State of the Lakes Ecosystem Conference 2008

Background Paper

Nearshore Areas of the Great Lakes 2009

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1.0 Introduction

Notice to Readers

This background paper is intended to provide a concise overview of the status of the nearshore conditions in the Great Lakes. The information presented by the authors was selected as representative of the much greater volume of data, and therefore does not include all research or monitoring information available. The chapters were prepared with input from many individuals representing diverse sectors of the Great Lakes community.

The intent of this paper was to provide the basis for discussions at SOLEC 2008. Participants were encouraged to provide additional specific information and references for use in preparing the final, post-conference version of the paper. Together with the information provided by SOLEC discussants, the paper is part of the 2009 State of the Great Lakes reports. These reports provide key information required by managers to make informed environmental decisions.

The Nearshore Areas of the Great Lakes

The theme for SOLEC 2008 was "The Nearshore." In 1996, SOLEC focused on the nearshore lands and waters of the Great Lakes where biological productivity is greatest and where humans have maximum impact. In 2008, the conference concentrated on what has changed with respect to the nearshore environments since 1996. Additional conditions and issues not evaluated in 1996 were also addressed.

Several Great Lakes indicators were identified for the SOLEC grouping "Coastal Zones," but only a few were reported. To enhance the discussions by participants at SOLEC 2008, a more comprehensive summary about the current environmental conditions in the nearshore area was desired. This background paper on the current status of nearshore areas of the Great Lakes, authored by Great Lakes expert researchers and managers, strives to provide this summary.

For SOLEC 1996, four background papers about the nearshore zones were prepared: *Impacts of Changing Land Use* (Thorp *et al.* 1997); *The Land by the Lakes: Nearshore Terrestrial Ecosystems* (Reid and Holland 1997); *Coastal Wetlands* (Maynard and Wilcox 1997); and *Nearshore Waters of the Great Lakes* (Edsall and Charlton 1997). They are summarized in the document "*State of the Lakes Ecosystem Conference 1996: Highlights of Background Papers*," available at www.epa.gov/glnpo/solec/solec_1996.

For SOLEC 2008, the chapters in this background paper focus on the question, "What has changed since 1996?" Assessments of current environmental conditions or issues that were not evaluated in 1996 are also included. Each chapter was intended to include:

- an assessment of the State of the Ecosystem, which describes the status (good, fair, poor, or mixed) and trends (improving, deteriorating, or unchanging) of the ecosystem component in question, presented lake-by-lake, if appropriate.
- a discussion of current and future pressures that could be expected on the nearshore environment.
- suggested management implications to mitigate the pressures.

For this paper, "nearshore" is defined as beginning at the shoreline or the lakeward edge of the coastal wetlands and extending offshore to the deepest lakebed depth contour where the thermocline typically intersects with the lakebed in late summer or early fall (Edsall and Charlton 1997, Fig. 1). It should be noted that other definitions of the nearshore exist. For example, Mackey 2009a defines *nearshore zones* as areas encompassed by water depths generally less than 15 m. Mackey 2009b further defines the *nearshore* as "including higher energy *coastal margin* areas and lower energy *nearshore open-water* areas." *Coastal margin* areas are located between ordinary high water (OHW) and the 3-m isobath, where the shoreward limit is defined by the intersection of the OHW with a beach, bluff, revetment, seawall, or other shoreline feature (Mackey 2008b). Substrates are generally coarser-grained than those found in deeper water and may be highly mobile in response to

Figure 1. Nearshore waters of the Great Lakes.
Source: Adapted from Edsall and Charlton (1997).

wave-driven littoral processes. *Nearshore open-water* areas are located between the 3-m isobath lakeward to the 15-m isobath (Mackey 2008b). This area is dominated by processes more characteristic of the open-lake, but are also subject to higher wave energies and associated littoral or nearshore processes during major storm events. Substrates are generally finer-grained, but may be reworked during storm events. These nearshore subdivisions are based on the concept that habitat zones can be defined, in part, by the dominant physical processes that act within those zones, with boundaries constrained by existing limnological and biological datasets (Johnson *et al.* 2007).

Progress from 1996-2008

In 1996, the authors of the *Nearshore Waters* paper commented that among the most destructive human activities for the nearshore waters has been the introduction of exotic species. In 1996, there were ~166 documented invasions of non-indigenous aquatic species in the Great Lakes since the early 1800s. In 2008, at least 184 invasions were reported. Although nutrient loadings to the Great Lakes have been reduced in the past 30 years, many physical, chemical and biological changes to the nearshore environment remain. The current authors also discuss emerging issues that affect the nearshore environment: botulism, harmful algae blooms, viral hemorrhagic septicemia (VHS), and shoreline development, among other stressors. VHS, a deadly fish virus and an invasive species that is threatening Great Lakes fish, is not constrained to nearshore environments, but it does affect nearshore fish populations, and human activity could be a factor in its spread.

The authors of 1996 *Nearshore Terrestrial-Land by the Lakes* paper concluded that the most pressing need for this ecosystem component was a conservation strategy that would protect ecologically significant ecosystems within 19 geographic "biodiversity investment areas." In 2006, The Nature Conservancy Great Lakes Program and the Nature Conservancy of Canada Ontario Region released the Binational Conservation Blueprint for the Great Lakes. The Blueprint identified 501 areas across the Great Lakes that are a priority for biodiversity conservation for their exceptionally unique and diverse species, communities and physical features.

The main finding of the 1996 *Impacts of Changing Land Use* paper was that development of farm and natural lands in both urban and rural areas presented the single largest threat to the Great Lakes basin ecosystem. Indeed, the current author of the *Impacts of Land Use Change on the Nearshore* chapter noted that the continued rapid expansion and growth of urban and suburban areas and associated infrastructure is the single most significant land use/land cover change (~60%) within the U.S. portion of the Great Lakes basin over the last decade. Much of the newly developed land was converted from agricultural or early successional vegetation lands. Moreover, in the Chicago area, changes in urban and suburban land use between 1992 and 2001 (19%) far exceeded those predicted based on population growth (2.2%). The role that higher crop prices (driven by investments in biofuel production) may play in the decline in the loss of agricultural lands is also explored.

The authors of the 1996 Coastal Wetlands of the Great Lakes paper acknowledged that although the more than 216,000 hectares (534,000 acres) of Great Lakes coastal wetlands are a considerable ecological, biological, economic and aesthetic resource, there were not enough detailed and comprehensive data about the coastal wetlands to report confidently on their current conditions and trends in viability, health, or success of current protection and restoration efforts. They suggested the development of coastal wetland indicators in the following categories: physical and chemical, individual and population level, wetland community, landscape, and social and economic. They also suggested the following management challenges:

- "There is no comprehensive inventory and evaluation of Great Lakes coastal or even inland wetlands."
- In the U.S., "Individual states have also completed wetland inventories and evaluations, however methodologies are not consistent and the level of detail and amount of field-based data varies."
- "Work has been initiated to develop indicators for wetland degradation and to choose monitoring sites and appropriate monitoring strategies. However, there is no international consensus on these matters."

In 2000, the U.S. Environmental Protection Agency (U.S. EPA). Great Lakes National Program Office (GLNPO) funded the creation of the Great Lakes Coastal Wetlands Consortium to expand the coastal wetland monitoring and reporting capabilities of the U.S. and Canada under the Great Lakes Water Quality Agreement. The purpose of the Consortium was to design a long term, binational coastal wetland monitoring program. Indicators suggested through the SOLEC process were evaluated and protocols tested. In early 2008, a final report detailed indicators, protocols for monitoring, and costs. Major accomplishments include:

- A map of the more than 216,000 hectares (534,000 acres) of known coastal wetlands
- A new classification system consisting of three major categories: lacustrine, riverine, and barrier-protected that was then applied to the mapped coastal wetlands
- Field-tested sampling protocols
- A statistical sampling design
- A database that will house future data

These and other improvements in assessing coastal wetlands from 1996 to the present day are detailed in this report in the chapter *Great Lakes Coastal Wetland Ecosystem*.

Acknowledgments
Authors:
Elizabeth K. Hinchey, Illinois-Indiana Sea Grant liaison to the U.S. EPA GLNPO, hinchey.elizabeth@epa.gov
Rita Cestaric, Program Analyst, U.S. EPA GLNPO, cestaric.rita@epa.gov

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2.0 Impacts of Land Use Change on the Nearshore

Introduction

As termed in the SOLEC 1996 background paper on Nearshore Waters of the Great Lakes, development is defined as "human use of land connected with industrial, residential, agricultural, and transportation activities that substantially alters the natural landscape or affects the ecosystem." Virtually the entire Great Lakes basin has been altered or impacted by anthropogenic activities due to development, and these changes have both directly and indirectly impacted the nearshore areas of the Great Lakes. Significant anthropogenic changes began more than 150 years ago as the Great Lakes basin was settled and natural areas (forests, prairie, and wetlands) were converted to agricultural and urban use. Many of these changes continue today. The focus of this background paper is explore how continuing changes in the land use and land cover may directly or indirectly impact nearshore zones of the Great Lakes.

Environmental Zone	Low Energy Area	High Energy Area
Coastal Margin OHW – 3 m Isobath	Embayments, tributary mouths, coastal wetland habitats	Open Coasts, island fringes
Nearshore Open Water 3 m – 15 m Isobath	Open water area – water depths greater than 10 m	Open water area – water depths less than 10 m, shallow reef complexes
	Limited Exposure Short Fetch Distance Fine-grained, soft substrates	*Open Exposure Long Fetch Distance Coarse-grained, hard substrates, bedrock*

Table 1. Hydrogeomorphic Characteristics and Dominant Physical Processes.
Nearshore environmental zones are defined by water depth, hydrogeomorphic characteristics, and dominant physical processes.
Source: Courtesy of Habitat Solutions NA.

The Nearshore

For the purposes of this discussion, the "nearshore" includes higher energy *coastal margin* areas and lower energy *nearshore open-water* areas (Table 1). *Coastal margin* areas are located between ordinary high water (OHW) and the 3-m isobath, where the shoreward limit is defined by the intersection of the OHW with a beach, bluff, revetment, seawall, or other shoreline feature. Substrates are generally coarser-grained than those found in deeper water and may be highly mobile in response to wave-driven littoral processes. *Nearshore* open-water areas are located between the 3-m isobath lakeward to the 15-m isobath. These areas are dominated by processes more characteristic of the open-lake, but would also be subject to higher wave energies and associated littoral or nearshore processes during major storm events. Substrates are generally finer-grained, but may be reworked during storm events. These subdivisions of the nearshore are based on the concept that habitat zones can be defined, in part, by the dominant physical processes that act within those zones with boundaries that are also defined (and constrained) by existing limnological and biological datasets (Johnson *et al*. 2007).

Landscapes and Watersheds

The linkages that relate land use change to the nearshore are controlled by physical characteristics of the basin and the processes that move water across (and through) basin landscapes into the Great Lakes. Unlike watersheds, which are usually delineated by surface-water hydrology, *landscapes* are defined by and include the integrated components of land and water area (i.e. geology, geomorphology, and land cover) upon which natural processes act within the Great Lakes basin (Mackey 2005). Watersheds are a subset of landscapes and are defined (and limited) by the area that collects surface waters that feed a main stream and associated tributaries. Even though landscapes are typically considered to represent areas of regional extent, the term is applicable to multiple scales. Definitions of the integrated components of land and water area include (Mackey 2005):

- *Geology* – surface and subsurface distribution of geologic materials; soils; hydrophysical characteristics (e.g., permeability, porosity, aquifers, aquatards).
- *Geomorphology* – shape, pattern, distribution, and physical features of the land surface; landforms and drainage pattern (topography, slope, hydrography, channel morphology and bathymetry, connectivity and pattern).
- *Land Cover* – shape, pattern, and distribution of biological and anthropogenic features on the land surface; land use.

Connecting Landscapes to the Nearshore Zone

The impacts of changes in land use/land cover are both direct and indirect. For example, nearshore impacts include fragmentation and destruction of terrestrial and aquatic habitat; loss of native plant communities and wildlife; altered flow regimes caused by water withdrawals, diversions, channelization, and/or redirection of waste and stormwater flows; increased runoff and reduced groundwater recharge due to "hardening" of the landscape; point, non-point, point, bacterial, nutrient, and atmospheric contaminant and pollution discharges; and altered thermal regimes due to power production, channelization, and altered flow regimes (dams and reservoirs). All of these stressors affect the ecosystem both directly and indirectly and at multiple scales.

Two projects were recently completed that address the affects of changes in land use/land cover and impacts of those changes on the Great Lakes ecosystem. The U.S. EPA-funded Great Lakes Environmental Indicators (GLEI) project developed a suite of indicators to describe the stressors and stressor gradients acting within the basin at multiple scales. These indicators were developed using multivariate analyses to assess the response of biological communities to changes in 207 individual bio-physical stress variables identified in the basin (Niemi *et al*. 2006). Based on these analyses, an overall Stress Index can be quantified for individual watersheds within the U.S. Great Lakes portion of the basin (Danz *et al*. 2007, Fig. 1).

What is *not* well understood are how changes in land use/land cover that occur many kilometers inland from the Great Lakes impact the nearshore zones of the Great Lakes. **Landscapes and watersheds are connected to the Great Lakes via hydrology, i.e. surface and groundwater flows into the Great Lakes via rivers and streams.** Hydrologic impairments alter natural flow regimes and contribute to water quality degradation by increasing surface runoff, sediment and contaminant loads, and affects how biological communities utilize energy and materials as water moves through the system. For example, there is a time-distance relationship between water and the benefits that water provides to the ecosystem. The time that water stays within the system is a function of flow velocity, direction and distance traveled, and pathways and connections within, or on, the landscape. Constrained by existing impairments, the ecological value of a gallon (or litre) of water varies as a function of its location and residence time on, or within, the landscape. This time-distance dependency for riverine systems is clearly demonstrated by the work by Poff *et al*. (1997) and subsequent work by Richter *et al*. (1998), Richter and Richter (2000), Baron *et al*. (2003), and others.

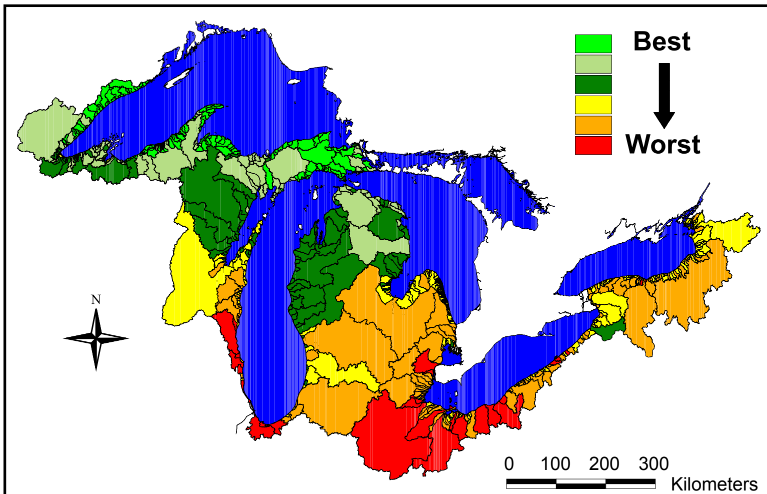


Figure 1. The overall Stress Index derived from 207 individual stress variables for the U.S. portion of the Great Lakes basin by the Great Lakes Environmental Indicators project.
Source: Modified from Niemi *et al.* (2008).

A Great Lakes Protection Fund-funded project designed to identify and value hydrologic restoration opportunities at watershed and subwatershed scales explored ways to assess how ecological benefits of water are related to the pathways that water takes across, or through, the landscape (Apfelbaum *et al*. 2007). A set of geospatial analysis tools was developed to link changes in land use/land cover to hydrologic alteration and impairments in Great Lakes watersheds. These analysis tools can be used to identify and evaluate potential hydrologic restoration opportunities at multiple scales within the basin. The products of this work compliment the results of the GLEI project. For example, a screening tool was developed to evaluate variables from more than 20 commonly available geospatial datasets, and as a result identified six fundamental land use/land cover variables that when analyzed statistically can be used to quantify the degree of existing hydrologic impairment for individual watersheds (Apfelbaum *et al*. 2007, Fig. 2). When compared with the GLEI overall Stressor Index, the correspondence between these two indices is readily apparent.

The similarities between indices suggest that biological communities not only respond directly to changes in land use/land cover, but also to the hydrologic impairments created by those changes in land use/land cover as well. This cause-effect relationship can be used to assess how changes on the landscape may affect the nearshore zones of the Great Lakes, as waters flowing across or through the landscape must pass through the nearshore zone into the open lake.

Hydrologic impairments affect not only the ability of natural processes to convey energy, water, materials, and biota, but also alter the benefits that water provides to the nearshore ecosystem. Both the coastal margin and nearshore open water zones are also affected by changes in water level and are subject to both direct and indirect anthropogenic impacts, not only at the sediment-water interface, but in adjacent watershed areas as well. Waters derived from the landscape carry with them sediment, contaminants, and energy that may significantly impact the nearshore zones of the Great Lakes. It is through this hydrologic coupling that changes in land use/

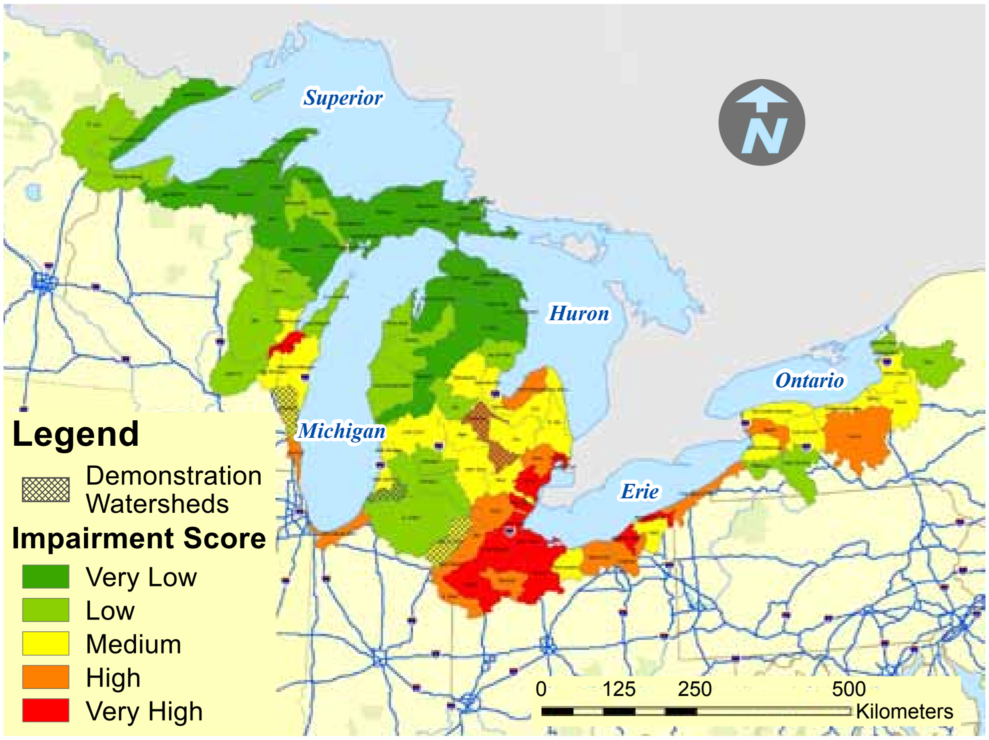


Figure 2. Relative potential surface hydrologic impairment (U.S. Great Lakes basin). Relative hydrologic impairment derived from six hydrologic variables for 8-digit HUC watersheds for the U.S. portion of the Great Lakes basin.
Source: Apfelbaum *et al.* (2007).

land cover are transferred across landscapes into the nearshore zones of the Great Lakes.

Land Use/Land Change over the Past Decade

At regional scales, changes in land use/land cover changes are typically evaluated be comparing high-resolution multispectral satellite imagery and/or high-resolution aerial photography taken at discrete time intervals (e.g. Fig. 3). To assist in the development of a new suite of indicators, recent work by the U.S. EPA-supported GLEI project evaluated land use/land cover changes for the period 1992 through 2001 for the U.S. portion of the Great Lakes basin (Wolter *et al.* 2006). Approximately 2.5% or 798,755 hectares (1,973,766.59 acres) of the U.S. portion of the Great Lakes basin experienced some type of land use change between 1992 and 2001 (Table 2, Wolter *et al.* 2006). These changes were dominated by conversion of forested and agricultural lands to either high or low intensity development, transportation (roads), and/or early successional vegetation (upland grasses and brush). Low-intensity development increased by 33.5%, high-intensity development increased by 19.6%, and transportation (road) area increased by 7.5%. **The continued rapid expansion and growth of urban and suburban areas and associated infrastructure is the single most significant land use/land cover change (~60%) within the U.S. portion of the Great Lakes basin. Much of the newly developed land was converted from agricultural or early successional vegetation (ESV) lands. Moreover, in the Chicago area, Auch *et al.* (2004) found that changes in urban and suburban land use between 1992 and 2001 (19%) far exceeded those predicted based on population growth (2.2%) (Wolter *et al.* 2006).** Forested and agricultural lands decreased by ~2.3% each, which is a significant decline from the 9.8% loss reported by U.S. EPA for the previous decade (Wolter *et al.* 2006). This decline in the loss of agricultural lands may be related to higher crop prices that *may* be driven by investments in biofuel production. This topic is discussed more fully below.

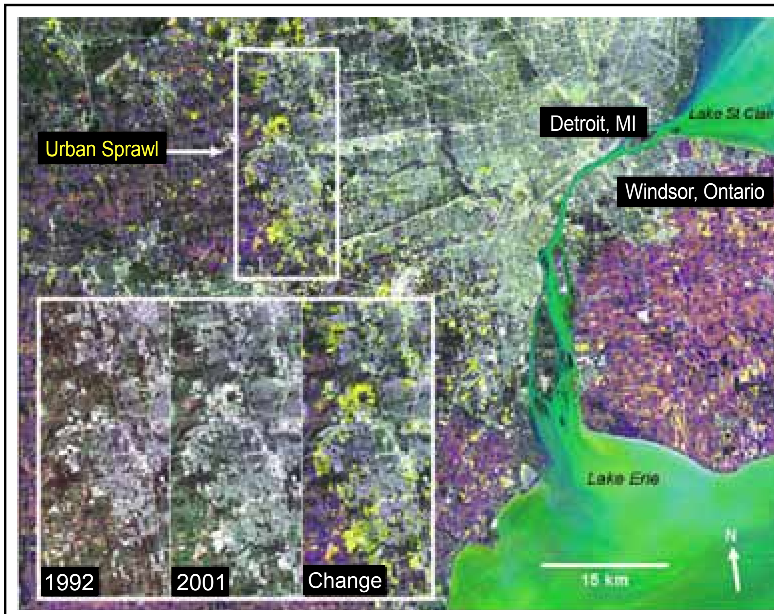


Figure 3. False color change composite of Landsat sensor data showing land use/land cover changes (yellow) in the Detroit Michigan area between 1992 and 2001.
Source: Wolter *et al.* (2006).

Wolter *et al.* 2006 grouped the most common land use changes into 10 transition categories which can then be summarized into three general types of land use change – agriculture to developed (210,068 hectares (519,089.33 acres) or 26.3%), forest to early successional vegetation (180,690 hectares (446,494.71 acres) or 22.6 %), and forest to developed land (154,681 hectares (382,225.08 acres) or 19.4 %). Figure 4 illustrates the 10 transition categories and dominant types of land use change that have occurred during the period 1992 through 2001.

Attribute Measured	Shoreline Buffer Zones 0-1 km	0-5 km	0-10 km	Whole Basin
Total area (ha)	647,440	2,686,163	4,936,957	31,525,961
Area unchanged (ha)	616,447	2,592,019	4,777,057	30,727,206
Area changed (ha)	30,994	94,144	160,120	798,755
Percent of area changed	4.8%	3.5%	3.2%	2.5%
Percent of area unchanged	95.2%	96.5%	96.8%	97.5%
Non-developed to developed (ha)	151,889	50,145	83,592	393,719
% of buffer area	2.3%	1.9%	1.7%	-
% of basin area	0.1%	0.2%	0.3%	1.2%
% of all basin transitions	1.9%	6.3%	10.5%	49.3%
% of basin non-dev. to dev.	3.9%	12.7%	21.2%	100.0%

Table 2. Change in non-developed land to developed land for the period 1992 to 2001 within buffer zones located 0-1 km, 0-5 km, and 0-10 km landward from U.S. Great Lakes shorelines.
LULC data are based on a comparison of 1992 NLCD and GL2001 land use land cover change datasets.
Source: Wolter *et al.* (2006).

Pastor and Wolter (2002) describe how certain types of land use/land cover transitions are transient and short-term. For example, conversion of forest to non-developed lands such as early successional vegetation will be short-lived as those lands will succeed back into forest cover. However, conversion of forest to developed residential or commercial lands will likely be long-term, as the probability of conversion back into undeveloped forest lands is extremely low. **Within the U.S. portion of the Great Lakes basin, ~49% of the land use/land cover changes that occurred between 1992 and 2001 were from non-developed to developed land with minimal probability of being converted back into a natural state (Wolter *et al.* 2006).** Note also that two of the three types of general land use change are considered to be *permanent* and long-term.

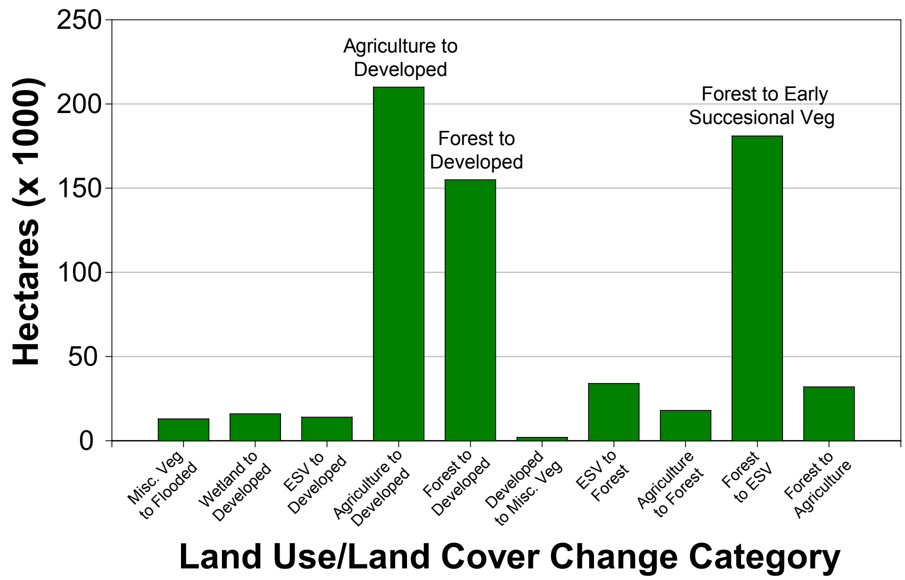


Figure 4. Distribution of land use / land cover change categories for the whole basin. Three change categories were dominate between 1992 and 2001 – Agriculture to Developed, Forest to Developed, and Forest to Early Successional Vegetation (ESV).
Source: Wolter *et al.* (2006).

In addition to population growth and economic development, recent increases in the price of diesel fuel and gasoline in combination with Federal (U.S.) subsidies for biofuel production have made crop and/or land use conversion to row-crop agriculture (e.g. corn, soybeans) economically attractive. Most of these changes have occurred after the Wolter *et al.* 2006 paper was published and therefore are not included in available land use/land cover change analyses.

Even though Federal subsidies for ethanol production are not new, the price of gasoline and desire for renewable fuel sources have contributed to a doubling of the price of corn and soybeans in the U.S. that started in 2005 (Fig. 5). Higher prices may provide an economic incentive to increase corn or soybean production by converting agricultural or other natural lands into row crop agriculture. If this conversion occurs, it is anticipated that sediment, nutrient, and agricultural contaminant loadings to Great Lakes tributaries and nearshore zones will increase.

However, **fuel and crop price increases are a recent phenomena (since 2005), and *currently available land use/land cover change mapping does not adequately capture* these potential changes in land use.** In fact, an examination of annual crop planting data for Midwestern States suggests that crop switching and/or conversion to agricultural lands has *not* yet occurred (Fig. 6). Moreover, the **USDA and most state agricultural agencies do not (currently) capture statistical data for crops grown for biofuels production. A possible indicator of land use conversion (and/or crop switching) would be the percentage of crops (corn or soybeans) grown for biofuels production within a watershed.**

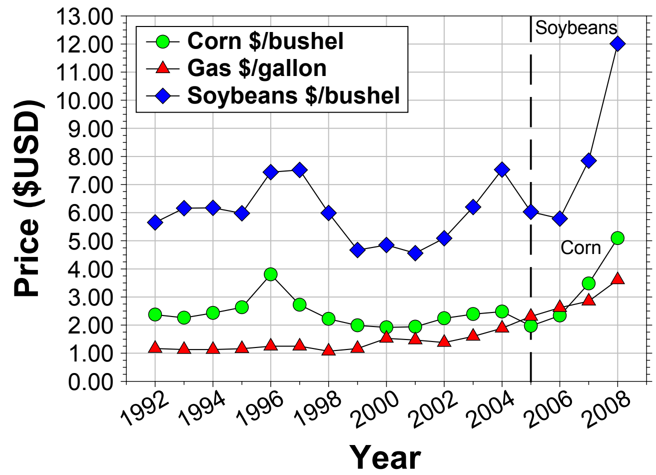


Figure 5. Comparison of Ohio Crop and Gasoline Prices, 1992 - 2007.
Within the Midwest region, higher gasoline prices has created an increased demand for corn and soybeans to produce biofuels (ethanol and biodiesel). Since a gas prices have exceeded $2.00/gallon in 2005, the price for a bushel of corn (or soybeans) has more than doubled. Higher prices may provide an economic incentive to increase corn or soybean production by converting agricultural or other natural lands into row crop agriculture.
Source: USDA, National Agricultural Statistics Service.

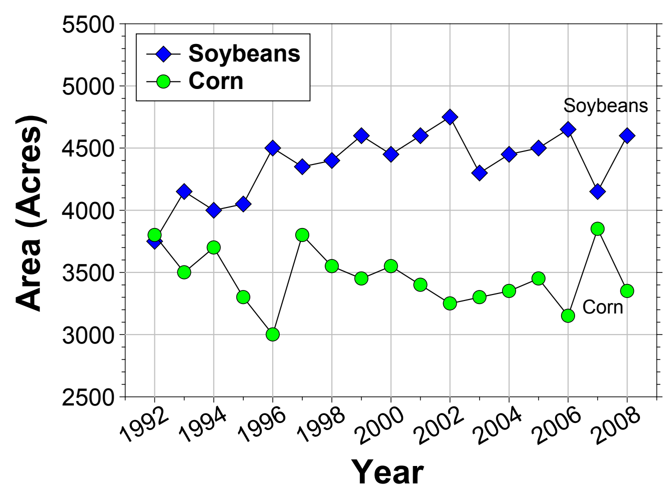


Figure 6. 1992 – 2007 Crop Plantings (Ohio Acreage).
Even though prices for corn and soybeans have increased since 2005, plantings for these crops have not increased. Note that spring 2008 was extremely wet which may have significantly reduced planted acreage due to an inability to get equipment into the fields. Additional data are needed to confirm that agricultural (or other) lands are being converted to corn and/or soybean crops in response to a high demand for biofuels.
Source: USDA, National Agricultural Statistics Service.

Wolter *et al*. (2006) also analyzed land use/land cover changes within three buffer zones adjacent to the coast: 0 to 1 km, 1 to 5 km, and 5 to 10 km from the coastline. Within these buffer zones, the dominant land conversion is from forested land to developed land. The results of these analyses show that more than 21% of the newly developed land within the basin occurred within 10 km of a Great Lakes coastline (Table 2). Of note is the conversion of wetlands into developed land, 12.8 % within 1 km of the coastline, 14.9 % within 1 to 5 km of the coastline, and 10.7% within 5 to 10 km of the coastline. **Between 1992 and 2001, 38.4% of the conversions from wetland to developed land occurred within 10 km of a Great Lakes coastline (Wolter *et al*. 2006)**. The loss of wetlands is especially problematic given that they are supposedly protected by law (e.g. Section 404, Clean Water Act, 1972).

Associated with conversion to developed lands (urban, suburban, and roads) is an increase in imperviousness that reduces water retention on the landscape, increases stormwater runoff, and increases sediment, bacterial, and chemical contaminant loads into the Great Lakes (e.g. Center for Watershed Protection, 1994, Environment Canada and U.S. Environmental Protection Agency, 2005). Moreover, areas immediately adjacent to the coastline typically do not drain into a stream or river, but directly into the Great Lakes. These “interfluves” exist between riverine watersheds and may not have the benefit of riparian wetlands or stormwater treatment systems to process sediments, nutrients, and contaminants as in larger riverine watersheds. These sources of sediment and nutrients may significantly degrade *local* water quality in adjacent coastal margin and nearshore areas.

Alterations at the Land–Water Interface (Shoreline Modifications)

Associated with increasing development (or redevelopment) in the 0–1 km buffer zone are physical modifications to the shoreline to protect property and infrastructure from erosion caused by waves and flooding during wind-driven storm events, and to provide recreational and commercial access to the Great Lakes. These physical modifications to the shoreline have disrupted coastal and nearshore processes, flow and littoral circulatory patterns, and altered nearshore habitat structure. For example, anthropogenic alterations to river mouths and the "armoring" of shorelines modify flow paths and disrupt nearshore coastal processes that create and maintain coastal margin and nearshore habitats.

Many native species require relatively shallow, well-oxygenated waters flowing though coarse gravel and cobble substrates with protected interstitial spaces. In many cases, spawning areas are adjacent to nearshore nursery areas and rely on regional circulation patterns to transport larval fish into adjacent nursery areas. Reductions in the volume of available littoral sand has lead to the "coarsening" of nearshore substrates and the gradual replacement of mobile sand sheets with relatively stable heterogeneous coarse-grained lag deposits (cobbles and boulders) resting on bedrock or cohesive clay substrates. The loss of protective sand sheets has significantly altered the pattern and distribution of nearshore aquatic habitats and has created ideal conditions for colonization by lithophyllic organisms such as dreissenids, round gobies, and other non-native species.

Irrespective of habitat impacts, continued coastal development (and redevelopment) has led to an increase in the amount of shore protection along Great Lakes coastlines. Examples of shoreline protection structures include dikes, revetments, breakwalls, seawalls, jetties, piers, retaining walls, boat docks, groins, gabions, etc.. The Ohio Division of Geological Survey has monitored the Ohio Lake Erie coastline to identify areas subject to erosion. As part of this monitoring and mapping effort, a comprehensive inventory of shore protection and navigation structures was created in 2000. Historical shore structure inventories along with aerial photographs and maps were used to quantify changes in the amount of shore protection that existed historically along the Ohio Lake Erie shoreline by coastal county. Figure 7 illustrates how the percentage of protected shoreline changed through time. As of 2000, more than 75% of the Ohio Lake Erie coastline was protected (98% in Lucas County near Toledo, Ohio). Most of these structures were installed or upgraded within the past three decades in response to historically higher water levels and more intense coastal development.

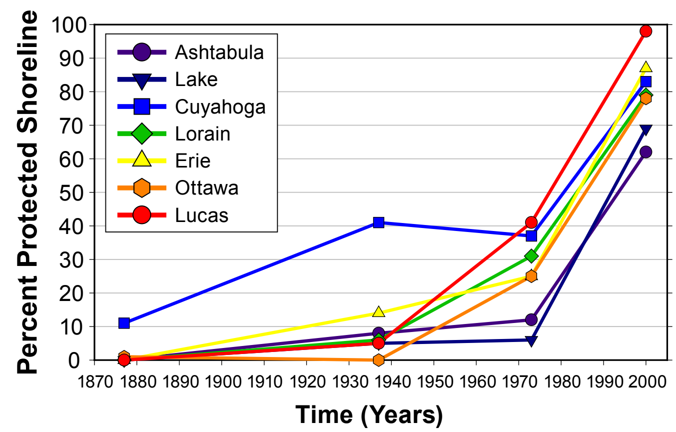


Figure 7. Change in amount of shore protection along the Ohio Lake Erie Coastline by coastal county, 1870 – 2000. As of 2000, approximately 75% of the Ohio Lake coastline was armored. Recent coastal mapping by the Ohio Division of Geological Survey shows that these trends have continued into the present in response to development (and redevelopment) of Great Lakes coastal areas.
Source: Ohio Department of Natural Resources, Division of Geological Survey.

Recent recession-line mapping by the Ohio Division of Geological Survey shows that there has been a significant reduction in measured erosion rates between 1990 and 2004. The reduction in erosion rates is thought to be due, in part, to increases in amount of developed and protected shoreline in combination with somewhat lower Lake Erie water levels since 1999. **Continued coastal redevelopment and expanding suburban growth along the coasts of all of the Great Lakes from urban centers suggest that these trends will continue into well into the future.**

In 2007, an indicator called the Shoreline Alteration Index (SAI) was developed based on the Ohio shore structure inventory and an assessment of biological compatibility of various types of shore protection structures in the Western basin of Lake Erie (Livchak and Mackey 2007). Data from the Western basin of Lake Erie were used to test and validate the index. Shore protection along Ohio's Western Lake Erie shoreline is generally effective with respect to erosion and flood control, but it is not biologically or ecologically compatible (Fuller and Gerke 2005).

Livchak and Mackey (2007) proposed to use the ratio of protected to unprotected shoreline as a measure of physical alteration of the land-water interface. In other words, a value of zero (0) would represent an unmodified natural shoreline and a value of one (1) would represent a highly modified or 100% engineered shoreline.

Unprotected 100% Protected

0 ⟷ 1

For a given reach of shoreline, these values would then be multiplied by the ratio of structures that have poor biological compatibility, where zero (0) would represent no biological or ecological impact (high compatibility) and one (1) would represent significant biological or ecological impact (low compatibility).

High Biological Compatibility — Low Biological Compatibility

$0 \longleftrightarrow 1$

The resulting SAI would range from zero (0) representing an unaltered shoreline to one (1) representing a highly altered shoreline. Within the context of this proposed indicator, alteration means impacted biological or ecological functions caused by modifications to the shoreline and/or associated coastal processes.

Unaltered — Highly Altered

$0 \longleftrightarrow 1$

The advantage of this approach is that as structures are removed and/or modified to provide habitat enhancements, the indicator will shift toward a more unaltered or natural state. Conversely, if the number and extent of biologically incompatible shoreline structures increases, the indicator will shift toward a more altered state.

Simply put, the SAI is a measure of protected shoreline length that is physically and biologically unfavorable. The greater the SAI value, the more altered the shoreline is. The SAI is scaleable to any reach length, and can be applied to present day and historical data for comparison and trend analyses.

Clearly, Great Lakes shorelines can not be returned to the unprotected "natural" shorelines that existed before development began in the 1800s. Given this reality, it is recommended that new shore protection structures along the coast be designed to be more biologically compatible by mimicking and maintaining natural coastal processes. It is also recommended that management strategies be developed to encourage rehabilitation of existing structures with "habitat" enhancements to restore natural habitat functions and processes in nearshore zones. Moving toward biologically compatible shore protection structures is an essential component to restoration of Great Lakes nearshore zones. More specific management recommendations are provided in Livchak and Mackey (2007).

Non-Point Source Loadings and BMPs

For more than two decades, improvements in managing soil loss, nutrients, and non-point source loadings have been implemented on agricultural landscapes. These best management practices (BMPs) are designed to improve agricultural efficiencies, retain soil and nutrients, and protect water quality. BMPs can effectively change the hydrologic response of agricultural lands and minimize harmful impacts to rivers, lakes, and the nearshore zones of the Great Lakes. Effective implementation of BMPs over large areas can cause a considerable improvement in water quality and significantly reduce sediment, nutrient, and contaminant loadings into the Great Lakes. One of the most successful BMPs is conservation tillage, where fields are not tilled between crop rotations (no-till), or where tillage is minimized to leave plant residue on the soil surface to stabilize the soil surface and reduce erosion by water. Conservation tillage has been actively promoted since the late 1980s and the acreage under conservation tillage has steadily increased in the Great Lakes basin.

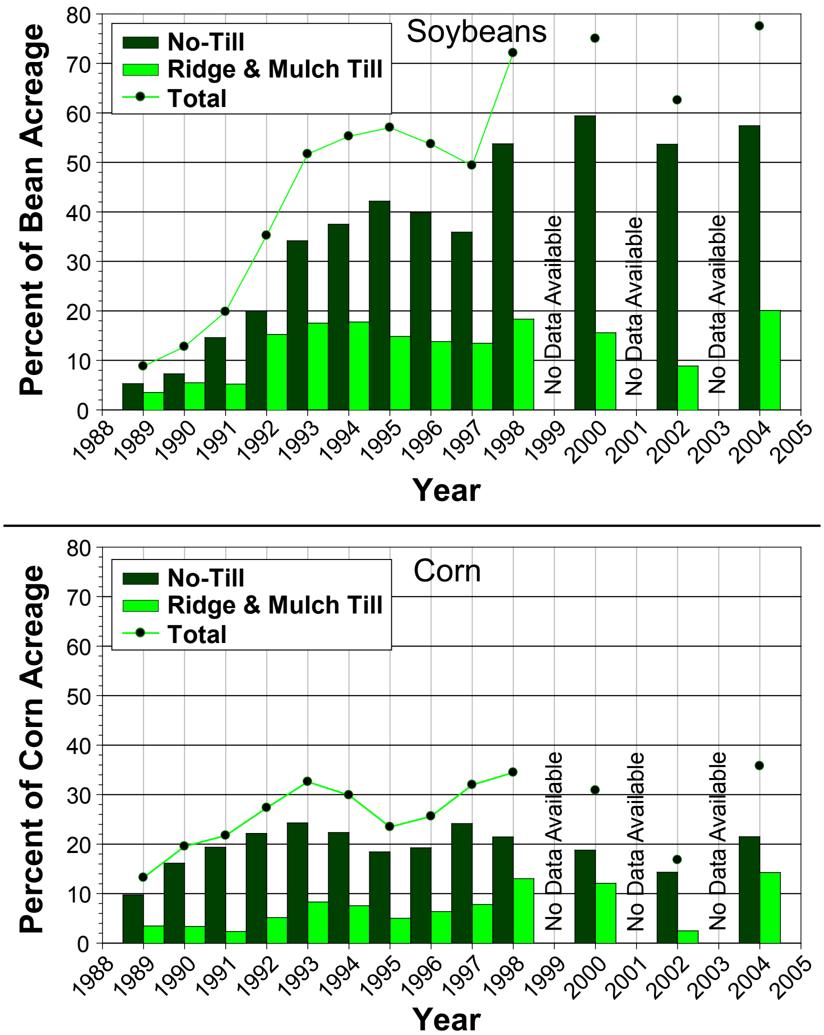
In northwest Ohio (a major source of loadings into Lake Erie), currently ~55 to 60% of the bean acreage is no-till and ~20 to 25% of the corn acreage is no-till in the Sandusky and Lower Maumee River watersheds (Figs. 8a and b). Based on these plots, conservation tillage in these watersheds increased from 1996 to 2000, and then leveled off and/or declined slightly though 2004. Natural Resources Conservation Service (NRCS) believes that these acreages have not changed significantly since 2004 (Steve Davis, NRCS, personal communication). Agricultural land use in these watersheds is predominately row crop agriculture and is focused on beans, corn, and winter wheat. Long-term trends in soil, nutrient, and contaminant loadings are described elsewhere in this background paper. However, continued implementation and refinement of these BMPs is a critical component to protecting and restoring Great Lakes nearshore zones.

Summary

Land use/land cover changes in watersheds have altered flow paths to tributaries, changing flow regimes and dramatically increasing sediment and nutrient loads, causing channel erosion and instability, and degrading the quality of tributary flows into the Great Lakes. Tributary waters must flow through coastal margin and nearshore habitats to reach the open lake, and are therefore affected by anthropogenic actions in the watersheds. Chemical contaminants, nutrients, and fine-grained sediments have adversely affected nearshore habitat structure and ecosystem function. Even though steps have been taken to slow the rate of degradation, continued population growth and associated changes in land use/landcover in Great Lakes watersheds will continue cause further degradation of coastal margin and nearshore habitats.

Acknowledgments

Author: Scudder D. Mackey, Ph.D. Habitat Solutions NA, scudder@sdmackey.com



Figures 8a and b. Time series plots illustrating percent soybean and corn acreages under conservation tillage in the Sandusky River Watershed, Ohio.

Approximately 55 to 60% of the soybean acreage and 20 to 25 % of the corn acreage are under no-till conservation tillage. Corn and soybean conservation tillage has remained relatively constant since 2004.

Source: Steve Davis, Natural Resources Conservation Service - USDA, Lima Service Center, Lima, OH.

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3.0 Coastal Terrestrial Ecosystems

State of the Ecosystem

Introduction

The Great Lakes coast[1] is over 28,300 km (17,585 mi) in length – a distance greater than half the equatorial circumference of the Earth – making it the longest freshwater coast in the world (Table 1). Driven by its close proximity to the world's largest freshwater seas, the dynamic Great Lakes coastal terrestrial zone has been a catalyst for species and ecosystem diversity. Many of the terrestrial endemic species in the Great Lakes basin have evolved in the last 10,000 years in response to this coastal influence, and approximately 200 disjunct species persist due to the unique conditions of the coastal environment (Henson *et al.* 2005, TNC 1999). A large number of globally rare ecosystems have also developed in response to the special conditions of the Great Lakes coast. The Great Lakes basin includes one of the most diverse assemblages of ecological systems in the United States and southern Canada (Cormer *et al.* 2003, NatureServe 2008), and over 25 globally rare vegetation communities that are restricted to the Great Lakes coast have been documented (NatureServe 2008). Many of these communities are the focus of this report.

Lake System	*Coastal Ecoreaches[1]*	*Total Coast (km)*	*Coastal Area[2] (ha)*
Superior	S1,S2,S3a,S3b,S4a,S4b,S4c,S5a,S5b, S6a, S6b,S6c,S7a,S7b,S7c,S7d,S7e,LS	6,479	583,485
Huron	HG1a,HG1b,HG1c,HG1d,HG2a,HG2b, HG3,HG4a, HG4b, HG5,HG6,HG7a, HG7b,HG7c,HG8a,HG9,HG10,LH	11,376	790,156
Michigan	M1,M2a,M2b,M3,M4a,M4b,M5,M6a, M6b,M6c,M7a,M7b,LM	2,478	381,267
Erie	E1,E2,E3,E4,E5,E6a,E6b,E7a,E7b, E7c,E7d,LE	2,687	247,864
Ontario	OS1,OS2,OS3a,OS3b,OS4a,OS4b, OS4c OS5,OS6,OS7,LO	3,969	357,322
Lake St. Clair	SC1,SC2,SC3	1,314	70,457
Total		28,303	2,430,551

Table 1. Summary of Great Lakes Coastal Systems.
[1] = See Figure 1.
[2] = Defined as 2 km inland from the coast and the area of all islands.
Source: Coastal Ecoreaches based on Reid *et al.* (1999).

The Great Lakes coastal terrestrial zone is also a region under many pressures. No other part of the Great Lakes basin has the same depth and diversity of human history. For millennia coastal ecosystems have attracted human settlement for their access to transportation, natural resources, water and aesthetics. Today, the coastal terrestrial zone contains the largest concentrations of urban, industrial and recreational land uses in the Great Lakes basin. New development in the basin continues to be concentrated in coastal areas (Wolter *et al.* 2006). The actions taken in the next few decades may determine our effectiveness in conserving many coastal terrestrial ecosystems of the Great Lakes.

The state of the coastal terrestrial systems is inextricably connected to the health of the lakes, a linkage that has been well documented in terrestrial/riverine ecosystems, but is just being understood in large lake systems. Development of the shorelines of freshwater lakes can have a significant impact on nearshore aquatic habitats, nutrient cycles, physical processes and species assemblages (Scheuerell & Schindler 2004), including fish populations and richness (Brazner 1997). Within the Great Lakes, the health of the coastal terrestrial ecosystems is linked with the health and diversity of the nearshore waters. Fish and zooplankton communities are generally lower in nearshore waters adjacent to developed coasts (Goforth & Carman 2005), especially as they relate to changes in substrate composition and stability. Shoreline development and modifications alter nearshore substrate processes and may facilitate invasions of nearshore aquatic invasive species (Meadows *et al.* 2005), and degree of shoreline development may provide a terrestrial-based indicator of the relative integrity of nearshore aquatic systems. This linkage highlights the importance of coastal conservation. Protection of coastal terrestrial ecosystems conserves globally unique species and communities and supports the maintenance of nearshore processes and aquatic biodiversity.

Scope and Purpose of this Report

This report provides an update of the original SOLEC 1996 chapter on coastal terrestrial ecosystems, *Land by the Lakes* (Reid and Holland 1997), and has two primary objectives:

- To update baseline information on the coastal terrestrial ecosystems.
- To identify trends in these systems, and answer the question: *What has changed since 1996?*

1 Includes mainland and islands of the Great Lakes.

To address the first objective, this report has included the assembly and analysis of the best available spatial data on Great Lakes coastal terrestrial ecosystems, much of which was not available for the original report (Appendices A and B). This includes coastal mapping for Canada (Environment Canada, Ontario Ministry of Natural Resources) and the U.S. (National Oceanic and Atmospheric Administration), and classifications and descriptions of coastal terrestrial ecosystems from the Great Lakes region (NatureServe 2008), Ontario and U.S. Great Lake states – this included element occurrences (EOs) of coastal terrestrial vegetation communities. The taxonomy of some of the 1996 coastal terrestrial ecosystems has been changed to reflect the names of Great Lakes ecological systems (NatureServe 2008), and two ecosystems were added (Table 2). Great Lakes Islands, originally included in the 1996 report, now have a separate SOLEC indicator report (#8129) and are not addressed in this report. Coastal wetlands and aquatic nearshore habitats are being covered in other reports for SOLEC 2008.

Coastal Terrestrial Ecosystems Addressed in this Report	SOLEC 1996 Name
1. Great Lakes Sand Beaches	Sand Beaches
2. Great Lakes Foredunes	Sand Dunes
3. Coastal Back Dune Complexes	Sand Barrens
4. Bedrock Shores	Bedrock and Cobble Beaches
5. Cobble Beaches	Bedrock and Cobble Beaches
6. Shoreline Cliffs	Limestone Cliffs and Talus Slopes
7. Shoreline Bluffs	Unconsolidated Shoreline Bluffs
8. Lakeplain Prairies	Lakeplain Prairies
9. Arctic-Alpine Disjunct Communities	Arctic-Alpine Disjunct Communities
10. Atlantic Coastal Plain Disjunct Communities	Atlantic Coastal Plain Disjunct Communities
11. Rich Coastal Fens	New
12. Shoreline Alvars	Shoreline Alvars
13. Coastal Rock Barrens	Coastal Gneissic Rocklands
14. Great Lakes Coastal Forests	New

Table 2. Summary of Coastal Terrestrial Ecosystems, Cross-walked with SOLEC 1996 Terms.

This project established a data-driven baseline of the location and extent of these coastal terrestrial ecosystems. Results of this analysis were generated for each of the coastal ecoreaches in the Great Lakes (Fig. 1). Boundaries of the coastal ecoreaches are based on Reid *et al.* (1999). Five additional coastal ecoreaches were created and used in the analysis to include offshore islands.

