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Coastal Wetlands

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State of the Lakes Ecosystem Conference 1996

Background Paper

COASTAL WETLANDS

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Notice to Readers

This Background Paper is one of a series of such papers that were prepared to provide a concise overview of the status of the nearshore conditions in the Great lakes. The information they present has been selected as representative of the much great volume of data. They therefore do not present all research or monitoring information available. The Papers were prepared with input from many individuals representing diverse sectors of society.

The Papers provided the basis for discussions at SOLEC 96. Participants were encouraged to provide specific information and references for use in preparing the final post-conference versions of the Papers. Together with the information provided by SOLEC discussants, the Papers have been be incorporated into the 1997 State of the Great Lakes report, which provides key information required by managers to make better environmental decisions.

Coastal Wetlands

1.0 Introduction

Great Lakes coastal wetlands occupy a transitional position between aquatic and terrestrial environments. They provide important habitat for many species of plant, fish and wildlife and perform valuable ecological functions. Over the past two centuries, coastal wetlands have been increasingly degraded as a result of human activities. The size of coastal wetlands has decreased and many have disappeared. Recently, there has been growing recognition of their importance to the flora, wildlife and human society in the Great Lakes basin. At the same time, concerns are mounting over the increasing pressures on nearshore areas, and coastal wetlands in particular.

In order to act wisely to manage, conserve, and restore Great Lakes coastal wetlands, all stakeholders—from landowners, user groups, and non-governmental organizations to all levels of government in Canada and the United States—must understand the role of coastal wetlands in providing a healthy ecosystem for the sustenance of human and all other life. They must also understand the pressures affecting the coastal wetlands, the extent to which they are degraded, and the gaps in our knowledge.

This paper expands on the paper *Aquatic Habitat and Wetlands of the Great Lakes* (Dodge and Kavetsky, 1995) given at the State of the Lakes Ecosystem Conference (SOLEC) in 1994. That paper provided a general evaluation of the state of aquatic, inland, and coastal wetland habitats in the Great Lakes basin. The goal of this paper is to provide a more focused synthesis of the state of Great Lakes coastal wetlands. Specifically, it aims to answer the following questions:

1. What are Great Lakes coastal wetlands and how in general do they work?
2. What are the functions and values of coastal wetlands?
3. What are the major pressures threatening them?
4. What are the best ways to determine their health?
5. What is the current state of health of coastal wetlands in the individual Great Lakes?
6. What are the gaps in our information on the state of coastal wetlands and how can we best fill them?

The answers to many of these questions remain incomplete. This paper will address the important role of wetland science and research in the management, conservation and restoration of Great Lakes coastal wetlands.

2.0 Overview of the Ecology of Coastal Wetlands

Wetlands have been defined in Canada as:

> *"land that is saturated with water long enough to promote wetland or aquatic processes as indicated by poorly drained soils, hydrophytic (e.g. water-loving) vegetation, and various kinds of biological activity adapted to wet environments."*
> (National Wetlands Working Group, 1988)

Similar definitions of wetlands have been adopted in the United States (e.g., Cowardin *et al.*, 1979). Great Lakes coastal wetlands are those wetland communities located between permanent aquatic and permanent upland environments along the shores of the lakes. For the purposes of this paper, they extend up to the 100-year floodline of the lakes. They differ from inland wetlands in that they are shaped by large-lake processes, including waves, wind tides, seiches, and especially the seasonal and long-term fluctuations in water levels. A general overview of their ecological characteristics is provided below.

2.1 Types of Coastal Wetlands

Marshes are the most common type of coastal wetlands (Figure 1). Marshes are generally defined as periodically or continually flooded wetlands characterized by non-woody emergent vegetation that is adapted to living in shallow water or moisture-saturated soils. They are the most prevalent wetland type in coastal wetlands since their vegetation can tolerate the large short- and long-term fluctuations in water levels that occur in the Great Lakes; they actually require these fluctuations to maintain their diversity (Harris *et al.*, 1981; Keddy and Reznicek, 1986; Wilcox, 1989a). Emergent plants dominate these marsh communities, cattails (*Typha*) usually being the most common. Some of these emergents are found in water as deep as 1.5 metres (5 feet), but most occur in shallower waters.

The strand community occurs at or just above the water line, where seasonal water-level fluctuations and waves cause erosion (Keddy and Reznicek, 1986). These communities are narrow and are usually dominated by annual herbs. Above the strand, less flooded wetland communities, termed "wet meadows", exist where slope and substrate conditions allow (Keddy and Reznicek, 1986). They are often diverse communities dominated by sedges, grasses and other herbs.

Lakeward from the emergent marshes, aquatic communities occur, dominated by floating-leaved plants such as water lilies (*Nuphar* and *Nymphaea*), and submergent plants such as pondweeds (*Potamogeton*) and coontail (*Ceratophyllum*). Under several wetland classification systems, these plant communities are regarded as wetland communities down to the 2-metre (6.5-foot) water depth (National Wetlands Working Group, 1988; Ontario Ministry of Natural Resources, 1993).

Many coastal wetlands contain swamp communities along the landward margin. Swamps are wetlands dominated by trees or shrubs that occur in a variety of flooding regimes, with standing water present during most or just a small part of the year. They are found only along the upland margin of coastal wetlands, since the woody vegetation that characterizes them cannot tolerate the extensive flooding regimes of the

Great Lakes. Many of these swamp communities are influenced by the Great Lakes only during periods of high water levels. Woody vegetation will also invade marsh communities during extended low-water phases of the lakes but will die-back during high-water years.

