin.do?locale=en
PALSAR	L-band SAR	4, 23cm, L-HH, L-HV, L-VH, L-VV	7-100m	40-350km	2006-present	$125	ASF www.palsar.ersdac.or.jp/e/index.shtml
Airborne Radar GeoSAR	X-, P-band SAR	3cm X-VV 86cm P-full polygon	1.25-3m (X) 1.25-5m (P)	20 km	2002-present		http://southport.jpl.nasa.gov/html/projects/geosar/geosar.html www.earthdata.com/servicessubcat.php?subcat=ifsar

Sensor	Frequency	# Spectral Bands	Spatial Resolution	Size/ revisit time	Operation period	Cost	Source
Airborne Radar (AIRSAR)	C-, L-, P - band SAR Also TOPSAR (DEM)	4, 5.7cm C-band full polygon, 25cm L-band full polygon, 68cm P-band full polygon	2.5 - 12m	As tasked	1988- 2005 not in operation; JPL will fly if commissioned	Free - $750	http://airsar.jpl.nasa.gov/documents/faqs.htm#p4, http://airsar.jpl.nasa.gov/main.htm
Airborne Radar Fugro Earthdata GeoSAR	X-, P-band IFSAR	3cm X-VV 86cm P-full polygon	1.25-3m (X) 1.25-5m (P) 3-5m DEM 36cm P.Lidar Night or day, through clouds and vegetation	12-14km swaths with up to 1200 km flight lines Revisit as needed	2002-present	$30 to $170 /sq. km No licensing. Clients free to share and use as they see fit.	http://southport.jpl.nasa.gov/html/projects/geosar/geosar.html www.earthdata.com/servicessubcat.php?subcat=ifsar

Innovative Remote Sensing Methods

Canadian Wetlands Inventory Approach

Plans for the Canadian Wetland Inventory (CWI) have been developed to create a consistent map of wetlands in all areas of Canada using satellite imagery (see www.cwi-icth.ca/). The CWI will use a classification scheme defined in the Canadian Wetland Classification System: bog, fen, marsh, swamp, and shallow water. As with the National Wetland Inventory (NWI) of the United States, it will not map categories of upland areas. The minimum mapping unit planned is one hectare, and the data source planned is 30-m Landsat ETM from circa 2000 and 30-m resolution Radarsat (12.5-m pixel spacing). Canada contains approximately 25% of all of earth's wetlands, which previously have not been comprehensively mapped. Fournier et al. (2007) concluded that combining Landsat-ETM+ with Radarsat-1 images will help depict the spatial and temporal variability of wetland classes. Toyra et al. (2001) and Toyra and Pietroniro (2005) found that radar images may be critical in many areas to distinguish upland from wetland, which is often difficult with optical imagery alone. Grenier et al. (2005 and 2007) as well as others have also found that differentiation between swamp and other wetland classes improved with Radarsat-1 images.

Hybrid Multispectral and Imaging Radar for Wetland Mapping, Inundation Monitoring, and Change Detection

Wetlands have historically been one of the most difficult ecosystems to classify using remotely sensed data, partially due to the high variability in wetland morphology. Bourgeau-Chavez et al. (2004) developed unique hybrid Synthetic Aperture Radar (SAR) and multispectral imaging methods to monitor Great Lakes' coastal and inland ecosystems and surrounding land uses that consist of three elements: 1) SAR techniques for mapping inundation extent; 2) hybrid SAR-optical sensor techniques for mapping wetlands and adjacent habitat and land use including invasive species; and 3) a hybrid radiometric/categorical multispectral approach for mapping changes in land cover and land use (see www.glc.org/wetlands/pdf/GD-landscapeReport.pdf for full details).

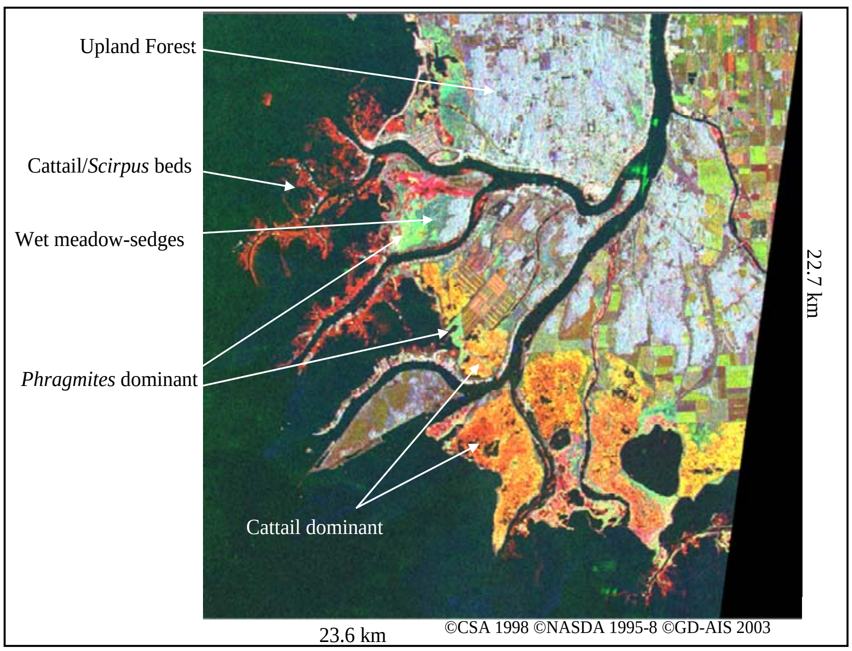


Figure 8-7. Three date false color composite of Radarsat3 , October 1998 (red), JERS 10, August 1998 (green), and JERS 28, March 1995 (blue) illustrating fine-resolution mapping of wetland plant cover over Lake St. Clair.

Wetland Mapping

Many techniques focus on using multispectral data, such as Landsat or Aster, alone or in combination with ancillary data sets such as soils and topography for wetland mapping. Bourgeau-Chavez et al. (2004) found that SAR and multispectral sensors complement each other in the classification and monitoring of wetland ecosystems and that SAR represents one of the most promising sensor types for improving wetland mapping capability. While multispectral data measure spectral reflectance and emittance characteristics of various cover types and wetness in open canopied ecosystems, SAR is sensitive to variations in biomass, structure and soil moisture and flood condition of landscapes including forests and other closed canopy ecosystems. Forested wetlands are the most difficult to identify remotely because of the inability of traditional multispectral sensors to "see" beneath the canopy. Radar can not only penetrate a closed canopy to detect flooding, but since radars are active systems, can acquire data acquired independently of solar illumination and cloud cover conditions. Thus, data can be collected during specific conditions relevant to finding seasonally flooded wetlands or seiche-influenced wetlands. These SAR data can be used not only to detect and define wetlands, but also to monitor extent of inundation and in some cases level of inundation (Bourgeau-Chavez et al. 2005).

Current spaceborne SARs are mainly of a single frequency, but multiple SAR sensors with different frequencies (and polarizations) and from multiple dates can be used together to effectively map and monitor a given region. The longer wavelength (lower frequency) SARs allow for mapping and monitoring of high biomass ecosystems such as forests and tall, dense herbaceous vegetation (e.g. L-band 23 cm JERS and PALSAR) while shorter wavelength sensors (higher frequency) allow for mapping and monitoring lower biomass, herbaceous (e.g. C-band 5.7 cm Radarsat, ERS, Envisat) ecosystems. Together, two SAR frequencies allow for a wider range of mapping capability than either frequency alone. Further, by fusing sensor data operating in the visible, infrared and microwave (SAR) spectrums in a GIS, a robust method for monitoring wetland type, areal extent, adjacent land use/land cover, invasive species and proximity to other anthropogenic stressors can be attained. Methods were evaluated and developed for this very purpose under a pilot study for the Great Lakes Coastal Wetlands Consortium The pilot study covered relatively small subsets of the Great Lakes basin (Bourgeau-Chavez et al. 2004), but encompassed a range of landscape types (urban/rural, coniferous/deciduous, and temperate/boreal).

The most cost-effective, robust and implementable methodology identified created one categorical map from SAR and another from the optical sensor data, then merged the categories from these initial maps. Ideally, the initial categorical maps would be made from data covering multiple seasons and years to capture the inter-annual and intra-annual trends in plant phenology and inundation patterns (since SAR is sensitive to the extent of inundation, care must be taken when mapping seasonally flooded and tidally influenced coastal wetlands).

A simple maximum likelihood classifier was applied to the 6 to 12 input SAR bands, and separately to the 18 input Landsat TM bands. Then the categories from each data set were combined in the GIS, using category specific rules. Water is generally well-categorized by Landsat but its location can be validated via SAR (for example, Landsat missed *Scirpus* beds along the St. Clair River delta, labeling them open water). SAR tended to confuse urban and forested wetlands, which could be separated via Landsat, while Landsat tended to confuse bare rock with urban, which could be separated via SAR. For many of the classes, "wetness" from the SAR was used to validate the wetland class from the Landsat. A finer range of wetland species types was attainable with the SAR (*Typha, Phragmites, Scirpus*, wet meadow, etc, see Fig. 7), and these were validated with the "wetland" class from the Landsat. Pilot maps resulted in 94% overall accuracy when compared to NWI and 65-72% when compared to 1992 NLCD and 2001 IFMAP, and 89% accuracy when compared to field truth over a complex of wetland ecosystems.

Monitoring Extent of Inundation

The ability of SAR data to detect and monitor inundation also provides an ability to monitor changes in wetland hydrologic condition across a landscape. The pilot study reviewed two methods to derive inundation extent of forested wetlands from L-band SAR; a thresholding technique on an individual date JERS image to include only "bright" pixels that potentially represent inundated woody wetland areas at a single point in time; and a multitemporal technique that utilized several dates of JERS imagery to produce a seasonal inundation map. Because urban areas and row structured forests (plantations) also appear "bright" in SAR imagery, an existing wetland map can be intersected in a GIS with the SAR-derived product to eliminate confounding features. Figure 8-8 shows a multidate SAR-derived inundation map, where red areas are the extent of inundation for the period of 1992-95 overlaid on the NWI. Only those potentially inundated areas labeled "scrub-shrub" or "forested" wetland in NWI were retained as actual inundated areas.

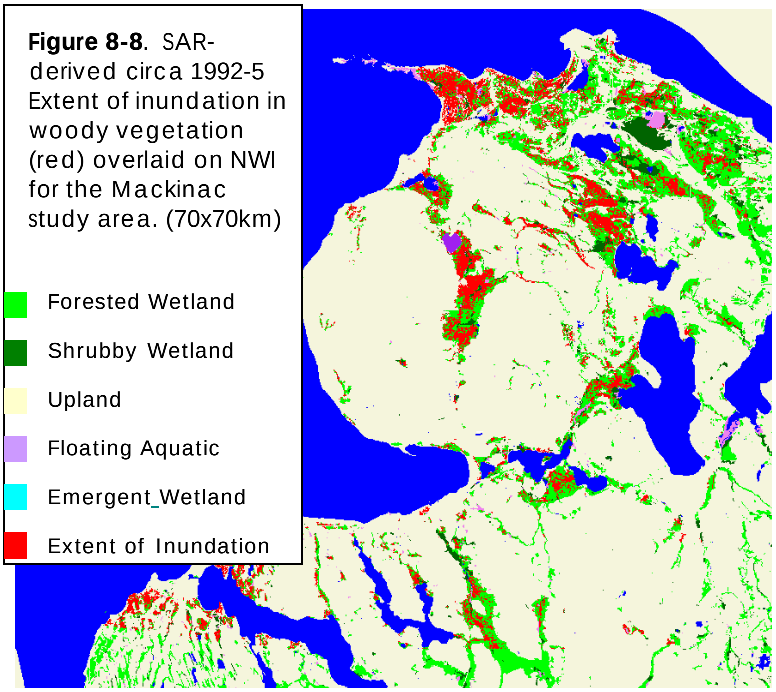


Figure 8-8. SAR-derived circa 1992-5 Extent of inundation in woody vegetation (red) overlaid on NWI for the Mackinac study area. (70x70km)

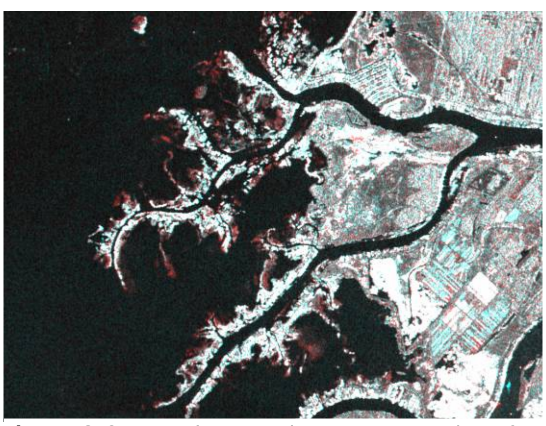


Figure 8-9. Two-date Radarsat composite of wetlands at the St. Clair River Delta. Red- 27 Oct. 1998, Cyan- 3 Oct. 1998. (11x15 km)

The launch of ALOS PALSAR (June 2006) allows the use of the JERS prototype methods for mapping the extent of inunation to be employed coincident with field verification and validation and evaluation of lake level data and precipitation patterns. Previous studies have also used general changes in hydrology (e.g. lake levels, precipitation) to validate changes in the inundation extent maps that were created with SAR (Hess *et al.* 1995, Townsend 2001, Wang 2004).

C-band data (e.g. Radarsat) may also be used to monitor changes in inundation. As an example, a change of 19-cm in the water level of Lake St. Clair resulted in a significant change in the backscatter from the *Typha/Scirpus* beds along the fingers of the delta (red areas in Figure 8-9) in the Consortium pilot study.

Effective Change Detection Technique

Knowing what has changed and when along the coasts will help resource managers and scientists understand the timeframe of the imposed stressors (development, invasive species, etc) and evaluate their effects on ecosystems. Traditional change detection techniques are either 1) categorical, comparing categorizations of data collected on two different dates, or 2) radiometric, comparing the radiometric properties of data collected on two different dates. The Hybrid Change Detection procedure recommended by Jensen, et al. (NOAA 1993) and described in Bourgeau-Chavez, et al. (2004) effectively combines components of the categorical and radiometric approaches to reduce both omission and commission errors (Figure 8-10, 150x150 km). Errors in categorical change detection result when a pixel that has not actually changed cover type is erroneously assigned to a different type, because of a lack of perfect radiometric normalization between data sets, and because the signature sets used to categorize the two data sets are not identical. This type of error can be effectively eliminated by solely accepting a categorical change when the magnitude of the associated radiometric change is greater than expected, due solely to radiometric mismatches between the data sets. Conversely, the addition of a categorical change test to a radiometric change detection provides a basis for assigning labels to the types of changes that the radiometrically based change detection has identified. Changes in condition_may also be assessed by examining the nature of radiometric change within categorically unchanged cover types. The hybrid change detection procedure was illustrated in the pilot study report as a cost-effective and timely hybrid change detection procedure by using existing categorical maps from two time periods and coincident (month/date-usually mid-summer) multispectral radiometric data from each time period to detect change. The two categorical maps must first be adjusted to match labels, and limitations are with the categorical map with the fewest categories. This method was illustrated using IFMAP as the current map for northern Michigan study sites and NWI, and MIRIS as the 1970s maps. More than 10% radiometric change and 4-14% categorical change was observed for the study wetlands in northern Michigan, but implementation of the hybrid procedure reduced the amount of “real” change to 1.3-3.8%. For the nine northern Michigan counties studied, 2,546 -ha were converted from wetland to upland with only 3-ha changing from upland to wetland, an additional 124-ha went from wetland to open water. Finally, 1,304-ha changed from emergent to woody wetland.

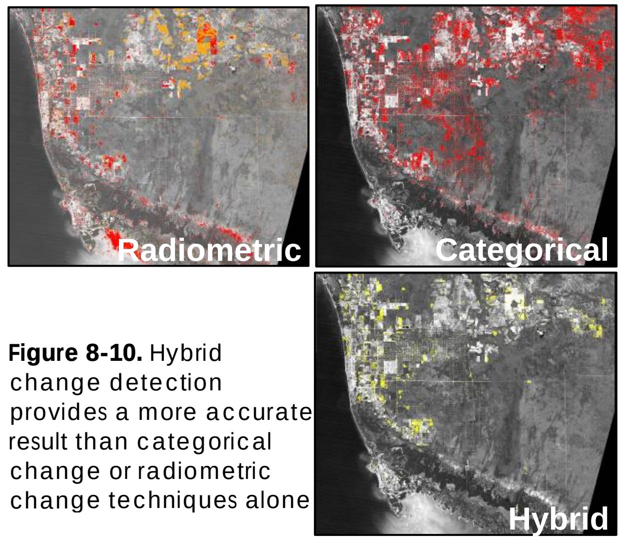


Figure 8-10. Hybrid change detection provides a more accurate result than categorical change or radiometric change techniques alone

Remote Assessment of Invasive Plants

Some kinds of invasive wetland plants can be effectively assessed remotely. Basinwide assessments can be made using the sort of broad-scale SAR-based approaches described in Bourgeau-Chavez (2004) and above, but it is recommended that these be supplemented with finer scale approaches at specific wetlands of concern. Lopez et al. (2004) demonstrated the implementation of a moderate-to-fine scale protocol (with minimal field activities), using remote sensing and landscape ecological approaches to determine the presence, distribution and plant-stand structural characteristics of *Phragmites australis* at the Point Mouille Wetland Complex in western Lake Erie.

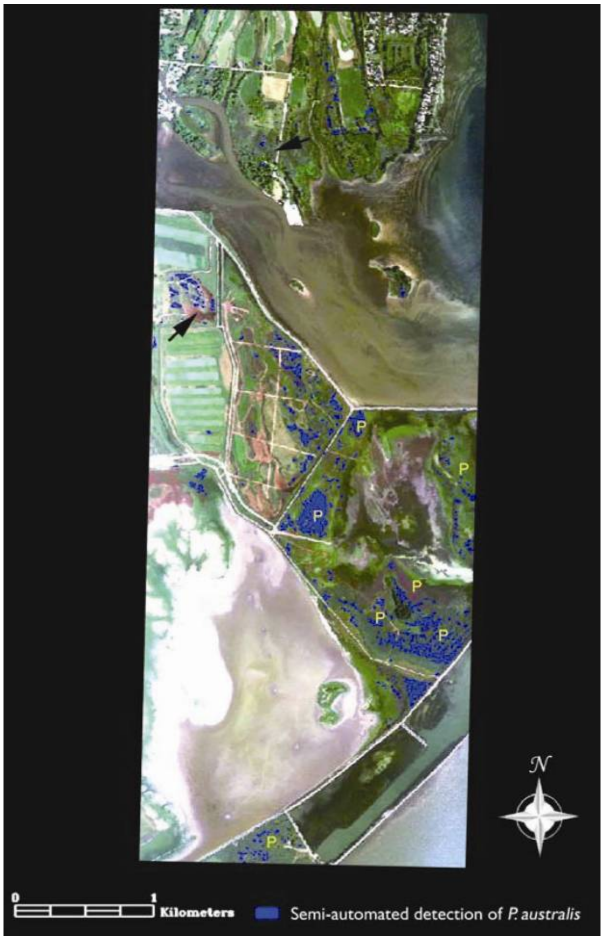


Figure 8-11. Results of a Spectral Angle Mapper classification indicating likely areas of relatively homogeneous stands of Phragmites australis (blue), field-sampled patches of Phragmites (black arrows) and validated Phragmites, (yellow) overlaid on a natural-color image of Pointe Mouillee wetland complex (from Lopez et al., 2004).

The technique applied was a supervised classification of PROBE-1 (with identical specifications to the HyMAP sensor; Table 8-2) airborne hyperspectral data, using the ENVI Spectral Angle Mapper (SAM) algorithm, a semiautomated processing technique for comparing image spectra to a spectral library. PROBE-1 spectra were collected from 3 x 3 pixel (approximately 12m x 12m) homogeneous areas of *Phragmites* (as determined from traditional field transect sampling). The SAM algorithm was then used to determine the similarity between the spectra of homogeneous *Phragmites* and all other pixels in the scene by calculating the spectral angle between them over each spectral band. Classified pixel types representing potentially homogeneous *Phragmites* stands identified by the SAM classification (Figure 8-11) were validated by comparing their distribution to areas of *Phragmites* observed in black and white aerial photos and contemporaneous field data collections with the aid of the ENVI Mixture Tuned Matched Filtering algorithms.

Accuracy assessment of any remote-sensing-derived landscape indicator is imperative. A three-tiered approach to accuracy assessment of the semi-automated *Phragmites* maps was used: Tier-1) testing presence/absence of *Phragmites* using a comparison of semiautomated vegetation maps to recent stereo aerial photographs; Tier-2) testing presence/absence of *Phragmites* using stratified random field samples of the mapped areas; and Tier-3) testing of *Phragmites* percentage cover and structure using random field samples of mapped areas. At Pointe Mouillee, Tier-1 accuracy assessment, which compared vegetation maps to 1:15840 scale black and white stereo aerial photographs and field notes, indicated that approximately 80% of the areas mapped as *Phragmites* are located within true *Phragmites* stands, while Tier-2 accuracy assessments that compare vegetation maps to field samples resulted in a 91% accuracy.

Recommendations for Remote Sensing Synthesis Products

An important emerging approach to multiscalar ecological monitoring efforts is the implementation of remote sensing synthesis products. To address the unique logistical and ecological elements of the Consortium goals for coastal wetlands basin-wide, we recommend a synthesis of the previous two methodologies to accurately and routinely monitor coastal areas for the presence and change in extent and composition utilizing the hybrid procedure, followed by targeted wetland assessments for invasive plant species in selected wetlands of interest. The hyperspectral approaches discussed above could then be utilized to precisely map the location of plant species (e.g., *P. australis,* or other targeted plant species) and the structural characteristics of the plant stands within wetlands of special interest to stakeholders. The synthesis of various remote sensing approaches will ensure that the broad-scale goals of the Consortium and the accuracy requirements for addressing the ecological processes within a wetland are both incorporated into map outputs for the Great Lakes. Such synthesis map products will ensure that monitoring of management practices and restoration success progress is recorded accurately and completely for the Great Lakes basin.

GLEI Stressor Gradient

As part of the GLEI project, 3,591 watersheds were delineated for coastal areas throughout the U.S. side of the Great Lakes (Figure 8-12) as summary units for a wide variety of anthropogenic stressors (Hollenhorst et al. 2007).

More than 200 variables in seven categories of anthropogenic stress were summarized for these watersheds. Principal components analysis (PCA) within seven categories of stress (agriculture, human population, atmospheric deposition, point sources, land cover, soils, and shoreline protection) was used to reduce dimensionality and derive overall stressor gradients (Danz et al.)

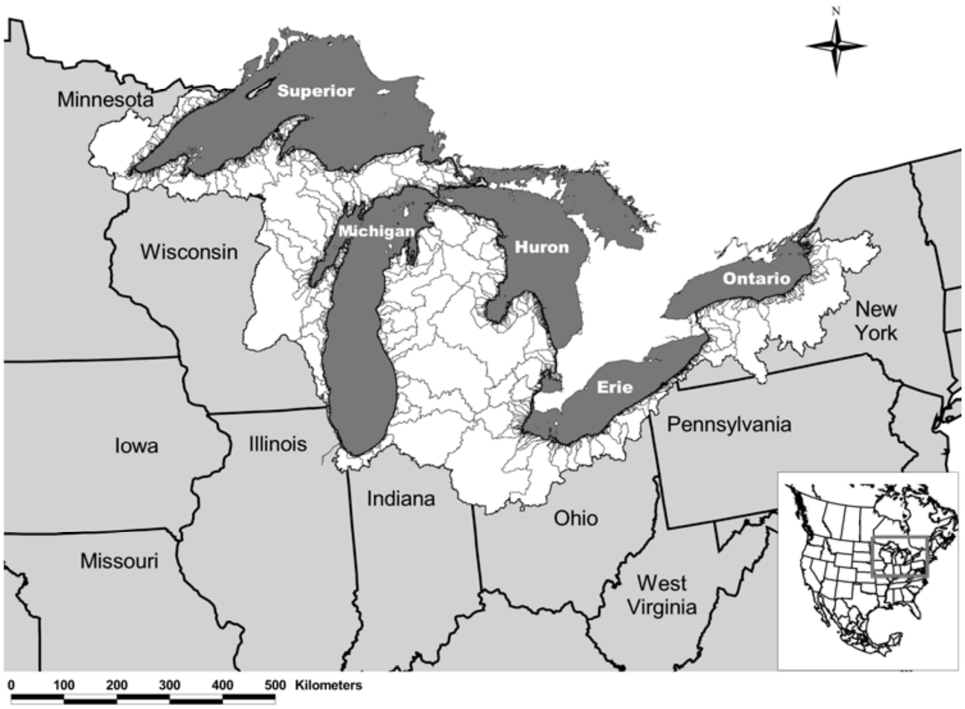


Figure 8-12. Watersheds (3,591) delineated for the U.S. side of the Great Lakes basin. (2007).

More recently, this effort has been expanded to include the Canadian side of the Great Lakes using compatible watershed delineations (5,890 watersheds) and integrated stressor summaries focused on the most significant stresses (initially, land use, population density, and road density). These watershed summaries and derived stressor gradients provide a framework for selecting wetland monitoring sites stratified across these gradients, and also a context for interpreting field data on wetland condition.

The delineations were accomplished with an ArcHydro data model, which allows for watershed delineations that incorporate existing maps of streams to create hydrologically corrected elevation models (Maidment 1997). We used map data representing connected stream networks of the National Hydrologic Data Base (http://nhd.usgs.gov) combined with National Elevation Data (http://ned.usgs.gov). Using ArcHydro, sinks (areas in the elevation data that are lower in elevation than their surroundings) were filled to ensure flow continuity, flow direction was delineated, and accumulated flow was calculated. Areas with high flow accumulation (defined as areas receiving flow from an upstream area of at least 3,000 30- x 30-meter pixels) were designated as streams, which roughly coincides with streams mapped at 1:24,000. Catchments were then delineated for stream lengths between stream confluences. Connected networks of streams flowing to the Great Lakes coast were individually identified, and all the streams and the catchments within that network were given a network-level identification number. Discrete watersheds flowing to the coast were then uniquely identified and merged to form a hierarchical network of highly detailed watersheds flowing to the Great Lakes coast. Polygons representing "coastal interfluves" (the land areas between river mouths and their watersheds that drain directly to the shorelines Fig. 6) were delineated by intersecting the coastal watershed boundaries with a polygon representing the terrestrial portion of the Great Lakes basin derived from satellite imagery (Wolter *et al.* 2006).

After coastal interfluve polygons and stream watershed polygons were combined into a single map layer (creating a total of 3,591 U.S. Great Lakes stream watersheds and interfluves and 5,890 integrated U.S./Canadian stream watersheds and interfluves), they were ordered and numbered along the coast from the U.S./Canadian border in western Lake Superior, counter-clockwise around all of the Great Lakes. Watershed delineations were visually assessed for errors, and edited when necessary, using ancillary map data including streams, aerial photos and USGS scanned quad maps (Digital Raster Graphics 1:24 000 and 1:250 000). Ordering the watersheds with sequential identification numbers along the coast provided a framework for scaling watersheds and their related stressors along the entire Great Lakes shoreline. Watersheds and associated stressors adjacent to an area of interest are easily identified by their consecutive ID numbers (Figure 8-13), providing the means to summarize and assess the effects of watershed-scale anthropogenic stresses delivered to specific coastal ecosystems.

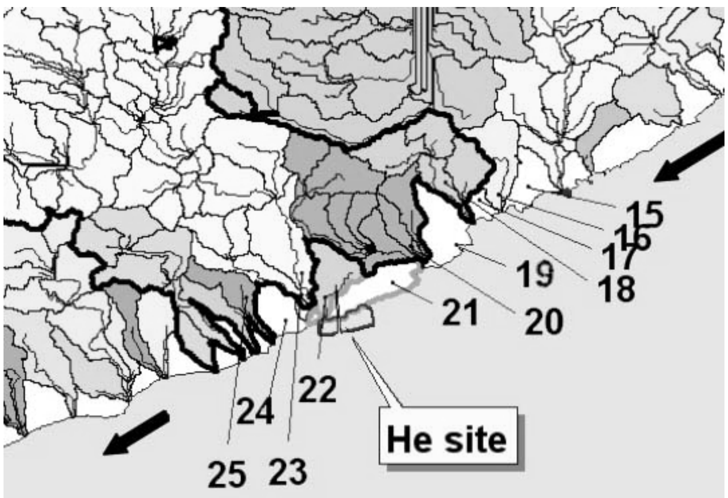


Figure 8-13. Ordered and numbered stream and coastal interfluve watersheds along the Great Lakes coastline near a high energy site (HE). Arrows represent direction of predominant long-shore currents.

The relative contribution of stress effects from adjacent land areas along the coast varies greatly, based upon seasonal currents, storm and wind events, near-shore topography and other local conditions. Spatial ordering of watersheds provides the means to account for stressor effects contributed from outside a particular ecosystem's immediate watershed (for example, by long shore currents; Figure 8-13). As stressor delivery mechanisms are further understood and mapped, this scalable watershed framework can be used to differentially weight the contributions to a specific site from nearby watersheds based on proximity and prevailing currents, and to better represent the lake-ward delivery of sediments, contaminants, and other waterborne stressors to coastal areas. This framework might also be applied to circulation models for embayments and harbors or large lakes, providing an ordered link between stressors in the watershed and the receiving body of water.

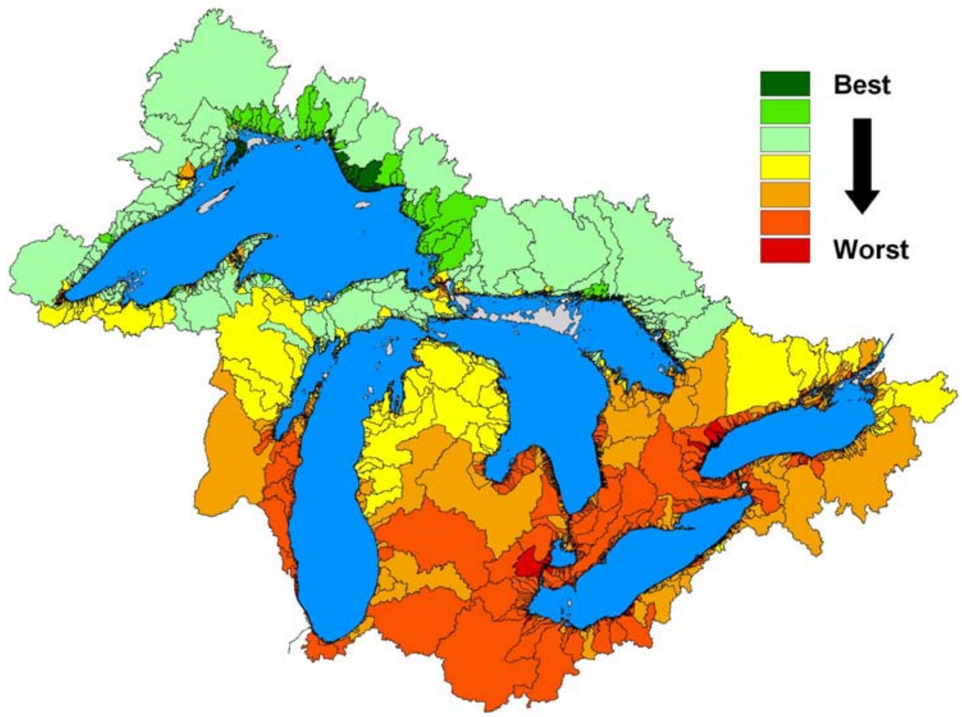


Figure 8-14. Integrated Sum-Rel score for the 3,590 U.S./Canadian Great Lakes watersheds (T. Hollenhorst, NRRI, University of Minnesota et al. in prep).

For the GLEI Project, U.S. watersheds were delineated and a wide variety of anthropogenic stressor variables were summarized and analyzed as describe above. For the integrated U.S./Canadian watersheds, landcover, human population density, and road density were summarized to derive an integrated Sum-Rel score (Figure 8-14; Host et al. 2005), calculated per the following steps:

1. Variables transformed:
   proportions: tr-value = arcsin (sqrt(value))
   density: tr-value = ln (value + minimum non-zero value)
2. Transformed values normalized:
   nr-value = (tr-value – tr-mean) / (stand dev of tr-value)
3. Transformed, normalized variables standardized:
   st-value = (nr-value – min_nr-value) / (max_nr-value – min_nr-value)
4. Standard, normal transformed values (st-value) for each stressor summed:.
   sum-rel = st-value (land cover*) + st-value (popul) + st-value(road density)

Recommended Long-Term Landscape Monitoring Protocols

Coastal Wetland Mapping and Monitoring

Needs for coastal wetland monitoring exist at the local, county, tribal, state and federal levels. Not all management levels will be interested in creating a regional scale map for their specific needs, but following a common protocol will ensure that maps from different areas can later be merged to assess larger regional areas or can be compared to maps from other projects and time periods to determine change. Since maps with different classification systems are difficult to combine later, we recommend that a common classification system be used, and the highest category possible be mapped. To the extent possible, projects should also map the surrounding land cover and land use, due to their importance as indicators and correlates of wetland condition. This approach has already been used in developing an integrated habitat classification and map of the Lake Erie basin, partly based on the Consortium classification system (L. Johnson et al. NRRI, Univ. of Minnesota Duluth; http://www.glc.org/eriehabitat) (see sections below).

Design

To support Great Lakes coastal wetland assessment and management into the future, we recommend a two-tier wetland mapping system, combining (I) a moderate resolution (15-30 m) satellite-based mapping of the entire basin every five years; and (II) a high-resolution (1 m or better) airborne or satellite-based map of one lake basin per year on a rotating basis. This two-step approach allows for a consistent baseline map from synoptic moderate-resolution data sources using semi-automated techniques at the regional scale every five years, together with a fine-resolution map allowing more detailed discrimination of wetland boundaries and wetland type. It is not expected that the fine-resolution maps, which are labor-intensive to produce, can be created in a single year for the entire basin. However, highly sensitive areas (e.g. wetlands in high population areas or areas of rapid land cover/land use change) will need to be mapped at high resolution with greater frequency.

It is recommended that both the moderate- and fine-resolution mapping consist of a combination of data sources from multiple frequencies to aid in wetland discrimination and deal with issues such as cloud cover and changing wetland inundation and plant phenology. Using satellite data allows for multitemporal and multispectral analysis in mapping wetlands that are dynamic throughout the seasons and allows automated change detection techniques to be used to update existing maps, such as NWI. Combining SAR and optical-IR data, as was described earlier, improves wetland delineation accuracy, especially for forested wetlands, which are often missed by traditional optical remote sensing techniques. Multiple sensor approaches allow checks of the data against each other to better define class types. While such methods have been demonstrated for 30-m satellite data (Bourgeau-Chavez et al. 2004, Fournier et al. 2007), it is realized that fine-scale airborne SAR data are not as readily available as the moderate-resolution satellite data, and although some satellite sensors offer higher resolution data, it may not be fine enough to be comparable with airborne optical-IR data. Newly generated maps should be compared to existing maps and imagery using hybrid radiometric and categorical change detection techniques as were described earlier. The change detection procedures not only provide valuable temporal information about the wetlands, but also serve as a check on the new map of whether or not it is an actual change in type or just a change in condition or categorical error.

It is recommended that the NWI classification system be used for mapping wetlands (http://www.fws.gov/nwi/Pubs_Reports/ Class_Manual/class_titlepg.htm). This system is hierarchical, with levels from systems and subsystems, to classes (emergent, forested, scrub-shrub) to subclasses and dominance types. At the very least, U.S. managers should start by updating and improving the existing NWI maps and contributing the updates to the NWI Master Geodatabase (http://wetlandsfws.er.usgs.gov/NWI/index.html). Surrounding upland areas should be mapped along with wetland classes. It is recommended that they be mapped according to the Land Use Land Cover Anderson Level II Classification System (http://landcover.usgs.gov/pdf/anderson.pdf).

Data collection and management

In mapping wetlands and adjacent land cover/land use, it is essential that all data sources be calibrated appropriately prior to analysis. Using data that have not been calibrated properly leads to increased misclassification errors. Information on calibration must be available on the specific product's web page. It is important that data be georeferenced to as high a precision as possible, typically within a pixel. This is especially important when data are compiled from multiple seasons and multiple sensor sources. Using data from multiple seasons, typically spring, summer and fall, will increase the number of classes that can be identified with any data source. When using change detection to update a map, it is important that anniversary date data be used, which for optical-IR data is typically during the peak growing season (July-August for the Great Lakes). The raw imagery should be kept along with the map and change products. This allows easier updates and comparisons with future maps. All data should be stored with metadata using the FGDC standard format, and all data should be made publicly available on a website such as AmericaView (americaview.org) or GLIN (www.great-lakes.net/).

Landscape Monitoring in Coastal Watersheds

Coastal wetlands are impacted by both local factors and by stressors acting at the watershed scale. In terms of assessment and monitoring, it is important to quantify stressors operating at both spatial scales. The protocols described in this section are designed to monitor key landscape indicators that quantify watershed-scale changes relevant to coastal wetlands. The basic strategy will be to identify data sources that are updated on a regular basis across the basin, define watershed-scale spatial summary units appropriate for coastal wetlands, enumerate key landscape metrics for these units, and describe a monitoring process that allows the identification of trends in key landscape stressor variables across the basin.

Design

The basic design for this monitoring effort is a comprehensive, population-level analysis based on a synoptic data set, following criteria noted below. An example analysis is given below, using the extent of a monitoring effort in the Lake Superior basin (see Fig 8-6). Given the large spatial extent covered in this monitoring effort and the comparatively slow rates of change of landscapes (1-3%/yr is typical), a 2-5-year revisit design is recommended, depending upon rates of development among the various regions of the Great Lakes. It needs to be recognized that many of the data suggested for this effort are updated on a periodic or aperiodic basis, and that resampling is not always synchronized across state, provincial, or federal levels; consequently, monitoring will frequently be based on a "best available data" approach.

Watershed-scale landscape metrics will be summarized using a high-resolution, multiscale delineation of U.S. and Canadian Lake Superior watersheds using the ArcHydro data model (Maidment and Morehouse 2002); this product is currently being developed under funding from the Great Lakes National Program Office, and will be available at the time monitoring begins.

The ArcHydro approach uses standard Digital Elevation Models (DEMs) to delineate individual watersheds for each steam segment (reach) between stream confluences. Stream reaches are numbered in sequence so that each catchment includes a unique identification label and the "next-down" identification of the catchment into which it flows (Fig. Arc1). An important part of this design is that maintaining this network identity allows watersheds to be scaled by concatenating stream reaches, and consequently providing a platform to summarize key landscape metrics at multiple spatial scales. Equally important, this system also allows the identification of coastal interfluves (Fig 6): land areas between stream mouths that drain directly to the lake. While small in area, coastal interfluves account for most of the shoreline length and many coastal wetlands are associated with interfluves. Moreover, this approach alleviates problems in quantifying stressors to wetlands which may not have strong hydrologic connections to adjacent stream watersheds. Although not immediately imperative, improved availability of higher resolution terrain data and the utilization of watershed delineation tools that make use of these finer resolution datasets (e.g., LiDAR) will result in improved watershed models, and consequently improve the reliability of watershed model development in lake plain regions.

Source data

Source data for watershed-scale assessment and monitoring must meet several criteria:

- Comparable data sets must be available for both the U.S. and Canadian sides of the Lake Superior basin.
- They must be collected on a time-relevant scale (5-10) years.
- They must be well-institutionalized – i.e. data sets that are critical for ecological, social, or economic reasons, and have a highly likelihood of being maintained into the future.
- They are strong proximal or ultimate drivers of impairments to coastal wetlands.

Land Use/Land Cover (LULC) is one of the key data sets, as it quantifies compositional and structural aspects of landscapes with strong links to the function of coastal ecosystems. There are many sensors and mapping products that quantify LULC over time, with broad variation in classification and spatial resolution. Table 3 below, presents a suite of data sources that fit the above criteria, and have been used on other ecological monitoring or assessment efforts (Danz et al. 2007, Host et al. 2006).

Table 8-3. List of datasets suitable for ecological monitoring efforts.

DATA SET	U.S. SOURCE	CANADIAN SOURCE
Agricultural inputs	Natural Resource Inventory	Canada Census of Agriculture
Dams	National Inventory of Dams	Land Information Ontario
Land Use/Land Cover	ENHANCED NLCD	Land Information Ontario
Nutrient inputs	SPARROW DATA/Ag data	Ag data
Pollution discharge	NPDES	CA National Pollution Release Inventory
Population density	U.S. Census	Canadian Census
Power plants	EGRID2002	Hazards Atlas
Transportation	U.S. Tiger	Land Information Ontario
Water intake	Various sources	Hazards Atlas
Water diversions	Various sources	Land Information Ontario

Data synthesis and transformation

In terms of linking landscape to the health of aquatic ecosystems, numerous studies have found that relatively simple classification schemes (Anderson Level II http://landcover.usgs.gov/pdf/anderson.pdf) show good correlations with physical and chemical properties of aquatic systems (Richards et al. 1997, Johnson et al. 2006). Because of the binational nature of this study, we recommend a classification resolution approximating Anderson Level II (finer-scale classification can easily be aggregated to this level). There is a broad range of spatial resolution available; given the extent described above, the moderate spatial resolution available through the National Land Cover Dataset (30m) is appropriate for this monitoring.

Various metrics can be computed to quantify the composition and spatial structure of the landscape. These are complemented by other point- and line-based data that quantify other key environmental stressors: roads, population density, hydrological alterations, and a number of point sources such as pollution discharge, dams, and power plants. The following Table 4 lists landscape metrics that have been used in environmental indicator and assessment work which fit the data criteria, and are relevant toward watershed monitoring.

Table 8-2. List of selected landscape metrics used in environmental indicator and assessment work.

DATA SET	Landscape metrics
Agricultural inputs	PC1
Dams	Count density (dams/unit area)
Land Use/Land Cover	Percentages of land use types Patch size descriptors (mean, SD, CV) Patch density (patches/unit area) Patch diversity (Shannon H') Edge density Percent impervious surface (via road density or Landsat model)
Nutrient inputs	PC1
Pollution discharge	Point source density (count or weighted count per unit area)
Population density	Individuals/ km2
Power plants	Point source density (count or weighted count per unit area)
Transportation	Road density (km road/ km2)
Water intake	Density weighed by volume
Water diversions	# diversions per unit area

Once data have been synthesized, there are three useful types of transformations to make the data comparable. The first are normalizing transformations; landscape data often have different levels of skewness, kurtosis or modality that confound both summary statistics and analysis. The arcsine square root transformation is appropriate for proportional land use/land cover data (e.g. % agriculture in watershed). Road density and point source densities can be normalized with a natural log transformation [Ln(value + the minimum non-zero value)]. A second stage of transformation involved scaling the data in terms of its variability: [(value – minimum value)/standard deviation]. Finally, to put data on a common scale, landscape data can be rescaled on a 0-1 basis: (normalized value – minimum normalized value)/(max. normalized value – min. normalized value). The result of this final step is to give equal weight to all stressors.

Interpretation

The landscape metrics described above comprise a suite of indicators that, from a monitoring perspective, can be used to illustrate changes over time. These can be interpreted in two ways. First and simplest, the watershed changes related to individual coastal wetlands can be compared across time periods, and relative or absolute changes in the metrics quantified. The metrics can also be interpreted on a lakewide basis. For example, the above approach will allow the identification of stressor gradients, including reference watersheds – the upper end of the stressor gradient that quantifies the least impacted systems, and "at-risk" watersheds – those occupying the lower end of the gradient. Other watersheds can then be ranked along this stressor gradient, and tracked over time. This gradient approach provides a means to answer the question "Is this watershed moving towards or away from reference condition, and by how much?" The ability to understand these changes can be used as a benchmark for assessing the success of restoration activities and identify wetlands which are coming under increased stress.

Implementation Approaches

Dissemination Strategies, Datasets, and Product Synthesis

The landscape metrics data will need to be broadly disseminated and widely publicized to maximize utility and uptake. For those decision makers and researchers whose work depends on timely access to the data, ensuring ease-of-use and continuity of operations is crucial. To this end, the Great Lakes Information Network (GLIN: www.great-lakes.net) website will be utilized. Since 1993, GLIN has been a recognized information service providing "one-stop shopping" for Great Lakes-related resources. Owing to its strong network of state, provincial, federal and regional partner agencies and organizations, GLIN has become a necessary component of informed decision making, and a trusted and reliable source of information for those who live, work or have an interest in the Great Lakes basin.

Dissemination Strategies

The Maps and GIS section of the GLIN website (http://gis.glin.net) provides a centralized location to discover, publish, and acquire geospatial data for areas within the Great Lakes basin. The site has four major components: 1) a portal for viewing and exploring the Great Lakes and associated data layers, 2) a data portal (GLIN GIS) through which GIS and geospatial data for the Great Lakes can be published and acquired, 3) a gallery of downloadable images depicting Great Lakes geophysical data, and 4) a collection of links and tools intended to connect users to additional resources relating to Great Lakes datasets.

Through the GLIN GIS data portal, geospatial data is made widely available through a multiplicity of file formats (e.g. PDF, KML, SHP) and as OGC Web services. These data can be downloaded and incorporated into a user's GIS application (e.g. Google Earth, uDig, ArcGIS) or visualized and interacted with using the site's integrated web mapping applications. FGDC-compliant metadata accompanies each dataset and is published through external clearinghouse nodes (i.e. GeoSpatial Onestop) to support data discovery in both the U.S. and Canada.

Datasets

A variety of data sets will be available via the GLIN GIS data portal. In addition to the existing data sets available (framework and otherwise), several data sets relating landscape metrics are planned to be offered, including:

Wetland inventory

- Stressor Gradient(s)
- Watersheds
- Land cover
- Population density
- Road density
- Other stressors

Biologic data

- Species range maps
- Exotic species distribution

Monitoring data

- Monitoring site selection
- Monitoring data

Product Synthesis

In addition to data downloads, data may be uploaded for placement on the GLIN site. This will allow for integration of local level mapping and monitoring data as well as regional scale data products created by individual organizations.

All data uploaded will require FGDC-compliant metadata, and reports of accuracy assessment. Classification maps should be categorized using the NWI classification system for mapping wetlands (http://www.fws.gov/nwi/Pubs_Reports/_Class_Manual/class_titlepg.htm) and the Land Use Land Cover Anderson Level II Classification System (http://landcover.usgs.gov/pdf/anderson.pdf) for mapping uplands. Data products will be checked for continuity and accuracy before publication on GLIN.

References

Albert, D.A., Wilcox, D.A., Ingram, J.W., and Thompson, T.A. 2005. Hydrogeomorphic classification for Great Lakes coastal wetlands. Journal of Great Lakes Research 31(Suppl. 1):129-146.

Bailey, R. G., 1987, Suggested hierarchy of criteria for multi-scale ecosystem mapping. Landscape and Urban Planning 14, 313-319.

Bourgeau-Chavez, L.L., K.Riordan, M. Nowels, and N. Miller. 2004. Final Report to the Great Lakes Commission: Remotely Monitoring Great Lakes Coastal Wetlands using a Hybrid Radar and Multi-spectral Sensor Approach. Project no. Wetlands2-EPA-06.82pp. www.glc.org/wetlands/pdf/GD-landscapeReport.pdf.

Bowes, M.A. 1989. Review of the geomorphological diversity of the Great Lakes shore zone in Canada. University of Waterloo, Waterloo, Ontario. Heritage Resources Center Technical Paper no. 4.

Brazner, J. C. N P. Danz; G. J. Niemi; R. R. Regal; A. S. Trebitz; R. W. Howe; J. M. Hanowski; L. B. Johnson; J. J.H. Ciborowski; C. A. Johnston; E. D. Reavie; V. J. Brady; G. V. Sgro. 2007. Evaluation of geographic, geomorphic and human influences on Great Lakes wetland indicators: a multi-assemblage approach. Environmental Indicators 7:610-635.

Chow-Fraser, P. 2002. Binational GIS database of coastal wetlands for Lake Ontario and the St. Lawrence: a demonstration project. Completion Report. Fishery Research Program. Great Lakes Fishery Commission.