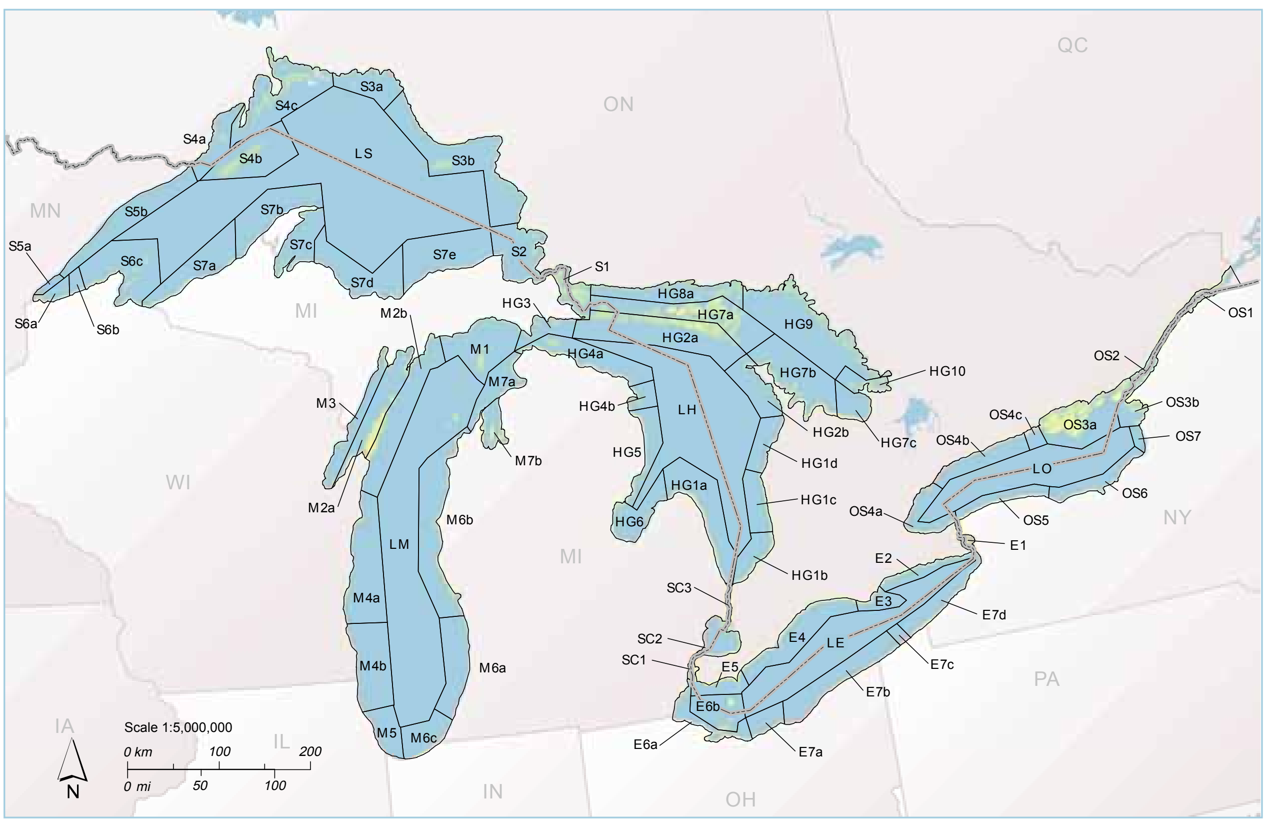

Figure 1. Great Lakes Coastal Units.
Sources: Nature Conservancy of Canada - Ontario Region (2007), OMNR (2007), ESRI Data & Maps (2006), Natural Resources Canada, Canada Centre for Cadastral Management (2003), NOAA, Coastal Services Center (2002), and U.S. EPA (2000).

The second objective of the report is to identify the trends and pressures on the coastal terrestrial ecosystems based on a literature review. In addition, an analysis to quantify the condition of each coastal unit based on an assessment of shoreline alteration and land cover is included. This analysis provides a general index of the health of coastal terrestrial ecosystems around the basin.

Results

Ecosystem Summary, Distribution, Status and Trends

The following section provides a summary for each of the 14 coastal terrestrial ecosystems identified in Table 2. For each coastal terrestrial ecosystem the global status of the ecosystem (based on status ranks of the component vegetation communities – Appendix B) and general background information on the composition and functions of the ecosystem are provided. A table on each coastal terrestrial ecosystem provides a summary of its distribution, status and trends.

3.1 Great Lakes Sand Beaches

Global Status: Vulnerable

Related Coastal Terrestrial Ecosystems: *Great Lakes Foredunes, Coastal Back Dune Complexes, Cobble Beaches*

SOLEC 1996: Sand Beaches

Background: Great Lakes Sand Beaches include the active beach area below the high watermark. They have specific physical requirements and are restricted to a narrow zone along the Great Lakes. They are very active systems, formed when waves and wind deposit sand that has eroded from other places onto an exposed shoreline. Sand beaches are dynamic, and sand may be washed away with erosive storms or ice transport, or be blown inland to form sand dunes - they can also migrate with changing water levels. These are high energy environments and tend to be very open with have low plant richness and cover and little soil development (Kost *et al*. 2007). Up-rooted trees or surficial organic matter accumulation may allow for changes in the sediment or vegetation characteristic of the beach, but these changes are usually temporary.

Distribution, Status and Trends – Great Lakes Sand Beaches

Lake System *Total/ % of Coast*	***Coastal Reaches***[1]	***Key Coastal Reaches***[2]	***Status/ Trend***
Superior 618 km/9.5%	S1,**S2**,**S3a**,**S3b**,S4a,**S4c**,**S5a**,**S5b**,**S6a**,S6b,**S6c**,S7a,S7b, S7d,**S7e**,LS	S2,S7e	Good/ Unchanging
Michigan 1515 km/61.1%	**M1**,M2a,**M2b**,**M3**,**M4a**,**M4b**,**M5**,**M6a**,**M6b**,**M6c**,**M7a**,**M7b**,**LM**	M1,M2a,M3,M6b,M7b	Mixed/ Unchanging
Huron 709 km/6.2%	HG1a,HG1b,HG1c,HG1d,HG2a,**HG2b**,**HG3**,**HG4a**,HG4b, HG5,HG6,HG7a,HG7b,**HG7c**,HG8a,HG9,**HG10**	HG4a,HG5	Mixed/ Unchanging
St. Clair 16 km/1.2%	SC1,SC2,SC3	SC1,SC2,SC3 (primarily in SC2)	Poor/ Undetermined
Erie 387 km/14.4%	E1,E2,**E3**,E4,**E5**,**E6a**,**E6b**,E7a,**E7b**,**E7c**,**E7d**, **LE**	E2,E3,E4,E5,E6a,E7d	Mixed/ Unchanging
Ontario 139 km/3.5%	OS1,OS2,OS3a,**OS3b**,OS4a,OS4b,OS4c,**OS5**,OS6,**OS7**	OS1,OS3a,OS4a,OS5,OS5,OS6,OS7	Mixed/ Unchanging

[1] = Based on coastal mapping and element occurrence (EO) data. Boldface denotes coastal reach with documented EOs. Includes beach and dune EOs.
[2] = Key Coastal Reaches include >10% of the total extent of the ecosystem in the context of each Great Lake.

Approximately 3,385 km (2,100 mi) of sand beaches occur on the Great Lakes. Sand beaches characterize much of the Lake Michigan shoreline (especially on the eastern shore), and large examples also occur on Lake Erie sand spits, Nottawasaga Bay (Huron), eastern Lake Superior and eastern Lake Ontario. Great Lakes Sand Beaches are considered globally rare by NatureServe with fewer than 100 occurrences and are considered rare in Ontario and all U.S. states (NatureServe 2008). Among the documented occurrences, the average size is approximately 10 ha (24.7 acres) (NatureServe 2008). Elements of this community can occur in association with other coastal ecosystems including dunes and eroding bluffs. Only one type of sand beach has been identified (NatureServe 2008) (Appendix A); this community is characterized by sea rocket (*Cakile* sp.) in association with American beachgrass (*Ammophila breviligulata*). Sand beach ecosystems are intricately linked with dunes and coastal barrens, and typically form the first interface between dune and the lake.

Many key sand beaches are in existing parks and protected areas, and most beaches are not directly impacted by site development, although shoreline hardening and structures that alter nearshore sand movement can have impacts over large areas of the coast by reducing sand deposition. Most beaches in protected areas are subject to high levels of recreational use. Stewardship of these sites is improving, although enhancements could be made. These include reduced vehicle use and beach "cleaning" that removes organic matter.

3.2 Great Lakes Foredunes

Global Status: Vulnerable – Apparently Secure
Related Coastal Terrestrial Ecosystems: *Great Lakes Sand Beaches, Coastal Back Dune Complexes*
SOLEC 1996: Sand Dune

Background: Great Lakes Foredunes are defined as open stabilized foredunes, and are formed along open sandy shores with consistent winds that transport the sand inshore (Reid and Holland 1997). Dune formation is a dynamic process that is linked to erosion and wind deposition, including initial dune formation during the recession of ancient lakes, erosion of the remaining bluffs and deposition of this sediment onto beaches where it is transported into dunes (Kost *et al*. 2007). Foredunes are formed when vegetation such as American beachgrass causes wind to drop sand, which accumulates and is then colonized by grasses such as prairie sandreed (*Calamovilfa longifolia*) and little bluestem (*Schizachyrium scoparium*) and trees/shrubs such as eastern cottonwood (*Populus deltoides*), balsam poplar (*Populus balsamifera*), sand cherry (*Prunus pumila*) and willow (*Salix* sp.) species (Reid and Holland 1997). Component plant communities vary from sparsely vegetated dunes to communities dominated by grasses, shrubs, and trees, depending on the degree of sand deposition, sand erosion, and distance from the lake. Dune systems are very important for the biodiversity of the Great Lakes region. Less than 40% of Great Lakes dune plant species also grow in maritime dunes (NatureServe 2008). Forested dunes and associated barrens and wetlands associated with secondary dunes formations are treated under Coastal Sand Barrens and Forested Dunes. Great Lakes Foredunes always occur in association with sand beaches.

Distribution, Status and Trends – Great Lakes Foredunes

Lake System	*Coastal Reaches*[1]	*Key Coastal Reaches*[2]	*Status/ Trend*
Superior	S2,S3a,S3b,S4c,S6a,S6c,S7e	S3a,S3b,S6a,S6b	Good/ Unchanging
Michigan	M1,M2b,M3,M4a,M4b,M5,M6a,M6b,M6,M7a,M7b,LM	M1,M2b,M6b,M7a	Mixed/ Improving
Huron	HG2b,HG3,HG4a,HG7c,HG10	HG10	Mixed/ Improving
St. Clair	Does not occur.	-	-
Erie	E3,E5,E6a,E6b,E7b,E7d,LE	E6a	Mixed/ Improving
Ontario	OS3b,OS5,OS7	OS7	Mixed/ Improving

[1] = Based on element occurrence (EO) data.
[2] = Key Coastal Reaches include over five documented EOs, or the highest number of EOs for the lake.

Approximately 30,000 ha (74,000 acres) of sand dunes (including Back Dune Complexes) can be found along the Great Lakes coastline (EC and USEPA 2007) – this is the world's largest collection of freshwater sand dunes. Dunes occur on all the Lakes, but are most common on the southeastern shore of Lake Superior, eastern Lake Michigan, southern Lake Huron and eastern Lake Ontario. Approximately 2-3% of the Lake Huron coast includes dunes (Peach, personal communication).

Six foredune communities have been identified from the Great Lakes coast, most of which are globally rare (NatureServe 2008) (Appendix A). The most common and widespread dune community is Great Lakes Beachgrass Dune. Characteristic species include American beachgrass, prairie sandreed, and in stabilized areas little bluestem. This community is closely related to the shrub dominated dune systems including common juniper (*Juniperus communis*) and sand cherry. The Northern Great Lakes Dune Grassland is more poorly documented, and known only from Lake Superior. Cottonwood Dune is the only tree community that occurs on stabilized foredunes. This community occurs in dune fields and on the most stable dune ridges in the southern Great Lakes region and is very rare globally. While there has historically been a significant decline in occurrences due to residential development, many of the remaining examples have been identified and protected. However, at some of these sites, including those in parks, inappropriate uses continue to threaten this fragile ecosystem (Bakowsky 1998a), although there are increasing examples of dune stewardship on public and private lands that is resulting in the rebuilding of foredunes (Featherstone, personal communication). Dune awareness and stewardship programs have been initiated by the Michigan Natural Features Inventory and the Lake Huron Centre for Coastal Conservation.

3.3 Coastal Back Dune Complexes

Global Status: Vulnerable

Related Coastal Terrestrial Ecosystems: *Great Lakes Foredunes, Great Lakes Coastal Forests*

SOLEC 1996: included in Sand Barrens

Background: This ecosystem includes a complex of forests, wetlands and barrens that are associated with stabilized back dunes. This report only includes those dunes that are part of the present day lakeshore. In some cases these communities can extend inland for several kilometres and show evidence of past lake levels (e.g. Oak Openings in Ohio, Indiana Dunes National Lakeshore). This ecosystem does not include open sandy areas that are not related to the coast. Coastal Back Dune Complexes often occur as a series of alternating ridges and swales. The ridges typically support dry forests and the swales between the ridges are often close enough to the water table to support wetland communities. The composition and structure of this ecosystem is highly variable around the basin. For example, six major subtypes of Great Lakes Dune and Swale have been described for Michigan based on location and dune structure.

Distribution, Status and Trends – Coastal Back Dune Complexes

Lake System	***Coastal Reaches[1]***	***Key Coastal Reaches[2]***	***Status/ Trend***
Superior	S2, S5b, S6a, S6c, S7a, S7b, S7c, S7d, S7e	S5b	Mixed/ Deteriorating
Michigan	M1, M2a, M2b, M3, M4a, M4b, M5, M6a, M6b, M6c, M7a, M7b	M1,M2b,M4b,M5,M6b,M6c	Mixed/ Deteriorating
Huron	HG2a, HG3, HG4a, HG5, HG6, LH	HG3,HG4a,	Mixed/ Deteriorating
St. Clair	Does not occur.	-	-
Erie	E7c	E7c	Good/ Unchanging
Ontario	No documented element occurrences, but known to occur (Bonanno *et al.* 1998).	-	**-**

[1] = Based on element occurrence (EO) data. Includes EOs for Wooded Dunes and Swale Complex, Beach Ridge, Interdunal Wetland and Great Lakes Barren. Prairie and savanna EOs near coast are also included.
[2] = Key Coastal Reaches include 5+ documented EOs.

All four documented Great Lakes Forested Dunes, Barrens & Swales vegetation communities are globally rare (NatureServe 2008) (Appendix A). 1) Wooded Dune and Swale Complexes have been documented at nearly 100 occurrences throughout the region and often occur where post-glacial streams enter an embayment and provide a sand source. Dune ridges in the northern Great Lakes typically include jack pine (*Pinus banksiana*), red pine (*Pinus resinosa*), white pine (*Pinus strobus*), common juniper, bearberry (*Arctostaphylos* sp.) and creeping juniper (*Juniperus horizontalis*). Those in the southern Great Lakes are characterized by eastern cottonwood, black oak (*Quercus velutina*) and white pine. Occurrences in eastern Lake Ontario are dominated by red oak (*Quercus rubra*) and red maple (*Acer rubrum*) (Bonanno *et al.* 1998). Swales include open wetlands or swamps. Complexes located in embayments protected from winds tend to be formed entirely of very low ridges dominated by wetland vegetation (e.g. parts of Point Pelee National Park). This ecosystem has also been classified according to its upland and wetland components. 2) Interdunal Wetlands are found in the southern Great Lakes and in parts of northern Lake Michigan; 36 occurrences have been documented, totaling 539 ha (1,132 acres). 3) Great Lakes Dune Pine Forest is found on dune systems of Lake Michigan and Lake Huron where it is a component of a Wooded Dune and Swale Complex. It is restricted to drier, sandy soils on dune tops or ridges. This forest system is closely associated with 4) Great Lakes Pine Barrens, a coniferous savanna characterized by scattered trees and low shrubs. This ecosystem is not tracked in Ontario, although many occurrences exist (e.g. Pinery and Wasaga Beach Provincial Parks).

Unlike the more active sand beaches and dunes that typically occur between this ecosystem and the lake, forested dunes and swales are more susceptible to being developed. All Great Lakes Forested Dunes, Barrens and Swales are considered to be globally rare and many sites have been degraded. High quality occurrences are found in Lake Superior on the Apostle Islands National Park. This ecosystem has been poorly documented in Ontario and is not specifically tracked.

3.4 Bedrock Shores

Global Status: Vulnerable – Secure (variable by community type)
Related Coastal Terrestrial Ecosystems: *Cobble Beaches, Shoreline Cliffs, Arctic-Alpine Disjunct Communities, Coastal Fens, Shoreline Alvars, Coastal Rock Barrens, Coastal Forests*
SOLEC 1996: Bedrock Beach/ Cobble Beach (this system was divided by SOLEC in 1998; Reid *et al.* 1999)

Background: Bedrock shores include basic and acidic exposed bedrock that is < 1 m (3.28 ft) in height. These shores can range from bare bedrock to bedrock overlaid with cobble. The bedrock may be horizontal or tilted, rounded or blocky, and may include ledges. The leading edge of the shoreline may be heavily impacted by wave action and winter ice movement and typically has little or no vegetation (Kost *et al*. 2007). Narrow areas of exposed rock at less than a meter above the lake are generally moist and support mosses and liverworts, and scattered vascular plants. Vegetation cover and height increases inland. Above the zone of wave and ice influence, woody vegetation becomes dominant. These dry systems are often the edge of other ecosystems including alvars and acidic rock barrens (Reid and Holland 1997, Kost *et al*. 2007).

Distribution, Status and Trends – Bedrock Shores

Lake System *Total/ % of Coast*	***Coastal Reaches[1]***	***Key Coastal Reaches[2]***	***Status/ Trend***
Superior 1863 km/28.7%	S1,S2,S3a,S3b,S4a,S4b,S4c,**S5a**,**S5b**,S6b,**S6c**,S7a,**S7b**,**S7c**,S7d, S7,**LS**	S4b,S5b,S6c	Good/ Improving
Michigan 270 km/10.9%	**M1**,**M2a**,**M2b**,M3,M7a,LM	M2a,M2b,M7a,LM	Mixed/ Deteriorating
Huron 2953 km/26.0%	HG1a,HG1b,HG1d,**HG2a**,**HG2b**,**HG3**,HG4a,**HG4b**, **HG7a**,HG7b,HG7c,HG8a,HG9,HG10	HG2a,HG2b,HG3,HG8a,HG9	Good/ Improving
St. Clair 24 km/1.8%	SC1	SC1	Poor/ Unchanging
Erie 221 km/8.2%	E1,E2,E6a,E6b,E7a,E7b,E7d	E1,E2,E6b,E7d	Mixed/ Deteriorating
Ontario 655 km/16.5%	OS1,OS2,OS3a,**OS3b**,OS4a,OS4b,OS4c OS5,OS6,OS7	OS1,OS2,OS3a,OS3b	Mixed/ Deteriorating

[1] = Based on coastal mapping and element occurrence (EO) data. Boldface denotes coastal reach with documented EOs.
[2] = Key Coastal Reaches include >10% of the total extent of the ecosystem in the context of each Great Lake.

Bedrock shores are classified by Alkaline and Non-Alkaline types (NatureServe 2008) (Appendix A). Alkaline types may consist of alkaline igneous, metamorphic, or sedimentary rocks and three types have been documented. The most common is 1) Great Lakes Basalt – Conglomerate Bedrock Shore along Lake Superior that consists of basalts, volcanic conglomerates, and localized rhyolites. This ecosystem is associated with Arctic-Alpine Disjunct Communities. 2) Great Lakes Sandstone Bedrock Shore is restricted to small areas of Lake Superior and Lake Huron, typically in association with sandstone cliffs. 3) Great Lakes Limestone-Dolostone Bedrock Shore occurs in an arch from the southern Bruce Peninsula to Drummond Island and the Door Peninsula, with scattered occurrences in the Lake Huron Shore of Michigan's lower peninsula, Lake Erie and eastern Lake Ontario.

Non-Alkaline Bedrock shore is comprised on Great Lakes Granite – Metamorphic Bedrock Shore characteristic of the Canadian Shield. This sparsely vegetated shore community is found along Lake Superior, Lake Huron and a very small portion of Lake Ontario.

Almost 6,000 km (3,728 mi) of bedrock shore occurs in the Great Lakes, primarily in the north. Sandstone and Limestone – Dolostone Bedrock Shores are considered to be globally rare. Large areas of Great Lakes Basalt – Conglomerate and Granite – Metamorphic Bedrock Shores are protected along Lake Huron and Lake Superior (e.g. the newly created Georgian Bay Shoreline and Islands Conservation Reserve at 17,828 ha (44,054 acres).

3.5 Cobble Beaches

Global Status: Vulnerable – Secure (variable by community type)
Related Coastal Terrestrial Ecosystems: *Great Lakes Sand Beaches, Bedrock Shores, Shoreline Cliffs, Coastal Fens, Shoreline Alvars, Coastal Rock Barrens, Coastal Forests*
SOLEC 1996: Bedrock Beach/ Cobble Beach (this system was split by SOLEC in 1998; Reid et al. 1999)

Background: Cobble beaches are highly variable and can range from small cobbles to large boulders. This ecosystem is typically a dynamic environment of wind and, more significantly, waves, ice and changing water levels that can disturb the beach habitat and reconfigure the cobble and sediment. Vegetation is typically sparse, but also variable depending on exposure and the amount of fine sediments between the cobble (EC and U.S. EPA 2005). On storm beaches, cobbles can accumulate to a depth of several meters, and in these conditions, vegetation is often absent. Beaches with shallow accumulations of gravel and small cobble can have very rich plant communities, especially when the spaces between the cobble is filled with sand (Kost *et al*. 2007, Albert and Kost 2007).

Distribution, Status and Trends – Cobble Beaches

Lake System Total/ % of Coast	***Coastal Reaches***[1]	***Key Coastal Reaches***[2]	***Status/ Trend***
Superior 911 km/14.1%	S1,S2,S3a,S3b,S4a,S4c,**S5a**,**S5b**,S6c,S7a,S7b,S7c,LS	S1,S3b,S4a,S4c	Good/ Improving
Michigan 12 km/0.5%	**M1**,M2a,M2b,M4b,M7a	M2a,M2b,M7a	Mixed/ Deteriorating
Huron 1449 km/12.7%	HG1a,HG1b,HG1c,HG1d,**HG2a**,HG2b,**HG3**,**HG4a**,HG4b,HG5,HG7a,HG7b,HG7c,HG10,HG8a,HG9	HG2a,HG7a,HG7b,HG8a	Good/ Improving
St. Clair 3 km/0.2%	SC1	SC1	Poor/ Unchanging
Erie 48 km/1.8%	E1,E2,E3,E4,E6b,E7b,E7c,E7d	E2,E6b,E7b,E7d	Mixed/ Unchanging
Ontario 297 km/7.5%	**OS1**,OS2,OS3a,**OS3b**,OS4a,OS4b,OS4c OS5	OS1,OS3a,OS4b	Mixed/ Deteriorating

[1] = Based on coastal mapping and element occurrence (EO) data. Boldface denotes coastal reach with documented EOs.
[2] = Key Coastal Reaches include >10% of the total extent of the ecosystem in the context of each Great Lake.

Three cobble beach types have been described around the Great Lakes (NatureServe 2008) (Appendix A): 1) Limestone Cobble – Gravel Great Lakes Shores occur in central Lake Huron along the Niagara Escarpment and in Lake Ontario. While this type can be locally common, it does have restricted range. 2) Basalt – Diabase Cobble – Gravel Great Lakes shore type is common along the northern Great Lakes. 3) Non-alkaline Cobble – Gravel Great Lakes shore type is found along the shores of northern Great Lakes in the United States and Canada.

Limestone Cobble – Gravel and Non-alkaline Cobble – Gravel Great Lakes communities are ranked as globally rare. However, Non-alkaline Cobble – Gravel Great Lakes type is underreported in Ontario, and may be more common. Large areas of this system and Basalt – Diabase Cobble – Gravel Great Lakes shore type have been protected in Ontario in the last decade on Lake Superior and Huron.

3.6 Shoreline Cliffs

Global Status: Apparently Secure – Secure (variable by community type)
Related Coastal Terrestrial Ecosystems: *Bedrock Shores, Cobble Beaches, Coastal Rock Barrens, Coastal Forests*
SOLEC 1996: Limestone Cliffs/ Talus Slopes (scope was extended to include all cliff types)

Background: Shoreline cliffs are vertical or near vertical embankments of bedrock that occur along the present-day shore and are shaped by coastal processes including erosion and wave spray. Cliffs can generally be divided into three vegetation zones: ridge-top forest, cliff face and talus (Kost *et al*. 2007). Most cliff faces are subject to extreme temperature fluctuations, and support scattered herbs and ferns in fissures, and stunted trees along ledges (Reid and Holland 1997). Talus slopes occur at the bottom of cliffs and are formed by large blocks of rock that have broken away from cliff faces (Reid and Holland 1997, Kost *et al*. 2007). Talus slopes tend to be unvegetated in the wave-wash area, with increasing herbs, then shrubs, then mixed forests as distance from the shoreline increases (Reid and Holland 1997). Cliffs can include many unique formations. In Michigan cliffs range from only

3-6 m (9.8-19.7 ft) to over 60 m (197 ft) tall (Kost *et al*. 2007). Along the Niagara Escarpment in the Great Lakes region, the cliff can reach well over 100 m (328 ft) above the shoreline and include sea caves, karst caves, over-hanging cliffs and "flowerpot" islands (Reid and Holland 1997, Kost *et al*. 2007).

Distribution, Status and Trends – Shoreline Cliffs

Lake System *Total/ % of Coast*	***Coastal Reaches[1]***	***Key Coastal Reaches[2]***	***Status/ Trend***
Superior 1390 km/21.5%	S1,S2,S3a,S3b,**S4a**,S4c,**S5b**,S6a,S6b,**S6c**,S7a,**S7b**,**S7c**,**S7d,S7e,LS**	S3a,S3b,S4c	Good/ Improving
Michigan 45 km/1.8%	**M2a**,**M2b**,**M3**,LM	M2b,M3,LM	Mixed/ Unchanging
Huron 2923 km/25.7%	**HG2a**,HG2b,**HG4b**,HG7a,**HG7b**,HG8a,HG9,HG10	HG8a,HG9	Mixed/ Improving
St. Clair	Does not occur.	-	-
Erie 118 km/4.4%	**E1**,E6a,E6b	E1,E6a	Mixed/ Unchanging
Ontario 226 km/5.7%	OS1,OS2,OS3a,**OS4a**,OS5	OS2	Mixed/ Unchanging

[1] = Based on coastal mapping and element occurrence (EO) data. Boldface denotes coastal reach with documented EOs.
[2] = Key Coastal Reaches include >10% of the total extent of the ecosystem in the context of each Great Lake. Some U.S. areas classified as cliffs appear to be bluffs (e.g. along lower Lake Michigan), and were re-classified as bluff based on physiographic descriptions and expert opinion. Some U.S. cliffs may be low cliffs (i.e. <1m (3.3 ft)), which in Ontario were classified as bedrock shore.

Four cliff communities have been documented in the Great Lakes region (NatureServe 2008) (Appendix A): 1) Great Lakes Shore Limestone – Dolostone Cliff community type occurs along the Bruce Peninsula, Manitoulin Island and the Niagara Gorge; 2) Basalt – Diabase Cliff community type is found along Lake Superior; 3) Granite – Metamorphic Cliff community type is found along the northern shoreline of Lake Superior and Huron; 4) Sandstone Cliff is found in the northern Great Lakes shorelines of the United States and Canada. The substrate is Precambrian sandstone, which in Michigan is exposed along the southern shoreline of Lake Superior.

Cliffs are a relatively common ecosystem along the Great Lakes, and include over 3,385 km (2,103 mi) of the coast. They are most abundant in the northern lakes. While none of the documented community types are listed as globally rare, several types have not been ranked. Limestone – dolostone and sandstone based communities appear to be the least common.

3.7 Shoreline Bluffs

Global Status: Apparently Secure (system has not been ranked)
Related Coastal Terrestrial Ecosystems: *Great Lakes Sand Beaches, Coastal Forests*
SOLEC 1996: Unconsolidated Shore Bluff

Background: Shoreline Bluffs are comprised of unconsolidated soil materials, including clay, till, silt, sand, gravel and loam. Bluffs tend to be relatively low in height (2-20 m (6.6-66 ft)), but in some areas can reach heights of up to 110 m (361 ft) (Reid and Holland 1997, NHIC 2008). Bluffs can be gently sloping to nearly vertical and can include a variety of topography including gullies and pinnacles (e.g. Chimney Bluffs along southern Lake Ontario). Steep slopes on bluffs are often bare and completely devoid of vegetation. The tops of bluffs and gently sloping bluff systems are often forested. Pioneer shrubs can be found in unstable populations along actively eroding bluffs. Bluff nesting birds such as bank swallows (*Riparia riparia*) and belted kingfishers (*Ceryle alycon*) use these systems.

Actively eroding bluffs are a source of sediments for beaches and are a key component in nearshore sediment processes. Some bluffs are protected by beach systems at their toe, which can reduce erosion (Reid and Holland 1997). Shore bluffs often contain seepage areas which can lead to the creation of wetland systems, including the unique hanging fens found in the shore bluffs at Bond Head on Lake Ontario in Ontario.

Distribution, Status and Trends – Shoreline Bluffs

Lake System *Total/ % of Coast*	***Coastal Reaches[1]***	***Key Coastal Reaches[2]***	***Status/ Trend***
Superior 108 km/1.7%	S1,S2,S3b,S4c,S6a,S6c,S7a,S7b,S7c,S7d	S1,S2,S7a	Mixed/ Unchanging
Michigan 354 km/14.2%	**M4a**, **M4b, M5**,M6a,M6b,M6c,M7a,M7b	M4a	Mixed/ Deteriorating
Huron 118 km/1.0%	HG1a,HG1b,HG1c,HG4a,HG4b,HG5,HG7a,HG7b	HG1b,HG1c,HG4a,HG5	Mixed/ Unchanging
St. Clair 53 km/4.0%	SC1,SC2,SC3	SC3	Mixed/ Deteriorating
Erie 337 km/12.5%	E1,E2,E3,E4,E5,E6a,E6b,E7a,E7b,E7c,E7d	E1,E4,E6a	Mixed/ Deteriorating
Ontario 324 km/8.2%	OS1,OS3a,OS3b,OS4a,OS4b,**OS5**, **OS6**,OS7	OS1,OS4a,OS4b	Mixed/ Deteriorating

[1] = Based on coastal mapping and element occurrence (EO) data. Boldface denotes coastal reach with documented EOs.
[2] = Key Coastal Reaches include >10% of the total extent of the ecosystem in the context of each Great Lake. Some U.S. areas classified as cliffs appear to be bluffs (e.g. along lower Lake Michigan), and were re-classified as bluff based on physiographic descriptions and expert opinion.

Bluffs have been poorly described around the Great Lakes, with few documented element occurrences and only one described type: Clay Shoreline Bluffs (NatureServe 2008) (Appendix A).

Shoreline bluffs occur along over 1,200 km (746 mi) of the coast, and can be found throughout the Great Lakes basin south of the Canadian Shield. Shoreline Bluffs have not been ranked, but given their very limited distribution, they are likely globally rare.

3.8 Lakeplain Prairies

Global Status: Critically Imperiled
Related Coastal Terrestrial Ecosystems: *Coastal Forests*
SOLEC 1996: Lakeplain Prairies

Background*:* Lakeplain prairies occur on glacial lakeplains in the southern Great Lakes. These lakeplain areas consist of rich and deep soil - generally a deep layer (1-3 m (3.3-9.8 ft)) of permeable sand with underlying heavy clay which excludes the water table and allows for seasonal flooding and drought (Kost *et al.* 2007). Flooding is common in the spring, often followed by dry conditions in the summer and fall. This flood-drought cycle excludes many trees and shrubs. Flooding in combination with frequent low intensity fires allows the prairie to retain open conditions (Kost *et al.* 2007).

Distribution, Status and Trends – Lakeplain Prairies

Lake System	***Coastal Reaches[1]***	***Key Coastal Reaches[2]***	***Status/ Trend***
Superior	Does not occur.	-	-
Michigan	M3,M4b,M5,M6b	M4b	Mixed/ Unchanging
Huron	HG6	HG6	Mixed/ Unchanging
St. Clair	SC2	SC2	Mixed/ Unchanging
Erie	E5	E5	Mixed/ Deteriorating
Ontario	Does not occur.	-	-

1 = Based on element occurrence (EO) data.
2 = Key Coastal Reaches include 5+ documented EOs, or the highest number of EOs for the lake.

Four Lakeplain Prairie vegetation communities have been documented (NatureServe 2008) (Appendix A). While some wet-mesic prairies extend inland, these four types are generally associated with coastal regions of the Great Lakes: 1) Lakeplain Mesic Oak Woodland and 2) Lakeplain Wet-Mesic Oak Opening are characterized by scattered oaks on moist soils; 3) Lakeplain Wet-Mesic Prairie are typically more open; 4) Lakeplain Wet Prairie is dominated by herbaceous cover including tall grasses and rich forb assemblages. Wetter sites are characterized by Lakeplain Wet Prairie and dominated by Prairie Cordgrass, Canada Bluejoint and sedges.

This ecosystem has a very limited global range, and is restricted to the southern portion of Lake Michigan and a narrow corridor from southern Lake Huron to Western Lake Erie. Most lakeplain prairies (and other tallgrass prairies in North America) were converted to agricultural areas in the 1800s, and only 1% of the original range remains today (Reid and Holland 1997). In Michigan approximately 0.5% of the original prairie present at the time of settlement remains (Comer *et al*. 1995). The St. Clair Clay Plains in Ontario once had over 35,000 ha (86,487 acres) of lakeplain prairie – today less than 2% remains (primarily on Walpole Island) (Tallgrass Ontario and NCC 2008). This ecosystem formerly occupied sites that are now urban and/or agricultural - areas around Chicago, Windsor and Detroit were probably dominated by lakeplain prairies – but are now heavily converted and few lakeplain prairie sites remain. Many of the remaining sites have been degraded due to alteration to groundwater hydrology and fire suppression, permitting increased dominance by woody species. There have been some recent improvements with better understanding, stewardship, land owner outreach and land securement (Cuthrell *et al*. 2000).

3.9 Arctic-Alpine Disjunct Communities

Global Status: Undetermined, probably Vulnerable
Related Coastal Terrestrial Ecosystems: *Bedrock Shores, Shoreline Cliffs (Basalt types)*
SOLEC 1996: Arctic – Alpine Disjunct Communities

Background: Arctic – Alpine Disjunct Communities occur in Lake Superior, in both Ontario and Minnesota. Populations of disjunct species have been noted from other locations, but communities are restricted to the cool shores of Lake Superior. These communities are relicts following the last ice age, and are found on islands, cliff, talus and other coastal habitats that support cold micro-climates. As the glaciers receded, vegetation that occurred along the ice margin either disappeared or followed the ice margin northward, to be replaced in the Lake Superior region by boreal forest. Only along the colder-than-normal micro-climates adjacent to the lake (and a few other specialized locations such as glaciere talus and some open cliff rims) did the conditions persist for which these species are adapted (Bakowsky 1998b). Vegetation is sparse and bare rock dominates. The richest sites usually exhibit the greatest diversity of physical structure, including crevices, rock pools, boulder fields and shore platforms. Few arctic – alpine disjunct animal species exist, but several species of disjunct snails including those in the *Vertigo* genus have been noted (NatureServe 2008).

Distribution, Status and Trends – Arctic-Alpine Disjunct Communities

Lake System	*Coastal Reaches*[1]	*Key Coastal Reaches*[2]	*Status/ Trend*
Superior	S2,S3a,S3b,S4a,S4c	S3a,S4c	Good/ Improving
Michigan	Does not occur.	-	
Huron	Does not occur.	-	-
St. Clair	Does not occur.	-	-
Erie	Does not occur.	-	-
Ontario	Does not occur.	-	-

[1] = Based on element occurrence (EO) data.
[2] = Key Coastal Reaches include 10+ documented EOs, or the highest number of EOs for the lake.

This community is well-documented from Ontario, with over 50 occurrences, but is not tracked in the U.S. NatureServe (2008) includes this community under Basalt (Conglomerate) Bedrock Lakeshore (Appendix A). This community occurs in many protected areas, and protection was increased through recent initiatives in Ontario including the creation of Lake Superior National Marine Conservation Area and several provincial Conservation Reserves. The new Marine Conservation Reserve protected some of the best examples of this community, including several plants species that were not protected elsewhere (Bakowsky 1998b). The Lake Superior North Shore Conservation Reserve (1,147 ha (2,834 acres)) also provides excellent representation of Arctic – Alpine Disjunct Communities (Foster and Harris 2002).

3.10 Atlantic Coastal Plain Disjunct Communities

Global Status: Critically Imperiled
Related Coastal Terrestrial Ecosystems: *Great Lakes Sand Beaches (small protected occurrences)*
SOLEC 1996: Atlantic Coastal Plain Communities

Background: Atlantic Coastal Plain Disjunct Communities are a suite of plants that have their primary distribution on the Atlantic seaboard, with scattered, disjunct populations in the Great Lakes. These populations were once connected, but became isolated as post glacial connections between the Great Lakes and Atlantic Ocean and Hudson River ended (Keddy 1991). In the Great Lakes, Atlantic Coastal Plain Disjunct Communities primarily occur on sandy or peaty shores with fluctuating water levels.

Distribution, Status and Trends – Atlantic Coastal Disjunct Communities

Lake System	Coastal Reaches[1]	Key Coastal Reaches[2]	Status/ Trend
Superior	Does not occur.	-	-
Michigan	M6a,M6b,M6c	all coastal reaches have one occurrence	Mixed/ Undetermined
Huron	HG9,HG10	HG9	Mixed/ Undetermined
St. Clair	Does not occur.	-	-
Erie	Does not occur.	-	-
Ontario	Does not occur.	-	-

[1] = Based on element occurrence (EO) data.
[2] = Key Coastal Reaches with the highest number of EOs for the lake.

Two Atlantic Coastal Disjunct Communities have been documented (NatureServe 2008) (Appendix A). Inland Coastal Plain Marsh is characterized by northern beaksedge, Virginia meadowbeauty (*Rhexia virginica*), longbeak beaksedge (*Rhynchospora scirpoides*) and Hall's bulrush (*Schoenoplectus hallii*). The other type, Bulblet Flatsedge Coastal Plain Sandy Pondshore, is reported from Ontario (NatureServe 2008), but it does not occur in Great Lakes coastal areas.

Atlantic Coastal Disjunct Communities are globally rare. These communities tend to be concentrated along the southern end of Lake Michigan, and inland lakes between the ancient Lake Algonquin shore and present-day Georgian Bay coast (Keddy and Sharp 1989). The Georgian Bay shoreline itself does host some of these communities, but is very high energy which makes it difficult for the seedbank to persist. The overall scarcity of moist sandy shorelines limits the distribution of these communities.

3.11 Rich Coastal Fens

Global Status: Imperiled – Critically Imperiled
Related Coastal Terrestrial Ecosystems: *Coastal Alvars*
SOLEC 1996: Not included (included as a coastal terrestrial feature by SOLEC in 1998; Reid et al. 1999)

Background: Coastal fens occur along level shorelines of northern Lake Michigan and Lake Huron (including southwestern Georgian Bay). There also appear to be a few scattered occurrences in southern Lake Superior in Wisconsin and on Isle Royal. These sites occupy embayments of open, sandy shorelines where limestone bedrock or cobble is at or near the surface. Shallow bedrock differentiates coastal fens from interdunal wetlands or panes, which occur on a sand substrate. Coastal fens are minerotrophic wetlands that receive groundwater inputs rich in calcium and magnesium carbonates and contain a rich assemblage of calciphilic plants. The hydrologic regime of coastal fens is directly linked to that of the Great Lakes. The water table varies with seasonal fluctuations in Great Lakes water levels including short-term changes due to seiches and storm surges, and long-term lake level fluctuations. Rich coast fens can expand and contract depending on lake levels and location (Mortsch *et al.* 2008).

Distribution, Status and Trends – Coastal Fens

Lake System	Coastal Reaches[1]	Key Coastal Reaches[2]	Status/ Trend
Superior	S6c*		Undetermined/ Undetermined
Michigan	M2b,M4b*	M2b	Mixed/ Undetermined
Huron	HG1d,HG2b	HG1d,HG2b	Mixed/ Deteriorating
St. Clair	Does not occur.	-	-
Erie	Does not occur.	-	-
Ontario	Does not occur.	-	-

[1] = Based on element occurrence (EO) data.
[2] = Key Coastal Reaches with the highest number of EOs for the lake.
* = may not be “rich” fen.

Coastal fens frequently occur as part of a larger coastal complex that may include Great Lakes marshes, bedrock shores, rich conifer swamp, and northern fen. The surrounding uplands of coastal fens are typically dominated by northern white cedar (*Thuja occidentalis*). Rich Coastal Fens include two documented vegetation communities (NatureServe 2008) (Appendix A). Shrubby-cinquefoil - Sweetgale Rich Shore Fen is dominated by low shrubs in association with graminoids. This community often occurs in complexes with the second vegetation community: Great Lakes Sedge Rich Shore Fen. The Sedge Rich Shore Fen occurs in wetter fens and is dominated by including Canada bluejoint (*Calamagrostis canadensis*), Kalm's lobelia (*Lobelia kalmii*), green sedge and twig-rush (*Cladium mariscoides*).

Both communities are considered globally rare (NatureServe 2008). Eleven high quality sites identified in Michigan and Wisconsin totalled 1,100 ha (2,718 acres) (Minc and Albert 1998). While poorly documented in Ontario, coastal fens have been recorded throughout the lower Great Lakes (Bakowsky 1995). The Ontario community of Coastal Meadow Marsh includes both shoreline fens and interdunal pannes, and some occurrences may include perched-prairie fens (Bakowsky 1995).

Although numerous examples of coastal meadow marshes occur in protected sites such as provincial parks, national wildlife refuges, and private nature reserves, not all of the types and rare species associations are represented in these areas (Bakowsky 1995).

3.12 Shoreline Alvars

Global Status: Imperiled – Critically Imperiled

Related Coastal Terrestrial Ecosystems: *Rich Coastal Fens, Bedrock Shores (limestone-dolostone types), Coastal Forests*

SOLEC 1996: Shoreline Alvars

Background: Alvars are naturally open habitats characterized by either a thin (less than 25 cm (9.8 in)), discontinuous or nonexistent covering of loamy sand or sandy loam soil over calcareous bedrock such as limestone or dolostone. Alvars can range from bare pavement to grassland to open woodland (NatureServe 2008). Vegetation consists mainly of sedges, grasses, mosses, lichens or small herbaceous plants (EC and USEPA 2005). Alvars are often subjected to flooding and/or ice scouring in winter and spring, and severe drought in summer (NHIC 2008).

Distribution, Status and Trends – Coastal Alvars

Lake System	*Coastal Reaches[1]*	*Key Coastal Reaches[2]*	*Status/ Trend*
Superior	Does not occur.	-	-
Michigan	M1,M2a,M3		Good/ Unchanging
Huron	HG2a,HG2b,HG4a,HG7a,HG7b,HG8a	HG2a,HG2b,HG4a,HG7b,HG8a	Good/ Improving
St. Clair	Does not occur.	-	-
Erie	E6b	E6b	Mixed/ Improving
Ontario	OS1,OS3a,OS3b		Mixed/ Unchanging

[1] = Based on element occurrence (EO) data and Reschke *et al*. 1999.
[2] = Key Coastal Reaches include endemic coastal community types.

Twelve of the 13 alvar vegetation communities identified in the Great Lakes basin occur on or near the coast. However, of these 12 systems only three are generally restricted to coastal terrestrial ecosystems: 1) Scrub Conifer/ Dwarf Lake Iris Alvar Shrubland; 2) Creeping Juniper – Shrubby – Cinquefoil Alvar Pavement; and 3) Chinquapin Oak – Nodding Onion alvar woodland (Natureserve 2008) (Appendix A).

Over 80 alvar occurrences have been documented from the Great Lakes coast. This ecosystem has a very limited range and is restricted to the shores of eastern Lake Ontario, the western Lake Erie Islands, the Door Peninsula, the limestone/dolostone arch from the southern Bruce Peninsula and Manitoulin Island to Drummond Island and very locally along Lake Michigan and Huron and the northeastern shore of Michigan's lower peninsula. All of the coastal endemic systems are considered globally imperiled. Scrub Conifer/Dwarf Lake Iris Alvar Shrubland is restricted to northern Michigan, and in Ontario on the southern shores of Manitoulin Island and the Bruce Peninsula. Ten occurrences of this community were documented, with a total area of 330 ha (815 acres). Creeping Juniper – Shrubby – Cinquefoil Alvar Pavement only occurs on the Bruce Peninsula, Manitoulin Island, the islands north of Manitoulin and at three sites in northern Michigan. Twenty-four occurrences of this community were documented, with a total area of about 1,093 ha (2,700 acres). Chinquapin Oak – Nodding Onion alvar woodland is found only in western Lake Erie on Pelee Island in southern Ontario, Canada (Reschke *et al*. 1999). This one occurrence has a total area of 12 ha (30 acres).

There has been significant progress in alvar conservation since the release of the technical report by the International Alvar Initiative (Reid and Potter 2007, Reschke *et al*. 1999). This includes protection of several large coastal alvars along the southern shore of Manitoulin Island and the Bruce Peninsula. Almost all of the alvars on Pelee Island are also now protected. Few coastal alvars have been protected in eastern Lake Ontario.

3.13 Coastal Rock Barrens

Global Status: Vulnerable – Apparently Secure
Related Coastal Terrestrial Ecosystems: *Bedrock Shores, Shoreline Cliffs, Alvars, Coastal Forests*
SOLEC 1996: Coastal Gneissic Rocklands (modified to include other coastal rocklands)

Background: This ecosystem includes coastal rock barrens that are within 2 km (1.2 mi) of the Great Lakes. While rock barrens both on and off the Canadian Shield have been included in this analysis, communities based on sedimentary rock (e.g. limestone and dolostone) are generally captured as alvar or open coastal forests. Rock barrens are not restricted to the coast in the Great Lakes region (NCC 2006), but coastal occurrences tend to be variants of inland types due to greater wind and storm exposure, which often limits or stunts tree growth (Jalava *et al*. 2005, Catling and Brownell 1999).

Distribution, Status and Trends – Coastal Rock Barrens

Lake System *Area (ha)/ % Coast*	***Coastal Reaches[1]***	***Key Coastal Reaches[2]***	***Status/ Trend***
Superior 9,474/ 1.6%	Sedimentary: S1,S2,S3b,S5a,S6a,S6c,S7a,S7d,S7e Canadian Shield:S1,S2,S3a,S3b,S4a,S4b,S4c,S5a,**S5b**,S6a,S6c, **S7a**,**S7b**,**S7c**	S1,S3a,S3b	Good/Improving
Michigan 8,974/ 2.4%	Sedimentary:M1,M2a,M2b,M3,M7a,LM	M1,M2a, M2b,M7a,LM	Undetermined*
Huron 73,299/ 9.8%	Sedimentary:HG1a,HG1b,HG1d,HG2a,HG2b,HG3,HG4a,HG4b,HG7a,HG7b,HG7c,HG10 Canadian Shield: HG8a,**HG9**	HG8a,HG9	Good/Improving
St. Clair	Does not occur.	-	-
Erie 942/ 0.3%	Sedimentary: E1,E2,E6,E7	E6	Undetermined*
Ontario 1,198/ 0.3%	Sedimentary: OS1,OS3a,OS3b,OS4b,OS4c,OS5,OS6,OS7 Canadian Shield: **OS2**,OS3a	OS1,OS3a, OS7	Undetermined*

[1] = Based on land cover mapping and element occurrence (EO) data. Boldface denotes coastal reach with documented EOs.
[2] = Key Coastal Reaches include >10% of all ecosystem.
* = Status assessment was not completed for this ecosystem south of the Canadian Shield.

Two major coastal rock barren types have been described on the Canadian Shield (NatureServe 2008) (Appendix A). 1) Gneissic or granitic barrens typically have over 30% bare bedrock and are characterized by common juniper with scattered red oak and white pine. Where soil does exist, it tends to be thin lacustrine sand. Depressions in the rock are often flooded after the spring thaw and rainfall (Macdonald 1986, NHIC 2008). This community is currently classified as Common Juniper Rocky Krummholz (NatureServe 2008), but inventory work from Ontario and Michigan have not been integrated, and further characterization of this ecosystem is required. Recent work has identified additional community types (Jalava *et al*. 2005). 2) Basalt bedrock systems are found along the Lake Superior shorelines of the United States and Canada where it occurs between bedrock shores and forest. Soils are thin and exposed areas of bedrock are common. This community consists of scattered trees, shrub thickets, and a layer of graminoids, mosses, and lichens. Common trees include balsam fir (*Abies balsamea*), paper birch (*Betula papyrifera*), white spruce (*Picea glauca*), red pine, white pine, red oak and eastern white cedar (*Thuja occidentalis*). The bedrock includes basalt, volcanic conglomerates, and localized rhyolites (Kost *et al*. 2007). It is unknown if any of the documented types are restricted to the coast. Types that are characterized based on wind-stunted tree growth (i.e. Krummholz) are probably a coastal type.

Coastal rock barrens on granite and basalt have been poorly described and documented. While these systems can be locally abundant, they do have a restricted range in the basin. The largest examples occur along the coast of northern and eastern Georgian Bay, the Thousand Islands area of Lake Ontario at the St. Lawrence River (Reid and Holland 1997, NHIC 2008), and parts of Lake Superior (NatureServe 2008). While development continues to occur in some areas, large areas have also been protected in recent years.

3.14 Great Lakes Coastal Forests
Global Status: Unknown
Related Coastal Terrestrial Ecosystems: *Coastal Back Dune Complexes, Bedrock Shores, Cobble Forests, Shoreline Cliffs, Shoreline Bluffs, Lakeplain Prairies, Shoreline Alvars, Coastal Rock Barrens*
SOLEC 1996: not included

Background: Approximately 61% of the Great Lakes basin is characterized by forest cover (Zuccarino-Crowe and Han 2007). These forests play a critical role in water quality and quantity within the watershed, and forest cover along tributaries is recognized as a key indicator of stream health (Environment Canada 2004). While we are beginning to get a better understanding of the link between the health of coastal lands and nearshore aquatic systems (Introduction), the ecology of Great Lakes coastal forests is poorly understood. Several studies have recognized the unique variations of forests along the Great Lakes coast. These variations are expressed in differences in structure and composition (particularly in the north), and specialized functions due to their close proximity to the lakes. The localized climactic variations in the coast, such as strong and persistent winds and more frequent lightening strikes and fire, alter forest structure (Kost *et al.* 2007). Dense fog and high humidity can also influence forests. Coastal forest characteristics documented from Lake Superior include a high richness and abundance of bryophytes, formation of peatlands (OMNR 1988a), stunted, "krummholz" trees (OMNR 1988b) and the development of unique forest stands on raised shoreline features (e.g. cobble ridges). Coastal forests also provide important functions for migratory songbirds due to the seasonal abundance of emerging aquatic insects. A recent study in western Lake Erie identified that forest patches near the coast are key migratory stopover sites (Ewert *et al.* 2005). While no endemic coastal forest types have been described, there is good evidence that coastal occurrences can be variants of communities that may be more widespread and common throughout the basin.