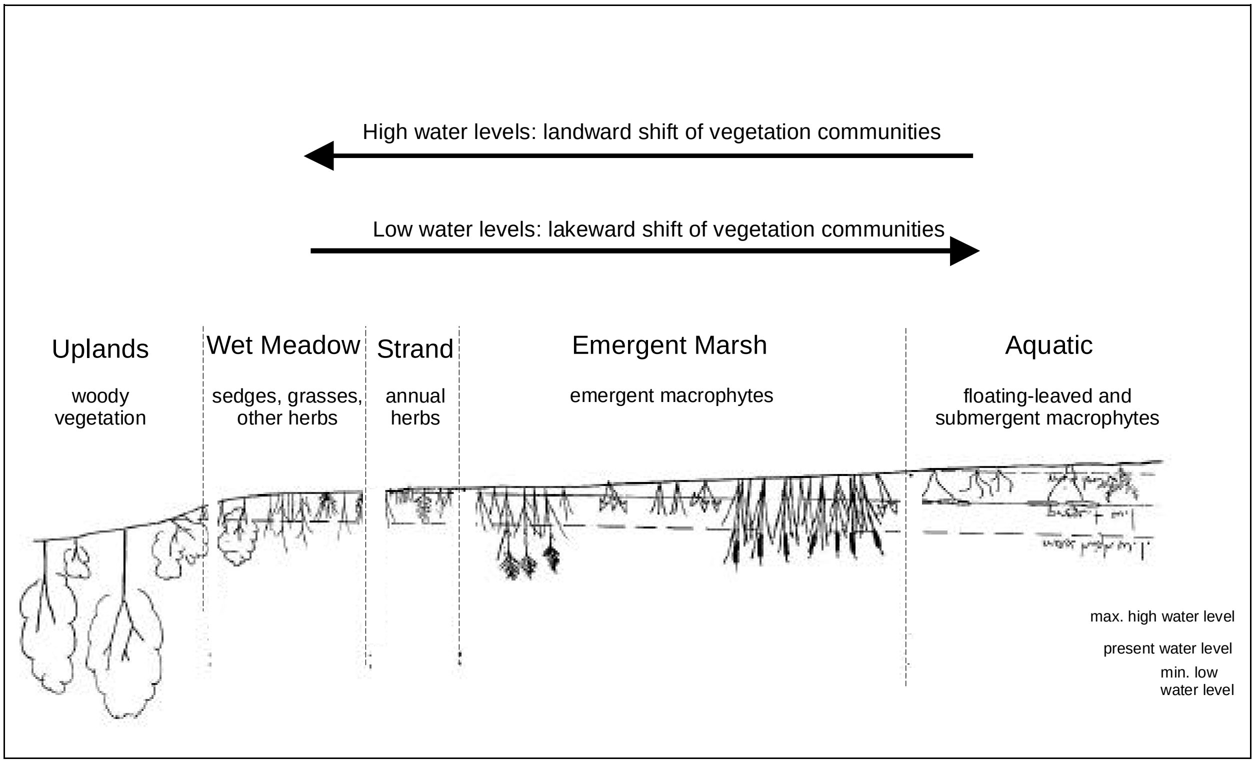


Figure 1. Generalized diagram of Great Lakes coastal marsh communities, showing the influence of fluctuating water levels.

Peatlands communities are sometimes present in coastal wetlands, and may be found along Lake Superior and in northern portions of Lakes Michigan and Huron. They accumulate peat and are characterized by a variety of mostly herbaceous species. They usually occur towards the landward margin of coastal wetlands, often within the wet meadow communities, but in some areas they may form floating mats that adapt to lake-level changes (e.g., Bete Grise wetlands on Lake Superior).

2.2 Geomorphological Settings

Coastal wetlands occur along the shorelines of the Great Lakes where erosive forces of ice and wave action are low, allowing the growth of wetland plants. They can occupy a variety of geomorphological settings (International Lake Erie Regulation Study Board, 1981; Figure 2).

Open shoreline wetlands are fringes of aquatic plants along the shore that can withstand wave energy (Figure 2a). The dominant vegetation is usually emergent, but submergent plants can also be present, not necessarily bordering a shoreline. The north shore of the Inner Long Point Bay on Lake Erie and the extensive bulrush marshes lining Saginaw Bay on Lake Huron are examples of open shoreline wetlands.