Danz, N.P., G.J. Niemi, R.R. Regal, T. Hollenhorst, L.B. Johnson, J.M. Hanowski, R. Axler, J.J.H. Ciborowski, T. Hrabik, V.J. Brady, J.R. Kelly, J.A. Morrice, J.C. Brazner, R.W. Howe, C.A. Johnston, and G.E. Host. 2007. Integrated gradients of anthropogenic stress in the U.S. Great Lakes basin. Environmental Management. 39:631-647.

Fournier, R. M. Grenier, A. Lavoie, R. Helie.. 2007. Towards a strategy to implement the Canadian Wetland Inventory using satellite remote sensing. Canadian Journal of Remote Sensing, in press.

Government of Canada and GLNPO (Great Lakes National Program Office). 1995. The Great Lakes: An Environmental and Resource Book. Third edition. Government of Canada, Toronto, Ontario, Canada, and U.S. Environmental Protection Agency, Great Lakes National Program Office. Chicago, Illinois. Internet accessible at the following URL: http://www.epa.gov/glnpo/atlas/index.html.

Grenier, M., Dermers, A.-M., Labrecque, S., Fournier, R., Drolet, B., and Benoit, M. 2005. La cartographie des terres humides au Québec dans le cadre de l'inventaire canadien des terres humides – approche méthodologique, 12e congrès de l'AQT, Ville de Saguenay,Québec, May 2005. [CD-ROM]. 8 p.

Grenier, M., Demers, A.-M., Labrecque, S., Benoit, M., Fournier, R.A., and Drolet, B. 2007. An object-based method to map wetland using RADARSAT-1 and Landsat-ETM images:test case on two sites in Quebec, Canada. Canadian Journal of Remote Sensing, in press.

Gutman, G., Janetos, A., Justice, C., Moran, E., Mustard, J., Rindfuss, R., Skole, D. and Turner II, B.J. (eds.) 2004. Land Change Science: Observing, Monitoring, and Understanding Trajectories of Change on the Earth's Surface. Kluwer Academic Publishers, New York, NY.

Herdendorf, C.E. 1988. Classification of geological features in Great Lakes nearshore and coastal areas. Protecting Great Lakes Nearshore and Coastal Diversity Profect, International Joint Commission/The Nature Conservancy, Windsor Ontario.

Herdendorf, C.E., S.M. Hartley, and M.D. Barnes. 1981. Fish and wildlife resources of the Great Lakes coastal wetlands within the Unites States. U.S. Fish and Wildlife Service report FWS/OBS-81/02 (multi-volume set), Washington, D.C.

Hess, L.L., J.M.Melack, S. Filoso, and Y. Wang. 1995. *IEEE* Trans. on Geoscience and Remote Sensing, 33(4)896-904.

Hollenhorst, T., Brown, T.N., Johnson, L.B., Ciborowski, J.J.H., Host, G.E. 2007. Methods for generating multi-scale watershed delineations for indicator development in Great Lake coastal ecosystems. Journal of Great Lakes Research; in press.

Host, G., J. Schuldt, J. Ciborowski, L.B. Johnson, T. Hollenhorst, C. Richards. 2005. Use of GIS and remotely sensed data for a priori identification of reference areas for Great Lakes coastal ecosystems. International Journal of Remote Sensing 26(23):5325-5342.

Ingram, J., K. Holmes, G. Grabas, P. Watton, B. Potter, T. Gomer, and N. Stow. 2004. Development of a Coastal Wetlands Database for the Great Lakes Canadian Shoreline, Final Report to the Great Lakes Commission (Wetlands2-EPA-03), 18pp.

Johnson, L.B., C. Richards, G. E. Host, and J.W. Arthur. 1997. Landscape influences on water chemistry in Midwestern stream ecosystems. Freshwater Biology. 37:193-207.

Johnson, L.B., G. E. Host, J. Olker, and C. Richards. 2006. Landscape and reach scale predictors of large wood abundance in low-gradient streams.In: (Hughes, R. M, L. Wang and P. W. Seelback eds). Landscape Influences on Stream Habitats and Biological Assemblages. American Fisheries Society Symposium 48:151-173.

Keough, J.R., T.A. Thompson, G.R. Guntenspergen, and D.A. Wilcox. 1999. Hydrogeomorphic factors and ecosystem response in coastal wetlands of the Great Lakes. Wetlands. 9(4):821-834.

Lopez, R.D., C.M. Edmonds, D.T. Heggem, A.C. Neale, K.B. Jones, E.T. Slonecker, E. Jaworski, D. Garofalo, and D. Williams. 2004. Accuracy Assessments of Airborne Hyperspectral Data for Mapping Opportunistic Plant Species in Freshwater Coastal Wetlands in (R.S. Lunetta and J.G. Lyon, eds.) Remote Sensing and GIS Accuracy Assessment. CRC Press, Boca Raton, FL. 304pp.

Lopez, R.D., D.T. Heggem, D. Sutton, T. Ehli, R. Van Remortel, E. Evanson, and L.A. Bice. 2006. Using Landscape Metrics to Develop Indicators of Great Lakes Coastal Wetland Condition. EPA/600/X-06/002. The United States Environmental Protection Agency, Washington, D.C. 31pp.

Lopez, R.D., D.T. Heggem, J.P. Schneider, R. Van Remortel, E. Evanson, L.A. Bice, D.W. Ebert, J.G. Lyon, and R.W. Maichle. 2005. The Great Lakes Basin Landscape Ecology Metric Browser (v2.0). EPA/600/C-05/011. The United States Environmental Protection Agency, Washington, D.C. Compact Disk and Online at http://www.epa.gov/nerlesd1/land-sci/glb_browser/GLB_Landscape_Ecology_Metric_Browser.htm.

Lopez, R.D., C.B. Davis, and M.S. Fennessy. 2002. Ecological relationships between landscape change and plant guilds in depressional wetlands. Landscape Ecology. 17:43-56.

MacArthur, R. and E.O. Wilson. 1967. The Theory of Island Biogeography. Princeton University Press, Princeton, New Jersey.

Maidment D., S. Morehouse, and S. Friese. 2002. Arc Hydro framework. Arc Hydro: GIS for Water Resources (D. Maidment and D. R. Redlands, eds). ESRI Press. California pp. 203-208.

Maidment, D.R. 1997. AGREE-DEM surface reconditioning system. http://www.ce.utexas.edu/prof/maidment/gishydro/ferdi/research/agree/agree.html.

Minc, L.D. 1997. Great Lakes coastal wetlands: an overview of abiotic factors affecting their distribution, form, and species composition. Michigan Natural Features Inventory, Lansing, MI.

Moffett, M.F., Dufour, R.L., and Simon, T.P. 2007. An inventory and classification of coastal wetlands of the Laurentian Great Lakes. Pp. 17-99 in T.P. Simon and P.M. Stewart, *Coastal* Wetlands of the Laurentian Great Lakes: Health, Habitat, and Indicators. AuthorHouse Press, Bloomington, IN.

Niemi, G.J, J. Kelly, and J. Ciborowski. 2007. Ecological indicators for the Great Lakes coastal region: a synthesis of results. Journal of Great Lakes Research, in press.

Omernik, J. M., 1987, Ecoregions of the conterminous United States. Annals of the Association of American Geographers 77, 118-125.

Owens, T. and K. D. Hop. 1995. Long Term Resource Monitoring Program standard operating procedures: Field station photo interpretation. National Biological Service, Environmental Management Technical Center, Onalaska, Wisconsin, August 1995. LTRMP 95-P008-2. 13 pp. + Appendixes A-E.

Richards, C., R.J. Haro, L.B. Johnson, and G. E. Host. 1997. Catchment and reach-scale properties as indicators of macroinvertebrate species traits. Freshwater Biology. 37:219-230.

Route, B. and J. Elias (eds). 2006. Phase III report: long-term ecological monitoring plan for the Great Lakes Network. U.S. National Park Service, Great Lakes Inventory and Monitoring Network. Technical Report GLKN.2006/02.

Smith, R.D., Ammann, A., Bartoldus, C. and Brinson, M.M. 1995. An approach for assessing wetland functions using hydrogeomorphic classification, reference wetlands, and functional indices. U.S. Army Corps of Engineers, Waterways Experimental Station, Vicksburg MS. Tech Rpt. TR-WRP-DE-9.

Tiner, R.W., H.C. Bergquist, G.P. DeAlessio, and M.J. Starr. 2002. Geographically Isolated Wetlands: A Preliminary Assessment of their Characteristics and Status in Selected Areas of the United States.

Townsend, P.A. 2001. Mapping seasonal flooding in forested wetlands using multi-temporal Radarsat SAR. Photogrammetric Engineering and Remote Sensing, 67(7):857-864.

Toyra, J. and Pietroniro, A. 2005 Towards operational monitoring of a northern wetland using geomatics-based techniques. Remote Sensing of Environment. 97:174-191

Toyra, J. Pietroniro, A., and Martz, L.W. 2001, Multisensor hydrologic assesment of a freshwater wetlands. Remote Sensing of Environment. 75:162-173.

Turner, M.G., R.H. Gardner, and R.V. O'Neill. 2001. Landscape Ecology in Theory and Practice. Springer-Verlag, New York, New York.

Wang, Y. 2004. Seasonal change in the extent of inundation on floodplains detected by JERS-1 Synthetic Aperture Radar data. International Journal of Remote Sensing, 25(13):2497-2508.

Wei, A. and Chow-Fraser, P. 2007. Use of IKONOS imagery to inventory coastal wetlands of Georgian Bay. Fisheries 32:167-173.

Wolter, P., C. Johnston, G.J. Niemi. 2006. Land use change in the U.S. Great Lakes basin 1992-2001. Journal of Great Lakes Research. 32:607-628.

Landscape-Based Indicators Glossary and Key Terms

Airborne hyperspectral data: A remote sensing data type that contains a relatively large number of spectral bands (typically more than 20) and is acquired by a sensor that resides on an airplane, at either a low or high altitude.
Airborne multispectral data: A remote sensing data type that contains a relatively small number of spectral bands (typically less than 10) and is acquired by acquired by a sensor that resides on an airplane, at either a low or high altitude.
ANOVA: Analysis of Variance test.
Anoxic: Condition which lack oxygen, typical of wetland soils.
C-CAP : The U.S. National Atmospheric and Oceanographic Administration's Coastal Change and Analysis Program.
CCRS: Canadian Center for Remote Sensing.
CWS: Canadian Wildlife Service.
Decision support: A set of software and/or database applications that are intended to allow users to search large amounts (e.g., in a clearinghouse) of information for specific reporting that can result in making (e.g., environmental) management decisions.
Ecological processes: The flow of energy and nutrients (including water) through an ecosystem.
Ecosystem: An interacting system consisting of groups of organisms and their nonliving or physical environment, which are interrelated.
Ecosystem approach: An approach to perceiving, managing and otherwise living in an ecosystem that recognizes the need to preserve the ecosystem's biochemical pathways upon which life within the ecosystems depends (e.g., biological, social, economic, etc.).
Ecological indicator: A characteristic of the environment that is measured to provide evidence of the biological condition of a resource (Hunsaker and Carpenter, 1990). Ecological indicators can be measured at different levels, including organism, population, community, or ecosystem. The indicators in this volume are measures of ecosystem level characteristics, at a broad scale (Jones *et al.*, 1997).
Ecosystem integrity: The inherent capability of an ecosystem to organize (e.g., its structures, processes, diversity) in the face of environmental change.
Endpoint: Endpoints describe a characteristic of an ecosystem of interest, and should be an ecologically relevant measurement. An endpoint can be any parameter, from a biochemical state to an ecological community's functional condition.
EPA: The United States Environmental Protection Agency.
Extirpation: The elimination or disappearance of a species or subspecies from a particular area, but not from its entire range.
Foot: 0.305 meters.
GIS: Geographic Information System(s).
GLNPO: U.S. EPA's Great Lakes National Program Office.
Herptile: A jargon term used to refer to both amphibians and reptiles.
HGM: Hydrogeomorphic (methodology).
Hyper-eutrophication: The undesirable overgrowth of vegetation and algae as a result of high concentrations of nutrients in wetlands; eutrophication greater than the typically higher levels of nutrients found in wetland relative to lakes, streams, and rivers.
IBI: Index of Biotic integrity
Indicator: In biology/ecology, any biological or ecological entity that characterizes the presence or absence of specific environmental conditions, as demonstrated by statistical correlations of ecologically meaningful relationships between the entity(ies) and the environmental condition(s).
Kilometer: 0.62 miles.
Land cover: A biological and/or physical description of the Earth's surface. It is that which overlays or currently covers the ground. This description enables various biophysical categories to be distinguished, such as areas of vegetation (trees, bushes, fields, lawns), bare soil, hard surfaces (rocks, buildings), and wet areas and bodies of water (watercourses, wetlands).
Land use: A social or economic description of land cover. For example, an "urban" land cover description can be described as a land use if particular information about the activities that occur in the urban area can be discerned, such as residential, industrial, or commercial uses. It may be possible to infer land use from land cover, and the converse, but situations are often complicated, and the links to land use are not always evident; unlike land cover, land use is difficult to infer from remote sensing imagery, or over vast areas of the landscape. For example, it is often difficult to decide if grasslands are used or not for agricultural purposes. Distinctions between land use and land cover and their definition have impacts on the development of classification systems, data collection, and geographic information systems in general.
Landsat: The satellite-based U.S. National Aeronautics and Space Administration project that, in the late 1960s and early 1970s, endeavored to observe land features from space. The program has evolved by the launching of a total of several satellites to date. Landsat imagery is used for a variety of Earth observations.
Landscape: A complex concept encompassing several definitions: For the purposes of this report, a landscape is an area containing a mosaic of land cover "patches," i.e., distinct areas that can be defined or mapped. The traits, patterns, and structure of a specific geographic area, including its biological composition, its physical environment, and its anthropogenic or social patterns.
Landscape characterization: The process of documenting the traits and patterns of the essential elements of the landscape.
Landscape ecology: The study of the distribution patterns of communities and ecosystems, the ecological processes that affect those patterns, and changes in pattern and process over time and space.
Landscape indicator: A measurement of the landscape, calculated from mapped or remotely sensed data, used to describe some other spatial or temporal pattern(s) of land use or land cover across a geographic area.

Landscape metrics: A measurement of a component or components (e.g., patches of forest) within the landscape, which is used to characterize composition and spatial configuration of the component within the landscape (e.g., forest size, fragmentation, proximity to other land cover types).
Landscape unit: A reference unit (usually of area) that is being measured, mapped, or described.
Laser altimeter - An instrument that uses a LiDAR to measure the height of the platform (spacecraft or aircraft) above the surface. The height of the platform with respect to the mean Earth's surface is used to determine the topography of the underlying surface.
LiDAR - A light detection and ranging sensor that uses a laser (light amplification by stimulated emission of radiation) to transmit a light pulse and a receiver with sensitive detectors to measure the backscattered or reflected light. Distance to the object is determined by recording the time between transmitted and backscattered pulses and by using the speed of light to calculate the distance traveled. LiDARs can determine atmospheric profiles of aerosols, clouds, and other constituents of the atmosphere.
Liter: 1.057 quarts.
Meter: 3.28 feet.
Metric: Any measurement value.
Mile: 1.61 kilometers.
Model: A representation of reality used to simulate a process, understand a situation, predict an outcome, or analyze a problem. A model is structured as a set of rules and procedures, including spatial modeling tools that relate to locations on the Earth's surface (Jones *et al.*, 1997).
MODIS: The satellite-based "Moderate Imaging Spectroradiometer." A project undertaken by the U.S. National Aeronautics and Space Administration that endeavored to improve our understanding of global dynamics and processes occurring on the land, in the oceans, and in the lower atmosphere.
ORD: U.S. EPA's Office of Research and Development.
Patch: A discrete land cover unit; for example, a "patch of forest" is a specific 25-hectare wooded area in Monroe County, Michigan.
Perforated: The condition of a patch where gaps in the patch exist, such as a gap in a forest patch, which may contain shrub, grass, or other nonforest land cover.
PRISM : Parameter-elevation Regressions on Independent Slopes Model.
Quantile: Each class contains an approximately equal number (count) of features. A quantile classification is well-suited to linearly distributed data. Because features are grouped by the number within each class, the resulting map can be misleading, in that similar features can be separated into adjacent classes, or features with widely different values can be lumped into the same class. This distortion can be minimized by increasing the number of classes.
Radar: An active radio detection and ranging sensor that provides its own source of electromagnetic energy. An active radar sensor, whether airborne or spaceborne, emits microwave radiation in a series of pulses from an antenna. When the energy reaches the target, some of the energy is reflected back toward the sensor. This backscattered microwave radiation is detected, measured, and timed. The time required for the energy to travel to the target and return back to the sensor determines the distance or range to the target.
RU.S.LE: Revised Universal Soil Loss Equation.
SAR: Synthetic Aperture Radar, a side-looking imaging radar that sends out its own microwave frequency energy source and measures the backscattered energy. SAR is a high-resolution ground mapping technique that takes advantage of the forward motion of a vehicle carrying a pulsed radar to synthesize the effect of a large antenna aperture. In other words, the larger the radar antenna (aperture), the higher the radar picture's resolution.
Satellite hyperspectral data: A remote sensing data type that contains a relatively large number of spectral bands (typically more than 20) and is acquired by a sensor that resides on an Earth-orbiting platform.
Satellite multispectral data: A remote sensing data type that contains a relatively small number of spectral bands (typically less than 10) and is acquired by a sensor that resides on an Earth-orbiting platform.
Scale: The spatial or temporal dimension over which an object or process can be said to exist as in, for example, the scale of forest habitat. This is an important factor to consider during landscape ecology assessments because measured values often change with the scale of measurement. For example, coarse scale maps have less detailed information than fine scale maps and thus exclude some information, relative to fine scale maps.
Seiche: Temporary displacement of water in a large lake owing to high winds or atmospheric pressure. The short-term water-level oscillations that result from a seiche are functionally analogous to ocean tides.
SOLEC: State of the Lakes Ecosystem Conference
Spatial database: A collection of information that contains data on the phenomenon of interest, such as forest condition or stream pollution, and the location of the phenomenon on the Earth's surface (Jones *et al.*, 1997).
Spatial pattern: Generally, the way things are arranged on the Earth's surface, and thus on maps. For example, the pattern of forest patches can be described by their number, size, shape, or proximity to other entities. The spatial pattern exhibited by a map can be described in terms of its overall texture, complexity, or by other landscape metrics.
STATSGO: State Soil Geographic (database).
System: An assemblage of interrelated elements or components that comprise a unified whole. An ecological system (ecosystem) is one type.
Thematic map: A map that shows the spatial distribution of one or more specific "data themes" (e.g., percentage of agriculture or human population).
U.S. EPA: United States Environmental Protection Agency.
U.S. FWS: United States Fish & Wildlife Service.

Watershed: A region or area shown in a map as a bounded area that might be actually bounded (on the ground) by ridge lines or other physical divides, which drain ultimately to a particular watercourse or body of water (Jones *et al.*, 1997).

Chapter 9
Cost Analysis for Sampling of Great Lakes Coastal Wetlands

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Introduction

Great Lakes coastal wetland monitoring involves many possible costs including paying and training staff, buying equipment, travel expenses, and processing of samples. Funding availability often determines how much sampling is feasible, therefore it is important to evaluate cost as a factor in developing a monitoring wetland program.

During the course of this project detailed cost estimates were assembled and analyzed for the following indicators: water chemistry, plants, invertebrates, fish, amphibians, birds, and landscape attributes. Cost estimates for each indicator included:

- the cost for each item of equipment needed to sample each indicator and whether it is likely to already be owned, if it is shared by several indicators, and if it is consumable
- cost estimates of salaries for technicians and professionals involved in sampling
- the length of time it takes each person to sample each wetland for each indicator
- the cost and time needed to train staff in the protocols for sampling each indicator
- cost estimates for external lab processing of water chemistry and invertebrate samples
- the costs per mile for automobile and boat travel

These cost estimates formed the basis for the development of the Excel-based Wetland Sampling Cost Estimator Tool. This tool presents cost information in a format most useful for monitoring agencies since it allows them to test an almost unlimited variety of scenarios and evaluate the relative differences in cost. Members of the Great Lakes Coastal Wetlands Consortium evaluated and verified the Cost Estimator Tool and its underlying assumptions and cost formulas.

Results from the Cost Estimator Tool indicate that total costs for the sampling of one wetland site vary from $1,395 to $5,223 with birds, amphibians and plants the least expensive indicators to sample respectively and invertebrates by far the most expensive indicator. The variable (per wetland) costs of sampling are greatest for invertebrates ($3,241), landscape attributes ($2,222) and fish ($1,029) and lowest for birds ($112) and amphibians ($160). The fixed costs (startup costs) are highest for water chemistry ($1,609) and invertebrates ($841) and lowest for amphibians ($106) and birds ($111). Costs decrease if either water chemistry or invertebrate samples are sent to external labs.

As a way of demonstrating the effectiveness of the tool, we tested and gave results for three scenarios that we titled minimalist, no-expense-spared and middle-ground cost estimations. The middle-ground and likely typical scenario for the sampling of all indicators in five sites would result in a cost of $99,828. A stripped down sampling program with only the three least expensive indicators (birds, amphibians and plants) sampled in five sites would cost $6,302. A sampling regime without regard to cost would run $179,777 for five wetland sites largely due to the high cost of training staff in landscape attribute monitoring.

The results from this study could be used to guide monitoring agencies in the process of making decisions regarding cost effective implementation of wetland monitoring programs in the Great Lakes.

Objectives and background

Great Lakes coastal wetland monitoring involves many possible costs including paying and training staff, buying equipment, travel expenses, and processing of samples. Funding availability often determines how much sampling is feasible, therefore it is important to evaluate cost as a factor in developing a monitoring wetland program.

During the course of this project detailed cost estimates were assembled and analyzed for the following indicators: water chemistry, plants, invertebrates, fish, amphibians, birds, and landscape attributes. The people responsible for writing protocols for each indicator evaluated all of these estimates and provided feedback and comments. The tasks involved in creating cost estimates for each indicator included:

- Determining all equipment needed to sample each indicator and identifying the following for each item: its cost, if it is likely to already be owned, if it is shared by several indicators, and if it is consumable;
- Developing estimates of salaries for technicians and professionals involved in sampling;
- Estimating how long it would take each person to sample each wetland for each indicator;
- Approximating the cost and time needed to train staff in the protocols for sampling each indicator;
- Procuring cost estimates for external lab processing of water chemistry and invertebrate samples; and
- Calculating costs per mile for automobile and boat travel

These cost estimates formed the basis for the development of the Excel-based Wetland Sampling Cost Estimator Tool. This tool presents cost information in a format most useful for monitoring agencies since it allows them to test an almost unlimited variety of scenarios and evaluate the relative differences in cost. The Partners Committee evaluated the tool and feedback was incorporated. The results from this study will be used to guide monitoring agencies in the process of making decisions regarding cost effective implementation of wetland monitoring programs in the Great Lakes.

Methods

Costs

Cost estimates were developed for each piece of equipment used in the sampling of each of the indicators. Costs were obtained from a variety of sources including reports developed from the 2002 Great Lakes wetlands sampling season, online research and phone calls to stores. When possible at least three cost estimates were found for each item. Cost estimates of equipment needed for each indicator are given in Tables 9-1 through 9-7. Also included in these tables is information on whether the item is consumable/non-consumable, generally owned/not owned by the sampling agency, and whether multiple indicators share the item. Table 9-8 includes costs for general equipment used during the sampling of all indicators. All equipment costs were verified by the people responsible for writing the protocols for each indicator namely: Don Uzarski (water chemistry/invertebrates/fish), Denny Albert (plants), Steve Timmermans (birds/amphibians), and Ric Lopez and Laura Chavez (landscape attributes).

Table 9-1. Cost estimates of equipment needed for the sampling of wetland water chemistry

Equipment	Cost (US$)	Consumable/ nonconsumable (C/N)	Generally owned/not owned (O/N)	Shared with other indicators (Y/N)	Used for field sampling/onsite lab processing (F/L)
Cooler	$8	N	N	N	F
Ice packs	$10	N	N	N	F
Gloves	$15	N	N	N	F
Whirlpaks	$1	C	N	N	F
Thermometer (2)	$20	N	N	N	F
Kimwipes	$5	C	N	N	L
Goggles	$13	N	N	N	L
Calibration rack	$66	N	N	N	L
Sample tubes	$42	N	N	N	L
Test-tube racks	$98	N	N	N	L
Nalgene bottles	$99	N	N	N	L
Standards (nutrients)	$16	C	N	N	L
Phosver 3	$4	C	N	N	L
Nitraver 3	$6	C	N	N	L
Nitraver 5	$5	C	N	N	L
Volumetric Flasks	$37	N	N	N	L
Graduated Cylinders	$158	N	N	N	L
Filters	$5	C	N	N	F
Beakers	$22	N	N	N	L
Pipettes	$231	N	N	N	L
Pipette tips	$103	N	N	N	L
Filtering Unit	$124	N	N	N	F
Hand pump	$124	N	N	N	L
Ammonia	$15	C	N	N	L
Alkalinity	$6	C	N	N	L
HCl	$6	C	N	N	L
Nitric acid	$3	C	N	N	L
Sulfuric acid	$5	C	N	N	L
NaOH	$6	C	N	N	L
Turbidity standard	$23	C	N	N	L
Conductivity standard	$3	C	N	N	L
pH standard	$3	C	N	N	L
Syringes	$245	N	N	N	L
Syringe filters	$37	C	N	N	L
GFC filters	$7	C	N	N	L
Secchi disk	$36	N	N	N	F
Hydrolab	$10,000	N	O	N	F

Table 9-2. Cost estimates of equipment needed for the sampling of wetland plants

Equipment	Cost (US$)	Consumable/ nonconsumable (C/N)	Generally owned/not owned (O/N)	Shared with other indicators (Y/N)
Plant bags and tags	$1	C	N	Y
Plant press and blotters	$90	N	N	Y
Rake (2)	$20	N	N	Y
Hand lens	$5	N	N	Y
Quadrat frame	$10	N	N	Y
1/2 inch Conduit	$3	N	N	Y
Field guides/taxonomic keys	$236	N	N	Y

Table 9-3. Cost estimates of equipment needed for the sampling of wetland invertebrates

Equipment	Cost (US$)	Consumable/ nonconsumable (C/N)	Generally owned/not owned (O/N)	Shared with other indicators (Y/N)	Specific to sweep nets/lab (S/L)
D-frame sweep nets (3)	$153	N	O	N	S
Shallow pans (3)	$24	N	N	N	S
Forceps (3)	$18	N	N	N	S
Eye droppers (3)	$1	N	N	N	S
Clicker counters (3)	$27	N	N	N	S
Pipettes (100)	$16	N	N	N	S
Petri dishes	$50	N	N	N	L
Scintillation vials (1500)	$227	N	N	N	L
Invertebrate identification books (2)	$150	N	N	N	L
Dissecting microscope	$1,201	N	O	N	L
Light source for scope	$289	N	N	N	L
Ethanol	$22	C	N	Y	-
Bottles for bug collection	$9	C	N	Y	-
Squirt bottles	$24	N	N	N	-

Table 9-4. Cost estimates of equipment needed for the sampling of wetland fish

Equipment	Cost (US$)	Consumable/ nonconsumable (C/N)	Generally owned/not owned (O/N)	Shared with other indicators (Y/N)	Specific to fyke/minnow (F/M)
Fyke nets - for 6 nets	$3,366	N	O	N	F
Metal conduit (as stakes for fyke net)	$60	N	N	N	F
Buoys	$5	N	N	Y	-
Rope for attaching buoys	$2	C	N	Y	-
Ethanol	$3	C	N	Y	-
Baking soda for putting out fish	$1	C	N	N	-
Fish ID books	$60	N	N	N	-
Buckets for holding fish	$20	N	N	N	-
Fish measuring boards	$15	N	N	N	-
Small dip nets (3)	$5	N	N	N	-
Nalgenes for keeping sample fish	$15	N	N	Y	-
Cable ties	$1	C	N	N	-

Table 9-5. Cost estimates of equipment needed for the sampling of wetland amphibians

Equipment	Cost (US$)	Consumable/ nonconsumable (C/N)	Generally owned/not owned (O/N)	Shared with other indicators (Y/N)
Field guides for amphibians	$47	N	N	N
Bird call tapes	$26	N	N	N
Metal electical conduit including stakes	$56	N	N	Y
Thermometer	$10	N	N	Y

Table 9-6. Cost estimates of equipment needed for the sampling of wetland birds

Equipment	Cost (US$)	Consumable/ nonconsumable (C/N)	Generally owned/not owned (O/N)	Shared with other indicators (Y/N)
Binoculars	$300	N	O	Y
Field guides for birds	$47	N	N	N
CD player and speakers	$75	N	O	N
Bird call CDs	$26	N	N	N
Metal electical conduit including stakes	$56	N	N	Y
Meter and volt-ohm	$5	N	N	N
Thermometer	$10	N	N	Y

Table 9-7. Cost estimates of equipment needed for the sampling of wetland landscape attributes

Equipment	Cost (US$)	Consumable/ nonconsumable (C/N)	Generally owned/not owned (O/N)	Shared with other indicators (Y/N)	Specific to GIS/Field (G/F)
Binoculars	$300	N	O	Y	F
GIS software	$18,495	N	O	N	G
Aerial photographs	$100	N	O	N	G
Airborne remote sensing data	$1,000	N	O	N	G
Satellite remote sensing data	$500	N	O	N	G
Spectroradiometer	$9,000	N	O	N	G/F
Plant bags and tags	$1	C	N	Y	F
Plant press and blotters	$90	N	N	Y	F
Rake (2)	$20	N	N	Y	F
Hand lens	$5	N	N	Y	F
Quadrat frame	$10	N	N	Y	F
1/2 inch Conduit	$3	N	N	Y	F
Field guides/taxonomic keys	$236	N	N	Y	F

Table 9-8. Cost estimates of equipment needed for general wetland sampling. These costs are shared by all indicators.

Equipment	Cost (US$)	Consumable/ nonconsumable (C/N)	Generally owned/not owned (O/N)
Boat			
14' flat-bottomed boat	$1,321	N	O
9.9 horsepower motor	$2,123	N	O
Boat trailer	$855	N	O
Boat sponge	$1	N	N
Grease kit	$10	C	N
Screwdrivers	$5	N	N
Set of wrenches	$10	N	N
Boat paddles (2)	$30	N	N
Rachet tie down (2)	$17	N	N
Anchor	$11	N	N
Fire extinguisher	$15	N	N
Jerry can	$8	N	N
Black auto goop	$7	C	N
Canoe			
Canoe	$786	N	N
Canoe paddles (2)	$21	N	N
Canoe blocks	$6	N	N
Tie down straps	$20	N	N
Motor for canoe	$500	N	N
Field equipment			
Backpack	$28	N	O
GPS unit	$145	N	O
Topo maps	$66	N	N
Compass	$35	N	N
Waders (3)	$150	N	O
Depth stick	$40	N	N
Tape measure - 100 m	$50	N	N
Tool box	$20	N	N
Gazetteer	$20	N	N
Digital camera	$200	N	N
case for digital camera	$22	N	N
Rite-in-the-rain paper	$10	C	N
Clipboards (2)	$10	N	N
Field paperwork organizers	$5	N	N
Flagging	$8	C	N
Stickers for labeling samples	$5	C	N
Tape	$2	C	N
Scissors	$4	N	N
Rope	$34	C	N
China markers	$6	C	N
Spare keys	$10	N	N
VHF radio	$143	N	O
Batteries for field equipment	$100	C	N
Sunblock	$20	C	N
Bandaids	$3	C	N
Asprin	$6	C	N
Antiseptic solution	$7	C	N
PFDs (4)	$174	N	N
CDs for data storage	$15	C	N
Flashlight (2)	$41	N	N
Dry bags (2)	$43	N	N
Fox 40 whistles (2)	$9	N	N
Cowhide gloves (3)	$19	N	N
Reflective tape	$26	C	N
Safety tape	$11	C	N
Duct tape	$15	C	N
Insect repellant (3)	$22	C	N
Zip loc freezer bags	$2	C	N
Pens/pencils	$5	C	N
Stop watch	$9	N	N
Safety kit	$19	N	N
Paper towels	$50	C	N

Table 9-9 shows total costs with reductions for shared items and consumables from Tables 9-1 through 9-7 combined. Table 9-10 shows cost estimates for equipment that might be already owned.

Table 9-9. Estimates of total costs and consumables for equipment to sample each indicator

	Costs with reductions for shared equipment	Consumables
Water chemistry	$1,609	$158
Plants	$365	$1
Invertebrates	$841	$31
Fish	$175	$7
Amphibians	$106	$0
Birds	$111	$0
Landscape attributes	$365	$1

Table 9-10. Estimates of costs for equipment possibly owned by agencies

Owned equipment values	Costs	Indicator affected or general equipment category
Hydrolab	$10,000	water chemistry
D-frame sweep nets (3)	$153	invertebrates
Dissecting microscope	$1,201	invertebrates
Fyke nets - for 6 nets	$3,366	fish
CD player with speakers	$75	birds/amphibians
Binoculars	$300	birds/landscape
GIS software	$18,495	landscape
Aerial photographs, airborne and satellite data for sites & spectroradiometer	$10,600	landscape
Backpack	$28	general
GPS unit	$145	general
Waders (3)	$150	general
VHF radio	$143	general
Canoe	$0	canoe
Canoe paddles (2)	$786	canoe
Canoe blocks	$21	canoe
Tie down straps	$6	canoe
Motor for canoe	$20	canoe
14' flat-bottomed boat	$1,321	boat
9.9 horsepower motor	$2,123	boat
Boat trailer	$855	boat
Boat sponge	$1	boat
Grease kit	$10	boat
Screwdrivers	$5	boat
Set of wrenches	$10	boat
Boat paddles (2)	$30	boat
Rachet tie down (2)	$17	boat
Anchor	$11	boat
Fire extinguisher	$15	boat
Jerry can	$8	boat
Black auto goop	$7	boat

Estimates of the time involved, people needed and training necessary to sample each indicator were developed using information from the 2002 wetland sampling effort reports and in consultation with the experts listed above. Estimates were tallied of the time required to sample each indicator per wetland per person and whether training was needed, and if so, how many hours it would take and how much training would cost. All of this information is presented in Table 9-11.

Table 9-11. Estimates of the sampling time, training time and training cost for wetland indicator sampling

Person-time values	Time per wetland per person (in hours)	Time required to train people (in hours)	Cost for training per person
Water chemistry w/lab time	18	8.5	$0
Water chemistry w/o lab time	2	0.5	$0
Plants	12	4	$0
Invertebrates (sweep netting w/lab time)	45	8.5	$0
Invertebrates (sweep netting w/o lab time)	15	0.5	$0
Fish (fyke nets)	32	0.5	$0
Amphibians	10	3	$125
Birds	7	6	$250
Landscape (GIS analysis)	5	16	$950
Landscape (field based inspections based on habitat)	24	120	$18,000
Landscape (remote sensing analyses)	80	160	$2,000

Water chemistry sampling time was calculated as 18 hours including lab time and two hours without lab time. The time per plant zone per person including field sampling and lab processing was calculated as 4.5 hours and 0.5 hours without lab time for four plant zones per wetland. No replicates are needed since these are covariates thus the spatial variability is handled by stratifying sites by plant zones. Plant sampling time estimates were based on the following. It will take approximately ten hours/person for two people to perform 15 samples per plant zone in two zones per wetland. Only one visit is necessary per wetland. Air photo interpretation will add an additional hour and plant identification another hour per person. This averages out to approximately twelve hours per person for plant sampling per wetland. Invertebrate sampling using sweep nets time was calculated as 45 hours including lab time and 15 hours without lab time. The time per sweep net per person including lab time was calculated as 3.75 hours and without lab time as 1.25 hours with three sweeps per plant zone and four plant zones per wetland. Sampling time per wetland for fish using fyke nets was calculated as 32 hours. This was determined as two hours per net per person with four nets per plant zone and four plant zones per wetland. The ten hours indicated for the amphibian survey was based on the approximate time it takes to complete three survey visits of about three hours each plus one hour of survey set-up time. For birds, sampling time per person per wetland was calculated as seven hours. This was based on the approximate time it takes to complete two survey visits of about three hours each (in this case, one MMP route consisting of six stations occurring at an individual wetland site plus some time to travel between stations) plus one hour of survey set-up time. Landscape analysis was broken into three categories: GIS analysis, field inspections based on habitat, and remote sensing analysis. Sampling time per wetland per person in hours for GIS analysis was calculated as five hours, for field inspections based on habitat as 24 hours and for remote sensing analysis as 80 hours.

Training time and costs vary according to the indicator being sampled. Training is required for both water chemistry and invertebrate sampling and each takes 8.5 hours including time to teach lab processing techniques and only 30 minutes if no lab training is needed (Dr. Donald Uzarski, Central Michigan University, personal communication 2007). All training for both water chemistry and invertebrate sampling can be done at no cost. Likewise, wetland plant and fish sampling can be done at no cost with plants requiring four hours in the field and fish, 30 minutes in the field (Dr. Dennis Albert, Michigan State University, personal communication 2007; Dr. Donald Uzarski, Central Michigan University, personal communication 2007). Amphibian and bird sampling will require six and three hours of training at a cost of $250 and $125, respectively (Dr. Steve Timmermans, Bird Studies Canada, personal communication 2007). Training in ArcGIS can be accomplished via a 16 hour course taken through ESRI, the developers of ArcGIS software, for $950 (ESRI 2007). Field based inspections based on habitat could be accomplished through a 120 hour training for $18,000 and remote sensing training would take 160 hours and cost $2,000 (Dr. Ricardo Lopez, U.S. EPA/ORD/NERL/ESD, personal communication 2007).

Per hour wages were determined for geographic information systems (GIS) professionals, biological technicians (hereafter referred to as technicians), and environmental scientists for the state government (hereafter referred to as professionals). The average salary of someone with five years of GIS experience across all Great Lakes states and provinces is $44,656 U.S. ($22.32 per hour; GISjobs.com 2007). This is from a web survey with an average response rate of 649 for each state/province in the Great Lakes. Median hourly earnings for biological technicians, according to the U.S. Bureau of Labor Statistics Office of Occupational Statistics and Employment Projections, as of May 2004 were $15.97/hour and for environmental scientists $23.43 ($46,850 per year; U.S. Bureau of Labor Statistics 2007).

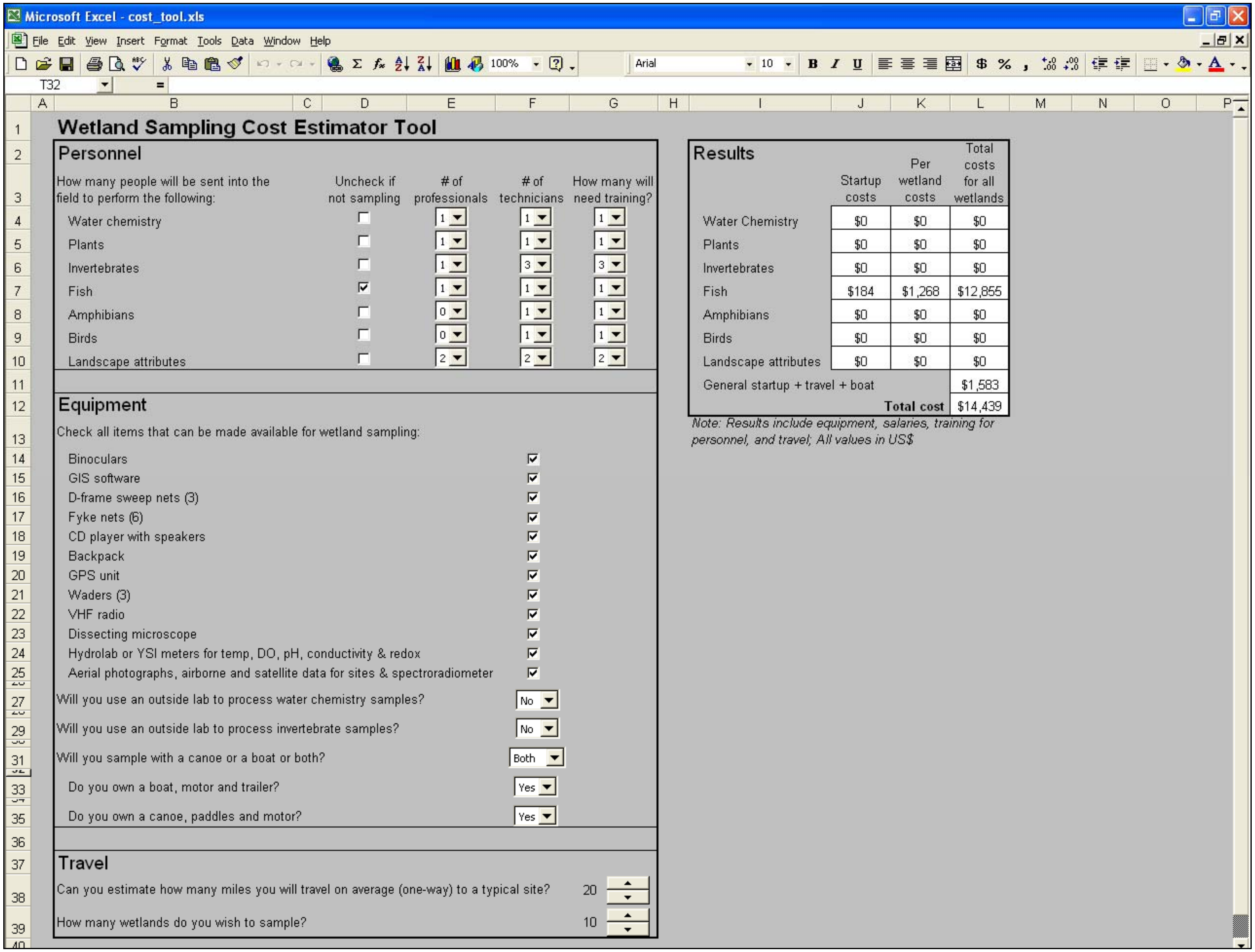
Sample processing for water chemistry and invertebrate samples can be done in house or the samples can be sent to an external lab. Costs per water chemistry sample for off-premises processing are $10/sample per parameter and generally four parameters are processed (three nutrients and alkalinity) and four plant zones are sampled. Therefore, total costs for external lab processing of water chemistry samples per wetland are $160 (Dr. Donald Uzarski, Central Michigan University, personal communication 2007). External lab processing of invertebrate samples to the lowest identifiable taxonomic group is $185 per sample for 10 or more samples. Generally, nine sweep net samples are collected per wetland so the total costs for external lab processing of invertebrate samples per wetland are $1,665 (GEI consultants 2007).

Travel distances to and from sampling sites vary considerably, however costs can be approximated given estimated average travel distances and estimated average costs per mile. Costs per mile include fuel, maintenance, tires, insurance, license/registration/fees, depreciation and finance for a large sedan in 2007 are $.742/mile (AAA 2007). Travel distances are estimated by the sampling agencies in the Cost Estimator Tool.

Indicator sampling may be performed using either a canoe with a motor or a flat-bottomed motor boat. In either case, if the sampling agency does not own the necessary equipment, it will need to purchase it. Costs are given for canoe and motor boat purchase and accessories in Table 8. If a canoe is used with a motor or a motor boat is used, operational costs will also be incurred. The motor will require gas and oil. The number of gallons consumed per hour can be estimated by multiplying horsepower used by 0.100. Thus, a 9.9 horsepower engine requires one gallon per hour (Boatsafe.com 2007). Assuming a gas:oil mixture of 50:1, one gallon of gas requires 2.56 oz of oil (computer support group, Inc 2007). Using prices from June 2007 for gas ($2.957/gallon) and oil ($3.99/16 oz), this relates to a combined cost of $3.60 to run the boat engine for one hour. For estimation purposes, we assumed that it takes two trips to and from a site by boat to complete all sampling at that site.

Cost estimator tool

Many decisions need to be made in the course of determining costs for indicator sampling in Great Lakes wetlands. We decided that the easiest way to provide the most information to sampling agencies was to create a Cost Estimator Tool (Figure 9-1) in Excel that would allow agencies to make decisions regarding indicators sampled, equipment, personnel, training, travel, sample processing, and number of sites to sample and see how those changes impact the startup costs, maintenance costs (per wetland costs) and total costs for indicator sampling. This tool was verified and tested by the members of the Partners Committee.



Microsoft Excel - cost_tool.xls

Wetland Sampling Cost Estimator Tool

Personnel

How many people will be sent into the field to perform the following:	Uncheck if not sampling	# of professionals	# of technicians	How many will need training?
Water chemistry	☐	1	1	1
Plants	☐	1	1	1
Invertebrates	☐	1	3	3
Fish	☑	1	1	1
Amphibians	☐	0	1	1
Birds	☐	0	1	1
Landscape attributes	☐	2	2	2

Equipment

Check all items that can be made available for wetland sampling:

- Binoculars ☑
- GIS software ☑
- D-frame sweep nets (3) ☑
- Fyke nets (6) ☑
- CD player with speakers ☑
- Backpack ☑
- GPS unit ☑
- Waders (3) ☑
- VHF radio ☑
- Dissecting microscope ☑
- Hydrolab or YSI meters for temp, DO, pH, conductivity & redox ☑
- Aerial photographs, airborne and satellite data for sites & spectroradiometer ☑

Will you use an outside lab to process water chemistry samples? No

Will you use an outside lab to process invertebrate samples? No

Will you sample with a canoe or a boat or both? Both

Do you own a boat, motor and trailer? Yes

Do you own a canoe, paddles and motor? Yes

Travel

Can you estimate how many miles you will travel on average (one-way) to a typical site? 20

How many wetlands do you wish to sample? 10

Results

	Startup costs	Per wetland costs	Total costs for all wetlands
Water Chemistry	$0	$0	$0
Plants	$0	$0	$0
Invertebrates	$0	$0	$0
Fish	$184	$1,268	$12,855
Amphibians	$0	$0	$0
Birds	$0	$0	$0
Landscape attributes	$0	$0	$0
General startup + travel + boat			$1,583
Total cost			$14,439

Note: Results include equipment, salaries, training for personnel, and travel; All values in US$

Figure 9-1. Example of the Cost Estimator Tool in Excel.

Assumptions and limitations

Many assumptions were necessary in the course of estimating costs to sample each indicator. We assumed that other than major pieces of equipment (those marked as owned in Tables 1-8), sampling agencies did not own equipment needed to monitor wetlands. This includes all consumables none of which are considered owned by sampling agencies at the start of the project. This may result in an overestimation of the startup costs involved in purchasing needed equipment. All consumables are on a per site basis, meaning each site will require an additional cost to buy more consumables, except general consumables, which are on a per season basis.

Costs were not included for meals or overnight stays. Instead, we are assuming that all sampling sites are close enough to enable driving out and back in one day. Similarly, we are assuming that the sampling agency owns a vehicle to travel to and from the sampling site and thus we are including no costs for car rental or purchase. In terms of travel costs, we also assume that the sampling agency will be traveling to each individual site from their home base (thus, not combining several sites into one trip). In terms of water transportation, we assume that agencies will either own a canoe or boat or buy one or both but not rent either.

Since the exchange rate changes daily, all costs are presented in U.S. dollars. Costs gathered from reports written in 2002 were converted to U.S. dollars using the June 2007 exchange rate. This was done to reflect the current similarity in currency though might result in a slight overestimation of some costs.

In terms of indicator sampling itself, we are assuming that if a sampling agency is sampling invertebrates, they will only be using sweep nets. Similarly, if the agency is sampling for fish, they will only be using fyke nets. However, if they are doing a landscape analysis, they will use both field and GIS methodologies.

The number of personnel needed does not change for water chemistry and invertebrate sampling regardless of whether the work is in the lab or the field. If personnel need training in any type of indicator sampling, they will receive pay during that training. However, so as not to have to differentiate whether professionals or technicians are receiving the training, we are calculating their pay as an average of the professional and technician's wages.

In terms of limitations, the cost tool will begin to lose effectiveness over time as costs for equipment and gas change and the tool is not updated with their inflation adjusted values. Similarly, salaries will increase and those will begin to be dated in the cost tool as well.