Distribution, Status and Trends – Great Lakes Coastal Forests.

Lake System *Area (ha)/ % Coast*	***Coastal Reaches[1]***	***Key Coastal Reaches[2]***	***Status/ Trend***
Superior 467,536/ 80.1%	All	S1,S2,S3a,S3b,S4a,S4c,S5b, S6b,S6c,S7a,S7c,S7d,S7e,LS	Good/ Improving
Michigan 110,173/ 28.9%	All	M1,M3,LM	Mixed/ Deteriorating
Huron 473,554/ 59.9%	All	HG2a,HG2b,HG3,HG4a,HG4b,HG5,HG7a,HG8a,HG9,HG10	Mixed/ Unchanging
St. Clair 6,727/ 9.5%	All	SC2	Poor/ Deteriorating
Erie 35,305/ 14.2%	All	E7d	Poor/ Deteriorating
Ontario 85,723/ 24.0%	All	OS7	Mixed/ Unchanging

[1] = Based on land cover mapping .
[2] = Key Coastal Reaches include >70% natural cover (include non-forested systems), or the coastal reach with the highest amount of land cover.

One type of coastal forest has been described: White Spruce – Balsam Fir Conglomerate Woodland (Faber-Langendoen 2001) which occurs between bedrock coasts and inland forests of Lake Superior (Appendix A). These forests are characterized by thin soils, exposed bedrock and open canopy.

There are approximately 1.2 million ha (2,965,265 acres) of coastal forests (defined as 2 km (1.2 mi) inland), comprising approximately 48% of the Great Lakes coastal terrestrial zone. Some of these forests overlap other coastal terrestrial ecosystems such as Coastal Back Dune Systems. There are significant differences in the distribution of this system, which is entirely attributable to changes in land use. While the coast of Lake Superior is still dominated by forests, Lake Michigan and Huron have higher forest cover in the north, while Lake Ontario and Erie have greater cover in the eastern portion of their shores.

Pressure [1]	
Major/ Widespread	(red)
Minor/ Local	(orange)
Indirect	(yellow)
Unknown	?

Pressure [1]	Great Sand Lakes Beach	Great Lakes Foredunes	Coastal Back Dune Complexes	Bedrock Shores	Cobble Beaches	Shoreline Cliffs	Shoreline Bluffs	Lakeplain Prairies	Arctic-Alpine Disjunct Communities	Atlantic Coastal Plain Disjuct Communities	Rich Coastal Fens	Shoreline Alvars	Coastal Rock Barrens	Coastal Forests
1. Residential & Commercial Development														
1.1 Housing & Urban Areas	Indirect		Major				Indirect					Minor		Major
1.2 Commercial & Industrial Areas							Indirect	Minor						
1.3 Tourism & Recreational Areas	Indirect	Major	Major	Indirect	Indirect	Indirect	Indirect				Minor	Minor	Minor	Minor
2. Agriculture & Aquaculture														
2.1 Annual & Perennial Non-Timber Crops							Indirect	Major						
2.3 Livestock Farming & Ranching			Minor											
3. Energy Production & Mining														
3.2 Mining & Quarrying	Minor	Minor	Minor	Minor		Minor								Minor
3.3 Renewable Energy				Minor		Indirect	Indirect							Minor
4. Transportation & Service Corridors														
4.1 Roads & Railroads		Minor	Major	Minor		Indirect	Indirect	Minor			Major	Minor	Minor	Major
5. Biological Resource Use														
5.2 Gathering Terrestrial Plants							Minor					Minor		
5.3 Logging & Wood Harvesting			Major			Indirect								Major
6. Human Intrusions & Disturbances														
6.1 Recreational Activities	Major	Major	Major	Minor	Minor	Minor		Minor		Minor	Major	Minor	Minor	Minor
7. Natural System Modifications														
7.1 Fire & Fire Suppression			Major					Major				?		
7.2 Dams & Water management/ Use	?	?			?			Major		Major	Major			
7.3 Other Ecosystem Modification	Major	Major	Major											
8. Invasive & Other Problematic Species & Genes														
8.1 Invasive Non-Native/ Non-native Species	Major	Major	Major	Minor	Minor	Minor	Minor	Minor		Minor	Major	Minor		Minor
8.2 Problematic Native Species														Minor
9. Pollution														
9.1 Household Sewage & Urban Waste Water			Minor								Minor			
9.3 Agricultural & Forestry Effluents								Minor						
9.4 Garbage & Solid Waste												Minor		
11. Climate Change & Severe Weather														
11.1 Habitat Shifting & Alteration		?	?		?						X			?
11.4 Storms & Flooding		?												

Table 3. Summary of Pressures to Coastal Terrestrial Ecosystems.
[1] = Pressure categories based on Unified Classification of Direct Threats (IUCN-CMP 2006).

Pressures

Coastal terrestrial ecosystems are some of the most threatened in the Great Lakes region because they occupy the same land-water interface where humans establish communities, industry and recreational land uses. This has resulted in the loss and degradation of many habitats that are of North American and global conservation concern, including endemic Great Lakes coastal habitats. In addition to their high intrinsic values, the status of coastal terrestrial ecosystems influences the quality and diversity of nearshore waters, and has influences on some aerial migratory species such as songbirds that use coastal areas as stop-over habitat.

An automated analysis of pressures on coastal terrestrial ecosystems was conducted through GIS based on general landcover and shoreline modification within each coastal eco-reach. Pressures were measured based on the percentage of urban cover and agricultural cover within 2 km (1.2 mi) of the coast, and the percentage of shoreline that was classified as "artificial". Urban land cover and artificial shorelines were scored higher than agricultural land uses as pressures to coastal terrestrial ecosystems. Coastal ecoreaches that occur in Canada and the United States were assessed separately. There is a large positive correlation between shoreline modification and urban land use (coefficient of correlation = 0.58) and a large negative correlation between shoreline modification and natural cover (coefficient of correlation = -0.67). Agricultural land use has a low correlation to artificial shorelines.

Based on this analysis the coastal ecoreaches under the greatest pressures (top 80th percentile) include the Duluth area in Lake Superior (S6a), southwestern portion of Lake Michigan (M5, M4b, M4a), the western and northern coast of Lake Ontario (OS4a, OS4b), the southern shore of Lake Erie (E7a, E7b, E7c), the Niagara River in the United States (E1), the Detroit and St. Clair Rivers (SC1, SC3), western Lake Erie in the U.S. (E6a, E6b) and Lake St. Clair in the U.S. (S2). These high pressure rankings are based on a high percentage of urban land cover (average 47.8%) and artificial shore (average 31.5%).

Coastal ecoregions with the lowest pressures include most of Lake Superior (S2, S3a, S3b, S4a, S4b, S4c, S6c, S7a, S7c, S7d, S7e), St. Marys River in the U.S. (S1), eastern Georgian Bay and the North Channel (HG8a, HG9), western Bruce Peninsula and Manitoulin Island (HG2a, HG2b, HG7a), northwestern Lake Huron (HG4a, HG3) and northern Lake Michigan islands and coast (M1, LM). These low pressure rankings are based on a low percentage of urban land cover (average 2.3%) and artificial shore (average 1.7%). These coastal terrestrial ecosystems also have lower agricultural cover.

The project also assembled information on protected areas along the Great Lakes coast to provide an assessment of land protection by regulated public lands (e.g. National Parks, Conservation Reserves, State Park, National Forest etc). While these designations do not protect coastal terrestrial ecosystems from all pressures, and variable resources uses are permitted, these areas are generally protected from future development. Land protection is much higher along coasts in the upper Great Lakes and many coastal ecoreaches have > 50% of the total area in public lands/ protected areas (e.g. S3a, S3b, S4b, S5b, HG9). In the lower lakes, only smaller coastal ecoreaches based on Lake Erie sandspits have higher levels of land protection (i.e. Long Point and Presque Isle). Most coastal ecoreaches in the lower Great Lakes have < 5% of the total area in public lands/ protected areas (e.g. E2, OS1, HG1c). The St. Mary's River also has little public lands/ protected areas.

The review of pressures on the coastal terrestrial ecosystems is based on a review of the literature and discussions with experts (Table 3). Identified pressures for each coastal terrestrial ecosystem were categorized into standard classes (IUCN-CMP 2006) based on their scope and potential severity.

The following provides a summary of information from the literature on pressures to coastal terrestrial ecosystems:

Great Lakes Sand Beaches: While the beach ecosystem is very dynamic and resilient to change, it is very susceptible to changes in coastal processes that reduce sand transport and deposition. Threats to sand beaches include: off-leash dogs and hyper-abundant populations of raccoon (*Procyon lotor*) that disturb fauna such as piping plover (*Charadrius melodus*) (Kost *et al*. 2007); heavy recreational use that disturbs fauna and tramples vegetation (Kost *et al*. 2007, WDNR 2006); off-road vehicles that disturb vegetation (Kost *et al*. 2007, WDNR 2006); beach grooming which removes vegetation and habitat (Kost *et al*. 2007, WDNR 2006); sand mining (WDNR 2006); creation of artificial shorelines and shoreline hardening which leads to a loss in the longshore sediment transport processes which naturally erode and replenish beaches and support their unique dynamic processes; invasive plants, zebra (*Dreissena polymorpha*) and quagga mussels (*Dreissena bugensis*) which change beach substrates; and housing development (WDNR 2006).

Beaches tend to become thinner and more narrow "down current" from jetties, breakwaters and other hardened shorelines. Protective beaches can be eroded, increasing wave energy onto backbeach dune and wetland systems. This problem is particularly pertinent on the sand beaches of Lake Ontario, Lake Erie and somewhat in western Lake Superior.

Great Lakes Foredunes and Coastal Backdune Complexes: Dunes face an extensive threat from human disturbance, and are being lost to development, sand mining, recreational trampling, invasive species (e.g. baby's breath (*Gypsophila paniculata*), spotted knapweed (*Centaurea stoebe*)), shoreline condominium and second home development, off-road vehicles and recreational use (Silk 2007). All of these practices are known to impact, level, degrade or destroy the dunes, and a loss of structure and dune vegetation leads almost immediately to dune erosion (Silk 2007). Blowouts can occur very quickly on a dune on which vegetation has been disturbed, and this gap is often immediately excavated by wind, leading to further loss of sand and vegetation and resulting in a large depression in the dune structure (Hill 1993). Erosion is a very serious threat for this community type as dunes can be a challenge to restore, and the loss of unique species can be irreversible. Boardwalks and dune walkovers have been constructed over some sand dunes and active restoration via the planting native beach grass and removal of invasive species has been shown to help preserve and restore dune ecology (Silk 2007). Shoreline alterations impacting coastal processes and beach raking have also been identified as pressures (Peach 2006). Other threats include deer browse, cottage development, high controlled water levels and invasive alien species (Bakowsky 1998a). Ridges and wetland swales have been degraded by off-road vehicles, heavy foot-traffic and invasive species (Kost *et al*. 2007). The invasive common reed (*Phragmites australis*) may establish in low interdunal areas and expand onto upland dunes. Many backdune areas are under threat of development for cottages and second homes.

Bedrock Shores: The threats to bedrock shores include trampling of limited vegetation by humans, invasive species and the use of off-road vehicles (Kost *et al*. 2007, WDNR 2006). Development of adjacent shorelines contributes to these pressures. Some localized aggregate operations along the coast also impact this system. Invasive species are more likely to occur at sites that lack a forest buffer (Kost *et al*. 2007)

Cobble Beaches: Cobble beaches ecosystems are resilient ecosystems because they are adapted to very dynamic conditions. Shoreline development can result in increased disturbances to cobble beaches including the removal of cobble and dock construction. Development can also increase associated human activity, such as shoreline recreation, pets (which can disturb fauna), off-road vehicle usage, and the introduction of invasive species (Adams 2007, Kost *et al*. 2007). Some cobble beaches could be impacted by regulation of Great Lakes water levels.

Shoreline Cliffs: Shoreline cliffs are highly enduring features with little commercial value (e.g. timber). Threats tend to be associated with land uses on adjacent lands and recreational uses. These include development, logging of adjacent forests causing cliff top erosion, foot traffic on cliff edges, rock climbing, quarrying and invasive plants (Kost *et al*. 2007, WDNR 2006). Some sections of shoreline cliffs are at risk for development, but for the most part the difficulty and instability of the terrain allows for some level of protection from human intervention. There may be a potential threat to the flora of diabase cliffs in Lake Superior through the inadvertent application of aerial herbicide, which is sometimes used as part of a silvicultural treatment in regenerating or re-planted forests (Bakowsky 2002).

Shoreline Bluffs: Threats which can affect sensitive bluff ecosystems include shoreline development, bluff-top development, mining and quarrying, and problems with invasive species. However, the main threats are associated with erosion. Clearing of adjacent lands for agriculture, deforestation, recreational facilities, trails and roads can cause disturbance of bluffs and tablelands which can exacerbate erosion (WDNR 2006). Further disturbance encourages erosion, often to the point where deep gullies are formed and changed to ravine systems, by which water will further erode the bluff. Shoreline stabilization and armouring is common at the base of many bluffs.

Lakeplain Prairies: The main threat to lakeplain prairies is continued conversion, alterations to groundwater and fire suppression (Albert and Kost 1998, Albert 1998). Ditching near existing sites, including protected areas, is one of the key threats, as this can increase the cover of woody species by lowering the water table. Beavers can also impact the landscape with flooding, which can suppress fires necessary to maintain open habitat, and increase the size of adjacent swamp and marsh communities at the cost of the loss of lakeplain prairie habitat. Grazing has also been identified as a localized pressure (WDNR 2006).

Arctic – Alpine Disjunct Communities: There is some evidence of trampling and uprooting of sensitive plant species in more highly used recreational areas. Second home development has recently become a significant threat to the Lake Superior coast. Second home development on the U.S. shore of Lake Superior has spiked markedly in price, thus shifting development pressure to the Canadian shore of Lake Superior. Large portions of the coast are unprotected, so this threat is likely to continue to increase in magnitude unless some level of protection is offered to the Lake Superior shores which support significant plant communities. Climate change could have a negative impact on this community.

Atlantic Coastal Plain Disjunct Communities: Threats to Atlantic coastal plain disjunct communities include shoreline recreational and residential development, which directly destroys habitat, especially for those species that tend to occupy the drier portion of the community gradient. Disturbance of these areas from recreational activities such as off-road vehicles, hiking, and boating can also be problematic for the generally sensitive plant species. Stabilized water levels are perhaps the most severe problem, as these plants rely on fluctuating water levels to maintain their populations, and periodic flooding kills woody species, which shade out coastal plain disjuncts (Kost *et al.* 2007, Reid and Holland 1997). Invasive species tolerant of periodic flooding have the potential to outcompete native species.

Rich Coastal Fens: Pressures to rich coastal fens include alterations to hydrology, development, road construction and upgrades, off-road vehicles and invasive species (Kost *et al*. 2007, Bakowsky 1995). The hydrology of these systems is very specific and contruction adjacent to the fen can result in hydrological changes that drastically alter the vegetation. Off-road vehicles can create ruts that alter surface flows. These systems are also vulnerable to invasive species, especially if the hydrology has been altered. Invasive species of greatest concern include glossy buckthorn (*Frangula alnus*), common reed, reed canary grass (*Phalaris arundinacea*), purple loosestrife (*Lythrum salicaria*) and narrow-leaved (*Typha* angustifolia)/ hybrid cattail (*Typha x glauca*) (Kost *et al*. 2007). Nutrient cycles and plant communities could also be disrupted by atmospheric deposition of nitrogen which could alter native plant dominance and promote invasive species.

Shoreline Alvars: Range-wide pressures to coastal alvar ecosystems are: development, off-road vehicles, grazing and browsing, exotic species, plant collecting and forestry (Reschke *et al*. 1999). Fire probably once played a very important role in limiting tree establishment in grassland alvars (Kost *et al*. 2007), but years of fire suppression have likely converted many grassland alvars to wooded ones. Many coastal alvars have been protected since the International Alvar Initiative (Reschke *et al*. 1999).

Coastal Rock Barrens: Threats to this coastal terrestrial ecosystem are mainly from shoreline development and recreational uses such as campsites and boat launches (Reid and Holland 1997, NHIC 2008). Other pressures include flooding due to dam construction, mineral extraction, fire suppression and recreational development (Catling and Brownell 1999), off-road vehicles and invasive species (Kost *et al*. 2007). The importation of fill for cottage septic systems may be a significant vector for invasive plants.

Coastal Forests: Pressures to coastal forests highly vary because of its wide distribution and diversity. In the south, development, deer browse and invasive species are key pressures. Some invasive insects, such as emerald ash borer (*Agrilus planipennis*), could alter the composition of large areas of forest. In northern Great Lakes coastal forests, incompatible forestry and mining are the major pressures. Climate change could alter micro-climactic conditions.

Management Implications

Understanding of the coastal terrestrial ecosystems of the Great Lakes has greatly increased in the last decade, and there have been significant increases in the amount of protected areas, improvements in management, greater recognition in policy and better community support and engagement in conservation. While this has reduced pressures for some coastal terrestrial ecosystems in some areas, these efforts need to be expanded. Since 1996, several important examples of Great Lakes coastal ecosystems have been significantly altered or destroyed by residential and second home development including dunes, bedrock beaches and coastal forests. There are also increasing threats related to wind development projects. Invasive species, including within most protected areas, continue to be a high threat.

Most of the growth in protected areas since 1996 has occurred in Ontario through the Ontario Living Legacy program (OMNR 1999) which resulted in the designation of several large coastal areas as Provincial Parks, Provincial Park additions, Conservation Reserves and Enhanced Management Areas. Some of the larger areas include Lake Superior Archipelago Conservation Reserve (51,577 ha (127, 450 acres)), Killarney Coast and Islands Provincial Park (13,791 ha (34,078 acres)), North Channel Inshore Waterway Provincial Park (7,132 ha (17,624 acres)), Lake Superior Shoreline Enhanced Management Area (19,605 ha (48,445 acres)) and the designation of the Lake Superior National Marine Conservation Area. Other protection efforts have been underway in the United States, including protection of much of the shoreline of the Keweenaw Peninsula, Michigan and application of conservation easements to many shoreline areas along the Detroit River. While land protection reduces some potential pressures to such as incompatible development, effective management of protected areas is required to protect the health of coastal terrestrial ecosystems.

Some of the management implications for consideration of future action are:

- There needs to be a binational effort to classify and map coastal terrestrial ecosystems of the Great Lakes. This project assembled the best available information, but these datasets are inconsistent in their approach and classification between Canada and the United States. Several ecosystem types are still relatively poorly understood and may require the description of additional types (e.g. bedrock shores). Other modifications to Great Lakes coastal classifications need to occur to better reflect ecosystem structure and composition. For example, cobble beaches are grouped by geology, but it has been recognized that structure is probably a more important determinant of vegetation communities (Kost *et al*. 2007) and better reflects coastal processes.

- Several coastal areas of the Great Lakes have not been fully inventoried. Information in this report can be used to identify potential sites in need of further inventory. For example, several coastal ecoreaches in Lake Superior (e.g. S1, S3b, S4a, S4c) have large areas of cobble beach, but no element occurrences (EOs) have been documented. While most coastal ecoreaches on Lake Michigan have EO data for sand beaches, only five of the 17 coastal eco-reaches on Lake Huron that have sand beaches have EO information (e.g. coastal ecoreach HG5 is a large sand beach area with no EO data). There needs to be a focussed effort to inventory coastal ecosystems, particularly those of global conservation concern. This information is needed to better inform management and policy decisions.
- Land protection and management of key sites needs to be a priority in the next ten years. Residential and recreational developments are rapidly expanding in many areas. Opportunities to protect some of these places will be lost. Coastal terrestrial ecosystems should be a focus of land conservation in the Great Lakes.
- Many important coastal terrestrial ecosystems are within protected areas and public lands. These sites need to have effective management plans that identify and mitigate potential threats, in particular invasive species and incompatible recreation.
- While coastal classification schemes and the approach of this report examine systems as separate units, in many places these ecosystems occur as diverse ecosystem complexes. Conservation of these large, diverse landscapes should be a priority. The integrity of many coastal systems is greatly enhanced by maintaining their landscape context, including forested buffers.

Comments from the authors

This report has generated information that can be used to report on each coastal ecoreach (e.g. length of coastal terrestrial ecosystems, pressures index, land cover, protected lands). This information could be used to provide contextual reports for each coastal ecoreach.

Acknowledgments

Authors:
Dan Kraus, Nature Conservancy of Canada – Ontario Region (Guelph, ON), dan.kraus@natureconservancy.ca
Gary White, Nature Conservancy of Canada – Ontario Region (Guelph, ON), gary.white@natureconservancy.ca

Contributors:

Dave Ewert, The Nature Conservancy
Rachael Franks Taylor, The Nature Conservancy
Bonnie Henson, Ontario Natural Heritage Information Centre
Mary Harkness, The Nature Conservancy

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Appendix A: Classification of Great Lakes Coastal Terrestrial Ecosystems

Ecosystems Addressed in this Report *SOLEC 1996 Name*	**Ecological System**[1] Vegetation Community [Common Name (Global Rank)[2]]	**Great Lakes State/ Provincial Classification**[3]	**Notes**
Great Lakes Sand Beaches *Sand Beaches*	**Great Lakes Dune** Great Lakes Beach (G3) Northern Great Lakes Dune Grassland (GNR)	Beach/ Shore Dunes, Great Lakes Type (IL) Sand /Gravel Beach (MI) Sand Beach (MN) Lake Beach – Sand Subtype (MN) Sand Beach (NY) Beach-Dune Community (OH) Sea Rocket Open Mineral Shoreline Type (ON) Reed-canary Grass Mineral Open Beach Type (ON) Great Lakes Sand Spit (PA) Great Lakes Sparsely Vegetated Beach (part of Great Lakes Region Beach-Dune-Sand Plain Complex) (PA) Great Lakes Beach (WI)	Primary sand beach below high water mark.
Great Lakes Foredunes *Sand Dunes*	**Great Lakes Dune** Great Lakes Beachgrass Dune (G3G5) Cottonwood Dune (G1G2) Sand Cherry Dune Shrubland (G2Q) Great Lakes Juniper Dune Shrubland (G3G4) Northern Great Lakes Dune Grassland (GNR) Shrub Dune Sparse Vegetation (GNR)	Beach/Shore Dunes, Great Lakes Type (IL) Primary Dune – Lake (IN) Open Dunes (MI) Great Lakes Dune (MI) Beachgrass Dune (MN) Juniper Dune Shrubland (MN) Great Lakes Dune (NY) Beach-Dune Community (OH) Little Bluestem-Switch Grass-Beachgrass Open Dune Type (ON) Little Bluestem-Long-leaved Reed Grass-Great Lakes Wheatgrass Open Dune Type (ON) Sand Dropseed - Flat Stemmed Bluegrass Open Sand Dune Type (ON) Sand Cherry Shrub Sand Dune Type (ON) Hop-tree Shrub Sand Dune Type (ON) Willow Shrub Sand Dune Type (ON) Dogwood Shrub Sand Dune Type (ON) Juniper Shrub Sand Dune Type (ON) Red Cedar Treed Dune Savanna Type (ON) Cottonwood Treed Dune Savanna Type (ON) Balsam Poplar Treed Dune Type (ON) Hackberry - Basswood - Oak Treed Sand Dune Type (ON) Sand Dune (PA) Great Lakes Region Bayberry – Cottonwood Community (part of Great Lakes Region Beach-Dune-Sand Plain Complex) (PA) Great Lakes Dune (WI)	Herbaceous and shrub dominated dunes above high water mark.
Coastal Back Dune Complexes *Sand Barrens*	**Great Lakes Dune and Swale** **Northern Great Lakes Interdunal Wetland** Great Lakes Wooded Dune and Swale Complex (G3) Great Lakes Dune Pine Forest (G3Q) Great Lakes Pine Barrens (G2) Interdunal Wetland (G3?)	Alkaline Shoredunes Pond/ Marsh, Great Lakes Type (IL) Barrens, Central Midwest Type (IL) Wetland Panne (IN) Interdunal Wetland (MI) Wooded Dune and Swale Complex (MI) Great Lakes Barrens (MI) Beach Ridge Shrubland (Lake Superior) (MN) Beach Ridge (PA) Great Lakes Region Bayberry – Mixed Shrub Palustrine Shrubland* (PA) Great Lakes Region Palustrine Sandplain* (PA) Great Lakes Region Dry Sandplain* (PA) * part of Great Lakes Region Beach-Dune-Sand Plain (PA) Great Lakes Barrens (WI) Great Lakes Ridges and Swale (WI) Great Lakes Barrens (WI) Interdunal Wetland (WI)	Defined by stabilized back dunes and includes a complex of upland and wetland communities. Modified from 1996 report to include all communities that occur in complex.
Bedrock Shores *Bedrock and Cobble Beaches*	**Great Lakes Alkaline Rocky Shore and Cliff** Great Lakes Limestone - Dolostone Bedrock Shore (G3) Great Lakes Basalt - Conglomerate Bedrock Shore (G4G5) **Great Lakes Acidic Rocky Shore and Cliff** Great Lakes Granite - Metamorphic Bedrock Shore (GNR) Great Lakes Sandstone Bedrock Shore (G3G4)	Cobble Shore (NY) Basalt Bedrock Lakeshore (MI) Limestone Pavement Lakeshore (MI) Volcanic Conglomerate Bedrock Lakeshore (MI) Lake Superior Rocky Shore (MN) Dry Bedrock Shore (Lake Superior) (MN) Wet Rocky Shore (Lake Superior) (MN) Lake Beach (Lake Superior) Bedrock Subtype (MN) Shrubby Cinquefoil Carbonate Open Bedrock Beach Type (ON) Sandstone Bedrock Beach/ Bar Ecosite (ON) Granite Bedrock Beach/ Bar Ecosite (ON) Great Lakes Alkaline Rockshore (WI) Bedrock Shore (WI)	Typically bedrock that occurs above the high water mark or storm surges. Modified from 1996 report (cobble and bedrock split) because of significant differences in vegetation communities. Two major sub-types can generally be defined by coastal unit.

Ecosystems Addressed in this Report *SOLEC 1996 Name*	**Ecological System[1]** Vegetation Community [Common Name (Global Rank)[2]]	**Great Lakes State/ Provincial Classification[3]**	**Notes**
Cobble Beaches *Bedrock and Cobble Beaches*	**Great Lakes Alkaline Rocky Shore and Cliff** Great Lakes Limestone Cobble –Gravel Shore (G2G3) Great Lakes Basalt – Diabase Cobble – Gravel Shore (G4G5) **Great Lakes Acidic Rocky Shore and Cliff** Great Lakes Non-alkaline Cobble – Gravel Shore (G2G3) Great Lakes Sandstone Bedrock Shore (G3G4)	Limestone Cobble Shore (MI) Sandstone Cobble Shore (MI) Cobble Beach (MI) Gravel/ Cobble Beach (Lake Superior) (MN) Wet Rocky Shore (Lake Superior) Cobble Subtype (MN) Lake Beach (Lake Superior) Gravel-Cobble Subtype (MN) Cobble Shore Wet Meadow (NY) Wormwood Gravel Open Beach Type (ON) Red Cedar-Common Juniper Shingle Shrub Beach Type (ON) Willow Gravel Shrub Beach Type (ON)	Typically cobble/ gravel that occurs above the high water mark or storm surges. Modified from 1996 report (cobble and bedrock split) because of significant differences in vegetation communities. Cobble beaches were treated separately by SOLEC in 1998. Two major sub-types can generally be defined by coastal unit.
Shoreline Cliffs *Limestone Cliffs and Talus Slopes*	**Great Lakes Alkaline Rocky Shore and Cliff** Great Lakes Shore Limestone - Dolostone Cliff (G4G5) Great Lakes Shore Basalt – Diabase Cliff (GNR) **Great Lakes Acidic Rocky Shore and Cliff** Great Lakes Shore Granite - Metamorphic Cliff (GNR) Great Lakes Shore Sandstone Cliff (G4G5)	Sandstone Lakeshore Cliff (MI) Basalt Lakeshore Cliff (MI) Volcanic Conglomerate Lakeshore Cliff (MI) Dry Non-acid Cliff (MI) Moist Non-acid Cliff (MI) Moist Acid Cliff (MI) Dry Cliff (MN) Moist Cliff (MN) Exposed Mafic Cliff (Lake Superior) (MN) Sheltered Mafic Cliff (Lake Superior) (MN) Exposed Felsic Cliff (Lake Superior) (MN) Calcareous Cliff Community (NY) Moist Cliff (WI) Moist Cliff (WI)	Ontario has over 20 cliff/ talus communities. None of these are classified as coastal Modified from 1996 report to include all coastal cliff types that had been documented. Two major sub-types can generally be defined by coastal unit.
Shoreline Bluffs *Unconsolidated Shoreline Bluffs*	**None?** Clay Seeps (GNR)	Poorly Consolidated Slope, Midwest Type (IL) Great Lakes Bluff (NY) Open Clay Bluff (ON) Open Sand/ Clay Bluff Type Great Lakes Region Scarp Woodland (part of Great Lakes Scarp Complex) (PA) Clay Seepage Bluff (WI)	Also reported from Michigan and Ontario.
Lakeplain Prairies *Lakeplain Prairies*	**Great Lakes Wet-Mesic Lakeplain Prairie** Lake Plain Mesic Oak Woodland (G2) Lakeplain Wet-Mesic Prairie (G2) Lakeplain Wet-Mesic Oak Opening (G1) Lakeplain Wet Prairie (G2G3)	Wet Prairie (IL) Prairie – Sand Wet (IN) Prairie - Sand Wet-Mesic (IN) Lakeplain Wet-Mesic Prairie (MI) Lakeplain Oak Openings (MI) Lakeplain Wet Prairie (MI) Fresh-Moist Tallgrass Prairie (ON) Fresh-Moist Pin Oak-Bur Oak Tallgrass Savannah Type (ON) Fresh-Moist Black Oak-White Oak Tallgrass Woodland Type (ON) Fresh-Moist Pin Oak Tallgrass Woodland Type (ON) Bluejoint-Prairie Slough Grass Tallgrass Meadow Marsh Type (ON) Wet-Mesic Prairie* (WI) Wet Prairie (WI) *Wisconsin wet prairie types include lakeplain coastal types and interior prairies.	
Arctic-Alpine Disjunct Communities *Arctic-Alpine Disjunct Communities*	**Great Lakes Alkaline Rocky Shore and Cliff**	Great Lakes Arctic-Alpine Basic Open Bedrock Shoreline Type (ON)	Also nested with non-alkaline bedrock shores (basalt), but treated separately due to special features.
Atlantic Coastal Plain Disjunct Communities *Atlantic Coastal Plain Disjunct Communities*	**None?** Inland Coastal Plain Marsh (G2?) Bulbet Flatsedge Coastal Plain Sandy Pondshore (G2)	Coastal Plain Marsh (MI) Atlantic Coastal Plain Shallow Marsh Type (ON)	Wetland/ terrestrial interface.
Rich Coastal Fens *New*	**Great Lakes Alkaline Rocky Shore and Cliff** Shrubby-cinquefoil – Sweetgale Rich Shore Fen (G1G2) Great Lakes Sedge Rich Shore Fen (G1G2)	Graminoid Coastal Meadow Marsh Type (ON) Shrubby Cinquefoil Coastal Meadow Marsh Type (ON) Shore Fen (WI) Calcareous Fen (WI)	Ontario types could also be included as Cobble Beach (alkaline). Wetland/ terrestrial interface.
Shoreline Alvars *Shoreline Alvars*	**Great Lakes Alvar** Scrub Conifer/Dwarf Lake Iris Alvar Shrubland (G1G2) Creeping Juniper – Shrubby Cinquefoil Alvar Pavement (G2)	Alvar (MI) Calcareous Pavement Barrens (NY) Alvar (OH) Scrub Conifer-Dwarf Lake Iris Shrub Alvar Type (ON) Creeping Juniper – Shrubby Cinquefoil Dwarf Shrub Alvar Type (ON) Alvar (WI)	This report only includes alvar types that are generally restricted to the coastal area of the Great Lakes. Modified from 1996 report to only include alvar communities that are influenced by the coastal environment.

Ecosystems Addressed in this Report *SOLEC 1996 Name*	**Ecological System[1]** Vegetation Community [Common Name (Global Rank)[2]]	**Great Lakes State/ Provincial Classification[3]**	**Notes**
Coastal Rock Barrens *Coastal Gneissic Rocklands*	**Great Lakes Acidic Rocky Shore and Cliff** **Great Lakes Alkaline Rocky Shore and Cliff** Common Juniper Rocky Krummholz (G3G4) Basalt Bedrock Glade (G?)	Northern Bald (MI) Volcanic Conglomerate Bedrock Glade (MI) Basalt Bedrock Glade (MI) Bedrock Shrubland (Lake Superior) (MN) Lake Superior Rocky Shore/ Bedrock Shrubland/ Bedrock Outcrop Complex (MN) Blueberry Granite Shrubland Barren Type (ON)* Oak – Red Maple – Pine Treed Granite Barren Type (ON)* Pitch Pine Treed Granite Barren Type (ON)* Chokeberry Granite Shrubland Barren Type (ON) Common Juniper Granite Shrubland Barren Type (ON) Jack Pine Treed Granite Barren Type (ON) Red Cedar Treed Granite Barren Type (ON) Dry Granite Barren Type (ON) Dry Moss Non-Calcareous Open Rock Barren Type (ON) Non-Calcareous Poverty Oat Grass Rock Barren Meadow Type (ON) Non-Calcareous Tuffted Hairgrass Rock Barren Meadow Type (ON) Raspberry Non-Calcareous Shrub Rock Barren Type (ON) Cinquefoil Non-Calcareous. Shrub Rock Barren Type (ON) White Pine - Oak - Red Cedar Non-Calcareous Treed Rock Barren Type (ON) *Ontario community types with documented coastal occurrences.	Modified to include all coastal rock barrens (except alvars). Rock barrens that are influenced by the coastal environment. Occurs as a narrow band between bedrock shores (non-alkaline) and interior rock barrens.
Great Lakes Coastal Forests *New*	**None?** Great Lakes Spruce – Fir Basalt Bedrock Shore (GNR)		Forests that occur within 2 km of the coast and are influenced by the coastal environment.

[1] = NatureServe (2008)
[2] = Global Rank Descriptions:
G1 Critically Imperiled—At very high risk of extinction due to extreme rarity (often 5 or fewer populations), very steep declines, or other factors.
G2 Imperiled—At high risk of extinction due to very restricted range, very few populations (often 20 or fewer), steep declines, or other factors.
G3 Vulnerable—At moderate risk of extinction due to a restricted range, relatively few populations (often 80 or fewer), recent and widespread declines, or other factors.
G4 Apparently Secure—Uncommon but not rare; some cause for long-term concern due to declines or other factors.
G5 Secure—Common; widespread and abundant.
[3] = Sources for state/ provincial classification:
Illinois: White and Madany (1978)
Indiana: Indiana Department of Natural Resources (2008); Homoya et al. (1988)
Michigan: Kost *et al.* (2007)
Minnesota: Minnesota Department of Natural Resources (2008); Minnesota Natural Heritage Program (1993)
New York: Edinger *et al*. (eds) (2002)
Ohio: Anderson (1982)
Ontario: Ontario Natural Heritage Information Centre (2008)
Pennsylvania: Fike (1999)
Wisconsin: Wisconsin Department of Natural Resources (WDNR 2006)

Appendix B: Data Sources

<u>Shoreline Mapping</u>

The distribution and extent of nearshore coastal ecosystems were measured using a combination of spatial shoreline data and element occurrence information. These data were also used to determine the extent of artificial shoreline.

The following ecosystems were assessed using shoreline mapping information from Environment Canada and NOAA: Sand Beach, Bedrock Shore, Cobble Beach, Shoreline Cliff and Shoreline Bluff. Table A1 provides a summary of the shoreline mapping information that was available for Canada and the U.S. and how it was cross-walked.

Table A1. Shoreline Mapping.

ID	Environment Canada Shoreline Classification Morphology	Class
1a	Exposed Bedrock Bluff less than 1 metre elevation	Bedrock Shore
1b	Exposed Bedrock Bluff 1-5 metre elevation	Shoreline Cliff
1c	Exposed Bedrock Bluff greater than 5 metre elevation	Shoreline Cliff
2	Retaining Wall/Harbour Structure/Breakwaters	Artificial
3	Shelving Bedrock	Bedrock Shore
4	Exposed Sediment Bluff	Shoreline Bluff
5a	Sand Beach: Depositional	Sand Beach
5b	Sand Beach: Erosional or Transitory	Sand Beach
6	Sand Barrier With Lagoon	Sand Beach
7a	Pebble Beach	Cobble Beach
7b	Pebble/Cobble Beach	Cobble Beach
7c	Cobble Beach	Cobble Beach
8	Rip Rap	Artificial
9	Boulder Beach	Cobble Beach
10	Mixed Beach	Cobble Beach
10	Mixed Beach (40% Boulder, 30% Cobble, 30% Sand)	Cobble Beach
10	Mixed Beach (40% Pebble, 40% Cobble, 20% Boulder)	Cobble Beach
10	Mixed Beach (40% Sand, 60% Pebble)	Cobble Beach
10	Mixed Beach (50% Boulder, 30% Cobble, 20% Sand)	Cobble Beach
10	Mixed Beach (50% Boulder, 50% Cobble)	Cobble Beach
10	Mixed Beach (50% Cobble, 50% Boulder)	Cobble Beach
10	Mixed Beach (50% Sand, 10% Pebble, 35% Cobble)	Sand Beach
10	Mixed Beach (50% Sand, 25% Pebble, 25% Cobble)	Sand Beach
10	Mixed Beach (50% Sand, 50% Cobble)	Sand Beach
10	Mixed Beach (50% Sand, 50% Pebble)	Sand Beach
10	Mixed Beach (60% Boulder, 20% Cobble, 20% Sand)	Cobble Beach
10	Mixed Beach (60% Boulder, 30% Cobble, 10% Sand)	Cobble Beach
10	Mixed Beach (60% Boulder, 40% Cobble)	Cobble Beach
10	Mixed Beach (60% Sand, 20% Pebble, 20% Cobble)	Sand Beach
10	Mixed Beach (60% Sand, 40% Pebble)	Sand Beach
10	Mixed Beach (70% Boulder, 30% Cobble)	Cobble Beach
10	Mixed Beach (70% Cobble, 30% Boulder)	Cobble Beach
10	Mixed Beach (70% Pebble, 20% Cobble, 10% Boulder)	Cobble Beach
10	Mixed Beach (70% Sand, 15% Pebble, 15%Cobble)	Sand Beach
10	Mixed Beach (70% Sand, 30% Cobble)	Sand Beach
10	Mixed Beach (70% Sand, 30% Pebble)	Sand Beach
10	Mixed Beach (80% Boulder, 20% Cobble)	Cobble Beach
10	Mixed Beach (80% Cobble, 20% Boulder)	Cobble Beach
10	Mixed Beach (80% Cobble, 20% Sand)	Cobble Beach
10	Mixed Beach (80% Pebble, 20% Cobble)	Sand Beach
10	Mixed Beach (80% Pebbles, 20% Boulders)	Sand Beach
10	Mixed Beach (80% Sand, 10% Cobble, 10% Boulder)	Sand Beach
10	Mixed Beach (80% Sand, 10% Pebble, 10% Cobble)	Sand Beach
10	Mixed Beach (80% Sand, 20% Boulder)	Sand Beach
10	Mixed Beach (80% Sand, 20% Cobble)	Sand Beach
10	Mixed Beach (80% Sand, 20% Pebble)	Sand Beach
10	Mixed Beach (90% Cobble, 10% Boulder)	Cobble Beach
10	Mixed Beach (90% Sand, 10% Pebble)	Sand Beach
11	Low Vegetated Bank (Grass or Trees)	Other
12	Delta Mud Flat	Wetland
13a	Fringing Wetland	Wetland
13b	Broad Wetland	Wetland

ID	NOAA/TNC Shoreline Classification Morphology	Class
1	High (>15m) bluff; cohesive, moderately to highly erodible, generally linear shore, gullied, subject to dramatic cyclical failure due to groundwater and other processes.	Shoreline Cliff
2	High (>15m) bluff with beach; higher sand content, high to moderate readability, beach may act as protection, subject to dramatic cyclical failure due to groundwater and other processes.	Shoreline Cliff
3	Low (<15m) bluff; moderate erodibility.	Shoreline Cliff
4	Low (<15m) bluff with beach; moderate erodibility.	Shoreline Cliff
5	Sandy/silty banks; highly erodible.	Shoreline Bluff
6	Clay banks; very cohesive, highly erodible.	Shoreline Bluff
7	Sandy beach/dunes; low to moderate erodibility, depends on sediment budget.	Sand Beach
8	Coarse beach; cobbles, pebbles, boulders.	Cobble Beach
9	Baymouth-barrier beaches; wide beaches fronting established wetlands or embayments, overwash and erosion/accretion processes present.	Sand Beach
10	Bedrock (resistant); igneous/metamorphic rocks.	Bedrock Shore
11	Bedrock (non-resistant); sedimentary rocks.	Bedrock Shore
12	Low Riverine/Coastal Plain; flood prone, low to moderate erodibility.	Other
13	Open Shoreline Wetlands; mostly emergent vegetation.	Wetland
14	Semi-protected wetlands; protected by natural features such as baymouth barriers.	Wetland
15	Composite; based on different stratigraphy	Other
16	Artificial; areas where anthropogenic features / structures have totally obscured the natural, geomorphic shoreline.	Artificial
17	Unclassified; data unavailable, inaccurate or indecipherable.	Other

Land Cover

Land cover data (Table A2) were used to identify coastal forests and rock barrens, and as a measure of coastal pressures (i.e. amount of natural, urban and agricultural land cover).

Table A2. Land Cover.

PLC28	PLC2000	NLCD2001
CLASS	DESC_	Class_name
Water	Water - deep clear	Background
Coastal Mudflats	Water - shallow / sedimented	Unclassified
Intertidal Marsh	Settlement / Infrastructure	Developed, High Intensity
Supertidal Marsh	Sand / Gravel / Mine Tailings	Developed, Medium Intensity
Freshwater Coastal Marsh / Inland Marsh	Bedrock	Developed, Low Intensity
Deciduous Swamp	Mudflats	Developed, Open Space
Conifer Swamp	Forest Depletion – cuts	Cultivated Crops
Open Fen	Forest Depletion - burns	Pasture/Hay
Treed Fen	Forest - regenerating depletion	Grassland/Herbaceous
Open Bog	Forest - sparse	Deciduous Forest
Treed Bog	Forest - dense deciduous	Evergreen Forest
Tundra Heath	Forest - dense mixed	Mixed Forest
Dense Deciduous. Forest	Forest - dense coniferous	Scrub/Shrub
Dense Coniferous. Forest	Marsh - intertidal	Palustrine Forested Wetland
Coniferous. Plantation	Marsh - supertidal	Palustrine Scrub/Shrub Wetland
Mixed Forest Mainly Deciduous	Marsh - inland	Palustrine Emergent Wetland
Mixed Forest Mainly Coniferous	Swamp - deciduous	Estuarine Forested Wetland
Sparse Coniferous. Forest	Swamp - coniferous	Estuarine Scrub/Shrub Wetland
Sparse Deciduous. Forest	Fen - open	Estuarine Emergent Wetland
Recent Cutovers	Fen - treed	Unconsolidated Shore
Recent Burns	Bog - open	Bare Land / Barren Land
Old Cuts and Burns	Bog - treed	Open Water
Mine Tailings, Quarries, and Bedrock Outcrop	Tundra Heath	Palustrine Aquatic Bed
Settlement and Developed Land	Agriculture - Pasture / abandoned fields	
Pasture and Abandoned Fields	Agriculture - cropland	
Cropland	Other - unknown	
Alvar	Other - cloud / shadow	
Unclassified (Cloud & Shadow)		

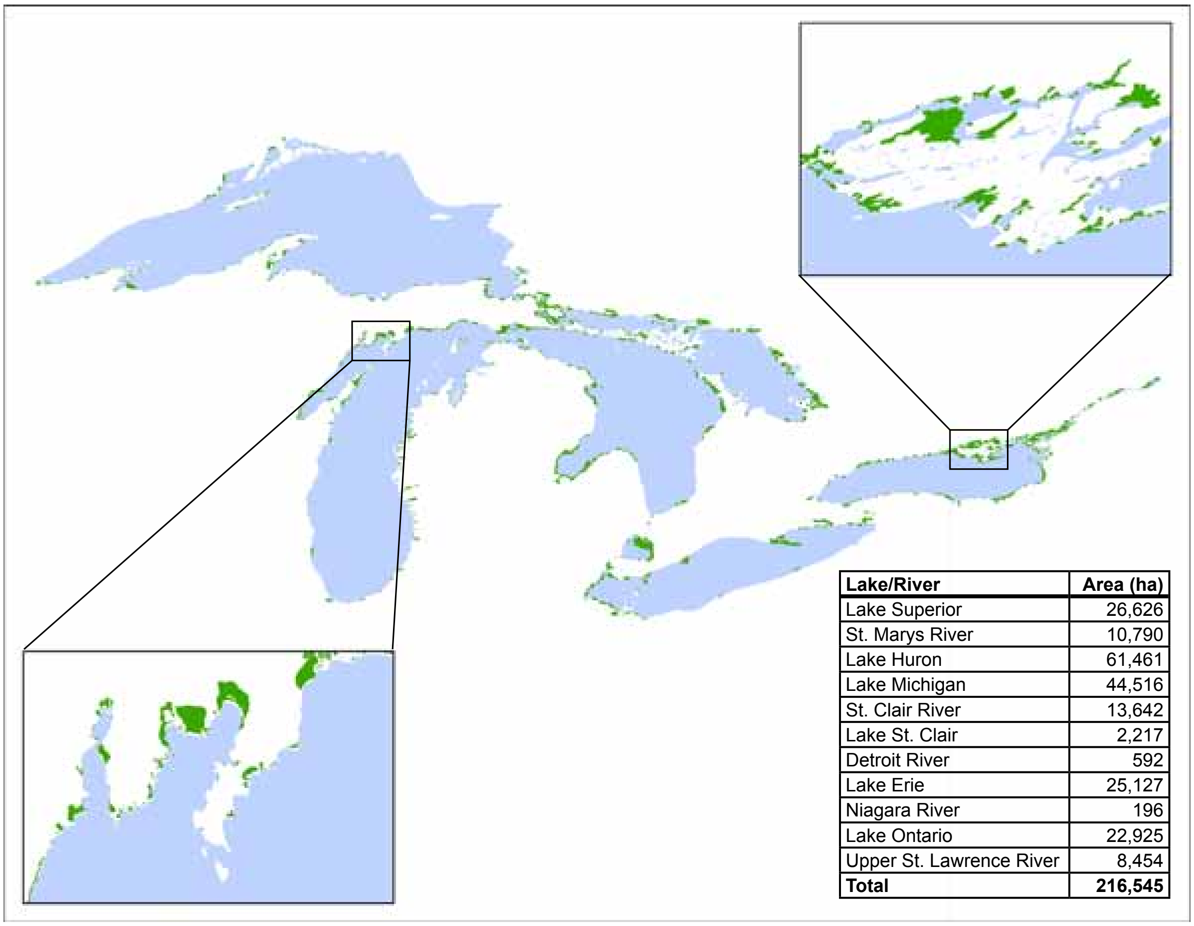
Key				
Natural	Water	Urban	Agricultural	Unclassified

4.0 Great Lakes Coastal Wetland Ecosystem

State of the Ecosystem

Background

More than 216,000 hectares (534,000 acres) of coastal wetlands are directly influenced by the waters of the Great Lakes. Under the United States Clean Water Act, the term wetlands means, “Those areas that are inundated or saturated by surface or ground water at a frequency and duration sufficient to support, and that under normal circumstances do support, a prevalence of vegetation typically adapted for life in saturated soil conditions.”



Lake/River	Area (ha)
Lake Superior	26,626
St. Marys River	10,790
Lake Huron	61,461
Lake Michigan	44,516
St. Clair River	13,642
Lake St. Clair	2,217
Detroit River	592
Lake Erie	25,127
Niagara River	196
Lake Ontario	22,925
Upper St. Lawrence River	8,454
Total	**216,545**

Figure 1. Great Lakes coastal wetland distribution and total area by lake and river.
Source: Great Lakes Coastal Wetlands Consortium. http://www.epa.gov/glnpo/solec/sogl2007/4510_CoastalWetlandAreaByType.pdf

The functions of Great Lakes coastal wetlands - biological, chemical, and physical processes that occur naturally within a wetland - include the storage and cycling of nutrients and organic materials carried by rivers and streams to the Lakes; food web production; biological productivity; groundwater recharge; stream base flow maintenance; and, habitats for a wide range of Great Lakes species. Many fish species, for example, depend upon coastal wetlands for some portion of their life cycles. Coastal wetlands have functions and values including water quality improvement, flood storage, water supply, erosion protection, and fish spawning habitats.

Water fluctuations are necessary to maintain this highly productive system. Temporary water fluctuations are caused by wind and “tides” known as seiches. Seasonal fluctuations reflect the yearly hydrologic cycle of the Great Lakes. Multi-year fluctuations are caused by basinwide, continental or global changes in climate. Coastal wetland plant life is most affected by water fluctuations. Low water levels expose bottom sediments which allow seeds to germinate. High water levels may flood out vegetation and dilute nutrient concentrations. In many areas where the natural systems have been highly modified, vegetated coastal wetlands persist only because of intensive management that may include water level controls.

There are three major categories of coastal wetlands (Table 1). Lacustrine wetlands are controlled directly by the waters of the Great Lakes. They are affected by lake level fluctuations, nearshore currents, seiches and ice scour. Riverine wetlands occur in rivers, tributaries and connecting channels that flow into or between the Great Lakes. Barrier protected wetlands have become separated from the Great Lakes by a barrier beach or other barrier feature. The barriers protect the wetland from the waves.

Five different types of vegetation can be found in Great Lakes coastal wetlands. Floating plants may be rooted under water, but have leaves that float on the surface. Submerged plants are rooted under water and grow entirely underwater. Emergent plants have roots that might be underwater, but grow and flower above the surface of the water. Wet meadow vegetation is less tolerant of

Table 1. Great Lakes coastal wetland classification system.
Source: Great Lakes Coastal Wetland Consortium.