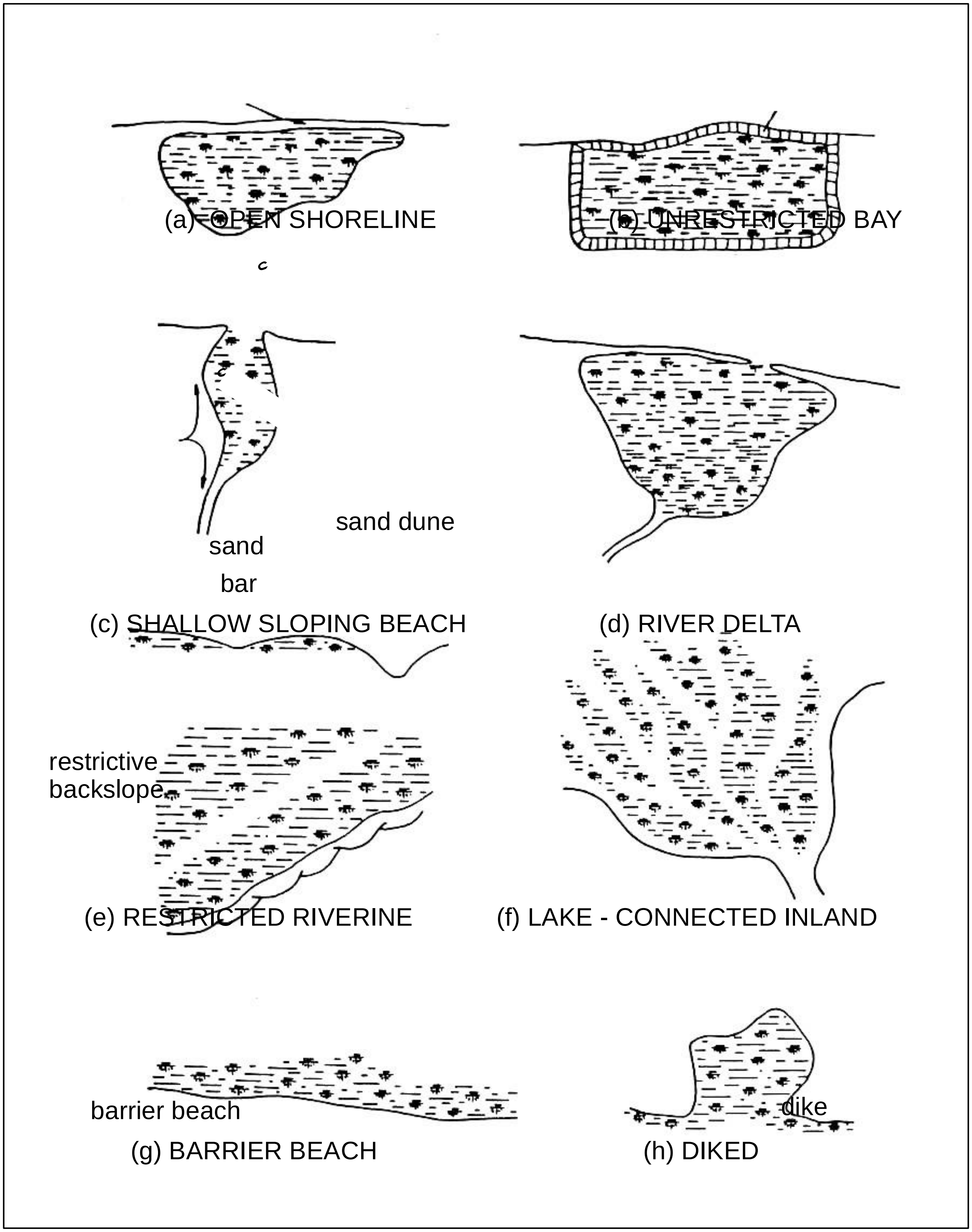


Figure 2. Geomorphological settings of Great Lakes coastal wetlands (from ILERSB 1981).

Wetlands in unrestricted bays are also open to the lake but are typically found in shallow, sheltered areas protected from the full force of wave action (Figure 2b). They are characterized by a marshy fringe along the shoreline. Depending on its size and depth, the whole bay may be covered in vegetation, including submergent plants. This wetland type also includes typical open shoreline areas that are sheltered by an island or peninsula—for example, Black River Bay and Bay of Quinte on Lake Ontario and Little Bay de Noc on Lake Michigan.

Shallow sloping beach wetlands are areas with very gentle to flat slopes on sand substrate (Figure 2c). Sand bars often give them some protection from waves. Very small variations in lake levels can have widespread effects on vegetation zones in these wetlands as a result of the shallow slopes. Cecil Bay Marsh and selected areas along the north shore of Lake Michigan are good examples of shallow sloping beach wetlands, as are beach portions of the large sand spit formations of Lake Erie (Long Point, Presque Isle, Point Pelee, and Pointe aux Pins).

River deltas are low islands and shallow zones formed by sedimentary deposits at a river mouth (Figure 2d). The normally gentle slope allows for extensive shifting of vegetation zones when water levels fluctuate. The large deltaic islands at the mouth of the St. Clair River along the northern edge of Lake St. Clair are examples.

Restricted riverine or drowned river-mouth wetlands are characterized by marsh vegetation bordering a river course upstream from the lake (Figure 2e). These wetlands are protected from the direct energy effects of waves but are subject to river currents that can reverse in response to lake-level changes. The extent of the vegetated wetland may be restricted by the backslope on the landward side and the deeper water of the river channel on the other. Many examples of these wetlands exist, including the Kakagon Sloughs on Lake Superior and the Betsie and Pere Marquette River wetlands on Lake Michigan.

Lake-connected inland wetlands occur within their own basins but have an outlet to the lake and are subject to lake-level fluctuations (Figure 2f). Such wetlands can have a definite steep backslope or a gradual slope permitting some shifting of vegetation zones with changes in water regime. Inflowing streams and groundwater discharge from the drainage basin may also contribute to the water supply of these wetlands. Examples include Bibon Lake near Lake Superior and Duck Lake near Lake Michigan.

Barrier beach wetlands occur where nearshore processes deposit a sand beach across a bay, resulting in an embayment connected to the lake by a channel, but protected from wave action by the beach (Figure 2g). During periods of low lake levels or low flow from incoming streams, the lake connection can be temporarily closed by sand deposition. Bark Bay and Siskiwit Bay on Lake Superior and Oshawa Second Marsh on Lake Ontario are examples of barrier beach wetlands.

Diked wetlands are isolated from the lake by human-made structures that provide protection and also allow manipulation of water levels to manage vegetation (Figure 2h). These wetlands are adjacent to the lakes but are isolated from them except when water levels are altered by pumping. The diked, managed wetlands along the shorelines of eastern Lake St. Clair and western Lake Erie are examples of diked wetlands.

2.3 Important Ecological Processes

Great Lakes coastal wetlands are complex ecosystems with many ecological factors combining to determine their ecological characteristics. Mitsch (1992) provides a useful conceptual model showing the major forcing functions affecting Great Lakes coastal wetlands (Figure 3). This is a simple but useful model, since it clearly illustrates the major forces that can affect the presence, extent and ecological characteristics of coastal wetlands. Many of these forcing functions also act as important stressors, and coastal wetlands can actually be regarded as stress-controlled ecosystems. Important natural and human stressors are discussed in greater detail in section 4.