Another limitation is the need to lump some things that may not in reality always be lumped. For instance, for the purposes of the tool, we asked for the total number of people that would be needed to sample water chemistry and invertebrates. There is no space to change that number depending on whether this is referring to labwork or fieldwork therefore the total number of personnel is used to calculate costs for both. This likely results in an inflated value for personnel costs.

Similarly, it is difficult to decide how many sites will be visited in the course of the same day so travel costs are calculated as if only one site will be visited per day with no overnight stays. This limitation in the model may serve to increase travel costs.

Overall, the cost tool was designed to be overly conservative and produce higher values than might be reasonably expected if cost cutting measures were taken (combining sites in one trip, using staff time wisely, sharing equipment, etc).

Results

Experts stated that the number of professionals and technicians needed to sample each of the indicators are as follows: water chemistry – 1 professional, 1 technician; plants – 1 professional, 1 technician; invertebrates – 1 professional, 3 technicians; fish – 2 technicians; amphibians – 1 technician; birds – 1 technician; landscape attributes – 2 professionals, 2 technicians. Given these assumptions and without taking training into consideration and holding all other costs constant, the total cost for sampling each of the indicators are given in Table 9-12.

Table 9-12. Estimates of startup, per wetland and total costs for the sampling of each indicator at one site and ten sites all ten miles away.

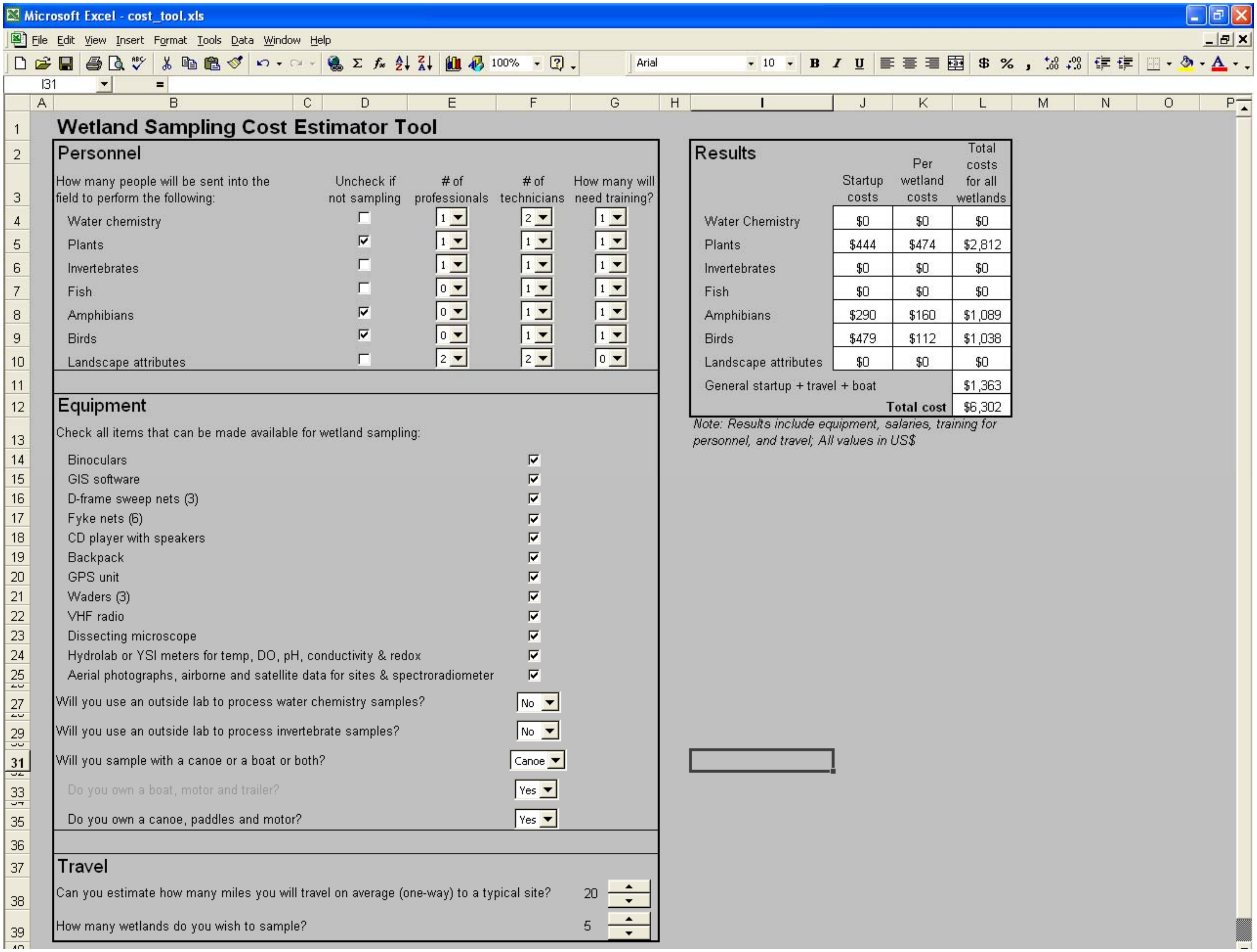
Indicator	Startup costs	Per wetland costs	Total costs for all wetlands	Total costs (including general startup + travel + boat) for 1 site	Total costs (including general startup + travel + boat) for 10 sites
Water chemistry	$1,609	$867	$2,318	$3,490	$6,855
Plants	$365	$474	$838	$2,010	$6,537
Invertebrates	$841	$3,241	$4,051	$5,223	$34,658
Fish	$175	$1,029	$1,197	$2,368	$11,893
Amphibians	$106	$160	$266	$1,438	$3,138
Birds	$111	$112	$223	$1,395	$2,664
Landscape attributes	$365	$2,222	$2,586	$3,758	$24,023

Results show that water chemistry has the highest startup costs at $1,609 with invertebrates also quite high at $841. The rest of the indicators have startup costs ranging from $106 for amphibians to $365 for plants and landscape attributes. Per wetland costs for the indicators vary considerably from $112 for birds to $3,241 for invertebrates. Invertebrate per wetland costs are high due to the cost of invertebrate sampling processing. This scenario assumes that sample processing will be done in house. Per wetland costs would drop to $2,766 if samples are sent to an external lab. The high cost of the in house sample processing is due to the salaries that must be paid to trained staff for the time involved in invertebrate identification. Water chemistry samples are also assumed to be processed in house with a per wetland cost of $867. These costs would drop to $397 if samples are instead sent to an outside lab. This scenario assumes just one wetland site is being sampled so total costs for all wetlands are calculated as just the startup costs added to the per wetland cost. Total costs vary from $223 for bird sampling to $4,051 for invertebrate sampling. General startup costs plus the cost of boat maintenance and travel (assuming 10 miles to the site) total $1,172 and this value was held constant during assessment of indicator costs. Total costs, which include general startup costs, boat maintenance and travel, vary from $1,395 to $5,223 with birds being the least expensive indicator to sample and invertebrates the most expensive indicator.

Increasing the number of sites being sampled from one to ten has a minimal impact on the cost of sampling birds, amphibians and plants. The cost of sampling invertebrates is still the highest at $34,658 and landscape attributes is still the second highest at $24,023. However, the cost of sampling fish increases from the fourth highest cost for one site to the third highest cost for ten sites ($11,893) and water chemistry, which was formerly the third highest cost, becomes the fourth highest when sampling ten sites ($6,855). This change happens because the variable costs of sampling are greater for fish than for water chemistry.

Case studies

Many scenarios are possible with the cost estimator tool. Therefore, we picked three case studies to represent the three most likely scenarios encountered by agency staff. One is the minimalist scenario in which only the three least expensive indicators (birds, amphibians and plants) were sampled, only technicians were trained, all items were borrowed from other agencies or otherwise made available without having to make specific purchases, lab samples were processed in house, and a canoe was purchased instead of a boat (Figure 9-2). A no-expense-spared scenario was also modeled in which in all indicators were sampled, everyone received training, many items were bought new, all lab samples were sent out for processing, and a new boat was purchased (Figure 9-3). The third scenario involved a combination of the two scenarios described above to arrive at possibly the most realistic scenario in which all indicators were sampled, only technicians received training, a combination of new and used items were used, some indicator samples were processed in house (invertebrates) while others (water chemistry) were sent out for processing, and a previously owned boat was used (Figure 9-4).


Microsoft Excel - cost_tool.xls

Wetland Sampling Cost Estimator Tool

Personnel

How many people will be sent into the field to perform the following:	Uncheck if not sampling	# of professionals	# of technicians	How many will need training?
Water chemistry	☐	1	2	1
Plants	☑	1	1	1
Invertebrates	☐	1	1	1
Fish	☐	0	1	1
Amphibians	☑	0	1	1
Birds	☑	0	1	1
Landscape attributes	☐	2	2	0

Equipment

Check all items that can be made available for wetland sampling:

- ☑ Binoculars
- ☑ GIS software
- ☑ D-frame sweep nets (3)
- ☑ Fyke nets (6)
- ☑ CD player with speakers
- ☑ Backpack
- ☑ GPS unit
- ☑ Waders (3)
- ☑ VHF radio
- ☑ Dissecting microscope
- ☑ Hydrolab or YSI meters for temp, DO, pH, conductivity & redox
- ☑ Aerial photographs, airborne and satellite data for sites & spectroradiometer

Will you use an outside lab to process water chemistry samples? No

Will you use an outside lab to process invertebrate samples? No

Will you sample with a canoe or a boat or both? Canoe

Do you own a boat, motor and trailer? Yes

Do you own a canoe, paddles and motor? Yes

Travel

Can you estimate how many miles you will travel on average (one-way) to a typical site? 20

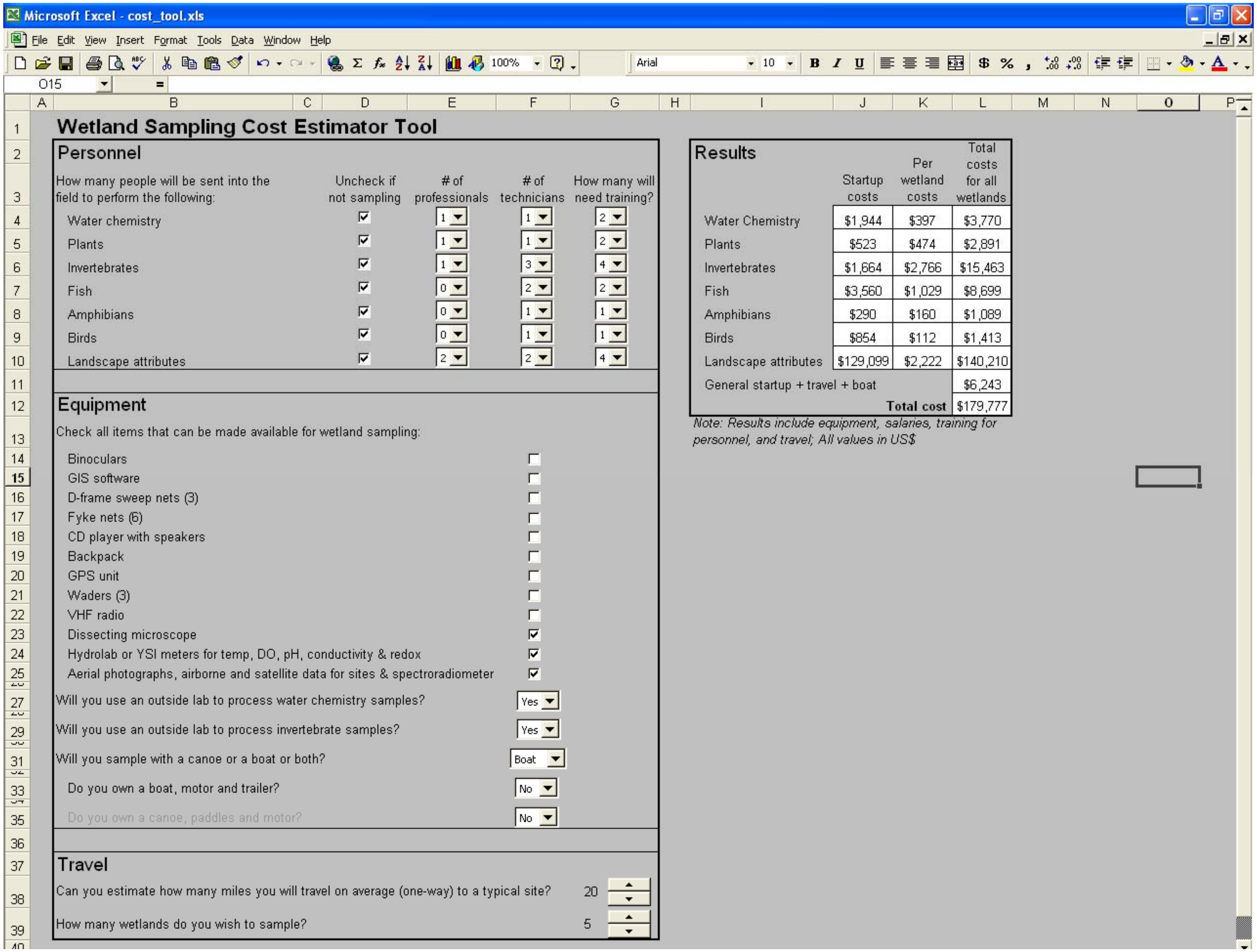
How many wetlands do you wish to sample? 5

Results

	Startup costs	Per wetland costs	Total costs for all wetlands
Water Chemistry	$0	$0	$0
Plants	$444	$474	$2,812
Invertebrates	$0	$0	$0
Fish	$0	$0	$0
Amphibians	$290	$160	$1,089
Birds	$479	$112	$1,038
Landscape attributes	$0	$0	$0
General startup + travel + boat			$1,363
Total cost			$6,302

Note: Results include equipment, salaries, training for personnel, and travel; All values in US$

Figure 9-2. Cost estimate for the minimalist scenario



Microsoft Excel - cost_tool.xls

Wetland Sampling Cost Estimator Tool

Personnel

How many people will be sent into the field to perform the following:	Uncheck if not sampling	# of professionals	# of technicians	How many will need training?
Water chemistry	☑	1	1	2
Plants	☑	1	1	2
Invertebrates	☑	1	3	4
Fish	☑	0	2	2
Amphibians	☑	0	1	1
Birds	☑	0	1	1
Landscape attributes	☑	2	2	4

Equipment

Check all items that can be made available for wetland sampling:

Binoculars	☐
GIS software	☐
D-frame sweep nets (3)	☐
Fyke nets (6)	☐
CD player with speakers	☐
Backpack	☐
GPS unit	☐
Waders (3)	☐
VHF radio	☐
Dissecting microscope	☑
Hydrolab or YSI meters for temp, DO, pH, conductivity & redox	☑
Aerial photographs, airborne and satellite data for sites & spectroradiometer	☑

Will you use an outside lab to process water chemistry samples? Yes

Will you use an outside lab to process invertebrate samples? Yes

Will you sample with a canoe or a boat or both? Boat

Do you own a boat, motor and trailer? No

Do you own a canoe, paddles and motor? No

Travel

Can you estimate how many miles you will travel on average (one-way) to a typical site? 20

How many wetlands do you wish to sample? 5

Results

	Startup costs	Per wetland costs	Total costs for all wetlands
Water Chemistry	$1,944	$397	$3,770
Plants	$523	$474	$2,891
Invertebrates	$1,664	$2,766	$15,463
Fish	$3,560	$1,029	$8,699
Amphibians	$290	$160	$1,089
Birds	$854	$112	$1,413
Landscape attributes	$129,099	$2,222	$140,210
General startup + travel + boat			$6,243
		Total cost	$179,777

Note: Results include equipment, salaries, training for personnel, and travel; All values in US$

Figure 9-3. Cost estimate for the no-expense-spared scenario

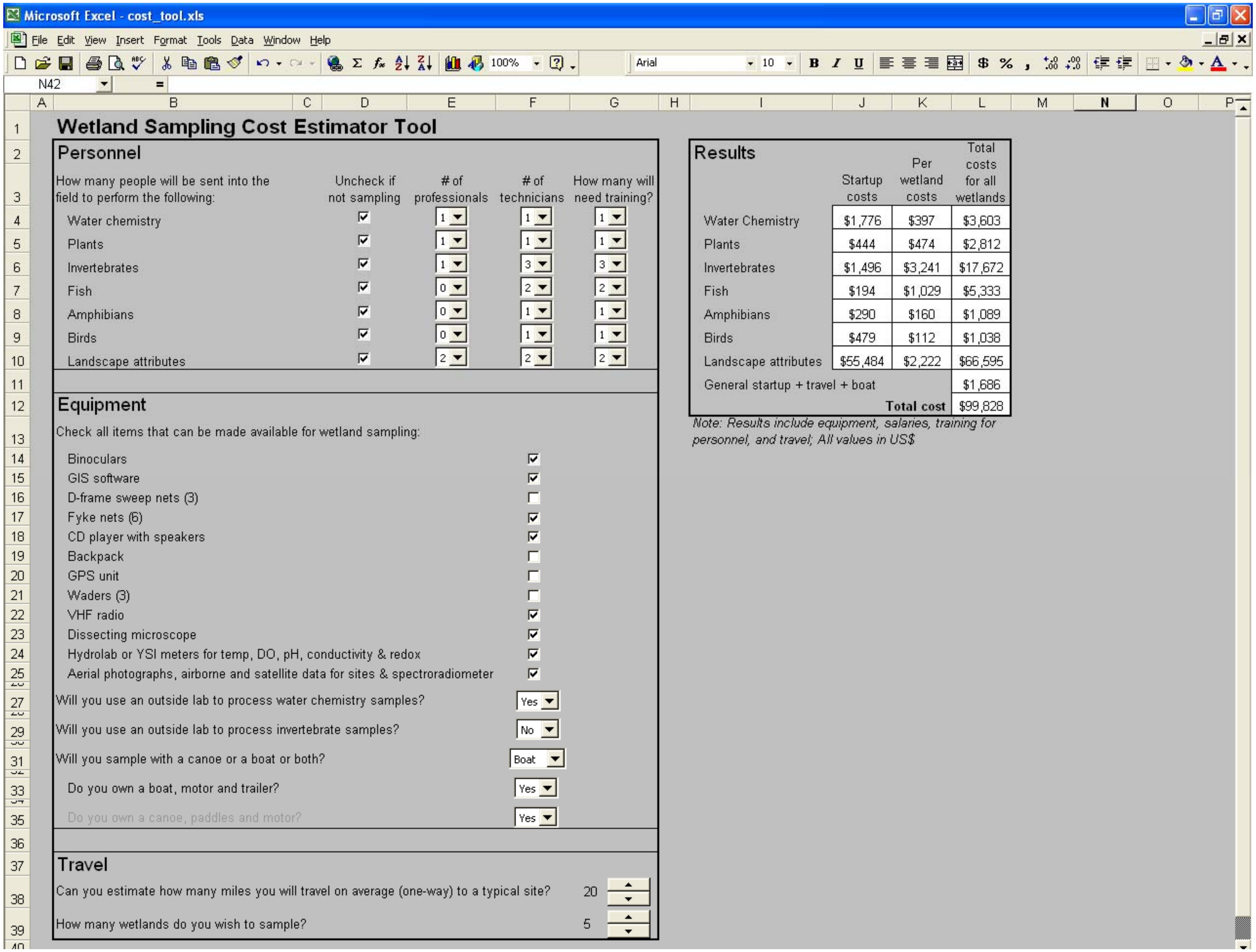


Figure 9-4. Cost estimate for the middle-ground scenario

All three scenarios assumed that five sites were sampled and that all were 20 miles from the sampling agency. The results show that the costs for sampling under the minimal scenario were estimated at ($6,302), no-expense-spared scenario ($179,777) and middle-ground scenario ($99,828).

Under the minimalist scenario, just the three least expensive indicators were sampled (birds, amphibians, and plants). The startup costs for each of the indicators were minimal (birds $479, amphibians $290, plants $444) and the costs for consumables were minor (birds and amphibians $0, plants $1). Few people were needed and most of the work could be performed by technicians without the help of professionals (1 technician for birds and amphibians, 1 professional and 1 technician for plants). Further, none of the typically owned equipment needed to be purchased by the sampling agencies. All of these factors helped to minimize costs.

The no-expense-spared scenario presented a very different story. In this scenario all indicators were sampled and very little equipment was assumed to already be owned (only the dissecting microscope, hydrolab or related water chemistry sampling equipment, and aerial photographs) resulting in higher startup costs ranging from $290 for amphibians to $129,099 for landscape attributes. This high landscape attribute cost is largely the result of the training needed for professional/technical staff ($110,239). Landscape attribute startup costs fall to $365 when calculated without training. It was also assumed that a boat would need to be purchased adding $4,414 to the general startup costs.

The middle-ground scenario is approximately half the cost of the no-expense-spared scenario with many of the same benefits as it also includes the sampling of all indicators. The most substantial cost ($55,484) in this scenario is that of training technicians in landscape attribute sampling, a cost which is buried in the startup costs for that indicator. This scenario represents the most likely real circumstances as agencies will most likely have access to much of the needed equipment including a boat and some staff will most likely already have some form of training or can take advantage of on-the-job training.

Summary

This project attempted to produce a tool that could be used by monitoring agencies to estimate costs for sampling wetlands using a variety of indicators. The tool allows agencies to make decisions regarding the indicators sampled, equipment, personnel, training, travel, sample processing, and number of sites to sample and see how those changes impact the startup costs, maintenance costs (per wetland costs) and total costs in a wetland monitoring program. The indicators researched included: water chemistry, plants, invertebrates, fish, amphibians, birds, and landscape attributes. This user-friendly tool allows monitoring agencies to enter a variety of scenarios and choose the most cost-effective combination of wetland indicators given their financial means.

Our results showed that total costs for the sampling of one wetland site would vary from $1,395 to $5,223 with birds, amphibians and plants the least expensive indicators to sample respectively and invertebrates by far the most expensive indicator. The variable (per wetland) costs of sampling are greatest for invertebrates ($3,241), landscape attributes ($2,222) and fish ($1,029) and lowest for birds ($112) and amphibians ($160). The fixed costs (startup costs) are highest for water chemistry ($1,609) and invertebrates ($841) and lowest for amphibians ($106) and birds ($111). Costs decrease if either water chemistry or invertebrate samples are sent to external labs.

As a way of demonstrating the effectiveness of the tool, we tested and gave results for three scenarios that we titled minimalist, no-expense-spared and middle-ground cost estimations. The middle-ground and likely typical scenario for the sampling of all indicators in five sites would result in a cost of $99,828. A stripped down sampling program with only the three least expensive indicators (birds, amphibians and plants) sampled in five sites would cost $6,302. A sampling regime without regard to cost would run $179,777 for five wetland sites largely due to the high cost of training staff in landscape attribute monitoring.

References

AAA. "Your Driving Costs" 29 June 2007, www.aaaexchange.com/Assets/Files/20073261133460.YourDrivingCosts2007.pdf.

CSG, Computer Support Group, Inc. "Marine Gas Oil Mixture Ratio Calculator" 29 June 2007, www.csgnetwork.com/marineoilfuelcalc.html.

ESRI. "ESRI Training and Education: Course Catalog" 29 June 2007, http://training.esri.com/gateway/index.cfm?fa=search.results&searchterm=&softwaretype=ArcGIS+9&trainingformat=1&cannedsearch=0&sortby=default&oldSearchTerm.

GEI consultants. "Fee schedule and payment terms" July 31 2007, www.chadwicklaboratory.com/invertebrateprocessing.html.

GISjobs.com, LLC. "GISjobs.com Salary Survey." 29 June 2007, www.gisjobs.com/survey/.

Nautical Know How, Inc. "Everything You Ever Wanted to Know about Fuel" 29 June 2007, www.boatsafe.com/nauticalknowhow/fuel.htm.

U.S. Bureau of Labor Statistics. "Environmental Scientists and Hydrologists: Earnings" 29 June 2007, www.bls.gov/oco/ocos050.htm#earnings>.

Appendix 9-1. Wetland Sampling Cost Estimator Tool

The Wetland Sampling Cost Estimator Tool is intended to give users maximum flexibility in making decisions regarding the development of a cost-effective wetland sampling monitoring program. The costs used in this tool are based on the use of Consortium protocols only. The tool is available in Microsoft Excel format only and is accessible via the Internet where this document is posted.

Chapter 10

Data Management System

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Introduction

Purpose of the Data Management System within the Great Lakes Coastal Wetlands Consortium

The Great Lakes Coastal Wetlands Consortium has worked for several years to evaluate select State of the Lakes Ecosystem Conference (SOLEC) indicators as tools for the long-term monitoring of coastal wetland health throughout the Great Lakes. The final result is a set of protocols for gathering and assessing data related to aspects of coastal wetlands ecosystems. Because of the variety of topics being considered, the geographic extent of the region and the number of organizations involved, the Consortium recognized the need for a data-sharing mechanism for use by its members.

The Consortium was seeking a standardized approach that could be applied across the region, allowing data gathered by any of its members to be easily shared, compared and integrated into analytical processes. A centralized, online data management system (DMS) was chosen as the approach to handle this need. The DMS was conceived as an Internet-based application housed on the Consortium's website and open to the research community. Data gathered in the field and from laboratory processes would be recorded in standardized formats and uploaded to a data archive. These data files would be indexed by site, date and protocol. They could then be retrieved using the same parameters.

Status of the System

The first iteration of the Consortium's DMS consists of 1) an online database for indexing and archiving data files, 2) an online user interface that includes tools for submitting data files to the archive and for locating and retrieving files that are already stored there, and 3) a data template that will allow field measurement results to be prepared and submitted in a uniform format. The data template was considered an important component for the current system because it allows researchers and field personnel to record data in a variety of settings, while ensuring that data will be readily useable by others. The template has been designed as a stand-alone document and was formatted for use with Microsoft Excel and other compatible spreadsheet software.

Data providers are required to register before they can upload files. Active members of the Consortium's development committees were registered as users when the system was created. New data providers will have to submit a registration request and be approved by Consortium staff before they will be allowed to upload files. Data users will be asked to register as a means of tracking the system's audience, but access to the data files will not otherwise be restricted.

As of this report, the DMS contains only sample data files. Registered users can download and view them as part of orienting themselves to the system and to the data template. The system is ready to accept files containing actual data at any time.

Summary of Resources

The DMS consists of 1) a PHP/mySQL database connected to a data file archive on the Great Lakes Coastal Wetlands Consortium web site (http://www.glc.org/wetlands/cwc/), 2) online data file submission and retrieval forms and 3) an Excel-based data file template for use by investigators as they prepare their data for submission (see Appendix I). The system is essentially self-contained and could be moved to another server with only limited modification.

System Design

Internet Software

The file archiving database behind the DMS was built using PHP and mySQL and is published using an Apache webserver. This is an industry standard, widely supported software configuration that can be readily maintained and updated. It is currently housed on an Apache server managed by the Great Lakes Commission. Users connect to the database via the Internet using a standard web browser. The web interface allows the user to search the repository database and locate files, which can then be downloaded to the user's local computer.

Data Handling Design and Software

The data archived in the DMS are stored as Microsoft Excel files. Once downloaded, the data files can be opened and manipulated using Microsoft Excel or other compatible spreadsheet software on the user's personal computer. A file archive approach was chosen by the DMS design team because it allowed field personnel to record data at their convenience and in a format that would be readily useable during other monitoring, analysis and reporting phases. It also allowed the DMS design team to match the protocol development timeline used by the Consortium's Scientific Committee.

Data File Template

A template for storing field data was developed based on protocols for each of the wetland characteristics being measured. The template consists of an Excel spreadsheet containing worksheets for each of 20 wetland assessment methods or indicator characteristics. Field teams will use Consortium protocols to measure indicators for the sites they investigate, record their results, then submit the completed file for any given investigation event to the DMS. The files will be stored with critical metadata to allow the database to be searched by date, site, wetland type and/or protocols used. Template parameters can be found in Appendix I.

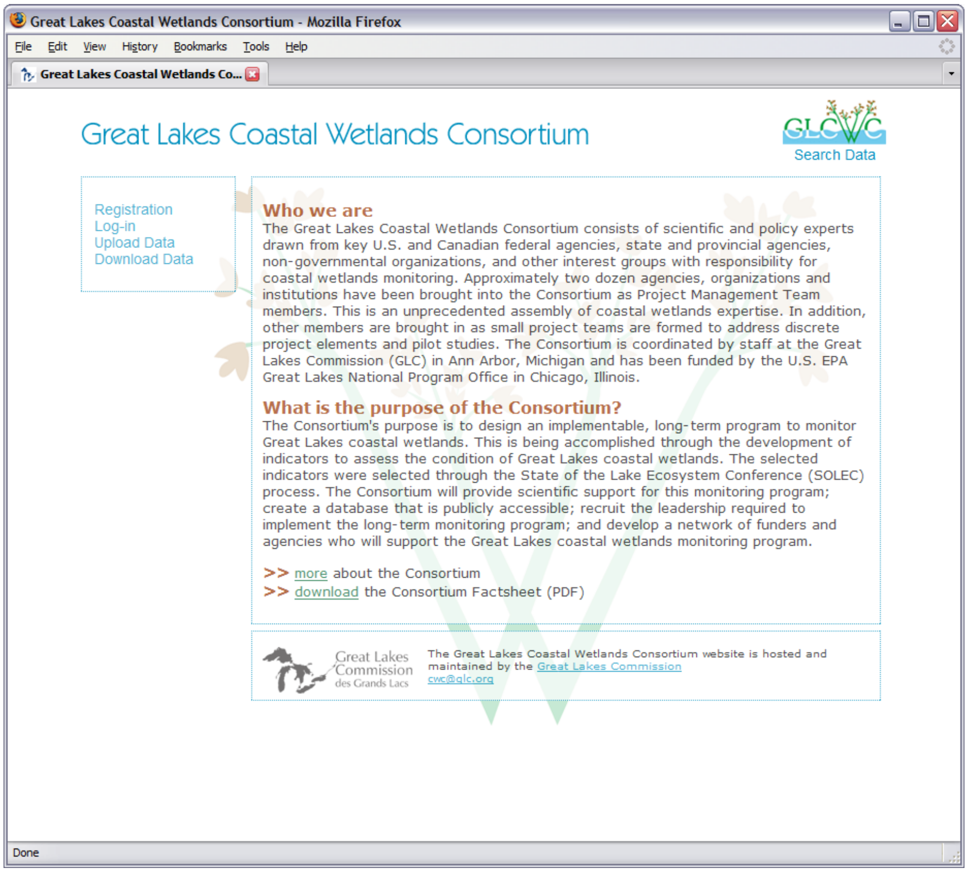
The Microsoft Excel workbook was chosen as the data input software for the first iteration of the DMS because it is a standard application. The software is available for Microsoft Windows-based laptops and Macintosh computers, and the file format can be used in Linux-based software. Data can be entered at the investigator's convenience, then uploaded to the DMS using a standard web browser at any time that internet access is available.

Data retrieval takes place through an online search of the DMS which returns Excel files for the selected sites and dates. For multisite comparisons or temporal analyses, the investigator is required to process the individual files to meet his or her needs.

System Inputs and Outputs

DMS Website

The DMS is accessed through the Great Lakes Coastal Wetlands Consortium website at http://www.glc.org/wetlands/cwc/index.html. Users are offered background information about the Consortium and the DMS, and links to the system's various components.



Data Uploads

Data files are uploaded to the DMS through an interactive web page. This form requires investigators to provide basic reference information at the time the file is uploaded. The mandatory file characteristics that must be entered serve as metadata within the DMS, allowing searches based on the date that a given site visit took place; the specific site location, either by name or by geographic coordinates; the type of wetland being investigated and/or the investigations carried out at that site.

Data Downloads

Data files are retrieved through an interactive web page. This form requests characteristics about the site (name or geographic location), protocol and/or date of interest and then returns the archived Excel files that match the search parameters.

Appendix 10-1. Data File Template

Data are stored in the Coastal Wetlands DMS as preformatted Excel workbooks. A template is provided on the Great Lakes Coastal Wetlands Consortium website, http://www.glc.org/wetlands/cwc/index.html. The Excel workbook template contains spreadsheets for each of the procedures specified by the Consortium's protocols so that data for a given site and sampling date can be stored in a single file.

The template structure is diagrammed below:

Template Worksheet Name	Template Worksheet Fields
SITE	Site name
	Site ID
	Sample date
	Wetland classification
	Associated waterbody
	Latitude
	Longitude
	Projection
	Comments
NEW_ELECTRO_SAMPLING	Site name
	Site ID
	Plant community
	Fluvial zone
	Vegetation zone
	Gear
	Voltage
	Amps
	GPP seconds fished
	Total time fished (minutes)
	Length fished (meters)
	Width fished (meters)
	Start time (EDT)
	% fish captured
	Species
	Length (cm)
	Weight (g)
	Condition
	Comments

SWEEP NETTING	Site name
	Site ID
	Plant community
	Date
	Picking method
	Sample ID
	Comments

ACTIVITY TRAPS	Site name
	Site ID
	Plant community
	Trap #
	Set depth
	Set date
	Clear date
	Sample ID
	Comments
HESTER-DENDY	Site name
	Site ID
	Plant community
	Set depth
	Set date
	Clear date
	Sample ID
	Comments
UV LIGHT TRAPS	Site name
	Site ID
	Plant community
	Trap #
	Set date
	Clear date
	Sample ID
	Comments
FYKE NETS	Site name
	Site ID
	Plant community
	Trap #.
	Net size
	Set depth
	Set date
	Clear date
	Species
	Length

	Weight (g)
	DELT
	Comments

MINNOW TRAPS	Site name
	Site ID
	Plant community
	Trap #
	Set depth
	Set date
	Clear date
	Species
	Length
	Weight (g)
	DELT
	Comments

ELECTROFISHING	Site name
	Site ID
	Plant community
	Buoy #
	Start time (EDT)
	Sampling effort (min)
	% fish captured
	Species
	Length
	Weight (g)
	DELT
	Comments

GILL NETS	Site name
	Site ID
	Plant community
	Net set number
	Net size
	Set depth
	Set time
	Clear time
	Species
	Length
	Weight (g)
	DELT
	Comments

NEW_FYKE_SAMPLING	Site name
	Site ID
	Plant community
	Trap #
	Net size
	Set depth
	Set date
	Clear date
	Species
	Length
	Weight (g)
	DELT
	Comments
VEGETATION	Site name
	Site ID
	Plant community
	Quadrat #
	Sample #
	Date
	Water depth (m)
	Sediment
	OM depth
	Sampling point location
	Distance from point (m)
	Degrees from point
	Dimensions
	Sampling time
	Species
	% Species cover
BIRDS	Site name
	Site ID
	Plant community
	Route ID
	Route name
	Date
	Visit
	Station
	Species
	Count
	Outfly
	Indicator species
	Presence
	Birdair

AMPHIBIANS	Site name
	Site ID
	Plant community
	Route ID
	Route name
	Date
	Visit
	Station
	Species
	Count
	In
	Indicator species
LANDSCAPE ALTERATION	Site name
	Site ID
	Project
	Date
	Crew
	Plant zone
	Dewatering in or near wetland
	Point source inlet
	Installed outlet, weir
	Ditch inlet
	Tile inlet
	Unnatural connection to other waters
	Presence of barriers (dams, waterfalls)
	Tree removal
	Tree plantations
	Mowing or grazing
	Shrub removal
	Coarse woody debris removal
	Removal or emergent vegetation
	Presence of livestock hooves
	Presence of vehicle use
	Presence of grading/bulldozing
	Presence of filling
	Presence of dredging
	Sediment input (from inflow or erosional)
	Areas of land in high public use
	Proximity to navigable channels (m)
	Proximity to recreational boating activity (m)
	Proximity to roadways that receive regular traffic (m)
	# of dwellings
	# of industries
	# of other buildings

	# of boat docks
	# of paved parking lots
	# of dirt parking lots
	# of boat launches
	% hardened shoreline
	% eroding shoreline
	% shoreline containing a visible dirt road
	% shoreline containing a visible paved road
	Habitat types adjacent to wetland (est. %, groundtruthing)
	Land-use classes adjacent to wetland (est %, groundtruthing)
	Note construction sites or obvious sedimentation
	Note highway, rail, levees, berms, boardwalks or other such structures built in or around wetland including whether or not the structure appears to restrict hydrological connection
	Categorical degree and type of direct human activity - categories number coded in sequence with increasing activity
	Comments
CONTAMINATED SEDIMENTS	Site
	Vegetation zone
	Plant type
	Sample
	Log number
	Date sampled
	% solids
	% TOC
	Naphthalene (mg/kg)
	Acenaphthylene (mg/kg)
	Acenaphthene (mg/kg)
	Fluorene (mg/kg)
	Phenanthrene (mg/kg)
	Anthracene (mg/kg)
	Fluoranthene (mg/kg)
	Pyrene (mg/kg)
	Benzo(a)anthracene (mg/kg)
	Chrysene (mg/kg)
	Benzo(b)fluoranthene (mg/kg)
	Benzo(k)fluoranthene (mg/kg)
	Benzo(a)pyrene (mg/kg)
	Indeno(1,2,3-cd)pyrene (mg/kg)
	Dibenzo(a,h)anthracene (mg/kg)
	Benzo(g,h,i)perylene (mg/kg)
	Total PAH Compounds (mg/kg)
	DDD (ug/kg*)
	DDE (ug/kg*)

	DDT (ug/kg*)
	Total PCBs (ug/kg*)
	Ammonia (mg/kg)
	Chromium (mg/kg)
	Lead (mg/kg)
	Cadmium (mg/kg)
	Mercury (mg/kg)
WATER QUALITY	Site name
	Site ID
	Plant community
	Date
	Time
	Sample #
	Sample date
	Volume of water
	Water depth (cm)
	Secchi depth (m)
	Turbidity (NTU)
	Water temp. (deg C)
	Air temp. (deg C)
	pH field
	Dissolved oxygen (mg/L)
	Chlorophyll a (mg/L)
	Redox potential (mohms)
	Conductivity field (?S/cm)
	Total dissolved solids (ppm)
	Salinity (PSS)
	Comments
PICTURES	Roll #
	Picture #
	Site name
	Site ID
	Date
	Description
CREW	Date
	Site name
	Site ID
	Crew
	Weather
	Description of day's activities

Chapter 11
Partnerships for Implementation

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Partnerships for Implementation

The Great Lakes Coastal Wetlands Consortium (Consortium) was formed in 2000 through funding from the U.S. Environmental Protection Agency (U.S. EPA), with the goal of producing a cohesive, long-term program to monitor Great Lakes coastal wetlands. Staff from the Great Lakes Commission served as coordinator and secretariat for the Consortium and more than 50 partners contributed to the development of the plan from the initial pilot studies through the drafting of the final monitoring protocols.

In 2002, initial stakeholder meetings were coordinated on both sides of the border to raise awareness of the Consortium's intention of developing a science-based, binational coastal wetland monitoring protocol for the Great Lakes. Presentations and discussion groups were used to begin partner engagement. Since the initial outreach, the Consortium has been a significant presence at the State of the Lakes Ecosystem Conferences (SOLEC), where representatives from a variety of agencies and organizations from around the basin meet to discuss Great Lakes issues and science. The biennial SOLEC conferences have offered a venue for presentation of Consortium protocol developments and results from pilot investigations. From the beginning, it has been clear that agencies and organizations wishing to adopt Consortium protocols would need assistance in implementing the monitoring plan and forming partnerships to optimize staff, funding and equipment resources.

The Consortium's Partnerships for Implementation Committee (PIC) was formed to aid interested agencies and organizations in implementing the protocols outlined in this document. The first task of the PIC was to identify various agencies and organizations that are currently conducting coastal wetland monitoring or other wetland monitoring programs. To do so, the committee utilized the Great Lakes Commission's 2006 report titled *Environmental Monitoring Inventory of the Great Lakes Basin*, which assessed gaps and overlaps in observing systems and monitoring programs throughout the basin. The gap analysis summarized monitoring efforts for 21 areas, highlighted potential gaps in monitoring coverage, and provided recommendations for improvement.

A second task of the PIC was to identify agencies and organizations that might benefit from adoption of the Consortium basinwide, standardized monitoring protocols and to analyze whether these entities would have the capacity to conduct this monitoring. This task was accomplished through discussion and through a telephone survey to collect information from agency and organization contacts. Survey questions addressed aspects of current or former coastal wetland monitoring activities, staff or volunteer expertise, available equipment, funding mechanisms, and protocol training requirements.

Finally, the PIC was assigned the responsibility of suggesting an implementation strategy to interested agencies, so the process of possibly adopting (or adapting) these protocols would be less daunting for organizations that already lack sufficient resources for existing tasks. The implementation strategy presented in this chapter is based on existing coastal wetland monitoring efforts in the Great Lakes basin and adaptive management strategies to make it more readily implementable. This chapter highlights the findings of the PIC.

The Need for Partnership

Over the last two decades, Great Lakes coastal wetlands have received increasing attention regarding the need for a system, and associated indicators, to effectively monitor coastal wetland quantity and quality, as well as loss and degradation. Although many institutions and organizations devote resources to monitoring and/or restoring specific Great Lakes coastal wetlands, no single organization has overarching, basinwide responsibility for collecting, interpreting and disseminating monitoring information for wetlands. Biological, chemical, physical and landscape information is highly fragmented across federal, state, provincial, tribal/First Nations and local agencies, organizations and governments. For example, encroachment by human development and by aggressive invasive plant species has substantially transformed natural coastal wetlands, but the magnitude of these changes cannot be quantitatively assessed because of the lack of comprehensive data throughout the basin (Great Lakes Regional Collaboration, 2005). Data fragmentation severely compromises science-based water resources management decisions for the basin. In September 2004, the U.S. Government Accountability Office, a group charged with oversight of congressional decisions, responded by issuing a report entitled *Great Lakes: Organizational Leadership and Restoration Goals Need to be Better Defined for Monitoring Restoration Progress* (GAO-04-1024), which identified coordination of restoration and monitoring activities as a key challenge facing Great Lakes leaders.

Common protocols for the monitoring of Great Lakes ecosystem components have, prior to this effort, not been established between the U.S. and Canada or between the states and provinces. Consistency in monitoring protocols and coordination of activities will considerably enhance the quality of the information base for development and reporting of indicators. Indicators are the gauges that provide information on the state of the Great Lakes to citizens, resource managers and stakeholders. Indicators detail the conditions at a particular point in time, allow us to monitor changes over time, provide a basis for management decisions, and allow us to track the success of actions intended to restore the ecosystem. When appropriately formulated and implemented, indicators should be an integral part of the decision-making process regarding the Great Lakes system. Indicators build significantly on observing and monitoring programs by integrating the information produced by these programs with our understanding of the ecosystem to provide information regarding the past, current and future response of the system to stressors. When built upon a firm scientific basis, a comprehensive suite of indicators can help explain observed changes in the ecosystem and may lend some predictive ability regarding future changes (Great Lakes Regional Collaboration, 2005).

Partnerships among agencies will be imperative to ensure the success of implementing a Great Lakes coastal wetlands monitoring program and its associated indicators and monitoring protocols. Federal, state, provincial, tribal/First Nation and local governments, agencies and organizations are already responsible for satisfying various monitoring mandates. For example, the U.S. federal *Clean Water Act* requires that states and tribes monitor and report on the condition of all waters of the United States, including jurisdictional wetlands. Similarly, the Canadian *Clean Water Act* requires all provinces to report and measure actions taken to protect drinking water sources. Coordinated monitoring efforts are also essential to the success of binational efforts such as Lakewide Management Plans (LaMPs) and the Great Lakes Water Quality Agreement (GLWQA). The establishment and success of the Consortium is proof that partnerships already exist, and that multiple diverse agencies can work closely together to achieve the common goal of monitoring Great Lakes coastal wetlands.

Existing and Historical Great Lakes Coastal Wetland Monitoring

In 2006, the Great Lakes Commission developed a report based on its inventory of Great Lakes monitoring activities that assessed gaps and overlaps in observing systems and monitoring programs. The report included policy recommendations to address gaps and improve effectiveness of monitoring efforts (Great Lakes Commission, 2006). The gap analysis compared results from the monitoring inventory to monitoring needs identified through the SOLEC indicator process, and summarized monitoring efforts for 21 resource areas.

In order to identify current monitoring efforts, the PIC reviewed the gap analysis and found that the majority of sampling programs are conducted at the state/provincial level, followed by federal governments, local governments, universities, nongovernmental organizations and, finally, private organizations. Overall, wetland monitoring programs in general, and specifically coastal wetland monitoring programs, were severely lacking, even though both the United States and Canada have identified the need for wetland monitoring. Reviewing the gap analysis in conjunction with a review of U.S. and Canadian monitoring policies revealed a number of existing federal programs that would benefit and mandates that would be better met through the establishment of a consistent Great Lakes coastal wetland monitoring program. Consortium protocols would be an excellent jump start to such a program.

In the United States, land-use permit decisions are affected by both federal and state legislation and policy. The U.S. Army Corps of Engineers (Corps), under Section 404 of the Clean Water Act (U.S. CWA), has federal authority to issue permits for activities in wetlands. Most states utilize the Corps' authority in this regard, but a few states (e.g. Michigan) have adopted their own legislation for wetlands permitting and protection. Many water quality monitoring efforts are based on the requirements of the U.S. CWA. Wetlands are included as waters of the U.S. (40 CFR 122.2, 40 CFR 230.3, and 40 CFR 232.2, U.S. CWA Section 502(7)). However, these monitoring programs are often poorly and inconsistently funded or are improperly designed and carried out, making it difficult to collect a sufficient number of samples over time and space to identify changes in system condition, or to estimate average conditions with statistical rigor (U.S. EPA, 2002).

Existing water quality monitoring programs based on the requirements of the U.S. CWA, outlined below, would benefit from the addition of a wetland monitoring component:

- Water Quality Standards: U.S. CWA Section 303
  States are required to establish water quality standards defining specific goals for all waters of the United States. States must identify each waterbody's designated uses (recreation, water supply, aquatic life, agriculture), develop criteria to protect those uses, develop anti-degradation policies, and address implementation issues (e.g., low flows, mixing zones). Wetlands are often assigned the same designated uses and criteria of adjacent rivers or lakes, which may be ecologically inappropriate. Water quality standards could be specifically tailored to coastal wetlands, providing a consistent basis for the development of policies and technical procedures for managing activities that impact wetlands (U.S. EPA, 2001).

- Tracking and reporting conditions: U.S. CWA Section 305(b)
  Under U.S. CWA Section 305(b), states and tribes are required to report on the quality of all U.S. waters. States must determine if a waterbody satisfies the criteria associated with each of its designated uses. The reporting requirement also has the practical aspect of offering individuals and public officials an opportunity to better understand the implications of their decisionmaking on the condition of their state's water resources (U.S. EPA, 2001). The addition of wetland data to these reports may thus influence federal, state and local permitting and other policies.

- Identifying impaired waters and total maximum daily load implementation plans: U.S. CWA Section 303(d)
  U.S. CWA Section 303(d) requires states and tribes to identify impaired waters and develop total maximum daily loads (TMDLs) for those waters. The addition of wetland monitoring to these monitoring programs would provide information on whether wetlands need to be added to or removed from the list of impaired waters. In addition, wetland monitoring would support the development of restoration plans for waters that do not meet TMDL standards, thus aiding in the recovery of impaired waters (U.S. EPA, 2001).

- Influencing federal permits and licenses: U.S. CWA Section 401
  U.S. CWA Section 401 water quality certification gives states and tribes broad authority to certify, condition, or deny any federal permit or license that would violate the state's established water quality standards. Wetland monitoring would provide more information on the condition of water bodies that could be impacted by federal decisions, and would allow for better analysis of permit applications. (U.S. EPA, 2001).

- Evaluating effectiveness of nonpoint source controls, restoration, and Best Management Practices: U.S. CWA Section 319

> Many federal, state, and local programs attempt to restore wetlands and require best management practices to reduce the amount and impact of nonpoint source pollution. Few programs evaluate the impact of these activities on the overall ecological condition of wetlands. Monitoring wetlands would allow evaluation of the effectiveness of restoration and best management practices designed to improve the condition of wetlands. (U.S. EPA, 2001).