<table>
<tr><td rowspan="6">Types of Lacustrine Wetlands and Their Definitions</td><td colspan="4">Lacustrine Wetlands</td></tr>
<tr><td colspan="4">Controlled directly by waters of the Great Lakes and are strongly affected by lake-level fluctuations, nearshore currents, seiches and ice scour</td></tr>
<tr><td rowspan="2">Open lacustrine wetlands</td><td rowspan="2">• These lake-based wetlands are directly exposed to nearshore processes with little or no physical protection by geomorphic features.
• This results in little accumulation of sediment vegetation development to relatively narrow nearshore bands.</td><td>Open shoreline wetlands</td><td>• These 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.</td></tr>
<tr><td>Open embayment wetlands</td><td>• They 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.</td></tr>
<tr><td rowspan="2">Protected lacustrine wetlands</td><td rowspan="2">• These are also a lake-based system, but characterized by increased protection by bay or sand-spit formation.
• This protection results in increased sediment accumulation, shallower off-shore profiles, and more extensive vegetation development.</td><td>Protected embayment wetlands</td><td>• They can be completely vegetated with emergent or submergent vegetation.</td></tr>
<tr><td>Sand-spit embayment wetlands</td><td>• These project along the coast and 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.</td></tr>
<tr><td rowspan="6">Types of Riverine Wetlands and Their Definitions</td><td colspan="4">Riverine Wetlands</td></tr>
<tr><td colspan="4">Occur in rivers and creeks that flow into or between the Great Lakes</td></tr>
<tr><td>Open - drowned river mouth wetlands</td><td colspan="3">• These wetlands may not 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.</td></tr>
<tr><td>Barred - drowned river mouth wetlands</td><td colspan="3">• These wetlands maintain a relatively constant connection to the lakes.</td></tr>
<tr><td>Connecting channel wetlands</td><td colspan="3">• These wetlands include the large connecting rivers between the Great Lakes; the St. Marys, St. Clair, Detroit, Niagara, and St. Lawrence Rivers.
• They are distinctive from the other large river wetlands (drowned river mouth) by their general lack of deep organic soils and their often strong currents.</td></tr>
<tr><td>Deltas</td><td colspan="3">• These are formed of alluvial materials, both fine and coarse, and support extensive wetlands that extend out into the Great Lake or connecting river.</td></tr>
<tr><td rowspan="4">Types of Barrier Enclosed Wetlands and Their Definitions</td><td colspan="4">Barrier Enclosed Wetlands</td></tr>
<tr><td colspan="4">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.</td></tr>
<tr><td>Barrier beach lagoon wetlands</td><td colspan="3">• 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.</td></tr>
<tr><td>Swale complexes</td><td colspan="3">• These occur between re-curved fingers of sand spits and those that occur between relict beach ridges.</td></tr>
</table>

flooding and represents a transition from wetland to terrestrial. The shrub zone contains woody plants that grow above the water line, but is influenced by periodic flooding.

A diversity of animals inhabits coastal wetlands. Phytoplankton is at the base of the food chain. Macroinvertebrates such as insects, snails, molluscs and worms cycle nutrients through the system by breaking down coarse vegetation; they are also food for fish and birds. Ninety percent of the more than 200 species of Great Lakes fish spend some part of their life cycle in Great Lakes coastal wetlands. Fish such as northern pike (*Esox lucius*), yellow perch (*Perca flavescens*) and bowfin (*Amia calva*) spawn in coastal marshes. Birds, reptiles and amphibians use coastal wetlands as resting, feeding and nesting habitat.

This report summarizes the environmental status and trend of Great Lakes coastal wetlands. It provides details of coastal wetland indicator reports and outlines current and probable future pressures on coastal wetland resources. It outlines possible management actions needed to monitor, protect and restore, and manage Great Lakes coastal wetlands. And it describes how assessing the status and trend of coastal wetlands has changed since SOLEC 1996.

<u>Status and trend summary</u>

The status of the Great Lakes coastal wetland system is *mixed* and the trend is *deteriorating* due to habitat loss and deterioration, invasive species, water level stabilization, and contaminants. Declines in populations of species that use wetlands almost exclusively for breeding, combined with an increase in some wetland edge and generalist species, suggest changes in wetland habitat conditions may be occurring. The status and trend are based on observations or best professional judgment and on indicator reports.

- Over the past decade, statistically significant declining trends were detected for American toad (*Bufo americanus*), bullfrog (*Rana catesbeiana*), chorus frog (*Pseudacris triseriata*), green frog (*Rana clamitans*), and northern leopard frog (*Rana pipiens*). Wetland bird species with significant basinwide declines were American coot (*Fulica americana*), black tern (*Chlidonias niger*), blue-winged teal (*Anas discors*), common grackle (*Quiscalus* quiscula), common moorhen (*Gallinula chloropus*), least bittern (*Ixobrychus exilis*), undifferentiated common moorhen/American coot, northern harrier (*Circus cyaneus*), pied-billed grebe (*Podilymbus podiceps*), red-winged blackbird (*Agelaius phoeniceus*), sora (*Porzana carolina*), tree swallow (*Tachycineta bicolor*), and Virginia rail (*Rallus limicola*).
- Mechanical disturbance of coastal sediments appears to be one of the primary vectors for introduction of non-native invasive species to coastal wetlands. Intact wetlands, on the other hand, may be a refuge for native fishes, at least with respect to the influence of round gobies (*Neogobius melanostomus*).
- A disturbing trend is the expansion of frogbit (*Hydrocharis morsus-ranae*); it is a floating plant that forms dense mats capable of eliminating submergent plants. Frogbit is found from the St. Lawrence River and Lake Ontario westward into Lake Erie.
- With diet the primary source of exposure, contaminants such as polychlorinated dioxins, furans, polychlorinated biphenyls (PCBs) measured in snapping turtles (*Chelydra serpentina*) are persistent and bioaccumulative. This indicates that contamination still persists throughout the aquatic food web.
- In 2007, low Lake Superior water levels resulted in devastation of Kakagon Sloughs (Wisconsin) wild rice (*Zizania palustris*) beds. Bad River Tribe natural resource personnel reported that many wild rice beds resembled mud flats. Low water levels could lead to an influx of non-native species such as purple loosestrife (*Lythrum salicaria*).
- The status of Georgian Bay and the North Channel coastal wetlands of Lake Huron are good based on McMaster University researchers' evaluation of more than 100 wetlands. Some degradation was noted in southeastern Georgian Bay due to anthropogenic disturbances.
- Water level control in Lake Ontario has resulted in a decrease in plant and animal diversity in coastal wetlands. The International Joint Commission has completed a five-year study on the impacts of water level controls on shoreline habitats and properties, shipping, and small boat use.

<u>Status and trend by indicator</u>

The SOLEC 2004 paper *The Great Lakes Indicator Suite: Changes and Progress 2004*, contains descriptions of 13 indicators deemed relevant to determine the status and trend of Great Lakes coastal wetlands. Based on the work of the Durham coastal wetland managers and other Great Lakes coastal wetland scientists, previous SOLEC authors, the Coastal Wetland Consortium, and the Great Lakes Environmental Indicators (GLEI) collaborators, six coastal wetland indicators are now recommended to effectively and efficiently monitor Great Lakes coastal wetlands. In addition, other chemical and physical coastal wetland information such as turbidity, conductivity, phosphorus, and nitrogen, will be collected to help interpret indicator data.

Three indicators suggested in the 2004 report are not considered specific to the coastal wetland indicator suite. *Contaminants in Snapping Turtle Eggs (4506)*, *Phosphorus and Nitrogen Levels (4860)*, and *Effect of Water Levels Fluctuations (4861)* are associated with coastal wetlands, however are broader in the context of overall ecosystem health and should therefore not be included in the coastal wetland suite. Four indicators—*Coastal Wetland Restored Area by Type (4511)*, *Sediment Flowing into Coastal Wetlands (4516)*, *Human Impact Measures (4864)*, and *Land Cover Adjacent to Wetlands (4963)*—are not feasible to monitor at this time. The recommendation is to eliminate these indicators. One other indicator, *Sediment Available for Coastal Nourishment (8142)*, was suggested after the 2004 report and is applicable to the entire Great Lakes shoreline so should not be considered solely a coastal wetland indicator.

The names for the six indicators below have changed since the *State of the Great Lakes 2007* report (Environment Canada and U.S. Environmental Protection Agency 2007). More detailed information is found in each indicator's status and trend report.

Extent and composition of coastal wetlands (SOLEC indicator 4510): mixed, deteriorating
The status of this indicator has not been updated since the *State of the Great Lakes 2005* report. One conclusion of the 2005 report was that wetlands continue to be lost and degraded, yet the ability to track and determine the extent and rate of this loss in a standardized way is not yet feasible. A GIS database providing the first spatially explicit seamless binational summary of coastal wetland distribution in the Great lakes system was completed in 2004. Coastal wetlands totaling 216,743 hectares (535,584 acres) were identified up to Cornwall, Ontario. However, due to existing data limitations, estimates of coastal wetland extent, particularly for the upper Great Lakes are acknowledged to be incomplete. Despite significant losses in some regions, the Lakes and rivers still support a diversity of wetland types. Stressors to coastal wetlands continue to contribute to the loss and degradation of coastal wetland area including filling, dredging, draining for conversion to other uses, shoreline modification, water level regulation, and sediment and nutrient loading from watersheds.

The 2005 report also concluded that many of the pressures result from direct human actions and therefore, with proper consideration of the impacts, can be reduced. Because of growing concerns around water quality and supply, which are key Great Lakes conservation issues, and the role of wetlands in flood attenuation, nutrient cycling and sediment trapping, wetland changes need to be monitored closely.

Coastal wetland invertebrate communities (SOLEC indicator 4501): not assessed
Development of this indicator is still in progress. In 2002, the Great Lakes Coastal Wetlands Consortium conducted extensive surveys of wetland invertebrates of the four lower Lakes. The data are not entirely analyzed to date. However, the Consortium adopted an Index of Biotic Integrity that was applied in wetlands of northern Lake Ontario. Physical alteration and eutrophication continue to be a threat to coastal wetland invertebrates due to promotion of non-native vegetation and destruction of plant communities as well as changes to the natural hydrology.

Coastal wetland fish communities (SOLEC indicator 4502): not assessed
Lakes Erie and Ontario tend to have more wetlands containing cattail communities and therefore, fish communities of lower richness and diversity. The seven wetlands sampled in Lake Superior contained relatively unique vegetation types so fish communities of these wetlands were not directly compared with those of wetlands of other lakes. There appear to be no wetlands in the U.S. portion of Lake Erie that have experienced minimal anthropogenic disturbance. Comparatively, northern Lakes Huron and Michigan wetlands have relatively high quality coastal wetland fish communities.

Bluntnose minnows (*Pimephales notatus*) and johnny darters (*Etheostoma nigrum*) are almost absent from Lake Michigan's lower bay wetland sites. Species associated with plants and clearer water—rock bass (*Ambloplites* sp.), sand shiners (*Notropis stramineus*), and golden shiners (*Notemigonus crysoleucas*)—are present in upper bay samples, but absent from lower bay samples. In 2003, there were no alewives (*Alosa pseudoharengus*) or gizzard shad (*Dorosoma cepedianum*) at an upper Green Bay site. Likewise, the fish assemblage structure in Cootes Paradise, a highly degraded wetland in Lake Ontario, is very different from other less degraded wetlands analyzed in one study. Water quality is one factor in determining plant communities and that in turn influences fish community structure. Groups of fish species in reference wetlands tend to have similar water temperature and aquatic productivity preferences.

Based on intensive fish sampling prior to 2003 at more than 60 sites spanning all the Great Lakes, round gobies have not been sampled in large numbers at any wetland or have been a dominant member of any wetland fish community. Therefore, it seems likely that wetlands may be a refuge for native fishes, at least with respect to the influence of round gobies. There is little information on the habitat preferences of the tubenose goby (*Proterorhinus marmoratus*) within the Great Lakes with the exception of studies on the Detroit River. Because this goby shares habitats with fishes from many different habitats, however, it is suggested that the tubenose goby will expand its geographic range within the Great Lakes.

Ruffe (*Gymnocephalus cernuus*) have never been found in high densities in coastal wetlands anywhere in the Great Lakes. In one study it was concluded that coastal wetlands in western Lake Superior provide a refuge for native fishes from competition with ruffe. The mudflat-preferring ruffe avoids wetland habitats due to foraging inefficiency in dense vegetation that characterizes healthy coastal wetland habitats. Therefore, further degradation of coastal wetlands could lead to increased dominance by ruffe in shallow water habitats.

Grasshead carp (Ctenopharyngodon idellus), bighead carp (*Hypophthalmichthys nobilis*), and silver carp (*Hypophthalmichthys molitrix*) have escaped aquaculture operations and are now in the Illinois River and migrating toward the Great Lakes through the Chicago Sanitary Canal. These species represent a substantial threat to food webs in wetlands and nearshore habitats with macrophytes.

Coastal wetland amphibian communities (SOLEC indicator 4504): mixed, deteriorating

Amphibian data have been collected at 548 routes across the Great Lakes basin since 1995. Thirteen species were recorded during the 1995-2007 period. Spring peeper (*Pseudacris crucifer*) was the most frequently detected species. Spring peeper populations are increasing. Green frog was detected in more than half of the survey stations. Grey treefrog (*Hyla versicolor*), American toad, and northern leopard frog were common. Statistically significant declining trends were detected for American toad, bullfrog, chorus frog, green frog, and northern leopard frog. Anecdotal and research evidence suggests that wide variations in occurrence of many amphibian species at a given site is a natural and ongoing phenomena.

Coastal wetland bird communities (SOLEC indicator 4507): mixed, deteriorating

Since 1995, Marsh Monitoring Program volunteers have collected bird data at 508 discrete routes across the Great Lakes basin. Fifty six bird species that use marshes for feeding, nesting or both throughout the Great Lakes basin were recorded. The red-winged blackbird was the most commonly recorded non-aerial foraging bird observed followed by the swamp sparrow (*Melospiza georgiana*), marsh wren (*Cistothorus palustris*), and yellow warbler (*Dendroica petechia*). Among birds that nest exclusively in marsh habitats, the most commonly recorded species was marsh wren followed by Virginia rail, common moorhen, pied-billed grebe, American coot and sora. Among species that typically forage in the air above marshes, tree swallow and barn swallow (*Hirundo rustica*) were the two most commonly recorded bird species.

Species with significant basinwide declines were American coot, black tern, blue-winged teal, common grackle, common moorhen, least bittern, undifferentiated common moorhen/American coot, northern harrier, pied-billed grebe, red-winged blackbird, sora, tree swallow, and Virginia rail. Statistically significant basinwide population increases were observed for common yellowthroat (*Geothlypis trichas*), mallard (*Anas platyrhynchos*), northern rough-winged swallow (*Stelgidopteryx serripennis*), purple martin (*Progne subis*), trumpeter swan (*Cygnus buccinator*), willow flycatcher (*Empidonax traillii*), and yellow warbler. American bittern (*Botaurus lentiginosus*) and marsh wren populations did not show a significant trend in abundance indices from 1995 through 2005. Differences in habitats, regional population densities, timing of survey visits, annual weather variability and other factors will likely interplay with water levels to explain variation in wetland dependent bird populations.

Coastal wetland plant communities (SOLEC indicator 4862): mixed, undetermined

The state of the wetland plant community is quite variable, ranging from good to poor across the Great Lakes basin. There is evidence that the plant component in some wetlands is deteriorating in response to extremely low water levels in some of the Great Lakes, but this deterioration is not seen in all wetlands within these lakes. In general, there is slow deterioration in many wetlands as shoreline alterations introduce non-native species. Trends in wetland health based on plants have not been well established.

Turbidity of the southern Great Lakes has reduced with the expansion of zebra mussels (*Dreissena polymorpha*), resulting in improved submergent plant diversity in many wetlands. However, in Saginaw Bay, Green Bay, and Lake Ontario, agricultural sediments have resulted in highly turbid waters which support few or no submergent wetland plants.

In the southern Great Lakes, almost all wetlands are degraded by either water level control, nutrient enrichment, sedimentation, or a combination of these factors. Probably the strongest demonstration of this is the prevalence of broad zones of cattails (*Typha* sp.), reduced submergent diversity and coverage, and prevalence of non-native plants. Low water conditions have resulted in the almost explosive expansion of reed in many wetlands, especially in Lake St. Clair and southern Lake Huron, including Saginaw Bay. In most Great Lakes urban settings, almost complete wetland loss has occurred along the shoreline. Shoreline hardening is eliminating wetland vegetation. Mechanical alteration of the shoreline is fostering the introduction of non-native species.

A disturbing trend is the expansion of frogbit, a floating plant that forms dense mats capable of eliminating submergent plants, found from the St. Lawrence River and Lake Ontario westward into Lake Erie. This expansion will probably continue into all or many of the Great Lakes. It appears that undisturbed marshes are not easily colonized by non-native species such as purple loosestrife and reed canary grass (*Phalaris arundinacea*). As these species become locally established, seeds or fragments of plant may be able to establish when water level changes create appropriate sediment conditions. The worst wetland invasive species is the asian carp, whose mating and feeding result in loss of submergent vegetation in shallow marsh waters.

Pressures

Future pressures on the coastal zone will likely include continuing loss and degradation of important coastal wetlands, water level decrease or stabilization, sedimentation, contaminant and nutrient inputs, and continued invasion of non-native plants and animals. Human-induced global climate change has the potential to result in severe changes in coastal wetland habitats. The following summary of pressures on the coastal wetland system is based on an analysis by indicator report authors.

<u>Agriculture</u>

Agriculture degrades wetlands in several ways, including nutrient enrichment from fertilizers, increased sediments from erosion, increased rapid runoff from drainage ditches, introduction of agricultural non-native species such as reed canary grass, and destruction of inland wet meadow zone by plowing and diking, and addition of herbicides. In the southern lakes, Saginaw Bay, and Green Bay, agricultural sediments have resulted in highly turbid waters which support few or no submergent plants.

<u>Urban development</u>

Urban development degrades wetlands by hardening shoreline, filling wetland, adding a broad diversity of chemical pollutants, increasing stream runoff, adding sediments, and increasing nutrient loading from sewage treatment plants. In most urban settings, almost complete wetland loss has occurred along the shoreline.

<u>Residential shoreline development</u>

Along many coastal wetlands, residential development has altered wetlands by nutrient enrichment from fertilizers and septic systems, shoreline alterations for docks and boat slips, filling, and shoreline hardening. Agriculture and urban development are usually less intense than local physical alteration which often results in the introduction of non-native species. Shoreline hardening can completely eliminate wetland vegetation.

<u>Mechanical alteration of shoreline</u>

Mechanical alteration takes a diversity of forms, including diking, ditching, dredging, filling, and shoreline hardening. With all of these alterations, non-native species are introduced by construction equipment or in introduced sediments. Changes in shoreline gradients and sediment conditions are often adequate to allow non-native species to become established.

<u>Introduction of non-native species</u>

Non-native species are introduced in many ways. Some were purposefully introduced as agricultural crops or ornamentals, later colonizing in native landscapes. Others arrived as weeds in agricultural seed. Increased sediment and nutrient enrichment allow many of the worst aquatic weeds to out-compete native species. Most of the worst non-native species are either prolific seed producers or reproduce from fragments of root or rhizome. Non-native animals have also been responsible for increased degradation of coastal wetlands. One of the worst invasive species has been asian carp, whose mating and feeding result in loss of submergent vegetation in shallow marsh waters.

1996 – 2008: Changes in assessing coastal wetlands

The SOLEC 1996 paper, *Coastal Wetlands of the Great Lakes* (Maynard and Wilcox 1997), presented an overview of coastal wetland ecology, ecological functions and values, and stressors. The authors suggested the development of coastal wetland indicators in the following categories: physical and chemical, individual and population level, wetland community, landscape, and social and economic. The status of coastal wetlands based on expert information was given for each of the Great Lakes, the St. Mary's River, St. Clair River, Lake St. Clair, Detroit River, Niagara River, and St. Lawrence River. Among the authors' conclusions were the following management challenges:

- "There is no comprehensive inventory and evaluation of Great Lakes coastal or even inland wetlands."
- In the U.S., "Individual states have also completed wetland inventories and evaluations, however methodologies are not consistent and the level of detail and amount of field-based data varies."
- "Work has been initiated to develop indicators for wetland degradation and to choose monitoring sites and appropriate monitoring strategies. However, there is no international consensus on these matters."

The background paper for SOLEC 1998, *Biodiversity Investment Areas, Coastal Wetland Ecosystems* (Chow-Fraser and Albert 1998), identified and described a multitude of wetland inventory databases and classification systems in use throughout the basin. The Great Lakes shoreline was divided into eco-reaches based on fish and avifaunal uses and diverse coastal wetlands identified. The authors concluded: "We recognize that the value of the eco-reach must reflect the distribution of wetlands as well as size, distribution and quality…Unfortunately, information regarding wetland size and quality is incomplete, and we were not able to conduct a systematic comparison of eco-reaches with respect to these parameters."

Although coastal wetlands have critically important ecological values and functions, coastal wetland data are not available binationally or basinwide; no one entity has the responsibility to oversee the coordination of coastal wetland data. The conclusion: a binational monitoring program is needed to assess the health of Great Lakes coastal wetlands, an integral part of the Great Lakes basin ecosystem.

In 2000, the U.S. EPA Great Lakes National Program Office funded the creation of the Great Lakes Coastal Wetland Consortium to expand the coastal wetland monitoring and reporting capabilities of the U.S. and Canada under the Great Lakes Water Quality Agreement. The Consortium was coordinated by Great Lakes Commission staff and consisted of scientific and policy experts drawn from key U.S. and Canadian federal agencies, state and provincial agencies, non-governmental organizations, and other interest groups with responsibility for coastal wetlands monitoring. Approximately two dozen agencies, organizations and institutions were brought into the Consortium as Project Management Team members. In addition, other members were brought in as small project teams formed to address discrete project elements and pilot studies.

The purpose of the Consortium was to design a long term, binational coastal wetland monitoring program. Indicators suggested in the SOLEC papers were evaluated and protocols tested. In early 2008, a final report detailed indicators, protocols for monitoring, and costs. Major accomplishments include:

- A map of the 217,000 hectares (536,219 acres) of known coastal wetlands;
- A new classification system consisting of three major categories: lacustrine, riverine, and barrier-protected that was then applied to the mapped coastal wetlands;
- Field-tested sampling protocols;
- A statistical sampling design; and,
- A database that will house future data.

In 2002 and 2003, the initial work of the Consortium was field tested at 15 sites in the Regional Municipality of Durham on the north shore of Lake Ontario. The project was designed to improve coordination among stakeholders, standardize monitoring methods in order to compare results among wetlands and watersheds, and improve the condition of wetlands in this highly urbanized region through support of meaningful management decisions. In turn, the Durham Region Coastal Wetland Monitoring Project provides a blueprint for implementing a basinwide coastal wetland monitoring program.

A U.S. project, Great Lakes Environmental Indicators (GLEI), researched the development of an integrated set of environmental indicators to assess the condition of the shoreline, including coastal wetlands. This project combined field and existing data to link stressors with environmental indicators and recommended a suite of hierarchically-structured indicators. Consortium and GLEI project partners worked together to determine coastal wetland monitoring protocols that are feasible and cost effective yet result in useful data.

Management Implications

Over the past seven years, a group of dedicated Great Lakes coastal wetlands experts mapped the extent of Great Lakes coastal wetlands; created a coastal wetland classification system and applied it to the mapped wetlands; developed an indicator sampling design and process; and built a database. The pieces are in place to implement a long-term coastal wetland monitoring program. Data from this program will, over time, improve coastal wetland system assessment and allow management agencies to better target protection and restoration of coastal wetland resources. The management challenge is to provide the resources needed to monitor Great Lakes coastal wetlands over the long term.

Comments from the Authors

Authors of the indicator papers have recommended the following actions to monitor, protect and restore, and manage Great Lakes coastal wetlands.

Monitor

- Continue to monitor coastal wetland in order to determine impacts from water level stabilization, sedimentation, contaminant and nutrient inputs, climate change and invasion of exotic species.
- Maintain high quality wetland habitat as well as associated upland areas adjacent to coastal wetlands.
- Monitor amphibians according to a five-year rotational cycle in order to sufficiently monitor noteworthy changes in population indices and trends in species occurrence or relative abundance to environmental factors.
- Monitor the contaminant status of snapping turtles on a regular basis across the Great Lakes basin where appropriate. Once the usefulness of the indicator is confirmed, a U.S. program that is complementary to the Canadian program is required to interpret basinwide trends
- Monitor the response of reed canary grass to rising water levels.
- Monitor following disturbance of coastal sediments to reduce new introductions of non-native plants.

Protect and restore

- Address impacts detrimental to wetland health such as water level stabilization, invasive species and inputs of toxic chemicals, nutrients and sediments.
- Conserve and restore wetland habitats to ensure their functioning.
- Incorporate buffer strips along steams and drains to mitigate the effects of agriculture and urban sediments on coastal wetlands.
- Reduce algal blooms by more effectively applying fertilizer.

Manage

- Establish regional goals and acceptable thresholds for species-specific abundance indices and species community compositions.
- Thoroughly clean equipment to eliminate non-native seed sources.
- Verify the relationships between wetland-adjacent land cover and the functions of coastal wetlands.
- Uniformly measure adjacent land cover field parameters across the region to determine accurate information.

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5.0 Nearshore Waters of the Great Lakes

5.1 Nutrients and the Great Lakes Nearshore, Circa 2002-2007

Overview

In the last 10-20 years, there has been increasing concern about ecological changes in the nearshore region of the Great Lakes. Effects are directly related to changes in nutrient loading and biogeochemical interactions that involve invasive dreissenid mussels, water quality, and benthic macroalgal growth. Edsall and Charlton (1997) noted some early trends related to mussels, *Cladophora,* nutrients, chlorophyll, and light in their background paper prepared for SOLEC 1996. This chapter revisits the themes of Edsall and Charlton (1997), using data from the first decade of the 2000s. Some previously-noted trends have continued. For example, nutrient concentrations often appear higher in nearshore waters, but this trend depends on the nutrient form and the lake being considered. Recent lower lake studies report no real distinction between nearshore and offshore in terms of nutrients and chlorophyll at specific locations. Such studies suggest that decreases in nearshore chlorophyll and nutrient concentrations involve mussels and have lead to renewed growth of *Cladophora*.

While we have some information for a nearshore assessment, it is largely *ad hoc*. This chapter has relied primarily on a large-scale research project supplemented with data from regular offshore monitoring, and information from selected recent site-specific research. Water quality protection would benefit from information collected by a regular, consistent, and Great Lakes-wide monitoring to include the nearshore; one such planned effort is described briefly. Additionally, there are some powerful mapping technologies being evaluated to assist with assessment.

State of the Ecosystem

In 1996, Edsall and Charlton (1997) reported that there were few data to assess nutrient status that were explicitly from nearshore zone sampling. Nearshore nutrient impressions were largely limited to observations of local spatial trends from a few site-specific studies and some temporal trends at a set of Canadian water intake locations (later summarized in Nicholls *et al*. 1999). Lacking a systematic information base for the nearshore, Edsall and Charlton (1997) used data from existing open water surveillance and monitoring programs (Environment Canada [EC] and U.S EPA Great Lakes National Program Office [GLNPO] 2007) to describe decadal trends in the lakes leading up to the mid-1990s. Their impressions of the mid-1990s included the following related to the nearshore:

(1) Nutrients and chlorophyll tended to be elevated closer to shore and decreased moving offshore.
(2) Exceedance of Total Phosphorus (TP) guidelines (10–15 µg/L) were noted in Lake Ontario (nearshore) and Lake Erie (nearshore and offshore).
(3) The levels of nearshore chlorophyll *a* relative to TP were low after dreissenid mussel infestation (which occurred in late 1980s in Lake Erie, thereafter in other lakes), compared to observations at those same locations pre-mussel invasion.
(4) Long-term declines in TP and chlorophyll at shallow (~3-17 m) water intake stations were evident for all the lakes from the 1970s through the late 1980s. Some chlorophyll declines may have continued into the 1990s, whereas further TP declines were less apparent.
(5) The reappearance of the attached benthic (bottom-dwelling) alga *Cladophora* in shallow waters was noted in the mid/late 1990s. *Cladophora* was a problem in former decades, prior to Phosphorus (P) abatement, when excessive growth and drift to shorelines lead to widespread problems of beach fouling/odor.

This chapter revisits these themes, using recent information. As initial background for SOLEC 2008, this is not an exhaustive review, but is intended to capture the flavor of conditions in the nearshore during the current decade.

<u>Assessment</u>

Basis

There has been no regular or consistent monitoring and assessment of Great Lakes coastal systems, including the shallow open nearshore, semi-enclosed embayments, or coastal wetlands. The focus of this chapter is open nearshore[1] waters, not excluding larger

1 There are a variety of operational definitions of nearshore (cf. U.S. EPA 1992, Edsall and Charlton 1997, Mackey and Goforth 2005). The shoreward extent is variously considered, especially as to how far it should extend up tributary mouths and whether small, semi-enclosed embayments should be included or considered a separate class of coastal system. The offshore "boundary" has been considered to be a certain depth or distance from shore, or combination thereof; usually, a deepest extent to about 10-30 m (to include intersection of the summer thermocline with the bottom) has been considered. The depth

bays like Saginaw Bay and Green Bay. To my knowledge, Gregor and Rast (1979, 1982) last attempted a quasi-synoptic examination of nearshore trophic status, including nutrients, using data from the mid-1960s to early 1970s. Their final evaluation was limited to Canadian shorelines (Gregor and Rast 1982), due to adequacy of data. In the last 30+ years, there have been many periodic research efforts, but these usually have focused on a given site or basin/region within a lake. It has been rare to have comparable information available across the nearshore of the whole region (Nicholls *et al*. 1999). A recent analysis of gaps in Lake Michigan monitoring concluded there were limited, disconnected efforts in nearshore monitoring (Lake Michigan Pilot Study 2008).

LAKE	TP (µg/L) *[SRP (µg/L)]*	NO_3^- (mg-N/L) *[TN (mg-N/L)]*	Silicate (mg-Si/L)	Chlorophyll *a* (µg/L)
Superior*	6.43 (<mdl - 19.21) *[2.37 (<mdl - 7.73]*	0.33 (0.14 - 0.50) *[0.40 (0.18 – 0.76)]*	2.23 (1.75 - 4.40)	1.07 (0.27 - 5.72)
Huron **	6.89 (<mdl - 33.70) *[1.57 (<mdl - 10.04)]*	0.26 (0.01 – 0.33) *[0.40 (0.22 – 0.56)]*	1.31 (0.85 - 2.22)	1.29 (0.27 - 12.67)
Michigan	7.73 (<mdl - 32.24) *[1.52 (<mdl - 7.61)]*	0.26 (0.11 - 0.49) *[0.43 (0.22 - 0.72)]*	0.91 (0.32 - 2.38)	1.52 (0.42 - 7.52)
Erie	17.81 (<mdl - 59.32) *[3.0 (<mdl - 13.34)]*	0.43 (0.22 - 0.98) *[0.70 (0.32 - 1.52)]*	0.86 (0.32 - 2.17)	6.23 (0.81 - 30.89)
Ontario	5.57 (<mdl - 64.77) *[1.83 (<mdl - 10.31)]*	0.35 (0.06 - 0.49) *[0.58 (0.17 - 1.13)]*	0.83 (0.16 - 12.84)	2.27 (0.41 - 6.57)

* highest TP concentration was near Duluth and St. Louis River outflow, one suspicious high SRP value (46.3) omitted
** higher values are from 4 stations in Saginaw Bay in 2007

Table 1. Mean (and range) of summer concentrations in nearshore waters of the Great Lakes from recent water column measurements, 2002-2007.
The sampling stations (n=535) represent a range of depths to about 30 m, and/or 1-10 km from shorelines, depending on the lake. Data are primarily, but not exclusively, from along the U.S. shore. Mdl = method detection limit, which varied by year but ranged from 1-4 µg/L for TP and 1.2-2.5 µg/L for SRP. Averages have been estimated assuming values of 1/2 mdl for samples <mdl.
Source: U.S. EPA, Mid-Continent Ecology Division, Duluth, MN.

Most recently, there have been some directed efforts to take a more dedicated look at nearshore waters as a component of lake-wide assessment efforts; these include the recent Lake Erie Millennium assessment efforts, and a binational lower food web assessment in Lake Superior (2005/2006) as part of continuing efforts at internationally-coordinated monitoring in each lake on a five-year rotating basis. Nearshore research has increased, so the information base is expanding, even if it is not yet systematic and consistent.

LAKE	TP (µg P/L)	NO_3^- (mg-N/L)	Silicate (mg Si/L)	Chlorophyll *a* (µg/L)
Superior	2.13 (0.89 - 3.77)	0.34 (0.29 - 0.36)	2.17 (1.62 - 2.79)	0.96 (0.11 - 2.07)
Huron	1.86 (0.98 - 3.65)	0.31 (0.22 - 0.38)	1.40 (0.77 - 1.75)	0.57 (0.21 - 1.59)
Michigan	2.41 (1.17 - 4.54)	0.23 (0.15 - 0.32)	0.90 (0.13 - 2.02)	0.90 (0.45 - 1.79)
Erie	9.28 (2.75 - 96.5)	0.20 (0.04 - 0.72)	0.60 (0.06 - 2.29)	3.70 (1.28 - 24.0)
Ontario	5.37 (2.93 - 7.32)	0.21 (0.12 - 0.29)	0.15 (0.01 - 0.15)	2.51 (1.01 - 2.51)

Table 2. Mean (and range) of summer concentrations in offshore waters of the Great Lakes from recent water column measurements, 2001-2007.
Number of stations vary by lake, n=501 total. Values are epilimnion composites.
Chlorophyll mean does not include 2007 values which were not yet reported.
Source: Based on monitoring data provided by U.S. EPA, Great Lakes National Program Office (GLNPO).

For the recent period of about 2001-2007 there is a body of information collected in a region-wide effort. Nutrient (and other) data were collected on nearshore and coastal ecosystems by U.S. EPA researchers (e.g., Yurista *et al*. 2005, 2006, Yurista and Kelly 2007, Morrice *et al*. 2007, Reavie 2007, Kireta *et al*. 2007, Trebitz *et al*. 2007, Peterson *et al*. 2007); the data were, in part, collected in association with the Great Lakes Environmental Indicators Project (Niemi *et al*. 2007, Niemi and Kelly 2007). The nutrient data compiled here from recent EPA efforts emphasize U.S. nearshore waters[2]. Studies generally used stratified random sampling

sometimes depends on shoreline/bathymetry and is sometimes fashioned for each lake (e.g., Lake Superior's Minnesota shore has a precipitous drop to deep water very close to shore and Lake Erie's western basin never reaches 30 m). Generally, the nearshore must be characterized operationally since there is no consistent, defensible, and unique definition (from an ecological perspective, given the open boundaries) for all purposes; the focus of studies examined here is simply on the "open" nearshore waters (i.e., excluding semi-enclosed embayments, or coastal wetlands, but not specifically excluding river mouth outflow areas) as deep as about 30 m (shallower in Lake Erie), and generally <1 km to as much as 4-5 km from shore.

2 Sampling was conducted to represent nearshore conditions in a zone as shallow as about 5 m and as deep as 30 m, depending on the lake. The majority of values summarized are in the 10-20 m range, where there is a well-mixed layer through most of the water column. There are, in general, declining concentrations for many nutrient forms with increasing depth across this nearshore zone. It is cautioned that assessments are indeed sensitive to the depth ranges used for sampling, and comparison of different "nearshore" studies must always consider this issue.

schemes within and across the lakes (cf. Danz *et al.* 2005, 2007); data provide a representative range and capture average conditions well enough to make some example comparisons within and across the lakes. Nearshore data are contrasted to offshore nutrient concentrations measured in the same time period in the ongoing U.S. EPA GLNPO monitoring program. Simple use of these data here is intended to provide a current perspective, and is not a detailed statistical analysis.

Concentrations and variability

The summaries of nutrient and chlorophyll *a* for both nearshore and offshore waters across the Great Lakes (Tables 1, 2) show values and ranges consistent with other recent reports for various specific locations (cf. Lake Erie [Davies and Hecky 2005, Higgins *et al.* 2006, Depew *et al.* 2006, Smith *et al.* 2007]; Lake Ontario [Hall *et al.* 2003, NYSDEC 2005, Hecky, *et al.* 2007, Holeck *et al.* 2008, Malkin *et al.* 2008]; Lake Michigan [Carrick *et al.* 2001]; Lake Huron [Fahnenstiel *et al.* 2008]). In general, concentration ranges are wide within each lake and the concentration ranges of nearshore and offshore locations are overlapping; nearshore and offshore locations typically have similar low-end concentrations near or below detection limits for some analyses. It is usually the case that nutrient and chlorophyll variability is higher in the nearshore (Table 3), which reinforces a classic view.

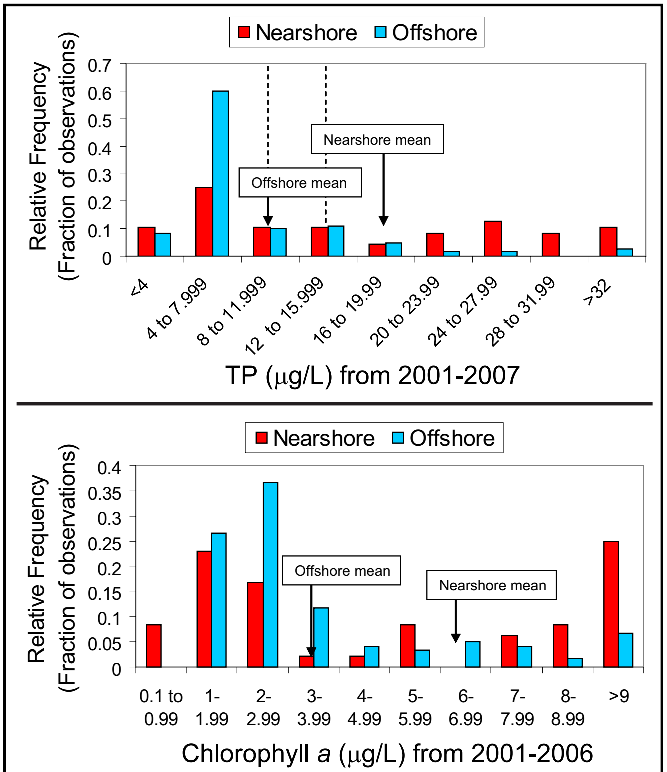

Figure 1. Frequency distribution of summer Total phosphorus (µg/L) and chlorophyll *a* (µg/L) in Lake Erie, in the 2001-2007 period.
Dotted lines are guidelines for Lake Erie, 10 µg/L or 15 µg/L depending on the basin. The offshore mean was slightly <10 µg/L and the nearshore mean was >15 µg/L. There is no guideline for chlorophyll *a*.
Source: U.S. EPA, Mid-Continent Ecology Division and U.S. EPA, GLNPO.

LAKE		TP	NO_3^-	Silicate	Chloride	Chlorophyll
Superior	Nearshore (n=207)	48%	14%	13%	26%	106%
	Offshore (n=111-130)	69%	31%	7%	6%	38%
Huron	Nearshore (n=89)	73%	24%	24%	29%	163%
	Offshore (n=84-98)	28%	10%	19%	7%	46%
Michigan	Nearshore (n=130)	83%	22%	56%	25%	69%
	Offshore (n= 66-74)	27%	13%	54%	3%	36%
Erie	Nearshore (n=48)	82%	46%	52%	21%	100%
	Offshore (n=140)	111%	51%	95%	19%	84%
Ontario	Nearshore (n=60)	155%	27%	193%	14%	55%
	Offshore (n=48-56)	19%	22%	62%	3%	36%

Table 3. Variability (coefficient of variation, CV%) compared for nearshore and offshore data summaries for the Great Lakes during 2001-2007 period.
Sources: U.S. EPA, Mid-Continent Ecology Division and U.S. EPA, GLNPO.

For many analytes and most lakes, the mean and overall distribution of samples is biased to higher levels within the nearshore (Fig. 1) and the average levels thus tend to be higher in shallower nearshore waters, again reinforcing the classic view. This is not the case for all analytes nor for all lakes; one example of this exception is shown for Lake Superior's nitrate (NO_3) and Total Nitrogen (TN) levels (Fig. 2).

Recognizing the considerable variability, it is still instructive to look at average conditions (Figs. 3-5) across the lakes. Two overall patterns are highlighted. One is exemplified by TP and chlorophyll, where levels tend to appear higher on average in the nearshore (Fig. 3); Lake Ontario is an exception in this data set[3].

3 The majority of sampling that was conducted in Lake Ontario was in June 2003 and earlier in the summer than most sampling (biased to August and early September). The values for Lake Ontario appear low compared to a modest sampling we also conducted at several sites in 2004 and in relation to some other summer summaries (Holeck *et al.* 2008, Hecky *et al.* 2007). Moreover, the western nearshore end of the lake, which is nutrient rich, was not sampled as part of our studies. On the other hand, recent studies in both Lake Ontario and Lake Erie suggest there are nearshore areas which are less distinct from the offshore, an effect which is attributed to mussels and *Cladophora* (Smith *et al.* 2007, Hecky, *et al.* 2007).

A second pattern is contrasting. NO_3 and silicate concentrations (Fig. 4) are very similar between nearshore and offshore waters in the upper lakes (Superior, Huron, Michigan); but for the two lower lakes, the nearshore appears substantially higher in both silicate and NO_3. Interestingly, Lake Erie's and Lake Ontario's nearshores are more enriched in NO_3 compared to all other nearshore and offshore waters (Fig. 4c). Ratios between P, N, and silicate can affect the plankton community; in this regard there appear to be some ecologically-significant differences, from upper to lower lakes. The contrasting patterns suggest that, from lake to lake, there are some different relationships between nearshore and offshore interactions and nutrient cycling. For example, Lake Superior has some rather distinct differences in TP and chlorophyll concentrations inshore to offshore, but not for NO_3 or silicate. In contrast, there appears a strong inshore-offshore gradient in NO_3, TP, *and* chlorophyll concentrations in Lake Erie. Reasons may be complex, but some lake-to-lake and within-lake differences likely relate to watershed use (see later section).

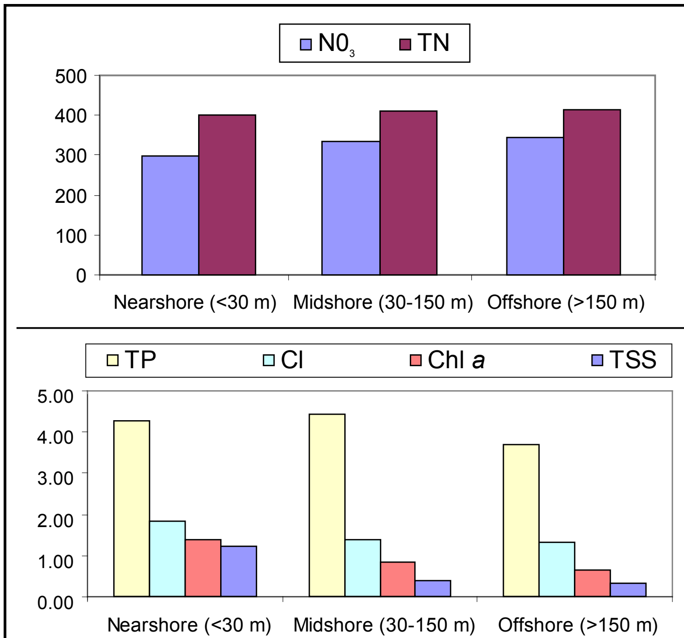

Figure 2. Comparison of mean summer concentrations in epilimnion water composites in Lake Superior.
A 52-station sampling was conducted across three depth strata in 2006. Concentrations units are as indicated in Table 1, except for N forms, which are in µg-N/L.
Source: U.S. EPA, Mid-Continent Ecology Division.

Assessment of recent nutrient levels

One way to assess concentrations is in relation to nutrient loading targets provided under the Great Lakes Water Quality Agreement (GLWQA). Conversion of loading to an equivalent average ambient lake-wide concentration is potentially confounded by a number of things including benthic algal growth, like *Cladophora*, and invasive dreissenid mussels, each of which can temporarily remove P from water and store it in biomass. Lake Erie's GLWQA based-loading targets have been equated to ~10-15 µg/L TP (Eastern vs. Western basins, respectively), when expressed as basin-wide concentrations. Lake Michigan's average concentration at the loading target (5,600 metric tons) previously was estimated as 7 µg/L when expressed as an average concentration; the newest high-resolution mass-balance model runs suggest the loading target would translate to a lakewide concentration of ~7.5 µg/L (Pauer *et al.* 2008). Pending a future revision of the GLWQA, it is nonetheless clear at this time that nearshore waters are recommended as a primary focal point (IJC 2006). There are no specific criteria for the nearshore of different lakes, but due to volume differences nearshore loading could be at least 2-4x the lake-wide estimate and still satisfy a lake-wide loading target. Using rough "guideline" values of 7.5 µg/L, 10 µg/L, and 15 µg/L TP as simple touchstones, the data sets explored above reveal the following, based on n = 501

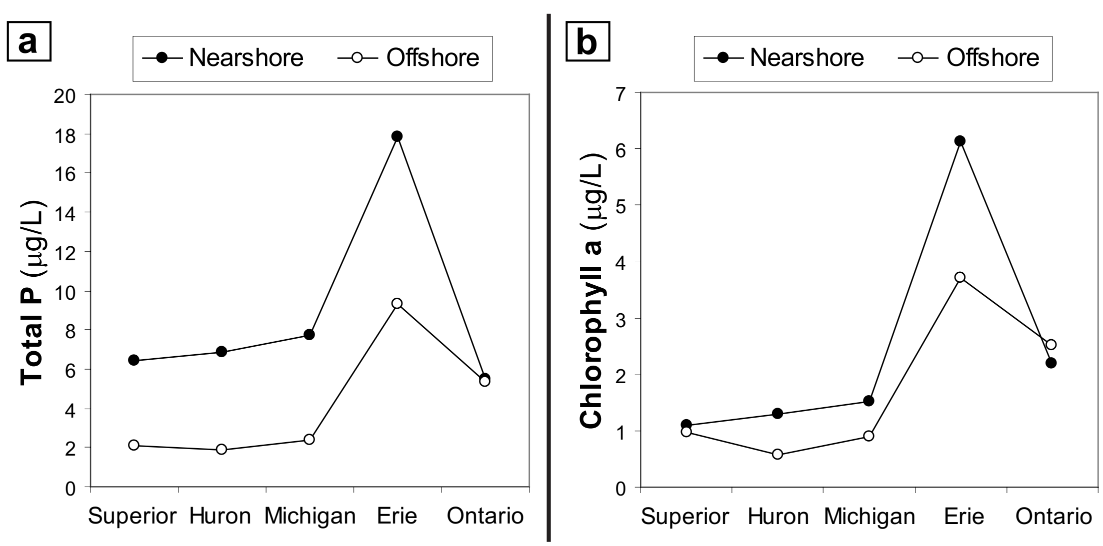

Figure 3. Comparison of nearshore and offshore data by lake for sampling during the 2001-2007 period. a) Total phosphorus; b) Chlorophyll a.
Mean summer values for each lake (see Tables 1-2).
Source: U.S. EPA, Mid-Continent Ecology Division and U.S. EPA, GLNPO.

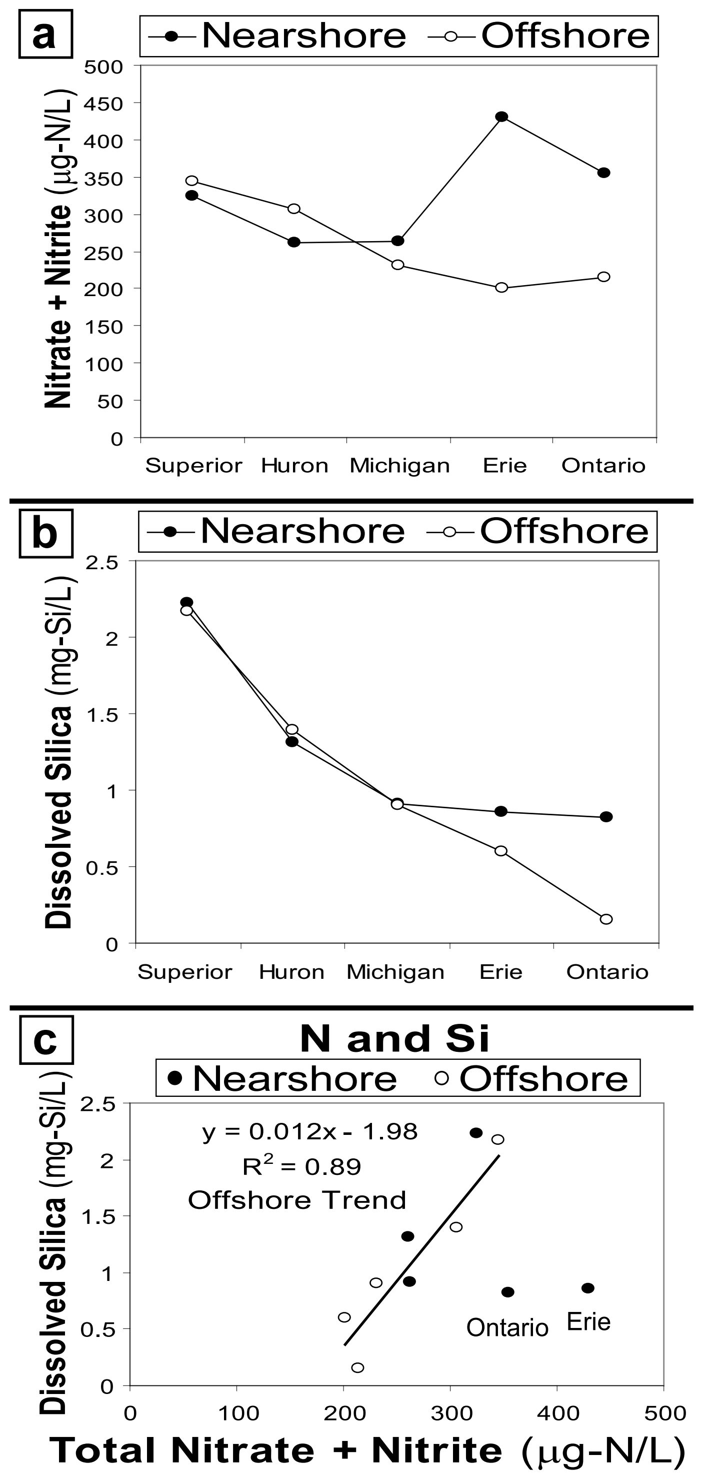

Figure 4. Comparison of nearshore and offshore data by lake for sampling during the 2001-2007 period. a) Nitrate + nitrite; b) Silicate; c) Silica vs. (Nitrate + nitrite).
Mean summer values for each lake (see Tables 1-2).
Source: U.S. EPA, Mid-Continent Ecology Division and U.S. EPA, GLNPO.

offshore stations sampled 2001-2007 and n = 535 nearshore stations sampled 2002-2007:

≥ 15 µg/l TP	3% of **Offshore (**epilimnion) samples; only exceeded in Lake Erie 8% of **Nearshore** samples; mostly Erie, but found in all lakes
≥ 10 µg/l TP	7% of **Offshore** (epilimnion) samples; only exceeded in Lake Erie 18% of **Nearshore** samples; mostly Erie, many sites in each lake
≥ 7.5 µg/l TP	10% of **Offshore** (epilimnion) samples; only Lake Erie 36% of **Nearshore** samples; occurs in all lakes

This simple comparison and the others in figures presented make it clear that the nearshore waters have, in general, higher TP levels at local sites and on average, compared to offshore waters, which is neither surprising nor unexpected based on historical observations. Recent data also reinforce the notion that Lake Erie's TP levels continue to be high.