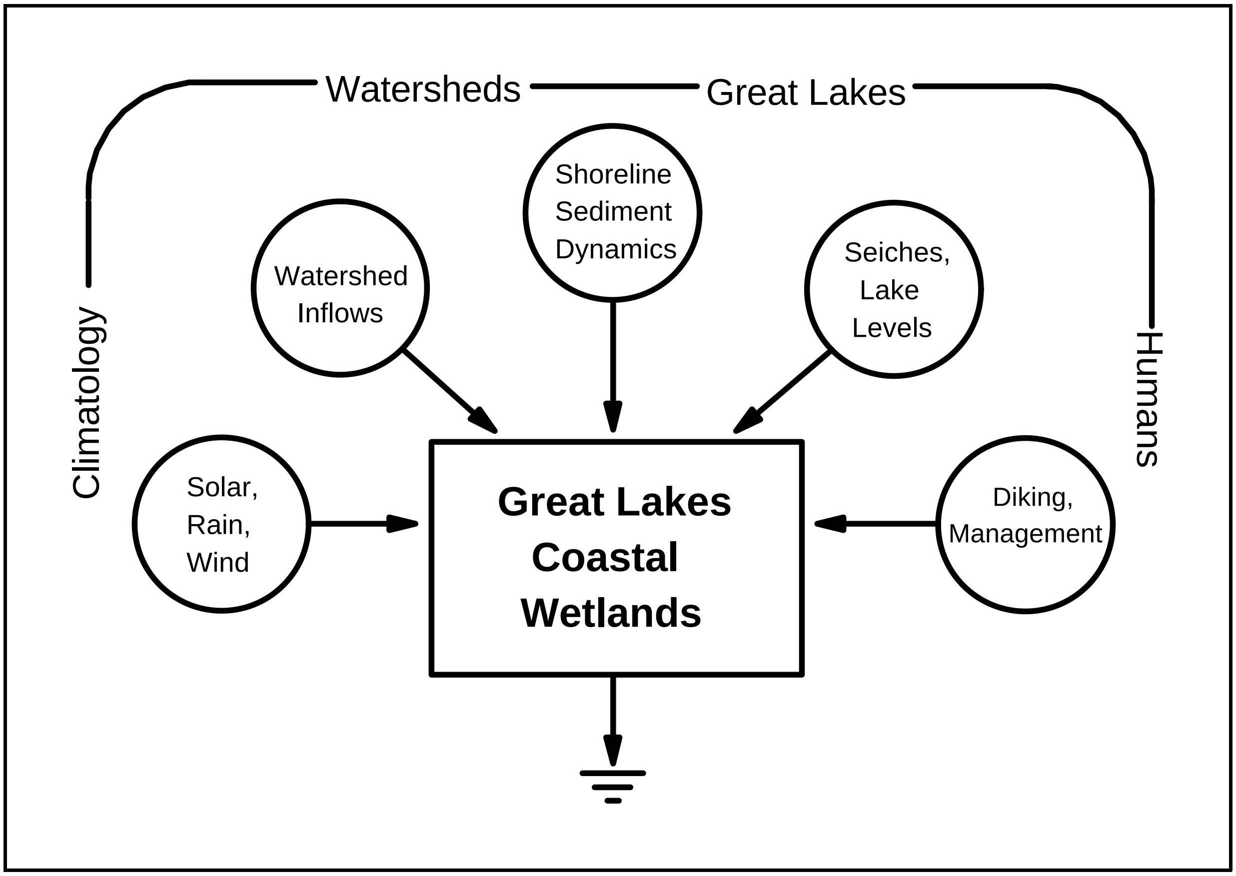


Figure 3. Conceptual model showing major forcing functions that effect Great Lakes coastal wetlands (from Mitsch, 1992).

Climatic factors drive many of the basic physical and biological cycles in wetlands, as well as many of the other forcing functions. For instance, sun energy allows for photosynthesis and the growth of plants; and wind produces waves, causing erosion of wetlands. Where coastal wetlands have inflowing streams or rivers, loadings from upland watersheds are important in determining the inputs of nutrients and sediments into the wetlands. These inputs vary depending on the size of the watershed and its land use characteristics. The tributaries themselves are often intimately connected with coastal wetlands, and many species of flora and fauna use both wetland and water course habitats.

Shoreline sediment dynamics control the patterns of sediment deposition through a variety of physical processes such as coastal currents and storm events. Shifting shoreline sediments can influence many important features, such as the location of wetlands and the degree of circulation of wetland waters with lake waters.

Coastal wetlands are also heavily influenced by *water level fluctuations*, both the short term fluctuations associated with seiches and the longer term seasonal and between-year fluctuations (Wilcox, 1989a). Seiches, wind-driven changes in water levels, are common features of the Great Lakes. For instance, in lower Green Bay on Lake Michigan, Sager *et al.* (1985) measured 269 seiche events in a one-year period, with a mean amplitude (height) of 19.3 centimetres (7.6 inches) and a mean period of 9.9 hours. The effects of seiches are unclear, but they appear to act similarly to tides in marine coastal marshes, allowing exchange of nutrients and detritus between wetlands and the lakes.

Longer term water level fluctuations are also very important for coastal wetlands. Differences between recorded all time high- and low-water levels range from 1.1 to 2 metres (3.6 to 6.5 feet) depending on the lake (International Joint Commission, 1989). These changes have a profound impact on wetland plant communities, causing landward or lakeward shifting of vegetation communities. Numerous buried seeds allow wetland plants to quickly respond to these changes in water levels (Keddy and Reznicek, 1986). As a result, coastal wetlands are dynamic ecosystems. They require these extreme water level fluctuations, both high- and low-water levels, to maintain habitats and the diversity of plant and animal species. Fluctuating water levels also allow wetlands to be more extensive and more productive than they would be if water levels were stable. The effects of lake-level fluctuations are considered in greater detail in the discussion on stressors, section 4.

Human influences such as the control of lake levels, pollutants, diking of wetlands, and modification of shorelines also have a major effect on coastal wetlands of the Great Lakes. These human-induced stressors are also considered in greater detail in section 4.

The forcing factors discussed above and their potential interactions, along with the diversity of geomorphological settings and vegetation types, illustrate the difficulty of determining general ecosystem models for Great Lakes coastal wetlands. In many cases, individual wetlands have unique ecosystem conditions and cannot easily be compared with one another.

In an attempt to begin forming a unified theory of the processes controlling coastal wetland ecosystems, Heath (1992) provided the following preliminary list of common ecological characteristics shared by coastal wetlands in terms of their nutrient dynamics:

> Coastal wetlands all share a temperate climate.
> Their nutrient regimes are closely linked to their hydrologic regimes.
> They are pulse-fed with nutrients on irregular schedules as a result of these hydrologic regimes.
> They support highly productive macrophyte and phytoplankton communities, which in turn appear to support large populations of bacteria and zooplankton.
> They are relatively shallow, so exchange between the water column and the sediments is rapid.
> Interactions between sediment and water column are important in determining nutrient dynamics.

A very wide range of biogeochemical conditions (pH and oxidation potentials) occur,— ranging from productive, alkaline, oxygen-saturated water column to acidic, highly reducing conditions of sediments—allowing for complex biogeochemical processes.

3.0 Ecological Functions and Values

Wetlands were once regarded as wastelands with few redeeming values, precluding "beneficial" land-use activities. They were drained or converted for other uses. In the past decade or two, as wetlands have been drained and converted, their diminished positive attributes have become more evident. Wetlands can play a role in many important functions of upland and aquatic systems, physical and biological processes, and wildlife and human activities. Not every wetland serves every role, but most wetlands provide some combination of the following potential functions and values (The Conservation Foundation, 1988):

- flood conveyance, by transporting flood waters from upstream to downstream;
- flood storage, by storing flood water and releasing it slowly;
- sediment control, by reducing water velocity and allowing sediment deposition;
- protection from storms, by acting as wave barriers to the erosion of shorelines;
- water supply, by recharging ground-water aquifers and acting as direct sources;
- water quality improvement, by removing excess nutrients and many chemical contaminants;
- food chain production and export, by providing sources of food for many species of fauna in and adjacent to wetlands;
- habitat for flora and fauna, by providing suitable habitats for many plants, spawning, nursery and feeding areas for many fish and shellfish and breeding, nesting, feeding, and protected areas for many species of waterfowl and other fauna;
- biodiversity reservoirs, by providing habitat for nearly 35% of all rare, threatened and endangered animal species;
- food for humans, by producing harvestable grains, fish, and invertebrates;
- commercial products, such as timber from forested wetlands, fur resources and baitfish;
- recreation, by serving as sites for fishing, hunting, and observing wildlife;
- historic and archaeological values, by serving to understand historical events and native cultures;
- education and research, by providing opportunities for nature observation and scientific study; and
- open space and aesthetic values, by providing areas of diversity and beauty for recreational and visual enjoyment.