Recognizing the need for guidance on implementation of wetland monitoring programs, the U.S. EPA released *Elements of a State Water Monitoring and Assessment Program for Wetlands* in April 2006. The report indicates that a state's progress in developing a comprehensive wetland monitoring program will serve many federal, state, and local program goals, including the need to:

- Establish a baseline of wetland condition and/or report changes in wetland condition;
- Evaluate the environmental consequences of a federal action or group of actions, including the effectiveness of compensatory wetland mitigation;
- Evaluate the performance of wetland restoration projects;
- Evaluate the cumulative effects of wetland loss and/or restoration, and develop watershed plans for the recovery of impaired water bodies that are listed pursuant to U.S. CWA Section 303(d); and
- Refine or create wetland-specific water quality standards pursuant to U.S. CWA Section 303, including identification of appropriate reference conditions.

To accomplish these goals, the U.S. EPA recommends that states use a three-tiered approach to wetland monitoring. Level 1 involves assessing landscapes and watersheds using remote sensing to create a broad view of wetland condition. Level 2 involves creation of a Rapid Assessment Method (RAM) which uses simple field indicators to analyze the general condition of individual wetlands. Level 3 is based on intensive site investigations, and typically includes using Indices of Biological Integrity (IBI) or conducting a hydrogeomorphic function analysis. This final level is meant to evaluate the success of wetland restoration, or to provide a more detailed assessment of wetland condition for other purposes.

Since the release of the U.S. EPA's guidelines, a number of states have developed monitoring plans utilizing the three-tiered system. In order to comply with U.S. CWA guidelines, all states will eventually need to establish a long-term wetlands monitoring program. The Great Lakes states are all in various stages of developing and implementing monitoring strategies. Because Consortium protocols would fit into the level 3 analysis suggested by U.S. EPA, it is likely the protocols could be relatively easily incorporated into most states' strategies.

In Canada, land-use decisions are affected by both federal and provincial legislation and policy. However, while both the federal and provincial governments have wetland policies, neither has legislation specifically directed to the protection of wetlands. Ontario's wetland policy must be regarded by local governments through the *Provincial Planning Act*. The Canadian federal government delivers on its commitment to Great Lakes protection through domestic policies and legislation as well as through partnerships formed primarily with binational programs and local organizations.

For example, Environment Canada (EC) has taken a role as the lead federal agency participating in the Lakewide Management Plan (LaMP) process. The agency also coordinates provincial and local governments and stakeholders to meet Canada's commitments to ecosystem goals and in the monitoring of progress to achieve those goals. Partnerships are key to the success of the LaMP program. As such, EC has formed relationships with partners such as the Department of Fisheries and Oceans (DFO), which collects information on fish population and fish toxicity, the Ontario Ministry of the Environment (OMOE), which collects water quality, clarity and nutrient input information for the Great Lakes and tributaries, and the local Conservation Authorities (watershed management agencies), which collect information on local watershed natural resources. Coastal wetland monitoring contributes to the LaMP biennial reporting requirement, but LaMP priorities have previously focused more on protection and rehabilitation of wetland habitats than monitoring wetlands. Monitoring coastal wetlands would allow LaMP partners to begin to assess the biological and ecological outcomes of protection and rehabilitation efforts and to evaluate the role of such actions in improving the overall health of wetland ecosystems.

The Canadian federal government is also involved with monitoring programs through its commitment to the GLWQA. The GLWQA is implemented and expanded upon though the *Canada-Ontario Agreement: Respecting the Great Lakes Basin Ecosystem*, which obligates the provincial and federal governments to coordinate resources and work with stakeholders to protect water quality and the health of the Great Lakes ecosystem. The Canada-Ontario Agreement also calls for studies assessing the potential impacts of climate change on the Great Lakes and protection of the Great Lakes as a source of drinking water. Some researchers believe that climate change may cause significant drops in Great Lakes water levels. Since water level cycles are a major driver affecting coastal wetland function, persistent low water levels could have impacts on the diversity of current wetland plant and wildlife communities (Mortsch et al., 2006). At the same time, if water levels continue to drop, the role wetlands play in recharging aquifers, filtering pollutants, and trapping sediments will be even more important to the protection of the water supply for millions of people. The linkage between wetland functions and emerging global environmental impacts and trends further supports the need for a long-term coastal wetland monitoring program.

Wetland monitoring in Canada is also accomplished through other reporting methods established for specific conservation targets. For example, the *Migratory Birds Convention Act* of 1994 aims to protect migratory birds and their habitats. Many of these birds utilize and depend on healthy wetland habitats for components of their lifecycles. Thus, bird monitoring activities can contribute to assessments of wetland habitat. Adaptation of Consortium protocols would improve both bird and wetland monitoring in an efficient manner. Without wetland-specific drivers, wetland monitoring programs in Canada have historically been implemented as a series of localized, short-term efforts, geared at answering specific research questions. This does not provide for a broader ecosystem picture of the status of, or processes within the Great Lakes environment. A commitment by local agencies to use Consortium protocols for meeting specific targets would vastly increase the amount of reliable data available to satisfy legislative mandates such as those outlined in the *Migratory Bird Convention Act*.

As part of GLWQA commitments, both the Canada and the United States have committed to developing Remedial Action Plans (RAP) for restoring Areas of Concern (AOC), the most degraded waterways in the Great Lakes basin. The restoration and rehabilitation of wetlands have been identified within RAPs as crucial to the restoration of beneficial uses in AOCs. Wetland monitoring in the AOCs has been predominantly priority-based and is indirectly implemented through consolidating and assessing related datasets. Coastal wetland monitoring is essential in AOCs to determine RAP success, and the program would greatly benefit from utilization of Consortium protocols.

Based on the PIC's review of existing monitoring efforts, it appears that both the United States and Canada have a variety of programs that could adapt or adopt Consortium protocols, thus helping to satisfy the needs of the programs described above. Coastal wetlands monitoring may be separated into three types of indictors: biological, physical and chemical, and landscape indicators.

Biological Indicators

Currently, a number of programs monitor the biological characteristics of coastal wetlands in the Great Lakes basin. Some programs, such as the *Durham Region Coastal Wetland Monitoring* (Durham project) in Ontario and the *Critical Trends Assessment Program* in Illinois, are tracking several biological indicators for a small group of wetlands. Other programs, such as Ohio's *Wetland Bioassessment Program,* are more inclusive and seek to develop measures and assess the health and integrity of wetlands across several biological indicators. Ohio's program specifically uses IBIs for plant, invertebrate, fish and amphibian communities, which are similar to those methods specified in the SOLEC

Coastal Wetland Plant Community Health, Coastal Wetland Invertebrate Community Health, Coastal Wetland Fish Community Health, and Coastal Wetland Amphibian Diversity and Abundance indicators (SOLEC indicator numbers 4862, 4501, 4502, 4504, and 4862, respectively).

In Canada, the Durham project was established to assess coastal wetland biological communities and habitat in AOCs. The project is a partnership between the Central Lake Ontario Conservation Authority and Environment Canada – Canadian Wildlife Service (EC-CWS). The project was initiated to organize and consolidate regional indicators of coastal wetland health and to field-test monitoring protocols, which were developed for the goal of establishing a regional monitoring program on Lake Ontario. A number of IBIs were developed for this program in order to incorporate an assessment of biological community indicators, such as submerged aquatic vegetation, aquatic macroinvertebrates, fish, amphibians and breeding birds. Use of the IBIs allows the EC-CWS to conduct an assessment of coastal wetland ecosystem health in the Durham Region (Environment Canada and the Central Lake Ontario Conservation Authority, 2004a, and 2004b). Implementation of the program requires a partnership approach, where science and implementation committees are created to assist program implementation on a local level. The Durham project was developed in support of the Consortium and is intended to be a prototype framework for the long-term, binational monitoring program in the Great Lakes basin. The Durham project framework for coastal wetland monitoring has been adopted in other regions of the Great Lakes basin in Canada, and use of these protocols is likely to aid in the delisting of a number of AOCs.

Basinwide biological data sets for Great Lakes coastal wetlands appear to be limited to data collected by the *Marsh Monitoring Program* (MMP), which was developed by the EC-CWS and Bird Studies Canada (BSC). This program is a binational, basinwide, long- term monitoring program that coordinates the skills and interests of hundreds of citizens across the Great Lakes basin to help understand, monitor and conserve the basin's wetlands and their anuran and bird inhabitants (SOLEC indicator #4507). The MMP was initiated in 1994, and has been developed and expanded through the additional support of the U.S. EPA and the Great Lakes Protection Fund. The MMP protocols have contributed to the binational assessment of Great Lakes AOCs (Timmermans et al. 2004; Archer et al. 2006) and are currently incorporated into the Consortium monitoring plan. Over ten years of data have been collected through the MMP. These data are being used to support and help guide the management and remediation of marshes in Ontario and the Great Lakes (e.g., see Timmermans and McCracken, 2004). Several U.S. programs, such as the *Michigan Frog and Toad Survey* and *Frogwatch U.S.A* use methods similar to those used for the MMP for surveying amphibians.

Data collection for other types of biological indicators is not being conducted consistently across the basin. The Consortium protocols outlined in other chapters of this document offer a solution to address this gap.

Physical and Chemical Process Indicators

Few programs are currently using chemical and physical indicators such as nutrient loads, sedimentation, and existence of contaminants in the assessment of wetland health and integrity. Several short-term studies have examined the effects of nutrients and sediments on wetlands, and the Durham project includes assessment of water quality, sediment quality and watershed land use. However, a program to systematically track nutrient or sediment loads to coastal wetlands does not exist. Local sediment and chemical conditions in streams are frequently monitored but these programs rarely, if ever, extend to wetlands. Nutrient concentrations such as phosphorus and nitrogen levels (SOLEC indicator #4860) and sediment flowing into coastal wetlands (SOLEC indicator #4516) change rapidly over time, which could be one reason why programs do not exist to consistently track these indicators.

Many gaps exist in monitoring of physical parameters of Great Lakes coastal wetlands as well. Great Lakes water levels are monitored with lake level gauges maintained by the National Oceanic and Atmospheric Administration (NOAA) in the United States and Canada's DFO, but there are currently no programs addressing the effects of water level fluctuation on coastal wetlands (SOLEC indicator #4861). Similarly, contaminants are infrequently monitored.

The EC-CWS administers a program to study contaminants in snapping turtle eggs (SOLEC indicator #4506), which focuses primarily on Canadian and binational AOCs. There is no comparable U.S. program.

Landscape Indicators

Several SOLEC indicators cover large-scale ecosystem monitoring, which are efforts typically conducted using remote sensing tools such as satellite or aerial imagery and interpretation. Currently, an inventory effort to track changes over time does not exist. The Ontario Ministry of Natural Resources (OMNR) has recently developed a detailed land cover map for southern Ontario which will be useful in providing a landscape context to coastal wetlands. Land use changes are tracked as part of NOAA's *Coastal Change Analysis Program*, but wetland classification at this coarse scale can include only four types. The program revisits the Great Lakes every five years and tracks coarse-scale wetland area and land cover adjacent to coastal wetlands (SOLEC indicator #4863). Fine- scale land cover and land use maps are also generated by each of the Great Lakes states and provinces, while the U.S. Geological Survey (USGS) maintains the *National Land Cover Dataset* at a course scale for the entire U.S. These map products can be used to assess land use change adjacent to wetlands.

One of the most critical indicators for wetland management is the measure of coastal wetland area extent by type (SOLEC indicator #4510). Several ongoing efforts to map wetland areas exist throughout the Great Lakes basin. The U.S. Fish and Wildlife Service (U.S. FWS) operates the *National Wetlands Inventory* project, which delineates wetland polygons from aerial photographs for all U.S. wetlands (coastal and inland), except those in the state of Wisconsin, which has developed its own classification scheme. Several other states, including Ohio and Michigan, have developed additional inventories to supplement *National Wetlands Inventory* maps. In Canada, the OMNR developed the *Ontario Great Lakes Coastal Wetland Atlas*, a consolidation of all field evaluated wetlands inventories that have delineated wetland extent using similar methods, but with a different classification scheme from the U.S. inventories. In order to eliminate confusion for those who adopt Consortium protocols, the Consortium compiled all coastal wetlands inventories into a unified *Great Lakes Coastal Wetland Inventory* (see the Landscape-Based Indicators chapter of this document) with a single wetland classification system.

Framework for Implementation

As emphasized above, implementation of Consortium protocols will require ongoing partnerships among many agencies in order to successfully result in a basinwide data set. The PIC attempted to identify agencies that would be candidates for adopting all or some of the Consortium-recommended monitoring protocols for various portions of the Great Lakes basin.

U.S. Framework for Implementation

Federal Partners

The following U.S. federal agencies already have developed programs that could be modified to include certain Consortium protocols. Although it is not expected that any one of these agencies could take full responsibility for implementing this monitoring strategy, each entity has responsibilities and programs that would benefit from the adoption of the protocols, and/or each has the ability to serve as a useful partner to those that choose to implement them.

- *U.S. Fish and Wildlife Service (U.S. FWS)*
  The U.S. FWS is responsible for coordinating the compilation of wetland status and trends reports on a biennial basis. The agency is also responsible for developing and updating the National Wetlands Inventory.

- *U.S. Army Corps of Engineers (U.S. ACE)*
  The U.S. ACE provides technical and engineering support to the International Joint Commission, a binational organization established to advise the U.S. and Canada on the use and quality of Great Lakes waters. This support is particularly important for matters dealing with lake level regulation and impact assessments of proposed projects seeking permits. The agency also administers various programs that support state and local habitat restoration and protection projects. These activities frequently require monitoring, and could lend themselves to use of Consortium protocols. Finally, the U.S. ACE administers Section 404 of the U.S. CWA which provides authority for permitting changes within coastal zones adjacent to navigable waterways, including protection of wetland resources.

- *U.S. Environmental Protection Agency (U.S. EPA)*
  The U.S. EPA is the major federal agency supporting the GLWQA and the agency also manages development, implementation and reporting of SOLEC indicators and LaMPs. The agency also manages cleanup and restoration efforts within the 30 U.S. AOCs, including monitoring the progress of restored beneficial uses.

- *National Oceanic and Atmospheric Administration (NOAA)*
  NOAA's National Estuary Restoration Program and Coastal Zone Management Program provide funding for the purchase of ecologically important coastal properties. Both programs have distinct requirements for coastal wetlands landscape monitoring and could likely partner with agencies that adopt Consortium protocols.

- *U.S. National Park Service (U.S. NPS)*
  The U.S. NPS monitors wetlands within park boundaries both adjacent to and within the Great Lakes watershed. Some parks may have wetlands that could be monitored using Consortium protocols. If the agency chooses to implement this plan, it could provide great incentive to other property owners such as states and local governments, to monitor their coastal parks as well.

- *U.S. Natural Resources Conservation Service (NRCS)*
  NRCS conducts soil surveys and conservation needs assessments. This agency also maintains the National Resources Inventory to provide a basis for resource conservation planning activities, and to provide an assessment of the condition of private lands. NRCS programs designed to restore or enhance wetlands, such as the Wetland Reserve Program, have resulted in reduced wetland losses across the country.

- *U.S. Geological Survey (USGS)*
  The USGS Great Lakes Science Center is heavily involved in research on coastal ecology and processes. Currently the center is sponsoring research on the effects of low water levels on coastal wetlands and the effects of global climate change on dune and swale complexes. The USGS also has operational requirements for assessing hydrologic characteristics of streams, rivers and near shore waters of the Great Lakes. The agency also participates in conducting specialized research investigations on groundwater, overland flow, bacterial contamination of beaches and other water quality conditions. It is possible that scientists with USGS funding could implement Consortium protocols as a substitution for or along with their own methods for assessing biological indicators, thus allowing information to be collected for their own projects and for the benefit of anyone interested in Consortium data.

State Partners

In order to determine the capacities of each Great Lakes state for coastal wetlands monitoring, the PIC conducted telephone surveys with each state agency that would be most likely to conduct monitoring projects. Tables 10-1 and

10-2 summarize the responses to the survey, and identify wetland monitoring efforts for each state. Agencies queried for the survey were based on Great Lakes Commission contacts and the initial expressions of interest state agencies made during the formative stage of the Consortium. It should be noted that the PIC did not survey every state agency that may participate in wetland monitoring, but only those that would be expected to take a lead role in a coastal wetland monitoring effort. It is likely that the lead agency in each state would work with other state agencies and a number of partners, including the federal agencies listed above, nonprofit organizations, colleges and universities, local governments, and other state agencies to carry out the Consortium monitoring protocols efficiently.

The agencies identified in Table 10-1 all appear to have the ability to conduct a long-term monitoring program, though some agencies may be more likely to implement this plan since adopting Consortium protocols would coincide with their current monitoring mandates. Although availability of staff and equipment are limiting factors, it appears that each state has effective resources to conduct at least a portion of the recommended monitoring protocols. Table 10-2 displays information regarding each Great Lakes state's current staffing and equipment availability, as well as a description of the types of training that will likely be necessary.

Gaps in staff and equipment capacities could likely be addressed through coordination with other agencies. For example, the Land and Water Management Division of the Michigan Department of Environmental Quality, which is the wetlands regulatory agency for the state, does not possess fyke nets or macroinvertebrate survey equipment. However, representatives from the agency indicated that they could work with the Michigan Department of Natural Resources Fisheries Division to coordinate monitoring efforts and share equipment. Other survey participants also indicated that a good working relationship exists among natural resource agencies in their state. Coordination among these groups will allow easier implementation of the Consortium protocols. Even so, some initial funds to purchase equipment may be needed for implementation of these protocols. This funding could include contributions from a combination of federal and state sources with perhaps some contributions from other funding entities such as state trust funds and foundations.

Table 11-1. Results from Consortium Phone Survey: Current Agency Monitoring Efforts and Partnerships.

State	Agency	Coastal Monitoring Description	Other Wetland Monitoring	Partners
Illinois	Illinois Natural History Survey	The Critical Trends Assessment Program (CTAP) has monitored some coastal areas as part of the program's random sampling protocol	CTAP monitors wetland condition throughout the state on public and private land.	The Nature Conservancy, University of Illinois, Illinois Department of Natural Resources
Indiana	Indiana Department of Environmental Management	Currently no monitoring based on coastal wetlands alone.	Environmental Protection Agency (EPA) based monitoring strategy has been developed; on the ground monitoring has not yet begun. National Wetland Inventory (NWI) maps are being updated.	Indiana University; Ducks Unlimited
Michigan	Michigan Department of Environmental Quality (MDEQ), Land and Water Management Division	Currently no monitoring based on coastal wetlands alone.	Currently field testing Michigan Rapid Assessment Method (RAM), and planning to use indices of biological integrity (IBIs) in coastal and inland wetlands as part of a three tiered monitoring plan. NWI Maps are being updated.	Michigan Department of Natural Resources (MDNR); MDEQ Water Bureau; Ducks Unlimited
Minnesota	Minnesota Department of Natural Resources; Minnesota Pollution Control Agency	Some plots of the state's random sampling protocol fall in coastal areas, but currently no monitoring based on coastal wetlands alone.	Random wetland sampling using IBIs and Minnesota RAM	Other state agencies
New York	New York Department of Environmental Conservation (DEC), Division of Fish, Wildlife and Marine Resources	Currently no monitoring based on coastal wetlands alone.	Currently no wetland monitoring program has been developed. The states has been surveying streams for 20 to 30 years.	DEC Freshwater Wetlands Regulatory Program

State	Agency	Coastal Monitoring Description	Other Wetland Monitoring	Partners
Ohio	Ohio EPA	Near shore fish and macroinvertebrate IBIs used in coastal areas, some plots of the state's random sampling protocol fall in coastal areas.	Ohio RAM used to sample throughout the state,	Midwest Biodiversity Institute, Kenyon College, Ohio State University
Pennsylvania	Pennsylvania Department of Environmental Protection (PDEP), Pennsylvania Game Commission	Gannon University has been monitoring chemistry and habitat at Presque Isle for 20 years. PDEP has monitored coastal wetlands in the past as part of its three tiered random sampling monitoring plan	Random sampling of inland and coastal wetlands is conducted. Currently using NWI to develop detailed functional assessments of random wetlands	Pennsylvania Fish and Boat Commission, Pennsylvania Department of Conservation
Wisconsin	Wisconsin Department of Natural Resources	Working with Ontario to conduct a Marsh Monitoring program, which focuses on birds and amphibians.	Currently involved in a number of grant funded monitoring projects focusing on specific locations. The state has developed a wetland monitoring strategy and a Wisconsin RAM	Ontario Marsh Monitoring, University of Wisconsin, Northland College, Great Lakes Indian Fish and Wildlife Commission

Table 11-2. Results from Consortium Phone Survey – State agency staffing and available equipment for each Consortium indicator and anticipated training needs.

State	Macroinvertebrates		Fish		Plants		Birds and Amphibians		Landscape features		Training needs
	staff	equipment	staff	equipment	staff	equipment	staff	equipment	staff	equipment	
Illinois	In house expertise	Accessible	In house expertise	Accessible	In house expertise	Accessible	In house expertise	Accessible	In house expertise	ArcMap	Limited training on specific protocols may be needed
Indiana	In house expertise	Accessible	In house expertise for stream fish	No current access to fyke nets	In house expertise	Accessible	No staff currently available	bird and frog song CDs	In house expertise	ArcInfo	If new staff are hired, extensive training would be needed.
Michigan	Expertise available within other divisions	Accessible through other divisions	Expertise available within other divisions	Accessible through MDNR	In house expertise	Accessible	No staff currently available	Accessible	In house expertise	ArcView 3	Training on birds and amphibians would be needed as well as general training on use of specific protocols
Minnesota	In house expertise	Accessible	In house expertise	Accessible	In house expertise	Accessible	In house expertise	Accessible	In house expertise	ArcMap, ESRI	Depends on abilities of new hires.
New York	In house expertise	Accessible	No staff currently available	No current access to equipment	No staff currently available	Accessible	In house expertise	Accessible	In house expertise, limited by funding	ArcView 9.2	Depends on abilities of new hires.

State	Macroinvertebrates		Fish		Plants		Birds and Amphibians		Landscape features		Training needs
	staff	equipment	staff	equipment	staff	equipment	staff	equipment	staff	equipment	
Ohio	In house expertise	Accessible	In house expertise	No current access to fyke nets	In house expertise	Accessible	In house expertise	CD player with speakers	In house expertise	Arc View 9.2	New staff would need extensive training. Existing staff would need limited training on protocols
Pennsylvania	Expertise available within other state agencies	Accessible	Expertise available within other state agencies	Accessible	In house expertise	Accessible	No staff currently available	Accessible	In house expertise	Arc 1 and 2	Some training may be needed, but contractors would likely be hired to collect data.
Wisconsin	Collection: In house expertise. Identification: outside lab	Accessible	In house expertise	Accessible	In house expertise	Accessible	In house expertise	Accessible	In house expertise	Arc 9.2 and Erdas Imagine	Staff would need training on using specific protocols

Tribal Partners

Tribal governments were not included among the survey participants. It is expected that tribes, like the states, are in various points in the development of monitoring strategies. At this time, no tribe is known to have a fully developed wetland monitoring program. However, several tribes throughout the basin may have the ability to implement Consortium protocols. Many tribes are interested in the condition of coastal and other wetlands that support wild rice or specific wildlife such as turtles. Monitoring of these interests could be accomplished, in part, by tribal implementation of the protocols. Tribes could also consider becoming a part of existing monitoring programs, such as the MMP, in order to begin implementation of a coastal wetlands monitoring program. Again, coordination and funding will be the most important aspects of the tribes' abilities to participate.

Local Partners

Local partners in the U.S. include various universities, colleges, nonprofit organizations, local governments and conservation groups. Thousands of these groups exist throughout the Great Lakes basin, thus the PIC did not evaluate each to determine their potential for participation in Consortium monitoring strategy. However, groups such as the Nature Conservancy and Ducks Unlimited have a vested interest in maintaining wetland functions and many universities have academic and research programs that focus on coastal ecology. These organizations could further their goals of promoting a strong, viable coastal ecology in the region by implementing all or a portion of Consortium protocols. In addition, these groups may be able to use this methodology to answer specific research questions pertaining to coastal wetlands. Although cost and properly trained staff will be a limiting factor for local governments, it may be possible for interested municipalities to partner with each other or with various nongovernmental organizations to implement Consortium protocols for the purpose of assessing the health of important wetland resources in their communities.

Canadian Framework for Implementation

Federal Partners

Canada may choose to follow a previously established framework for implementation of Consortium protocols. The Great Lakes Wetlands Conservation Action Plan (GLWCAP) is an effort that has been highly successful at forging partnerships among government and nongovernmental interest groups with the goal of preventing further losses of wetlands in the Great Lakes basin. Through the GLWCAP, wetland conservation and monitoring activities are coordinated and priorities focused so that entities with limited resources and capacity can operate in a more efficient and effective manner. The GLWCAP provides the opportunity for government and interest groups to develop tools for use in wetland conservation and monitoring. Through this partnership these organizations have the means to promote the use and broader applicability of such tools throughout the Great Lakes basin. The GLWCAP has well-developed partnerships among wetland experts which will be extremely helpful in the implementation of Consortium protocols.

The following federal agencies are valuable potential partners of the Consortium due to their extensive expertise and relevant mandates:

<u>Environment Canada – Canadian Wildlife Service (EC-CWS)</u>

EC-CWS is mandated to protect migratory birds and their habitats (Migratory Birds Act (1994)), and to identify critical habitat on federal lands for species considered "at risk" according to the Committee on the Status of Endangered Species in Canada, and implement plans for their recovery, in accordance to the Species at Risk Act (2002). The EC-CWS has the wetland ecology expertise, excellent GIS capacity and most equipment necessary to carry out Consortium monitoring protocols in designated National Wildlife Areas that contain coastal wetlands.

A number of other federal monitoring programs have linkages to coastal wetland health and may have potential for future integration with a coastal wetland monitoring program:

- Ecological Monitoring and Assessment Network (EMAN)
  EMAN coordinates organizations and individuals involved in ecological monitoring, especially those who actively conduct long-term monitoring. EMAN also fosters collaboration to improve the effectiveness of ecosystem monitoring and to better detect, describe and report on ecosystem changes. EMAN works to coordinate efforts through use of standardized protocols in study design, sampling procedures, data analyses and reporting, and provides a database for community-based monitoring groups to share information and collection protocols. This system is an excellent example of the types of partnerships that could be used in GLCWC monitoring plan implementation.

- Water Survey of Canada
  This national hydrometric program provides real-time, long-term, surface water quantity data and information, including information about the Great Lakes and its tributaries. Wetland diversity and function is directly related to natural water level fluctuations, with coastal wetlands influenced by both lake levels and stream flow or discharge.

- National Wildlife Toxicity Program (NWTP)
  The National Wildlife Toxicity Program aims to establish cause-effect relationships between toxic substances in the environment and wildlife. Monitoring and evaluation studies occur throughout the Great Lakes basin and sites often include coastal wetlands. Integrating monitoring sites between the Consortium monitoring program and the NWTP could provide opportunities for resource and knowledge sharing.

- Parks Canada Agency (PCA)
  Parks Canada Agency is mandated to monitor and report on the ecological integrity of national parks in fulfillment of its responsibilities to the Canada National Parks Act (2001) (Zorn et al. 2006). Ecological integrity is determined through analysis of various indicators, one of which is a wetland ecosystem indicator. Among seven "measures" constituting the wetland ecosystem indicator, PCA selected the Bird Studies Canada (BSC) MMP/Consortium marsh bird and anuran monitoring protocols due to their potential value to inform wetland ecological integrity. BSC partnered with PCA in 2007 to oversee aspects of preparation for MMP/Consortium protocol application among each of PCA's five Great Lakes bioregion parks. Most of these parks contain varying amounts of coastal wetland habitat, especially Point Pelee National Park and St. Lawrence Islands National Park. Therefore, MMP/Consortium marsh bird and anuran monitoring protocols will be utilized at several of these wetland sites. Additionally, following its methodology selection process, PCA selected the Consortium aquatic vegetation sampling protocol (Zorn et al. 2006). Consequently, PCA is a potential partner to contribute marsh bird, anuran and wetland vegetation monitoring and assessment data to the Consortium data management system.

- Department of Fisheries and Oceans(DFO)
  The DFO is responsible, in part, for ensuring the existence of healthy and productive aquatic ecosystems within Canada's marine and freshwater environments. As an agency engaged in LaMPs, the DFO is committed to research, conserve and protect Great Lakes aquatic habitats and the aquatic species that depend on them. As such, the DFO has engaged in several fish and habitat-related research initiatives on the Great Lakes, some of which encompass coastal wetland habitats. The DFO could greatly benefit from being engaged as a partner of the Consortium to incorporate recommended fish monitoring protocols as part of sampling studies conducted within coastal wetland habitats.

Provincial Partners

The entire length of the Canadian shoreline of the Great Lakes lies within the province of Ontario. Thus, provincial programs and partnerships will be essential to successful implementation of the Consortium monitoring plan. The following agencies have programs and mandates that may benefit from adoption of Consortium protocols.

- Ontario Ministry of the Environment(OMOE)
  The OMOE monitors and assesses water quality on the Great Lakes as a partner of the LaMPs to deliver on the COA and the GLWQA. OMOE also coordinates water quality and quantity information for inland lakes and streams, including two, long-term, volunteer-based monitoring programs that may be of interest to a coastal wetland monitoring program. One is the Lake Partner Program, where citizens collect information about water clarity and nutrient inputs. A second is the Provincial Groundwater Monitoring Network, which, in partnership with all Conservation Authorities and several municipalities, collects and manages ambient groundwater level and quality information of key aquifers located across Southern Ontario, including the lower Great Lakes. Both of these programs provide key information toward building better hydrologic models for the Great Lakes and are very useful to monitor how lake hydrologic inputs are influenced by land use and water use to identify trends and emerging issues.

- Ontario Ministry of Natural Resources(OMNR)
  OMNR's primary objective is to protect and manage Ontario's natural resources, including several coastal wetland habitats. In particular, the OMNR Lake Erie Management Unit (LEMU) has been actively involved in wetland monitoring. Beginning in 2007, the OMNR is engaging in a three-year, multi-component ecological assessment study of Long Point Bay. This study will include fish community assessments, water quality monitoring, macroinvertebrate surveys, marsh bird and amphibian monitoring, and aquatic vegetation surveys, among other assessments. Preliminary discussions between BSC, EC-CWS and OMNR-LEMU staff have indicated that MMP/Consortium protocols will likely be utilized to meet marsh bird and anuran monitoring objectives. OMNR-LEMU will be utilizing the Consortium aquatic macroinvertebrate and, possibly, fish survey protocols. OMNR will continue their role as a willing and enthusiastic partner of the Consortium by submitting data generated through use of any Consortium-recommended protocols that they have adopted for their own purposes. The OMNR has also been involved in a number of remote wetland mapping initiatives. Their research and development expertise in these technologies will be an asset to the monitoring of landscape indicators.

First Nation Partners

The First Nations have a close connection with the environment and a vested interest in the management and conservation of the Great Lakes resource. There are at least 20 First Nations communities along the Great Lakes shoreline that have been identified as containing coastal wetland habitat. Many First Nations communities have contributed to or implemented a number of natural resource programs and ecosystem management plans to protect and restore coastal wetlands. Building partnerships with First Nation peoples and communities in the science and monitoring of coastal wetlands and finding ways to link traditional knowledge and values with current environmental challenges will continue to be an important part of partner engagement for wetland conservation decision making.

Nongovernmental Partners

In Canada, wetland monitoring programs have historically been implemented as a series of localized, specific and short-term efforts. Although these programs have been effective in meeting priority needs, differing scientific questions and protocols among constituent program members limits coastal wetland data integration.

Bird Studies Canada (BSC)

BSC's MMP marsh bird and amphibian monitoring protocols have been adopted by the GLCWC for use to provide long-term marsh bird and anuran monitoring. BSC is well positioned to provide much data in this regard through use of its extensive volunteer monitoring network. Queries of the MMP database will identify those monitoring routes which occur at coastal marsh-type wetlands, and resulting data will be submitted through the appropriate channels. BSC staff periodically conduct coastal wetland assessments as part of various special projects, which may include: MMP marsh bird and amphibian surveys, and associated habitat characterizations; physical/chemical water quality measurements; aquatic macroinvertebrate community assemblage assessments; landscape feature/land use descriptions; and fish surveys. As such, BSC staff have expertise and access to various equipment required to conduct these activities.

Conservation Authorities

Conservation Authorities (CA) are generally the best equipped local organizations to implement Consortium coastal wetland monitoring protocols. CAs are local watershed management agencies that deliver services and programs that protect and manage water and other natural resources in partnership with government, landowners and other organizations. Many CAs are mandated to monitor and assess ecological condition and integrity within their watersheds. These mandates are often related to CA responsibilities to oversee watershed-level protection of constituent municipalities' drinking water sources, as required by the Government of Ontario's *Clean Water Act* (2006). Since many CA jurisdictions include coastal areas or their major interconnecting waterways, several already engage in coastal wetland monitoring or assessment activities for various parameters and in various intensities. In many cases, these coastal wetland sampling activities are components of larger, watershed-wide ecological assessment or inventory projects.

CAs participating in monitoring projects can be considered current and natural partners of the Consortium for protocol implementation. In an effort to assess the current monitoring roles of various CAs and to gauge the potential of each CA's involvement in implementation of Consortium protocols, the PIC included many of Ontario's CAs in the phone survey. The results of the survey are summarized below and in Tables 10-3 and 10-4.

Among those CAs whose representatives responded to inquiries, Credit Valley Conservation Authority (CVCA), Grand River Conservation Authority (GrRCA), Niagara Peninsula Conservation Authority (NPCA) and Raisin Region Conservation Authority (RRCA) are all involved in some degree of coastal wetland monitoring. A primary coastal wetland sampling focus for these CAs is wetland vegetation monitoring, which in some cases occurs in conjunction with similar sampling at inland wetlands. Anuran monitoring has also occurred at CVC, GrRCA, and NPCA coastal wetland sites, the latter two of which use the MMP/Consortium protocol.

The St. Clair Region Conservation Authority and Quinte Conservation are not currently conducting coastal wetland monitoring activities, but may be able to in the future, provided funding is available. Each has most of the in-house expertise and equipment necessary to implement Consortium protocols, although staff training would be required. Quinte Conservation, in particular, has formerly partnered with CWS to monitor coastal wetland habitats using Consortium protocols, and currently partners with BSC to deliver local MMP volunteer training workshops. Cataraqui Region Conservation Authority (CRCA), encompassing the Kingston, Ontario region, is another example of an organization with several coastal wetlands with its jurisdiction, but currently lacking a wetland monitoring/assessment initiative. CRCA also chairs the Kingston Wetlands Working Group, a coalition committed to protecting and restoring wetland ecosystems in the Kingston area. Lakehead Region Conservation Authority, within the Lake Superior watershed, currently has no dedicated biological monitoring staff and little in-house expertise required to adopt Consortium protocols. However, much coastal monitoring potential exists in this region given the large extent of coastal wetland habitat, provided that adequate funding sources can be secured. There is a good possibility that these organizations will be supportive of the Consortium's coastal wetland monitoring plan and should be engaged and explored further.

Other Localized Nongovernmental Organizations

Aside from CAs, other potential Canadian local partners include nongovernmental and nonprofit research organizations. One example is the St. Lawrence River Institute of Environmental Sciences (SLRIES), based in

Cornwall, Ontario, which has a mandate to conduct research and promote community action relating to large river systems, with a focus on the St. Lawrence River. The SLRIES has been involved with water quality monitoring and fish and macroinvertebrate sampling within the St. Lawrence River and its surrounding coastal wetland habitats. The Royal Botanical Gardens (RBG), located within Hamilton and Burlington, Ontario, has a research arm that is involved with significant biotic and abiotic monitoring activities within Cootes Paradise Marsh, a marsh complex located at the western end of Lake Ontario. In conjunction with local partners, the RBG tests water quality, conducts wetland vegetation surveys, summer fish surveys, annual marsh bird and anuran monitoring, migratory bird surveys, turtle surveys and GIS-based wetland land cover assessments. The RBG is currently utilizing MMP/Consortium marsh bird and anuran monitoring protocols, carried out by staff and local MMP volunteers.

All contacted organizational representatives were receptive, and in many cases, enthusiastic about the objectives of the Consortium. There is common interest among these organizations to adopt Great Lakes basinwide standardized coastal wetland monitoring protocols. Providing that issues of funding can be adequately addressed to offset implementation costs, CAs and the nonprofit groups listed above represent ideal and likely partners for protocol implementation.

Table 11-3. Current coastal wetland monitoring efforts and partnerships among potential Canadian Consortium partners who responded to information inquiries.

Organization	Jurisdiction	Great Lake Basin	Coastal Monitoring Description	Partners
Bird Studies Canada	Great Lakes basin	N/A	Various coastal wetlands are monitored by volunteers using Marsh Monitoring Program protocols as part of larger monitoring network, and by staff. Periodic water quality assessments conducted by staff and some volunteers.	Various Conservation Authorities, Environment Canada, U.S. Environmental Protection Agency, St. Lawrence River Institute of Environmental Sciences, Area of Concern Remedial Action Plan committees, various community volunteer monitoring groups, Marsh Monitoring Program volunteer participants
Central Lake Ontario Conservation Authority	Encompasses 15 watersheds within the municipalities of Oshawa, Pickering, Uxbridge, Clarington, Ajax and Whitby	Lake Ontario	Leads Durham Region Coastal Wetland Monitoring Project activities	Canadian Wildlife Service, Ganaraska Region Conservation Authority, Toronto and Region Conservation Authority
Credit Valley Conservation	Credit River watershed	Lake Ontario	Wetland vegetation surveys and anuran surveys currently ongoing	University of Guelph, local naturalist clubs and community groups
Ganaraska Region Conservation Authority	Ganaraska River watershed	Lake Ontario	Contributes to Durham Region Coastal Wetland Monitoring Project activities	Canadian Wildlife Service, Central Lake Ontario Conservation Authority, Toronto and Region Conservation Authority
Grand River Conservation Authority	Grand River watershed	Lake Erie	Primarily vegetation monitoring at Dunnville Marsh on Lake Erie	Ontario Ministry of Natural Resources, University of Waterloo

Table 11-3. (Continued)

Organization	Jurisdiction	Great Lake Basin	Coastal Monitoring Description	Partners
Niagara Peninsula Conservation Authority	Ontario and Lake Erie portion of the Niagara River watershed	Lake Ontario/Lake Erie	Currently engaged in anuran monitoring at two marsh locations	Ontario Ministry of Natural Resources
Quinte Conservation	Moira, Napanee and Salmon River watersheds, and Prince Edward County	Lake Ontario	None currently; have worked with Canadian Wildlife Service to implement coastal wetland monitoring and assessment activities for various biotic and abiotic parameters	Bird Studies Canada
Raisin Region Conservation Authority	Raisin River watershed and surrounding smaller watersheds	St. Lawrence River	Primarily vegetation mapping and fish habitat monitoring within St. Lawrence River shoreline marshes	None for coastal wetland monitoring/assessment activities
Royal Botanical Gardens	Cootes Paradise Marsh and surrounding tributaries, located at western end of Lake Ontario	Lake Ontario	Monitioring and assessment activities of various biotic and abiotic parameters within Cootes Paradise Marsh and surrounding tributaries	McMaster University, Bay Area Restoration Council, various other community volunteer groups
St. Clair Region Conservation Authority	Ontario portion of the St. Clair River watershed	Lake Erie	None currently	N/A
Toronto and Region Conservation Authority	Watersheds located within the City of Toronto	Lake Ontario	Contributes to Durham Region Coastal Wetland Monitoring Project activities	Canadian Wildlife Service, Central Lake Ontario Conservation Authority, Ganaraska Region Conservation Authority

Table 11-4. Expertise and equipment availability, and training requirements for each Consortium indicator, among potential Canadian Consortium partners who responded to information inquiries.

Organization	Macroinvertebrates		Fish		Plants		Birds and Amphibians		Landscape features		Training needs
	staff	equipment	staff	equipment	staff	equipment	staff	equipment	staff	equipment	
Bird Studies Canada	In-house expertise	Accessible	In-house expertise	Accessible	No current in-house expertise	None currently available	In-house expertise	Accessible	In-house expertise	ArcView	Staff training to conduct wetland plant surveys would be required.
Central Lake Ontario Conservation Authority	In-house expertise	Accessible	In-house expertise	Accessible	In-house expertise	Accessible	In-house expertise	Accessible	In-house expertise		
Credit Valley Conservation	In-house expertise	Accessible	In-house expertise	Accessible	In-house expertise	Accessible	In-house expertise for anuran surveys only	Accessible	In-house expertise	ArcView, ArcGIS	Staff would need training to use specific protocols. Funding required to hire a staff member trained to conduct bird surveys.
Ganaraska Region Conservation Authority	In-house expertise	Accessible	In-house expertise	Accessible	In-house expertise	Accessible	In-house expertise	Accessible	In-house expertise	ArcView	Further staff training would be required to implement macroinvertebrate surveys and bird and amphibian monitoring
Grand River Conservation Authority	In-house expertise	Accessible	In-house expertise	Accessible	In-house expertise	Accessible	In-house expertise	Accessible	In-house expertise	ArcView, online GIS mapping	Staff would need training to use specific protocols

Table 11-4. (continued)

Organization	Macroinvertebrates		Fish		Plants		Birds and Amphibians		Landscape features		Training needs
	staff	equipment	staff	equipment	staff	equipment	staff	equipment	staff	equipment	
Niagara Peninsula Conservation Authority	In-house expertise	Accessible	In-house expertise	No current access to fyke nets	In-house expertise	Accessible	In-house expertise	Accessible	In-house expertise	ArcGIS	Further staff training would be required to implement macroinvertebrate, fish and vegetation surveys
Quinte Conservation	No current in-house expertise	Accessible	In-house expertise	No current access to fyke nets	In-house expertise	Accessible	In-house expertise	Accessible	In-house expertise	ArcGIS	Further staff training would be required to implement fish, plant surveys and bird, amphibian monitoring. Staff training required for invertebrate sampling.
Raisin Region Conservation Authority	In-house expertise	Accessible	In-house expertise	No current access to fyke nets	In-house expertise	Accessible	In-house expertise	Accessible	In-house expertise	ArcView	Further staff training would be required to implement macroinvertebrate surveys and bird and amphibian monitoring
Royal Botanical Gardens	In-house expertise	Accessible	In-house expertise	No current access to fyke nets	In-house expertise	Accessible	In-house expertise	Accessible	No staff currently available		Further staff training would be required to implement macroinvertebrate surveys
St. Clair Region Conservation Authority	In-house expertise	Accessible	In-house expertise	No current access to fyke nets	In-house expertise	Accessible	In-house expertise	Accessible	In-house expertise	ArcView	Further staff training would be required to implement wetland vegetation sampling and bird and amphibian monitoring
Toronto and Region Conservation Authority	In-house expertise	Accessible	In-house expertise	Accessible	In-house expertise	Accessible	In-house expertise	Accessible	In-house expertise		

Implementation Strategy

In order for implementation of this plan to be successful an organization such as the Great Lakes Commission (possibly via the Consortium or similar entity) will be essential to coordinate monitoring initiation, data collection and communication among partners. As part of the implementation process, a series of workshops will be necessary to train state, provincial, and other partners in the various aspects of this coastal wetlands monitoring plan. Training workshops would likely take place in most Great Lakes jurisdictions, with the possibility of combining entities (such as Illinois and Indiana) that do not have a large number of coastal wetlands in their jurisdiction to monitor. The purpose of such workshops will be to engage prospective partners, discuss the monitoring protocols and identify plausible frameworks for implementing this Great Lakes coastal wetlands monitoring plan.

From its inception, the Consortium has been a partnership of federal, state, provincial, university, nonprofit and other stakeholders from both the U.S. and Canada. Communication among the various partners was essential throughout all phases of the development of this plan – from the original pilot studies where monitoring protocols were tested through the drafting of final protocols.

Due to the Great Lakes basinwide nature of the monitoring called for in this plan, communication will continue to be an essential aspect throughout the plan's implementation. Field personnel will not only need to report their data and findings to their respective agency or organization, but will also be charged with sharing their monitoring data and information with field partners across the basin and their respective agencies. This will facilitate the comparison of data and results necessary for the development of periodic basinwide monitoring reports.

In addition, a central data hub will be needed to coordinate communication and serve as a data storage and information center. The entity housing this hub will be charged with producing periodic updates on the health, status and trends of Great Lakes coastal wetlands based on the data submitted by all agencies and organizations who conduct the monitoring. These reports will be circulated widely throughout the Great Lakes via a wide spectrum of communication channels, including a web site serving as the clearinghouse of information on Great Lakes coastal wetlands. Other means of communicating these reports include various listservs, newsletters, and presentations at meetings and conferences across the Great Lakes basin, including the biennial State of the Lakes Ecosystem Conference. See Chapter 10 titled "Great Lakes Coastal Wetlands Consortium Data Management System" for more on the Consortium data sharing process.

A second essential part of Consortium monitoring implementation will be a dedicated source of funding for each entity wishing to adopt these protocols. This is, perhaps, the greatest obstacle potential partners will face in adopting this plan or a portion thereof. Most agencies and organizations described above receive only periodic funding allocations directed toward wetland monitoring and assessment tasks, or larger watershed-scale studies that incorporate wetland sampling activity. In the U.S, only Illinois and Minnesota have funds that are annually allocated to wetland monitoring, and these sources are rarely enough to carry out an intensive monitoring program. Other states must rely solely on periodic streams of federal funding and grants, which creates a "patchwork" of wetland monitoring over space and time. On the Canadian side, Conservation Authorities also must contend with various and limited funding resources.

Hence, monitoring coordinators should strive to identify and procure dedicated funding sources that can be earmarked for Great Lakes coastal wetland monitoring. Especially during the infancy stages of implementation, intense efforts on the part of all partners will be required to secure funding. Optimally, a dedicated source of funding for the program should be procured, and a portion of the funds should be used as "seed money" to engage partner jurisdictions in implementation of this plan. It is expected that partners will utilize their own resources to the extent possible, with funding targeted to help fill gaps in personnel, equipment and other essential needs. For nonfederal partners a logical place to start would be federal programs – e.g., the CWA Section 106 water pollution control grant program, or other U.S. EPA and EC program grants, etc. – which should consider giving preference to projects using Consortium monitoring protocols as a "best practice" or standard. A variety of potential funding sources are also listed below.

Funding in the United States

The following sources, though not directly targeted toward coastal wetland monitoring, may allow states and tribes to identify funding to implement the Consortium monitoring plan, at least in the short term:

- U.S. CWA Section 106 Water Pollution Control Grant Program
  This program provides grants to states, tribes, and interstate agencies to develop and implement water monitoring programs, including wetlands. These funds can be used for a wide range of water quality activities including restoration and water quality surveys.

- EPA Wetland Program Development Grants
  This federal source of funds helps states, tribes and local governments develop new monitoring programs or improve existing programs. States may be able to use this program to fund pilot programs or to develop a comprehensive wetland monitoring strategy that includes Consortium protocols. However, this source is currently limited to development, rather than implementation, of programs and will likely be insufficient to fuel monitoring programs to a significant degree.

- U.S. CWA Section 104(b)(3) State Wetlands Grant Program
  This program makes grants available to states, tribes, local governments, and nongovernmental organizations to conduct wetlands projects. These wetlands projects emphasize the development of a comprehensive monitoring and assessment program, as well as refining the protection of vulnerable wetlands and aquatic resources. These grants may also be used to conduct surveys, studies and investigations related to causes, effects, prevention and extent of pollution.

- NOAA State Sea Grant Offices
  Each Sea Grant state office offers a variety of funding opportunities for Great Lakes research. While most of this funding is focused towards new and specific Great Lakes research questions, it is possible that funds could be obtained if Consortium protocols were being utilized by a university to study a particular aspect of coastal wetlands.

- NOAA Coastal Zone Management Grants
  NOAA annually allocates funds to coastal states for a variety of coastal projects, including research and monitoring.

- U.S. EPA Great Lakes National Program Office
  Funding opportunities are periodically available to conduct monitoring in the Great Lakes basin.