Nutrients and chlorophyll

One of the interesting patterns between nearshore and offshore conditions appears in the relationship between average lake values for TP and chlorophyll (Fig. 5). Gregor and Rast (1982) had pointed out that nearshore waters generally contained lower chlorophyll concentrations for a given TP level than offshore waters, during the 1960s and 1970s, well prior to mussel invasions. Edsall and Charlton (1997), Nichols *et al.* (1999) and Depew *et al.* (2006), among others, all confirmed that where mussels invaded, a lowered water column chlorophyll relative to TP resulted. Figure 5 shows that, for the 2001-2007 period, the nearshore characteristically and distinctly differed from the offshore with respect to a lower chlorophyll at a given TP level. The suggested difference, about 10% lower chlorophyll in nearshore waters, is similar to that described for the nearshore by Gregor and Rast (1979, 1982) for pre-mussel conditions. Curiously, Lake Superior, the only lake where nearshore and offshore has not yet experienced a mussel invasion, is not an exception; it is worth noting that Gregor and Rast (1979, 1982) as well as others have recognized that chlorophyll-TP relationships may be altered by suspended solids and light, among other factors not involving invasive species.

The possible exception to the trend in Figure 5 is Lake Ontario, although a caveat for Ontario data was footnoted previously. Recent reports for Lake Ontario and eastern Lake Erie do however suggest that, because of extended mussel populations and associated, extensive re-growth of *Cladophora* (e.g., Higgins *et al.* 2006, Hecky *et al.* 2007, Smith *et al.* 2007, Malkin *et al.* 2008), the dynamic between TP loading and planktonic chlorophyll has been altered. The suggestion is that shunting of P through mussels and then to benthic algae is concomitant with lowering of water column TP, and lower chlorophyll because of mussel filtering; together this new ecology may create nearshore areas that are not very different from more offshore waters. We do not fully know about dynamics for all areas, which may involve time-varying changes in loading rates, water movement/circulation, mussels, benthic algae, and TP/chlorophyll trends; but there are compelling illustrations at some locations where nearshore-offshore differences in nutrients or chlorophyll are slight and/or indistinguishable. Perhaps the most important reminder is that use of nutrient concentrations alone, as simple assessment criteria, is not always simple.

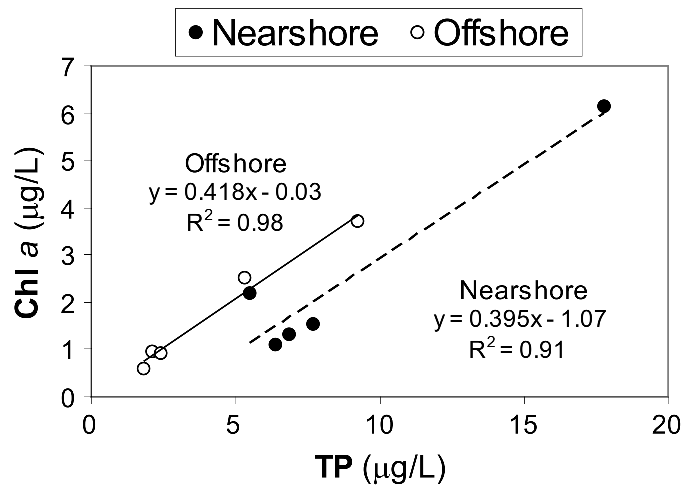

Figure 5. Mean Chlorophyll a – TP relationship for nearshore and offshore of each of the five lakes for summer during the 2001-2007 period.
Lines show linear regression models independently fit to each depth strata. Averages are by lake.
Source: U.S. EPA, Mid-Continent Ecology Division and U.S. EPA, GLNPO.

<u>Trends</u>

Generational and decadal patterns

Nearly a scientific generation ago, Gregor and Rast (1979) compiled nearshore data for pre-phosphorus abatement/GLWQA periods (late 1960s to early 1970s). Although more sparse on the U.S. side, data were available for most of the lakes. The range was from <3 µg/L (detection limits) to >100 µg/L. The entire Lake Ontario nearshore routinely exceeded 15 µg/L, as did Lake Erie. Some locations in Lake Huron exceeded 10 µg/L or even 15 µg/L, principally in Saginaw Bay and the Midland, ON area. Areas noted in Lake Michigan with very high values (>15 µg/L) included those off Milwaukee and east of Chicago, and much of Lake Michigan was 7-10 µg/L. In Lake Superior, high values (>15 µg/L) included areas in Thunder Bay and in the western arm around Duluth.

In 1996, Edsall and Charlton (1997) noted that some sites in Lake Ontario and Erie exceeded 10 µg/L or even 15 µg/L TP. Quasi-synoptic information does not appear to be available.

The above summary for the current decade suggests exceedance of 15 µg/L occurred in the nearshore. Eighteen percent of samples taken in the nearshore exceeded 10 µg/L and over one-third were above 7.5 µg/L. In general, recent concentrations may be comparable to the nearshore of the 1990s, but at a regional level, it is not really possible to make strong comparisons of the 2000s era data with the preceding two decades, barring some additional, more comprehensive data. The issue of conducting a consistent, comprehensive collection of nearshore data continues today.

Overall assessment

By many observers' eyes, nearshore conditions are low (if not also declining) in overall water and habitat quality, especially within the lower lakes (cf. Mackey and Goforth 2005, Niemi *et al*. 2007). By *any* observer's eyes, nearshore conditions are spatially variable and temporally highly dynamic. These ecosystems have been continuously changing in response to changes in external loading as well as internal factors such as the mussel invasion. Open nearshore and even offshore waters are changed by mussel invasions in all the lakes, but Superior, whose edges though have been recently invaded by the quagga mussel (Grigorovich *et al*. 2008).

Pressures (that directly or indirectly affect status of nutrients)

Studies have recently re-emphasized the old notion that the lakes, even as large as they are, exist in a basin. Also, coastal waters are frontline receiving regions that are sensitive to basin-wide trends. Recent findings emphasize that there are numerous human activities on the landscape that create pressures which can trickle down to affect nutrient concentrations and ecological responses in coastal and open nearshore waters.

<u>Landscape changes</u>

The Great Lakes terrestrial basin, at least the U.S portion, has continued to change and be developed. Wolter *et al*. (2006) estimated that 2.5% of the area (798,755 hectares [1,793,767 acres]) experienced a land use/land cover change from 1992 to 2001, and this rate exceeded that predicted by the rate of population growth. Moreover, the change is heavily biased to the near-coastal zone. From Wolter *et al*. (2006): "…49.3% of the change that occurred within the watershed [the U.S. basin draining to the Great

Lakes] between 1992 and 2001 involved transitions of non-developed land to developed land. …This steady increase in hardened surface area is of particular concern for near-shore areas of the Great Lakes and the watershed as a whole. Over 21% (~84,000 hectares [207,569 acres]) of all newly developed land within the basin between 1992 and 2001 occurred within 10 km of a shoreline, even though this only represents 0.27% of the whole watershed."

Figure 6 illustrates the relationship between the basin's landscape condition and nutrient concentrations in the lakes—the scale is lakewide, both offshore and in the aggregate frontline receiving waters of the nearshore. At more local scales, the connection between landscape condition metrics and the resultant downstream concentrations in the water of coastal ecosystems has become strongly established for coastal wetlands, and the effect generally carries, somewhat diluted, to embayments and the more open nearshore (cf. Danz *et al*. 2007, Niemi *et al*. 2007, Trebitz *et al*. 2007, Kireta *et al*. 2007, Reavie 2007, Yurista and Kelly 2007). Morrice *et al*. (2007) demonstrated that the coastal wetland nutrient concentrations (TN, TP) and chlorophyll are influenced by an aggregate of human activities, i.e., not just from agriculture (e.g., Fig. 6), but including land use change, the density of human populations, point sources, and other atmospheric and terrestrial features modified by humans.

The broad scale or site-specific effects of changes in nearshore water quality from landscape changes on the order of 2.5% of the entire watershed may not be easy to predict. Significant effects on coastal waters may be more keyed to some types of landscape changes than others, and sensitive to the spatial mosaic of land use throughout the watershed. Continuing research efforts will help define these connections and perhaps offer some managed growth alternative. Nonetheless, the recent direction of landscape change would indicate the prospect of increased loading to coastal waters, and this should be expected from the aggregate increase in various human activities.

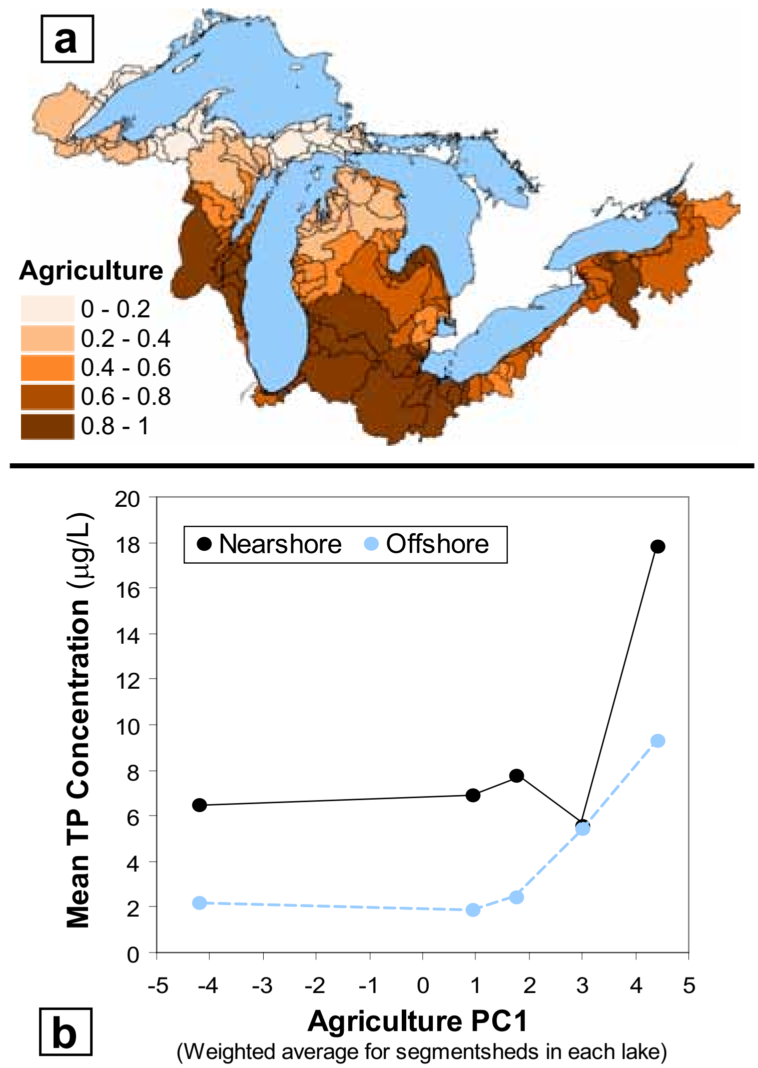

Figure 6. Agriculture landscape metric and TP concentrations across the Great Lakes.
a) The distribution of an agriculture Principal Component (PC1) from Danz *et al.* (2005, 2007).
The summary metric is based on GIS data (circa 1990s to 2000) for 21 agricultural-chemical variables on 762 segmentsheds (Hollenhorst *et al.* 2007) across the entire U.S. basin.
b) Trends in summer TP (µg/L), as related to the agriculture PC1. Calculated for entire U.S. basin draining to each given lake. Concentrations are the simple arithmetic mean for all data within the 2001-2007 period (Tables 1 and 2).
Sources: a) Danz *et al.* (2005, 2007) and Hollenhorst *et al.* (2007); b) Danz *et al.* (2005).

Management Implications
The nature and strength of landscape influences on nearshore lake processes are being quantitatively described. At the same time we can project that human populations and activities in the Great Lakes coastal zones will continue to rise. These two intersecting trends should provide both impetus and means to relate watershed-based pressure and nearshore state, and therefore to formulate general land management plans. It will take more effort to bring pressure-state projections to local and small watershed levels, as these scales demand more detailed spatial modeling. The will to establish land use, zoning and land management practices will likely become a pressing management topic. This is a complex issue interwoven with societal and economic drivers, not just environmental pressures and ecological responses.

Comments from the Author

On the need for consistent monitoring

There is broad recognition that the nearshore has not been regularly or comprehensively sampled (e.g Mackey and Goforth 2004, IJC 2006, SOLEC 1996, this chapter). Recent studies demonstrate that the variability in the nearshore can be overcome with adequate sampling, which in the past has hindered the attempt. Development of explicit nearshore nutrient criteria or benchmarks might be considered; future monitoring/assessments would be strengthened and could be indexed against such benchmarks. There are also recent approaches that have successfully incorporated nearshore and offshore sampling into unified whole lake assessments. We should strive to do so, on a more regular basis.

An upcoming effort led by the U.S. EPA's Office of Water is the National Coastal Survey, to be conducted with coastal States' participation. The survey, planned for 2010, will be the first in the U.S. to report on the Great Lakes coastal condition through a thorough sampling of the nearshore at about 250 sites. The data will provide an opportunity to make both regional-scale assessments and assessments for each of the lakes on a repeating cycle (every five years). Although it presently is planned only for the U.S. shoreline, this is the kind of program necessary to survey the nearshore on a consistent and unbiased basis, and it may be a continuing platform to work towards an integration of monitoring from the basin to the offshore.

On technology and trends in our ability to examine landscape-nearshore linkages

It is interesting to compare images of Gregor and Rast (1979) with images that can be generated today (Fig. 7). Gregor and Rast (1979, 1982) classified nearshore waters and felt that variations in trophic status "compared favorably" with geographic land areas and shorelines described by their relative potential for nutrient export based on soil, land use, and hydrologic characteristics (described by Johnson *et al*. 1978). Gregor and Rast (1979, 1982) viewed the direct cause-effect relationship between land use and nearshore trophic status as a qualitative, but obvious, finding for the data of the early 1970s.

The generational advances of remote sensing and an ability to compile extensive spatial data in GIS layers allow characterization of the entire Great Lakes basin (Fig. 7). There is now a framework to study the influence of landscape-derived pressures on the nearshore; there are many scales (Hollenhorst *et al*. 2007) still to be explored. Recent advances in nearshore sampling strategies show that continuous sensing with towed in situ sensors is feasible and can provide spatially-explicit water quality information across vast nearshore regions. Nearshore variability can be sampled as a virtual census of the entire water column (both horizontally and vertically) with a variety of sensors, and the suite of available sensors continues to expand. Results have indicated strong, quantifiable links between water quality and biology in the nearshore and indicators of landscape condition in the adjacent watersheds (Fig. 8). In conclusion, the future of nearshore assessment is bright; the technological means to quantify linkages and better fulfill the vision of Gregor and Rast (1979, 1982) is available. Time will tell how successful we can be in putting these technologies into practice on a sustained basis to aid management decisions.

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Author: John R. Kelly, U.S. EPA, Office of Research and Development, National Health and Environmental Effects Research Laboratory, Mid-Continent Ecology Division, Duluth, MN 55804

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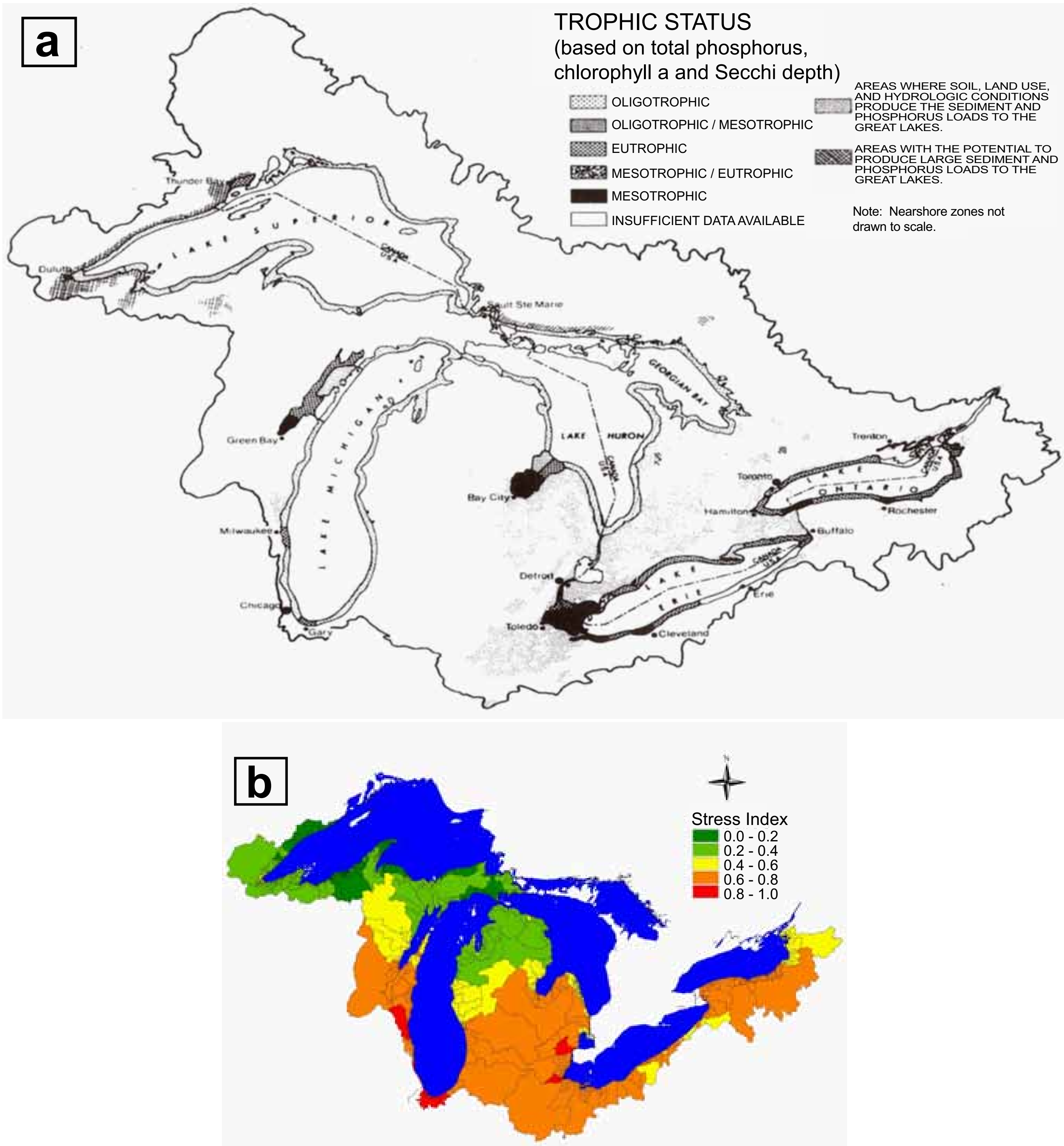

Figure 7. Perspectives on landscape and nearshore condition from the 1970s and the early 2000s.
a) Summary figure from Gregor and Rast (1979) to illustrate nearshore areas of different trophic status and potential relationship to landscape characteristics.
b) Summary figure from Niemi *et al*. (2007).
Response-based cumulative landscape stress index. Derived from landscape attributes circa 2000 for 762 segmentsheds of the U.S. shoreline and calibrated to biological response in receiving coastal systems.
Sources: a) Gregor and Rast (1979); b) Niemi *et al*. (2007).

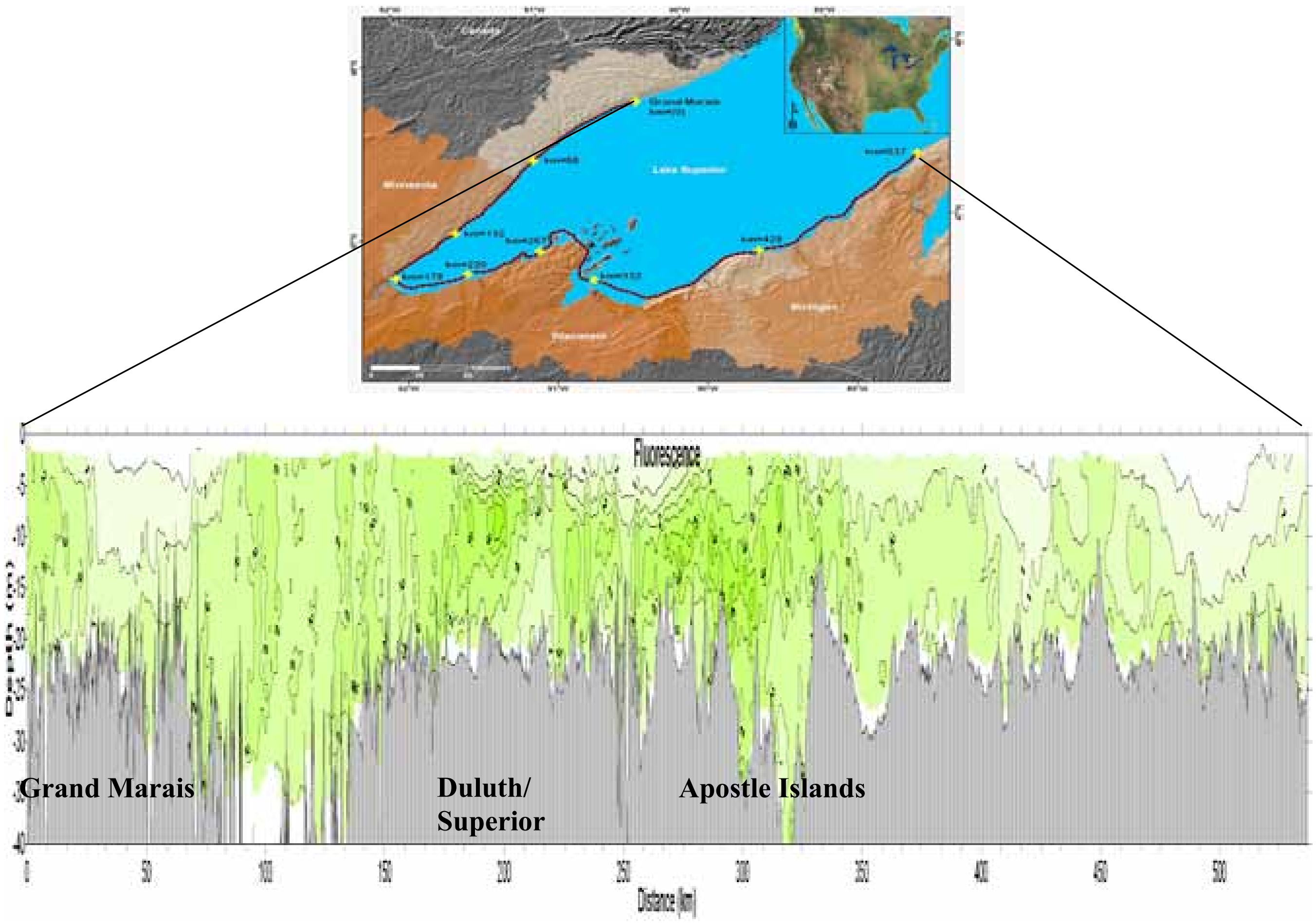

Figure 8. A shoreline nearshore transect over 537 km track in western Lake Superior surveyed with continuous in situ sensors oscillated throughout the water column (Modified from Yurista and Kelly, 2007).
Upper panel shows track with adjacent watersheds, where watershed colors are scaled to show different agriculture PC1 values (as in Figure 8). Lower panel shows in situ fluorescence, calibrated relative to chlorophyll a*,* along the entire track. Values are high near Duluth and along the south shore to the Apostle Islands, in association with higher agricultural PC1 scores. Yurista and Kelly (2007) provide multivariate regression models that relate water quality along the track to adjacent shoreline landscape metrics.
Source: Modified from Yurista and Kelly (2007).

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5.2 Nonindigenous Species (NIS)

State of the Ecosystem

Nearshore and coastal waters provide habitat for all 184 nonindigenous species (NIS) introduced to the Great Lakes since 1840; none are restricted exclusively to offshore areas. These habitats have been profoundly altered by NIS, with effects ranging from uprooting of wetland plants by common carp to direct and indirect creation of microhabitats by dreissenid mussels. The status of Great Lakes nearshore waters with respect to NIS is **poor**. Since 1996, 18 new NIS (Table 1) have been discovered – a rate of 1.5/year. This rate is higher than the long-term discovery rate (1.1/year since 1840), but lower than the rate since the opening of the St. Lawrence Seaway in 1959 (1.8/year) (Fig. 1). Despite the slightly lower discovery rate in the last decade, any increase in the number of NIS in the Great Lakes represents a **deteriorating** trend since additional NIS may portend further disruption of existing food webs, in many cases in unpredictable and/or undesirable ways.

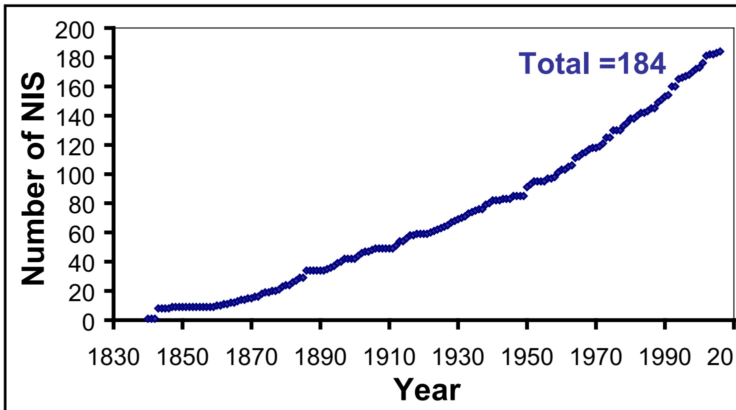

Figure 1. Cumulative number of aquatic NIS discovered in the Great Lakes basin since 1840.
Sources: Mills *et al.* (1993); Ricciardi (2001); Grigorovich *et al.* (2003); Ricciardi (2006).

Of the 18 NIS introduced since 1996, 12 are attributed to the ship vector and nine are native to Eurasia--proportions consistent with historical patterns (Kelly *et al.* in press). Lake Michigan and Lake Ontario were first discovery sites for seven and six species, respectively; Lake Erie, Lake St. Clair and connecting waters hosted four; and Lake Superior harbored one—*Gammarus*

Year	NIS	Common Name	Region of Origin	Lake of First Discovery	Vector
1996	*Heteropsyllus nr. nunni*	harpacticoid copepod	Atlantic North America	Lake Michigan	Shipping
1997	*Acineta nitocrae*	suctorian	Eurasia	Lake Erie	Shipping
1998	*Cercopagis pengoi*	fish-hook waterflea	Ponto-Caspian	Lake Ontario	Shipping
1998	*Schizopera borutzkyi*	harpacticoid copepod	Ponto-Caspian	Lake Michigan	Shipping
1999	*Daphnia lumholtzi*	waterflea	Africa	Lake Erie	Unintentional release
1999	*Nitokra incerta*	harpacticoid copepod	Ponto-Caspian	Detroit River	Shipping
2000	*Heterosporis* sp.	microsporidian	Unknown	Lake Ontario	Unknown
2001	*Gammarus tigrinus*	amphipod	Atlantic NA	Lake Superior	Shipping
2001	*Psammonobiotus communis*	testate amoeba	Ponto-Caspian	Lake Ontario	Shipping
2001	*Rhabdovirus carpio*	SVC spring viraemia of carp	Eurasia	Lake Michigan	Unknown
2002	*Cylindrospermopsis raciborskii*	cyanobacterium	South America	Lake Michigan	Unknown
2002	*Piscirickettsia cf. salmonis*	muskie pox	Unknown	Lake St. Clair	Unknown
2002	*Psammonobiotus linearis*	testate amoeba	Ponto-Caspian	Lake Ontario	Shipping
2002	*Psammonobiotus* sp.	testate amoeba	Ponto-Caspian	Lake Ontario	Shipping
2002	Ranavirus sp.	largemouth bass virus (LMBV)	Unknown	Lake Michigan	Unintentional release
2003	*Enteromorpha flexuosa*	green alga	Widespread	Lake Michigan	Shipping
2005	Novirhabdovirus sp.	Viral Hemorrhagic Septicemia (VHS) virus	Atlantic North America	Lake Ontario	Shipping
2006	*Hemimysis anomala*	mysid shrimp	Ponto-Caspian	Lake Michigan	Shipping

Table 1. NIS discovered in the Great Lakes since 1996.
Sources: Ricciardi (2001); Grigorovich et al. (2003); Ricciardi (2006); Great Lakes Aquatic Nonindigenous Species Information System (GLANSIS) (http://www.glerl.noaa.gov/res/Programs/ncrais/glansis.html).

tigrinus (amphipod)—which was also found in Lake Huron one year later. This distribution is generally consistent with historical patterns (Fig. 2), although discoveries have become more prevalent in Lake Michigan in recent years. Species discovered since 1996 that have the greatest potential to disrupt Great Lakes nearshore ecosystems are *Cercopagis pengoi* (fishhook waterflea) (discovered 1998), viral hemorrhagic septicemia (VHS) (discovered 2005), and *Hemimysis anomala* (bloody-red shrimp) (discovered 2006). *Cercopagis*, present in Lakes Ontario, Erie, and Michigan, preys on zooplankton, impacts native zooplankton species community composition, and competes with planktivorous fish for food. VHS, a virus originally believed to affect only salmonid species, is responsible for die-offs of muskellunge, smallmouth bass, northern pike, freshwater drum, gizzard shad, yellow perch, round goby, lake whitefish, Chinook salmon, and walleye in all the Great Lakes except Lake Superior. *Hemimysis*, a mysid shrimp that has become established in Lakes Ontario, Michigan, and Erie, was predicted to invade the Great Lakes because of its likelihood of surviving transport in ship ballast water and its extensive recent invasion history in Europe (Ricciardi and Rasmussen 1998). *Hemimysis* is a shallow water mysid that resides at depths from 0.5 to 50 m (generally 6 to 10 m) (Salemaa and Hietalahti 1993), whereas the Great Lakes native *Mysis relicta* (opossum shrimp) prefers deeper waters. *Hemimysis* has the potential to be both a food competitor with young fish and a food source for older fish.

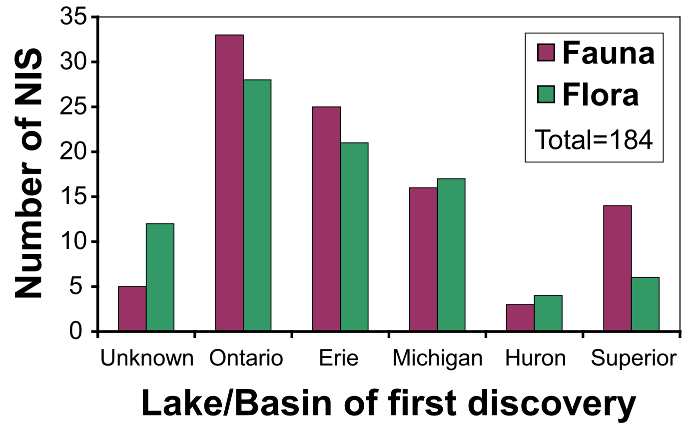

Figure 2. Location of first discovery for NIS in the Great Lakes since 1840.
Discoveries in connecting waters between Lakes Huron, Erie, and Ontario were assigned to the downstream lake. Species that were widespread at the time of discovery were assigned to the unknown category.
Source: Great Lakes Aquatic Nonindigenous Species Information System (http://www.glerl.noaa.gov/res/Programs/ncrais/glansis.html).

No new fish species have been discovered since 1996, but several fish diseases are cause for concern. VHS, spring viremia of carp (SVC), and largemouth bass virus (LMBV) have each caused die-offs of fish in recent years. The VHS virus affects many (> 40) fish species and appears to have significant potential for further spread in and around the Great Lakes. Concern about the transfer of VHS to other waters led to regulation of the baitfish industry in all U.S. Great Lakes states; baitfish that are to be transported to waters other than those in which they were collected must be certified disease free. SVC has caused large die-offs of ornamental koi in aquaculture facilities in Virginia and North Carolina. Carrier carp have been isolated from the Calumet-Sag Channel (Lake Michigan basin) that connects Lake Michigan to the Mississippi drainage and from Hamilton Harbor, Lake Ontario. LMBV has been detected in fish in Lake St. Clair and the Bay of Quinte, Lake Ontario although no large fish kills have been reported to date in the Great Lakes basin. Large kills have occurred in several southern states and appear to be related to thermally-stressed fish. In addition to viruses, five protozoa and one bacterium have been discovered since 1996. This shift in the pattern of discovery toward microscopic organisms likely reflects greater research efforts to identify new NIS.

Pressures

Ballast water discharge

New regulations in Canada (2006) and in the United States (2008) require transoceanic ships declaring no ballast on board to flush their ballast tanks with saline water, but the method does not provide 100% efficacy. While planktonic organisms will be flushed or killed with close to 100% efficiency (Gray *et al.* 2007), species with resistant life stages may still gain entry. Also, NIS may still be transferred within the Great Lakes by "lakers"—vessels that do not leave the Great Lakes-St. Lawrence Seaway system, but do transfer ballast water between Great Lakes ports (Rup 2008). New ballast water treatment technologies (heat, UV light, chemicals, and filtration) show promise for both oceangoing and lake vessels, particularly when used in combination, although their application to Great Lakes conditions needs further attention.

Other vectors

NIS may continue to be introduced and spread by other vectors. Baitfish may contain more than one species, including NIS like round gobies (*Neogobius melanostomus*). In addition, infected baitfish could vector VHS to inland lakes. Asian carp species (bighead, silver) from the Mississippi drainage still threaten to enter Lake Michigan through the Chicago Sanitary and Ship Canal, despite the presence of an electric barrier. Growth in aquaculture, live gardens, and the aquarium trade increase the risk that NIS will be introduced either intentionally or unintentionally (Cohen *et al*. 2007).

Synergistic effects

Combined effects of water quality change, climate change, and facilitative interactions between NIS may increase the pressures exerted on nearshore waters of the Great Lakes. NIS may act in concert with one another with results that are more severe than the effect of any NIS alone (Ricciardi 2001, 2005). For example, recurring outbreaks of avian botulism resulting in the deaths of large numbers of waterfowl in Lakes Erie and Ontario are thought to result from the combined effects of dreissenid mussels and round gobies. It has been suggested that mussels, through deposition of pseudofeces, create environmental conditions that promote the pathogenic bacterium, and round gobies, through their ingestion of mussels, transfer bacterial toxin from the mussels to higher levels of the food web (Yule *et al*. 2006). Warming temperatures and changing water quality (e.g. increasing clarity, declining nutrients) may enhance the success of established NIS that have a broader range of environmental tolerance as compared with native species.

Range expansions of established NIS

Although there have been no new vascular plant discoveries in the Great Lakes since 1996, several established invasive plant species continue to spread. Since 1996, new records of purple loosestrife (*Lythrum salicaria*) have been documented in all Great Lakes states except Indiana and Illinois (USGS 2008). Purple loosestrife replaces cattail and other native wetland plants resulting in the alteration of the structure and function of wetlands. Large infestations reduce native foods and cover for wildlife and can impede water flow. *Phragmites australis*, or common reed, is also spreading throughout the Great Lakes basin. Recent research demonstrates the presence of two genotypes—one native and one invasive. It is the invasive European genotype that has expanded its range in the Great Lakes basin in areas such as Lake St. Clair; Long Point, Lake Erie; and Green Bay, Lake Michigan. *Phragmites* forms dense monospecific stands, altering native wetland plant and wildlife communities. Additional macrophytes including *Hydrilla verticillata* and *Cabomba caroliniana* (carolina fanwort) are currently found in water adjacent to the Great Lakes, and could pose significant problems in shallow wetland areas if introduced.

Dreissenid mussels have continued to expand their range, with quagga mussels (*Dreissena bugensis*) replacing zebra mussels (*Dreissena polymorpha*) in numerous nearshore and offshore habitats in Lakes Erie, Michigan, and Ontario. Dreissenid mussels may be partially responsible for lack of improvement in nearshore water quality despite distinct improvements in offshore waters due to declines in phosphorus loadings. Hecky *et al*. (2004) suggest that dreissenids sequester phosphorus in nearshore areas through their filtering activity and through deposition of pseudofeces (nearshore shunt hypothesis).

Management Implications

The introduction of each new NIS adds ever-increasing complexity to Great Lakes food webs. Before the effects of any one invader are known, another arrives, confounding research results and forcing modification of previously successful management strategies in the face of uncertainty. Prevention of new introductions will require aggressive vector management (e.g. ballast water exchange, to be replaced by ballast water treatment, for all vessels) coupled with continued monitoring to determine the efficacy of preventative measures. New ballast water regulations for transoceanic No Ballast Onboard (NOBOB) vessels should reduce the risk of introduction of new NIS in Great Lakes waters, but interlake transfer of ballast water by vessels that do not leave the Great Lakes will continue to spread existing NIS among the lakes. Transfer of unexchanged ballast water to the Great Lakes by vessels originating from coastal ports of North America must also be explored. Some species, including the amphipod *Gammarus tigrinus*, may have entered the lakes via ballast discharge from a coastal vessel. Nearshore and coastal habitats in the Great Lakes continue to be significantly impacted by NIS and are areas that require increased attention by scientists, managers, and policymakers.

Comments from the authors

To better assess nearshore and coastal waters, facilitative and/or synergistic effects should be assessed. Data access is typically quite good; NOAA's Great Lakes Aquatic Nonindigenous Species Information System (GLANSIS) provides reliable information. Endpoints that would infer achievement of good quality nearshore waters are no new NIS discoveries, a decrease in the discovery rate, and confinement of existing NIS to current distributions (no spread). It must be acknowledged, however, that time lags between introduction and discovery of NIS could result in further finds of NIS in the Great Lakes even after the vectors responsible for their introduction have been muted or eliminated.

Acknowledgments

Authors:

Kristen T. Holeck, Department of Natural Resources, Cornell University, Cornell Biological Field Station, Bridgeport, NY
Edward L. Mills, Department of Natural Resources, Cornell University, Cornell Biological Field Station, Bridgeport, NY
Hugh MacIsaac, Great Lakes Institute for Environmental Research, University of Windsor, Windsor, ON, Canada
Anthony Ricciardi, Redpath Museum, McGill University, Montreal, QC, Canada

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5.3 Viral Hemorrhagic Septicemia in the Great Lakes

State of the Ecosystem

Background

Viral hemorrhagic septicemia virus (VHSv) is a fish pathogen reportable to the World Organization for Animal Health (OIE). First reported as a disease of European rainbow trout (*Oncorhynchus mykiss*) in 1938, it was not until 1963 that a virus (VHSv) was identified as the pathogen responsible. Since that time, three (3) VHSv genotypes have been isolated from fish in Europe, and in 1988, a fourth genotype was isolated from marine fishes in the Pacific Northwest (Meyers and Winton 1995). One of the European genotypes significantly affects freshwater salmonids and pike, whereas the remaining two affect marine fishes (Jim Winton, personal communication). Gagné *et al.* (2007) reported the isolation of VHSv genotype IV from brown trout (*Salmo trutta*), mummichog (*Fundulus heteroclitus*), striped bass (*Morone saxatilis*), and three-spined stickleback (*Gasterosteus aculeatus*) from New Brunswick and Nova Scotia, Canada. Genotype IV was detected in the Great Lakes in 2003 and 2005 although it is unknown how VHSv was introduced into the Great Lakes basin. The Great Lakes strain of VHSv is most similar to the Atlantic strain of the virus isolated by Gagné *et al*. (2007) and suspected vectors for the introduction and spread within the Great Lakes include ballast water, movement of live fish (possibly baitfish) into the Great Lakes, and the natural migration of fish. The strain of VHSv found in the Great Lakes is known as VHSv-IVb. Signs of disease in fish infected with VHSv include pale gills and organs, bloated abdomens, bulging eyes, darker body color and hemorrhaging (bleeding) on the body and in the organs. Bleeding is the most commonly reported sign of disease.

2005 Reports

During the spring of 2005, a large mortality event affecting freshwater drum (*Aplodinotus grunniens*) occurred in the Bay of Quinte, Lake Ontario and VHSv was isolated from the diseased fish (Lumsden *et al.* 2007). Although this was the first report of VHSv in the Great Lakes, it was not the first isolation of the virus from the Great Lakes. Biologists at Michigan State University had isolated an unknown virus from a muskellunge (*Esox masquinongy*) caught in Lake St. Clair in the spring of 2003, but did not pursue identification of the virus until learning of the Lake Ontario isolation. Confirmation of the Lake St. Clair isolation as VHSv was made in December 2005 (Elsayed *et al*. 2006).

2006 Reports

In 2006, VHSv was determined to be a causative factor in mortality events in Lake Erie, Lake Ontario, Lake St. Clair, St. Lawrence River, and Conesus Lake (NY). The detection of VHSv in walleye (*Stizostedion vitreum*) from Conesus Lake was the first inland detection of the virus in the Great Lakes basin. Within the first year after detecting VHSv, fifteen warm and cool water species were known to be susceptible to the virus in the Great Lakes including freshwater drum, gizzard shad (*Dorosoma cepedianum*), muskellunge, round goby (*Neogobius melanostomus*), walleye, and yellow perch (*Perca flavescens*). Other Great Lakes fish species that were shown to be carriers (no large fish kills reported) of VHSv-IVb in 2006 included bluegill (*Lepomis macrochirus*), bluntnose minnow (*Pimephales notatus*), emerald shiner (*Notropis atherinoides*), redhorse sucker (*Moxostoma* sp.) and smallmouth bass (*Micropterus dolomieui*).

In a press release dated January 25, 2007, the Michigan Department of Natural Resources (MI DNR) reported that VHSv had been isolated from chinook salmon (*O. tshawytscha*), lake whitefish (*Coregonus clupeaformis*), and walleye from the Thunder Bay (Alpena, MI) and Rogers City, MI, regions of northern Lake Huron during the fall of 2006. Although mortality was not associated with this report, the fish did show clinical signs of VHSv. Additionally, the MI DNR reported detecting VHSv in an archived lake whitefish sample originally collected in the fall of 2005 near Cheboygan, MI, by the Chippewa Ottawa Resource Agency (CORA), a tribal organization located in the upper peninsula of Michigan.

2007 Reports

Freshwater drum kills were observed in Little Lake Butte des Morts and Lake Winnebago in the spring of 2007, the first reports of VHSv in Wisconsin waters (WI DNR News Release May 18, 2007). Both lakes are part of the Lake Winnebago system and are in the Great Lakes Basin. Additional detections of VHSv were made in smallmouth bass, lake whitefish, and brown trout collected from Wisconsin waters of Green Bay and Lake Michigan near the Door County Peninsula (WI DNR News Release May 24, 2007).

A significant fish kill occurred on Budd Lake in Clare County Michigan in the spring of 2007. Fish species affected included black crappie (*Pomoxis nigromaculatus*), bluegill, largemouth bass (*M. salmoides*), muskellunge, pumpkinseed sunfish (*L. gibbosus*), and yellow perch (MI DNR press release May 17, 2007). Budd Lake is land-locked, with virtually no flow in or out, suggesting that the source of VHSv to the lake was probably a live-fish introduction such as baitfish (Gary Whelan, personal communication).

The state of New York was the site of numerous fish kills in 2007 that were associated with VHSv. In May, a significant kill of smallmouth bass and rock bass (*Ambloplites rupestris*) occurred at Skaneateles Lake in New York's Finger Lakes region (NY DEC press release June 19, 2007). A lake trout collected from Skaneateles Lake also tested positive for VHSv. VHSv was also detected in rainbow trout collected from the Little Salmon River, sunfish collected from the Seneca-Cayuga Canal, and sunfish and koi carp (*Cyprinus carpio*) collected from a farm pond in Ransomville. The farm pond was infected when the owner transferred infected fish from nearby Twelve Mile Creek as part of a fish rescue operation (NY DEC press release July 23, 2007).

The only reported fish kill in Ontario associated with VHSv took place in Hamilton Harbour, Lake Ontario in May. There were low numbers of dying fish of several species reported, and the virus was isolated from two diseased freshwater drum (John Lumsden, personal communication).

By the end of 2007, the list of fish species susceptible to VHSv had been expanded to include 25, with some species known to be more susceptible to disease and dying than others. In the Great Lakes, these species included game and commercial food fish, baitfish, predators and preyfish, and native and invasive species. This list has since been expanded to include more than 28 fish species. Mortalities have not occurred in all species listed as susceptible. Most Great Lake jurisdictions had also implemented monitoring programs to test fish from a variety of locations within the Great Lakes basin by the end of 2007. Several detections of VHSv were made in these monitoring programs.

<u>2008 Reports</u>
The Wisconsin DNR reported a round goby kill in Lake Michigan waters just south of Milwaukee in May of 2008 (WI DNR press release June 5, 2008). Yellow perch collected nearby as part of surveillance efforts by the DNR also tested positive (WI DNR press release June 13, 2008). Similarly, rock bass and round goby collected from Illinois waters of Lake Michigan near Waukegan tested positive for VHSv, but did not show clinical signs of the disease (IL DNR press release July 2, 2008).

Sea lamprey (*Petromyzon marinus*) collected from northern Lake Huron tributary streams tested positive for VHSv. The animals were collected from the Cheboygan River, Green Creek, and Ocqueoc River during routine sea lamprey trapping operations in early June and screened for VHSv by the La Crosse Fish Health Center (LFHC) as part of the National Wild Fish Health Survey. Clinical disease signs were not observed in the lamprey screened. The results suggest that sea lamprey may serve as a vector for spread of the virus throughout the Great Lakes basin.

The first detection of VHSv outside of the Great Lakes basin was made from muskellunge collected from Clear Fork Reservoir (OH) in April 2008. Clear Fork Reservoir is located in north central Ohio and drains to the Ohio River. Ovarian fluid samples taken as part of routine fish health screening of spawning fish by the Ohio Division of Wildlife tested positive for VHSv-IVb at the LFHC, the first isolation using ovarian fluids. Clinical disease signs were not observed in the muskellunge.

Pressures
<u>Biological Impacts</u>
The virus has been detected in the St. Lawrence River muskellunge population and unusually high mortalities have occurred in this population since 2005. Casselman *et al*. (2008) reported that most of the muskellunge carcasses from the St. Lawrence River were larger, mature fish likely in the age-classes of peak fecundity. Analysis of creel census data from pre- and post-mortality years (2003-2007) indicated a 49% reduction in catch of mature individuals (Casselman *et al*. 2008).

Population-level effects due to VHSv-linked fish kills have not been reported at other sites in the Great Lakes basin. The Bay of Quinte in Lake Ontario was the site of a large freshwater drum kill in 2005, the first kill associated with VHSv in the Great Lakes. Assessments of the Bay of Quinte freshwater drum population by the Ontario Ministry of Natural Resources have not shown a decline (Christie *et al*. 2008). Ontario and Michigan combined assessment data indicate that VHSv-linked fish kills in 2003 and 2006 did not have a significant impact on the adult muskellunge population in Lake St. Clair (Yunker *et al*. 2008). Kayle and Wright (2008) reported that the yellow perch population in Lake Erie does not appear to have been affected by the VHSv-related kills that occurred in the Central Basin in 2006.

It appears that fish populations already under stress from other pressures are most vulnerable to population-level impacts resulting from fish kills associated with VHSv. Large populations that have good representation at all year-classes and strong food webs appear to be more resilient to VHSv-related mortalities, however this will not be known with certainty for several more years until one generation has cycled through the populations.

Regulatory Impacts

As a response to the significant scale of the VHSv outbreaks in the Great Lakes during the spring and summer of 2006, the USDA Animal and Plant Health Inspection Service (APHIS) issued a Federal Order on October 24, 2006. The initial order prohibited the interstate movement of VHSv-susceptible species from Illinois, Indiana, Michigan, Minnesota, New York, Ohio, Pennsylvania, and Wisconsin, as well as the importation of the same species from the Canadian provinces of Ontario and Quebec. Upon gathering additional information, APHIS amended the Federal Order on November 14, 2006, to allow for interstate movement from the affected states under certain conditions if the fish were for human consumption or if the fish tested negative for VHSv according to specified standards. Additional amendments have been made to the list of susceptible species and to allow for catch and release fishing. APHIS' interim rule for VHSv was published in the Federal Register on September 9, 2008 however, the effective date for this rule has been delayed indefinitely (Federal Register 2009) to provide APHIS with additional time to make adjustments to ensure the rule will be successfully implemented.

The states of Illinois, Indiana, Michigan, New York, Ohio, Pennsylvania, and Wisconsin have also adopted VHSv rules. Rules vary by state, but generally place limits on live fish (including baitfish) movements and require testing for VHSv prior to intra- or interstate transfer or release. The state of New York has adapted rules requiring testing for eight additional fish pathogens for intrastate movements or importations into the state.

The Canadian Food Inspection Agency, the federal agency responsible for fish disease control and investigation, has not placed any restrictions on the movement of fish species susceptible to VHSv. Quebec has taken steps toward the development and implementation of fish movement restrictions to help protect against the spread of VHSv. In Ontario, the OMNR first took action in January 2007 to slow the spread of VHSv out of the Great Lakes. Recent actions include the establishment of a VHS Management Zone that includes VHSv positive waters in Ontario. Restrictions have been placed on where baitfish may be transported, where eggs are collected and where fish can be stocked.

Management Implications

The scale of the VHSv outbreak in 2006, the subsequent Federal Order, and state/provincial regulations have had significant impacts on the operations of Federal, State, Provincial and Tribal natural resource agencies, as well fish-related industries and the private sector. For resource agencies, the most significant impact has been, and will continue to be, the impact of new restrictions on the movement of warm and cool water fishes. Most jurisdictions developed new restrictions, implemented the changes and worked with stakeholder groups to advise and educate them on the changes. Monitoring programs were developed and implemented and new practices were adopted for warm and cool water rearing programs which are a major component of Great Lakes basin hatchery programs. Historically, fish health inspections have not been performed on warm and cool water fish species. Often these species are not at the culturing facility long enough for inspection laboratory tests to be completed prior to stocking, or are reared using extensive culture methods, which require additional effort to sample. In these instances, brood stock (which is often from wild stocks) may need additional testing prior to egg take to ensure that the virus is not passed down from parents to progeny, or young fish may need to be held longer prior to stocking so testing can be completed. Costs associated with the additional fish health testing have stressed the limited budgets of Great Lakes resource agencies.

Natural resource agencies have also altered their warm and cool water fish rearing programs in response to the VHSv outbreaks that have occurred since 2006. The Michigan Department of Natural Resources suspended its muskellunge and walleye rearing programs in 2007; these programs resumed on a limited basis in 2008 (Gary Whelan, personal communication). Many natural resource agencies have also limited wild gamete collection to sites that have not tested positive for VHSv, and all agencies have adopted new egg disinfection protocols to limit the risk of spreading VHSv.

The new regulations have not had a significant impact on salmonid fish operations since cold water species have historically received fish health inspections.

Conclusions

Viral hemorrhagic septicemia is a new introduction into the Great Lakes, introduced prior to 2003. To date, VHSv has been confirmed to be present in all of the Great Lakes except Lake Superior, and inland lakes and streams in Michigan, New York, Ohio, and Wisconsin. The detection of VHSv in Clear Fork Reservoir in Ohio in 2008 was the first isolation of the virus outside of the Great Lakes basin. The Chicago Waterway links Lake Michigan to the Mississippi River basin, providing an additional entry point for VHSv to make its way to the Mississippi River. Movement of live fish, including baitfish, will contribute to the spread of the Great Lakes strain of VHSv through the Great Lakes basin and other regions of the United States and Canada.