The important ecological functions and values associated specifically with Great Lakes coastal wetlands are reviewed in the following section.

3.1 Ecological Functions

3.1.1 Flood Storage

Inland wetlands can perform an important role by storing flood waters and slowly releasing them to downstream areas after the flood peak. In a coastal setting, wetlands can do little to affect water-level changes due to floods because of the overriding effects of lake level. However, coastal wetlands with a narrow connection to the lakes, such as drowned river-mouth, lake-connected inland, and barrier beach wetlands do play a role during flooding—for instance, by storing flood waters while lake levels are reaching equilibrium.

3.1.2 Sediment Control

Coastal wetlands are important for sediment control. Sediments in flood waters drop from suspension as water velocity or turbulence decreases, allowing for the deposition of sediments in the wetland, reducing turbidity, and improving clarity in downstream or adjacent lake waters (Boto and Patrick, 1978). Deltaic wetlands and wetlands in and near mouths of tributary rivers are especially important for sediment control. Their emergent vegetation slows the flow of flood waters, allowing for sediment deposition (e.g., Meeker, 1996).

3.1.3 Water Quality Improvement

Water quality improvement is another important function of coastal wetlands, and this involves several processes. First, many nutrients and contaminants are attached to fine sediment particles, so the deposition of sediment also removes nutrients and contaminants from the water column (Heath, 1992; Matisoff and Eaker, 1992). Second, wetland plants, including emergents, submergents and the attached algae (periphyton), also perform an important role by removing many nutrients from the water column and the sediments through direct uptake for growth (Wetzel, 1992; Heath, 1992). Third, the dynamic biogeochemical environment of wetlands also allows for the transformation and removal of many nutrients and contaminants (Matisoff and Eaker, 1992). The active microbial environments of the sediments allow for the decomposition of some contaminants.

Other important biogeochemical processes in wetlands include the mobilization of phosphorus and heavy metals from the sediments, the control of inorganic carbon speciation and pH, and the uptake and release of organic carbon during growth and decomposition (Carpenter and Lodge, 1986).

Photosynthesis by wetland plants also produces oxygen, which may be released to the atmosphere or remain in the water and sediment, increasing their dissolved oxygen concentrations. Under some circumstances, however, decomposition can deplete dissolved oxygen.

The water-quality functions that involve deposition and burial of pollutants in sediments are less important in coastal wetlands exposed to extensive wave action, because sediments are routinely redistributed by the force of the waves.

3.1.4 Shoreline Erosion Protection

Another important function of coastal wetlands is their role as barriers against wave action and erosion. Emergent plants form a permeable barrier that dissipates wave energy and reduces or prevents erosion of the shoreline (Dean, 1978). In wetlands with extensive emergent communities, such as the bulrush (*Scirpus*) marshes that line portions of Saginaw Bay of Lake Huron, the lakeward margin of plants can reduce wave energy reaching the interior of the wetland. Although severe storms or ice can be sufficiently destructive to remove stands of plants along the lakeward margin, coastal wetlands sustain little permanent damage since the vegetation can regrow in subsequent years. Only those coastal wetlands that have direct exposure to the lakes perform this function, such as open shoreline wetlands, unrestricted bays and shallow sloping wetlands.

3.1.5 Habitat for Plants, Fish and Wildlife

Because they have a combination of upland and aquatic characteristics, Great Lakes coastal wetlands provide diverse habitats and support a diversity of plants, fish, and wildlife. The differences in water depth, sediment type, wave exposure, chemistry of water supplies, and other factors combine with temporal variations in water levels to create diverse environmental conditions and niches for a great number of species of wetland and aquatic plants (macrophytes) in Great Lakes coastal wetlands (Keddy and Reznicek, 1986; Keddy, 1990; Wilcox, 1993; Wilcox *et al.*, 1993). The fluctuations in water levels are especially important in maintaining diverse assemblages of plant species (Keddy, 1990).

Macrophyte assemblages in coastal wetlands also provide very diverse structural habitats for aquatic and wetland fauna. The relationships between the macrophyte community structure in wetlands and the various individual components of the faunal community are generally understood, but they are well-documented in only a few specific aquatic systems (e.g., Engel, 1985; Wilcox and Meeker, 1992). However, general knowledge of habitat use by various groups of organisms can be coupled with studies of macrophytes and faunal communities to gain a general understanding of the role of Great Lakes coastal wetlands as habitat for different groups of fauna.

Studies of invertebrates are not uncommon in the Great Lakes, but coastal wetlands have been largely ignored (Krieger, 1992). Available studies show them to support very diverse invertebrate assemblages as a result of the diverse conditions present (Krieger, 1992). Perhaps the most extensive data on invertebrate use of wetlands in the Great Lakes come from Brady (1992), who found greater biomass and numbers of macroinvertebrates in sediments with vegetation than in unvegetated sediments. In the vegetated areas, there was greater diversity of invertebrates in the vegetation than in the underlying sediments.

Although many studies of fish communities have been conducted in the Great Lakes and long-term studies continue, relatively few have investigated fish communities in coastal wetlands. Whillans (1987) determined that over 90 percent of the roughly 200 fish species in the Great Lakes are directly dependent on coastal wetlands for some part of their life cycle. Jude and Pappas (1992) summarized available data on fish species of the Great Lakes and reported that 47 species were closely associated with coastal wetlands. These fish may use wetland habitat on a permanent or temporary basis. Uses include feeding, shelter, spawning, nursery, dispersal of young, and migratory wandering. Several species are important for commercial and sports fisheries as discussed in section 3.2.

Studies of reptiles and amphibians in wetlands of the Great Lakes are largely lacking, although efforts to characterize their importance to amphibians are under way through the Marsh Monitoring Program (Environment Canada, 1995; Chabot, 1996). These wetlands are important egg-laying, nursery, and adult-feeding habitats for many species of amphibians and reptiles. Even the more terrestrial toads use the warm, food-rich, and protected shallow waters of wetlands during parts of their life cycles (Weller, 1987).