- U.S. ACE – Estuary Restoration Act of 2000 (Estuaries are defined under the Act to include the Great Lakes.)
  The purpose of the Act is to promote the restoration of estuary habitat, to develop a national Estuary Habitat Restoration Strategy for creating and maintaining effective partnerships within the federal government and with the private sector, to provide federal assistance for and to promote efficient financing of estuary habitat restoration projects, and to develop and enhance monitoring, data sharing, and research capabilities.

- USGS National Water Quality Assessment Program (NAWQA)
  USGS maintains and operates a monitoring network of surface water gauging stations on streams and rivers draining to the Great Lakes. Data from this multi-state monitoring network provides the USGS and its many collaborators with information on surface water flows, quantity of available water, and water quality characteristics. The goal of the NAWQA program is to develop is to develop long-term consistent and comparable information on streams, ground water, and aquatic ecosystems to support sound management and policy decisions. Although this program is not geared specifically towards coastal wetland monitoring, there is potential to build Consortium protocols into various aspects of restoration and/or monitoring work conducted with this funding.

- U.S. Fish and Wildlife Service
  The U.S. FWS administers several wetland and habitat restoration programs including the National Coastal Wetlands Conservation Grant Program, the Coastal Program, the Partners for Fish and Wildlife Program, and the Fisheries and Habitat Conservation Program. Again, it may be possible to build Consortium protocols into monitoring components of projects funded by these grants.

- *Private Foundations and Consortia*
  An array of private charitable organizations exists across the region. Many have explicit funding programs to promote sustainable ecological principles that rely upon fully functional coastal wetland complexes. Included in this category are endowments such as the multi-state Great Lakes Protection Fund and Great Lakes Fisheries Trust.

Funding in Canada

Environment Canada makes funding, incentives, rebates and other financial programs available to individuals and organizations to support activities that foster environmental sustainability in Canada. Although most of these incentive programs will not support the long-term implementation of a coastal wetland monitoring program, they could provide opportunities to target restoration activities, based on the results of a monitoring program, and the monitoring protocols advocated in this document may be applicable to some of the monitoring requirements of these programs.

- EcoAction Community Funding Program
  EcoAction provides financial support to community groups for projects that have measurable, positive impacts on the environment. Funding can be requested for projects that focus on improving the environment and increasing environmental awareness and capacity in the community.

- Great Lakes Sustainability Fund
  This program provides technical and financial support to projects that implement and help advance the RAPs that have been developed for Canada's AOCs. Priority funding areas include fish and wildlife habitat rehabilitation and stewardship, contaminated sediment assessment and remediation, and innovative approaches to improve municipal wastewater effluent quality. Some pilot programs in Canada's AOCs have already successfully implemented Consortium protocols.

- Habitat Stewardship Program for Species at Risk
  Funding from this program supports projects that contribute to the recovery of endangered, threatened and other species at risk, and to prevent other species from becoming a conservation concern. Coastal

wetlands provide habitat to many species at risk and Consortium protocols could potentially be used to monitor recovery projects or existing habitat.

- Funding Technologies for the Environment
  This group helps broker innovative technology solutions that address Canada's environmental priorities. In terms of the Consortium, this could include implementing the techniques outlined in the "Landscape Based Indicators" chapter of this document.
- Remote sensing technologies could be used to monitor fish and wildlife habitat or changes in land use in the basin.

Using Adaptive Management as an Implementation Strategy

The task of implementing a new program can be daunting and frustrating to agencies that are already overburdened with responsibilities and stretched thin by funding limitations. When considering whether or not to undertake the challenge of adopting Consortium protocols, it is important to convey to agencies and organizations the potential benefits to Great Lakes programs that could come about as a result of focused, consistent resource monitoring at a basinwide level. It is also important for existing Consortium leaders to be responsive to the monitoring needs and existing programs of potential partners, and develop and adapt implementation approaches to recognize those needs and qualities. The Consortium recognizes that agencies will need an implementation strategy in order to successfully negotiate the challenges that are inherent in adopting or adapting new programs.

Adaptive management is a formal, systematic, and rigorous approach to learning from the outcomes of management actions, accommodating change and improving management. It involves synthesizing existing knowledge, exploring alternative actions and making explicit forecasts about their outcomes. Adaptive management was developed in the 1970s by C.S. Holling and co-workers at the University of British Columbia and the International Institute for Applied Systems Analysis. Since then, it has been applied to a range of specific issues, including rehabilitation of salmon stocks in the Columbia River Basin, management of acid rain, and water management in the Florida Everglades (Nyberg, J.B. 1998). Its application to other natural resource activities is now receiving increasing attention.

Coastal wetlands are complex and dynamic. As a result, our understanding of ecosystems and our ability to predict how they will respond to management actions is limited. These knowledge gaps lead to uncertainty over how best to manage Great Lakes coastal wetlands. Despite these uncertainties, wetland managers must make decisions and implement plans. Adaptive management is a way for wetland managers to proceed with this responsibly in the face of such uncertainty. It provides a sound alternative to either "charging ahead blindly" or "being paralyzed by indecision", both of which can foreclose management options, and have social, economic and ecological impacts. Thus, the Consortium believes adaptive management may be the ideal implementation method for agencies who adopt any of the protocols outlined in this document.

The application of adaptive management includes six main steps, as outlined below. The framework formed by these six steps is intended to encourage a more thoughtful, disciplined approach to management, without constraining the creativity that is vital to dealing effectively with uncertainty and change (Nyberg, J.B. 1998).

Step 1 (problem assessment) is often completed in facilitated workshops. Participants define the scope of the management problem, synthesize existing knowledge about the system, and explore the potential outcomes of alternative management actions. Explicit forecasts are made about outcomes, in order to assess which actions are most likely to help the agency meet management objectives. During this exploration and forecasting process, key gaps in understanding of the system (i.e., those that limit the ability to predict outcomes) are identified. Managers may be faced with questions such as: How do I implement the plan in a way that will meet management objectives? How do we adjust our current monitoring program to include monitoring of coastal wetlands? Which of several possible actions should we implement?

Thus, during step 1, it will be important that agencies discuss the advantages and disadvantages of implementing Consortium protocols and what it means to them, as well as to overall monitoring efforts within the Great Lakes basin. This step may be essential to formulating cohesive grant applications and for presenting program adoption to management or decision makers within the organization. This step is also essential to identify the ways in which implementation of Consortium protocols will aid the agency in achieving its Great Lakes and wetland management goals.

Step 2 (design) involves designing a management plan and monitoring program that will provide reliable feedback about the effectiveness of the chosen actions. Ideally, the plan should also be designed to yield information that will fill the key gaps identified in Step 1. It is useful to evaluate one or more proposed plans or designs, on the basis of costs, risks, informativeness and ability to meet management objectives. To complete step 2, agencies should complete a written strategy detailing how Consortium protocols will be implemented. Such a strategy should include the following information:

- Details of partnerships that will be pursued to optimize available equipment and personnel
- Potential funding options
- A list of sites where monitoring will occur
- A list of dates when monitoring should occur and be completed
- A list of personnel who will conduct the monitoring
- An outline of information that will be included in monitoring reports
- An analysis of costs that will be incurred as a result of implementing this program (see cost analysis chapter of this document)

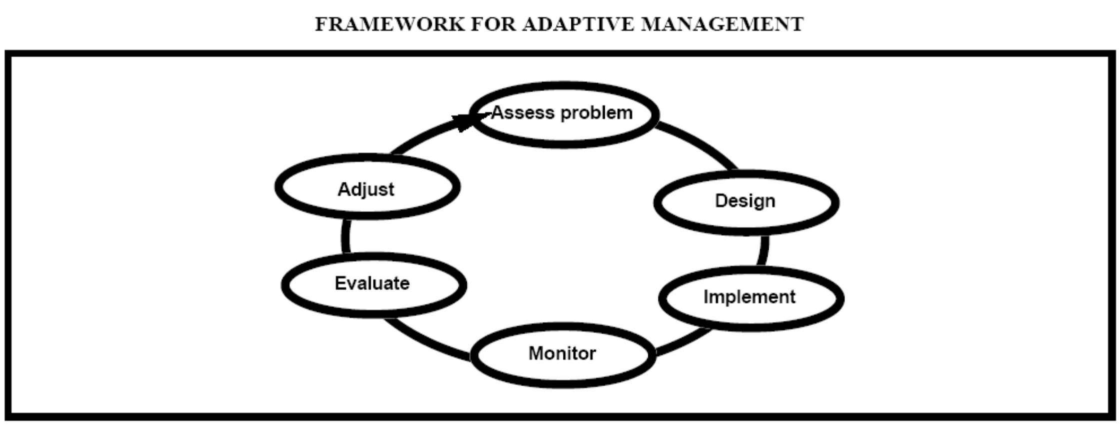

Figure 11-1. Framework for Adaptive Management

In Step 3 (**implementation**), the above plan should put into practice, meaning monitoring using Consortium protocols will begin. In Step 4 (**monitoring**), the agency must evaluate the effectiveness of implementing Consortium protocols in meeting the objectives set forth in step 1. Step 5 (**evaluation**) involves comparing the actual outcomes to forecasts and interpreting the reasons underlying any differences. In other words, managers must evaluate their monitoring program and determine if the proper protocols were chosen, whether the protocols have been valuable to the overall monitoring program, how monitoring can be improved to better meet the agency's monitoring objectives and whether new partnerships can be initiated to further enhance program potential.

Finally, step 6 **(adjustment)** involves correcting the design created in step 2 to reflect the new understanding gained from the monitoring and evaluation steps. Understanding gained in each of these six steps may lead to reassessment of coastal wetland management strategies, new questions, and new options to try in a continual cycle of improvement. In each new monitoring cycle, all 6 steps should be repeated to ensure continuous improvement. Spending a small amount of time each year completing the steps can ensure the agency continues to make the best decisions for its staff, the public, and the resources it seeks to protect.

In reality, some of the steps outlined will overlap, some will have to be revisited, and some may be need to be completed in more detail than others. However, all six steps are essential. Omission of one or more will hamper the ability to learn from management actions. In addition, documenting the key elements of each step, and communicating results are crucial to building a "legacy of knowledge", especially for projects that extend over a long time. For example, state, provincial and tribal/First Nation monitoring personnel should communicate with one another and share successes, problems and lessons learned. Likewise, state, provincial, and tribal/First Nation agencies should communicate with federal agencies. Finally, all feedback loops should return to a central coordinator, in this case, the Consortium communication hub, which will serve as a clearinghouse of information.

References

Archer, R.W., S.T.A. Timmermans, and C.L. Robinson. Monitoring and Assessing Marsh Habitats in Great Lakes Areas of Concern: Final Project Report. Bird Studies Canada, Port Rowan, Ontario. 302 pp.

Canadian Wildlife Service and Central Lake Ontario Conservation Authority 2004. Durham Region Coastal Wetland Monitoring Project: Year 2 Technical Report.

Environment Canada and Central Lake Ontario Conservation Authority. 2004a. Durham Region Coastal Wetland Monitoring Project: Year 2 Technical Report. Downsview, ON: ECB-OR. 177 pp. + appendices

Environment Canada and Central Lake Ontario Conservation Authority. 2004b. Baseline Conditions of Durham Region Coastal Wetlands: Preliminary Findings 2002- 2003. Downsview, ON: ECB-OR. May 2004. 36 pp.

Environment Canada – Canada Wildlife Service. 2007. Bay of Quinte Area of Concern: Coastal Wetland Status and Remedial Action Plan Delisting Target Recommendations. June 2007. Toronto, Ontario: EC-CWS 95 pp.

Environment Canada and Ontario Ministry of Natural Resources. 2003. The Ontario Great Lakes Coastal Wetland Atlas: A Summary of Information (1983-1997).

Great Lakes Commission. 2006. Environmental Monitoring Inventory of the Great Lakes Basin. Ann Arbor, Michigan.

Great Lakes Regional Collaboration. 2005. Great Lakes Regional Collaboration Strategy: Near Term Action Plan and Long Term Recommendations to Restore and Protect the Great Lakes.

Loftus, K.K., Smardon, R.C. and Potter, B.A. 2004. Strategies for the Stewardship and Conservation of Great Lakes Coastal Wetlands. Aquatic Ecosystem Health & Management, 7(2):305–330.

Mortsch, L.,J. Ingram, A. Hebb, and S. Doka(eds.). 2006. Great Lakes Coastal Wetland Communities: Vulnerability to Climate Change and Response Adaptation Strategies. Final report submitted to the Climate Change Adaptation Program, Natural Resources Canada. Environment Canada and the Department of Fisheries and Oceans, Toronto, Ontario. 251pp + appendices.

Nyberg, J.B. 1999. An Introductory Guide to Adaptive Management for Project Leaders and Participants, Forest Practices Branch, B.C. Forest Service.

Timmermans, S.T.A., G. E. Craigie and K. Jones. 2004. Marsh Monitoring Program: Areas of Concern Summary Reports 1995 – 2002. Bird Studies Canada, Port Rowan, Ontario.

Timmermans, S.T.A. and J. McCracken. 2004. Marsh Havens: Improving Marsh Habitats for Birds in the Great Lakes Basin. Bird Studies Canada, Port Rowan, Ontario. 15 pp.

U.S. Environmental Protection Agency. 2006. Elements of a State Water Monitoring and Assessment Program for Wetlands. Washington, D.C.: Office of Wetlands, Oceans and Watersheds.

U.S. Environmental Protection Agency. 2002. Methods for Evaluating Wetland Condition: #4 Study Design for Monitoring Wetlands. Washington, D.C.: Office of Water, EPA 822-R-02-015.

U.S. Environmental Protection Agency. 2001. Wetland Monitoring and Assessment. Washington, D.C.: Office of Water, Office of Wetlands, Oceans and Watersheds, EAP 843-F-01-002g.

Zorn, P. et al. 2006. Parks Canada/EMAN: Selecting a Suite of Wetland Ecosystem Monitoring Protocols. Draft Report. Parks Canada. Ontario Service Centre, Ecosystem Conservation Section, Ottawa, Ontario.

Monitoring Great Lakes Coastal Wetlands:
Summary Recommendations

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Introduction

In previous chapters, Consortium scientists – with input from Great Lakes Environmental Indicator (GLEI) project scientists – have recommended multiple biological metrics for monitoring the condition of Great Lakes coastal wetlands for plants, invertebrates, fish, amphibians and birds. Also recommended is a design for sampling Great Lakes coastal wetlands that allows users to monitor condition of these wetlands on an annual basis. With a combination of repeated site visits and random sampling of other marshes on an annual basis, users can establish status and trends (positive, negative, no change) of wetland condition for a given site, region or for all Great Lakes coastal wetlands.

The objective of this chapter is to provide an overview of how these protocols can be integrated into a standardized sampling regime that can be used by local, state, provincial, tribal/First Nation, federal, and international agencies and nongovernmental organizations from the United States and Canada. The goal is to standardize the procedures so that status and trends data from several local, provincial, state and tribal agencies can be shared with and used by federal and international organizations and reporting entities (e.g., GLC, GLFC, Environment Canada, U.S. EPA, U.S.ACE, SOLEC) to track status and trends for the entire Great Lakes basin and/or for each of the Great Lakes (e.g., Lakewide Management Plans).

A program to obtain a database on changes in landscape, chemical and physical parameters from year to year is also recommended. Such a database will enable users to independently monitor changes temporally while providing data that will enable scientists and managers to quantitatively measure changes in biotic indicators and relate them to changes in landscape (e.g., land use/land cover/roads, wetland area) and physical/chemical indicators (e.g., lake level, wetland chemistry).

An Overview of the Monitoring Program

The ideal monitoring program should allow governmental agencies and NGOs to assemble one or more teams of investigators to monitor and analyze status and trends data from Great Lakes marshes in their jurisdiction and make these data available for use by organizations that need to monitor status and trends at regional, individual lake and Great Lakes basin levels. Such a program would need to employ staff or contract with consulting firms and/or universities, or use trained volunteers to monitor status and trends at local to international scales.

Composition of the team assigned to wetland sampling

Ideally, each team would have specialists who would have the expertise and training to carry out the proposed sampling design in a timely manner and collect, enter and analyze data on landscape, physical, chemical and biotic indicators. The team members should also have the appropriate background in statistics and use of databases to enter collected data and the ability to quantitatively analyze and integrate the data into graphs, tables and reports on status and trends. The team should include individuals with expertise in collecting and using GIS/landscape, plant, invertebrate, fish, amphibian, bird and physio-chemical data. The team should also include persons with enough background in experimental design and quantitative analyses to analyze those data. It might be possible to reduce the staff members needed on such a team to three individuals who could be trained to accomplish and/or supervise all of the needed tasks with help from seasonal workers or volunteers. A team would likely need to include a plant ecologist, an invertebrate/fish ecologist, and an amphibian/bird ecologist with one or more of these staff members having sufficient training in use of GIS/GPS systems, chemical and physical data collection and analyses and experimental design/statistical treatment of data to perform the needed tasks. Each team member would have the ultimate responsibility in their area of expertise but would have to be willing to work together as an integrated team to obtain needed samples and data for metrics.

Many agencies already have the expertise on staff or may be able to obtain it from other sources. Since these staff members already have responsibilities, recruitment and training of team members may be necessary. Thus, a series of training sessions are likely to be necessary initially and, perhaps annually, to share experiences in implementing Consortium monitoring protocols and agree on any changes that might be needed from year to year. One team member could be designated as the overall team coordinator/manager. For states or provinces such as Michigan or Ontario with wetlands located on most or all of the Great Lakes, more than one team may have to be assembled to cover the large number of coastal wetlands in their jurisdiction. There would be a need to coordinate activities for multiple teams if that is required.

Schedule of Team Activities

Prior to the field season, team members would obtain or check to be sure that all supplies and equipment would be available and functional when needed. They would also have to plan for and schedule time to obtain data on all indicators and activities for each of the following:

1) Randomly select the marshes to be sampled in the upcoming field season using a list of Great Lakes coastal wetlands within state, regional, tribal or provincial jurisdiction and responsibility. An initial inventory of Great Lakes coastal wetlands is available on the Consortium web site.

2) Obtain permission to sample selected marshes from the private, nongovernmental or public agency that owns/manages the marsh. If access to the site cannot be obtained, or if the site cannot be accessed from shore or by boat, randomly select another site as a replacement.

3) Amphibian sampling: The schedule for amphibian sampling is likely to begin in April and extend into June, but timing is dependent on temperature and other weather conditions during frog and toad breeding season (see chapter on amphibian indicators and guidelines established for frog and toad calling surveys). Frog and toad calling surveys require working at night so compensatory time off during the day is likely to be needed for staff involved in these surveys. Many states and provinces already collect such data, and it may be possible to obtain data on Great Lakes coastal wetlands from the coordinators of these surveys and/or from the Bird Studies Canada coordinator. It is likely, however, that many of the marshes selected in Steps 1 and 2 will have to be sampled by members of the monitoring team and supplemented by volunteer survey data where such data are available. NOTE: It should be possible to recruit a team member with a vertebrate biology background to be in charge of amphibian and bird surveys.

4) Bird sampling: Surveys should be done during active breeding season which tends to be from May through early July. (See Chapter 7 on bird indicators for details.) The lead staff person for this task could be the same person responsible for amphibian surveys or two separate team members would need to be assigned responsibility for amphibian and bird sampling.

5) Invertebrate sampling should be scheduled in July and August since this is the time when most invertebrates are present as mid- to late-instars. (See Chapter 4 on invertebrate indicators for details.) NOTE: A second team member with experience in invertebrate and fish biology should be recruited for invertebrate/fish sampling, sample processing, and data analyses or two individuals could be assigned as leaders of these tasks.

6) Fish Sampling should be scheduled from mid-June through mid-September. Ideally, sampling should be conducted in late July or early August, after emergent vegetation nears peak biomass, but metrics do perform well slightly outside of this time period. Since fish are to be identified in the field and released, an expert taxonomist should be present. Some species are more difficult to identify. Therefore, specimens may occasionally have to be obtained and returned to the lab for identification under a dissecting microscope.

7) Plant sampling should occur after dominant marsh plants are near peak biomass and in bloom or putting on seed. For most Great Lakes wetlands, this occurs from early- to mid-July through senescence in mid-September. A plant ecologist who has the ability, or can be trained, to identify dominant plants on sight and use field guides and taxonomic keys to identify >90 % of plants in marshes within agency jurisdiction should be the third member of the team if the agency plans to have only a three-member team assigned to bioassessment of Great Lakes wetlands.

8) At least one of the team members should have some background in interpretation of aerial/satellite imagery and enough knowledge with manipulation of GIS databases to determine land use/land cover data for all marshes sampled. Many students in environmental biology, ecology, and fisheries and wildlife now have GIS/GPS training included as part of their curriculum.

9) Between field seasons, team members supplemented with student or temporary helpers should be able to process samples taken during the field season (e.g., sort, identify and enumerate invertebrates and analyze chemical samples), enter all data using approved quality control procedures, obtain all imagery for the marshes and/or their watersheds, and – using the imagery, field notes and data on water quality, water levels, etc. from various sources – independently calculate the position of each of the sampled marshes along physical/chemical disturbance gradients. The database compiled by the GLEI project at the segment-shed level would be a useful source for such data initially once each site is placed in the appropriate segment-shed.

10) Prepare the annual summary report including data on biotic indicators in comparison to physical/chemical indicators and interpretation of data collected during the field season.

Recommended Indicators and Procedures

Experimental Design/Wetland Selection

The statistical design recommended for the project is from N. S. Urquhart, S.G. Paulsen and D.P. Larsen (1998). It calls for a combination of randomly selecting and sampling 14 wetlands within a region or a percentage of these within a state's or other agency's jurisdiction each year. Additional wetlands will be randomly selected each year to establish status; this is coupled with resampling a subset of these wetlands each year to establish trends. (See Chapter 1 on statistical design for details.)

Plant Indicators

Nine plant indicators were recommended using the following procedures: (1) Using aerial photos, map wet meadow and emergent plant zones and, with photos or GPS units in field, map patches of invasives; (2) Overlay a random grid in each zone or select three transects that will cross typical areas of each dominant plant zone; and (3) Sample 15 randomly selected 1.0 m^{-2} quadrats in each zone or along the transects; sample dry and flooded parts of each plant zone. Based on data obtained from these quadrats, calculate the following eight metrics. (See Chapter 3 on plant indicators for further details.)

1) Invasive Plant Cover for Entire Site;
2) Invasive Plant Cover for Wet Meadow and Dry Emergent Zones;
3) Invasive Plant Cover for Submergent and Emergent Flooded Zones. Invasive Frequency for Entire Site;
4) Invasive Frequency for Wet Meadow and Dry Emergent Zones;
5) Invasive Frequency for Submergent and Emergent Flooded Zones;
6) Mean Conservatism (Native Species)* for Entire Site;
7) Mean Conservatism (Native Species)* for Wet Meadow and Dry Emergent Zones; and
8) Mean Conservatism (Native Species)* for Submergent and Emergent Flooded Zones.

* Calculate mean conservatism using values and procedures from the Floristic Quality Index for Michigan.

Invertebrate Indicators

Invertebrate indicators have only been developed for lacustrine (fringing or lake edge) wetlands. Data should be collected from riverine and drowned river mouth wetlands as well (submerged, water lily, emergent zones, etc.), since indicators are being developed and may be available for them soon. Invertebrates should be sampled from each dominant plant zone present in lacustrine wetlands including the wet meadow zone if flooded, the inner emergent zone (*Schoenoplectus* and/or *Typha*) zone, and outer emergent zone. Collection of three replicates per zone is required. (See Chapter 4 on invertebrate indicators for details.)

Metrics used in each plant zone include:

1) Odonata (Dragon and Damselflies) richness (number of taxa collected that are dragon flies and damsel flies);

2) Percent of total numbers of invertebrates caught that are Odonates;
3) Crustacea plus *Mollusca* richness (total number of taxa of amphipods, isopods, crayfish, shrimp, total snails, limpets and clams caught);
4) Total genera richness (number of genera present) in entire sample;
5) Percent of total numbers of invertebrates caught that were Gastropods (snails);
6) Percent of total numbers of invertebrates caught that were Sphaeriidae (finger nail clams);
7) Total number of taxa in the entire sample (= richness);
8) Evenness index; and
9) Shannon index.

Additional metrics are available for inner and outer emergent zones. (See Chapter 4 on invertebrate indicators for details.)

Fish Indicators

Fish indicators have been developed based on fyke net sampling of each wetland for one net night per plant zone using a minimum of three fyke nets per plant zone. Alternative methods of sampling such as electrofishing are also likely to work but additional work to cross validate those sample devices with fyke nets used to sample Great Lakes coastal wetlands will be needed before they can be used routinely. Fourteen fish indicator metrics for bulrush (*Schoenoplectus*) dominated wetlands are recommended; 11 metrics for cattail (*Typha*) dominated wetlands are also available and have been published. (See Chapter 5 on fish indicators for details of what these metrics are and how to calculate them.)

Amphibian Indicators

Amphibian community metrics were developed by Bird Studies Canada and Environment Canada from nine years of data collected through Bird Studies Canada by trained volunteers. Frog and toad call survey data spanned 60 Great Lakes wetlands in the United States and Canada. (See Chapter 6 on amphibian indicators for recommended protocols). The possibility of this being done using existing frog and toad surveys within individual states or provinces exists but would need to be cross-validated with some preliminary studies.

The amphibian community index of biotic integrity (IBI) includes three metrics:

1) Total species richness;
2) Species richness of woodland species; and
3) Probability of detecting a woodland species within a wetland.

Bird Indicators

The marsh bird community IBI was developed by Bird Studies Canada and Environment Canada using data on wetlands collected by trained volunteers. These surveys were conducted in the evening from 6-10 p.m. from routes consisting of 1-8 points per route. Monitoring at each point along the route consisted of five minutes of passive recording of birds present within 100 meters of the point using visual and auditory observations, followed by five minutes of playback recordings of the calls of secretive birds such as rails, followed by an additional five minutes of recording birds observed visually or from calls. Surveys are conducted three times during breeding season. (See Chapter 7 on bird indicators for details.) A major difference between Consortium and GLEI scientists was use of early morning surveys by GLEI researchers versus evening surveys conducted by Consortium scientists. The evening surveys can be more easily combined with amphibian surveys using the Consortium protocols recommended here, but many ornithologists tend to use morning surveys. Data suggest that either morning or evening surveys can be used. The IBI incorporated bird guilds that represented disturbance-sensitive marsh-nesting birds and general marsh-users.

The bird community IBI includes three metrics:

1) Abundance of non-aerial foragers;
2) Abundance of marsh nesting obligates; and
3) Species richness of area-sensitive marsh nesting obligates.

Appendix A. Great Lakes Coastal Wetlands Classification

Great Lakes Coastal Wetlands Classification
First Revision (July 2003)

D. A. Albert, J. Ingram, T. Thompson, D. Wilcox,
on behalf of the Great Lakes Coastal Wetland Consortium
(GLCWC)

Great Lakes coastal wetlands can be separated into three specific systems based on their dominant hydrologic source and current hydrologic connectivity to the lake. These systems are different than those defined by the National Wetlands Inventory (NWI) (Santos and Gauster 1993). NWI defines three *systems*, Lacustrine, Riverine, and Palustrine. All of these NWI systems can have *classes (Aquatic bed* or *Emergent)* that are included within our wetland classification, but many of the classes are not wetland classes but hydrologic or substrate classes, such as *rock bottom, unconsolidated bottom, unconsolidated shore,* or *open water.*

Each wetland polygon mapped for the GLCWC will be given a four character code. The first character (**-**---) will be for the *hydrologic system*. The second character (-**-**--) will be for the *geomorphic* type. The third and fourth characters (--**--**) are further *geomorphic modifiers*.

1. **Lacustrine (L---)** system wetlands are controlled directly by waters of the Great Lakes and are strongly affected by lake-level fluctuations, nearshore currents, seiches and ice scour. Geomorphic features along the shoreline provide varying degrees of protection from coastal processes. Lacustrine, as defined by NWI, would also include dammed river channels and topographic depressions not related to Great Lakes. NWI does not consider wetlands with trees, shrubs, persistent emergents, emergent mosses or lichens with greater than 30% cover. In contrast, we consider these vegetation cover classes to be included within our lacustrine wetlands, focusing our classification on the lacustrine formation process. NWI only considers wetlands larger than 8 hectares (20 acres), while we include smaller wetlands. NWI will include wetlands smaller than 8 hectares if a) a wave formed or bedrock features forms part or all of the shoreline or has a low water depth greater than 2 meters in the deepest part of the basin.

2. **Riverine (R---)** system wetlands occur in rivers and creeks that flow into or between the Great Lakes. The water quality, flow rate and sediment input are controlled in large part by their individual drainages. However, water levels and fluvial processes in these wetlands are influenced by coastal processes because lake waters flood back into the lower portions of the drainage system. Protection from wave attack is provided in the river channels by bars and channel morphology. Riverine wetlands within the Great Lakes also include those wetlands found along large connecting channels between the Great Lakes with very different dynamics than smaller tributary rivers and streams. NWI excludes palustrine wetlands, which they define as dominated by trees, shrubs, persistent emergents, and emergent mosses or lichens, from riverine systems. In contrast, we include all of these types of vegetation within our riverine system.

3. **Barrier-Protected (B---)** system wetlands have originated from either coastal or fluvial processes. However, due to coastal processes the wetlands have become separated from the Great Lakes by a barrier beach or other barrier feature. These wetlands are protected from wave action but may be connected directly to the lake by a channel crossing the barrier. When connected to the lake, water levels in these wetlands are determined by lake levels, but during seiche related water-level fluctuations, wetland water levels are tempered by the rate of flow through the inlet. During isolation from the lake, groundwater and surface drainage to the basin of the individual wetland provides the dominant source of water input,

although lake level may influence groundwater flow and, hence, wetland water levels. Inlets to protected wetlands may be permanent or ephemeral. Nearshore processes can close off the inlet from the lake. The ability of the nearshore processes to close the inlet is related to the rate of sediment supply to the shoreline, grain size and sorting of sediment, type and duration of nearshore processes, lake level elevation and rate of change, and discharge rate of water exiting the inlet. The greater part of most of these wetlands would be classified by NWI as palustrine system, with small water bodies or streams within the wetland possible being classified as inclusions of either lacustrine or riverine system.

Within these hydrologically based systems, Great Lakes coastal wetlands can be further classified based on their geomorphic features and shoreline processes.

1) Lacustrine System (L---)

Open Lacustrine (LO--)
These lake-based wetlands are directly exposed to nearshore processes with little or no physical protection by geomorphic features. This exposure results in little accumulation of sediment vegetation development to relatively narrow nearshore bands. Exposure to nearshore processes results in little to no organic sediment accumulation, and variable bathymetry, ranging from relatively steep profiles to more shallow sloping beaches.

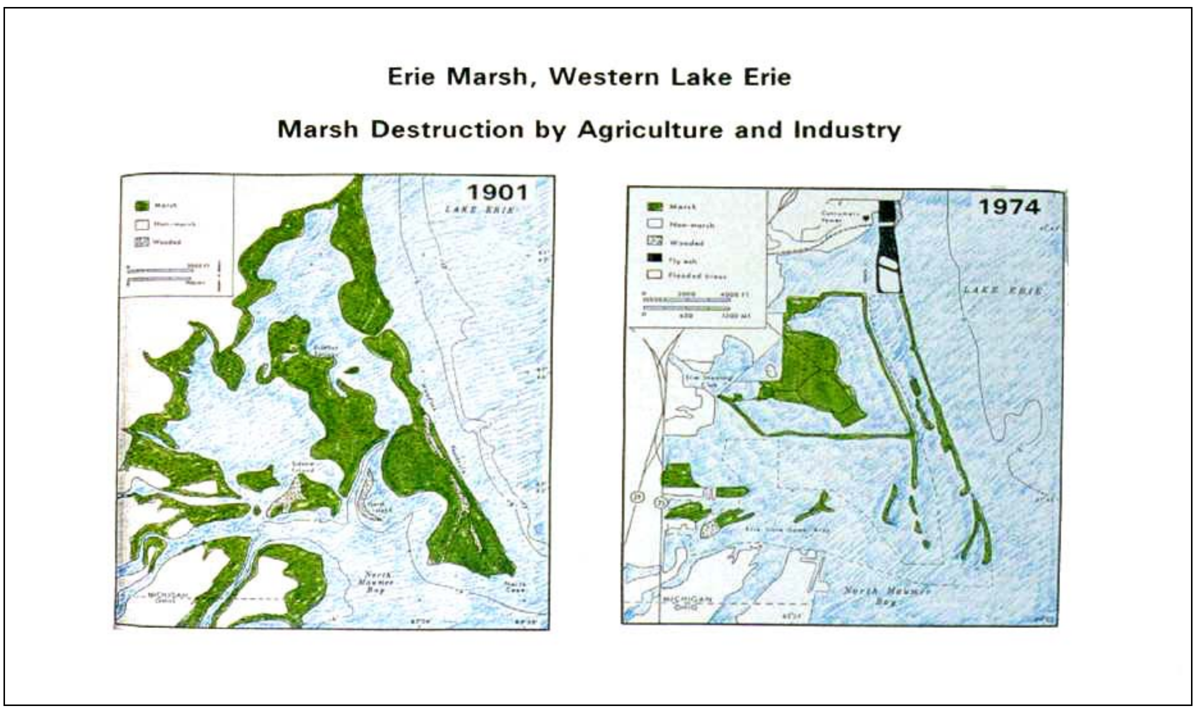
Open Shoreline. (LOS-) These wetlands are typically characterized by an erosion-resistant substrate of either rock or clay, with occasional patches of mobile substrate. The resultant expanse of shallow water serves to dampen waves which may result in sand bar development at some sites. There is almost no organic sediment accumulation in this type of environment. Vegetation development is limited to narrow fringes of emergent vegetation extending offshore to the limits imposed by wave climate. Some smaller embayments also fit into this class due to exposure to prevailing winds. Most of these have relatively narrow vegetation zones of 100 meters or less. Examples include Epoufette Bay and wetlands in the Bay of Quinte on Lake Ontario. Mapping of *open shoreline* wetlands will be restricted to those identified by either Herdendorf et al. (1981a-f) or NWI. Many *open shorelines* do not have large enough areas of aquatic plants to be identified from aerial photography.

Open Embayment. (LOE-) This can occur on gravel, sand, and clay (fine) substrate. The embayments are often quite large – large enough to be subject to storm-generated waves and surges and to have established nearshore circulation systems. Most bays greater than three or four kilometers in diameter fit into this class. These embayments typically support wetlands 100 to 500 meters wide over wide expanses of shoreline. Most of these wetlands accumulate only narrow organic sediments near their shoreline edge. Saginaw Bay, St. Martin Bay, Little Bay de Noc, Green Bay, and Black River Bay all fit in this category.

Protected Lacustrine (LP--)

This wetland type is also a lake-based system, however it is characterized by increased protection by bay or sand-spit formation. Subsequently, this protection results in increased sediment accumulation, shallower off-shore profiles and more extensive vegetation development than this type's open lacustrine counterpart. Organic sediment development is also more pronounced.

Protected Embayment. (LPP-)
Many stretches of bedrock or till-derived shorelines form small protected bays, typically less than three or four kilometers in width. These bays can be completely vegetated with emergent or submergent vegetation. At the margins of the wetlands there is typically 50 to 100 cm of organic accumulation beneath wet meadow vegetation. Examples include Duck Bay and Mackinac Bay in the Les Cheneaux Islands on Lake Huron, Matchedash Bay on Lake Huron, and Bayfield Bay on Wolfe Island in Lake Ontario.



Sand-Spit Embayment. (LPS-) Sand spits projecting along the coast create and protect shallow embayments on their landward side. Spits often occur along gently sloping and curving sections of shoreline where there is a positive supply of sediment and sand transport is not impeded by natural of man-made barriers. These wetlands are typically quite shallow. Moderate levels of organic soils are typical, similar to those found in other protected embayments. Examples include Pinconning Marsh on Saginaw Bay, Dead Horse Bay on Green Bay, and Long Point on Lake Erie.

2) Riverine System (R---)

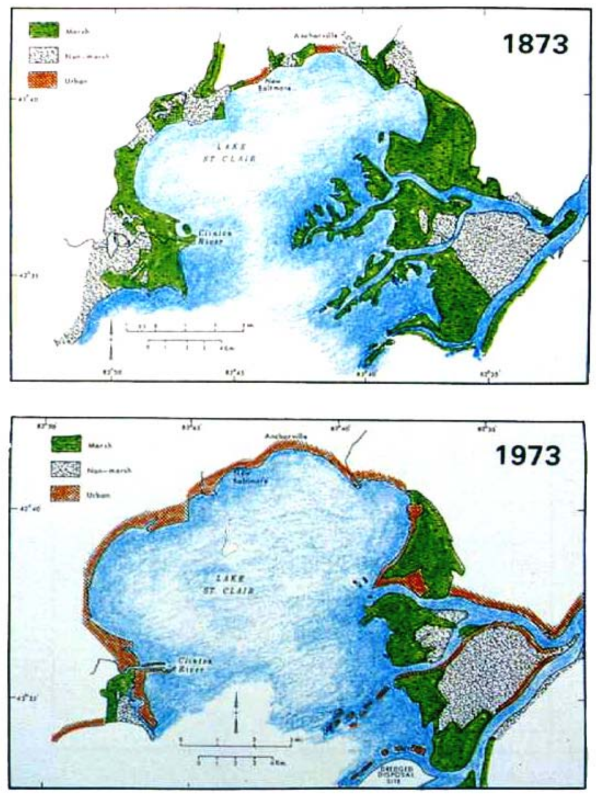
Drowned River-Mouth (RR--)
The water chemistry of these wetlands can be affected by both the Great Lakes and river water, depending on Great Lakes water levels, season, and amount of precipitation. These wetlands typically have deep organic soils that have accumulated due to deposition of watershed-based silt loads and protection from coastal processes (waves, currents, seiche, etc.). The terms "estuarine" or "fresh-water estuarine" have been used by some researchers (Herdendorf et al. 1981a) as alternatives to *drowned river-mouth*.

Open, Drowned River-Mouth. (RRO-)
Some drowned river-mouths don't have barriers at their mouth, nor do they have a lagoon or small lake present where they meet the shore. The wetlands along these streams occur along the river banks and their plant communities are growing on deep organic soils. Examples include the West Twin River on the Wisconsin shore of Lake Michigan, the Kakagon River on the Wisconsin shore of Lake Superior, and the Greater Cataraqui River on the Ontario shore of Lake Ontario.

Barred, Drowned River-Mouth. (RRB-)
Most streams that are considered drowned river-mouths actually have a barrier that constricts the stream flow as it enters the lake. Very often, a lagoon forms behind the barrier. However unlike barrier beach wetlands, these wetlands maintain a relatively constant connection to the lakes. These lagoons seldom support large wetlands (possibly as the result of earlier destruction of the wetland by human management). The vegetation is concentrated where the stream enters the lagoon (if present), but can extend several kilometers upstream, typically forming a fringe of emergent and submergent vegetation along the edges of the channel. Organic deposits are often greater than two meters thick. Examples include the Betsie, Pentwater and Manistee Rivers in Lake Michigan, and Duffins Creek in Lake Ontario.

Connecting Channel (RC--)
This wetland type includes the large connecting rivers between the Great Lakes; the St. Marys, St. Clair, Detroit, Niagara, and St. Lawrence Rivers. These wetlands are distinctive from the other large river wetlands (drowned river mouth) by their general lack of deep organic soils and their often strong currents. The St. Marys and St. Lawrence contain some of the most extensive fringing shoreline and tributary drowned river mouth wetlands in the Great Lakes, while those along the Detroit and Niagara have been largely eliminated or degraded. The Detroit River still has major beds of submergent aquatic plants, as does shallow Lake St. Clair. Connecting channels contain several types of wetlands, each with their own code. These include open shoreline (Connecting Channel, open shoreline (RCOS)), open embayment (Connecting Channel, open embayment (RCOE)), protected embayment (Connecting Channel, protected embayment (RCPP)), sand-spit embayment (Connecting Channel, sand-spit embayment (RCPS)), open drowned river mouth (Connecting Channel, open drowned river mouth (RCRO)), barred drowned river mouth (Connecting Channel, barred drowned river mouth (RCRB)), and deltaic (Connecting Channel, delta (RCD-)), which will be noted as subtypes in the attribute tables of wetlands.

Alteration of Marshes on St. Clair River Delta, Lake St. Clair



Delta (RD--)

Deltas formed of alluvial materials, both fine and coarse, support extensive wetlands that extend out into the Great Lake or connecting river. These are extensive wetlands, typically with 30 to 100 cm of organic soils associated with their wet meadow zone, and often with deep organics occupying abandoned distributary channels and interdistributary bays. Two examples are the St. Clair River and Munuscong River (bordering the St. Marys River) deltas.

3) Barrier-Enclosed (B---)

Barrier Beach Lagoon (BL--)

These wetlands form behind a sand barrier. Because of the barrier, there is reduced mixing of Great Lakes waters and the effects of coastal processes are minimized. Multiple lagoons can form and water discharge from upland areas and incoming drainages may also contribute significantly to the water supply. These wetlands are common at the east end of Lake Ontario and also on the Bayfield Peninsula in western Lake Superior. Thick organic soils characterize these wetlands in Lake Superior and in many, but not all, of the Lake Ontario wetlands. Examples of barrier beach lagoon wetlands include Second Marsh, North Sandy Pond, and Round Pond of Lake Ontario and Bark Bay, Siskiwit Bay and Allouez Bay of Lake Superior. In addition to barrier beach lagoons, *tombolo* are present in selected areas of the Great Lakes. These are defined as islands attached to the mainland by barrier beaches, some of which consist of one or two lagoons with deep organic soils. This feature may also be classified in the swale complex category depending upon the dominant geomorphological features. Small barrier beach lagoons often are completely dominated by vegetation, with no open water remaining; such completely vegetated barrier beach lagoons will be called **Successional Barrier Beach Lagoons** and will be coded **BLS-**.

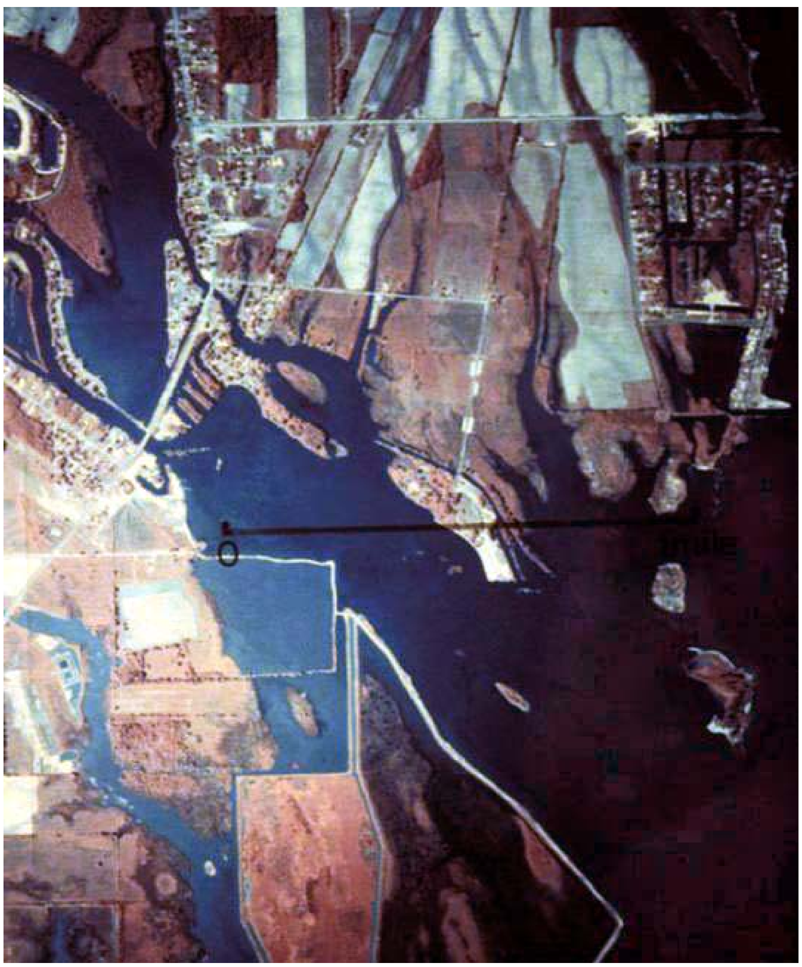
Swale Complexes (BS--)

There are two primary types of swale complex wetlands – those that occur between recurved fingers of sand spits and those that occur between relict beach ridges. These are known respectively as *sand-spit swales* **(BSS-)** and *ridge and swale complexes* **(BSR-)** (also referred to as dune and swale and strandplain). The former are common within some of the larger sand spits of the Great Lakes, primarily Presque Isle and Long Point on Lake Erie and Whitefish Point on Lake Superior. Numerous small swales are separated from the Great Lakes, often becoming shrub swamps with shallow organic soils. Within these sand-spit formations, there are often embayments which remain attached to the Great Lakes, thus maintaining their herbaceous flora.

Ridge and swale complexes are composed of a series of barrier beaches separated by narrow swales. These systems commonly occur in embayment where there is a high supply of sediment are form in response to quasi-periodic fluctuations in lake level. For many of these complexes, only the first couple of swales are in direct hydrologic connection to the lake, but in some, like Pte. Aux Chenes along northern Lake Michigan, the connection continues for hundreds of meters. Organic soil depths are quite variable, as is the vegetation, which ranges from herbaceous to swamp forest. Another example is the Ipperwash Inter-dunal Wetlands Complex on Southern Lake Huron, Ontario.

A rare, third type of swale complex may include *tombolo*. While some are classified as barrier beach features **(BLT-)**, others consist more dominantly of a series of beach ridges **(BSR-)** with small swales and shallow organic soils, and could thus be classified as a ridge and swale complex.

<u>System Modifiers of Naturally Occurring Great Lakes Wetlands</u>



The hydrology and/or geomorphology of all Great Lakes coastal wetlands have been impacted by human activities within the Great Lakes basin. These impacts are through whole lake regulation, watershed alteration or activities within the wetland itself (i.e. diking, dredging and in-filling). Direct modification of the hydrological connection with the lake results in different hydrologic and wetland community responses to Great Lake events (e.g. high/low water level) than those responses observed in non-modified wetlands with the same classification. Identification of human modifiers in naturally occurring coastal wetlands is important to understanding coastal processes and response to change and thus should be noted when classification is undertaken. System modifiers will not be coded, but will be listed in an attribute table.

References

Chow-Fraser, P and D.A. Albert. 1998. *Biodiversity Investment Areas: Coastal Wetlands Ecosystems. Identification of "Eco-reaches" of Great Lakes Coastal Wetlands that have high biodiversity value*. A discussion paper for the State of the Lakes Ecosystem Conference, 1998. Chicago, IL: U.S. Environmental Protection Agency, and Burlington, ON: Environment Canada.

Herdendorf, C. E., S. M. Hartley, and M. D. Barnes (Eds). 1981a. *Fish and wildlife resources of the Great Lakes coastal wetlands within the United States, Vol. 1: Overview.* U.S. Fish and Wildlife Service, FWS/OBS-81/02-v1.

Herdendorf, C. E., S. M. Hartley, and M. D. Barnes (Eds). 1981b. *Fish and wildlife resources of the Great Lakes coastal wetlands within the United States, Vol. 2: Lake Ontario.* U.S. Fish and Wildlife Service, FWS/OBS-81/02-v2.

Herdendorf, C. E., S. M. Hartley, and M. D. Barnes (Eds). 1981c. *Fish and wildlife resources of the Great Lakes coastal wetlands within the United States, Vol.3: Lake Erie.* U.S. Fish and Wildlife Service, FWS/OBS-81/02-v3.

Herdendorf, C. E., S. M. Hartley, and M. D. Barnes (Eds). 1981d. *Fish and wildlife resources of the Great Lakes coastal wetlands within the United States, Vol. 4: Lake Huron.* U.S. Fish and Wildlife Service, FWS/OBS-81/02-v4.

Herdendorf, C. E., S. M. Hartley, and M. D. Barnes (Eds). 1981e. *Fish and wildlife resources of the Great Lakes coastal wetlands within the United States, Vol. 5: Lake Michigan.* U.S. Fish and Wildlife Service, FWS/OBS-81/02-v5.