Significant fish kills, particularly in spring, are expected to occur as VHSv spreads into these new areas. Additionally, naïve fish populations or year classes will be susceptible to periodic disease outbreaks of VHS in the future.

Acknowledgments

Author: Ken Phillips, La Crosse Fish Health Center, U.S. Fish and Wildlife Service, 555 Lester Avenue, Onalaska, WI 54650

Collaborator: Elizabeth Wright, Fish Health and Aquaculture, Ontario Ministry of Natural Resources, elizabeth.wright1@ontario.ca

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5.4 *Cladophora* in the Great Lakes: Guidance for Water Quality Managers

State of the Ecosystem

Introduction

Cladophora is a native, filamentous, green alga that is found attached to solid substrate in all of the Laurentian Great Lakes (Fig. 1). The alga grows sparsely in a few locations in Lake Superior (Jackson *et al*. 1990), is typically associated with tributary and point source phosphorus (P) inputs in Lake Huron (Auer *et al*. 1982) and occurs as widespread blooms in the comparatively P-rich waters of Lakes Erie (Higgins *et al*. 2005a), Michigan (Greb *et al*. 2004) and Ontario (Wilson *et al*. 2006). While *Cladophora* can successfully colonize offshore reefs where supported by whole-lake nutrient conditions, it is the nuisance growths observed in nearshore regions of Lakes Erie, Michigan and Ontario (Fig. 2) that have drawn the attention of those involved in public recreation, operation of utilities and water quality management. Public awareness of the problem has been heightened by reports in the popular press of beach fouling and the shutdown of nuclear power plants, concerns that incidences of avian botulism are linked to *Cladophora*, (New York Sea Grant and Pennsylvania Sea Grant 2001) and scientific studies linking *Cladophora* and human pathogens (Byappanahalli *et al*. 2003, Ishii *et al*. 2006, Olapade *et al*. 2006, Englebert *et al*. 2008). Nuisance growth of *Cladophora*, with attendant beach accumulation, will demand the attention of those re-writing the Great Lakes Water Quality Agreement (GLWQA) because the negative effects of the phenomenon are manifested in a manner and at locations that influence public perception of water quality.

Figure 1. *Cladophora* in its growth habit in Lake Michigan off Milwaukee, Wisconsin.
Source: Image by Harvey Bootsma.

The Historical Context

Cladophora has been known to the Great Lakes scientific community for over 150 years, with nuisance conditions noted as far back as the mid-20th century (Taft and Kishler 1973). Regulatory and research interest became more focused with the publication, in the mid-1970s, of an International Joint Commission (IJC) report entitled, "*Cladophora* in the Great Lakes" (Shear and Konasewich 1975). Although the 1978 GLWQA specifically referenced nuisance algae problems and excessive *Cladophora* growth was identified as an emerging issue (Task Group III), it was concluded that there was insufficient scientific information available to develop effective control strategies (Vallentyne and Thomas 1978).

Following publication of the IJC report, the U.S. Environmental Protection Agency and the Ontario Ministry of the Environment supported a series of scientific and modeling initiatives, seeking to develop a more complete scientific understanding of the *Cladophora* problem. The results of these and other studies were presented in a special issue of the *Journal of Great Lakes Research* devoted to the ecology of filamentous algae (Auer 1982). It was the general sense of this body of work that the P management strategies being implemented under the GLWQA could lead to the control of nuisance conditions.

There is evidence that P control strategies have played a role in reducing nuisance conditions of *Cladophora* growth. Canale and Auer (1982a) reported a dramatic local decline in *Cladophora* biomass following implementation of P removal at a wastewater treatment facility at Harbor Beach, Michigan on Lake Huron. The work of Painter and Kamaitis (1987) strongly suggests that P abatement efforts had a marked effect on *Cladophora* in Lake Ontario. They reported that, between 1972 and 1982-83, *Cladophora* biomass and *Cladophora* tissue (stored) P levels declined almost 60% in response to a 67% reduction in spring soluble reactive phosphorus (S_{RP}) concentrations. Levels of *Cladophora* biomass observed in 1982-83 were generally at or below the threshold for nuisance conditions (<50 gDW/m^2; cf., Canale and Auer 1982a). If one considers these few reports as representative of the post-P abatement, pre-dreissenid period, it can be concluded that the management strategies mandated under the GLWQA achieved the desired effect (cf. Neilson *et al*. 1995). Interest in *Cladophora*, as evidenced in the publication record of the *Journal of Great Lakes Research*, began to decline in the mid-1980s and the issue of nuisance growths received little attention through the balance of the 20th century.

Resurgence?

A suite of papers recently published in the Journal of Great Lakes Research (Higgins *et al*. 2005a, 2005b, 2006) and a workshop convened at the Great Lakes Water Institute of the University of Wisconsin – Milwaukee (Bootsma *et al*. 2004a) have signaled a rekindling of attention to the topic of nuisance *Cladophora* growth. It is not clear to what degree renewed interest reflects a true resurgence of the problem as the relative dearth of data makes it difficult to compare the magnitude of past *Cladophora* problems with those reported currently (Young and Berges 2004). No systematic, basinwide surveys of *Cladophora* distribution and biomass were made during the period of peak interest and little is known about nearshore P levels or *Cladophora* colonization over the period of declining attention (Higgins *et al*. 2005a).

It is clear, however, that nuisance growth of *Cladophora* is a significant water quality problem as we move into the 21st Century. Over the period 1995-2002 (an interval following dreissenid establishment), the Ontario Ministry of the Environment supported a series of surveillance investigations into shoreline fouling by *Cladophora* in Lake Erie where nuisance blooms were a regular occurrence. Survey results, published by Higgins *et al.* (2005a), indicate that *Cladophora* colonizes nearly 100% of the available substrate along the north shore of Lake Erie and that abundance (standing crop) reaches levels equivalent to those of the 'nuisance growth' period of the 1970s. The Ontario Water Works Research Consortium initiated studies of the occurrence of *Cladophora* in Western Lake Ontario in 2002. In late summer (a sub-optimal period) of 2003, *Cladophora* coverage at a 5m depth at 25 locations along the lake's north shore averaged 57% and attained a greater substrate coverage than in similar surveys in 1981 and 1991 (Wilson *et al.* 2006). Anecdotal evidence for Lake Michigan suggests an increase in *Cladophora* biomass in recent years (Greb *et al*. 2004) with a noticeable increase in the number of incidents of beach fouling along the Lake Michigan shoreline (Bootsma *et al*. 2004b). Today, *Cladophora* is abundant along Wisconsin's entire Lake Michigan shoreline with colonization exceeding 80% in areas of suitable substrate (Greb *et al*. 2004) and with nuisance levels of standing crop (200-400 gDW/m^2, Bootsma *et al*. 2004b).

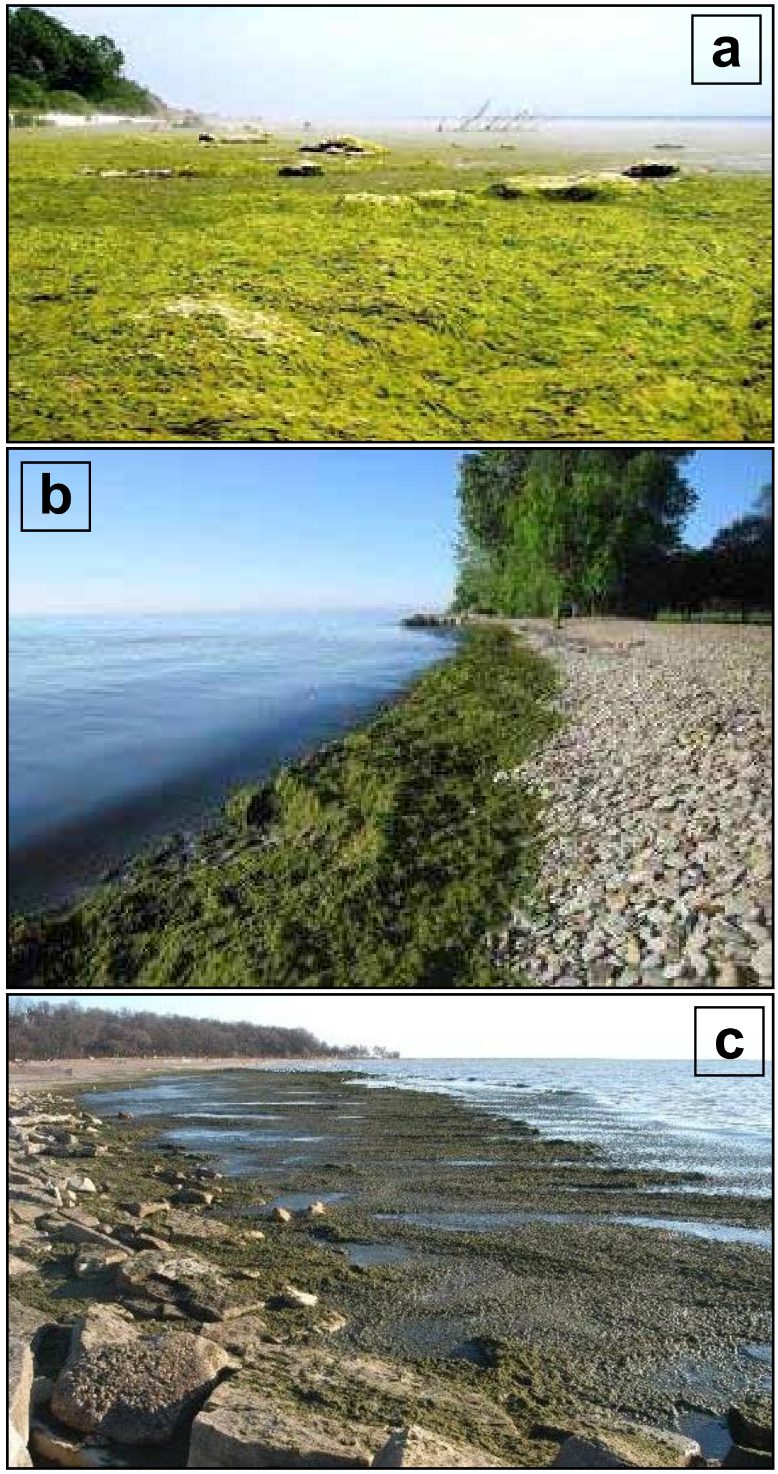

Figure 2. a) *Cladophora* accumulation along the shoreline of Lake Erie (Rock Point Provincial Park), b) Lake Ontario (Coronation Beach), and c) Lake Michigan (Bradford Beach).
Sources: a) Image by Scott Higgins; b) Image by Sairah Malkin; c) Image by Milwaukee Metropolitan Sewerage District.

The high *Cladophora* abundance in these lakes is somewhat paradoxical in light of the fact that concentrations of dissolved P in the pelagic zones have been declining and, with the exception of Lake Erie, are below the target levels set by the Great Lakes Water Quality Agreement (Barbiero *et al*. 2002, Dolan and McGunagle 2005). This, along with observations of extensive *Cladophora* coverage in regions that are relatively remote from point nutrient sources (e.g. Greb *et al*. 2004), suggests that there have been fundamental changes in how nutrients and energy move through these large ecosystems. These changes may also be reflected in other recent trends, including the decline in plankton abundance in Lakes Huron and Michigan (Environment Canada and U.S. EPA 2007), declines in the benthic amphipod *Diporeia* spp. (Nalepa *et al*. 2005), changes in the condition of lake whitefish and salmonids (Schneeberger *et al*. 2005, Claramunt *et al*. 2007), decimation of the yellow perch population (Marsden and Robillard 2004), and increased prevalence of type E botulism in fish and birds. Causes of these various trends require further exploration, but there are plausible mechanisms by which they may be connected (e.g. Hecky *et al*. 2004). For example, consumption of plankton by dreissenids may promote *Cladophora* growth by increasing water clarity and nutrient supply in the nearshore zone, while at the same time depleting pelagic food resources. Therefore, the problem of excessive *Cladophora* growth should not be considered in isolation, but within the larger ecosystem context. While excessive *Cladophora* growth is a problem in itself, it may reflect ecosystem changes that have larger ecological and economic consequences.

Pressures

How Does Your Garden Grow?

Like other aquatic and terrestrial plants, *Cladophora* requires a suite of inorganic nutrients to support growth and flourishes over a particular range of temperature and light conditions. There is consensus that P is the growth-limiting nutrient for *Cladophora* in the Great Lakes (see Higgins *et al*. 2008 for a review) and P has been and remains the appropriate target for management actions. Where S_{RP} levels meet the growth requirement lakewide, nuisance conditions may be observed wherever solid substrate is present, extending to depths where light availability limits growth. Lakewide support of *Cladophora* growth occurs in Lakes Erie, Michigan and Ontario (as described above) and management of nuisance growth will require attention to whole lake phosphorus levels. In cases where S_{RP} levels do not meet the growth requirement lakewide, nuisance conditions occur in the vicinity of point sources of nutrients, with the extent of colonization being limited by P availability (dilution by whole lake waters) or the light environment (with increasing depth offshore). As with some other algae, *Cladophora* has the capacity to store P beyond its immediate needs (Auer and Canale 1982a). Exposure to transient sources of P (e.g. plume migration and runoff events) for less than one day can provide sufficient P to support a ten-fold increase in biomass (Auer and Canale 1982b). It should also be noted that mixed conditions occur where a site is impacted by both whole lake and point source conditions. Managers should bear this in mind when evaluating the impact of controlling one source of P or the other. The case of nuisance *Cladophora* growth in the Lake Michigan nearshore may provide an example of such a case.

The response of *Cladophora* growth to P availability is non-linear, an occurrence which has importance when developing expectations for the outcome of nutrient management programs. The growth rate of *Cladophora* increases in a linear fashion as the amount of stored P increases from its minimum value, then becomes less sensitive to additional increase in available P and eventually reaches an asymptote (Fig. 3). From a management perspective, this figure should be examined from the opposite direction, i.e. high levels of P availability. Where *Cladophora* growth is supported by whole-lake nutrient levels, initial reductions in available P may not yield a striking response because the system remains within the P-saturated region of the curve. Subsequent reductions, however, will place the system within the linear region where changes in *Cladophora* growth will track changes in P loading.

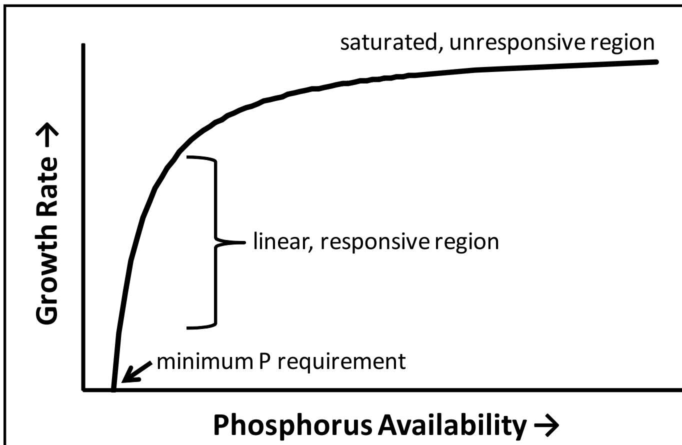

Figure 3. The relationship between phosphorus availability and *Cladophora* growth.
Source: Adapted from Auer and Canale (1982a).

Given an adequate supply of nutrients, *Cladophora* growth is governed by conditions of light and temperature. The alga grows most rapidly in late spring and early summer (May-June in Lake Huron) when water temperatures are in the optimum range (13-17 °C, Graham *et al*. 1982). The mid-summer sloughing period (Canale and Auer 1982b, Higgins *et al*. 2005a), where *Cladophora* detaches from the substrate and accumulates on beaches, occurs as temperatures reach 22-24 °C (July-August in Lake Huron). However, no experimentally-verified relationship between sloughing and temperature has been developed, and the mechanisms responsible for sloughing remain poorly understood (cf. Higgins *et al*. 2008). Light availability determines the depth to which *Cladophora* may colonize substrate at a particular site. An important metric in this regard is the compensation point, i.e. the light intensity above which net growth is positive. Graham *et al*. (1982) determined that this critical light intensity lies between

25 and 35 $\mu E \cdot m^{-2} \cdot s^{-1}$ for temperatures ranging from 5-20 °C. Assuming an incident light intensity of 1000 $\mu E \cdot m^{-2} \cdot s^{-1}$ and a light extinction coefficient representative of pre-dreissenid conditions (e.g. 0.46 m^{-1} for Lake Ontario, Auer *et al*. 2008), the maximum depth of colonization by *Cladophora* would be on the order of 8 m, with optimal light intensities occurring in shallower waters (1.5-3.0 m). The significance of these growth mediating environmental conditions as influenced through nutrient enrichment and ecosystem changes with respect to light penetration is discussed below.

Management Implications

Modeling Support for Management

The critical role of mathematical modeling in providing support for water quality management is now widely recognized. A build and measure approach, where remedial actions are implemented and assessed iteratively without guidance from model projections, has been largely rejected. This is especially the case for large lake ecosystems where high costs and long response times can lead to significant socioeconomic burdens. For example, P control measures mandated by the GLWQA benefited from rigorous model testing before implementation.

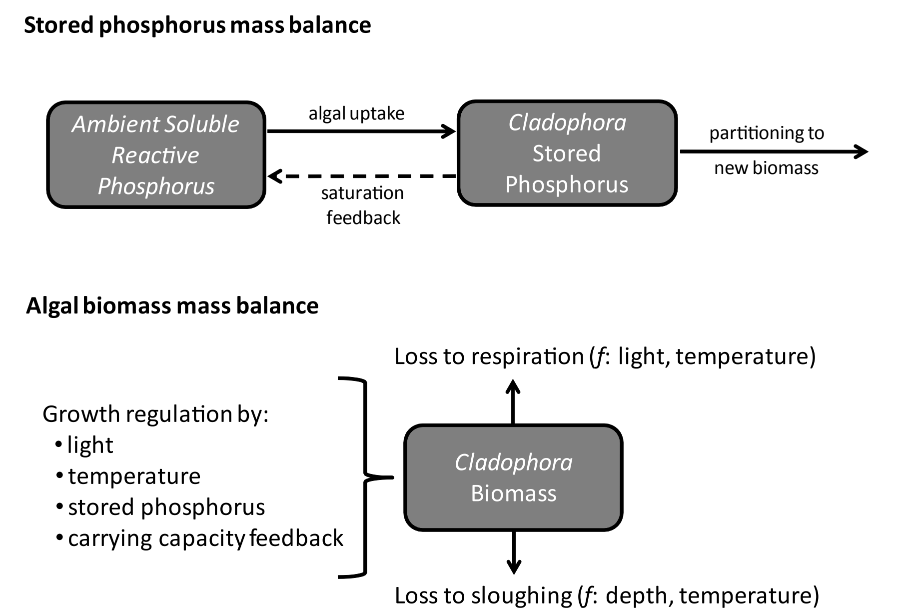

Figure 4. A mass balance framework for modeling *Cladophora*.
The mass balance for ambient soluble reactive phosphorus is presented in Figure 6.
Sources: Adapted and re-drawn from Canale and Auer (1982b) and Tomlinson *et al*. (2009).

The first model for Great Lakes *Cladophora* was developed by Canale and Auer (1982b; and accompanying papers). More recently, two modeling tools (CGM, the *Cladophora* Growth Model (Higgins *et al*. 2005b) and GLCM, the Great Lakes *Cladophora* Model (Tomlinson *et al*. 2009)) have been developed by expanding on and revising that framework. The CGM was applied to Lakes Erie (Higgins *et al*. 2005b) and Ontario (Malkin *et al*. 2008) and the GLCM to Lakes Huron and Michigan (Tomlinson *et al*. 2009). CGM and GLCM developers joined forces in a binational effort to examine the impacts of P management and ecosystem changes associated with the proliferation of dreissenids (Auer *et al*. 2008, discussed below).

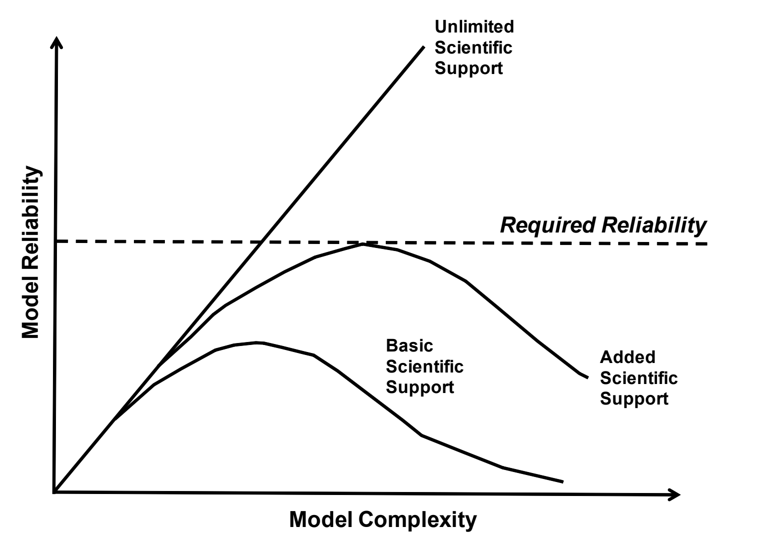

Figure 5. The relationship between model complexity and model reliability, illustrating the role of scientific studies in improving reliability.
Source: Adapted, modified and re-drawn from Chapra (1997).

Models for *Cladophora* in the Great Lakes are based on the principle of mass balance, a concept which may be likened to a checking account, i.e. the rate of change in the account balance is equal to inputs from deposits less outputs to checks written plus or minus changes due to 'reaction' such as interest or fees for bad checks. In its application to *Cladophora* (Fig. 4) the mass balance includes inputs (or gains) due to growth, outputs (or losses) due to respiration and a loss 'reaction' associated with physical detachment (sloughing). The mass balance itself is straightforward; however, characterization and quantification of the factors mediating the input, output and reaction terms (e.g. the roles of light, temperature and nutrients) must be well supported by science. While it may seem that the more comprehensive (i.e. complex) a model becomes, the better it represents nature, adding complexity without appropriate scientific support leads to a decline in model reliability (Fig. 5), an important concern in management applications. The art in modeling (and perhaps in managing) is to select an approach that resides at the optimum position on the complexity-reliability continuum.

Not Your Mother's Ecosystem

Research efforts in the 1980s and 1990s made it clear that the distribution and abundance of *Cladophora* were governed by P availability (Auer and Canale 1982a, b, Painter and Kamaitis 1987) and the underwater light climate (Graham *et al*. 1982, Lorenz *et al*. 1991). It has been concluded from hindcast modeling (Auer *et al*. 2008) that P loading reduction mandated under the GLWQA achieved the desired effect with respect to nuisance conditions. It is also clear, however, that nuisance *Cladophora* growth has today reclaimed its position as a serious water quality problem in the Great Lakes. Scientists familiar with the ecology of *Cladophora* have recognized that changes in the Great Lakes associated with the dreissenid invasion could have profound (Lowe and Pillsbury 1995, Higgins *et al*. 2005a, b) and previously unrecognized (Hecky *et al*. 2004, Higgins *et al*. 2008) effects. Dreissenid mussels can potentially impact *Cladophora* growth by providing substrate for attachment (Wilson *et al*. 2006), altering pathways of P cycling (Hecky *et al*. 2004) and modifying the underwater light climate (Holland 1993, Howell *et al*. 1996, Auer *et al*. 2008).

With respect to alteration of the underwater light climate, the case is undeniable. Auer *et al*. (2008) estimated that, following the establishment of dreissenids, the average light attenuation coefficient for Lakes Erie, Michigan and Ontario dropped from 0.46 to 0.29 per meter, extending the depth to which *Cladophora* could colonize substrate by 6 m. Model calculations indicated a corresponding increase in *Cladophora* growth potential of ~50%, an amount sufficient to significantly offset reductions in growth potential achieved previously through management of P loads.

A second effect, alteration of pathways for P cycling, remains an intriguing, but unproven hypothesis. The underlying premise is that filtration of the water column by mussels, with subsequent excretion of soluble phosphorus (the nearshore P shunt, Hecky *et al*. 2004) would provide a source of P for *Cladophora* that was previously unavailable. The hypothesis is intellectually satisfying because mussels have the potential to capture and recycle particulate inorganic P originating from nearshore sources that would historically have been transported to offshore depositional sites before being solubilized and made available to the algae. Further, mussels capture and recycle particulate organic P in the form of phytoplankton, an activity which may promote *Cladophora* growth by increasing dissolved P availability (Heath *et al*. 1995, Arnott and Vanni 1996) while eliminating a competitor for those resources.

Into the 21st Century

Managers seeking to control the nuisance growth of *Cladophora* will encounter a Great Lakes ecosystem profoundly changed by the proliferation of dreissenids. A binational modeling study (Auer *et al*. 2008) concluded that gains made through P loading reduction have been offset by dreissenid-driven changes in water clarity that extended the depth of colonization of *Cladophora*, increasing total production. Attendant impacts relating to dreissenid mediation of P cycling have not been isolated and identified. Barring a dramatic reduction in mussel abundance, it is unlikely that the Great Lakes light environment will return to pre-dreissenid conditions. This leaves the management of nearshore P levels as the only means of addressing the conditions of nuisance *Cladophora* growth presently experienced in Great Lakes waters. That management effort will require an integrated program of scientific study, mathematical modeling and field monitoring to establish targets for P control and to assess the efficacy of remedial measures. Such a program would also inform other management decisions not directly related to *Cladophora*. For example, an improved understanding of P and carbon exchange between the pelagic and nearshore zones will provide insight into how plankton consumption by dreissenids may affect food supply for pelagic and nearshore fish communities.

Hindcast Assessment

No systematic, comprehensive, basinwide monitoring programs for *Cladophora* have ever been implemented. Our knowledge of the extent and magnitude of the *Cladophora* problem consists of observations by individual investigators at isolated sites and regional surveys conducted by state and provincial authorities for limited periods. Because of this, scientists exploring the apparent resurgence of *Cladophora* cannot confidently state that conditions have truly worsened, only that nuisance conditions are occurring at present (cf. Auer *et al*. 2008). It would be prudent, as a prelude to development and implementation of new P management strategies, to utilize archival remote sensing data (see below) and hindcast modeling to properly characterize the development of today's conditions.

Supporting Science

Development of a management plan for *Cladophora* in the Great Lakes nearshore will be guided by model simulations, testing the system response to changes in P loads. The current models incorporate a framework linking external P loads to the ambient nutrient concentration to which the alga is exposed (Fig. 6). That framework is no longer complete in its description of those linkages. Scientific studies will be required to describe the role of the nearshore shunt in mediating P dynamics, identifying and quantifying pathways that have evolved with the advent of dreissenid populations. This new framework should accommodate the transformation of in-lake (i.e. phytoplankton) and watershed (i.e. terrigenous) particulate P to S_{RP} (dashed lines in Fig. 6) and the dynamics of *Cladophora* utilization of that P (ambient $S_{RP} \rightarrow$ P stored in the alga) in the post-dreissenid ecosystem.

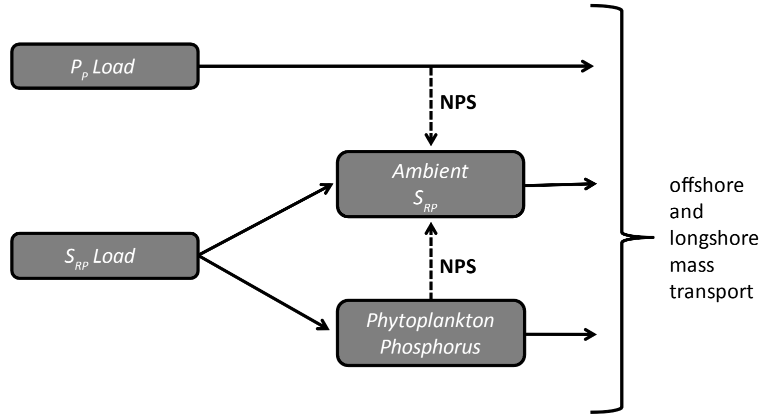

Figure 6. Conceptual model for soluble reactive phosphorus (S_{RP}) and particulate phosphorus (PP) dynamics in the nearshore.
Dashed lines indicate changes to the phosphorus cycle hypothesized to have resulted from dreissenid colonization (i.e. the nearshore phosphorus shunt, NPS).
Source: Adapted from concepts developed by Hecky *et al.* (2004).

In addition to science that directly supports *Cladophora* models, there is a need for research that addresses eco-dynamics in nearshore zones supporting large amounts of benthic algae biomass. This growth sequesters a significant amount of P and produces large amounts of organic carbon, but the fate of these materials is unknown. Critical questions include the contribution of this carbon and P to the nearshore food web, and the effect of decomposing algae on dissolved oxygen and redox conditions in the nearshore benthos.

Modeling

The *Cladophora* models currently available to the management community (CGM and GLCM) compare favorably with those routinely applied in simulating nutrient-phytoplankton dynamics in offshore waters. The nature of the *Cladophora* issue requires that only a single species be addressed, making a rigorous characterization of the alga's physiology more tractable (although recent outbreaks of other filamentous algae, such as *Lyngbya* sp., in Lake Erie may eventually expand the need for physiological and ecological studies). The reliability of *Cladophora* models for management applications would benefit from additional consideration of sloughing mechanisms and from further testing of model capabilities in simulating the response to the light environment in the post-dreissenid era.

The true challenge from a modeling perspective is to place the subroutines describing P kinetics within the context of a nearshore P model. Here, the model would simulate ambient S_{RP} conditions by accommodating TP loads, cycling of particulate P through the dreissenid shunt, uptake of S_{RP} and horizontal and vertical transport. The only extant example of such an application is that of Canale and Auer (1982b) for a site on Lake Huron, however this framework does not include cycling by dreissenids and the treatment of mass transport would be considered quite simple by today's standards. It will be necessary to integrate models for *Cladophora* growth with newly-developed information on P cycling and couple these with a nearshore hydrodynamic (mass transport) model.

Monitoring

Efforts to manage nuisance growth of *Cladophora* through P management must be supported by a comprehensive and systematic monitoring program, documenting biological, chemical and physical conditions over a statistically-defined grid in time and space. The appropriate metric for assessing the status of the *Cladophora* problem is annual biomass production, as it is this that determines the quantity of algae available for transport to the extreme nearshore, fouling beaches and clogging water intakes. It is infeasible to measure production directly; however, it may be estimated as the product of the alga's areal coverage, its biomass density and its growth rate (~ P status).

It is believed that extension of areal coverage to new habit has occurred in response to dreissenid-induced increases in transparency. Reductions in ambient P levels, resulting from newly-implemented management programs, will stress *Cladophora* populations colonizing substrate at the lower limits of available light, leading to a reduction in areal coverage. Areal coverage may be effectively monitored through remote sensing using established (Fig. 7a, cf. Lekan and Coney 1982) and emerging technologies (Fig. 7b).

Monitoring biomass density, in a manner similar to that for chlorophyll in pelagic habitats, has historically been a favored metric for assessing the status of *Cladophora* populations. Biomass density presents particular challenges with respect to *Cladophora*, however, because substrate is irregularly colonized (sand/silt patch, uncolonized solid substrates) and because the stochastic sloughing phenomenon uncouples standing crop from production. These challenges may be overcome by expanding the space and time scale of the monitoring program, but this is logistically prohibitive. Benthic sampling often requires SCUBA, which is technically more demanding and time-consuming than conventional water quality sampling with bottles deployed from a research vessel. The most promising avenue in this regard may be evolving remote sensing technologies that can quantify biomass as well as areal coverage.

P status may be one of the most powerful metrics for assessing the status of *Cladophora* as the relationship between stored P and growth (and thus production) is well defined. Because the alga has the capability to accumulate P beyond its present needs, stored P levels provide an integrated picture of the ambient S_{RP} environment (information not available from grab samples of ambient S_{RP}). This approach was successfully used to assess the response of *Cladophora* to P controls in Lake Ontario (Painter and Kamaitis 1987). Monitoring of stored P also offers advantages logistically as the required level of sampling intensity is more tractable. However, it is important that irradiance is also monitored, as light availability alters the relationship between ambient dissolved P and *Cladophora* P status (Bootsma *et al*. 2004b).

Summary

Cladophora is a filamentous alga that grows attached to solid substrate in nearshore waters and on offshore reefs in the Great Lakes. Where P resources are sufficient, the alga can grow to nuisance proportions, fouling beaches and clogging water intakes. It is believed that P management efforts implemented in the latter decades of the 20th century were successful in reducing the frequency of nuisance conditions. Changes in the underwater light climate, occurring in response to colonization by dreissenids, permitted *Cladophora* to expand its range and increase overall production to levels that resulted in significant beach accumulation and problems with water intake structures.

Management of the apparent resurgence in *Cladophora* growth will appropriately focus on further reductions in ambient levels of S_{RP}. The identification of target loads for P should be guided by mathematical models of *Cladophora* growth. It will be necessary to couple those models with simulations of nearshore P dynamics, taking into account the role of dreissenids in mediating P cycling. Emerging remote sensing technologies and on-site measurements of the stored P content of the alga hold promise as a means of assessing the response of *Cladophora* populations to management actions.

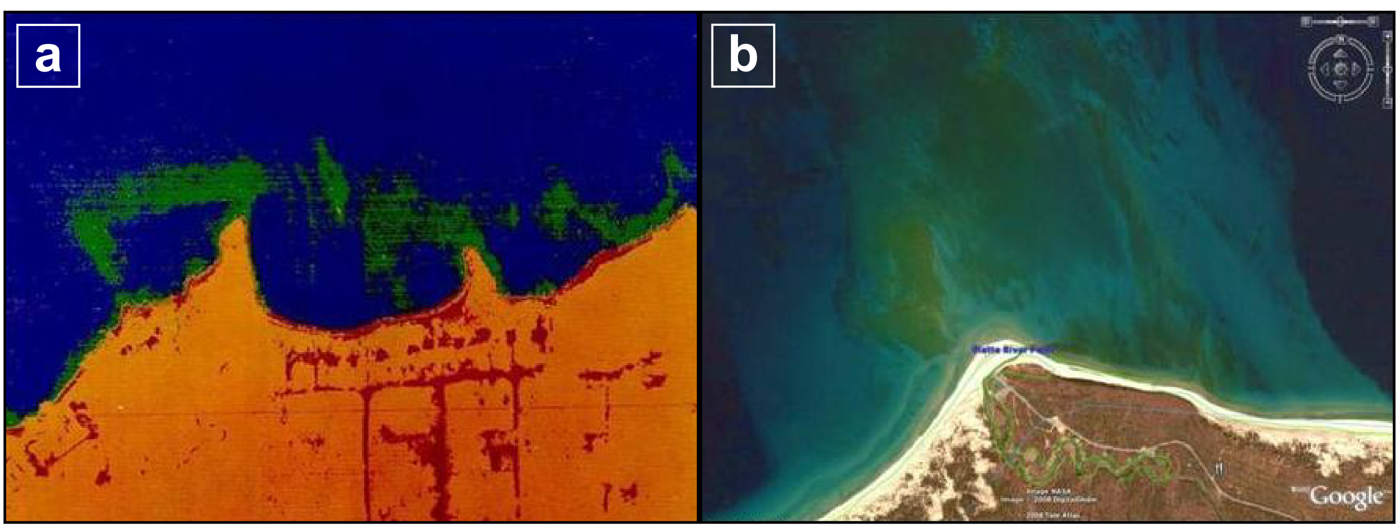

Figure 7. Remote sensing of *Cladophora*.
a) aircraft-generated, multispectral scanner output for Lake Huron at Harbor Beach, Michigan.
b) Platte River mouth, Lake Michigan.
Sources: a) Lekan and Coney (1982); b) Digital Globe, 2003. Pan-sharpened color image of Platte River Point from a June 2nd, 2003 Digital Globe Quickbird image. Retrieved using Google Earth Professional on July 25, 2008.

Acknowledgments
Authors:
Martin T. Auer, Ph.D., Michigan Tech
and
Harvey A. Bootsma, Ph.D., Great Lakes WATER Institute University of Wisconsin-Milwaukee

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5.5 Harmful Algal Blooms (HABs) in the Great Lakes: Current Status and Concerns

Introduction

Cyanobacterial and algal[1] blooms are a long-standing issue in eutrophic waters with high anthropogenic or natural nutrient loading. Widespread blooms (planktonic and attached, e.g., *Cladophora*) were a recognized impairment in offshore and nearshore areas in the Great Lakes in the 1960s and 1970s (e.g., Munawar and Munawar 1996, 2000, Higgins *et al*. 2008). Concerns at that time were based around impaired aesthetics; taste and odour (T&O); foodweb decline; fouling of beaches, water intakes and fishing nets; and economic impacts. These were addressed largely by targeting total phosphorus (TP) and chlorophyll *a* (chl*a*) levels, mitigated through reductions in point-source nutrient loadings. Recently, however, there has been an apparent resurgence in algal blooms in parts of the Great Lakes, accompanied by the potential production of toxins or harmful metabolites, compounds which were unidentified in the 1970s. In fact, there is a widespread perception[2] that harmful algal blooms (HABs) are increasing worldwide (e.g., Hallegraeff 1993) and that they may be linked to the cumulative effects of human development.

<u>Definition of HABs</u>

There are no quantitative definitions of HABs. With current publicity, the terms 'HABs', 'harmful' and 'bloom' are often used synonymously in reference to all types of algal outbreaks. In fact, 'bloom' is an ambiguous term, currently defined only by qualitative descriptors (e.g., Smayda 1997). Pearl (1988) further differentiates 'harmful' from 'non-harmful' blooms by their qualitative impacts on: i) water quality, biota or physico-chemical characteristics; ii) health risks from toxins or heightened microbial activity; or iii) aesthetics or recreation.

HABs in the Great Lakes are generally associated with planktonic toxic cyanobacteria, but HABs involve a variety of species and are particularly problematic in coastal areas. These events are often highly sporadic and dynamic in nature, showing episodic patterns which vary seasonally and annually in severity and geographical range. Importantly, as a coastal phenomenon, their appearance is often unlinked with current monitoring targets. Great Lakes monitoring programs continue to evaluate planktonic (subsurface) chl*a* as a measure of total algal biomass and productivity, but that metric is often irrelevant to identifying HABs.

Impacts can include: risks to human and animal health via toxins, carcinogens, teratogens, or irritants in drinking water; other drinking water impairment (T&O, aesthetics); fouling of water intakes, fish nets and shoreline; bacterial growth in rotting mats (including potential pathogens, e.g., *E. coli*); beach closures (affecting recreation and tourism); tainting of fish, shellfish, and processed food (harming commercial and recreational fisheries and other food industries); food web integrity and structure, and environmental degradation such as anoxia. HABs thus include *Cladophora*, other benthic or littoral macroalgal proliferation, and planktonic blooms. All represent current concerns in the Great Lakes and are addressed below.

State of the Ecosystem - Harmful Algal Blooms

<u>Background</u>

The ability of HABs species to proliferate is dependent on the nature of the environment and its seasonal and spatial variance. The operational definition of the nearshore zone thus has an important bearing on assessing, monitoring and managing HABs. In the Great Lakes, the nearshore has been statically defined as the zone between the edge of the shoreline or wetlands and the deepest lake contour at the late summer thermocline (if established). It includes connecting channels and waters, lower tributaries and unstratified areas around islands and shoals (Edsall and Charlton 1997). Yet in function, these coastal regions are highly dynamic, with long- and short- term spatially and temporally variable boundaries

The size of nearshore zones varies enormously among and within the Great Lakes (~1-10% of Lake Superior to 60-90% of Lake Erie, Edsall and Charlton 1997), as does the degree to which each zone is influenced by physical and climatic factors (e.g., runoff erosion; thermal bar; upwelling and downwelling; alongshore, nearshore, and offshore currents; circulation patterns; surface and ground water inputs; ice formation). This translates to a highly variable littoral community structure and activity. Nearshore

1 'Algae' in this paper denotes both eukaryotic algal taxa and cyanobacteria.

2 Toxins are only recently recognized as a threat from algal blooms. With few historical data, this perception is based more on anecdotal evidence and not quantified information. Reports may be biased due to increasing public awareness. Most sites are not monitored, many blooms are not identified, and visible blooms are not the only sources of the toxins.

biotic assemblages are further shaped by regional differences in bottom substrate, daily and seasonal ranges in water levels and temperature, and impacts of human development on the shoreline (e.g., deforestation, agriculture, industry, urbanization, wetland drainage and dredging, water level regulation). The lower Great Lakes are considerably more impacted by human disturbance, and they are also significantly more prone to algal blooms.

Biochemical impacts of HABs

T&O compounds and toxins are often assumed to be manageable by controlling excess algal growth. However, there is often a very poor relationship between algal biomass and the presence of these metabolites. Their production may involve a variety of genetic and biochemical pathways, the same or different taxa, and cell-specific variability in production capacity and output, which is also related to genetics and environmental factors (Watson 2003).

Toxicity, T&O or other impacts are difficult to predict. One or more of ~200 known toxins and T&O compounds are produced by many different species, but current resources and knowledge limit our ability to characterize and evaluate impacts. The issue is complex and effective field sampling is difficult. Outbreaks can be episodic, erratic and involve planktonic or benthic biota. Incidence and levels of toxins, T&O, visible blooms, and algal abundance (cell counts, biomass, or chl*a*) may or may not be related. For example, *Microcystis* does not produce 'earthy' T&O (geosmin and 2-MIB) and is often odourless, while odour-causing species (e.g., *Anabaena*, *Lyngbya*) may or may not be toxic. Genetic capacity and cell production can vary for toxins and T&O among species, cell populations and environments. Potential producers and morphologically similar species co-occur,e.g., *Microcystis aeruginosa* and *M. wesenbergii*; *Anabaena flos-aquae* and *A. lemmermanii* (e.g., Rinta-Kanto *et al*. 2005, Jüttner and Watson 2007). Variance among analytical and sampling methods often generates inconsistencies among reported levels (G. Boyer unpublished data).

Toxins

Cyanobacterial toxins have no taste or odour. Because they were identified relatively recently, there are no long-term records, hence any long-term changes in severity and occurrence are difficult to verify. They were unknown when beneficial use impairments (BUI) were defined for Areas of Concern (AOCs), and they are still largely not addressed by most Great Lakes management programs. Current (and limited) sampling is often reactive, often fails to capture episodic events, and is biased towards research in high-risk areas. Yet concern has been growing since the first report of a toxic outbreak in western Lake Erie (Brittain *et al.* 2000). Recent lakewide surveys since 2000 (e.g., MERHAB-LGL, EC)[3] found detectable toxin levels in many areas, especially in the Lower Lakes or coastal areas with moderate to severe impairment (Boyer 2007, Watson *et al.* 2008a, b). Toxin levels at most offshore sites are generally very low, but in nearshore zones with advanced eutrophication (e.g., harbours, embayments and river mouths, including Bay of Quinte, Oswego Bay, Sandusky Bay, Maumee Bay, Saginaw Bay, and Hamilton Harbour) they can often exceed drinking water guidelines, particularly where present as surface or windblown shoreline scums.

The most commonly reported toxins in the Great Lakes and other waters are microcystins (MC). Exposure though ingestion or inhalation can cause liver failure and death or increased risk of cancer with long term chronic exposure. Numerous structural variants differ in toxicity.[4] Microcystin-LR (MC-LR) is the most widespread and toxic and is the basis for many guidance levels (Codd *et al.* 2005). MCs are produced by a range of cyanobacteria species, some of which cause outbreaks in the Great Lakes, notably *Microcystis* spp. (e.g., Boyer 2007). MC and hepatotoxic nodularin are stable, even to boiling, and may impair food webs. Guidance levels are few and vary among agencies,[5] especially for recreational areas with high public exposure and risk. In Lakes Ontario and Erie, neurotoxic anatoxin-a and saxitoxins have been detected at both high and low levels (Boyer 2007, Watson *et al.* 2008a, b). There are no data on the occurrence of lipopolysaccharides (LPS), produced by all cyanobacteria and widely believed to cause gastroenteritis, skin and eye irritations, hay fever, asthma and blistering (although this is debated, e.g., Stewart *et al*. 2006).

3 NOAA Monitoring and Event Response in the Lower Great Lakes; Environment Canada.

4 >90 MC variants (congeners) now identified.

5 E.g. , WHO, Health Canada GLs for total MC of 1-1.5 µg/L for *treated* drinking water respectively; recreational water ~10- ±20 µg/L; Watson *et al.* ibid; currently still on the U.S. EPA Critical Contaminant List.

Taste and odour

T&O impairment is widespread in the Great Lakes. Most of the recorded outbreaks and incidental reports of this impairment have not been traced to their biological origin(s). T&O compounds have no known human health effects, but can impart significant consumer alarm and drinking water treatment costs (e.g., Engle *et al.* 1995). T&O compounds, however, can function in foodwebs as powerful chemical signals, acting as grazer deterrents or toxins (e.g., Watson 2003). Numerous algal volatile organic compounds (VOCs) are known, which vary in odour, potency, seasonal dynamics and treatment implications. One or more planktonic or benthic species may co-produce different VOCs, which may be cell-bound until death, continuously released, or triggered only by cell lysis. Benthic and planktonic diatoms and chrysophytes can produce lipid derivatives[6] causing fishy or cucumber odours in low to moderately productive waters. In remediated, mesotrophic and eutrophic waters such as the Great Lakes, T&O is caused frequently by terpenoids[7] (geosmin, 2-methylisoborneol (MIB)), and to a lesser extent, pigment derivatives (β-cyclocitral)[7] or methyl- and isopropyl sulphides[8]. Hidden or detached benthic, littoral and epiphytic cyanobacteria (e.g., *Lyngbya*, *Oscillatoria*, *Gloeotrichia*) are significant geosmin and MIB sources in nearshore areas of the lower Great Lakes and channels (St. Lawrence River, Maumee River, Bay of Quinte, Watson *et al*. 2005 and unpublished data) affecting shorelines and drinking water supplies. The anaerobic breakdown of any excessive bloom material is also a frequent T&O source. Rotting mats of *Cladophora, Lyngbya* and other attached algae are major sources of septic, sewage or sulphur odours along beaches and shorelines in the Great Lakes and connecting channels, driven inshore by wind or currents.

Most jurisdictions have not regulated T&O, and there are no quantitative guidance levels in drinking or recreational waters. T&O is listed under the Canadian Drinking Water Quality Guidelines "aesthetic effects" and is a listed BUI (treated municipal supplies). T&O impairment occurs in over a third of AOCs, mostly in the Lower Lakes, but likely is more widespread (Watson *et al.* 2007, Watson *et al.* 2008a, b). There has been little or no direct monitoring or quantification of T&O, other than by some drinking water treatment facilities, and it is usually deduced by environmental assessment programs (e.g., Remedial Action Plans (RAPs)) using often unrelated measures (e.g., chl*a*, nutrient levels, Keene 2002, Watson *et al.* 2008a,b).

<u>Great Lakes: current status of HABs in individual lakes</u>

As noted above, there are no long term trends in toxins and T&O because HABs data are limited. Hence, only a qualitative assessment of the current status in each Lake can be made here.

Lake Superior – Status: good

There is very little quantitative current information on HABs in Lake Superior. To our knowledge, severe HABs outbreaks have not been documented recently in Lake Superior, although cyanobacteria, including *Microcystis*, are detected in samples taken during routine monitoring. Algal biomass remains mostly at low levels, although there may be some local impairment near shoreline development (J. A. Thompson and J. Kelly, U.S. EPA MED, Duluth, personal communication). A recent survey of drinking water utilities showed few reported T&O issues, which may or may not be of algal origin. Intermittent outbreaks have been reported from one drinking water utility (Moore and Watson 2007).

Lake Michigan – Status: mixed

Lake Michigan has a fairly extensive nearshore zone as defined by the 9 m or 27 m depth contour (10%, 26% area, respectively), which nevertheless only accounts for a small fraction of the total volume (0.4%, 4%, respectively). Yet the nearshore area has a key influence on the lake ecosystem. Lake Michigan has the largest groundwater input (79% hydrological loading) due to nearshore aquifers, and water levels recently have been lower than long-term normal. Resuspension during mixing and storm events generate extensive late winter-early spring plumes of resuspended sediments along the eastern shore, which have a significant effect on the light regime and nutrient cycling and transport. These events also influence the biological community by introducing resuspended diatom plumes characteristic of more eutrophic waters and modifying the spatial distribution of other phytoplankton and microbiota. Cyanobacteria blooms are reported in some coastal regions in eutrophic embayments such as Green Bay and Muskegon Bay. Shoreline and beach fouling by *Cladophora,* stimulated by nutrient loading from nearshore sources, represent a

6 Synthesized during lysis.

7 Synthesized over growth and mainly cell-bound.

8 Synthesized over growth and continuously released.

potential source of bacteria for beaches and groundwater by trapping bacterial flora (washed in from runoff and other sources) during their growth, which are then deposited along shores by currents and storms.

Lake Huron – Status: mixed

Lake Huron is one of the more oligotrophic of the Great Lakes, yet excessive phytoplankton and potentially toxic HABs occur in some nearshore areas, notably Saginaw Bay and Northern Georgian Bay (Fahnenstiel *et al*. 2008, Scheiffer and Scheiffer 2002). These two areas differ markedly in drainage basin development, HABs species, and associated impairment. Saginaw Bay has a large and extensively developed catchment, and it develops toxic summer outbreaks of *Microcystis aeruginosa*. These blooms appear to be genetically distinct with a greater MC production capacity than HABs populations of M. *aeruginosa* in other Great Lakes, e.g., Western Lake Erie (Dyble *et al*. 2008, Fahnenstiel *et al*. 2008). Highest toxin levels occur in shallow regions with high TP concentrations. Northeast Georgian Bay watershed is far less developed, but it has extensive wetlands and a growing cottage industry. The region has generally good water quality, but a few nearshore areas show high TP and chl*a* levels, including Sturgeon Bay (Diep *et al*. 2006). The upper stratified basin of Sturgeon Bay experiences hypolimnetic anoxia, accompanied by sediment nutrient release and severe annual blooms during fall turnover, which impair shorelines and water quality (Schieffer 2003). Samples collected during a partnered MOE-EC two-year characterization of these blooms showed a predominance of diatoms, N-fixing *Aphanizomenon* and *Anabaena*. Toxin levels (MC, Anatoxin-a) were at or below detection over the entire season (Watson and Howell 2007).

Similar to Lake Superior, there are few issues with drinking water T&O outbreaks in Lake Huron, with outbreaks reported at a single area (Moore and Watson 2007). However, macroalgal impairment is a major concern in some areas. Recently, complaints of fish-net fouling by attached chlorophytes have increased (*Spirogyra cf. circumlineata*, *Stigeoclonium*; Watson and Milne unpublished). Rotting mats of beached green macroalgae are increasingly impacting aesthetics, recreation and tourism along some shorelines. Notable occurrences were observed along Saginaw Bay and, more recently, along the southeast coast, largely caused by *Cladophora* and Chara, respectively. Recent studies by United States and Canadian agencies (MDEQ, MNR, OME, EC) have raised new concerns about the health implications of these events due to the detection of human fecal indicators (*E. coli*, *Enterococcus*) and evidence of differential survival in the beached mats and in situ beds of the macroalgae (Lake Huron Binational Partnership 2008-2010 Action Plan 2008). Patchy sites have also shown elevated *E. coli* counts associated with algal debris buried in beach sand. There is a perceived increase in the range and severity of these events, which demonstrate different patterns, thereby suggesting that several (unresolved) factors contribute to the problem. *Cladophora* is more clearly associated with suspected nutrient discharge, while *Chara* is more widespread and not clearly linked to local inputs (Howell *et al.* 2005).