Information on use of wetlands by birds is more common than for other groups of organisms, perhaps because of greater visibility, common associations of certain bird taxa with wetlands, and intensive management of wetlands for certain species, especially waterfowl. In terms of waterfowl, a total of 24 species of ducks, 4 species of geese, and 3 species of swans are known to use Great Lakes wetlands (Prince *et al.*, 1992). Some waterfowl species use them for nesting, but they are also very important as staging areas during spring and fall migration. The most important wetland areas are characterized by a hemi-marsh condition (Weller and Spatcher, 1965) and have high interspersion of different habitats—namely emergent marsh, strand, aquatic zones and open water (Prince *et al.*, 1992). The wet meadow, shrub, and forest zones above the water line in Great Lakes wetlands are of limited use for waterfowl, except for species that use the vegetation for nesting and migrant dabbling ducks that may feed there during times of high water. Coastal wetlands of the Great Lakes serve as important habitat for many birds other than waterfowl, and some are important stopover areas for migratory passerines and shorebirds (Glooschenko *et al.*, 1987).

The muskrat is a key mammal in coastal wetlands of the Great Lakes, as well as in much of North America. Muskrats can substantially alter wetland habitat by cutting emergent vegetation, such as cattails and bulrushes, for food and shelter. The unvegetated pools around lodges, formed by cutting activity, create open areas within the wetland often favoured by birds (Weller, 1987). Beavers also use wetlands of the Great Lakes in some locations, causing similar habitat-altering effects. Many other mammals use wetlands to a lesser extent.

3.1.6 Food Web Production and Export

Wetland plants (macrophytes) and the algae and bacteria that grow on them (epiphytes) are the base of the food web in wetlands (Mitsch and Gosselink, 1993). Epiphytes can be very important because the macrophyte assemblages and their detritus have very large surface areas for colonization by epiphytes (Wetzel, 1992). This allows the primary productivity of epiphytic communities to sometimes exceed that of the macrophytes on which they grow.

Coastal wetland food webs can be very complex (Krieger, 1992). Living macrophytes are a direct food source for many aquatic organisms, including invertebrates, waterfowl, fish and muskrats. The epiphytic algae and bacteria communities growing on the living and dead macrophytes are important food sources for fauna at lower trophic levels, such as invertebrates. These invertebrates are important as food sources for fauna at higher trophic levels, such as fish and waterfowl.

Food is also exported from coastal wetlands in several forms. For instance, many species of fish use coastal wetlands for early life stages, and then return to aquatic communities (Jude and Pappas, 1992) where they can become forage for fish and birds. Large numbers of waterfowl also use coastal wetlands as staging areas during migration and feed heavily before continuing their migration (Prince *et al.*, 1992). Exports of dissolved and particulate organic matter from coastal wetlands into the nearshore lake environment may also be important for nearshore aquatic food webs (Wetzel, 1992), although little work has been done to determine the extent and importance of this export.

3.1.7 Biodiversity Reservoir

Wetlands in general are known to provide habitat for many of the plant and animal species listed as threatened or endangered. About one-fourth of the plant species, one-half of the fish species, two-thirds of the birds, and three-fourths of the amphibians listed as federally threatened or endangered in the U.S. are associated with wetlands (Mitsch and Gosselink, 1993). In Ontario, at least eight species of rare breeding birds are closely associated with Great Lakes coastal wetlands, namely great egret, bald eagle, king rail, Wilson's phalarope, Forster's tern, black tern, prothonotary warbler and yellow-headed blackbird (Austen *et al.*, 1994).

Several of the habitat components in coastal wetlands such as the coastal permanent marshes are also deemed globally imperilled (The Nature Conservancy, 1994) and are therefore important for their biodiversity.

3.2 Human-Use Values

Human-use values are related to those services, products or other opportunities that are directly or indirectly valuable to human society. Many studies have attempted to value the human-use benefits of wetlands in general and, to a lesser extent, Great Lakes coastal wetlands (LMSOFT, 1995). Important human-use values in Great Lakes coastal wetlands are summarized in Table 1. More detailed examples are presented following the table to illustrate a few of these human-use values.

Table 1. Human-use values associated with Great Lakes coastal wetlands.

Roles	**Examples of Products, Services and Experiences**	**Examples of Benefits to Society**
Life Support		
Regulation / Absorption	Nutrient transformation and storage, toxins absorption, storm protection, stabilization of biosphere processes.	Nutrient and contaminant reduction, erosion control, local health benefits.
Ecosystem Health	Nutrient cycling, food chain contributions, habitat, biomass storage, reservoir of genetic and biological diversity.	Maintenance of Great Lakes ecosystem integrity, risk reduction.
Social / Cultural		
Science / Information	Research opportunities, archeological sites, unique ecosystems.	Better understanding of Great Lakes ecosystem through research and education.
Aesthetics / Recreational	Bird-watching, photographic opportunities, canoeing, recreational fishing, waterfowl hunting.	Direct benefits to users' personal enjoyment, benefits to tourism industry and local economies.
Cultural / Psychological	Historical, cultural, religious and spiritual uses.	Social cohesion, maintenance of culture, values to future generations, symbolic values.
Production		
Subsistence Production	Harvests of waterfowl, fish, rice and rushes for subsistence.	Food, fibers, self-reliance for communities, maintenance of traditions.
Commercial Production	Production of foods (commercial fishing), fibers (e.g., wood), fur pelts.	Products for sale, jobs, income, contributions to GNP.

Source: modified from Bond *et al.* (1992)

3.2.1 Storm Protection

Storms can have large impacts on coastal shorelines (Kreutwizer and Gabriel, 1992; Angel, 1995). Storms in Lake Erie can be especially sudden and violent due to its shallow depth and orientation (Bedford, 1992), so its shoreline is especially susceptible to flooding and erosion. Several built-up areas such as cottage developments are located along its shorelines. Coastal wetlands along Long Point in Lake Erie act as a buffer to incoming storms (Lawrence and Nelson, 1994). For instance, a storm in December 2, 1985 at Long Point caused $10 million (Cdn) in damage to shorelines but no damage was reported on wetland properties. Coastal wetlands in general act to dissipate the high energies associated with severe storms

(Dean, 1978; Farber and Costanza, 1987). The value of coastal wetlands for storm protection would depend on their size and location as well as the location of potentially affected roads and buildings.