Herdendorf, C. E., S. M. Hartley, and M. D. Barnes (Eds). 1981f. *Fish and wildlife resources of the Great Lakes coastal wetlands within the United States, Vol.6: Lake Superior.* U.S. Fish and Wildlife Service, FWS/OBS-81/02-v6.

Keough, J.R., T.A. Thompson, G.R. Guntenspergen, and D.A. Wilcox. 1999. Hydrogeomorphic factors and ecosystem responses in coastal wetlands of the Great Lakes. *Wetlands* 19(4): 821-834.

Maynard, L. and D. Wilcox. 1997. *Coastal Wetlands of the Great Lakes*. A discussion paper for the State of the Lakes Ecosystem Conference, 1996. Chicago, IL: U.S. Environmental Protection Agency, and Burlington, ON: Environment Canada.

Minc, L.D. and D.A. Albert. 1998. *Great Lakes Coastal Wetlands: Abiotic and Floristic Characterization*. Michigan Natural Features Inventory.

Validation and performance of an invertebrate index of biotic integrity for Lakes Huron and Michigan fringing wetlands during a period of lake level decline

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Development of indicators of 'ecosystem health' for the Great Lakes was identified as a major need at the State-of-the-Lakes Ecosystem Conference in 1998, 2000, and 2002. Our goal was to develop an invertebrate-based index of biotic integrity that was robust to water level fluctuations and applied to broad classes of lacustrine wetlands across wave-exposure gradients. Our objectives were to evaluate the performance and test the robustness of our preliminary index (e.g., Burton et al., 1999) at a range of water levels, eliminate any problems with the index of biotic integrity, remove the preliminary status, test the index on similar wetlands of Lake Michigan, and establish stressor:ecological-response relationships. Twenty-two sites, both open- and protected-fringing lacustrine marshes of Lake Huron and Michigan were selected for study. Correspondence analysis and Mann-Whitney U tests were used to test the robustness of existing metrics and search for additional metrics. Wilcoxon Signed Rank tests were used to determine if metrics were responding to inter-annual water level fluctuation. Principal components analysis and Pearson correlations were used to establish stressor:ecological response relationships. Analyses confirmed the utility of most of the metrics suggested in our preliminary index, but we recommended several improvements. With improvements, the index was able to place all sites in a comparable order of disturbance that we placed them a priori based on adjacent landuse/landcover, limnological parameters and observed disturbances. The improved index worked very well from 1998 through 2001 despite the substantial decreases in lake level over this time-period. Analyses of 2001 data collected from similar fringing wetlands along the northern shore of Lake Michigan suggested that the index could also be used for fringing wetlands of northern Lake Michigan. We are confident that our index is ready for implementation as a tool for agencies to use in assessing wetland condition for Lakes Huron and Michigan fringing wetlands.

Keywords: coastal wetlands, Great Lakes, IBI, invertebrates

Introduction

Wetlands of the Great Lakes are subject to multiple anthropogenic disturbances. These disturbances are superimposed on systems that experience a wide variety of natural stress resulting primarily from a highly variable hydrologic regime (Burton et al., 1999, 2002; Keough et al., 1999). These wetlands are classified into geomorphological classes, reflecting their location in the landscape and exposure to waves, storm surges and lake level changes (Albert and Minc, 2001). Fringing wetlands form along bays and coves and leeward of islands or peninsulas. The location of the shoreline, with respect to long-shore current and wind fetch, determines the type of wetland found along the shoreline (Burton et al., 2002). The greater the effective fetch

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(e.g., Burton et al., this issue), the more the wetland is exposed to waves and storm surges until a threshold is reached where wetlands no longer persist. The separation of variation due to anthropogenic disturbance from variation due to natural stressors related to water level changes over long and short term periods is central to predicting community composition and in turn developing indices of biotic integrity (IBI) for these systems.

Development of indicators of 'ecosystem health' for the Great Lakes was recognized as a major need at the State-of-the-Lakes Ecosystem Conference (SOLEC) in 1998 in Buffalo, New York and progress in developing indicators was the emphasis of the SOLEC Conference in 2000 in Hamilton, Ontario and again in 2002 in Cleveland, Ohio. Among the indicators listed by the task force at SOLEC 98 were IBIs for coastal wetlands based on fish, plants and macroinvertebrates. These were also emphasized in the 2000 and 2002 conferences, but minimal progress in developing such indicators was reported at those conferences.

Wilcox et al. (2002) attempted to develop wetland IBIs for the upper Great Lakes using fish, macrophytes, and microinvertebrates. While they found attributes that showed promise, they concluded that natural water level changes were likely to alter communities and invalidate metrics. In an earlier paper, we developed a preliminary macroinvertebrate-based bioassessment procedure for coastal wetlands of Lake Huron (Burton et al., 1999). This system could be used across wide ranges of lake levels, since it included invertebrate metrics for as many as four deep- and shallow-water plant zones with a scoring system based on the number of inundated zones present.

While Great-Lakes wide studies of aquatic macrophytes indicate that similar geomorphic wetland types support distinctively different plant assemblages in geographically distinct ecoregions (Minc, 1997; Chow-Fraser and Albert, 1998; Minc and Albert, 1998; Albert and Minc, 2001), several plant zones are common to many of these systems. In our preliminary invertebrate-based IBI (Burton et al., 1999), we collected invertebrates from four plant zones characteristically inundated in fringing lacustrine wetlands of Lake Huron and northern Lake Michigan during high water years, and used invertebrate metrics from each of these zones in the IBI. By developing metrics for each wetland plant zone across a water level gradient from wet meadow to deep-water emergents, we assumed that we could compensate for absence of the higher elevation zones (e.g., wet meadow) during low lake level years by placing more emphasis on metrics from zones that remained inundated. As lake levels have fallen sharply since 1998, we have tested this assumption and report the results in this paper.

Our goal was to develop an IBI that is robust to water level fluctuations and applies to broad classes of lacustrine wetlands across natural wave exposure gradients. The broad class of wetlands we chose for the first stage of IBI development was fringing, lacustrine marshes (Burton et al., 1999). Fringing, lacustrine marshes are the most common type of wetlands of Lake Huron and the northern shore of Lake Michigan. They were included in three classes in the classification of Great Lakes wetlands by Albert and Minc (2001): Northern Great Lakes marshes, Northern rich fens, and Saginaw Bay lakeplain marshes. All of the wetland types included in our broader definition of fringing, lacutrine marshes are characterized by having a species of *Scirpus (* e.g., *Scirpus acutus, Scirpus americanus,* or *Scirpus validus* or combinations of two or more of these species) as the dominant plants in the two outer emergent zones (Burton et al., 1999) and by having wet meadow zones dominated by a combination of *Carex* spp. (*Carex stricta, Carex lasiocarpa,* and/or *Carex viridula*) and *Calamagrostis canadensis*. We initiated IBI development for this broad wetland class in Lake Huron (Burton et al., 1999) and have begun testing it in other lakes and wetland types. However, the data presented in this paper are only from open- and protected-embayment marshes (fringing) of Lake Huron, and northern Lake Michigan.

The objectives of this study were to: 1) evaluate the performance and test the robustness of our preliminary IBI (e.g., Burton et al., 1999) at reduced water levels when fewer plant zones per site were inundated; 2) identify and eliminate any problems and make improvements to the IBI where necessary; 3) remove the preliminary status from the Burton et al. (1999) IBI; 4) test the applicability of the IBI in similar wetlands of Lake Michigan; and 5) establish stressor: ecological-response relationships that could be used to manage high quality wetlands and restore degraded ones.

Methods and materials

Study sites

Both open- and protected-fringing lacustrine marshes of Lakes Huron and Michigan were selected for study (Figure 1). Site selection was based primarily on site access, inundation status, and degree of human disturbance to the marshes. Depths rarely exceeded one meter and were as shallow as 10 cm. The plant communities at each site changed along a depth gradient from

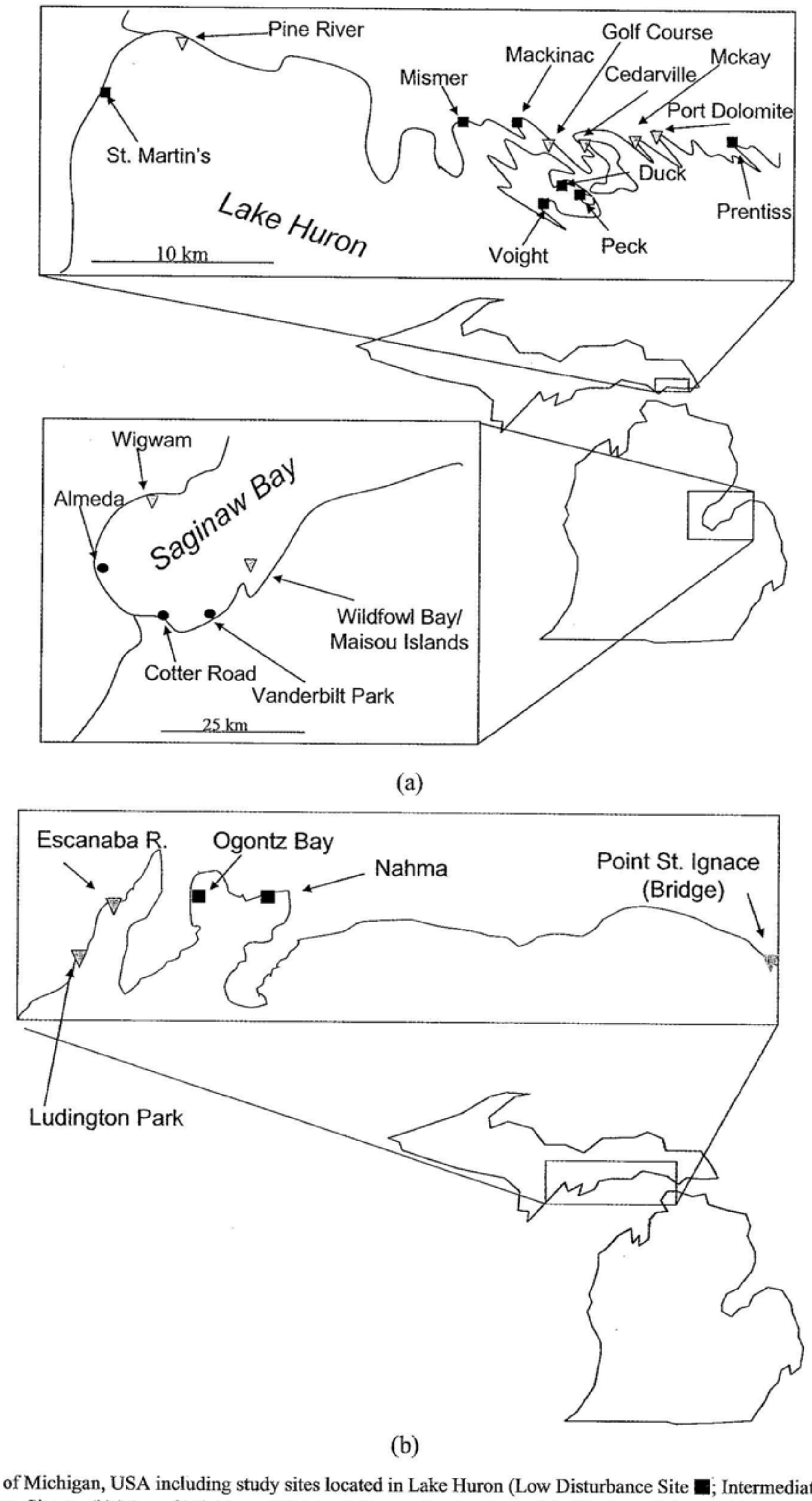


Figure 1. (a) Map of Michigan, USA including study sites located in Lake Huron (Low Disturbance Site ■; Intermediate Disturbance Site ∇; High Disturbance Site ●; (b) Map of Michigan, USA including study sites located in Northern Lake Michigan, Low Disturbance Site ■; Intermediate Disturbance Site ∇; High Disturbance Site ●).

open water to shore and typically included an outer *Scirpus* zone in deep, wave swept areas of the marsh, an inner *Scirpus* zone in deep areas subject to less wave impact, a transitional zone that sometimes included *Typha angustifolia* as a dominant, and a wet meadow zone. The wet meadow zones extended to upland ecosystems directly or graded into shrub and forested wetlands depending on topography of the site. Table 1 lists locations, dominant vegetation, and wave exposure classification (exposed or protected) for all sites included in this study. Major anthropogenic disturbances and a priori disturbance classification for each site are listed in Table 2.

Saginaw Bay study sites

Saginaw Bay sites were located along the eastern and western shores of Saginaw Bay (Figure 1a). The Saginaw River is likely the most important impact to Saginaw Bay sites as wetlands of the inner bay (Almeda, Cotter Rd. and Vanderbilt Park) have more degraded water quality than those of the outer bay (Wigwam and Wildfowl Bays). Vegetation at the Saginaw Bay sites generally followed the pattern of monodominant stands of *Scirpus* in the outer, exposed areas of the marshes grading into transitional communities often including *Typha, Phragmites australis*

Table 1. Saginaw Bay, northern Lake Huron, and northern Lake Michigan site location including the dominant vegetation types present, and exposure class. Exposure class is a representation of approximate fetch and exposure to waves and storm surges.

Site	Site Location		Dominant Vegetation†			Exposure Class
	°Lat.(N)	°Long.(W)	Wet Meadow	Inner *Scirpus*	Outer *Scirpus*	
Saginaw Bay						
Wildfowl Bay	43.801	83.462	*C., C.c.,T.*††	*S.p., S.v., S.a.*	*S.p., S.v., S.a*	Exposed/ Protected
Wigwam Bay	43.963	83.856	*J.*	*S.p.*	*S.p.*	Exposed
Vanderbilt Park	43.600	83.661		*S.p.*	*S.p.*	Exposed
Almeda	43.801	83.923		*S.p., E.*	*S.p., E.*	Exposed
Cotter Road	43.652	83.865	*C.s., C.c., S.p.*			Exposed
Northern Lake Huron						
Duck Bay	45.966	84.389	*C.s., C.l ,T.***	*S.a.*	*S.a.*	Protected
Peck Bay	45.946	84.358	*C.s., C.l.*	*S.a.*	*S.a.*	Protected
Voight Bay	45.941	84.412	*C.s., C.l.*	*S.a.*	*S.a.*	Exposed
Mackinac Bay	46.001	84.409	*C.s., C.l.*	*S.a.*	*S.a.*	Protected
Mismer Bay	46.007	84.462	*C.s., C.l.*	*S.a.*	*S.a.*	Protected
Prentiss Bay	45.988	84.226	*C.s., C.l.*	*S.a.,T.*	*S.a.*	Protected
St. Martin's Bay	46.020	84.513		*S.a.*	*S.a.*	Exposed
Pine River	46.038	84.622			*S.a.*	Exposed
Golf Course	45.983	84.383		*S.a.*	*S.a.*	Exposed
Port Dolomite	45.985	84.252		*S.a.*†††	*S.a.*	Exposed
Cedarville Bay	45.996	84.362		*S.a.**		Protected
Northern Lake Michigan						
Ogontz	45.832	86.781		*S.a.*	*S.a.*	Exposed
Nahma	45.852	86.631		*S.a.*	*S.a.*	Exposed
Pt. St. Ignace 'Bridge'	45.845	84.739		*S.a.*	*S.a.*	Exposed
Escanaba	45.817	87.052	*T.***	*S.a.*	*S.a.*	Exposed
Ludington Park	45.738	87.056		*S.a.*		Protected

†*S.p.-Scirpus* pungens Vahl, *S.v* = *S. validus, S.a.* = *S. acutus, C.* = *Carex spp., C.s.* = *C. stricta, C.l.* = *C. lasiocarpus, C.c.* = *Calamagrostis canadensis, E.* = *Eleocharis spp., J.* = *Juncus, T.* = *Typha sp.*

††The wet meadow at Wildfowl Bay was nearly dry in 1998 and was dry in subsequent years.

†††The Port Dolomite site has seeps that are likely from settling ponds from the dolomite mining operation. *Cladophora* was observed growing around these seeps.

*The Cedarville site had dense filamentous green algae, *Elodea canadensis,* and *Myriophyllum spicatum.*

**The *Typha stands* at the Duck Bay and Escanaba sites were scattered within the wet meadow.

Table 2. Saginaw Bay, northern Lake Huron, and northern Lake Michigan sites noting known major disturbances and a priori disturbance classification.

Site	Major Disturbances	*a priori* Disturbance Classification
Northern Lake Huron		
Duck Bay	No dwellings, one private dock	Low Impact
Peck Bay	Adjacent dwellings (limited)	Low Impact
Voight Bay	Adjacent dwellings (limited)	Low Impact
Mackinac Bay	Adjacent dwellings (limited), highway	Low Impact
Mismer Bay	Adjacent dwellings (limited), highway	Low Impact
Prentiss Bay	Adjacent dwellings (limited), highway	Low Impact
St. Martin's Bay	Sediment from the Pine River (limited)	Low Impact
Pine River	Substantial sediment from Pine R.	Intermediate Impact
Golf Course	Adjacent golf course	Intermediate Impact
Port Dolomite	Dolomite [(Ca, Mg) CO_3] mining	Intermediate Impact
Cedarville Bay	Sewage effluent, urban runoff, marine traffic	Intermediate Impact
Northern Lake Michigan		
Ogontz	Some adjacent dwellings, boat launch	Low Impact
Nahma	Nearby golf course, dwellings, road	Low Impact
Pt. St. Ignace 'Bridge'	Highway, bridge, urban area	Intermediate Impact
Escanaba	Nearby urban/industrial areas	Intermediate Impact
Ludington Park	Nearby urban/industrial areas	Intermediate Impact
Saginaw Bay		
Wildfowl Bay	State wildlife management area, some agriculture	Intermediate Impact
Wigwam Bay	Sparse shoreline development, some agriculture	Intermediate Impact
Vanderbilt Park	Quanicassee R. (agriculture), adjacent dwellings	Intense Impact
Almeda	Adjacent dwellings, agriculture	Intense Impact
Cotter Road	Agriculture, adjacent dwellings, Saginaw R.	Intense Impact

(Cav.) and *Pontederia cordata*. The Wildfowl Bay, Vanderbilt Park and Cotter Rd. sites had wet meadow zones that graded into terrestrial habitats (Table 1).

Northern Lake Huron sites

The northern Lake Huron sites were located in the Les Cheneaux Island complex along the southeastern end of Michigan's upper peninsula and along St. Martin's Bay, a large bay located west of the Les Cheneaux Islands (Figure 1a). Wetlands in this region had primarily forested catchments. Major impacts in the region included adjacent dwellings and boathouses and a two-lane highway running adjacent to or bisecting the wet meadows of the Mackinaw, Mismer and Prentiss Bays. The Cedarville Bay site was the only Northern Lake Huron site with substantial adjacent urbanization. Cedarville Bay was considered to be the most human-impacted area in the Les Cheneaux Islands (Kashian and Burton, 2000). The middle of the bay was occupied by a very large island with large numbers of residences, summer homes and docks on it. The town of Cedarville, its marina, and public boat launch occupied the northwestern shore of the bay, and many private residences, businesses, and docks (private and commercial) lined the mainland near the marsh.

The Golf Course site was located along a heavily used boat channel adjacent to a golf course. The Port Dolomite (Bush Bay) site was adjacent to a dolomite mining operation (Figure 1a). A small stream draining settling ponds from the adjacent dolomite mining operation entered the Bush Bay wetland via a culvert. Several dwellings were adjacent to the marsh, and boat traffic was common.

Peck and Voight Bays were located on Marquette Island (Figure 1a). Human impacts were low with only one residence located along the channel that leaded into the wetland. Voight Bay was on the windward side of the island with direct exposure to open-lake waves from Lake Huron (Figure 1). There were no human developments near the marsh. Boat traffic in both bays was limited, since neither were near main boat channels.

The Pine River site was located on the east side of St. Martins Bay (Figure 1). Only a narrow band of *Scirpus* approximately 100 m wide was present at this site. The Pine River entered the bay approximately 1 km west of the site. The river drained an agricultural region with red clay soils and was always quite turbid. The turbidity plume was usually pushed by prevailing winds along the shore into and past the sampled marsh. High turbidity levels at the site reflected this.

Northern Lake Michigan sites

Fringing wetlands similar to those sampled in Lake Huron were also common along the northern shore of Lake Michigan. We sampled a subset of these sites in 2001 to test whether the Lake Huron IBI would work for these wetlands (Figure 1b).

The Point St. Ignace (Mackinac Bridge) marsh was located immediately northwest of the Mackinac Bridge in Lake Michigan near the mouth of the Straits of Mackinac (Figure 1b). The Nahma and Ogontz marshes were located on Big Bay de Noc (Figure 1b). There were less than five dwellings adjacent to the Ogontz Bay marsh, and most of the adjacent riparian zone was forested. The Nahma site was near a golf course and adjacent to several dwellings. The Escanaba/Highway 2 site was located in Little Bay de Noc near an urban area along U.S. Highway 2 approximately 2 km north of the Escanaba River. The Ludington Park wetland was located approximately 10 km south of the Escanaba Highway 2 site in Ludington Park located in downtown Escanaba.

Chemical and physical measurements

Basic chemical/physical parameters were sampled from each plant zone each time biological samples were taken. Analytical procedures followed procedures recommended in Standard Methods for the Examination of Water and Wastewater (APHA, 1998). These measurements included soluble reactive phosphorus (SRP), nitrate-N, nitrite-N, ammonium-N, turbidity, alkalinity, temperature, dissolved oxygen (DO), chlorophyll *a*, oxidation-reduction (redox) potential, and specific conductance. Quality assurance/quality control procedures followed protocols recommended by APHA (1998).

Determination of anthropogenic disturbance

Wetlands that experienced a wide range of anthropogenic stressors were chosen for study. The extent of disturbance was determined using surrounding land use data in conjunction with limnological data and site-specific observations such as evidence of dredging, point-source pollution, and discharge into the wetland from drainage ditches or streams. If streams entered the wetland, land use from the stream catchment was considered when determining anthropogenic disturbance. Each site was placed into a very coarse disturbance category were breaks in the data occurred. For example, those sites that we considered to be ‘intermediately impacted’ had much less anthropogenic influence than those considered to have ‘intense impact’ and much more anthropogenic influence than those labeled as ‘low impact.’

Land use data were obtained from existing digitized maps, topographic maps, and personal observations; the primary data source was the Michigan Resource Information System (MIRIS, 1978) Land Cover Maps based on 1978 aerial photography. These data included: percent urban and agricultural area, number of adjacent dwellings, percent impervious surface, total length of adjacent roads, and the number of connecting drainage ditches. The MIRIS data were the most recent data available to us. Visual observations of these data and current land use suggested that land use had not changed substantially for most of the wetlands included in our study.

Macroinvertebrates sampling

Macroinvertebrate samples were collected with standard 0.5 mm mesh, D-frame dip nets from late July through August. July–August is when emergent plant communities achieve maximum annual biomass and larger and easier to identify, late instars of most aquatic insects are present in the marsh.

Dip net sampling consisted of sweeps at the surface, mid depth and just above the sediments, incorporating all microhabitat at a given location. Nets were emptied into white pans and 150 invertebrates were collected by attempting to pick all specimens from one area of the pan before moving on to the next. Special efforts were made to ensure that smaller and sessile organisms were not ignored. Beginning in 1999, we modified this procedure to limit the amount of picking-time required at each site and to semi-quantify our samples. Individual replicates were picked for one-half-person-hour, organisms were tallied, and picking continued to the next multiple of 50. Therefore, each replicate sample contained either 50, 100, or 150 organisms. This procedure made it easier to compare samples on a catch per unit effort basis. The number of organisms remaining in the pan was nearly always exhausted to the point where finding just a few more organisms required a substantial effort. Three replicate dip net samples were collected in each plant zone to obtain a measure of variance associated with sampling.

Specimens were sorted to lowest operational taxonomic unit, usually genus or species for most insects, crustaceans and gastropods. Difficult to identify insect taxa such as Chironomidae were identified to tribe or family, and some other invertebrate groups including Oligochaetes, Hirudinea, Turbellaria, Hydracarina, and Sphaeridae were identified to family level or, in a few cases, to order. Taxonomic keys such as Thorp and Covich (1991), Merritt and Cummins (1996), and mainstream literature were used for identification. Accuracy was confirmed by expert taxonomists whenever possible.

Metric development and testing

Burton et al. (1999) developed metrics for their published IBI by initially analyzing data graphically by constructing box plots including the 10th, 25th, 50th, 75th, and 90th percentiles as recommended by Barbour et al. (1996). When attributes from Burton et al. (1999) showed an empirical and predictable change across a gradient of human disturbances, Mann-Whitney U tests were performed on these to test for significant differences between those sites designated a priori as being either impacted or reference sites. Burton et al. (1999) used 1997 data to develop IBI metrics for Lake Huron wetlands and tested these metrics by calculating IBI scores using data collected in 1998.

We expanded on Burton et al. (1999) analyses in this paper using our 1998 data (from Burton et al. (1999) and newly collected data from 1999 through 2001 to test the performance of the IBI during this period of rapid decline in lake levels. We initially calculated IBI scores using the 1999 through 2001 data compared the results to our gradient of disturbance established a priori. Additional analyses were then employed using the larger data set to search for any new metrics that could improve the IBI. Instead of the graphical approach used previously, we used correspondence analyses (CA) (SAS version 8, SAS Institute Inc., Cary, NC, USA) of invertebrate community composition to determine if sites would ordinate according to predetermined gradients of anthropogenic disturbance. Correspondence analyses were performed individually on Inner and Outer *Scirpus* zone data. Taxa represented by less than 20 total individuals (from all replicates from all sites combined) per zone in any one year were eliminated from the analysis. This resulted in approximately 40 taxa being used in each analysis. Unknown taxa were also included in the analysis to ensure that those taxa that could not be identified to a finer resolution were not either responsible for ecoregional differences or potential indicators of disturbance. Total taxa collected was also included. A separate CA was conducted for each plant zone for each year for 1998, 1999, and 2000. The 1999 data were most complete and were used to identify key taxa. These key taxa were then analyzed for each of the three years from 1998 through 2000. When reference sites separated from impacted site, groups of individual taxa containing the most inertia responsible for the separation were deemed potential metrics. Mann-Whitney U tests (SYSTAT version 5.0, Evanston, Illinois) were then used to determine if density of each of these taxa at reference sites were significantly different from its density at impacted sites. This allowed us to confirm the utility of our initial metrics and identify additional ones.

As in Burton et al. (1999), we used medians in place of means as measures of central tendency for measuring assemblages of invertebrates. Invertebrate parameters are highly variable, and medians are more resistant to effects of outliers. Therefore, we used medians to dampen the influence of outliers.

Testing and validation of the IBI

We continued to collect data from a subset of the original sites of Burton et al. (1999), providing us with our best indication of temporal variability. We calculated IBI scores by site (all plant zones present) as well as by individual plant zones (simulating a situation where only one plant zone had been inundated) and compared these scores within and among years. This exercise was used to determine which, if any, individual plant zones were most subject to inter-annual variability and to identify problematic plant zones that could give conflicting results if sampled alone.

Testing metrics robustness from inter-annual variation

We used Wilcoxon Signed Rank tests (SYSTAT version 5.0, Evanston, Illinois) on individual metrics through time to search for metrics that may have been responding to water level fluctuations. Significance was set at $p < 0.05$. Analyses were only done on two Inner *Scirpus* data sets, since these two data sets were the only ones available that were large and complete enough to permit this type of analysis. The analysis comparing 1998 to 1999 metrics included data from Duck, Mackinac, Prentiss, Mismer, St. Martin's, and

Cedarville (n = 6). The second analysis was done using data from 1997 through 2000, but only included Duck, Mackinac, and Mismer (n = 3), since these were the only wetlands sampled every year over this four-year period.

Test of the applicability of the IBI in similar wetlands of Lake Michigan

We sampled five similar fringing wetland sites in Lake Michigan (Figure 1b). We applied the IBI with improvements to those data to see if the IBI would place the Lake Michigan sites in the correct sequence along a disturbance gradient that had been identified a priori with land use data and other observation following the procedures detailed below. This was in attempt to provide evidence that the Lake Huron IBI could be extended to similar fringing wetlands in Lake Michigan. As a reference, we sampled many of our Lake Huron sites during this time-period as well.

Establishing stressor—ecological response relationships

Principal Components Analysis (PCA) using SAS version 8 (SAS Institute Inc., Cary, NC, USA) was used to establish Principal Components (PCs) based on chemical/physical parameters as well as surrounding (1 km buffer) land use/cover data (MIRIS, 1978). Principal components analysis was performed on the correlation matrix using untransformed SRP, NH_4, NO_3, SO_4, Cl, turbidity, chlorophyll a, alkalinity, DO, redox, and specific conductance data while additional analyses were done using percent adjacent agriculture, urbanization, shrub-range land, swamps, and the total length of roads within a 1 km buffer. Pearson Correlations (SYSTAT version 5.0, Evanston, Illinois) between individual metrics and PCs were used to establish stressor-ecological response relationships. The PCs were then decomposed to explore relative contributions of individual stressors. These analyses were performed on 1999 and 2001 Inner and Outer *Scirpus* data sets because they were the most complete.

Results

Testing and validation of the preliminary IBI

We calculated IBI scores using the preliminary IBI (Burton et al., 1999). The IBI ranked the majority of wetlands in order of anthropogenic disturbance, with only zero to four sites placed out of order in any given year. We evaluated the metrics for each of the four plant zones individually to determine the efficacy of an IBI based on only a single zone. The inner and outer *Scirpus* and wet meadow zone metrics worked well when present. Metrics based on the inner *Scirpus* zone proved to be almost as effective as were metrics based on summing values from all inundated zones present, and would be the single zone to use if only one zone is to be sampled. The *Typha* zone was rarely sampled, due to lack of inundation or absence at a site, and IBI metrics for this zone did not consistently rank sites by degree of disturbance. In the preliminary IBI, we proposed four diversity and richness metrics based on combined data from all zones present. These combined zone metrics proved to be ineffective in ranking sites along a disturbance gradient. Based on these results, we recommend dropping the *Typha* zone metrics from the IBI and calculating the four diversity and richness metrics for each zone rather than calculating them using combined data for all zones.

Correspondence analyses

Correspondence analyses were performed on data from the Inner *Scirpus* zone collected from 1998 through 2000 and for the Outer *Scirpus* zone from 1999 through 2000 (the 1998 outer *Scirpus* data were excluded because data were only collected from two sites). The CAs were used to identify either ecoregional, disturbance, or other underlying gradients. After completion of preliminary CAs, it was apparent that ecoregional differences were driving the ordinations. Therefore, we initially used 1999 data to identify those taxa responsible for the ordination of the sites according to ecoregion. The 1999 data set was the most balanced with respect to number of sites sampled from each ecoregion (Saginaw Bay and northern Lake Huron sites are in two different ecoregions). Correspondence analyses ordinated 1999 Inner and Outer *Scirpus* zone site data by ecoregion (northern Lake Huron sites clustered separately from Saginaw Bay sites). We identified and removed taxa responsible for the most inertia separating the sites by ecoregion (Table 3) and ran the correspondence analysis again (Figure 2a). With taxa responsible for ecoregional differences removed (Table 3), the sites ordinated by disturbance (Figure 2b). The taxa showing ecoregional differences in 1999 were also removed from data from other years before running correspondence analyses, and sites for each year ordinated based on degree of disturbance after these taxa had been removed. In 2000, due to low water, we only obtained data from Northern Lake Huron. When the taxa identified as having

Table 3. Taxa from the Inner and Outer *Scirpus* zone that contributed to the most inertia responsible for ordinating the sites based on ecoregion in correspondence analyses.

Taxa from the Inner Scirpus Zone Responsible for Ecoregional Inertia				Taxa from the Outer Scirpus Zone Responsible for Ecoregional Inertia			
Class	Order	Family	Genus	Class	Order	Family	Genus
Crustacea	Decapoda			Crustacea	Amphipoda	Gammarid	*Gammarus*
Bivalvia	Veneroida	Dreisseniidae	*Dreissena*	Crustacea	Amphipoda	Crangonctidae	*Crangonyx*
Gastropoda	Lymnophila	Lymnaeidae	*Fossaria*	Gastopoda	Lymnophila	Lymnaeidae	*Fossaria*
Gastropoda	Lymnophila	Lymnaeidae	*Pseudosuccinea*	Insecta	Tricoptera	Leptoceridae	*Mystacides*
Gastropoda	Lymnophila	Physidae	*Physa gyrina*	Insecta	Tricoptera	Leptoceridae	*Nectopsyche*
Gastropoda	Mesogastropoda	Hydrobiidae	*Amnicola*	Insecta	Hemiptera	Corixidae	*Sigara*
Insecta	Diptera	Ceratopogonidae	*Atrichopogon*	Insecta	Hemiptera	Corixidae	*Trichorixa*
Insecta	Odonata	Libellulidae	*Libellula*	Tubificidae			
Insecta	Odonata	Coenagrionidae	*Enallagma*				
Insecta	Hemiptera	Corixidae	*Trichocorixa*				
Insecta	Coleoptera	Halipidae	*Halipus*				
Insecta	Coleoptera	Gyrinidae	*Gyrinus*				
Insecta	Trichoptera	Leptoceridae	*Oecetis*				

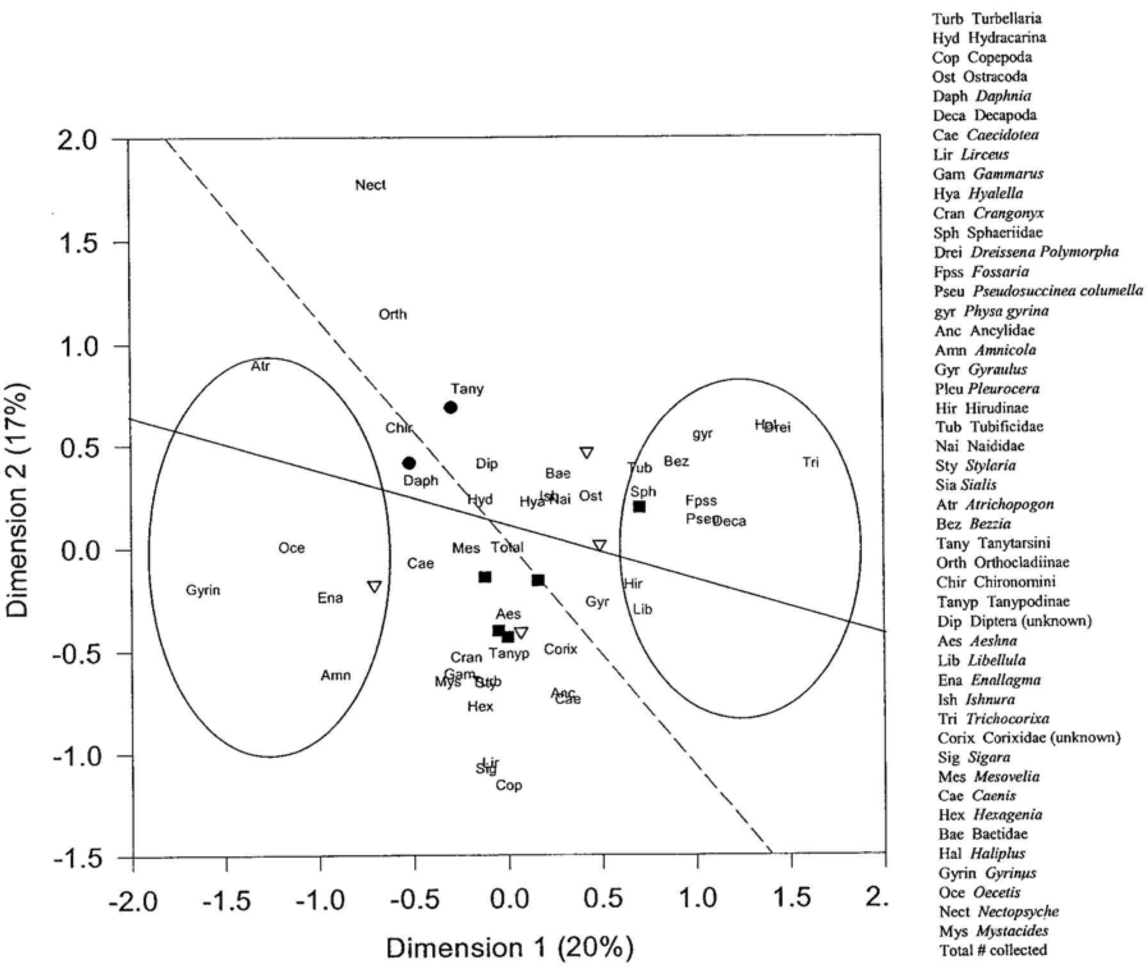
ecoregional differences in 1999 (Table 3) were removed from the 2000 analysis, ordination based on anthropogenic disturbances was much improved even though no Saginaw Bay sites were included in the data set.

We used the CAs not only to search for additional metrics, but also to determine if any of our previous metrics may have included responses to ecoregion instead of disturbance. In the Inner *Scirpus* zone, few taxa removed due to ecoregional differences were major contributors to metrics. The caddis fly, *Oecetis*, was included in the Ephemeroptera plus Trichoptera taxa richness metric. *Oecetis* was more often found at Saginaw Bay, but was quite rare even in those sites decreasing its influence on the metric. Thus, its removal from the analyses did not have a significant effect on the metric. The Odonate *Enallagma* was generally common at all sites, but tended to be at higher densities in Saginaw Bay sites. Conversely, *Libellula* was more common in Northern Lake Huron than it was in Saginaw Bay marshes. Differences in these two taxa may have offset each other in the Odonata taxa richness metric and in Odonata relative abundance metric, since these metrics worked well with or without these two genera included in the data set. The snail *Amnicola* tended to be more common in northern Lake Huron, and occurred in only one site in Saginaw Bay. Three other snails, *Fossaria spp.*, *Pseudosuccinea columella*, and *Physa gyrina* were all more common in Northern Lake Huron than in Saginaw Bay, contributing to separation by ecoregion. However, these taxa also separated sites based on disturbance within each ecoregion. Even though we removed these taxa from the CA so that they would not pull ecoregions apart in the analysis, we still believe these taxa are likely to be valuable metrics for an IBI. Ecoregional differences in individual taxa did affect the Gastropoda or Crustacea plus Mollusca metrics enough to warrant removing either metric from the IBI. *Dreissena* was much more common in Saginaw Bay than in Northern Lake Huron and may have counter-balanced differences in some gastropod taxa in the Crustacea plus Mollusca metrics. Decapods were rarely collected, but were more common in Northern Lake Huron than in Saginaw Bay. This may reflect differences in habitat between the two ecoregions rather than differences in anthropogenic disturbance. The Northern Lake Huron sites tended to have more cobble, pebble and boulder sized rocks and more submersed plants than did the Saginaw Bay sites. Decapods were relatively rare in samples from both ecoregions, and differences between the two regions did not affect the Crustacea plus Mollusca metric.

In most cases, a genus or species associated with one ecoregion was replaced by a closely related genus or species in the other, and therefore had little effect on the diversity and richness metrics or metrics at coarser taxonomic resolution. Three insects taxa were removed from the CAs, the family, Ceratopogonidae, a ceratopogonid genus, *Atrichopogon,* and the genus *Trichocorixa (*Corixidae). *Atrichopogon* was collected only at Saginaw Bay. *Trichocorixa* was only found at two sites in Northern Lake Huron and not at all in Saginaw Bay.

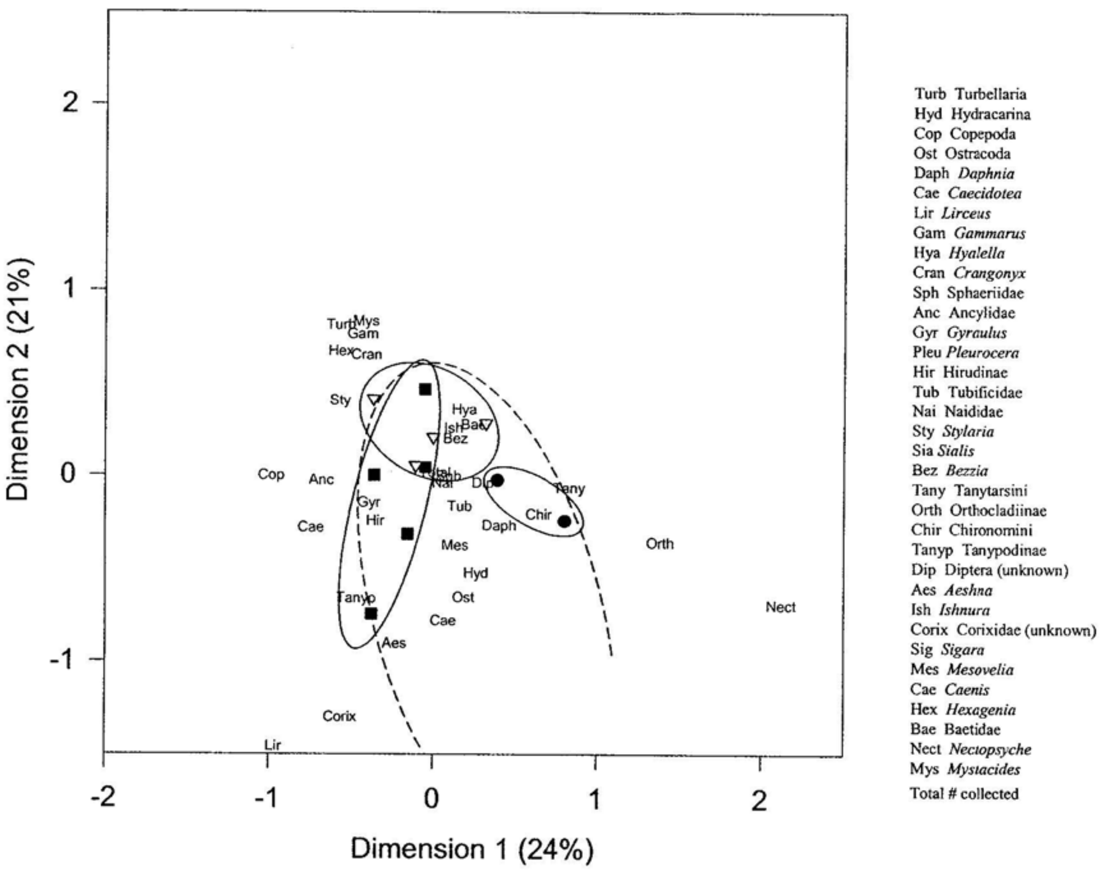
In the Outer *Scirpus* zone, two amphipods, *Crangonyx* and *Gammarus*, were more common in Saginaw Bay than in northern Lake Huron sites. Neither was used in metrics other than richness and diversity in the Outer *Scirpus*. As was the case in the Inner *Scirpus* zone, in the Outer *Scirpus* zone, the gastropod, *Fossaria*, and the Hemipteran, *Trichorixa*, were much more common in Northern Lake Huron. They were not good indicators in either ecoregion. Tubificids were common at sites in both ecoregions; however, two sites in Saginaw Bay had an over abundance of Tubificidae, one was a very impacted site, and the other was one of the least impacted in that ecoregion. Two Tricoptera were removed, *Mystacides* and *Nectopsyche*. *Mystacides* was more common in northern Lake Huron, while *Nectopsyche* was more common in Saginaw Bay. The Corixid, *Sigara*, was only found at one site in northern Lake Huron and was not found in Saginaw Bay in 1999.

Correspondence analyses of the data from 1999–2000 identified the same metrics that were proposed in the preliminary IBI based on 1997 and 1998 data



(a)

Figure 2. (a) Correspondence analysis including 1999 taxa collected from the Inner *Scirpus* zone of Lake Huron Sites. The solid line represents an estimated ecoregion gradient with Saginaw Bay sites toward the left side of the gradient and Northern Lake Huron sites on the right. The dashed line represents an estimated disturbance gradient with the most disturbed sites towards the top and the least disturbed sites near the bottom. Circles are drawn around those taxa responsible for the most inertia separating the data based on ecoregion; (b) Second run of a correspondence analysis including 1999 taxa collected from the Inner *Scirpus* zone of Lake Huron sites. Circled taxa from Figure 2a were removed from this analysis. The dashed line represents an estimated disturbance gradient. The ecoregion gradient no longer exists. Circles are drawn around sites with different levels of disturbance (symbols for Low Disturbance, Intermediate Disturbance, and High Disturbance Sites as in Figure 1). *(Continued)*



(b)

Figure 2. Continued

(Burton et al., 1999), thus providing support for the importance of the preliminary metrics. Two new metrics for Inner *Scirpus* were suggested by the CA results: (1) relative abundance of Isopoda (%) which decreased with disturbance, and (2) relative abundance of Amphipoda (%) which increased with intermediate disturbance.

Calculating IBI scores with new metrics and category score

Using results from calculation of preliminary IBI scores and the CAs, we dropped *Typha* zone metrics from the IBI, calculated the four richness and diversity metrics by plant zone, and adopted two new metrics for the Inner *Scirpus* zone. When the IBI scores were calculated with these changes included, the IBI worked nearly perfectly from 1997 through 2001 (Table 4). Even without these changes, however, the preliminary IBI metrics suggested by Burton et al. (1999) performed reasonably well. We should note that some sites sampled multiple years did sometimes change disturbance category from year to year. We cannot attribute this change to natural variation such as water levels. We detected no significant differences in metrics using Wilcoxon signed rank tests meaning that the inter-year metric variability did not change in a consistent direction as would be expected if annual water level changes were the driving forces for the observed differences. We do have to consider the temporal extent and recovery time of different types of disturbances. For example, a boat traveling through the wetland itself is certainly considered anthropogenic disturbance, but its impacts are likely not felt nearly as long as an almost continuous supply of agricultural runoff. If sampling was conducted shortly after one of these 'short-term' disturbances, the system was in fact disturbed to the degree detected at that time, but may have recovered within days or weeks. Therefore, we should not expect a given site to maintain a consistent level of perturbation.

Table 4. IBI placement of Lake Huron sites from 1997 through 2000. For each year, sites are listed in order of IBI ranking from least impacted to most impacted with an 'X' placed indicating which plant zones were sampled (WM = Wet Meadow; OS = Outer *Scirpus*; IS = Inner *Scirpus*) and into which overall category each site was placed.

Site	WM	OS	IS	Ex. Degraded	Degraded	Mod. Degraded	Mod. Impacted	Mild. Impacted	Reference
1997									
Mackinac	X	X	X						X
Duck	X	X	X					X	
Mismer	X	X	X					X	
Wildfowl	X	X	X			X			
Cotter Road	X					X			
Vanderbilt		X	X			X			
1998									
Peck			X						X
Duck			X						X
Mismer			X					X	
Mackinac			X					X	
St. Martins			X					X	
Prentiss			X					X	
Voight	X	X	X				X		
Cedarville			X				X		
Wildfowl	X	X	X				X		
1999									
Duck Bay		X	X						X
Mismer		X	X					X	
Mackinac		X	X					X	
Port Dolomite		X	X					X	
Prentiss		X	X					X	
St. Martins		X	X				X		
Wigwam		X	X				X		
Golf Course		X	X				X		
Wildfowl		X					X		
Vanderbilt		X	X				X		
Almeda		X	X				X		
Cedarville			X			X			
2000									
Mismer		X	X					X	
Duck		X	X					X	
Mackinac		X	X				X		
Pine River		X					X		
Cedarville			X				X		

Use of one-half person-hour count

Most often, 150 organisms were collected. Occasionally 50 or 100 organisms were collected from the Outer Scirpus zone. While the timed count did not prove useful as a semi-quantitative metric, it did not negatively affect the IBI. We recommend its use, particularly for the Outer Scirpus zone where invertebrates are sparser than they are in the Inner Scirpus or wet meadow zones making collection of 150 individuals too time consuming for wide spread use.

IBI response to water levels

We used Wilcoxon Signed Rank tests on individual metrics. There were no significant differences at

Table 5. A summary of p values for each metric in Wilcoxon Signed Ranks Tests using Inner *Scirpus* metrics from 1998 and 1999 ($n = 6$) corresponding to a 46 cm decrease in water levels over this period. Nearly identical results were obtained using data from 1997 through 2000 ($n = 3$). A significant difference ($p < 0.05$) would indicate that metric values were changing with time and water level fluctuation.