St. Clair River/Lake St Clair/Detroit River – Status: fair to good

Recent reports and surveys do not identify algal blooms as a problem, and chl*a* levels are generally low (~3-5 µg/L; Lake St. Clair Canadian Watershed Coordination Council 2005, Watson unpublished), although there is some spatial variance. However, a summary report issued in 1999 reported 'floating mats of submersed aquatic plants and algae' along the Western shoreline,[9] and several utilities report annual or intermittent T&O in water drawn from the St. Clair and Detroit Rivers (Moore and Watson 2007).

Lake Erie – Status: mixed to poor

Water levels in Lake Erie typically fluctuate about 36 cm/yr, but in some years up to 50 cm (e.g., 2002). There has been a steep decline in levels from a 1997 peak to below average during recent years, with significant fluctuations due to climate and storm events. This, together with the corresponding dynamics in the physical and chemical regime, has been accompanied by some disturbing trends in biota and system integrity. Not only does Lake Erie have the most extensive nearshore area, but toxic HABs are a particular concern and the focus of several recent studies. These studies have provided more insight into these events than for the other Lakes.

HABs biomass and impairment in Lake Erie

General trends: The operative definition of the nearshore area includes 60-90% of Lake Erie, including most of the Western Basin. Collective evidence points to important recent changes in coastal areas and the dynamic nature of the functional nearshore zone. Overall, the data indicate an apparent deterioration of the physical, chemical, and biological regimes, notably in the Western basin. These are not easily assessed using current monitoring methods and measures, which may provide contradictory or ambiguous

9 Lake St. Clair: Its Current State and Future Prospects conference summary report 1999; http://www.great-lakes.net/lakes/stclairReport/summary_00.pdf

evidence, particularly where basin-wide averages and/or surface (1 m) chl*a* concentrations are considered (Ghadouani and Smith 2005). Makarewicz (1993) reported a 70-98% reduction in the biomass of nuisance and eutrophic 'indicator' species[10] in the 1980s (e.g., diatoms *Stephanodiscus binderanus*, *S. niagarae*, *S. tenuis*, and the cyanobacterium Aphanizomenon *flos-aquae*), which generally correlated with TP levels. Other studies also suggest a decline in overall chl*a* levels and total or eutrophic species biomass in the Central and Eastern basins, which has been attributed to nutrient reduction, increased water transparency and grazing by invasive dreissenids. Conroy *et al*. (2005a) evaluated trends in biomass and chl*a* data (covering studies in 1970, 1983–88/89, 1989/90–93, 1996–2002) and concluded that average biomass has generally <u>increased</u> in all basins since the late 1980s minima. They also observed no consistent relationship between algal biomass and dreissenids or external TP loading (total or basin-specific), and they suggested that internal loading is becoming more important (e.g., Makarewicz *et al*. 2000, Matisoff and Ciborowski 2005). However, Conroy *et al*. (2005) also highlight different patterns among basins and seasons underlying basin-wide averages. Spring algal biomass in the Western basin decreased markedly in the 1980s to 1990s, but approached previous maxima in 2000-2002. Summer algal biomass also decreased significantly during the same time period, but then increased to about 50% of the earlier maxima. A similar, slightly less significant resurgence occurred in the Central basin. The Eastern basin showed a more variable interannual pattern, with an all-time maxima in the late 1990s. Recent levels (2000s) were still elevated. These generalized patterns overlay significant spatial (horizontal and depth-related) variance among sites, particularly along shorelines and in the Western Basin (e.g., Carrick *et al*. 2005, Ghadouani and Smith 2005).

<u>Cyanobacteria</u>: Pre-remedial (1970s) summer-fall high cyanobacterial biomass was reported by Munawar and Munawar (1996), with a predominance of N-fixers (*Aphanizomenon*, *Anabaena*) and regional maxima indicating localized development or translocation by currents in the Western basin (Maumee-Peele; Sandusky), West-Central basin and Eastern basin (Erie, Buffalo). 'Bloom proportion' cyanobacterial levels (> 1000 µg/L) were reported only in the Western basin and far Eastern basin (Buffalo). Diatoms were dominant. Recently, Conroy *et al*. (2005) reported a resurgence in cyanobacterial biomass in all basins in summer since the mid-1980s, notably in the 2000s. Again, there was high interannual and spatial variability, but an overall increasing frequency of high cyanobacteria biomass (which may also reflect targeted sampling). Both total algal and cyanobacterial biomass showed no significant relationship with external TP loading and a poor relationship with chl*a* levels. Most of the increase in summer cyanobacteria was attributed to *Microcystis* spp., suggesting a long-term shift from N-fixers in the 1970s to non-fixers. This shift may reflect changes in nutrient supply or dreissenid activity. A 1998 survey by Barberio and Tuchman (2001) also showed a predominance of *Microcystis* and other chroococcales (*Aphanocapsa delicatissima*, *Chroococcus limneticus*).

<u>Toxins</u>: Lake Erie and associated channels and embayments are among the most severely HABs-impacted areas of the Great Lakes (e.g., Table 1). July to October outbreaks of planktonic and benthic taxa show significant interannual, seasonal and spatial variation in origin and impacts. Immense surface blooms (> 20 km^2) have been recorded in the Western basin near the Maumee and Sandusky Rivers, which are potential sources for HABs in Western and

<table>
<tr><th colspan="2">Cruise, date</th><th># samples</th><th>toxin</th><th>% samples toxic</th><th>max level µg/L</th><th>Comments</th></tr>
<tr><td>Brittain</td><td>Sep-96</td><td>44</td><td>MC</td><td>10</td><td>3.4</td><td>WB only</td></tr>
<tr><td rowspan="3">MELEE–VII</td><td rowspan="3">Jul-02</td><td rowspan="3">119</td><td>MC</td><td>7</td><td>0.7</td><td rowspan="3">whole lake; highest at Sandusky, Long Pt., Rondeau Bays</td></tr>
<tr><td>ATX</td><td>14</td><td>0.04</td></tr>
<tr><td>PSTs</td><td>0</td><td></td></tr>
<tr><td rowspan="2">MELEE–VIII</td><td rowspan="2">Jul-03</td><td rowspan="2">59</td><td>MC</td><td>41</td><td>0.65</td><td rowspan="2">whole lake; highest in WB & Sandusky Bay</td></tr>
<tr><td>ATX</td><td>5</td><td>0.11</td></tr>
<tr><td rowspan="2">Lake Guardian & OSU</td><td rowspan="2">Aug-03</td><td rowspan="2">48</td><td>MC</td><td>60</td><td>21</td><td rowspan="2">WB only, highest nr. Maumee R.</td></tr>
<tr><td>ATX</td><td>4</td><td>0.2</td></tr>
<tr><td rowspan="3">MELEE–IX</td><td rowspan="3">Jul-04</td><td rowspan="3">40</td><td>MC</td><td>38</td><td>>1</td><td rowspan="3">Highest nr. Maumee & Sandusky Bay</td></tr>
<tr><td>ATX</td><td>33</td><td>0.6</td></tr>
<tr><td>CYL</td><td>0</td><td></td></tr>
<tr><td rowspan="3">Limnos</td><td rowspan="3">Aug-04</td><td rowspan="3">13</td><td>MC</td><td>85</td><td>2.4</td><td rowspan="3">WB only</td></tr>
<tr><td>ATX</td><td>31</td><td>0.07</td></tr>
<tr><td>CYL</td><td>15</td><td>0.18</td></tr>
<tr><td colspan="7">MC=Microcystin; ATX=anatoxin-a; PSTs=saxitoxin + neosaxitoxin; CYL=cylindrospermopsin</td></tr>
</table>

Table 1. Summary of toxin levels in Lake Erie from 5 surveys.
Source: Boyer (2007).

10 See section on indicator species below

West-Central basins (e.g., Rinta-Kanto *et al*. 2005). Data from five targeted cruises during 2000-2004 measured a wide range in MC levels from detection limits (in 2002) to > 20 µg /L (in 2003). Toxicity and bloom distribution varied spatially and were not restricted to the Western basin. In 2003, highest MC concentrations were measured from Maumee Bay, Long Point Bay and Sandusky Harbour. Neurotoxins (anatoxin-a, saxitoxin, neosaxitoxin) and cylindrospermopsin occurred at or near detection limits. In 2001 and 2002, some significant localized MC occurrences were also reported from the Central and Eastern basins (Wendt Beach, Presque Isle, Port Dover; Murphy *et al*. 2003, Ghadouani and Smith 2005).

Variance in toxicity among species and strains means that microscopic identification, biomass or cell counts cannot predict toxin levels. MCs are the most common cyanobacterial toxins measured in Lake Erie. Recent work reported toxic *Microcystis* blooms from Maumee Bay with 5-100% variance in genetic potential for MC production and suggested that these blooms were the likely MC sources in far west and Long Point areas. In contrast, in Sandusky Harbor, subdominant *Planktothrix* and/or other unidentified taxa were the likely MC sources where cyanobacteria were dominated by non-MC producers (*Aphanizomenon, Anabaena*; Rinta-Kanto *et al.* 2005, Rinta-Kanto and Wilhelm 2006, Boyer 2007). Most impairment occurs at shorelines and beaches and can be manifested as fish or bird kills (e.g., Murphy *et al.* 2003). To date, however, Lyngbyatoxins (which can be inflammatory, vesicatory and tumour-promoting) have not been detected, including in the extensive mats of *Lynbya wollei* now proliferating in the Maumee Bay.

Spring and late fall samples are often overlooked, yet some species can show significant development during this period. *Cylindrospermopsis raciborskii*, first identified in Sandusky Bay in 2005, may develop localized high spring biomass (Conroy *et al*. 2007). This N-fixing species has a wide temperature tolerance (up to 30°C) and high P storage capacity. It is invading north from warm to mid-latitude regions and has a strain-specific potential to produce cylindrospermopsin, mediated by light (Dyble *et al*. 2006). *Cylindrospermopsis* is buoyancy-controlling, like *Microcystis*, but better adapted to turbid conditions, and it is found near rivers and as deep chlorophyll maxima in stratified waters. Therefore, it may be missed by discreet depth sampling regimes of current surveillance programs. To date, *Cylindrospermopsis* has not been found as a dominant species. Conroy *et al*. (2007) reported it as < 2% total algal biomass in 2005, except during early spring. It has been seen each year around Sandusky Bay, but not associated with the low levels of cylindrospermopsin or deoxycylindrospermopsin detected there or in other areas of the Western basin (e.g., Maumee River, Boyer unpublished data). The highly variable morphology of this and other species (including *Microcystis*, discussed above) may lead to misidentification of these cyanobacterial taxa. Non-heterocystous trichomes of *Cylindrospermopsis* can be easily misidentified as an *Oscillatoria* (*Planktothrix*) and overlooked, or misidentified as *Raphidiopsis curvata*, which has been identified in recent Maumee Bay samples. Strains of this species produce deoxycylindrospermopsin (e.g., Wilhelm and Li unpublished data, Gugger *et al.* 2005).

<u>Taste-odour</u>: Geosmin and 2-MIB are likely the cause of annual musty-muddy odour problems in drinking water supplied from the Western basin (e.g., Toledo). In addition, significant odour is produced by extensive rotting mats of shoreline attached algae. The planktonic cyanobacterial taxa which are currently problematic in Lake Erie (*Microcystis* and the local strain of *Planktothrix*) do not produce these or other T&O compounds which would impair drinking water supplies (e.g., Watson *et al.* 2008a).

<u>Benthic cyanobacterial impairment</u> is becoming a key issue in some areas. Recent severe impairments of beaches by thick mats of the cyanobacterium *Lyngbya wollei* have been reported in the mouth of the Maumee River (Western basin) at sites with high ambient P concentrations in the overlying water (Watson *et al.* 2008b). These have provoked significant media coverage and website postings[11]. The mats have not been found to produce any of the common toxins and represent no direct threat to human health (Quilliam, Wilhelm, and Boyer unpublished data). However, they do produce significant T&O problems and foul fishing nets, but their effects on bacterial levels on beaches and benthic foodwebs are unknown.

<u>Other HABs taxa</u>: In addition to the invasive cyanobacterial taxa noted above (*Cylindrospermopsis*, *Lyngbya wollei*) which produce direct impairments, numerous other taxa have been recorded in Lake Erie (cf., Mills *et al.* 1993, Patterson *et al.* 2005). These include invasive species (e.g., attached red algae (*Bangia atropurpurea*, *Chroodactylon ramosum*)), and diatoms (e.g., *Skeletonema potamos*, *S. subsalsum*, *Thalassiosira guillardii*, *T. lacustris*, *T. weissflogii*). Western and Central basin spring-summer biomass diatom maxima can include the invasive diatom *Actinocyclus normanii f. subsalsa*, which is indicative of eutrophic, polluted sites

11 e.g. http://www.westernlakeerie.org/phosphorousalgae.html; http://glhabitat.org/news/glnews606.html; http://www.epa.state.oh.us/dsw/inland_lakes/Lyngbya%20wollei.pdf

that might exhibit high conductivity, elevated levels of cations (Mg^{++}, Ca^{++}), fluctuating light levels and turbulent vertical mixing. Recent high spring abundances of the filamentous diatom *Aulacoseira islandica* in the Western basin (e.g., Barbiero and Tuchman 2001, S. Wilhelm unpublished data) have the potential to foul fishing nets, although to date there are no known reports of this impairment. Extensive mats of attached green algae, notably *Cladophora*, are increasing in abundance along shorelines.

These outbreaks are of concern for several important reasons: i) the production of noxious and potentially toxic metabolites by these taxa (odour, toxins); ii) fouling issues (beaches, nets); iii) impacts on aesthetics, tourist industries, and real estate values; iv) modified nutrient recycling, sequesterment or translocation (via detached material); v) their potential to act as substrates and attachment sites for bacterial development in recreational waters and beaches; vi) their adverse effects on food web integrity; and vii) their appearance is often unlinked with offshore nutrient levels.

<u>Causes and controls</u>: Past and recent work suggests that in general Lake Erie phytoplankton are P-limited (Guildford *et al.* 2005). Guildford *et al*. observed strong seasonality in measured P deficiency during 1997, which varied among basins, but was less acute in the Western basin. These and other authors have also detected short-term N-deficiency and P + N co-limitation (Wilhelm *et al.* 2003, Guildford *et al.* 2005). More recent bioassay and enrichment studies have suggested that plankton in the Eastern basin are co-limited by Fe, N and P, but N chemistry influences current phytoplankton structure in Lake Erie (Wilhelm *et al.* 2003, North *et al.* 2007).

Conroy *et al*. (2005b) report significant differences in PO4 and NH_4 turnover rates between quagga (*Dreissena bugensis*) and zebra mussels (*Dreissena polymorpha*), with quagga mussels tending to assimilate and possibly sequester more P or direct it more effectively to recruitment. They suggest that changes in mussel densities and distribution and increasing predominance of quagga mussels have important implications for the nutrient turnover rates in the nearshore areas. They also attribute, like some other authors, some of the apparent increased predominance of *Microcystis* to mussel activity (cf., Madenjian 1995, Vanderploeg *et al*. 2001, Barbiero *et al*. 2006), but the mechanism of influence is much debated. They calculated that in both 1998 and 2003, crustacean zooplankton excreted about three times more PO4 than dreissenids, highlighting the often forgotten role of zooplankton in nutrient turnover.

Overall, the risk of cyanobacterial dominance is driven by P in most Northern temperate fresh water systems, while short-term deficiencies and physico-chemical and foodweb processes mediate the response (e.g., Downing *et al*. 2001). Our current understanding of HABs outbreaks in the Great Lakes points to nearshore areas and drainage waters as most severely affected, and also possibly serving as sources of biota and toxins for the offshore waters. Current estimates of P-loading to the Great Lakes are inadequate, and in many cases, do not address the growing inputs from non-point sources from the watershed and shorelines. Recent research is also indicating that there may be several overlooked inputs from external and internal sources (e.g., Payton *et al.* 2008, Lowes and Young 2008).

Lake Ontario – Status: mixed

Lake Ontario has an extensive watershed development and urban input. Blooms of cyanobacteria and related impairments (toxins, T&O compounds) have been identified recently in some nearshore areas, notably AOCs. Circulation and exchange can result in plumes of affected water translocated into adjacent nearshore and offshore waters (Howell 2002, Hamblin and He 2003, Rao *et al*. 2003).

<u>Toxins</u>**:** Sporadic outbreaks of high MC levels have been reported in *Microcystis* blooms in nearshore areas (Watson *et al.* 2005, Boyer 2007, Hotto *et al.* 2007, Watson 2007). Data collected by larger Ontario municipal water treatment plants (e.g., Toronto, Hamilton, Deseronto) show episodes of elevated MC in raw water, but MCs are adequately removed by the treatment process. However, a potential risk exists for less advanced removal technology by small or private users (Watson *et al.* 2005, unpublished data). Spatial and temporal levels of these toxins in specific AOCs such as the Bay of Quinte, Hamilton Harbour and the Rochester Embayments indicate periods of severe impairment of nearshore sites by windblown accumulations of toxic material, where MC levels can reach levels in excess of 300 μg/L (Watson *et al.* 2003, 2005). Recent surveys have indicated the widespread occurrence of low concentrations of anatoxin-a in both nearshore and offshore sites in Lake Ontario (Boyer 2007, Yang 2007). Other toxins (saxitoxins and cylindrospermopsin) appear to be quite rare.

Taste-odour**:** Studies have identified three T&O patterns over the past five years which are, in general, unrelated to chl*a* or total cyanobacterial biomass. In the Northwest basin, widespread T&O is caused by abrupt and severe geosmin outbreaks, which afflict major municipal supplies between Hamilton and Cobourg in the most densely urbanized region of Canada. Late summer T&O peaks occur with considerable interannual variation in severity. Planktonic chl*a* and algal biomass remain very low and show much lower variability (2–7 µg/L; 100–500 µg/L, respectively). Climate and large-scale water movement play a key role in these events by transporting offshore pelagic T&O production by dispersed and patchy distributions of cyanobacteria (*Anabaena lemmermanii*) to nearshore water treatment plant intakes. The strength of the annual downwelling and associated T&O event varies among years with the duration and persistence of east winds (Rao *et al*. 2003, Watson *et al*. 2007, Moore and Watson 2007). In the Northeast end of the lake (Kingston basin) and upper St. Lawrence River, T&O is produced annually by both geosmin and MIB. This affects an extensive shoreline (200 km) and persists over a more prolonged period (September to November). Primary sources are littoral and epiphytic cyanobacterial biofilms in nearshore areas and macrophyte beds. Midstream amounts of pelagic chl*a* remain low. Geosmin and MIB co-occur or peak in succession over the season, and they vary in relative and absolute abundances (Watson and Ridal 2004, Ridal *et al*. 2007). The Bay of Quinte develops annual cyanobacterial blooms, with patchy mid-summer increases in geosmin and MIB and cyanotoxins (Watson *et al*. 1997, 2005), but shows less extensive T&O impairment than the other two more 'oligotrophic' areas. Although T&O reaches significant levels in some areas of the Bay of Quinte, the effects are localized with little impact on municipal drinking water supplies.

Benthic algal impairment is a major concern along many nearshore areas in Lake Ontario. Dense mats of *Cladophora* occur along many nearshore areas, creating issues of fouling drinking water treatment plant intakes and beaches (Higgins *et al*. 2008). In early spring, detached mats of the green algae *Spirogyra* and other related species in areas of the Lower St. Lawrence River and Northwest shoreline have recently been causing severe intake fouling in drinking water plants (Watson unpublished data). Severe impairment is also manifested by benthic mats of the cyanobacteria *Lyngbya cf. wollei* and epiphytic colonies of *Gloeotrichia pisum*, recently identified in the St. Lawrence River near the confluence of nutrient-rich tributaries (Vis *et al*. 2008). These populations of *Lyngbya* are non-toxic but show high geosmin production, likely the source of extensive drinking water T&O impairment in the Montreal area. Comparisons with *Lyngbya* populations from Maumee Bay (Lake Erie) show morphologically similar populations, but significant differences in cell geosmin production. The greater capacity is seen in the St. Lawrence River population.

Pressures

The cumulative effects of past and continued stressors continue to influence the response of Lake Ontario to remedial action. For example, major shifts in nutrient pools and recycling can result in time lags, increased variability and hysteresis, and more stringent remedial targets might be required than traditional models predict. Current and future concerns include: i) continued introduction of invasive species**,** as discussed above; ii) shoreline development and expanding urbanization, which will continue to affect point-source and non-point source loadings, timing, magnitude and bioavailability; and iii) climate change, which will continue to have significant effects on all components of the Great Lakes, including HABs.

Warming and increased storm events may favour higher productivity and more intense and widespread noxious blooms though such factors as:

- extended growing season
- altered patterns of runoff, circulation, mixing, resuspension and water column stability
- warmer ambient water temperatures
- changes in water levels, coastal erosion and littoral zones
- altered light regimes favouring algal taxa that are tolerant to high irradiance and UV (e.g., cyanobacteria)
- extension of distribution and success of warm water and/or invasive taxa
- indirect top-down and bottom up effects on water quality, nutrient cycling, respiration, remineralization, sediment and hypolimnetic oxygen demand, anoxia and nutrient release.

Management Implications - Concerns and recommendations

Compatibility of long term data: sampling regimes and methods

Different sampling regimes and analytical protocols (e.g., surface or integrated sampling; taxa enumeration; toxin analyses) employed by individual studies affect data comparability and interpretation of long-term trends (Kane *et al.* 2005, Conroy *et al.*

2005a, e.g., Table 2). The size and complexity of the Great Lakes means that many sampling regimes are inevitably sparse and likely to miss spatial and temporal peaks in algal abundance. Annual peaks shift in timing and size as a result of natural variability, and differences are generally greater in more impacted, eutrophic areas, e.g., Western Lake Erie and AOCs (Frost and Culver 2001, Conroy *et al.* 2005a). Furthermore, basin-wide seasonal means do not resolve temporal and spatial differences in biomass and taxa, and thus cannot identify problem areas or potential drivers.

Year	Reference	Sampling regime	Field methods
1970	Munawar and Munawar 1976	Apr- Dec, 4-week intervals, all basins, 25 stations	Van Dorn, 1, 5m, mixed- layer integrated
1978	Munawar and Munawar 1996	Jun-Sept; CB & EB only; 18 stations (different sites than 1970)	Van Dorn, 1, 5m depth, mixed-layer integrated
1978	Devault and Rockwell 1986	May-Nov, all basins, 9 cruises; 87 stations	Niskin; *stratified*: 1m, 1m above metalimnion, thermocline, hypolimnion, bottom. *Unstratified*: 1m, mid -depth, bottom-1m.
1983-1987	Makarewicz 1993	spring, summer, fall; all basins, 33 cruises, 21 stations	Niskin; *deep*: 1, 5, 10, 20m. *shallow* (West B) 1m, mid-depth, bottom-1m
1998	Barbiero and Tuchman 2001	spring (7-9 April) summer (2-4 Aug), 20 stations	Niskin; combined 0.5m, 5 m, 10 m, lower epilimnion
1996-2002	Frost and Culver 2001	late spring-late Sept.-Oct.; all basins; 30 - 80 stations	integrated tube 0-[2*SD]
2000-2006 Boyer;/ Watson/ Richardson	Boyer 2007, Watson *et al.* 2008a	late spring-late Sept.-Oct.; all basins; 30 - 80 stations	Van Dorne / Rosette 1m and integrated mixed layer

Table 2. Representative surveys of phytoplankton in Lake Erie and sampling regimes.
Sources: Conroy *et al.* (2005), Boyer (2007), Watson unpublished.

Littoral, benthic, epiphytic and meroplanktic algal populations are not addressed by most sampling programs, yet they can account for a high proportion of algal productivity or represent seed beds where surface blooms originate. Extensive attached algal or cyanobacterial beds have significant effects on nutrient pools and recycling. They effectively ‘decouple’ nutrient loading, ambient levels, and nearshore-offshore exchange, and they influence or mask relationships between biomass and nutrient levels or other environmental factors.

Many ‘state of the lake’ papers compare mean planktonic biomass and taxonomic composition among years, based on infrequent samples taken during the spring, summer and fall seasons. Alternative measures of algal abundance are often poorly correlated with productivity or measures of light regime. Chl*a* continues to be a target measure for management, yet there are often poor correlations between chl*a*, total algal biomass and levels of impairment. Conroy *et al.* (2005a) pointed out the inconsistency among seasonal means of chl*a* and algal biomass from early surveys and those from recent surveys, which showed resurgence in biomass, but minimum amounts of chl*a*. The authors suggested that the use of chl*a* in place of biomass may explain apparent contradictions among different recent studies regarding trends in Lake Erie, some of which conclude that biomass is still at a minimum, based on chl*a*.

Secchi depth (SD) is widely used to estimate the depth of the euphotic zone, and it as a basis for integrated samples (e.g., Table 2) using a constant conversion ratio between SD and photosynthetically active radiation (PAR). This relationship is functional and simple, but SD estimates can differ significantly seasonally and spatially from PAR extinction in the water column.

Recent advances in technology have increased the number of tools available to diagnose HABs. Examples include remote sensing, genetic probes, moored instrumentation and profilers, fluorescence-based measures, and genetic probes. All of these are extremely useful diagnostic tools, and when combined, can provide considerable insight into HABs occurrence, species, toxicity and ecology

(Wilhelm 2008). However, researchers should understand the limitations of these tools and use them in combination with other methodologies. Remote imaging from satellites has potential, but it measures only surface material and needs to be carefully groundtruthed with field samples. Fluorescence-based profiling of algal assemblages is gaining widespread, often indiscriminate, use as a measure of community structure, but this method needs careful calibration, preferentially with local biota. Comparison among individual instruments deployed in parallel has shown wide discrepancies (Boyer, unpublished data). Fluorescence data need to be interpreted with caution because wavelengths used to measure chromophytes and cryptophytes overlap with those used for the diatoms, and those used for cyanobacteria overlap with colored dissolved organic matter (CDOM). At low biomass, resolution is poor, notably between cyanobacteria and crytophytes (Boyer unpublished data, Watson and Kling unpublished data).

Impairment criteria

As noted above, current efforts to monitor algal populations target parameters that are often unrelated to levels of toxic or nuisance impairment and/or are based on non-quantitative measures. Toxins should be systematically investigated, particularly in high risk source waters, using regular monitoring at recreational and drinking water intake areas. Mid to late summer spatial surveys during high risk periods should be coupled with an alert-level framework such as that developed by the World Health Organization (Watzin *et al.* 2006). More effective criteria for T&O would include regular measures of the most problematic compounds (e.g., geosmin, MIB, isopropyl thiol, β-cyclocitral) in source waters and municipal supplies.

In the Great Lakes, considerable progress has been made in many areas towards Remedial Action Plan (RAP) goals, not the least of which has been an increased public awareness and participation in this initiative. However, remedial efforts are addressing a moving target. These ecosystems are under constant assault by an expanding human population and emerging threats. Advances in our understanding of these systems have not kept pace with these changes. Remedial and management programs should frequently revaluate the list of target goals, their acceptable levels, and progress toward them.

Nutrient levels may or may not predict toxin or odour outbreaks. Blooms appear to be local and nearshore in origin and can spread over considerable areas, likely the combined result of growth and translocation of surface scums. The relative importance of these different mechanisms is not well resolved. There are numerous incidental reports, media releases and websites that may inflate these issues. Most attention is focused on surface scums, which inevitably bias sampling efforts and perceived severity. The blooms can appear suddenly, giving the impression of rapid growth, but they could represent biomass which has been present and developing in the water column over a preceding undefined period of time.

The effects of invasive taxa can be numerous, both via direct impairments (e.g., blooms, toxins, odour, fouling, fisheries impacts) and indirect effects on ecosystem structure and function (e.g., food webs, nutrient pools and recycling, water quality). In addition, their appearance is of concern because of implications for i) vectors (predominantly ballast water) and ii) changes in the environment which might facilitate their establishment (e.g., temperature, substrate, salinity, pollutants). Other biota, such as macrophytes, may indirectly or directly affect the proliferation of HABs species by modifying light and nutrient levels, and/or providing substrate for epiphyte growth. The influence of invasive species of zooplankton (e.g., *Cercopagis pengoi*, *Bythotrephes cederstroemi)* and benthic grazers on HABs development in the Great Lakes is unknown.

Current models and sampling design

Traditional ecosystem models are sometimes derived from empirical relationships among seasonal averages for nutrients and algal biomass. Many are applied indiscriminately, without considering their underlying assumptions and limitations (e.g., Watson *et al.* 2008a). In particular, the models incorporate bias from sampling protocols, maxima and minima biovolumes, surface scums, deep layer chl*a* maxima, and other biomass aggregations. Depth-segregated maxima are a particular consideration for cyanobacteria populations, many of which are buoyancy-regulating or mat-forming taxa. Benthic and littoral algal communities can also be major sources of impairment. Different nuisance algal and cyanobacterial taxa respond very differently to stressors and nutrient loading. Many have developed different strategies to adapt to these factors. Current models do not adequately predict algal biomass maxima, nor levels of toxins and other related impairments of concern.

Scientists and managers are faced with two different strategies when designing sampling regimes. Each has its use and limitations, and each must meet the underlying question and management goals.

- Random sample design: This approach represents an unbiased sampling of nearshore or offshore influences and impacts. This strategy averages out maxima, may minimize key AOCs, and is often unable to resolve impairments and trace local causes.
- Sampling biased towards high risk, targeted areas: This approach utilizes time- and depth-resolved sampling, and periodic extensive spatial surveys during identified high risk periods (e.g., late summer). This approach provides a better assessment of extreme conditions, localized risk, and targets, but it may miss maxima.

Ideally, a combination of both strategies provides the best HABs assessment and monitoring framework. However, coordination and logistics of these programs are difficult, especially among multi-agency and international partners working within the large, highly fragmented Great Lakes basin.

Acknowledgments
Authors:
Sue B. Watson, Aquatic Ecosystem Management Research, Canada Centre for Inland Waters, National Water Research Institute, Environment Canada, sue.watson@ec.gc.ca, http://www.nwri.ca/staff/susanwatson-e.html
Gregory L. Boyer, Director, Great Lakes Research Consortium, State University of New York, glboyer@esf.edu

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5.6 Great Lakes Nearshore and Human Health

State of the Ecosystem

The variation in statuses and trends among the Great Lakes public health indicator topics create a challenge in assigning a specific ecosystem assessment that would accurately represent all indicators. Levels of polychlorinated biphenyls (PCBs) continue to decrease, but still drive advisories for limiting consumption of Great Lakes sportfish. Air quality is generally improving throughout the basin. Beach advisories, postings and closures suggest a combination of trends ranging from deterioration to improvement, and drinking water quality status remains good (Table 1).

ID #	Indicator Name	2009 Assessment (Status, Trend)				
		Lake				
		SU	MI	HU	ER	ON
4175	Drinking Water Quality	◆				
4177	Biological Markers of Human Exposure to Persistent Chemicals	?				
4200	Beach Advisories, Postings and Closures	US - ◆ CA - ➡	➡	US - ◆ CA - ➡	⬅	US - ◆ CA - ⬅
4201	Contaminants in Sport Fish	◆	➡	➡	◆	➡
4202	Air Quality	➡				

Status					Trend			
					➡	◆	⬅	?
Not Assessed	Good	Fair	Poor	Mixed	Improving	Unchanging	Deteriorating	Undetermined
Note: Progress Reports and some Reports from previous years have no assessment of Status or Trend								

Table 1. Human Health Indicators Assessment for 2009.
Source: U.S. EPA and Environment Canada, *State of the Great Lakes 2009*.

Contaminants in Sport Fish

Concentrations of organochlorine contaminants in Great Lakes sport fish are generally decreasing. However, in the United States, PCBs still drive advisories for limiting consumption of Great Lakes sport fish. In Ontario, most of the consumption advisories are driven by PCBs, mercury, and dioxins and furans. Toxaphene also contributes to a small proportion of consumption advisories for sport fish from Lake Superior and Lake Huron, according to the Ontario Ministry of the Environment (OMOE). In addition to an indicator of human health, contaminants in fish are an important indicator of contaminant levels in an aquatic ecosystem. Contaminants that are often undetectable in water can be detected in fish because of the bioaccumulation of organohalogen chemicals up the food chain.

Both the United States and Canada (Ontario) collect and analyze sport fish to determine contaminant concentrations to relate those concentrations to health protection values and/or to develop consumption advice to protect human health. The Great Lakes Fish Monitoring Program (U.S. EPA Great Lakes National Program Office (GLNPO)) and the Sport Fish Contaminant Monitoring Program (OMOE) have been monitoring contaminant levels in Great Lakes fish for over three decades.

Consumption advice for sport fish varies throughout the Great Lakes basin depending upon the agency or government responsible for issuing consumption advice. In the United States, the federal government does not issue consumption advice. Rather, individual states and tribes are responsible for this task. In Canada, OMOE is responsible for advising Canadians on the recommended frequency and meal size for fish consumption from sport fish collected in their waters. U.S. EPA GLNPO does collect and analyze contaminants in sport fish fillets and compares those concentrations to the categories set by the *Protocol for a Uniform Great Lakes Sport Fish Consumption Advisory* that was developed by the Great Lakes states.

Advised meals per month		PCBs (ppm)	Mirex (ppm)	Photomirex (ppm)	Toxaphene (ppm)	Mercury (ppm)	
General	Sensitive*					General	Sensitive*
8	8	<0.105	<0.082	<0.015	<0.235	<0.61	<0.26
4	4	0.105-0.211	0.082-0.164	0.015-0.031	0.235-0.469	0.61-1.23	0.26-0.52
2	Do not eat	0.211-0.422	0.164-0.329	0.031-0.061	0.469-0.939	1.23-1.84	>0.52
1	Do not eat	0.422-0.844	0.329-0.657	0.061-0.122	0.939-1.877	-	>0.52
Do not eat	Do not eat	>0.844	>0.657	>0.122	>1.877	>1.84	>0.52

Table 2. Ontario Ministry of the Environment Consumption Limits for General and Sensitive* Populations that are used in the *Guide to Eating Ontario Sportfish.*
* Women of child-bearing age and children under 15.
Source: Ontario Ministry of the Environment (2009).

According to OMOE data, the level of total PCBs in lake trout has continued to decrease since the early 1990s. In Lake Superior the data demonstrate fluctuations over time but with an overall decline. The most recent OMOE data collected in 2006 indicate a maximum consumption level of two meals per month while GLNPO data fall into the one meal per week category (Tables 2 and 3). OMOE advice to sensitive populations for sport fish from Lake Erie is for two meals per month, while GLNPO data fall into the one meal per month category. Current PCB concentrations in Lake Huron OMOE lake trout allow for the safe consumption of a maximum of two meals per month, while current GLNPO data fall into the one meal per week consumption advice category. Historically, the highest concentrations of PCBs in sport fish have been found in Lake Ontario by OMOE and in Lake Michigan by GLNPO (OMOE does not collect fish in Lake Michigan). From the late 1970s to 1999, PCBs in OMOE lake trout from Lake Ontario exceeded the "do not eat" consumption limit. Substantially lower concentrations have been found in the most recent samples in 2006 and 2007, and the current levels would permit consumption of two meals per month for the general population. Current GLNPO data for PCB concentrations in sport fish fall into the one meal per week category. GLNPO data for PCB concentrations in sport fish from Lake Michigan can be used to discern general trends due to multiple collection sites. These data display a general decline in PCB concentrations in coho and Chinook salmon fillets. The majority of current concentrations fall into the one meal month consumption advice category with one site falling into the one meal per week category. The U.S. EPA website (http://www.epa.gov/fishadvisories/states.htm) provides a link to fish consumption advisories issued by state and tribal environmental programs and departments of health for their local waterbodies.

Consumption Advice Groups	Concentrations		
	PCBs (ppm)	Hg (ppm)	Chlordane (ppm)
Unrestricted Consumption	0 – 0.05	0 <= 0.05	0 - 0.15
2 meals/ week		> 0.05 <= 0.11	
1 meal/ week	0.06 – 0.2	>0.11 <= 0.22	0.16 - 0.65
1 meal/ month	0.21 – 1.0	>.22 <= 0.95	0.66 - 2.82
6 meals/ year	1.1 – 1.9		2.82 - 5.62
Do not eat	>1.9	>0.95	>5.62

Table 3. Consumption limits for sensitive* populations, from the *Protocol for a Uniform Great Lakes Sport Fish Consumption Advisory.*
* Women of childbearing age and children under 15.
Source: Great Lakes Sport Fish Advisory Task Force (1993, 2001 unpublished, 2007)

Mercury in sport fish is another contaminant of concern due to the detrimental effects of methylmercury on neurological function and development. OMOE found that walleye and lake trout collected in Lake Erie demonstrate a considerable decline in mercury levels from 0.76 ppm in 1970 to 0.14 ppm in 2006. As a result, OMOE does not have a consumption advisory for this lake. However, GLNPO data fall into the two meals per week advice category. Similarly, in Lake Huron, mercury levels have declined over the last few decades, falling below the first level of concentration restriction for sensitive populations in Canada. Currently, GLNPO data fall into the one meal per week category for Lake Huron. The other lakes have also experienced declines in mercury concentrations in fish. According to GLNPO data, Lake Michigan sport fish fall into the one meal per month category. Based upon the most recent data available, Lake Ontario sport fish fall into the four meals per month category for OMOE fish and the one meal per week category for GLNPO data. The OMOE has set the advisory for Lake Superior sport fish at four to eight meals per month for sensitive populations due to consistency in mercury levels since 2000. GLNPO data fall into the two meals per week category. Again, the U.S. EPA website (http://www.epa.gov/fishadvisories/states.htm) provides a link to mercury-driven fish consumption advisories issued by state and tribal environmental programs and departments of health for their local waterbodies.

Since the 1970s, there have been declines in the levels of many PBT chemicals in the Great Lakes basin due to bans on the use and/or production of harmful substances and restrictions on emissions. However, because of their ability to bioaccumulate and persist in the environment, PBT chemicals continue to be a significant concern. Historically, PCBs have been the contaminant that most frequently limited the consumption of Great Lakes sport fish. In some areas, dioxins/furans, toxaphene (Lake Superior) or mirex/

photomirex (Lake Ontario) have been the consumption-limiting contaminants. OMOE has found toxaphene concentrations in Lake Superior lake trout ranging from 0.810 to 0.346 ppm between 1984 and 2006. According to these levels, consumption of up to four meals per month is permissible. Additionally, Health Canada recently has revised downward its tolerable daily intakes (TDIs) for PCBs and dioxins, an action which has increased the frequency of consumption restrictions caused by PCBs and dioxins/furans, and decreased the relative frequency of consumption restrictions for toxaphene and mirex/photomirex.

Air Quality

In general, the air quality status of the Great Lakes basin is mixed, but the trends show an overall improvement in air quality.

There have been significant improvements in air quality within the Great Lakes basin. For over a decade, there has been considerable progress in reducing urban or local pollutants, though somewhat less in recent years. Of these pollutants, ambient concentrations of carbon monoxide (CO), nitrogen dioxide (NO_2), sulfur dioxide (SO_2), lead and PM_{10} (particulate matter with a diameter of 10 microns or less) have all been substantially reduced since the 1990s. For example, CO and lead concentrations have decreased well over 70% across both the United States and Canada. Emissions of these pollutants have similarly shown large reductions, demonstrating the successes of instituting more stringent emission standards on a wide variety of sources including fuel combustion, transportation, and other industry; as well as efforts like the U.S. EPA Acid Rain Program and the Canada-wide Acid Rain Strategy for Post-2000.

Air toxics are also typically urban or local pollutants. Air toxics include a large number of pollutants that, based on toxicity and likelihood of exposure, have the potential to harm human health or adverse environmental and ecological effects. The U.S. EPA recently released the results of its National Assessment of Air Toxics (NATA) to identify and prioritize air toxics, emission source types and locations which are of greatest potential concern in terms of contributing to population risk. From a United States' national perspective, benzene is the most significant air toxic for which cancer risk could be estimated, contributing 25% of the average individual cancer risk identified in this assessment. Using data from existing monitoring networks, average annual urban concentrations of benzene have decreased 55% from 1994 to 2006. Short-term trends should be available soon as more data becomes available from a recently established National Air Toxic Trend Site (NATTS) network. In Canada, urban benzene concentrations have similarly decreased by 68% from 1991 to 2006. Concentrations should continue to decrease as the U.S. EPA projects that transportation source emissions of benzene will decrease by about 60% between 1999 and 2020.

Manganese compounds are another category of air toxics of special concern in the Great Lakes region. They are emitted by iron and steel production plants, power plants, coke ovens, and many smaller metal processing facilities.. According to the 1999 U.S. National Emissions Inventory (NEI), U.S.EPA Region 5 had the highest manganese emissions of all 10 U.S. EPA regions, contributing 36.6% of all manganese compounds emitted nation-wide. It appears that emissions controls have in recent years had an impact on ambient concentrations of manganese compounds as they decreased 28% between 2000 and 2006. Additional years of data may be needed to confirm this apparent trend. Canada has also reported significant voluntary reductions of some air toxic emissions through the Accelerated Reduction/Elimination of Toxics (ARET) program.

Regional pollutants such as ground-level ozone and fine particulates remain a concern in the Great Lakes basin, especially in the Detroit-Windsor-Ottawa corridor, the Lake Michigan basin, and the Buffalo-Niagara area. Ground-level ozone levels may be augmented in the region due to local onshore circulations that can trap pollutants for days below a maritime/marine inversion. Consistently high ozone levels are found in provincial parks near Lake Huron and Lake Erie, and western Michigan is impacted by transport across the lake from Chicago. Ozone levels in both countries have shown continued improvement since the 1990s; however, many areas remain in nonattainment of the U.S. ozone standard or have experienced exceedences of the Canada-wide Standards (CWS). Furthermore, Ontario seasonal means have experienced an overall increasing trend from 1980 to 2006, with the summer and winter means increasing by about 27% and 50%, respectively. The increases in these seasonal means appear to be largely related to reductions in NO_x emissions (changing atmospheric chemistry in urban areas) and rising global background ozone concentrations.

Fine particulates are a health concern because of their ability to penetrate deeply into the lungs compared to larger particles. In the United States, annual average $PM_{2.5}$ (particulate matter with a diameter of 2.5 microns or less) concentrations have declined nationally by 14% between 2000 and 2006. Similar trends are seen for daily $PM_{2.5}$ concentrations. However, there are three areas in the Great Lakes region that are designated as non-attainment for the $PM_{2.5}$ standard (Chicago-Gary-Lake County, Illinois-Indiana metropolitan area; Detroit-Ann Arbor, Michigan metro area; and the Cleveland-Akron-Lorain, Ohio metro area). In Canada, continuous $PM_{2.5}$ monitoring has only begun quite recently so there are not enough data to show any trends. However, recent data from Ontario indicate that five of the 18 designated sites exceeded the CWS target of 30 $\mu g/m^3$. Weather also plays an important factor in the formation and emission sources of $PM_{2.5}$. In colder months the greater demand for home and office heating creates more direct emissions of $PM_{2.5}$ emissions, while in warmer months, weather conditions are more conducive to $PM_{2.5}$ formation in the atmosphere. For example, in 2005, the industrial Midwest (including Wisconsin, Illinois, Indiana, Michigan, Ohio, Kentucky, and parts of West Virginia, Pennsylvania, and New York) had a temporary increase in $PM_{2.5}$ concentrations, likely the result of the colder-than-normal winter and the hotter-than-normal summer, which elevated nitrate and sulfate levels, respectively.

Beach Advisories, Posting and Closures

Health-related postings for beaches are based upon elevated levels of *Escherichia coli* (*E. coli*), or other indicator organisms, as reported by county health departments (United States), Public Health Units (Ontario), or municipal health departments in the Great Lakes basin. The bacteria criteria recommendations for *E. coli* from the U.S. EPA are a single sample maximum value of 235 colony forming units (cfu) per 100 ml. The state of Michigan, as permitted by U.S. EPA, uses 300 cfu per 100ml. For *Enterococci*, another indicator bacterium, the U.S. EPA recommended criterion is a single sample maximum value of 62 bacteria per 100 ml. If the levels of any indicator organisms exceed the recommended criteria, then swimming is either prohibited or advisories are placed to warn beachgoers and swimmers of the possible risk.

The percentage of Great Lakes beaches open the entire season remained nearly constant in the United States between 1998 and 2007 at an average 74%. Although it should be noted that the number of reporting beaches more than doubled between 2002 and 2004, and almost doubled again between 2004 and the past two years. In Canada, the percentage of beaches open the entire season averaged approximately 49% from 1998 to 2007. During the 2006 and 2007 seasons, the percentage of beaches posting more than 10% of the time averaged 9% in the United States and 42% in Canada. For consistent comparison, calculations derived from posting data are based on the months of June, July and August.

According to Great Lakes data for 2006 and 2007, the number of beach reports has increased significantly in the United States and slightly more than in previous years for Canada. The data illustrate that conditions have improved since 2004 and 2005, but have deteriorated in comparison to the data from 1998 to 2003. Affecting this data may be the fact that some beaches that were not directly situated on the Great Lakes were included in the Canadian dataset prior to 2004, but were excised from the data set in 2004. Also the United States included significantly more beach reports in this data, thus adding to trend analysis uncertainty.

The United States *Great Lakes Strategy 2002* has set a goal that by 2010 all Great Lakes beaches should be swimmable, which would require that 90% of all monitored, high priority Great Lakes beaches meet bacteria standards more than 95% of the swimming season. Using the strategy goal as a tool for assessment, it appears that only Lake Superior and Lake Huron currently meet the goal in the United States. For lakes Michigan, Erie and Ontario, many groups are in the process of collaborating to identify and remediate sources in an effort to reduce beach contamination. Unfortunately, in Canadian none of the lakes satisfied the key objective of the *Great Lakes Strategy*, and while there has been some deterioration, there have also been improvements in comparison to data from 2004 and 2005. Overall, the indicator is assessed as having a mixed status and an unchanging trend.

Drinking Water Quality

The purpose of this indicator is to evaluate chemical and microbial contaminant levels, assess the potential for human exposure to drinking water contaminants, and review the effectiveness of policies and technologies to ensure safe drinking water. In the United States, information is drawn from Water Treatment Plants (WTPs), which produce annual Consumer Confidence/Water Quality reports. This information is then verified and further supplemented using the Safe Drinking Water Information System (SDWIS). For Canada, the Ontario Ministry of the Environment (OMOE) produces annual reports from the Drinking Water Systems (DWSs) and other sources. Data for the 2007 operational year (if unavailable then for the 2006 operational year) were collected from 43 different WTPs in the United States, and in Canada data were collected from 74 different DWSs from January to June of 2004. It should also be noted that the United States focuses mainly on finished or treated drinking water, whereas Canada tests both raw and treated water.

The status of drinking water in the Great Lakes basin is best assessed through the use of 10 drinking water parameters, which include several chemical parameters, microbiological parameters, and other indicators of potential health hazard. An established standard then regulates these parameters. The U.S. EPA defines this standard as the Maximum Contaminant Level (MCL) and in Ontario the standard is defined as the Maximum Acceptable Concentration (MAC). Canada also has in place the Interim Maximum Acceptable Concentration (IMAC) with the purpose of managing parameters with insufficient toxicological data or when it is purely not feasible to establish a MAC.

The chemical contaminants atrazine, nitrate and nitrite were assessed in the report according to the standards set by the United States and Canada. In the Great Lakes basin, WTP levels of atrazine did not exceed the standard for finished water and no violations were reported. The same was true of Ontario with somewhat higher levels only being detected in raw water sources. For nitrate, detected levels never exceeded the contamination standards of either country, thus no health complications are likely to occur. There were only two violations in the United States between January 2006 and December 2006. In the United States, nitrite was rarely detected and where detected it was only in finished water for WTPs using rivers, small lakes or reservoirs as source water. No violations were reported for nitrite. Ontario had no nitrite contaminant levels exceeding MAC standards and no violations were reported.

Microbiological parameters evaluated include total coliform, *E. coli*, *Giardia*, and *Cryptosporidium*. In the United States, there were two WTPs with health-based violations as well as two monitoring and reporting violations for total coliform bacteria. Additionally, there was one monitoring and reporting violation for *E. coli*, but no WTPs had health based violations. Ontario did not find the presence of *E. coli* in any finished water samples, however small amounts were present in raw water samples. Ontario also detected total coliform in a few treated water samples and in many raw water samples.

Ontario adopted removal/inactivation regulations for *Giardia* and *Cryptosporidium*, but there are no data to report at this time. Neither *Giardia* nor *Cryptosporidium* were detected in finished water supplies from any of the WTPs in the United States Great Lakes basin, however consumer confidence and water quality reports discussed the presence of these microorganisms in the source waters (Lake Erie, Lake Huron, Lake Michigan, Lake Ontario, and small lakes/reservoirs). The reports illustrate the effectiveness of the WTPs at removing these microbial contaminants, but also the need for continued research on raw water in the Great Lakes basin. At this time it is not likely that any of the aforementioned microbial contaminants will lead to any serious health complications.

In addition to the assessment parameters of chemical and microbial contaminants, treatment techniques including turbidity, total organic carbon (TOC) in the United States and dissolved organic carbon (DOC) in Canada, also influence the safety of drinking water. Turbidity data in the United States are difficult to assess due to the different requirements and regulations for WTPs depending on the source water and treatment technique implemented. There were no health violations, but there were two monitoring and reporting violations, which occurred in June and July of 2007. In Ontario, the 2003-2004 Drinking Water Surveillance Program (DWSP) report indicated that 78 raw water samples, many of which originated from Lake St. Clair and the Detroit River, exceeded the aesthetic objective.

The U.S. EPA only had one monitoring and reporting violation for total organic carbon. For dissolved organic carbon, Ontario found that there were 110 violations identified from raw water samples based on their 2003-2004 data. Most of the high DOC results came from raw water originating from small rivers and lakes.

Pressures

Contaminants in Sport Fish

In the United States, state and tribal governments currently provide information to consumers regarding the consumption of sport-caught fish. The guidance and advice offered by these governments are not regulatory, though some states use federal commercial fish guidelines for the acceptable level of contaminants. Each state or tribe is responsible for the development of fish consumption advisories and tailoring the advice to meet the health needs of its citizens. As a result, advice may vary between state and tribal programs for the same lake and species. Ontario does maintain federally regulated advice and guidelines, and the data suggest that concentrations of PBT contaminants such as PCBs have declined in lake trout throughout the Great Lakes basin. However, concentrations still exceed current consumption limits thereby stressing the necessity for regular monitoring. Furthermore, the addition of chemicals of emerging concern into monitoring programs should be implemented to help stay ahead of the curve.

Air Quality

Air quality is in a complicated state as continued economic growth, population growth, and the associated urban sprawl threaten to offset emission reductions achieved by policies currently in place. Climate change may also bring about meteorological changes that are more conducive to increased ambient concentrations of many pollutants. There is also increasing evidence of changes to the atmosphere as a whole. Continuing health research is also producing evidence that existing standards may need to be lowered and that multi-pollutant effects may need to be addressed.