3.2.2 Nutrient Transformation, Removal and Storage

Coastal wetlands often receive excess nutrients from non-point sources such as agricultural runoff or septic systems, or from point sources such as wastewater treatment plants or industries. These excess nutrients cause more eutrophic conditions in the receiving lakes and bays, resulting in heavy algal growth, altered food chains and, in some cases, fish die-offs amongst other undesirable effects.

As a result of the high biological and geochemical activities of wetlands in general, they can act as important areas for the transformation, removal and storage of nutrients, before the excess nutrients enter the receiving water bodies (Johnston, 1991). Coastal wetlands with inflowing tributaries from urban or agricultural watersheds can therefore act to ameliorate water-quality conditions in the receiving lakes.

3.2.3 Non-consumptive Recreation

Non-consumptive recreational uses associated with Great Lakes coastal wetlands may include activities such as bird-watching, nature study, photography, general tourism and cottaging.

Bird-watching is a popular recreation that can draw large numbers of persons to coastal wetlands during migratory, staging and breeding periods (S. Wilcox, 1995). Several coastal wetlands along the Great Lakes are important for bird-watching and nature study—for example, Long Point Marsh and Point Pelee Marsh on Lake Erie and Presqu'ile Marsh on Lake Ontario.

Bird-watchers, hikers and other nature enthusiasts, together with cottaging, tourism and associated retail activity near some coastal wetlands can make substantial contributions to the local economies of popular areas (Raphael and Jaworski, 1979; Kreutzwiser, 1981; S. Wilcox, 1994). For instance, there are 1,232 cottage in the Long Point area, half of which front a body of water. The most important factor drawing these cottagers is the natural resources that are present; however, it is difficult to determine the specific contribution of coastal wetlands to their enjoyment.

3.2.4 Recreational Fishing and Hunting

Recreational fishing is very important in many coastal wetlands and is ranked in several studies as one of the highest human-use values associated with Great Lakes coastal wetlands (Raphael and Jaworski, 1979; Herdendorf *et al.*, 1986). The several important sport fish species strongly connected with these coastal wetlands include northern pike, muskellunge, largemouth bass, smallmouth bass, bluegill, yellow perch, white crappie, black crappie, channel catfish, black bullhead, brown bullhead, carp and bowfin (Raphael and Jaworski, 1979; Jude and Pappas, 1992). Many species of forage fish are also found there. At Long Point in Lake Erie, fishermen spent an average of 200,000 hours annually between 1978 and 1991 on recreational fishing (Craig, 1993), with a typical angling day of 4.7 to 5 hours per day (S. Wilcox, 1994).

Waterfowl hunting provides the basis for the recreational hunting industry along the coast of the southern Great Lakes. Coastal wetlands regularly provide breeding, migratory and wintering habitat for 24 species of swans, geese, dabbling ducks, bay ducks and sea ducks (Prince *et al.*, 1992).

Recreational fishing and hunting also indirectly contribute to local economies through the purchase of food, lodging, supplies, equipment, fuel, and guide services.

3.2.5 Commercial Fisheries

Commercial fisheries are associated with several extensive coastal wetland areas on the Great Lakes. For instance, a commercial fishery has operated in the Inner Long Point Bay on Lake Erie for 120 years (S. Wilcox, 1994). Commercial species that use the extensive coastal wetlands in this area for spawning, nursery or general habitat include bowfin, northern pike, carp, white sucker, brown bullhead, channel catfish, white bass, rock bass, pumpkinseed, bluegill, black crappie, yellow perch, walleye, sheepshead, smallmouth bass and largemouth bass (Craig, 1993). Using seine and hoop nets, between 200,000 and 350,000 pounds of fish have been harvested annually from Inner Long Point Bay between 1986 and 1992 (S. Wilcox, 1994). Various minnow species are also caught in coastal wetlands as part of an important bait fishery. Although commercial fisheries have a direct economic value, several studies have valued its total economic benefits below that of other activities such as sport fishing, non-consumptive recreation and waterfowl hunting (Raphael and Jaworski, 1979; Herdendorf *et al.*, 1986).

4.0 Stressors Affecting Great Lakes Coastal Wetlands

A stress can be defined as anything that changes the functioning of an ecosystem. There are five qualitatively different responses to stress (Indicators for Evaluation Task Force, 1996):

1. Continued operation of the ecosystem as before, in spite of being initially or temporarily unsettled;
2. Altered operation of the ecosystem, but retaining the original ecosystem structure (e.g., changes in the population size of different species);
3. Emergence of new ecosystem structures that augment or replace existing structures (e.g., new species or new food web paths);
4. Emergence of a new ecosystem with a quite different ecosystem structure; or
5. Complete ecosystem collapse with no regeneration.

Both natural and human-induced stressors affect the functioning of coastal wetlands. They are examined below.

4.1 Natural Stressors

Coastal wetlands are by nature stress-controlled systems as a result of the large-lake processes of the Great Lakes. An understanding of human-induced stresses to these wetlands therefore requires an initial understanding of natural stresses.

4.1.1 Water Level Change

The major natural stressor affecting Great Lakes coastal wetlands is water level change. Water levels of the Great Lakes have been systematically recorded by the U.S. and Canadian governments since 1860 (National Oceanic and Atmospheric Administration, 1992; Figures 4 and 5a–e). These fluctuations have varying magnitudes, frequencies, timing, and duration, each with different effects on wetlands. They are caused by a combination of short-term, seasonal, and longer-term weather conditions, as well as climate changes. They can have a frequency of hours (seiches), as well as seasonal, annual, and various multiple-year frequencies. As discussed earlier, effects of seiches or wind-tides are poorly understood, although they can affect zonation of plant communities (Batterson *et al.*, 1991).

The seasonal water-level fluctuations are also important. The seasonal timing of water-level declines in the Great Lakes is opposite to that of most inland wetlands. Peak high water-levels in coastal wetlands occur in the summer, with lows occurring in the winter. An early summer water-level peak and subsequent water-level decline allow more plants to grow from the seed bank than a later peak would (Merendino *et al.* 1990). The often unstable summer water levels result in more diversity of plant species than in wetlands with more stable conditions (Wilcox and Meeker, 1991). Seasonal water-level declines in the winter are also important since they can result in ice-induced sediment erosion (Geis, 1985).