Wilcoxon Signed Ranks Tests
Inner *Scirpus* Metrics: 1998 vs. 1999
(Water Level was 46 cm Lower in 1999 than in 1998)

Metric (Inner *Scirpus*)	p
Odonata Richness	0.083
% Odonata	0.310
Crustacea + Mollusca Richness	0.999
Genera Richness	0.157
% Gastropoda	0.180
% Sphaeriidae	0.317
Ephem + Trichop Richness	0.157
% Isopoda	0.317
Evenness	0.414
Shannon Diversity	0.999
Simpson Index	0.564

Duck, Mackinac, Prentiss, Mismer, St. Martin's, and Cedarville ($n = 6$).
Similar results for 97–00 using Duck, Mackinac, Mismer ($n = 3$).

the $p < 0.05$ level in Metrics over time with changing water levels for either the 1998 vs. 1999 ($n = 6$) or 1997 through 2000 ($n = 3$) analyses (Table 5). However, with more power of detection, Odonata genera richness ($p = 0.08$) may have decreased with water level decline between 1998 and 1999.

Relating stressor to ecological response

We used Pearson correlation matrices to search for relationships between chemical/physical and land-use/land-cover PCs and our metrics. We ran 302 total correlations and identified 53 significant ones (15 significant correlations would be predicted by chance alone at $p = 0.05$). We did not use a Bonferroni correction because n was low, ranging from 7 to 12. Therefore, these results should be viewed as suggesting hypotheses rather than being conclusive. These analyses suggest several possible relationships (Figure 3). Several examples of suggested relationships are also presented in Figure 4a, b, c. Wetlands with high percentages of adjacent land use in agriculture tended to have relatively higher pH, temperature, turbidity, alkalinity, $DO_{(daytime)}$, redox $potential_{(daytime)}$ and sulfate compared to wetlands with high percentages of land use in forests. If urbanization and roads were adjacent, the wetland tended to have higher chloride, nitrate, and ammonium concentrations and higher specific conductance values. If the adjacent land cover was predominantly swamps, alkalinity and specific conductance tended to be higher while $DO_{(daytime)}$, sulfate, redox $potential_{(daytime)}$, turbidity and soluble reactive phosphorous tended to be lower in the wetland. Adjacent shrub land correlated with low turbidity in the wetland. Adjacent agricultural land use and/or urbanization and roads or wetland chemical conditions that correlated with these adjacent land use/land cover parameters correlated with reduced % Sphaeriidae, % Crustacea + Mollusca, % Gastropoda, Shannon Diversity, Evenness, and % Odonata and increased Simpson Diversity. Adjacent shrub lands or decreased turbidity was also associated with lower % Sphaeriidae, % Crustacea + Mollusca, and % Gastropoda. Adjacent swamps, or the correlated chemical/physical conditions, tended to be correlated with increased Shannon Diversity, Evenness, and % Odonata. Adjacent agricultural land use or wetland chemical conditions that correlated with agriculture reduced Crustacea + Mollusca richness, Odonata richness, and total genera richness. Adjacent swamps or the related chemical/physical parameters correlated with increased Ephemeroptera + Trichoptera richness, increased total genera richness, and decreased Simpson Diversity. Adjacent agriculture correlated with decreased % Isopoda while adjacent swamps correlated with increased % Isopoda. Finally, as urbanization and roads increased adjacent to wetlands % Amphipoda in the wetland tended to decrease.

Discussion

Performance of the IBI with new metrics and category scores

Calculating the preliminary IBI (Burton et al., 1999) using data collected from 22 sites during 1997 through 2001 and using correspondence analyses to search for disturbance related metrics confirmed the utility of most of the metrics suggested previously. Several improvements suggested by these calculations include: 1) adding two new metrics to the Inner Scirpus zone, 2) removing the *Typha* zone from the IBI, and 3) calculating the four diversity metrics for each individual plant zone. With these improvements, the IBI was able to place all 22 sites in the same order that we placed them in based on adjacent land use/cover, limnological parameters and other observed disturbances. The improved IBI worked very well from 1998 through 2001

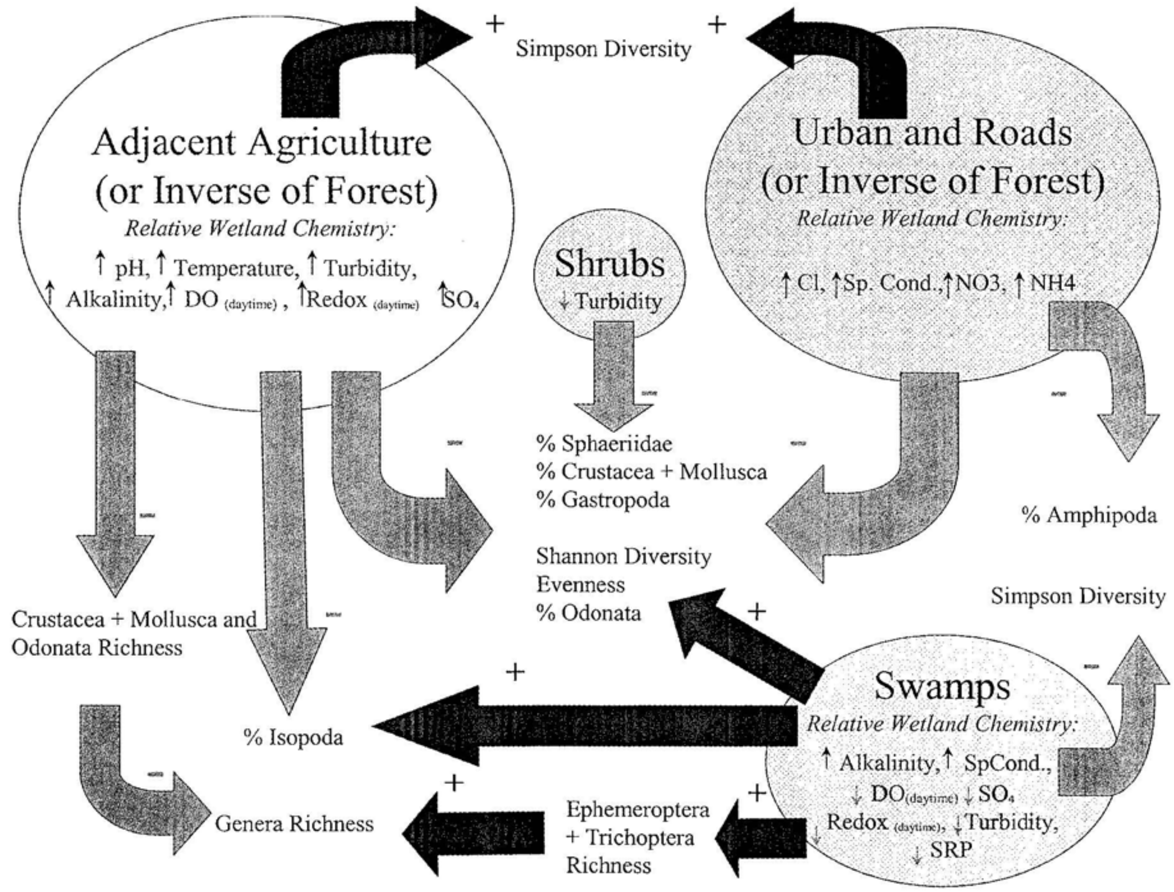
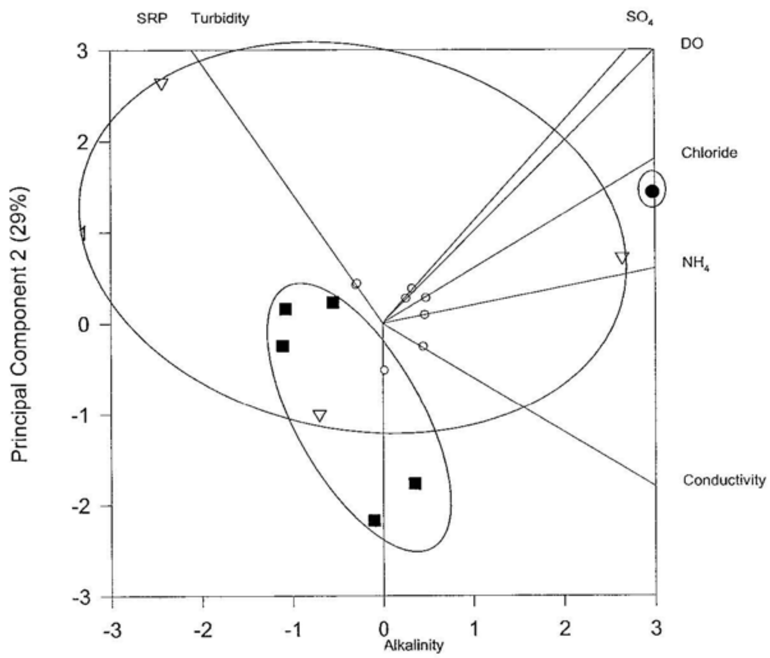


Figure 3. Conceptual drawing established using chemical/physical principal components, land use principal components, and biotic metrics in a Pearson correlation matrix.

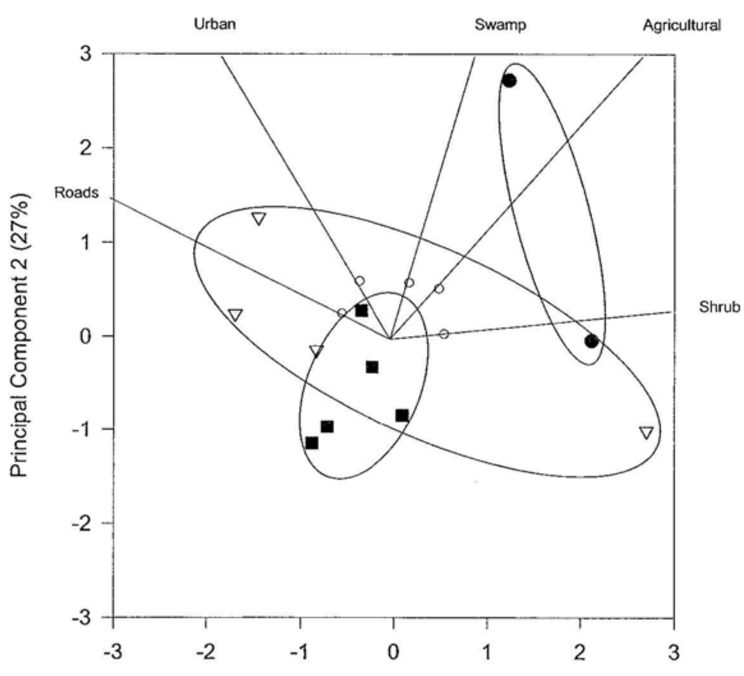
despite the rather substantial decreases in lake level over this time period. Analyses of 2001 data collected from similar fringing wetlands along the northern shore of Lake Michigan suggested that the Lake Huron IBI could also be used for fringing wetlands of northern Lake Michigan (Table 6).

One of the two new metrics suggested for use in the Inner *Scirpus* zone (relative abundance (%) of Amphipoda) does not increase or decrease with disturbance the way most of the metrics do. Instead, highest values for this metric occur at intermediate levels of disturbance. Conversely, the other metric, relative abundance Isopoda (%), decreased with disturbance. One possible explanation is that Isopoda and Amphipoda compete for resources when disturbance is low with isopods being the superior competitor. As isopod abundance decreases with increases in disturbance, amphipods, which appear to be less sensitive to disturbance, are subject to less competition and increase in abundance at intermediate levels of disturbance. As levels of disturbance continue to increase, the threshold for impacting amphipods is exceeded and amphipod relative abundance also decreases. Specifically, the relative abundance of isopods tended to decrease with increasing adjacent Agriculture and/or where wetland water chemistry included relatively higher pH, temperature, turbidity, alkalinity, $DO_{(daytime)}$, redox $potential_{(daytime)}$ and sulfate. Amphipods tended to decrease with increasing adjacent urbanization and roads and/or as chloride, nitrate, ammonium, and specific conductance values increased. Amphipods were much more common than isopods where sites experienced an intermediate amount of disturbance regardless of type of disturbance or ecoregion.

Due to low water, *Typha* zones were often not inundated during the period of rapid decline in lake levels from 1998 through 2001. Samples were collected from only two sites in 1998 and 1999, so our ability to test

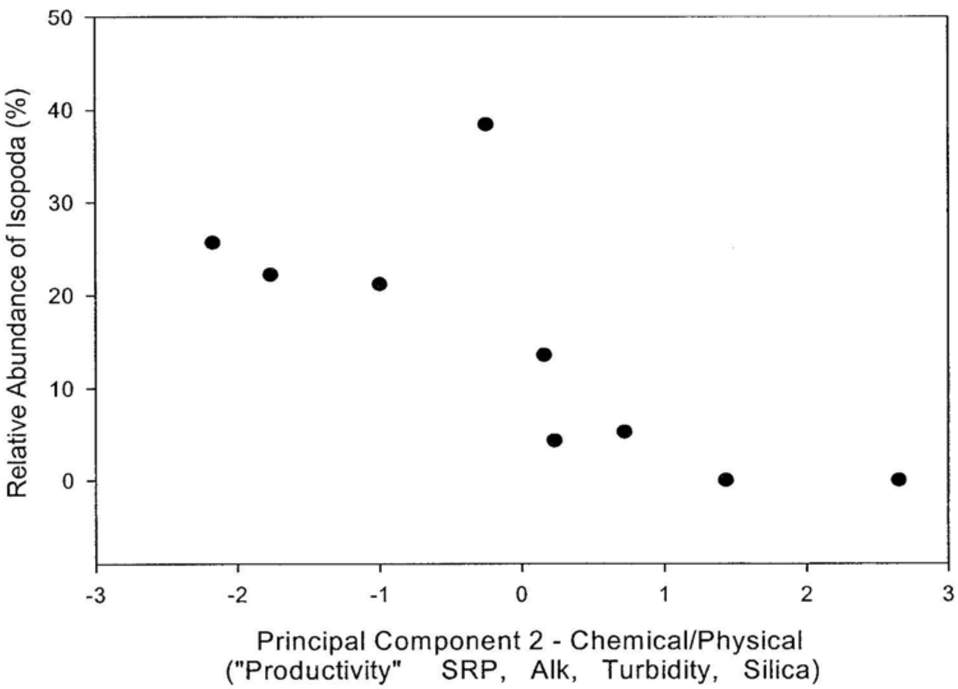


(a)



(b)

Figure 4. (a) Principal components analysis using 1999 Inner *Scirpus* chemical/physical variables. Circles are drawn around sites with different levels of disturbance. Small circles located on vectors near the origin represent actual eigenvectors; (b) Principal components analysis of 1999 Inner *Scirpus* sites using land use/land cover variables. Circles are drawn around sites with different levels of disturbance. Small circles located on vectors near the origin represent actual eigenvectors; (c) Pearson correlation ($r = -0.734$; $p = 0.024$; $n = 9$) between the relative abundance of isopods and chemical/physical principal component two. Symbols for Low Disturbance, Intermediate Disturbance, and High Disturbance Sites as in Figure 1. *(Continued)*



(c)

Figure 4. Continued

metrics for this zone was limited by sample size. Even so, the *Typha* zone metrics never ordinated the sites according to disturbance, and we recommend dropping the zone from the IBI. A possible reason for the failure of the *Typha* zone metrics to separate sites is that this zone tends to occur in very different areas of the wetlands in the two ecoregions included in this study. *Typha* zones in the more pristine northern Lake Huron sites were located in a transitional zone between wet meadow and Inner *Scirpus*. This was not the case for the more impacted Saginaw Bay sites. Monodominant stands of *Typha* were found in areas exposed to direct

Table 6. IBI placement of Lake Huron and Michigan sites from 2001. Each year includes IBI ranking from least impacted to most impacted with an X placed indicating which plant zones were sampled (WM = Wet Meadow; OS = Outer *Scirpus*; IS = Inner *Scirpus*) and into which overall category each site was placed.

Site	WM	OS	IS	Ex. Degraded	Degraded	Mod. Degraded	Mod. Impacted	Mild. Impacted	Reference
2001									
Mackinac		X	X					X	
Duck		X	X				X		
Nahma		X	X				X		
Ogontz		X	X				X		
Escanaba		X	X				X		
Bridge		X	X				X		
Cedarville			X				X		
Port Dolomite			X				X		
McKay			X			X			
Pine River		X				X			
Ludington Park		X				X			

wave action in Saginaw Bay as well as in protected wetlands behind islands or in the middle of *Scirpus pungens* stands. Exposure to waves can play a large role in determining invertebrate community composition regardless of the extent of anthropogenic disturbance (Burton et al., 2002). We did not have enough data from the *Typha* zone to separate variance due to anthropogenic disturbance from that of wave exposure. It may be that *Typha* zone metrics would prove useful if location of the zone in relation to wave action were taken into account as it was in metrics for the two *Scirpus* zones.

We recommend calculating the four richness and diversity metrics by plant zone instead of combining all of the plant zones present (e.g., Burton et al., 1999) to calculate these metrics. Since the number of plant zones inundated varies by wetland and year, a combined calculation means that diversity is being calculated from a variable number of habitats for any given wetland or year. Since wetlands with the most structural diversity would be a function of the number of plant zones included in the calculation, and since habitat diversity would likely be related to invertebrate diversity, the combined calculation should be dropped. By incorporating the metrics into each individual plant zone and adjusting category scores appropriately, we remove variation due to inequitable number of vegetation zones sampled.

With improvements incorporated (Table 7), we recommend dropping the 'preliminary' status from the initial IBI (Burton et al., 1999). Our data proved that this system could work well even during periods of rapid lake level decline as long as any of the three plant zones used in the improved IBI was present. The improvements and increased resolution also allowed us to introduce some new status categories. With these changes in place, we are confident that our IBI is ready for implementation as a tool for management and conservation agencies to use in assessing wetland condition for Lake Huron and Lake Michigan fringing, coastal wetlands.

Deviation from protocol

Our protocol was developed for sampling macroinvertebrates, and field crews were told to pick only macroinvertebrates. However, it was common to have microinvertebrates such as Copepoda and Cladocera in samples. These microinvertebrates were identified and included in the IBI database. Inclusion of such animals by our sampling crews suggests that this might occur when others use the IBI. To ensure that the IBI was robust to this common error, we used those data in calculations of metrics such as percent Crustacea plus Mollusca and the total richness and diversity metrics. Inclusion of the microinveretbrates had little effect on the IBI.

Use of one-half person-hour count

Use of the timed count did not improve the IBI, but as well did not have an negative impact. The timed count reduced time in the field. Without it, two or three individuals could spend up to four hours collecting three replicate samples from the Outer *Scirpus* zone alone.

IBI response to water levels

Others have suggested that the IBI approach would not work for coastal wetlands because natural water level fluctuations of the Great Lakes would likely alter communities and invalidate metrics (Wilcox et al., 2002). By sampling only defined and inundated vegetation zones, we removed enough variation associated with water level fluctuation to maintain metric consistency from year to year even though annual average lake levels increased to above average and then fell 1.08 m to near historic lows over the several year period included in our sampling effort. Except for Odonata genera richness, there were no significant differences in metric scores among years even though water levels declined. With more power of detection, Odonata genera richness ($p = 0.08$) may have decreased with water level decline. The Odonate metric played a crucial role in detecting anthropogenic disturbance within years, and the IBI was robust enough to accommodate among-year variation. Thus, we included this metric in the final IBI.

Relating stressor to ecological response

It is important not only to detect anthropogenic disturbance, but also to identify which disturbance or suite of disturbances is likely to be causing most of the observed changes in IBI metrics. Once specific disturbances are identified, managers can use this information to decide on best management options. Biota usually respond to a suite of correlated ambient conditions. Multivariate analyses were used to combine parameters for more power of detection. Once relationships were established, we decomposed combined parameters to the original parameters. Such relationships are strictly correlative, cannot be used to infer causation, and must be used with caution. It is difficult to determine the impact of adjacent land use or land cover on a given

Table 7. An index of biotic integrity (IBI) for Lakes Huron and Michigan fringing coastal wetlands. All values were based on the median of at least three replicates taken from each zone.

Metric	Score 0	Score 1	Score 3	Score 5	Score 7
Wet Meadow Zone: dominated by *Carex* and *Calamagrostis*					
Odonata taxa richness (Genera):		0	>0 to 3	>3	
		score = 1	score = 3	score = 5	
Relative abundance Odonata (%):		0 to <1	>1 to 5	>5	
		score = 1	score = 3	score = 5	
Crustacea plus Mollusca taxa richness		<2	2 to 6	>6	
(Genera):		score = 1	score = 3	score = 5	
Total Genera richness:		<10	10 to 18	>18	
		score = 1	score = 3	score = 5	
Relative abundance Gastropoda (%):		0 to 1	>1 to 25	>25	
		score = 1	score = 3	score = 5	
Relative abundance Sphaeriidae (%):		0	>0 to 3	>3	
		score = 1	score = 3	score = 5	
Evenness:		0 to 0.4	>0.4 to 0.7	>0.7	
		score = 1	score = 3	score = 5	
Shannon diversity index:		0 to 0.4	>0.4 to 0.9	>0.9	
		score = 1	score = 3	score = 5	
Simpson index:		>0.3	>0.15 to 0.3	0 to 0.15	
		score = 1	score = 3	score = 5	
Inner Scirpus Zone: Often dense Scirpus mixed with *Pontedaria* and submergents, protected from wave action					
Odonata taxa richness (Genera):		0	>0 to <1	1 to 2	>2
		score= 1	score = 3	score = 5	score = 7
Relative abundance Odonata (%):		0	>0 to <2	2 to 7	>7
		score = 1	score = 3	score = 5	score = 7
Crustacea plus Mollusca		0 to 2	>2 to 4	>4 to 6	>6
taxa richness (Genera):		score = 1	score = 3	score = 5	score = 7
Total Genera richness:		<10	10 to 14	>14 to 18	>18
		score = 1	score = 3	score = 5	score = 7
Relative abundance Gastropoda (%):		0	>0 to 2	>2 to 4	>4
		score = 1	score = 3	score = 5	score = 7
Relative abundance Sphaeriidae (%):		0	>0 to 0.05	>0.05	
		score = 1	score = 3	score = 5	
Ephemeroptera plus Trichoptera		0	>0 to 3	>3	
taxa richness (Genera)		score = 1	score = 3	score = 5	
Relative abundance Crustacea		<8	8 to 30	>30	
plus Mollusca (%):		score = 1	score = 3	score = 5	
Relative abundance Isopoda (%):	0	0 to 1	>1 to 10	>10 to 20	>20
	score = 0	score = 1	score = 3	score = 5	score = 7
Evenness:		0 to 0.4	>0.4 to 0.7	>0.7	
		score = 1	score = 3	score = 5	
Shannon diversity index:		0 to 0.4	>0.4 to 0.9	>0.9	
		score = 1	score = 3	score = 5	
Simpson index:		>0.3	>0.15 to 0.3	0 to 0.15	
		score = 1	score = 3	score = 5	

(Continued on next page)

Table 7. An index of biotic integrity (IBI) for Lakes Huron and Michigan fringing coastal wetlands. All values were based on the median of at least three replicates taken from each zone. *(Continued)*

Metric	Score 0	Score 1	Score 3	Score 5	Score 7
Relative abundance Amphipoda (%):					
If 40 to 60— and total score from inner Scirpus Zone (metrics 1 through 12) is greater than 41, then subtract 5;					
If 40 to 60— and total score from inner Scirpus Zone (metrics 1 through 12) is less than 41, then add 5.					
Outer Scirpus Zone : Sometimes relatively sparse, usually monodominant stands, subject to direct wave action.					
Odonata taxa richness (Genera):		0	>0 to <1	1 to 2	>2
		score = 1	score = 3	score = 5	score = 7
Relative abundance Odonata (%):		0	>0 to <1	1 to 2	>2
		score = 1	score = 3	score = 5	score = 7
Crustacea plus Mollusca		0 to 2	>2 to 4	>4 to 5	>5
taxa richness (Genera):		score = 1	score = 3	score = 5	score = 7
Total Genera richness:		<8	8 to 13	>13 to 17	>17
		score = 1	score = 3	score = 5	score = 7
Relative abundance Gastropoda (%):		0	>0 to 3	>3 to 5	>5
		score = 1	score = 3	score = 5	score = 7
Relative abundance Sphaeriidae (%):		0	>0 to 0.05	>0.05	
		score = 1	score = 3	score = 5	
Total number of families:		0 to 7	>7 to 12	>12	
		score = 1	score = 3	score = 5	
Relative abundance Crustacea		<8	8 to 30	>30	
plus Mollusca (%):		score = 1	score = 3	score = 5	
Evenness:		0 to 0.4	>0.4 to 0.7	>0.7	
		score = 1	score = 3	score = 5	
Shannon diversity index:		0 to 0.4	>0.4 to 0.9	>0.9	
		score = 1	score = 3	score = 5	
Simpson index:		>0.3	>0.15 to 0.3	0 to 0.15	
		score = 1	score = 3	score = 5	

When all vegetation zones were present, wetlands were scored as follows: A total score of 31 to 53 (0 to 15% of possible score) = 'Extremely Degraded', or 'in comparison to other Lake Huron wetlands, this wetland is amongst the most impacted'; a total score of >53 to 76 (>15 to 30% of possible score) = 'Degraded' or 'the wetland shows obvious signs of anthropogenic disturbance'; A total score of >76 to 106 (>30 to 50% of possible score) = 'Moderately Degraded' or 'the wetland shows many obvious signs indicative of anthropogenic disturbance'; A total score of >106 to 136 (>50 to 70% of possible score) = 'Moderately Impacted' or 'the wetland shows few, but obvious, signs of anthropogenic disturbance'; A total score of >136 to 159 (>70% to 85% of possible score) = 'Mildly Impacted' or 'the wetland is beginning to show signs indicative of anthropogenic disturbance'; A total score of > 159 to 182 (>85 to 100% of possible score) = 'Reference Conditions' or 'the wetland is amongst the most pristine of Lake Huron'. When a subset of vegetation zones were present, wetland category scores were adjusted as follows: Wet Meadow Only = 9 to 14; >14 to 19; >19 to 27; >27 to 34; >34 to 39; >39 to 45; Inner *Scirpus* only = 11 to 19; >19 to 29; >29 to 41; >41 to 53; >53 to 62; >62 to 72; Outer *Scirpus* only = 11 to 18; >18 to 26; >26 to 37; >37 to 48; >48 to 56; >56 to 65; Wet Meadow and Inner *Scirpus* = 20 to 33; >33 to 47; >47 to 66; >66 to 84; >84 to 99; >99 to 113; Wet Meadow and Outer *Scirpus* = 20 to 32; >32 to 46; >46 to 64; >64 to 82; >82 to 96; >96 to 110; Inner and Outer *Scirpus* = 22 to 38; >38 to 55; >55 to 79; >79 to 102; >102 to 119; >119 to 137.

fringing wetland. For example, Figure 3 seems to suggest that urban areas contribute more NO_3 and NH_4 to wetlands than do agricultural areas, since water in wetlands with adjacent urban land use contains more NO_3 and NH_4 than does water in wetlands with adjacent agricultural land use. An alternative explanation would be that increased inorganic N in the urban wetlands might not be processed as efficiently as it is in agricultural wetlands, so no conclusion about quantity of input from the adjacent area is warranted. We simply tended to find relatively higher NO_3 and NH_4 concentrations near urban areas where there was high run-off and lower productivity in the wetland. The conceptual drawing (Figure 3) shows the relationships between the metrics and the appropriate land use and/or the chemical/physical parameters that correlate with that land use. It does not necessarily suggest that a given land use/land cover taken alone will create the associated chemical/physical conditions in the wetland. It does, however, provide some insight into what potentially might be causing the degradation. Confirmation of the causative agent would then need to be established using a more experimental approach.

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References

Albert, D. A., Minc, L. D., 2001. Abiotic and Floristic Characterization of Laurentian Great Lakes Coastal Wetlands. Verh. Internat. Verein. Limnol. 27(6), 3413–3419.

APHA (American Public Health Association), 1998. Standard Methods for the Evaluation of Water and Wastewater. 20th edition. APHA, Washington, DC.

Barbour, M. T., Gerritsen, J., Griffith, G. E., Frydenborg, R., McCarron, E., White, J. S., Bastian, M. L., 1996. A framework for biological criteria for Florida streams using benthic macroinvertebrates. J. N. Amer. Benth. Soc. 15, 185–211.

Burton, T. M., Stricker, C. A., Uzarski, D. G., 2002. Effects of plant community composition and exposure to wave action on habitat use of invertebrate communities of Lake Huron coastal wetlands. Lakes & Reservoirs: Res. Manage. 7, 255–269.

Burton, T. M., Uzarski, D. G., Gathman, J. P., Genet, J. A., Keas, B. E., Stricker, C. A., 1999. Development of a preliminary invertebrate index of biotic integrity for Lake Huron coastal wetlands. Wetlands 19, 869–882.

Burton, T. M., Uzarski, D. G., Genet, J. A., (this issue). Invertebrate habitat use in relation to fetch and plant zonation in northern Lake Huron coastal wetlands. Aquat. Ecosyst. Health Manage.

Chow-Fraser, P., Albert, D. A., 1998. Biodiversity Investment Areas: Coastal Wetland Ecosystems. State of the Lakes Ecosystem Conference 1998, Chicago, IL.

Kashian, D. R., Burton, T. M., 2000. A comparison of macroinvertebrates of two Great Lakes coastal wetland: Testing potential metrics for an index of ecological integrity. J. Great Lakes Res. 26(4), 460–481.

Keough, J. R., Thompson, T. A., Guntenspergen, G. R., Wilcox, D. A., 1999. Hydrogeomorphic factors and ecosystem responses in coastal wetlands of the Great Lakes. Wetlands 19, 821–834.

Merritt, R. W., Cummins, K. W. (Eds.), 1996. *An Introduction to the Aquatic Insects of North America.* Kendall/Hunt Publ. Co, Dubuque, IA.

Minc, L. D., 1997. Great Lakes Coastal Wetlands: An Overview of Abiotic Factors Affecting their Distribution, Form, and Species Composition. A Report in 3 Parts. Michigan Natural Features Inventory.

Minc, L. D., Albert, D. A., 1998. Great Lakes Coastal Wetlands: Abiotic and Floristic Characterization. Michigan Natural Features Inventory.

MIRIS, 1978. Michigan Resource Information System. http://www.mcgi.state.mi.us/mgdl/?rel=thext&action=thmname &cid=0&cat=MIRIS+Base

Thorp, J. H., Covich, A. P., 1991. *Ecology and Classification of North American Freshwater Invertebrates.* Academic Press Inc. Harcourt Science and Technology Company, San Diego, CA.

Wilcox, D. A., Meeker, J. E., Hudson, P. L., Armitage, B. J., Black, M. G., Uzarski, D. G., 2002. Hydrologic variability and the application of index of biotic integrity metrics to wetlands: A Great Lakes evaluation. Wetlands 22(3), 588–615.

assemblages in the littoral zone of Great Lakes Areas of Concern. *Can. J. Fish. Aquat. Sci.* 51:1804–1822.

Prince, H.H., and Flegel, C.S. 1995. Breeding avifauna of Lake Huron. In *The Lake Huron Ecosystem: Ecology, Fisheries and Management*, eds. M. Munawar, T. Edsall and J. Leach, pp. 247–272. Amsterdam: SPB Academic Publishing.

———, Padding, P.I., and Knapton, R.W. 1992. Waterfowl use of the Laurentian Great Lakes. *J. Great Lakes Res.* 18:673–699.

Randall, R.G., and Minns, C.K. 2002. Comparison of a habitat productivity index (HPI) and an index of biotic integrity (IBI) for measuring the productive capacity of fish habitat in nearshore areas of the Great Lakes. *J. Great Lakes Res.* 28:240–255.

Simon, T.P. 1998. Modification of an index of biotic integrity and development of reference condition expectations of dunal, palustrine wetland fish communities along the southern shore of Lake Michigan. *Aquat. Ecosyst. Health Manage.* 1:49–62.

Thoma, R.F. 1999. Biological monitoring and an index of biotic integrity for Lake Erie's nearshore waters, In *Assessing the Sustainability and Biological Integrity of Water Resources Using Fish Communities*, pp. 417–461, ed. T. P. Simon. Boca Raton, Florida: CRC Press.

Uzarski, D.G., Burton, T.M., and Genet, J.A. 2004. Validation and performance of an invertebrate index of biotic integrity for Lakes Huron and Michigan fringing wetlands during a period of lake level decline. *Aquat. Ecosyst. Health Manage.* 7(2):269–288.

Weeber, R.C., and Vallianatos, M. (eds.) 2000. *The Marsh Monitoring Program 1995–1999: Monitoring Great Lakes wetlands and their amphibian and bird inhabitants.* Bird Studies Canada, Port Rowan, Ontario N0E 1M0, Canada in cooperation with Environment Canada and the U. S. Environmental Protection Agency.

Wilcox, D.A. 1995. The role of wetlands as nearshore habitat in Lake Huron. In *The Lake Huron Ecosystem: Ecology, Fisheries and Management*, eds. M. Munawar, T. Edsall, and J. Leach, pp. 223–245. Amsterdam: SPB Academic Publishing.

———, Meeker, J.E., Hudson, P.L., Armitage, B.J., Black, M.G., and Uzarski, D.G. 2002. Hydrologic variability and the application of index of biotic integrity metrics to wetlands: A Great Lakes evaluation. *Wetlands* 22(3):588–615.

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Fish Habitat Use Within and Across Wetland Classes in Coastal Wetlands of the Five Great Lakes: Development of a Fish-based Index of Biotic Integrity

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ABSTRACT. *The relative importance of Great Lake, ecoregion, wetland type, and plant zonation in structuring fish community composition was determined for 61 Great Lakes coastal wetlands sampled in 2002. These wetlands, from all five Great Lakes, spanned nine ecoregions and four wetland types (open lacustrine, protected lacustrine, barrier-beach, and drowned river mouth). Fish were sampled with fyke nets, and physical and chemical parameters were determined for inundated plant zones in each wetland. Land use/cover was calculated for 1- and 20-km buffers from digitized imagery. Fish community composition within and among wetlands was compared using correspondence analyses, detrended correspondence analyses, and non-metric multidimensional scaling. Within-site plant zonation was the single most important variable structuring fish communities regardless of lake, ecoregion, or wetland type. Fish community composition correlated with chemical/physical and land use/cover variables. Fish community composition shifted with nutrients and adjacent agriculture within vegetation zone. Fish community composition was ordinated from* Scirpus, Eleocharis, *and* Zizania, *to* Nuphar/Nymphaea, *and* Pontederia/Sagittaria/Peltandra *to* Spargainium *to* Typha. *Once the underlying driver in fish community composition was determined to be plant zonation, data were stratified by vegetation type and an IBI was developed for coastal wetlands of the entire Great Lakes basin.*

INDEX WORDS: *Coastal wetlands, fish, IBI, fish community composition, Great Lakes, bioassessment, land use effect.*

INTRODUCTION

Great Lakes coastal wetlands provide critical habitat for more than 80 species of fish (Jude and Pappas 1992). More than 50 of these species are dependent upon wetlands while another 30+ migrate into and out of them during different periods in their life history (Jude and Pappas 1992, Wilcox 1995). An additional 30+ species of fish may be oc-

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casional visitors to coastal wetlands based on occurrence in adjacent habitats (Jude and Pappas 1992). Coastal wetlands also provide habitat for 20+ species of mammals, large numbers of amphibians and reptiles (Wilcox 1995, Weeber and Vallianatos 2000) and 80-90 bird species including 28 species of waterfowl (Prince *et al.* 1992, Prince and Flegel 1995, Weeber and Vallianatos 2000). We have identified more than 250 taxa of invertebrates which utilize coastal wetlands (Burton *et al.* 1999, 2002, 2004; Cardinale *et al.* 1997, 1998; Gathman *et al.* 1999; Kashian and Burton 2000, and unpublished data). Similar numbers have been reported by others (e.g., see reviews by Krieger 1992 and Gathman *et al.* 1999). The actual number of species may be 3–4 times greater, given the difficulty in identification of larval invertebrates. Coastal wetlands are occupied by many rare plants with over 40 species listed for Lake Huron alone (Wilcox 1995). Despite their importance as habitats for so many organisms, knowledge about the biota of these wetlands is limited.

As transitional systems between land and water, coastal wetlands are among the first habitats impacted by disturbances from adjacent uplands and/or pollutants from upstream. Activities and pollutants that degrade wetland habitat often also pose threats to other near shore and deep water habitats if allowed to continue unabated. Since many pollutants accumulate in them and adjacent changes in land use tend to impact them first, coastal wetlands can provide "early warning" of potential threats to the Great Lakes ecosystem. The governments of Canada and the U.S.A. recognized this potential and initiated a process to identify and/or develop indicators of "ecosystem health" for wetlands and other Great Lakes habitats at the State-of-the-Lakes Ecosystem Conference (SOLEC) held in Buffalo, New York in 1998. Progress was reviewed and potential indicators were identified by working group members at SOLEC 2000 in Hamilton, Ontario. Potential indicators listed by the wetlands indicators working group included indices of biotic integrity (IBIs) based on invertebrates, fish, and plants even though no broadly accepted protocol was available at the time for any of these biotic groups.

Recognition of the need for a biotic-based assessment system accelerated our on-going research on development of invertebrate-based IBIs for coastal wetlands and culminated in publication of an invertebrate-based IBI for coastal wetlands (Burton *et al.* 1999, Kashian and Burton 2000, Uzarski *et al.* 2004). We also expanded efforts to obtain data on fish populations in coastal wetlands, with the goal of developing fish-based IBIs for major classes of coastal wetlands described by Keough *et al.* (1999) and modified by Albert *et al.* (2003).

Great Lakes coastal wetlands occupy a relatively small percentage of the Great Lakes shoreline (e.g., about 11% of the shoreline of the U.S. side of Lake Huron—Prince and Flegel 1995). Conversion of wetlands over the last 100 years has reduced the area of Great Lakes coastal wetlands by more than 50% with losses greater than 95% in some areas such as Western Lake Erie (Krieger *et al.* 1992). Sustainable management of the remaining wetlands and efforts to restore the large number of wetlands that have been converted to other land uses are critical to the long-term viability of the Great Lakes ecosystem. An important tool needed for management and restoration of coastal wetlands is a system of assessment which will allow managers to monitor the health of these and adjacent coastal systems on a routine basis so that trends in wetland condition can be established and used to identify threats to these ecosystems. Our overall goal was to develop a system of indicators of biotic integrity for coastal wetlands based on fish, invertebrates, and plants. Our goal in this paper is to document and provide details of a fish-based IBI for wetlands of the Great Lakes.

Minns *et al.* (1994) developed a fish-based IBI for marshes of Great Lakes Areas of Concern which included metrics sensitive to impacts by exotic fishes, water quality changes, physical habitat alterations, and changes in piscivore abundance related to fishing pressure and stocking. This system has not been extended outside of the limited and often highly impacted Areas of Concern. The work of Brazner (1997), Brazner and Beals (1997), and Minns *et al.* (1994) demonstrated relationships between fish populations and wetland and/or nearshore habitats which suggest that development of a fish-based IBI for coastal wetlands is possible. Recently, Randall and Minns (2002) used an IBI to assess habitat productivity of near shore areas (including coastal wetlands) of Lakes Erie and Ontario and compared results to those obtained using their Habitat Productivity Index. Thoma (1999) developed a fish-based IBI for near shore waters of Lake Erie. Despite such promising results, Wilcox *et al.* (2002) concluded that development of wetland IBIs for the upper Great Lakes using macrophytes, fish, and microinvertebrates was impractical. Even though some of their metrics showed potential, they concluded that natural water level changes from those that existed during data collection were likely to alter communities enough to invalidate metrics in subsequent years. We overcame this problem for invertebrates in fringing coastal wetlands by developing a method based on sampling any or all of four plant zones depending on the number of zones inundated (Burton *et al.* 1999, Uzarski *et al.* 2004). The IBI scores for a particular year were calculated by summing scores from each of the zones that were inundated when sampling occurred. As water levels decreased and zones were no longer inundated, the IBI scores changed, but metrics for even a single inundated zone proved to be effective in establishing wetland condition for fringing wetlands of Lakes Huron and Michigan as water level decreased by more than 1-meter from 1997 through 2002 (Uzarski *et al.* 2004). Based on these results, we hypothesized that fish-based IBI metrics developed using samples from each inundated plant zone, rather than using composited samples to develop one set of metrics for the entire wetland, would provide the flexibility needed to make the IBI useful over a wide range of lake levels. This makes our approach different than efforts of others including sampling associated with the REMAP project of U.S. EPA where composite samples for the entire wetland are used.

Objectives

The primary objective of this study was to explore relationships of fish populations among Great Lakes, ecoregions, wetland types, and plant zones and relate these differences to water quality and adjacent land use/cover. Using what we learned from these analyses, our second goal was to develop a fish-based system of biotic indicators of wetland ecological health that could be employed in a monitoring program by federal, state, provincial, and local agencies to detect effects of anthropogenic disturbance on the biotic integrity of Great Lakes coastal wetlands.

METHODS

Study Sites

Sixty-one sites spanning all five Great Lakes were selected for study. Five sites were located on Lake Superior, 18 on Lake Michigan, 13 on Lake Huron, 13 on Lake Erie, and 12 on Lake Ontario (Fig. 1). Each site was assigned designators based on lake (Superior, Michigan, Huron, Erie, or Ontario) ecoregion (E. Lake Superior, N. Lake Michigan, N.E. Lake Michigan, S.E. Lake Michigan, N. Lake Huron, Saginaw Bay Huron, Long Point Erie, N.W. Lake Ontario, and N.E. Lake Ontario), wetland type (open lacustrine, protected lacustrine, barrier-beach, and drowned river mouth), and vegetation type (*Sparganium* (bur-reed), *Scirpus* (bulrush) (inner and outer; e.g., Burton *et al.* 1999 and Uzarski *et al.* 2004), *Nuphar/Nymphaea* (lily), *Pontederia/Sagittaria/Peltandra* (pickerel weed/arrowhead/arrow arum), *Typha* (cattail), *Zizania* (wild rice), and *Eleocharis* (spike rush)) See Appendix A, available from the corresponding author's web site (http://www.gvsu.edu/wri/envbio/uzarski/index.htm), for specific site locations and classifications. Site selection was based on access and inundation. We sampled every site that we encountered if we were granted access and the site was inundated with enough water to set nets (approximately 25 cm).

Wetland Classification

Wetlands of the Great Lakes were classified into geomorphological classes that reflect location in the landscape and exposure to waves, storm surges, and lake level changes. Classes followed categories described by Albert *et al.* (2003) on behalf of the Great Lakes Wetland Consortium. Wetlands were categorized as *lacustrine* (fringing), *riverine*, or *barrier protected*. All 61 sites sampled fit into *open lacustrine*, *protected lacustrine*, *barrier-beach*, or *drowned river mouth* subcategories (Appendix A).

Chemical/Physical and Land Use/ Cover Measurements

Basic chemical/physical parameters were sampled within each vegetation zone fished. Analytical procedures followed those recommended in Standard Methods for the Examination of Water and Wastewater (APHA 1992). These measurements included soluble reactive phosphorus, ammonium-N, nitrite/nitrate-N, dissolved oxygen, temperature, turbidity, specific conductance, pH, and total alkalinity at all sites. Additional measurements of chlorophyll a, sulfate, chloride, and redox potential were made at approximately half of the sites. Quality assurance/quality control procedures followed protocols recommended by U.S. EPA.

Land use/cover data were obtained from existing digitized maps. When land use/cover data from more than one year were available, on-site observations were used to determine the most accurate map. For example, we found that maps digitized

FIG. 1. Map of Great Lakes basin showing the locations of 61 coastal wetlands sampled during the summer of 2002.

from aerial photographs taken in 1978 (available from the Michigan Center for Geographic Information) were more accurate at coarse resolution for many of the Michigan sites than newer available versions. Coarse categories, including agriculture, urbanization, roads, idle lands, wetlands and forests, were calculated for 1-km buffers around all sites except drowned river mouths. Land use/cover was calculated for the entire watershed at drowned river mouth sites. These data were verified with on-site observations where possible. Additional 20-km buffers were calculated around approximately half of the sites; we were unable to acquire these data for all sites.

Fish Sampling

Fish sampling was conducted using a minimum of three replicate fyke nets with 4.8-mm mesh in each dominant vegetation zone for one net-night. Sampling was conducted during the summer of 2002 and corresponded to the maturity of the vegetation in each system. Only dominant plant zones that could be definitively assigned to a dominant (i.e., visually much more than 50% composition by one species) type (*Sparganium*, *Scirpus*, *Nuphar/Nymphaea*, *Pontederia/Sagittaria/Peltandra*, *Typha*, *Zizania*, or *Eleocharis*) were sampled to partition variation due to structure or habitat type. We rarely encountered vegetation zones without an obvious dominant. However, when we did, these were avoided. Two sizes of fyke nets were used, 0.5-m × 1-m openings and 1-m × 1-m openings. Smaller nets were set in water approximately 0.25 m deep to 0.50 m; larger nets were set in water depths greater than 0.50 m. Leads were 7.3 m in length and wings were 1.8 m. The depth of water in each plant zone dictated the net size used since the only difference between large and small nets was the height. Each net was randomly placed perpendicular to the vegetation zone of interest with leads extending into the vegetation itself. Therefore, fishes either occupying the vegetation or using the edge were likely to be caught. Wings were set at 45° angles to the lead and connected to the outer opening on each side of the net. Fishes were identified to species and enumerated. Catches per net per night were recorded. Ten to 20 specimens of each species were chosen randomly for measurement, but these data were not included in this paper; please contact authors regarding these data if they can be of use.

Statistical Analyses

Chemical/physical and land use/cover data were analyzed using principal components analysis (PCA). Percentages were transformed using an arcsine square root before inclusion in the PCA. All variables entered into the PCA represented a normal distribution. Correspondence analysis (CA), detrended correspondence analysis (DCA), and non-metric multidimensional scaling (NMDS) were used to analyze fish data. All three indirect gradient analyses were used because an "arch effect" can sometimes confuse the interpretation of CA. DCA and NMDS were used to determine if the arch was present. Fish data were not transformed. When CA, DCA, and NMDS all showed similar results, only CA was used to describe relative fish communities.

Indirect gradient analyses (CA, DCA, and NMDS) were used to determine if fish composition was mainly structured by Great Lake, ecoregion, wetland type, or plant zonation. This was determined by overlaying these variables as a third dimension onto the first two dimensions of the CA. If fish community composition was structured by one of these variables, fish community composition would in turn group the sites by either lake, ecoregion, wetland type, or plant zonation. Therefore, the first run of the CA contained all taxa represented by more than three individuals in the total dataset (15,000 + fish in total). Following each run of the analyses, sites were coded using Great Lake, ecoregion, wetland type, and plant zonation. Biplots were then visually inspected for groupings. Chemical/physical and land use/cover data were combined using PCA. Eigenvalues were then correlated with factor loadings from CA in an attempt to associate fish community structure with abiotic factors. If no groupings were observed and factor loadings did not correlate with eigenvalues, then taxa responsible for the most inertia in each dimension were identified. If these taxa were either very rare or had the tendency to school, they were likely to overwhelm the analysis and therefore were removed before the next iteration was performed. This process continued until a gradient (either Great Lake, ecoregion, wetland type, or plant zonation) could be identified. Once a gradient was identified, direct gradient analysis (canonical correspondence analysis) was performed to determine accordance between the two approaches (direct and indirect gradient analysis). The above statistical analyses were solely performed to determine the underlying forcing factors in establishing fish community composition in Great Lakes coastal wetlands. In turn, results of these analyses were used to determine proper stratification (either by Great Lake, ecoregion, wetland type, or plant zonation) for a fish-based IBI. Once the forcing factor was determined, the entire dataset, including those fishes removed from the CA, was stratified and analyzed under the confines of this stratification using Spearman or Pearson correlation to search for metrics. These data were correlated with disturbance gradients established *a priori* using land use and chemical/physical data. Statistical analyses were performed using Systat 8.0, SAS V8, and Canoco for Windows.