Beach Advisories, Postings and Closures

Beach advisories, postings and closures all rely upon laboratory analysis of samples that may take 18 to 24 hours before processing is completed. Due to the time lag, the efficiency of posting and later lifting restrictions is reduced. The delay in developing a rapid test protocol for bacteriological indicators, as well as the costs, training, and collection times associated with rapid methods, is lending support to the use of predictive models to estimate when bacterial levels may exceed water quality standards. For instance, assuming contaminant sources remain consistent in the Great Lakes, past sample data may be used to forecast when elevated bacterial counts may occur (such as poor recreational water quality after a specific meteorological event).

Additional point and non-point source pollution at coastal areas due to population growth and increased land use may result in additional beach postings, particularly during wet weather conditions. In the United States, all coastal states (including those along the Great Lakes) have criteria as protective as U.S. EPA's recommended bacteriological criteria (use of *E. coli* or *Enterococci* indicators) applied to their coastal waters. Conditions required to post Ontario beaches as unsafe have become more standardized due to the 1998 Beach Management Protocol, but the conditions required to remove the postings remain variable.

Drinking Water Quality

The greatest pressure to the quality of drinking water within the Great Lakes basin is degraded runoff. Several causes for a reduction in quality include the increasing rate of industrial development on or near water bodies, low-density urban sprawl, and agriculture (both crop and livestock operations). Point source pollution, from wastewater treatment plants for example, can also contribute to the contamination of raw water supplies and can be considered an important pressure. Additionally, there is an emerging set of pressures derived from newly introduced chemicals of emerging concern (i.e., pharmaceuticals and personal care products, endocrine disruptors, antibiotics and antibacterial agents). Invasive species might also affect water quality, but to what extent is still unknown.

Management Implications

Contaminants in Sport Fish

Health risk communication and cooperation among national, state, and tribal governments is essential to develop and distribute the same message regarding safe fish consumption. Currently, only PCBs, mercury and chlordane (in draft form) have uniform advisory protocols across the United States Great Lakes basin. Additional uniform PBT advisories may be necessary in order to limit public confusion. Increased monitoring and reduction of PBT chemicals are also needed. Furthermore, potential negative health effects from exposure to PBT chemicals and the monitoring of contaminant levels in environmental media and bio-monitoring of human tissues should be addressed and/or improved upon.

Air Quality

In Canada, new ambient standards for particulate matter and ozone have been endorsed, with an achievement date of 2010. New, more protective ambient air standards for ozone and particulate matter have also been promulgated in the United States. Emission standards and residual risk analyses will continue to be promulgated for sources of toxic air pollution in the United States under the Clean Air Act. In December of 2000, both Canada and the United States signed the Ozone Annex to the 1991 U.S.-Canada Air Quality Agreement (Agreement), which commits both countries to reducing emissions of NO_x and VOCs. The United States and Canada have also undertaken cooperative modeling, monitoring, and data analysis as well as developed a work plan to address transboundary particulate matter issues. In 2007, the two governments announced that negotiations will start on a Particulate Annex to the Agreement. Efforts to reduce toxic pollutants will also continue under the North American Free Trade Agreement, the Security and Prosperity Partnership, and through United Nations-Economic Commission for Europe protocols.

Beach Advisories, Postings and Closures

States, provinces, and municipalities are continuing to identify point and non-point sources of pollution in recreational waters. Potentially harmful sources include combined sewer overflows (CSOs), sanitary sewer overflows (SSOs), malfunctioning septic systems, and poor livestock management practices, which can become exacerbated after heavy rainfall. In an effort to address these concerns, in 2007 U.S EPA issued grants to nine parties to participate in a pilot beach sanitary survey project at 61 Great Lakes beaches in the United States and Canada. The goal is to identify sources of pollution and evaluate the beaches and surrounding watersheds. Additionally, the Great Lakes Regional Collaboration Strategy's Coastal Health Chapter laid out goals: to achieve a 90-95% reduction in bacterial, algal and chemical contamination at all local beaches; and at the local level, individual contamination events will occur no more than 5% of available days per bathing season. Sources of these contamination events will be identified through standardized sanitary surveys, and remediation measures will be in place to address these events.

Ontario health units participate in beach management programs such as enhanced beach grooming, in-water and land debris clean-up, waterfowl and gull deterrent and public campaigns to encourage proper disposal of food (City of Toronto, 2006). Also, the Blue Flag program is becoming well-known and is an effective way of promoting clean beaches in Canada. It is an eco-label that is internationally recognized and only awarded to beaches that achieve high standards in areas such as water quality, education, environmental management and safety (Environmental Defense, 2008). In 2007, Ontario already had nine awarded Blue Flag beaches, and five candidate beaches.

Drinking Water

A more standardized and extensive monitoring program is needed to address newer parameters of concern that might not be listed by the U.S. EPA due to availability of resources or technology. Implementing a more extensive program should also successfully demonstrate a correlation between drinking water quality and the status of the Great Lakes basin. At this time, the finished drinking water data merely depict the efficiency of the WTPs rather than the overall water quality in the region. Source water data need to be reviewed to properly assess the state of the ecosystem.

Acknowledgments

Author:

Shelley Cabrera, Oak Ridge Institute of Science and Education (ORISE) Research Fellow, Appointed to the U.S. Environmental Protection Agency (U.S. EPA), Great Lakes National Program Office (GLNPO) 2008.

Contributors:

Todd Nettesheim, Environmental Protection Specialist, U.S. Environmental Protection Agency, Great Lakes National Program Office.

Elizabeth Murphy, Environmental Scientist, U.S. Environmental Protection Agency, Great Lakes National Program Office.

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5.7 Type E Botulism

State of the Ecosystem

<u>Background</u>

Botulism is a neuromuscular disease caused by several different strains of the bacterium, *Clostridium botulinum*. The type E strain is responsible for the botulism outbreaks that are currently affecting fish and large numbers of birds in the Great Lakes. Dormant spores of this bacterium are endemic to the region and are naturally abundant in all soils and sediments, but are not always in the vegetative state capable of producing botulism toxin. These spores are not only found in the sediments of the Great Lakes, but can also be found in the intestinal tracts of live, healthy animals. These spores are resistant to extreme temperatures and desiccation, and so are capable of remaining in the ecosystem for long periods of time (Domske 2003).

The botulism toxin is only produced when spores germinate and the bacterium enters the vegetative growth stage. This change occurs in anoxic environments containing a suitable nutrient source, such as in areas with decaying plant material, favorable temperatures, and pH levels (Brand *et al*. 1988). Once these factors lead to the production of the toxin, it is possible for the toxin to enter the food chain.

Animals, especially fish-eating birds, can contract botulism when they prey on other animals that harbor the toxin (CCWHC 2007). The effects of toxin poisoning include paralysis and often leads to death. Affected birds often have trouble holding up their heads (also known as limber neck) and may drown. Affected fish will lose their equilibrium and may be found floating or swimming erratically near the surface, which may actually attract birds to prey upon these fish. Dead fish and birds that wash up on the beach can become sources for *C. botulinum* growth, and shorebirds may ingest the toxins as they feed on maggots and carrion beetles within the decaying carcasses. Removal of dead birds (potential vectors) is important in dealing with an avian botulism outbreak. Rehabilitation of sick birds is limited due to the large geographic areas involved, but may be possible in cases when the birds did not ingest an acute dose of the toxin and anti-toxins and electrolytes are administered immediately, but it is frequently unsuccessful (USGS-NWHC 2006).

<u>Occurrence of Type E Botulism in the Great Lakes</u>

The frequency and severity of type E botulism outbreaks have gone through cycles over the last several decades (Fig. 1), with recent increases and expansion of affected areas and species leading to disturbing conclusions for the ecological health of the nearshore waters. Although outbreaks have been documented in the Great Lakes region as far back as 1963 (Kaufmann and Fay 1964), annual die-offs of birds and fish on the shores of Lake Huron began again in 1998, in Lake Erie in 1999, and in Lake Ontario in 2002 (CCWHC 2007). Over the past few years, botulism outbreaks have been particularly severe in Lake Michigan. Sleeping Bear Dunes National Lakeshore experienced an extensive botulism-related waterbird die-off in 2006 that killed nearly 3,000 grebes, gulls, cormorants, loons and mergansers (personal communication with Ken Hyde, Park Biologist for Sleeping Bear Dunes National Lakeshore (SLBE) 2007). In 2007, the Lake Michigan die-off impacted a much larger geographical area from Ludington State Park north, including most of the Michigan beaches in the Upper Peninsula. Including the 1,135 birds killed due to botulism at Sleeping Bear Dunes in 2007 (personal communication with Ken Hyde, SLBE 2007), the total estimates for that year reached 17,125 avian mortalities for the entire Great Lakes region (Fig. 2).

According to estimates compiled from the USGS National Wildlife Health Center's databases, a total of approximately 96,864 avian mortalities were attributed to type E botulism from 1963 through 2007 in the Great Lakes (USGS-NWHC 2008), although the actual number of deaths is likely much higher due to monitoring and reporting inconsistencies. These outbreaks involved a variety of species (Table 1); including species of special interest, such as lake sturgeon, loons, and endangered piping plovers. The mortalities in recent years have the potential to cause population and species level effects, which make this an important focus for future monitoring efforts.

Numerous state and federal agencies, universities, non-profits, and volunteer groups participate in botulism research, outbreak monitoring, clean-up, reporting and outreach. With the geographic area of occurrence expanding in recent years, keeping up with these tasks is increasingly difficult, as numerous jurisdictions are affected and resources are limited. Several workshops have been held in previous years to help foster coordination in dealing with the issue. The most recent workshop in June 2008 highlighted a series of focus areas in need of development within the research and management sectors. These included the desire for a more formalized botulism task force to help facilitate future activities, such as improved web-based reporting and tracking of outbreaks, database enhancement, development of cost-effective field-testing kits, and coordination and funding of additional research.

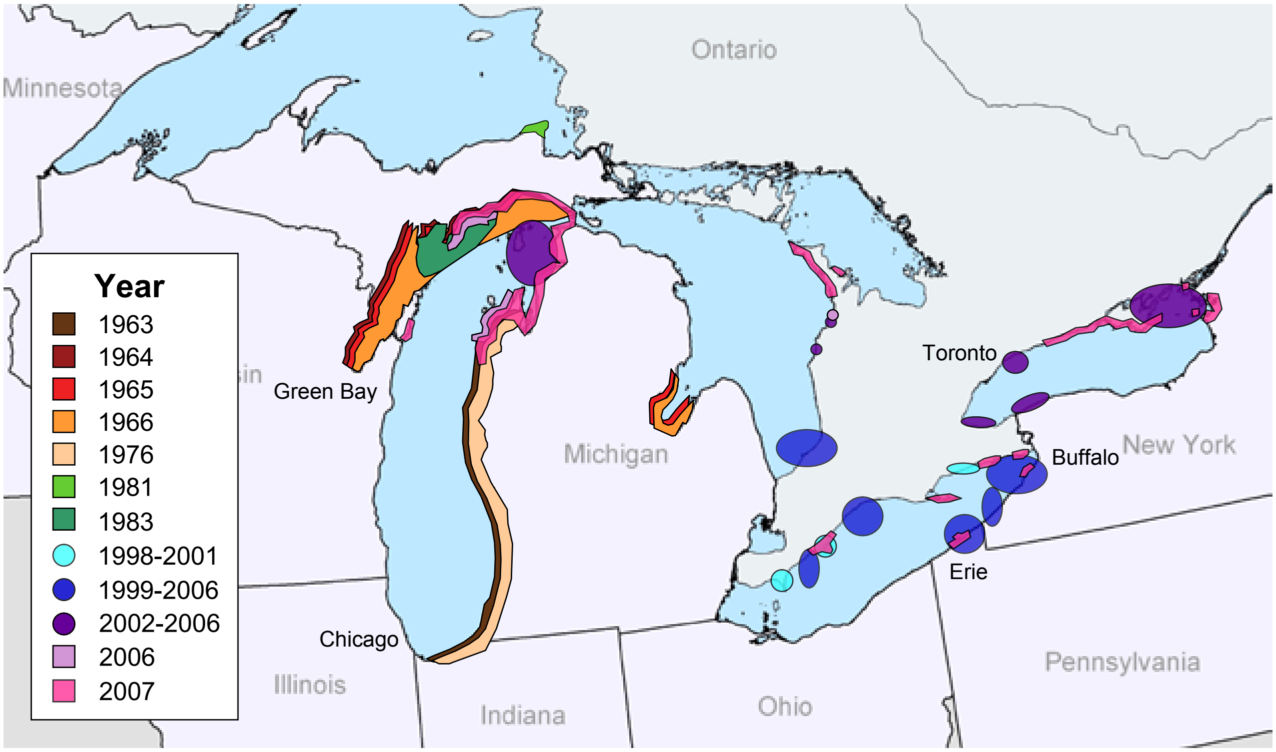

Figure 1. General distribution of type E botulism outbreaks, 1963 – 2007.
Highlighted areas are not drawn to scale, and are not representative of the exact areal extent of the outbreak. Areas highlighted with oval or circular marks refer to time frames as opposed to isolated years, and are not indicative of the outbreaks' severity.
Sources: Compiled from maps developed by Thomas Cooley (Michigan DNR, Wildlife Disease Lab); Eric Obert (Pennsylvania Sea Grant); Mark Jankowski (USGS – National Wildlife Health Center); and the Canadian Cooperative Wildlife Health Center (CCWHC).

Despite the evidence that the suspected current ecological pathway of botulism is heavily related to the impacts from a host of invasive species, the exact mechanism that transports it through the food chain has not been scientifically documented, nor were the causes of past historical botulism outbreaks in the 1960s (possibly linked with alewife die-offs, (Fay 1966)) fully understood. Additionally, appropriate control measures on a Great Lakes scale have not yet been developed for either the invasive species or the current suspected pathways. Research aimed at better understanding, or even disrupting, the environmental factors that lead to outbreaks is currently in progress, but actual prevention or mitigation may prove difficult. The ecological balance of the nearshore waters has apparently been upset to a point that allows these outbreaks to continue, and managers will be challenged to find the exact recipe of actions to restore a healthy equilibrium in a natural setting.

American Black Duck	Great Blue Heron	Piping Plover
American Coot	Greater Scaup	Red-breasted Merganser
American White Pelican	Grebe	Redhead Duck
Bald Eagle	Gull, unidentified species	Red-necked Grebe
Barred Owl	Hawk, unidentified species	Red-tailed Hawk
Belted Kingfisher	Heron, unidentified species	Red-throated Loon
Black-bellied Plover	Herring Gull	Red-Winged Blackbird
Blue Jay	Horned Grebe	Ring-billed Gull
Bonaparte's Gull	Killdeer	Rock Dove
Bufflehead	Lesser Scaup	Sabine's Gull
Canada Goose	Long-Tailed Duck	Sanderling
Canvasback Duck	Loon, unidentified species	Scaup, unidentified species
Caspian Tern	Mallard Duck	Scoter, unidentified species
Common Goldeneye	Merganser, unidentified species	Semipalmated Sandpiper
Common Loon	Northern Flicker	Sharp-Shinned Hawk
Common Merganser	Northern Yellow-shafted Flicker	Spotted Sandpiper
Common Tern	Oldsquaw Duck	White-winged Scoter
Double-crested Cormorant	Pheasant, unidentified species	Winter Wren
Duck, unidentified species	Pied-Billed Grebe	
Great Black-backed Gull	Pigeon, unidentified species	

Table 1. Great Lakes bird species affected by type E botulism.Represented species are from historical, as well as present day, outbreaks. Affected fishes are not listed here.
Source: USGS – National Wildlife Health Center, 2007, 2008.

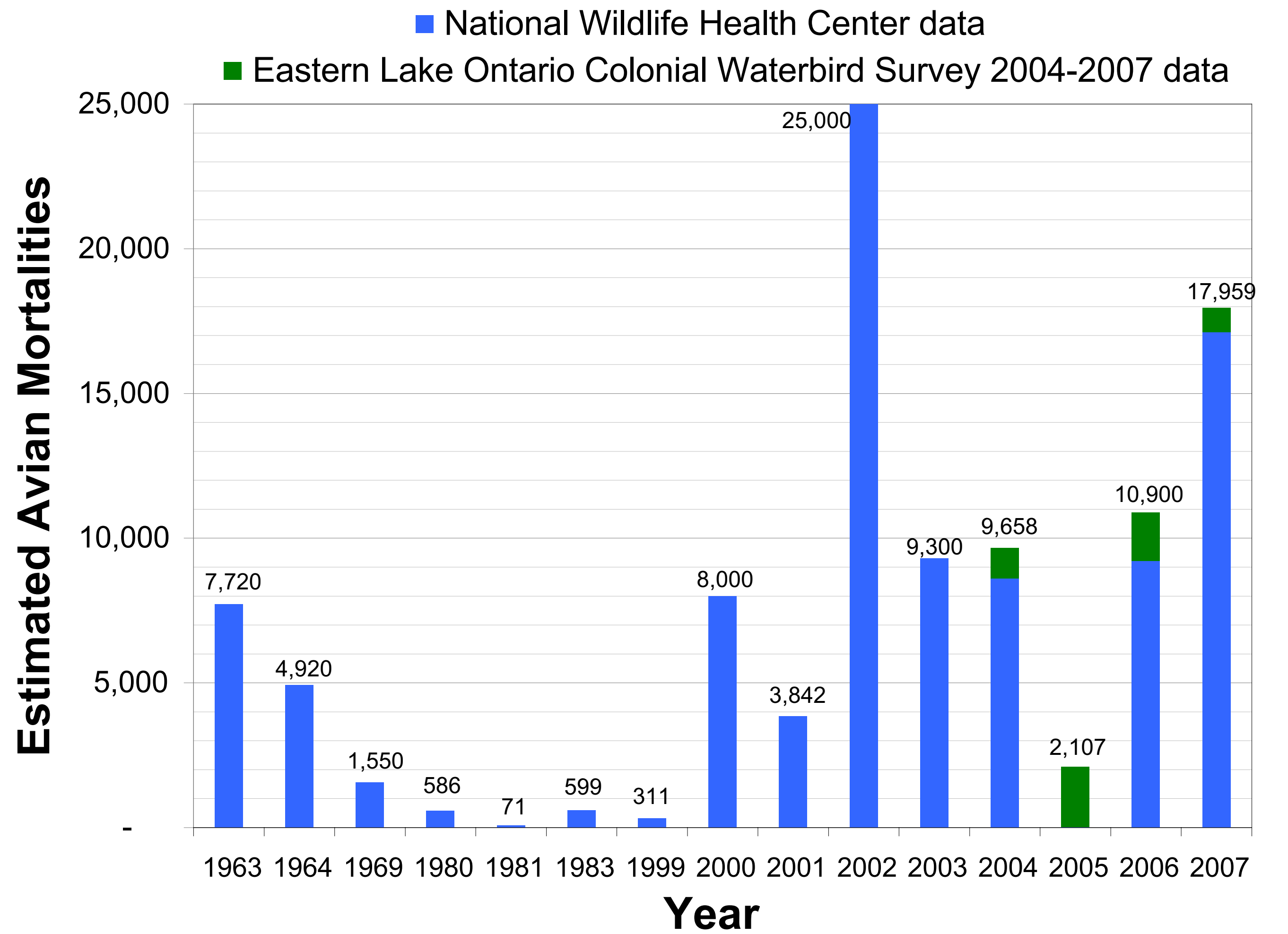

Figure 2. Estimated number of avian* mortalities attributed to type E botulism in the Great Lakes region.
Please note: These numbers are total reported estimates which include the actual counts of collected carcasses. The actual figures may vary, as all mortalities are not necessarily reported to these two databases. A comprehensive historical dataset of suspected botulism mortalities is not maintained by one entity at this time.
*See accompanying list of included species in Table 1.
Sources: USGS – National Wildlife Health Center maintained databases, 2008; Laird Shutt and Chip Weseloh, unpublished data from 2004-2007 Eastern Lake Ontario Colonial Waterbird Surveys, 2008.

Pressures

Many of the specific conditions needed for production of the botulism toxin can be facilitated by a variety of stressors. For example, the prolific growth of the native *Cladophora* algae, believed to occur because of increased water clarity and sunlight penetration resulting from the invasive Dreissenids' water filtration capabilities, is a likely factor which may be linked with botulism outbreaks. The subsequent decay of large mats of sloughed algae in the nearshore area may lead to pockets of anoxia in a rich growth medium, thereby creating an ideal environment for the vegetative state of *C. botulinum* and the resultant toxin production (Hecky *et al.* 2004). Additionally, other pressures linked to the growth of *Cladophora*, such as nearshore nutrient levels and cycling, may potentially influence botulism outbreaks.

Invasive species may also play a key role in the recent outbreaks. Current hypotheses under study suggest that invasive quagga mussel beds also create additional habitat for *C. botulinum* and accumulate the toxin. They may then facilitate transport of the toxin up the food chain as they are consumed by fish, especially by the round goby (Getchell and Bowser 2006). The round goby is a recent invader of the Great Lakes that has spread rapidly due to its ability to produce large numbers of young annually, and it feeds heavily on Dreissenid mussels. The gobies and native forage fish, after ingesting toxin-laden food items, are in turn consumed by larger predatory fish and piscivorous water birds. The obvious signs of this nearshore outbreak are evident in the numerous stretches of beach with dead and dying birds and fish strewn along the waters' edge.

Management Implications

The numerous fish and wildlife mortalities caused by botulism across a widening geographic region are a continuing cause for concern. Botulism is affecting native and sensitive wildlife populations, and it has implications for the overall ecological health of the Great Lakes. It may also impact tourism and the enjoyment of the many visitors to local beaches. Lastly, the frustration of not being able to mitigate the outbreaks and ambiguities around the risk posed to human health are issues of concern.

Type E botulism toxin poisoning cases in humans are extremely rare, with the only documented cases of human sickness originating in the Great Lakes region having resulted from the consumption of cold-smoked, vacuum packed fish during the 1960s. Botulinum toxins are heat-inactivated during cooking, thus using common safety precautions when handling fish or waterfowl and following correct food preparation guidelines help ensure maximum safety from the toxin. With the recent outbreaks in fish and birds becoming an increasingly public issue, there are frequent requests for official statements that specifically relate to the current situation. Most existing safety-related documentation includes general state agency food handling and preparation guidelines, or it refers to cases where specific fish curing and preparation methods led to production of the toxin during non-environmental outbreak conditions in Alaska. Recent laboratory-based studies investigating botulism's effects on fish and resulting toxin levels in their viscera and tissues have further supported the assumption that type E botulism associated with Great Lakes wildlife poses minimal human health risks (Yule *et al.* 2006). However, additional laboratory and field research and definitive government health agency statements regarding consumption of sport fish and waterfowl during an outbreak would assist in delivering a cohesive message to the general public about their safety when questions arise.

As long as botulism outbreaks continue to occur on an annual basis, Great Lakes managers will be called upon to facilitate coordination and support of the actions needed to understand, prevent, mitigate and respond to this problem.

Comments from the author(s)

The current historical data on botulism mortalities exists in numerous locations and with various inconsistencies. Mortality estimates presented in this report are not meant to be interpreted as actual counts, but should serve to highlight the overall magnitude of botulism's effects.

If the level of data quality could be improved, it would enable more rigorous data analysis projects that might begin to answer some of the research questions at hand. Refinement of a centralized reporting mechanism and data repository could also be beneficial for dealing with other existing wildlife diseases and those that have yet to come.

Acknowledgments

Author: Chiara Zuccarino-Crowe, Oak Ridge Institute for Science and Education (ORISE) Research Fellow on appointment to the U.S. Environmental Protection Agency (U.S. EPA), Great Lakes National Program Office (GLNPO), zuccarino-crowe.chiara@epa.gov

Contributors:

Anne Ballmann, DVM, Ph.D., Wildlife Disease Specialist, USGS - National Wildlife Health Center
David Blehert, Ph.D., Microbiologist, USGS - National Wildlife Health Center
Murray Charlton, Environment Canada - retired
Stacey Cherwaty, Environment Canada
Helen Domske, Coastal Education Specialist, New York Sea Grant
Elizabeth Hinchey Malloy, Ph.D., Great Lakes Ecosystem Extension Specialist, Illinois-Indiana Sea Grant
Ken Hyde, Wildlife Biologist, Sleeping Bear Dunes National Lakeshore, National Park Service
Elizabeth Murphy, MPH, Great Lakes Fish Monitoring Program Manager, U.S. EPA, GLNPO
Eric Obert, Extension Director, Pennsylvania Sea Grant
James Schardt, Life Scientist, U.S. EPA, GLNPO

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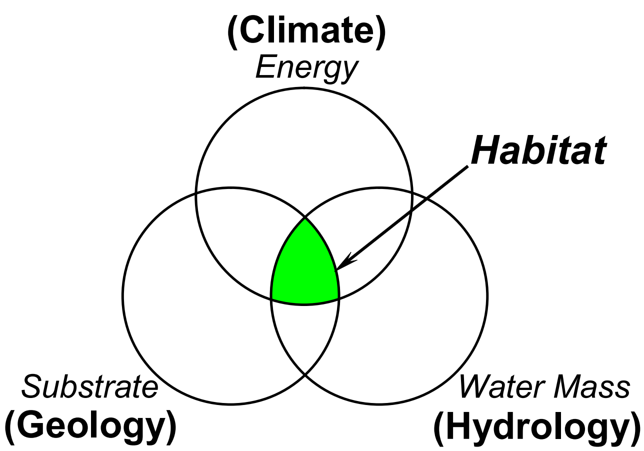
5.8 Nearshore Habitats of the Great Lakes

State of the Ecosystem

Anthropogenic activities have dramatically altered the Great Lakes basin through agricultural practices, urban development, industrial and commercial activities, and introduction of non-native species (Christie *et al.* 1987, Steedman and Regier 1987, Edsall 1996). These activities have altered the natural physical and ecological processes throughout the basin (Regier and Hartman 1973, Steedman and Regier 1987). The nearshore zone, in particular, has been heavily impacted by chemical pollution, nutrient enrichment, and physical alterations resulting from intense industrialization and urbanization (Krieger *et al.* 1992). The resulting habitat degradation is of great concern because Great Lakes littoral areas have high fish diversity and are important to the life histories of most native Great Lakes fishes (Goodyear *et al.* 1982, Lane *et al.* 1996a, b, Brazner 1997). Coastal margin and nearshore areas also have diverse wetland, benthic, and planktonic communities that comprise the lower portion of food web. These organisms provide other important ecosystem services as well.



- *Energy* – estimated from hydraulic calculations for both oscillatory and unidirectional flows.
- *Substrate* – bedrock, composition, texture, hardness, stability, porosity, permeability, roughness.
- *Water Mass* – depth, temperature, turbidity, nutrients, contaminants, and dissolved oxygen.
- *Habitat* – physical characteristics and energy conditions that meet the needs of a specific species and/or biological community for a given life stage.

Figure 1. Fundamental characteristics of aquatic habitat.
The “sweet spot” is where energy, substrate, and water mass characteristics all meet the needs of an organism for a given life stage, i.e. “habitat”.
Source: Mackey (2005).

The pattern and distribution of Great Lakes nearshore habitats are controlled, in part, by the underlying physical characteristics of the basin and interactions between energy, water, and the landscape (e.g., Sly and Busch 1992, Higgins *et al.* 1998, Mackey 2005). Coastal margin and nearshore aquatic habitats are three-dimensional and dynamic. **Aquatic habitats are defined by a range of physical characteristics and energy conditions that can be delineated geographically and meet the needs of a single species, biological community, or ecological function related to life stage** (Fig. 1). To be utilized as habitat, these physical characteristics and energy conditions must exhibit an organizational pattern, persist, and be “repeatable” – elements that are essential to maintain a sustainable and renewable resource (Peters and Cross 1992).

Within the Great Lakes, individual species, biological communities, and the ecosystem have adapted to and utilized the natural range of available habitats, including seasonal patterns and movement of water, energy, and materials through the system (e.g. Busch and Lary 1996, Jones *et al.* 1996). Moreover, coastal and nearshore habitats are created and maintained by interaction between coastal landscapes, water-level regimes, open-lake circulation processes and patterns, nearshore coastal processes, and the pathways and connections along which these processes act. Nearshore coastal processes include oscillatory and unidirectional flows generated by waves and currents. These factors control the distribution of materials and substrates in coastal margin and nearshore zones (areas encompassed by water depths generally less than 15 m) and also regulate the ecological utilization of energy, materials, and water as it is conveyed through these shallow-water systems.

Pressures

The habitat requirements for fish are highly variable and depend on the species and life stage of the organism. Benthic communities are highly dependent on substrate type and stability. For example, underwater video data show that complex habitat structure (rugosity) and areas with bathymetric relief are preferred habitats that attract a diverse range of fish species. Many species require relatively shallow, well-oxygenated waters flowing though coarse gravel and cobble substrates with protective interstitial spaces. In many cases, spawning areas are adjacent to nearshore nursery areas and rely on regional circulation patterns to transport larval fish into adjacent nursery areas. However, anthropogenic actions along the shoreline and in coastal watersheds have affected coastal and nearshore processes, pathways, and connections.

For example, anthropogenic alterations to river mouths and the "armoring" of shorelines modify flow paths and disrupt nearshore coastal processes that create and maintain coastal margin and nearshore habitats. Reductions in the volume of available littoral sand has lead to the "coarsening" of nearshore substrates and the gradual replacement of mobile sand sheets with stable heterogeneous lag deposits resting on bedrock or cohesive clay substrates (Fig. 2). The loss of protective sand sheets has significantly altered the pattern and distribution of nearshore aquatic habitats and has created ideal conditions for colonization by dreissenids, round gobies, and other non-native species that use coarse-grained substrates as habitat. Non-native species have altered the physical, chemical, and biological characteristics of historical spawning sites as well. Colonization by dreissenids has reduced or eliminated interstitial spaces (potential spawning habitat) in many coarse-grained substrates.

However, coarse-grained substrates show little evidence for active erosion and/or recent disturbance (Mackey unpublished data). These deposits are heavily colonized by dreissenids and *Cladophora* and form an armored pavement on the lakebed. Moreover, exposed cohesive clay deposits have been observed on the lakebed in approximately two-thirds of the nearshore sites surveyed. Multiple sites had cohesive clay deposits exposed on the lakebed either as flat eroded surfaces or elongate clay ridges and swales. These clay ridges range from 0.5 to 2 m in height from the lakebed with rippled coarse-grained sand and dreissenid shell fragments in the adjacent swales. Field observations and underwater video from multiple sites show that cohesive clay deposits are not colonized by dreissenids or *Cladophora* (Fig. 3). When cohesive clays are exposed on the lakebed, the surface of the cohesive clays starts to soften creating smooth slick surface that ablates very slowly during turbulent flow events (storms). The ablating clay surface prevents attachment of dreissenid bissle threads and if they do attach, they are swept clean by turbulent flows during the next storm event. Adjacent coarse-grained lag deposits (boulders, cobbles, gravel) are extensively colonized by dreissenids and *Cladophora* indicating that suitable hard substrates will be colonized at these locations (Goforth *et al*. 2008).

Recent nearshore habitat assessments and mapping work performed in Lake Michigan and in Lake Erie **suggest that many of the substrate and habitat changes are not new and are the long-term result of actions taken many decades earlier.** In other words, with respect to nearshore coastal processes, we have passed through several major habitat "tipping" points decades ago and are now attempting to manage the remaining habitat in severely degraded systems.

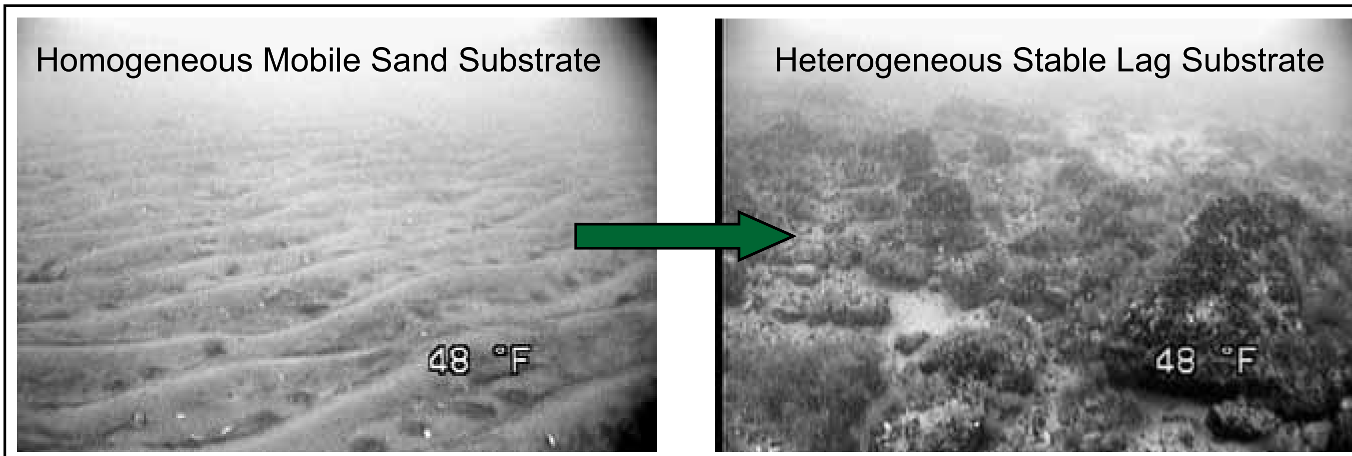


Figure 2. Underwater video images from Lake Michigan contrasting historic mobile sand substrate (left) with current stable cobble lag substrate (right).
Note extensive colonization of lag substrate by dreissenids and *Cladophora*. Wind Point survey site north of Racine, WI. 7 m, October 2005.
Source: Courtesy of Habitat Solutions NA, 2005.

Moreover, land cover changes in watersheds have altered flow paths to tributaries, changing flow regimes and dramatically increasing sediment and nutrient loads, causing channel erosion and instability, and degrading the quality of tributary flows into the Great Lakes. Tributary waters must flow through coastal margin and nearshore habitats to reach the open lake, and are therefore affected by anthropogenic actions in the watersheds. Chemical contaminants, nutrients, and fine-grained sediments have adversely affected nearshore habitat structure and ecosystem function. Even though steps have been taken to slow the rate of degradation, continued population growth and associated changes in land cover in Great Lakes watershed will continue cause further degradation of coastal margin and nearshore habitats.

Figure 3. Underwater video image of cohesive clay ridge (light blocky material) surrounded by medium to coarse sand and large cobbles/ small boulders.
Dreissenids colonize the hard boulder cobble substrates, but do not colonize the ablating cohesive clay deposits. Chiwaukee survey site south of Kenosha, WI. 8 m, October 2005.
Source: Courtesy of Habitat Solutions NA, 2005.

Through climate variability and/or artificial flow management, lower lake water levels may change open-lake circulation patterns and connectivity; alter open-lake thermal structure; affect nearshore coastal processes; and reduce hydraulic connectivity between coastal margin wetland/barrier systems and the Lakes. Continued coastal development pressures and submerged lands ownership issues do not bode well for natural ecosystem adjustments to long-term changes in Great Lakes water levels.

Management Implications

The trend towards habitat degradation is expected to continue, necessitating the implementation of enlightened management strategies to ensure the future sustainability of remaining nearshore habitats critical to maintaining native biodiversity. Ecological integrity is achieved by protecting and restoring water level regimes, nearshore coastal processes, and flow paths and connections that structure, organize, and regulate coastal margin systems and create regional-scale patterns that link coastal margin and open-lake areas within the basin.

Acknowledgments

Author: Scudder D. Mackey, Ph.D. Habitat Solutions NA, scudder@sdmackey.com

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5.9 Nearshore Physical Processes

State of the Ecosystem

Introduction

Physical characteristics and natural processes structure, organize, and define aquatic ecosystems and regulate the biological and chemical elements of the system (Poff *et al.* 1997, Richter *et al.* 1998, Richter and Richter 2000, Baron *et al.* 2003, Ciruna 2004). The nearshore physical processes of the Great Lakes are much more similar to marine coastal systems rather than the shallow inland lake systems which are commonly used as analogues to the Great Lakes (Mackey and Goforth 2005). These similarities and differences are primarily due to size, scaling, and energy issues. The Great Lakes are sizeable bodies of water with the potential to rival many marine systems with respect to wave energy and ability to erode and transport geologic materials along the coast.

The physical integrity of the nearshore is based on the idea that sustainable nearshore waters and ecosystems require protection and restoration of nearshore processes, pathways, and landscapes – the three fundamental components of physical integrity (Mackey 2005). Unlike traditional approaches that historically have relied upon the ongoing measurement and monitoring of site-based system components through time, a *process-based* approach considers changes in coastal processes due to altered pathways and landscapes in the coastal margin and nearshore areas.

Even though the impact of shoreline modifications on coastal processes has been known for many decades, the impact of altered coastal processes on nearshore habitat structure, coastal ecosystems, and nearshore water quality is not generally understood. This chapter will briefly explore the concept of physical integrity within coastal margin and nearshore waters and summarize how these concepts can be applied to assess regional changes in habitat structure and impacts on coastal ecosystems.

Nearshore Landscapes, Processes, and Pathways

Landscapes include and are defined by the integrated components of land and water area (i.e. geology, geomorphology, and land cover) upon which natural processes act within the Great Lakes basin (Mackey 2005). The most commonly used subunit of landscapes is watersheds. Watersheds are defined by surface and/or groundwater hydrology and represent the surface area that collects and channels water into tributaries that flow into a common main stem or channel. Even though landscapes and watersheds are typically considered to represent areas with some regional extent, the terms are applicable at multiple scales. Terrestrial watersheds are linked to the Great Lakes via hydrology, i.e. the movement of surface or groundwater across and through the landscape along flow paths (pathways) into a Great Lake. The flow paths are controlled by watershed components, generally surface relief and the composition (permeability) of underlying geologic materials within the watershed.

With respect to nearshore systems, coastal margin and nearshore landscape components include river mouths and coastal wetlands; beaches, dunes, and coastal margin swash zones; coastal morphology and composition (cohesive clay bluffs, bedrock, clay banks, thin sand barriers); available sediment supply; nearshore water depths and slope; and shoreline orientation (exposure to wave energy). All of these coastal landscape components are created, maintained, and connected by the interaction of nearshore coastal processes with the landscape (Mackey 2005).

Pathways are defined as the paths along which natural coastal processes act to convey energy, water, and materials through the nearshore system (Mackey 2005). Implied in this definition are: 1) functional pathways, which include functional and physical connections between physical components of the system that include how energy is distributed within a system, and 2) hydrologic pathways, which include flow paths, hydraulic connectivity, and how water, materials, and energy move through the system. Within nearshore systems, the primary transport mechanisms are linked to the open-lake and are driven by regional flow, wave, or storm-driven processes that transport water, materials, and energy into, through, and out of coastal margin and nearshore areas. The pathways along which coastal waters move are defined by littoral cells, i.e. reaches of coastline where water and sediments are transported laterally along the shoreline by the energy of waves breaking on the beach. The direction of movement is influenced by prevailing winds and/or the magnitude and frequency of storms and waves impinging on the shoreline.

These littoral cells may span nearshore areas adjacent to several terrestrial watersheds and may or may not be connected to or influenced by these terrestrial watersheds. Even though there are spatial "zones of influence" where tributary outflows may affect nearshore coastal processes for limited periods of time, these zones of influence are highly dynamic and may extend laterally across multiple watershed boundaries. The dynamic nature of these nearshore pathways and variability in coastal transport processes make any meaningful linkages between watersheds and coastal margin/nearshore areas exceedingly difficult. In most cases, traditional watershed paradigms can not be applied to nearshore coastal systems.

Below are descriptions of the hydrogeomorphic processes that may directly (or indirectly) influence coastal margin and nearshore areas of the Great Lakes. Coastal margin and nearshore processes dominate, but locally other processes may also influence the coastal margin and nearshore zones. Table 1 summarizes the attributes, pathways/area, and connectivity of these hydrogeomorphic processes.

- Fluvial processes – Processes associated with channelized flow. These processes and flows are highly dynamic; may be spatially and temporally episodic; are generally unidirectional (down slope); and act within or along linear stream corridors and/or drainage networks within watersheds. Fluvial processes are highly dependent upon lateral hydraulic connectivity with adjacent floodplain and watershed surfaces, and longitudinal down-slope hydraulic continuity and connectivity within stream channels.
- Groundwater processes – Processes associated with infiltration and groundwater flow – hydraulic continuity. These processes and flows may be dynamic; spatially and temporally episodic; unidirectional and/or bidirectional; and may act across broad landscape surfaces and/or within stream channels or lakes. Groundwater processes are highly dependent on potentiometric surface (water table elevation), surficial geology and soils (aquifers), hydraulic continuity (groundwater-surface water connections), and recharge area.
- Coastal margin and nearshore processes – Processes associated with wave and storm-generated currents and flows, except where influenced by fluvial processes and flows near river mouths. These processes and flows are highly dynamic, spatially and temporally variable and episodic, may be oscillatory (bidirectional) or unidirectional, are water-depth dependent; and generally act parallel to shore with a seasonal onshore-offshore component. Coastal margin and nearshore processes are highly dependent on shore-parallel hydraulic connectivity (littoral processes) and shore-normal hydraulic connectivity (deltaic, estuarine, wetland, barrier-dune hydraulic connectivity).
- Open-lake processes – Processes associated with wave and storm-generated currents and flows, superimposed over broad-scale hydraulic (riverine) or thermally driven (seasonal) flows. These processes and flows are dynamic, spatially and temporally variable and episodic, may be oscillatory (bidirectional) or broad-scale unidirectional flows, and act within and between lake sub-basins, major connecting and tributary channel inflow and outflow points. Broad-scale regional unidirectional flows act within and between lake sub-basins and major connecting and tributary channel inflow and outflow points. Open-lake processes are highly dependent on lateral hydraulic connectivity between adjacent water masses and major connecting and tributary channel inflows and outflows.

Ecological benefits of water are related to the spatial and temporal pathways within the landscape and the type and severity of impairments. The path that water takes across, or through, the landscape allows biological communities to utilize energy and materials as water moves through the system. There is a time-distance relationship between water and the benefits that water provides to the ecosystem. In general, as flow path complexity increases so do the ecological benefits. Constrained by existing impairments, the ecological value of a gallon of water varies as a function of its location and residence time on, or within, the landscape. Factors that control the time that water stays within the system are: flow velocity, path length (direction and distance traveled), and connections between landscape components. The importance of these factors is clearly demonstrated in riverine systems by the work by Poff *et al*. (1997) and subsequent work by Richter *et al*. (1998), Richter and Richter (2000), Baron *et al*. (2003), and others.

Similarly, in nearshore systems, the coastal processes that move water and nutrients along shore provide ecological benefits and create habitat structure. Additional complexity is introduced due to water exchanges between watersheds (river mouths), coastal margin environments (wetlands and embayments), and the open lake. The nearshore zone is the conduit through which those exchanges occur. Changes in Great Lakes water levels can directly affect where and how these water exchanges occur. Moreover, anthropogenic disruptions to nearshore coastal processes may directly impact these pathways and affect Great Lakes coastal and nearshore ecosystems.

Pressures

Landscape stressors create hydrologic impairments by altering flow characteristics and/or the functional connections and pathways between fundamental components within the system. Within the Great Lakes, all of the natural processes listed in Table 1 act along pathways or within hydrogeomorphic areas that have been impaired by anthropogenic activity. These impairments affect not only the ability of natural processes to convey energy, water, materials, and biota, but alter the benefits that water provides to the ecosystem as well. Physical modifications of the shoreline, altered water levels and flow regimes, and loss of littoral sediment supplies and hydraulic connectivity have changed the hydrologic interactions between watersheds, coastal margin and nearshore zones, and waters of the open lake.

Natural Process	*Attributes*	*Pathways/Area*	*Connectivity*
Fluvial Processes	• Channelized flow • Highly dynamic • Spatially and temporally variable and episodic	• Generally unidirectional (down slope) flow • Acts within or along linear stream corridors and/or drainage networks within watersheds	• Lateral hydraulic connectivity with adjacent floodplain and watershed surfaces • Longitudinal hydraulic down-slope continuity and connectivity within stream channels
Groundwater	• Infiltration and groundwater flow • Highly dynamic • Spatially and temporally variable and episodic	• Unidirectional and/ or bidirectional flows • Act across broad landscape surfaces and/or within stream channels or lakes	• Hydraulic continuity (groundwater-surface water connections) and recharge area • Potentiometric surface (water table elevation) – surficial geology and soils (aquifers)
Coastal Margin and Nearshore	• Wave and storm-generated currents and flows • Intermittent fluvial influence near river mouths • Highly dynamic • Spatially and temporally variable and episodic	• Oscillatory bidirectional and/or unidirectional flows • Act within or along both shore-parallel and shore-normal linear corridors with seasonal onshore-offshore components • Water-depth dependent	• Shore-parallel hydraulic connectivity (littoral processes) • Shore-normal hydraulic connectivity (deltaic, estuarine, wetland, barrier connectivity)
Open Lake	• Wave and storm-generated currents and flows • Superimposed over broad-scale hydraulic (riverine) or thermally driven (seasonal) flows • Spatially and temporally variable and episodic	• Oscillatory bidirectional and/or unidirectional flows • Broad-scale regional unidirectional flows • Act within and between lake sub-basins, major connecting and tributary channel inflows and outflows	• Lateral hydraulic connectivity with adjacent water masses • Hydraulic connectivity with major connecting and tributary channel inflows and outflows

Table 1. Physical Processes that affect Nearshore and Coastal Margin Zones.
Source: Mackey (2005).

The single most important anthropogenic factor disrupting nearshore coastal processes and pathways is increasing shoreline development and the physical alteration of the land-water interface. These changes fundamentally change the coastal processes and pathways along which those coastal processes operate. These changes impact not only local areas, but have cumulative regional impacts as well.

In shallow-water nearshore areas, nearshore sand and beach deposits are in fact part of the same littoral system and historically, thick sand deposits extended hundreds of meters offshore. As we have continued to develop and armor our shorelines, the amount of sediment available to keep our beaches supplied with sediment has been decreasing as shoreline armoring increases. Most of the sand-sized sediments that make up Great Lakes beaches are derived from direct erosion of coastal bluffs, which comprises approximately 90% of the total volume of littoral sediments along many Great Lakes coastlines (e.g. Bolsenga and Herdendorf 1993, Mackey 1995).

Coastal margin and nearshore zones are dynamic high-energy environments and sand is continually transported in a downdrift direction by waves and littoral currents. Without a continual supply of sand, beaches (and associated nearshore sand deposits) become progressively thinner and narrower through time. The loss of these sediments increases nearshore water depths thereby increasing available wave energy. Eventually, the sand deposit becomes thin enough that the entire deposit is mobilized during periods of significant wave activity, which accelerates the irreversible lakebed downcutting process.

Similar effects can be observed adjacent to large harbor structures. In these cases, large harbor structures extend well out into the nearshore zone disrupting natural littoral transport processes. As sand accumulates on the updrift side of the structures, beaches become wider and water depths become shallower. Downdrift of the structure, beaches become narrower and disappear, and water depths become deeper due to a loss of beaches and lakebed downcutting. The loss of sand due to shoreline armoring and/or large harbor structures results in coarse-grained lag deposits and increased substrate heterogeneity in the nearshore zone. These changes have created excellent habitat for lithophyllic invasive species (dreissenids and round gobies).

Impacts to local littoral sediment sources may also influence nearshore sand distributions. For example, the construction of dams on many Great Lakes tributaries has trapped significant quantities of coarse-grained sediment in the pools behind those dams. The entrapment of coarse-grained sediment by dams has reduced the available sediment supply river mouths. Moreover, most large river mouths are heavily altered by shore protection and/or bulkheads to facilitate shipping. These areas are also dredged on a regular basis to maintain navigable waterways.

Channel alterations due to dredging may alter tributary (river mouth), coastal margin, nearshore, and open-lake flow patterns and connectivity. Associated with armoring of river mouths, recent reductions in Great Lakes water levels have led to an increase in dredging activity in shallow-water nearshore areas. Not only do these dredged materials need to be disposed of, but the widening and/or deepening of navigation channels (particularly in river mouths) may significantly alter the flow regimes and pathways that transport water and materials into the Great Lakes. Channel modifications and bank hardening may have a significant detrimental effect on coastal margin, nearshore, and open-lake circulation, flow patterns, and hydraulic connectivity.

Loss of protective nearshore sediment supplies has resulted in erosion and resuspension of fine-grained cohesive sediments, thereby increasing turbidity and reducing nearshore water quality. This is particularly evident during major storm or wind events when large waves mobilize thin sand and gravel deposits that scour and erode the underlying cohesive clays. It is not uncommon to see turbid waters in the nearshore zone during major wind events, even though tributary loadings are minimal. The processes and mechanisms of nearshore lakebed downcutting are clearly described in Part III Chapter 5 of the Coastal Engineering Manual (Nairn and Willis 2002).

In riverine (fluvial) systems, altered flow regimes may cause increased bank and channel erosion, especially during major precipitation events, thereby increasing tributary sediment loads. Locally, these suspended sediments could have short-term detrimental impacts on coastal margin and nearshore areas by increasing turbidity, reducing water clarity, and potentially introducing harmful contaminants into the water column.

Currently, the cumulative impacts of altered flow regimes on the Great Lakes ecosystem are unknown, primarily because we have only started to consider the question. Existing data sets are inadequate to perform the assessment in a meaningful way (GLC 2003). Over the long term, altered flow regimes, diversions, and consumptive losses may lower water levels, thus changing open-lake circulation patterns and connectivity, nearshore coastal processes, and connectivity between coastal margin and wetland/barrier systems within the Great Lakes.

Management Implications

Within the context of physical integrity, sustainable natural processes are created when energy, water, and materials are conveyed through a system in ways that correspond to undisturbed natural conditions, maintain system integrity, and promote system resiliency and regeneration – irrespective of natural and anthropogenic perturbations. The importance of physical integrity to protection and restoration efforts cannot be overemphasized.

Current coastal margin and nearshore management paradigms focus on individual system components and do not consider impairments to the processes or pathways that connect and functionally link those components together. This is the main reason why local, state, provincial, and federal agencies have been singularly unsuccessful in managing coastal margin and nearshore habitats in any meaningful way. Moreover, most coastal regulatory programs are applied on a site-by-site basis (one property at a time) without due consideration of the long-term cumulative impacts on coastal margin or nearshore areas. Projected increases in population and associated growth and development in coastal areas will increase.

More effective management means taking into account nearshore coastal processes and the pathways along which those processes act in coastal margin and nearshore zones. Restoration or rehabilitation of nearshore physical processes can be accomplished by managing the shoreline at a coarser scale, say littoral cell by littoral cell, and by implementing solutions designed to mimic the functionality of these coastal processes.

Comments from the author: DEFINITIONS

Coastal Margin and Nearshore Areas

- Coastal Margin area – shallow water depths < 3 m
- Nearshore area – water depths > 3 m and < 15 m

Attributes of Landscapes

- Geology – surface and subsurface distribution of geologic materials; soils; hydrophysical characteristics (permeability, porosity, aquifers, aquatards…).
- Geomorphology – shape, pattern, distribution, and physical features of the land surface; landforms and drainage pattern (topography, slope, hydrography, channel morphology and bathymetry, connectivity and pattern).
- Land cover – shape, pattern, and distribution of biological and anthropogenic features on the land surface; land use.

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Author: Scudder D. Mackey, Ph.D. Habitat Solutions NA, scudder@sdmackey.com

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