Establishing Disturbance Gradients

Disturbance gradients were established using land use/cover and chemical/physical data. They were established using both principal components (PCs) and calculating rank sums using all chemical/physical and land use/cover data (1-km and 20-km buffers). Turbidity, specific conductance, and chloride were ranked directly with the greater values indicating disturbance. Extreme values, either very high or very low, for nitrate-N, ammonium-N, and soluble reactive phosphorus concentrations, as well as percent saturation of dissolved oxygen, and pH were considered indicators of disturbance (reasoning for this assumption is explained in the discussion section). Therefore, absolute values of the difference from the median concentration were used to establish a rank order for each of these parameters. These data, as well as land use/cover data, were used to establish ranks. Ranks were then combined into a grand rank producing the final disturbance gradient.

Land use/cover data were analyzed at two scales for more than half of our sites and both were incorporated into the final disturbance gradient for this subset of sites. The larger scale (20-km buffers) was used to represent the impacts to the nearshore region or the water source of the wetland and was double weighted. These data were not available for all sites. A finer scale (1-km buffer) was used to relate impacts much more locally and received a single weighting. Metrics were correlated with this disturbance gradient as well as with PC1 of the chemical/physical, land use/cover PCA.

IBI Development

Community attributes were correlated with PCs and the rank-sum disturbance gradients using Pearson and Spearman correlations, respectively. When community attributes or specific taxa correlated with established disturbance gradients, they were deemed metrics. When attributes did not significantly correlate with the disturbance gradients but did show a dichotomy between pristine and impacted sites, Mann-Whitney U tests were performed and these too were maintained. Those attributes, including many from the literature that showed an empirical response to disturbance using one of the above methods, were deemed metrics. Natural breaks in metric values were then used as cut-offs for score categories.

RESULTS

Chemical/Physical and Land Use/ Cover Measurements

Our chemical/physical and land use/cover data suggested a wide range of ambient conditions among our sites. However, we were not able to obtain a complete matrix for all of our parameters; some sites had missing values, especially the 20-km buffer. The 20-km buffer could only be calculated for 33 sites, and therefore, ranks and disturbance gradients could only be calculated with this variable for a subset of our sites. Chloride data were also only available from a subset of sites (Table 1a–c)).

Principal Components Analysis

Principal components analysis, including all of the chemical/physical and land use/cover data, produced results very similar to the last iteration of the CA. That is, the PCA was structured by vegetation zone especially in PC1. *Scirpus* sites were given low PC1 scores and *Typha* sites scored high with the remaining vegetation zones ordinated somewhere in between (Fig. 2). In combination, the two dimensions accounted for 37% of the variation in the dataset. In general, the PCA can be viewed as having three groupings, those that scored low in both PCs and those that scored high in PC1 and either low or high in PC2. Those sites that scored low in both PCs tended to have higher dissolved oxygen and pH as well as a high percentage of forest in the 1-km buffer surrounding the site. This grouping included nearly all *Scirpus* sites. The second grouping of the PCA included those sites with high PC1 scores and low PC2 scores. These sites tended to be composed of *Typha* and generally had high nutrients and a high percentage of adjacent land use in agriculture. Finally, the third grouping was also composed of mostly *Typha* sites scoring high in both PCs and was indicative of high run-off and percent urbanization. Nearly all remaining vegetation zones were placed between the first and second groupings discussed (Fig. 2). Consistent with biotic data in the CA, no patterns were visually detected when sites were coded by lake, ecoregion, or wetland type.

Correspondence Analysis

Rare or schooling taxa increased the variability in the data set and were often captured by chance alone. For example, schools of *Ameiurus melas* (black bullhead) and *Amia calva* (bowfin) were observed at nearly every site sampled, yet schools of these taxa were only caught at a few sites. When these taxa overwhelmed the first iteration of analyses, they had to be removed (see Table 2) and the entire process was repeated. Appendix B (available from the corresponding author's web site: http://www.gvsu.edu/wri/envbio/uzarski/index.htm) includes the mean catch per net for all species. After several iterations, the first pattern appeared (Fig. 3). Just as in the case of the PCA of the abiotic data, plant zone was the major driving factor of community composition, more so than even lake, ecoregion, or wetland type. Fish community composition was ordinated from *Scirpus, Eleocharis*, and *Zizania* to *Nuphar/Nymphaea,* and *Pontederia/Sagittaria/Peltandra* to *Sparganium* to *Typha.*

Correlation Between Abiotic and Biotic Data

Once the pattern appeared in the CA, a significant ($p = 0.001$) Pearson correlation was found between the first dimensions of the CA and the first PC (Fig. 4). The third dimensions (Great Lake, ecoregion, wetland type, and plant zone) were then applied to the correlation analysis just as they were in each PCA and CA. Once again, plant zone showed the only apparent relationship. The order of the plant zones in the correlation was identical to the CA and the PCA as well. The relationship seems to be better represented by a quadratic function, suggesting that a threshold in fish community composition is reached, but a linear correlation was applied and was significant. Direct gradient analysis (CCA) supported these results suggesting that the underlying gradient in the fish community data

TABLE 1A–C. Anthropogenic disturbance gradients of Inner and Outer* Scirpus *(1a),* Typha *(1b) and Lily (1c) zones in Great Lakes coastal wetlands using land use and water quality parameters sampled during the summer of 2002. Data represent ranks for each parameter; sum of the ranks was used to determine the disturbance gradient. Land use parameters included percent developed land (%Dev), percent agricultural land (%Ag), percent forested land^{-1} (%For^{-1}) and percent wetland/meadow^{-1} (%Wet Mead^{-1}) for both 1-km and 20-km buffers. Ranks for 20-km land use parameters were double weighted. Nitrate-N, pH and percent dissolved oxygen ranks were based on the absolute value of the measured value at a site minus the median of all sites. Principal components (PC) analysis was used to combine 13 chemical, physical and land use variables for* Typha *sites and the resulting PC1 scores represent increasing urbanization and agriculture.

Table 1a.	20-km Land Use				1-km Land Use				Water Quality						
	% Dev	% Ag	% For^{-1}	Wet Mead^{-1}	% Dev	% Ag	% For^{-1}	Wet Mead^{-1}	Cond. (μS cm^{-1})	pH	Turb. (NTU)	NO_3-N (mg L^{-1})	Cl^- (mgL^{-1})	% DO	
Inner *Scirpus*															
Mean ± SE:	2.9 ± 0.4	24.0 ± 6.7	63.0 ± 6.6	10.2 ± 1.0	16.1 ± 4.4	5.7 ± 3.0	42.4 ± 6.3	10.5 ± 2.3	292.2 ± 20.7	8.1 ± 0.1	8.5 ± 2.9	0.06 ± 0.03	11.7 ± 2.3	8.6 ± 0.6	
Range:	0.5–6.7	0.9–86.9	2.8–93.9	3.6–16.1	0.0–66.6	0.0–42.7	0.0–81.9	0.0–26.8	155.9–569.0	7.0–9.6	1.7–63.7	0.01–0.60	0.8–30.5	5.0–16.6	Rank Sum
Big Fish Dam	32	30	30	28	15	7	16	6	13	16	5		7	16	221
Rapid River	12	28	26	20	7	5	3	15	12	16	12		13	14	183
Lightfoot Bay	34	34	32	4	11	10	7	5	17	3	4		17	2	180
Garden Bay	30	18	10	30	12	1	6	11	9	14	7		9	17	174
Ogontz Bay	28	26	14	22	13	6	15	0	10	11	9		7	9	170
Sheppard Bay	22	22	28	14	6	10	13	7	8	5	14		10	11	170
Hill Island	18	24	24	18	4	10	12	4	16	12	11		12	5	170
Moscoe Channel	20	16	22	16	8	10	14	1	15	8	8		15	15	168
St. Ignace	6	32	16	34	2	10	9	13	11	9	2		6	7	157
Mackinac Bay	24	12	18	10	9	10	11	9	1	15	12		16	1	148
Hessel Bay	16	10	20	8	5	4	8	14	14	7	6		14	12	138
Cedarville	26	14	12	12	3	3	10	10	6	2	17		11	10	136
Escanaba	4	20	8	24	1	10	5	3	4	10	16		5	13	123
Pinconning	8	6	4	26	10	9	4	16	3	4	14		1	6	111
Wigwam Bay	10	8	6	32	14	8	0	12	5	1	3		3	4	106
Wildfowl Bay	14	4	2	6	15	10	1	2	7	6	1		4	7	79
Vanderbilt Park	2	2	0	2	15	2	2	8	2	13	9		2	3	62
Outer *Scirpus*															
Mean ± SE:	3.2 ± 0.5	25.1 ± 7.0	60.6 ± 6.8	11.1 ± 1.0	15.0 ± 4.6	6.3 ± 3.2	45.0 ± 6.2	11.2 ± 2.3	254.7 ± 18.0	8.5 ± 0.1	9.1 ± 1.7	0.04 ± 0.01	12.5 ± 2.8	105.3 ± 3.6	
Range:	0.6–6.7	2.7–86.9	2.8–77.6	3.6–16.1	0.0–66.6	0.0–42.7	0.0–81.9	0.0–26.8	101.2–366.0	7.8–9.5	2.3–25.3	0.01–0.12	2.9–35.1	78.8–124.1	Rank Sum
Big Fish Dam	32	30	30	22	14	8	15	4	11	6	4	14	9	9	208
Ogontz Bay	28	24	14	16	11	7	14	0	10	7	13	16	6	16	182
Sheppard Bay	24	20	28	8	5	11	12	6	13	11	8	15	13	6	180
Portage River	16	26	12	28	12	5	9	5	16	3	9	3	16	12	172
Garden Bay	30	16	10	24	10	1	5	10	9	15	14	4	8	11	167
Hill Island	20	22	24	12	3	11	11	3	15	11	15	2	12	2	163
St. Ignace	6	32	16	30	2	11	8	12	8	10	1	6	7	14	163
Moscoe Channel	22	14	22	10	7	11	13	1	14	15	10	1	14	7	161
Rapid River	14	28	26	14	6	6	2	14	2	4	12	7	10	1	146
Mackinac Bay	26	12	18	6	8	11	10	8	7	8	2	7	11	10	144
Hessel Bay	18	10	20	4	4	4	6	13	12	5	11	5	15	13	140
Escanaba	4	18	8	18	1	11	4	2	6	13	16	7	5	8	121
Wigwam Bay	12	8	6	26	13	9	0	11	5	1	6	7	4	4	112
Pinconning	10	6	4	20	9	10	3	15	4	2	4	7	1	5	100
Bradleyville	8	4	2	2	14	3	7	9	3	9	3	7	2	15	88
Vanderbilt Park	2	2	0	0	14	2	1	7	1	13	7	7	3	3	62

TABLE 1A–C. Continued.

Table 1b.	1-km Land Use				Water Quality				
	%Dev	%Ag	$\%For^{-1}$	%Wet $Mead^{-1}$	Sp. Cond. ($uS\ cm^{-1}$)	Turb. (NTU)	NO_3-N ($mg\ L^{-1}$)	PC1 Score	
Mean ± SE:	18.2 ± 4.5	28.8 ± 5.5	21.2 ± 4.2	22.5 ± 4.8	369.0 ± 31.2	11.2 ± 2.5	0.30 ± 0.08	0.14 ± 0.33	Rank
Range:	0.0–84.2	0.0–88.1	0.0–94.0	0.0–99.1	206.0–957.5	1.3–69.1	0.01–1.63	–2.96–3.97	Sum
Bluff Marsh	28	23	6	28	30	30	19	28	192
Helmers Pond	29	23	15	25	25	28	19	27	191
Thoroughfare	27	23	1	30	28	23	19	29	180
Little Rice Bay	30	23	1	29	26	22	18	30	179
Long Point	10	23	14	27	19	25	18	26	162
Rapid River	8	19	16	22	23	24	18	21	151
Parrott Bay	15	16	21	26	15	27	8	17	145
Crown Marsh	4	23	1	24	29	21	17	25	144
Presqu'ile	9	18	27	17	18	29	9	12	139
Lincoln	21	13	25	19	13	9	12	19	131
Coletta Bay	5	23	7	23	19	19	15	22	133
Lee Brown Marsh	25	3	8	15	27	14	15	23	130
Muskegon	20	14	28	12	12	16	15	13	130
Pentwater	26	10	26	18	8	5	14	20	127
Port Rowan	7	11	18	5	22	26	14	24	127
Hill Island Canada	18	23	30	1	16	12	8	18	126
Pere Marquette	24	17	29	9	7	4	10	15	115
Allen Rd	16	8	20	4	10	15	12	16	101
Booth's Harbor	19	5	19	1	9	20	12	10	95
South Bay	11	4	12	11	17	17	8	14	94
Robinson Cove	22	2	11	7	24	13	7	8	94
Bruce's Bayou	12	12	24	14	5	2	8	11	88
Little Black Creek	3	22	22	13	1	10	9	2	82
Pigeon	17	9	23	10	4	11	1	7	82
Frenchman's Bay	1	20	5	16	10	18	5	5	80
Hay Bay South	14	6	17	8	14	7	2	9	77
Port Britain	13	7	13	20	6	8	2	4	73
Bayfield Bay	23	1	9	6	21	3	1	6	70
Lynde Creek	6	15	10	21	2	1	1	1	57
Jones Road	2	21	4	1	3	5	1	3	40

Table 1c.	Watershed Land Use				Water Quality						
	%Dev	%Ag	$\%For^{-1}$	%Wet $Mead^{-1}$	Sp. Cond. ($uS\ cm^{-1}$)	Turb. (NTU)	NO_3-N ($mg\ L^{-1}$)	NH_4-N ($mg\ L^{-1}$)	SRP ($mg\ L^{-1}$)	Cl^- ($mg\ L^{-1}$)	
Mean ± SE:	4.1± 0.8	24.5± 4.2	54.4± 5.4	13.0± 1.7	352.6± 32.8	13.4± 2.7	0.26± 0.12	0.058± 0.016	0.01± 0.00	12.9± 3.7	
Range:	1.0– 9.4	0.1– 50.1	34.8– 87.3	7.3– 28.9	160.0– 553.9	3.0– 35.5	0.01– 1.48	0.03– 0.217	0.01– 0.02	0.7– 47.1	Rank Sum
Taquamenon	12	12	12	7	12	11	9	12	7	11	105
Baraga	11	11	11	3	11	12	12	7	7	12	97
Arcadia River	10	6	3	12	8	5	3	9	7	10	73
Lincoln	6	5	4	11	9	7	4	10	7	9	72
Pere Marquette	8	9	10	1	6	6	9	11	4	8	72
Little Pigeon	1	10	9	10	10	1	5	5	6	6	63
Muskegon	5	8	7	5	2	10	9	6	3	4	59
Pentwater	9	2	5	9	3	8	8	3	3	7	57
White	7	7	8	4	5	4	7	2	3	5	52
Norris Creek	3	4	6	8	7	3	2	1	2	3	39
Bruces Bayou	2	3	2	6	4	2	5	4	2	2	32
Pigeon	4	1	1	2	1	9	1	8	1	1	29

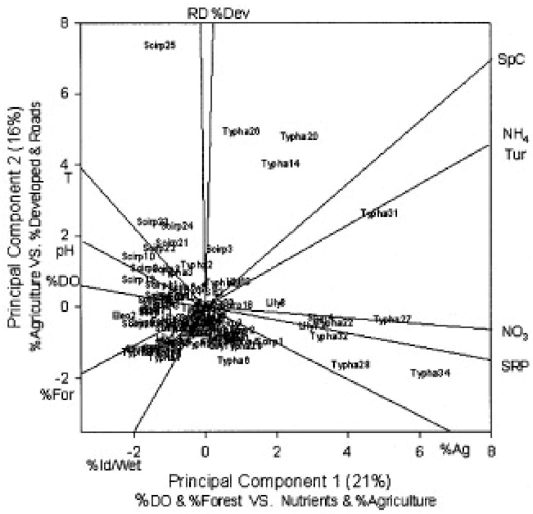

FIG. 2. Principal components analysis of 13 chemical/physical and land use (1-km buffer) parameters including specific conductance (SpC), ammonium-N (NH_4), turbidity (Tur), nitrate-N (NO_3), soluble reactive phosphorus (SRP), percent dissolved oxygen (%DO), pH, temperature (T), percent developed land (%Dev), percent agriculture (%Ag), percent idle lands and wetlands (%Id/Wet), percent forest (%For) and road density (RD) for 104 plant zones spanning all five Great Lakes sampled in 2002. Labels refer to vegetation type including* Typha *(Typha),* Scirpus *(Scirp),* Nuphar *and* Nymphaea *(Lily),* Zizania *(Ziz),* Sparganium *(Spar),* Pontederia/Sagittaria/Peltandra *(PSP) and* Eleocharis *(Eleo) with numbers referring to site location codes (available from the corresponding author as an appendix).

was established by the plant and/or abiotic data. This relationship suggested that not only were plants, fish communities, and the associated abiotic factors related, but also that they were somewhat predictable. Therefore, a fish-based IBI for the entire Great Lakes basin appeared to be feasible. From this point on, additional data analyses were performed after stratifying by plant zone.

Disturbance Gradient

The number of variables used to establish primary gradients varied with plant zone. For example, *Scirpus* was stratified into an outer wave-swept area and an inner protected area (e.g., Burton *et al.* 1999, Uzarski *et al.* 2004, Burton *et al.* 2004) and ranks of these data were averaged for the overall *Scirpus*-zone gradient. In the inner *Scirpus* zone, the median nitrate concentration was below our detection limit (0.01 mg l^{-1}) so nitrate could not be used in the gradient. Formulae used to calculate disturbance gradients for each plant zone can be found in Table 3 and the overall rank order of the sites can be found in Table 1a–c. The 20-km buffer proved important in showing that, for example, all Saginaw Bay sites tended to be more impacted than northern Lake Huron sites (large-scale differences in water quality), and the 1-km buffer was important in ordering sites within Saginaw Bay and the other regions.

Additional disturbance gradients were established using PCA for each plant zone. These were used to search for metrics that were not apparent from the primary gradients. Those variables that weighted the heaviest in PC1 of each analysis were identified and taken into consideration when searching for metrics. Those variables that weighted heaviest in PC1 for *Scirpus*, *Nuphar/Nymphaea*, and *Typha* were nitrate, chloride, and specific conductivity respectively.

IBI Development

Once it was revealed that plant zone was the major driving factor in establishing fish community composition, and the above analyses suggested that an IBI could be developed for all five Great Lakes, we stratified the entire dataset (including those taxa removed from iterations) and began to search for metrics. We were not assuming that the taxa that were eliminated in these iterations were not responding to vegetation, nutrients, and/or agriculture as the remaining taxa did. The taxa removed were simply masking gradients and community structure because they tended to school or were uncommon. Our sampling effort was not great enough to determine how schooling or rare taxa contribute to overall community composition because the tendency is to catch either large schools or rare taxa more by chance than by their true abundances with only three nets per plant zone.

Fish of 38, 39, and 30 taxa were identified in the *Scirpus*, *Typha*, and *Nuphar/Nymphaea-Pontederia/Sagittaria/Peltandra* zones, respectively. The *Nuphar/Nymphaea* and *Pontederia/Sagittaria/Peltandra* had to be combined post-hoc because sample size was simply too low for these communi-

TABLE 2. Fish species collected with fyke nets in coastal wetlands of the five Great Lakes in 2002. Fish species included in each iteration of the ordination analyses (42, 40, 34, 28 and 26-species analysis respectively) are indicated with "x". Functional feeding groups include: insectivore (INS), molluscivore (MOL), omnivore (OMN), piscivore (PISC), zoobenthivore (ZOB).

					Iteration of Ordination Analyses				
Species Name	Family Name	Common Name	Code	FFG	42-Sp	40-Sp	34-Sp	28-Sp	26-Sp
Labidesthes sicculus	Atherinidae	Brook silversides	BRS	INS	x	x	x	x	x
Catostomus commersoni	Catostomidae	White sucker	WHS	OMN	x	x	x	x	x
Ambloplites rupestris	Centrarchidae	Rock bass	ROB	PISC	x	x	x	x	x
Lepomis cyanellus	Centrarchidae	Green sunfish	GRS	INS	x	x	x	x	x
Lepomis gibbosus	Centrarchidae	Pumpkinseed	PUS	INS	x	x	x	x	x
Lepomis macrochirus	Centrarchidae	Bluegill	BLG	INS/PISC	x	x	x	x	x
Lepomis microlophus	Centrarchidae	Redear sunfish	RES	INS	x	x	x	x	x
Micropterus dolomieu	Centrarchidae	Smallmouth bass	SMB	PISC	x	x	x	x	x
Micropterus salmoides	Centrarchidae	Largemouth bass	LMB	PISC	x	x	x	x	x
Pomoxis nigromaculatus	Centrarchidae	Black crappie	BLC	INS/PISC	x	x	x	x	x
Cyprinella spiloptera	Cyprinidae	Spotfin shiner	SFS	ZOB	x	x	x	x	x
Cyprinus carpio	Cyprinidae	Common carp	COC	OMN	x	x	x	x	x
Notemigonus crysoleucas	Cyprinidae	Golden shiner	GOS	OMN	x	x	x	x	x
Notropis anogenus	Cyprinidae	Pugnose shiner	PNS	INS	x	x	x	x	x
Notropis heterodon	Cyprinidae	Blackchin shiner	BCS	OMN	x	x	x	x	x
Notropis hudsonius	Cyprinidae	Spottail shiner	STS	INS	x	x	x	x	x
Pimephales notatus	Cyprinidae	Bluntnose minnow	BNM	OMN	x	x	x	x	x
Pimephales promelas	Cyprinidae	Fathead minnow	FHM	OMN	x	x	x	x	x
Esox lucius	Esocidae	Northern pike	NOP	PISC	x	x	x	x	x
Fundulus diaphanus	Fundulidae	Banded killifish	BKF	INS	x	x	x	x	x
Ameiurus nebulosus	Ictaluridae	Brown bullhead	BRB	INS	x	x	x	x	x
Noturus gyrinus	Ictaluridae	Tadpole madtom	TPM	INS	x	x	x	x	x
Lepisosteus osseus	Lepisosteidae	Longnose gar	LNG	PISC	x	x	x	x	x
Perca flavescens	Percidae	Yellow perch	YEP	INS/PISC	x	x	x	x	x
Aplodinotus grunniens	Sciaenidae	Freshwater drum	FWD	INS/MOL	x	x	x	x	x
Umbra limi	Umbridae	Central mudminnow	CMM	INS	x	x	x	x	x
Amia calva	Amiidae	Bowfin	BOW	PISC	x				
Carpiodes cyprinus	Catostomidae	Quillback	QUB	OMN					
Moxostoma carinatum	Catostomidae	River redhorse	RIR	INS/MOL	x	x	x		
Moxostoma duquesnei	Catostomidae	Black redhorse	BRH	INS					
Pomoxis annularis	Centrarchidae	White crappie	WHC	INS/PISC	x	x	x		
Alosa pseudoharengus	Clupeidae	Alewife	ALE	OMN	x	x	x	x	
Dorosoma cepedianum	Clupeidae	Gizzard shad	GIZ	OMN	x	x			
Luxilus cornutus	Cyprinidae	Common shiner	COS	INS	x	x			
Macrhybopsis storeriana	Cyprinidae	Silver chub	SIC	INS					
Nocomis biguttatus	Cyprinidae	Hornyhead chub	HHC	INS					
Notropis atherinoides	Cyprinidae	Emerald shiner	EMS	INS	x	x			
Notropis heterolepis	Cyprinidae	Blacknose shiner	BNS	INS	x	x			
Semotilus atromaculatus	Cyprinidae	Creek chub	CRC	INS					
Esox americanus vermiculatus	Esocidae	Grass pickerel	GRP	PISC	x	x	x		
Lota lota	Gadidae	Burbot	BUR	PISC					
Gasterosteus aculeatus	Gasterosteidae	Threespine stickleback	TSS	INS					
Pungitius pungitius	Gasterosteidae	Ninespine stickleback	NSS	INS	x	x			
Neogobius melanostomus	Gobiidae	Round goby	ROG	OMN	x	x	x		
Ameiurus melas	Ictaluridae	Black bullhead	BLB	INS	x				
Ameiurus natalis	Ictaluridae	Yellow bullhead	YEB	INS/PISC					
Ictalurus punctatus	Ictaluridae	Channel catfish	CHC	INS/PISC	x	x			
Morone americana	Moronidae	White perch	WHP	PISC	x	x	x		
Etheostoma exile	Percidae	Iowa darter	IOD	INS					
Etheostoma nigrum	Percidae	Johnny darter	JOD	INS	x	x	x	x	
Percina caprodes	Percidae	Logperch	LOP	INS					

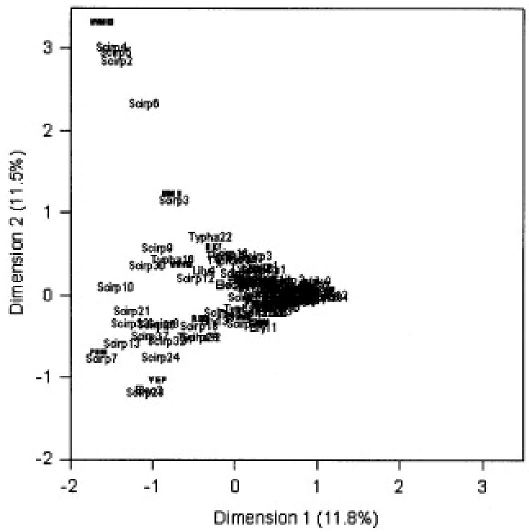

***FIG. 3.** Correspondence analysis of 26 fish species in 104 plant zones in coastal wetlands of the five Great Lakes sampled in 2002. Site labels refer to vegetation type including:* **Typha** *(Typha),* **Scirpus** *(Scirp),* **Nuphar** *and* **Nymphaea** *(Lily),* **Zizania** *(Ziz),* **Sparganium** *(Spar),* **Pontederia/ Sagittaria/Peltandra** *(PSP) and* **Eleocharis** *(Eleo) with numbers referring to site location codes (available from the corresponding author as an appendix). Fish codes are defined in Table 2.*

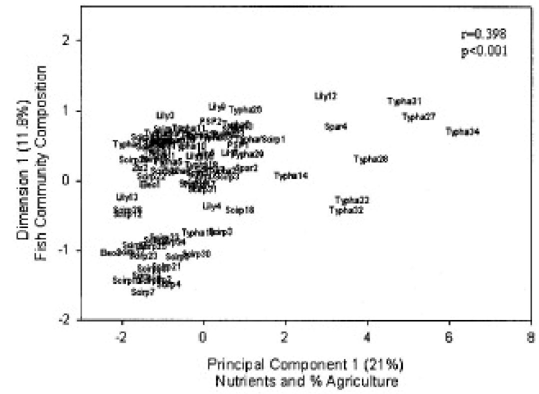

***FIG. 4.** Correlation between abiotic factors (combined in principle components analysis), and fish communities (represented by correspondence analysis), for 104 vegetation zones sampled during the summer of 2002. Labels refer to vegetation type including:* **Typha** *(Typha),* **Scirpus** *(Scirp),* **Nuphar** *and* **Nymphaea** *(Lily),* **Zizania** *(Ziz),* **Sparganium** *(Spar),* **Pontederia/Sagittaria/ Peltandra** *(PSP) and* **Eleocharis** *(Eleo) with numbers referring to site location codes (available from the corresponding author as an appendix).*

ties and the CA showed very similar fish communities in these two vegetation zones. Community attributes and indicator species were evaluated based on their ability to order sites according to anthropogenic disturbance. Additionally, 41 published metrics were also evaluated (Wilcox *et al.* 2002, Minns *et al.* 1994, and Simon 1998). Correlation and graphical interpretation yielded 14, 11, and 2 metrics for *Scirpus, Typha,* and *Nuphar/Nymphaea-Pontederia/Sagittaria/Peltandra,* respectively. Metric scores were established by searching for natural breaks in the metric values.

Fish data are inherently variable. In an attempt to remove some of this variability from the IBI, we eliminated data for plant zones when fewer fishes than a mean of at least 10 per net per plant zone had been caught before applying the IBI. Of the 22 *Scirpus*, 29 *Typha*, and 12 *Nuphar/Nymphaea- Pontederia/Sagittaria/Peltandra* sites fished, 5, 11, and 8, respectively, were excluded because of insufficient catches. We did not feel that these catches accurately reflected a "typical catch" for these sites (we recommend that if the user feels that he/she collected an atypical sample for a given site, the site is fished for an additional night). After removing sites with insufficient data, metric scores correlated with disturbance rankings at r = 0.891 for *Scirpus* and r = 0.824 for *Typha* (Fig. 5). Table 4 contains the final set of IBI metrics for *Scirpus* and *Typha* zones. No significant correlation was found between the disturbance ranking for the *Nuphar/Nymphaea* or *Pontederia/Sagittaria/Peltandra* sites and their respective candidate IBI metric scores. Therefore, no metrics could be developed for *Nuphar/Nymphaea* or *Pontederia/Sagittaria/Peltandra* either separately or together.

DISCUSSION

Principal Components Analysis

Uzarski *et al.* (2004) used a similar approach to examine invertebrate responses to human influences. They also used multivariate analyses to doc-

TABLE 3. Parameters used to establish anthropogenic disturbance gradients for four vegetation zones in coastal wetlands of the five Great Lakes using land use/cover and water quality data collected in 2002. Disturbance gradients were determined using the sum of the ranks of the parameters identified with "x" for each vegetation type. Principal component 1 represents increasing urbanization and agriculture from a principal components analysis combining 13 chemical/physical and land use/cover variables for* Typha *sites.

	Vegetation Zones			
Parameters	Outer *Scirpus*	Inner *Scirpus*	*Typha*	Lily
Land Use—20-km or watershed				
% Developed	x	x		x
% Agriculture	x	x		x
% Forest^{-1}	x	x		x
% Wetland & Meadow^{-1}	x	x		x
Land Use—1-km				
% Developed	x	x	x	
% Agriculture	x	x	x	
% Forest^{-1}	x	x	x	
% Wetland & Meadow^{-1}	x	x	x	
Water Quality				
Specific conductance	x	x	x	x
|pH - median pH|	x	x		
Turbidity	x	x	x	x
NO_3-N			x	x
|NO_3-N—median NO_3-N|	x			
NH_4-N				x
SRP-P				x
Cl	x	x		x
% DO—median % DO|	x	x		
PC1			x	

ument relationships between chemical/physical and land use/cover variables and related these to invertebrate attributes. Both King and Brazner (1999) and Uzarski *et al.* (2004) stressed that relationships between adjacent land use/cover and the chemical/physical conditions within the wetland are strictly correlative and cannot be used to infer causation. For example, Uzarski *et al.* (2004) data seemed to suggest that urban areas contribute more nitrate-N and ammonium-N to wetlands than do agricultural areas, since water in wetlands with adjacent urban land use tended to contain more nitrate-N and ammonium-N than did water in wetlands with adjacent agricultural land use. They explained that increased inorganic nitrogen in the urban wetlands might not be processed as efficiently as it is in agricultural wetlands. Therefore, no conclusion about quantity of input from the adjacent area was warranted (Jude *et al.* 2005). They simply tended to find relatively higher nitrate-N and ammonium-N concentrations in wetlands near urban areas where there was relatively higher runoff from the upland and lower productivity in the wetland itself. It does not necessarily suggest that a given land use/cover taken alone would create the associated chemical/physical conditions in the wetland. Our PCA suggested that agriculture was associated with higher nutrients in wetlands. However, this relationship was driven by seven of the 61 sites having extremely high nutrient concentrations as well as adjacent agriculture. Many sites with a high percentage of land use in agriculture actually had non-detectable dissolved nutrients in the water column. This may have been because these systems tend to have higher productivity and efficiently store excess nutrients in biomass. If sites with extremely high nutrients were removed from the analyses, results would have shown: 1) that agricultural sites either had very high or very low nutrient concentrations as was found for invertebrate populations (Uzarski *et al.* 2004), and 2) that relatively pristine sites had moderate nutrient concentrations.

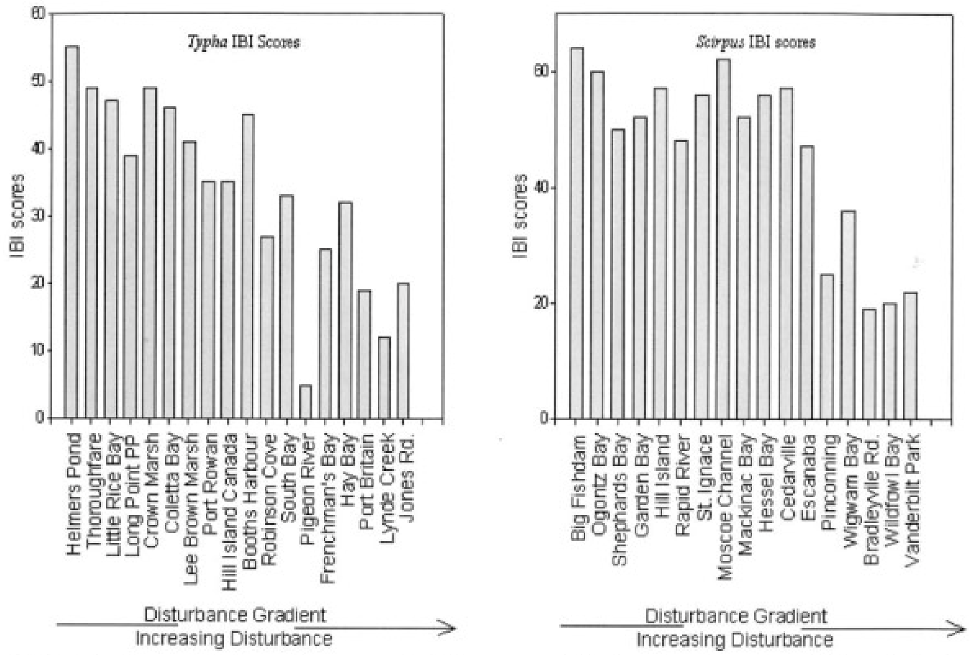

FIG. 5. Sum of IBI metric scores for* Scirpus *and* Typha *sites based on fish collected with fyke nets in 61 Great Lakes coastal wetlands in 2002. Sites are ordered by increasing disturbance. See Table 4 for IBI metrics.

Uzarski *et al.* (2004) sampled many of the same sites included in these analyses. They found an association between nutrients and urbanization because their (and our) most pristine sites had a relatively high concentration of cabins adjacent to the systems producing a relatively high "urbanization" component to the 1-km buffers around the sites. However, by using an additional buffer of 20-km it became apparent that most of the watershed was intact forest. These sites rarely had either non-detectable or very high nutrient concentrations (unpublished data from 1996 through 2003). This is likely the reason for a long struggle with using chemical/physical and land use/cover variables to detect moderate disturbance in biotic populations in wetlands. We believe that an approach similar to our method of establishing disturbance gradients may be a valuable tool for detection.

Correspondence Analysis

Rare or schooling fish taxa increased the variability in the data set and were often captured by chance alone. For example, schools of black bullhead and bowfin were observed at nearly every site sampled yet schools of these taxa were only caught at a few sites. When these taxa overwhelmed the first iteration of analyses, they had to be removed and the entire process was repeated. These data were not discarded from the study, but only from the exploratory analysis. There has been much debate in the literature regarding how to handle rare taxa. Studies involving fishes meet similar challenges when dealing with taxa that tend to school. The tendency is to occasionally capture rare taxa and to either catch many or no schooling taxa. When determining the importance in community composition of such taxa, studies will have to involve an enormous amount of sampling effort and this will likely be at the expense of the number of sites that can be visited. Our analysis suggests that, at least for the cosmopolitan taxa of the Great Lakes, plant zone or habitat structure was the major driving factor in shaping the community and we have no reason to believe that the same is not true for those rare or schooling taxa. However, our sampling effort was not great enough to establish such a relationship.

TABLE 4. Preliminary fish-based index of biotic integrity metrics for Great Lakes coastal wetlands derived from data collected in 2002. Scoring is to be conducted from mean values per net-night in* Scirpus *and* Typha *zones when a mean of at least 10 fish are captured per net per vegetation zone. If less than 10 are captured or a sample is suspected to be atypical, an additional net-night is recommended.

***Scirpus* Zone:**			
1. Mean catch per net-night:			
< 10 score = 0	10–30 score = 3	> 30 score = 5	
2. Total richness:			
< 5 score = 0	5 to < 10 score = 3	10 to 14 score = 5	> 14 score = 7
3. Percent non-native richness:			
> 12% score = 0	7 to 12% score = 3	< 7% score = 5	
4. Percent omnivore abundance:			
> 70% score = 0	50 to 70% score = 3	< 50% score = 5	
5. Percent piscivore richness:			
< 15% score = 0	15 to 25% score = 3	> 25% score = 5	
6. Percent insectivore abundance:			
< 20% score = 0	20–30% score = 3	> 30% score = 5	
7. Percent insectivorous Cyprinidae abundance:			
< 1% score = 0	1–2% score = 3	> 2% score = 5	
8. Percent carnivore (insectivore+piscivore+zooplanktivore) richness:			
< 60% score = 0	60–70% score = 3	> 70% score = 5	
9. White sucker (*Catostomus commersoni*) mean abundance per net-night:			
0 score = 0	> 0 to 0.4 score = 3	> 0.4 score = 5	
10. Black bullhead (*Ictalurus melas*) mean catch per net-night:			
0 score = 0	> 0 to 3 score = 3	> 3 score = 5	
11. Rock bass (*Ambloplites rupestris*) mean catch per net-night:			
0 score = 0	> 0 to 4 score = 3	> 4 score = 5	
12. Alewife (*Alosa psuedoharengus*) mean catch per net-night:			
> 11 score = 0	1 to 11 score = 3	< 1 score = 5	
13. Smallmouth bass (*Micropterus dolomieu*) mean catch per net-night:			
0 score = 0	> 0 to 5 score = 3	> 5 score = 5	
14. Pugnose shiner (*Notropis anogenus*) mean catch per net-night:			
0 score = 0	> 0 to 5 score = 3	> 5 score = 5	
***Typha* Zone:**			
1. Percent insectivore catch:			
< 40% Score = 0	40 to 80% score = 3	> 80% score = 5	
2. Insectivorous Cyprinidae richness:			
0 to 1 Score = 0	> 1 to 3 score = 3	> 3 score = 5	
3. Percent Centrarchidae abundance:			
0–30 score = 0	> 30 to 60 score = 3	> 60 to 80 score 5	> 80 score = 7
4. Centrarchidae richness:			
0 to 1 score = 0	> 1 to 3 score = 3	> 3 score = 5	
5. Mean Shannon Diversity Index:			
< 0.2 score = 0	0.2 to 0.7 score = 3	> 0.7 score = 5	
6. Mean evenness:			
< 0.2 score = 0	0.2 to 0.6 score = 3	> 0.6 score = 5	
7. Longnose gar (*Lepisosteus osseus*) catch per net-night:			
0 score = 0	> 0 to 0.5 score = 3	> 0.5 to 2 score = 5	> 2 score = 7
8. Largemouth bass (*Micropterus salmoides*) abundance per net-night:			
0 to 2 score = 0	> 2 to 30 score = 3	> 30 score = 5	
9. Rock Bass (*Ambloplites rupestris*) catch per net-night:			
0 to 1 score = 0	> 1 to 5 score = 3	> 5 score = 5	
10. Bluegill (*Lepomis macrochirus*) abundance per net-night:			
0 to 3 score = 0	> 3 to 20 score = 3	> 20 to 30 score = 5	> 30 score = 7
11. *Lepomis* catch per net-night:			
0 to 5 score = 0	> 5 to 20 score = 3	> 20 to 50 = 5	> 50 score = 7

Correlation between Abiotic and Biotic Data

Plant zones were ordered consistently in PC1 and CA1 suggesting that nutrients and the percent adjacent land use in agriculture were important in determining the plant zone found in the wetland. Fish community composition shifted with, and even within, plant zone with increasing nutrients and agriculture. However, it is also important to note that both the plant and abiotic data may also be correlated with parameters that we did not measure. These parameters include, but are not limited to, fetch and/or pelagic mixing and the accumulation of organic sediment. The order of the vegetation seems to represent an organic sediment gradient from *Scirpus* with the least amount to *Typha* with the most. Numerous studies have shown that macroinvertebrate communities also differ among plant zones (Burton *et al.* 1999, Burton *et al.* 2002, Burton *et al.* 2004, Uzarski *et al.* 2004). Fish community composition may be following a similar pattern based on food availability.

Disturbance Gradient

Turbidity, specific conductance, and chloride were ranked directly, with greater values indicating disturbance. Extreme values, either very high or very low, for nitrate-N, ammonium-N, and soluble reactive phosphorus concentrations, as well as percent saturation of dissolved oxygen and pH were considered indicators of disturbance. With respect to inorganic dissolved nutrients, we tended to find moderate concentrations at relatively pristine sites. Impacted sites often have either non-detectable values, because these systems are very productive and the nutrients are tied-up in organic matter and sediments, or nutrient concentrations that are so high that the communities do not assimilate them as quickly as they enter the system. Also, in a system experiencing cultural eutrophication, dissolved oxygen may be as high as 180% saturated during the day when we sample. In this case, percent saturation likely plummets at night when only respiration is taking place in the absence of photosynthesis. Likewise, a system with organic pollutants may have very low percent saturation (e.g., 50%) of dissolved oxygen due to decomposition of excess organic matter in the absence of photosynthesis. This can be caused by siltation, cloud cover, coverage of duckweed (*Lemna* or *Spirodela* spp.), and/or turbidity. Our pH measurements follow this relationship to some degree; a very high daytime pH may be indicative of extreme productivity, while very low daytime pH may be indicative of organic pollution.

Land use/cover data were analyzed at two scales and both were incorporated into the final disturbance gradient for a subset of our sites. The larger scale (20-km buffers) was used to represent the impacts to the nearshore region or the water source of the wetland and was double weighted. A finer scale (1-km buffer) was used to relate impacts much more locally and received a single weighting. The need for two scales was realized because the Saginaw Bay region represents the majority of agriculture in Michigan yet many areas around the bay have a relatively large forested area adjacent to the wetlands. This forested area undoubtedly intercepts excess nutrients that would have entered the wetland from the agricultural areas directly. However, impacts to the systems are coming through drainage ditches acting as conduits of pollution into the bay. These ditches, as well as the Saginaw River, often have extremely high nutrient loads, sometimes in excess of 40 mg L^{-1} nitrate-N (personal observation). When we determined land use for a 1-km buffer, land use for several of these sites was ~ 80% forested, yet when we determined land use for 20-km buffers, the same sites were ~ 80% agriculture. We felt it was appropriate to double weight the 20-km land-use buffer in the disturbance gradient because it better reflected the overall impacts of the adjacent landscape on the general water quality of the nearshore area. The nearshore water in turn inundated fringing wetlands.

IBI Development

Others have suggested that the IBI approach would not work for coastal wetlands because natural water level fluctuations of the Great Lakes would likely alter communities and invalidate metrics (Wilcox *et al.* 2002). By sampling only defined and inundated vegetation zones, Burton *et al.* (1999) and Uzarski *et al.* (2004) were able to remove enough variation associated with water level fluctuation to maintain metric consistency from year to year, even though annual average lake levels increased to above average and then fell 1.08 m to near historic lows over the several-year period included in those studies. Since our analyses were stratified by plant zone, it seems unlikely that changes in water levels will invalidate the IBI. As plant communities shift in location or change all together, fish communities associated with specific zones should seek preferred structure. In some years, a few wetlands may dry out completely. During these times, a fish-based IBI could only be applied to wetlands with at least one inundated plant zone present but could still be used to assess overall water quality changes in a given Great Lake or region of one of the Great Lakes using data from such wetlands.

Unfortunately, we were only able to develop metrics for two plant zones. While at least one of these zones can likely be found in most Great Lakes coastal wetlands, some will certainly lack both. In that case, this IBI will not apply. However, by maximizing the number of available protocols, we are increasing the likelihood that one will be applicable. Furthermore, using several IBIs utilizing different organisms at a given site should prove most robust and we recommend doing so whenever possible.

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REFERENCES

Albert, D.A., Ingram, J.W., Thompson, T.A., and Wilcox, D.A. 2003. Great Lakes Coastal Wetland Classification. *http://www.glc.org/wetlands/pdf/wetlands-class_rev1.pdf*

APHA. 1992. *Standard Methods for the Evaluation of Water and Wastewater.* 20th edition. Washington, DC: American Public Health Association.

Brazner, J.C. 1997. Regional, habitat, and human development influences on coastal wetland and beach fish assemblages in Green Bay, Lake Michigan. *J. Great Lakes Res.* 23:36–51.

_____, and Beals, E.W. 1997. Patterns in fish assemblages from coastal wetland and beach habitats in Green Bay, Lake Michigan: a multivariate analysis of abiotic and biotic forcing factors. *Can. J. Fish. Aquat. Sci.* 54 (8):1743–1761.

Burton, T.M., Uzarski, D.G., Gathman, J.P., Genet, J.A., Keas, B.E., and Stricker, C.A. 1999. Development of a preliminary invertebrate index of biotic integrity for Lake Huron coastal wetlands. *Wetlands* 19:869–882.

_____, Stricker, C.A., and Uzarski, D.G. 2002. Effects of plant community composition and exposure to wave action on invertebrate habitat use of Lake Huron coastal wetlands. *Lakes Reserv. Res. Manage.* 7:255–269.

_____, Uzarski, D.G., and Genet, J.A. 2004. Invertebrate habitat use in relation to fetch and plant zonation in northern Lake Huron coastal wetlands. *Aquat. Ecosyst. Health Manage.* 7(2):249–267.

Cardinale, B.J., Burton, T.M., and Brady, V.J. 1997. The community dynamics of epiphytic midge larvae across the pelagic-littoral interface: Do animals respond to changes in the abiotic environment? *Can. J. Fish. Aquat. Sci.* 54(10):2314–2322.

_____, Brady, V.J., and Burton, T.M. 1998. Changes in the abundance and diversity of coastal wetland fauna from the open water/macrophyte edge towards shore. *Wetlands Ecol. Manage.* 6(1):59–68.

Gathman, J.P., Burton, T.M., and Armitage, B.J. 1999. Distribution of invertebrate communities in response to environmental variation. In *Invertebrates in Freshwater Wetlands of North America: Ecology and Management,* eds. D.P. Batzer, R.B. Rader, and S.A. Wissinger, pp. 949–1013. New York: John Wiley & Sons, Inc.

Jude, D.J., and Pappas, J. 1992. Fish utilization of Great Lakes wetlands. *J. Great Lakes Res.* 18:651–672.

_____, Albert, D., Uzarski, D.G., and Brazner, J. 2005. Lake Michigan's Coastal Wetlands: Distribution, Biological Components and Threats. In *The State of Lake Michigan*, eds. M. Munawar and T. Edsall. Ecovision World Monograph Series, S.P.B. Academic Publishing, the Netherlands.

Kashian, D.R., and Burton, T.M. 2000. A comparison of macroinvertebrates of two Great Lakes coastal wetland: Testing potential metrics for an index of ecological integrity. *J. Great Lakes Res.* 26:460–481.

Keough, J.R., Thompson, T.A., Guntenspergen, G.R., and Wilcox, D.A. 1999. Hydrogeomorphic factors and ecosystem responses in coastal wetlands of the Great Lakes. *Wetlands* 19:821–834.

King, R.S., and Brazner, J.C. 1999. Coastal wetland insect communities along a trophic gradient in Green Bay, Lake Michigan. *Wetlands* 19 (2):426–437.

Krieger, K.A. 1992. The ecology of invertebrates in Great Lakes coastal wetlands: Current knowledge and research needs. *J. Great Lakes Res.* 18:634–650.

_____, Klarer, D.M., Heath, R.T., and Herdendorf, C.E. 1992. Coastal wetlands of the Laurentian Great Lakes: current knowledge and research needs. *J. Great Lakes Res.* 18:525–528.

Minns, C.K., Cairns, V.W., Randall, R.G., and Moore, J.E. 1994. An index of biotic integrity (IBI) for fish