Figure 4. Monthly lake level elevations of Lakes Michigan-Huron from 1860 to 1993 showing wide range of water level fluctuations (derived from National Oceanic and Atmospheric Administration (1992) and updates).

Figure 5a. Lake Superior water levels, presented as the monthly 1915–86 median levels, the maximum and minimum and those exceeded 10 or 90% of the time. (adjusted for current outlet conditions, from International Joint Commission Functional Group 2, 1989c)

Figure 5b. Lakes Michigan-Huron water levels, presented as the monthly 1915–86 median levels, the maximum and minimum and those exceeded 10 or 90% of the time. (adjusted for current outlet conditions, from International Joint Commission Functional Group 2, 1989c)

Figure 5c. Lake St. Clair water levels, presented as the monthly 1915–86 median levels, the maximum and minimum and those exceeded 10 or 90% of the time. (adjusted for current outlet conditions, from International Joint Commission Functional Group 2, 1989c)

Figure 5d. Lake Erie water levels, presented as the monthly 1915–86 median levels, the maximum and minimum and those exceeded 10 or 90% of the time. (adjusted for current outlet conditions, from International Joint Commission Functional Group 2, 1989c)

Figure 5e. Lake Ontario water levels, presented as the monthly 1915–86 median levels, the maximum and minimum and those exceeded 10 or 90% of the time. (adjusted for current outlet conditions, from International Joint Commission Functional Group 2, 1989c)

The annual and multiple-year water-level changes cause the greatest stress to coastal wetlands. High water levels periodically eliminate competitively dominant emergent plants, at frequencies that vary from lake to lake. In ensuing years when high levels recede, less competitive species are usually able to grow from dormant seeds or propagules, complete at least one life cycle, and replenish the seed bank before being replaced through competitive interactions (Keddy and Reznicek, 1986; Figure 6). The cycle then repeats itself.

Peak lake levels usually occur during multi-year periods of high lake levels, while lower lake levels occur during the intervening periods. In some years, extremely high water-levels compounded with storm activity can result in the loss of large areas of wetland (McDonald, 1955; Harris *et al.*, 1981; Farney and Bookhout, 1982). Annual and multiple-year fluctuations in water-levels continually change the character of the wetlands and have a large impact on flora and fauna. Although water-level fluctuations cause large stresses on coastal wetlands, they are ultimately vital in maintaining wetland diversity. They also allow wetlands to be more extensive and more productive than they otherwise would be if water levels were always stable (Busch *et al.*, 1989).

Figure 6. Simplified diagram of the effects of water level fluctuations on coastal wetland plant communities.

Over the longer term, water-level changes have also been recorded in the late-Holocene geologic record from the sequence of beach ridges that formed as lake levels generally declined (Wilcox and Simonin 1987, Jackson *et al.* 1988, Singer *et al.* 1996). A 4,000-year lake-level record is available for Lake Michigan and its hydrologic twin, Lake Huron, from elevations of foreshore deposits in beach ridges coupled with radiocarbon dates from the wetlands between the ridges (Thompson, *et al.* 1991; Thompson, 1992; Baedke and Thompson, 1993; Figure 7). This record shows a quasi-periodic behaviour with three scales of variation:

1. Short-term fluctuations with a range of 0.5 to 0.6 metres (1.6 to 2 feet) occur about every 30 years.
2. Intermediate-term fluctuations with a range of 0.8 to 0.9 metres (2.6 to 3 feet) occur about every 150 years.
3. Long-term fluctuations with a range of 1.8 to 3.7 metres (5.9 to 12.1 feet) occur about every 500 to 600 years.

Wetland plant communities in the Great Lakes have thus developed under a long-term hydrologic regime that has great variability.

Figure 7. Long-term water level fluctuations of Lakes Michigan-Huron over the last 3,000 years based on beach ridge development in Sleeping Bear Dunes National Lakeshore (modified from Baedke and Thompson, 1993).

4.1.2 Sediment Supply and Transport

Another major stressor affecting coastal wetlands is the constant change in the location and movement of sediments. These sediments can form barrier beaches and sand spits that protect wetlands; their erosion can expose wetlands to wave attack. If excess sediments are deposited onto existing wetlands, they can bury wetland communities. Sediment loads as little as 0.25 centimetres thick have a significant effect on the germination of many wetland plant species (Jurik *et al.*, 1994).

Coastal sediment processes are greatly affected by lake-level changes, both through net erosion and net deposition of sediments at specific wetland sites and through changes in sediment transport mechanisms. Waves from storms that occur during periods of high lake levels can erode materials not accessible at low stages and increase the load of sediment transported in the littoral drift. At low lake levels, sediments are exposed to transport by wind. These processes also serve to determine and perhaps change the exposure of a wetland to the forces of the open lake.

4.1.3 Ice and Storms

Other physical stressors affecting Great Lakes wetlands are ice and storms, both of which are affected by lake-level changes. Ice that forms before water levels decline in winter can come to rest on bare sediments and freeze them (Barnes *et al.*, 1994), thus affecting the survival and dominance of plants at those sites (Renman, 1989; Wilcox and Meeker, 1991). If frozen sediments are dislodged with the ice pack in spring and float away, sediments are lost (Geis, 1985). Large ice packs washing on to the shore during storms can also scour and gouge away wetland sediments. Large waves associated with storms not only erode sediments but can also physically destroy wetland vegetation.

4.1.4 Natural Biological Stressors

Natural stressors of Great Lakes wetlands include certain native plants and animals. Invasive emergent plants such as cattails (*Typha* species) can stress wetlands by forming monotypic stands that greatly reduce habitat diversity (Wilcox *et al.*, 1984). The most invasive species are narrow-leaf cattail (*Typha angustifolia*) and hybrid cattail (*T.* x *glauca*), but the invasive forms of these species may be non-native.

As discussed in section 3.1.5, the muskrat and beaver are important natural wetland stressors, as they can significantly alter wetland habitat by cutting vegetation for food and shelter.

Diseases that stress both plant and animal communities are also natural biological stressors.

4.2 Human-Induced Stressors

Humans impose further stresses on coastal wetlands. Some human-induced stressors exaggerate or reduce natural stressors, adversely affecting a system adapted to the natural range. Others add new stressors to which marshes are not naturally exposed.

4.2.1 Drainage

Coastal wetlands are drained for agricultural, urban or industrial land uses. Ditches and dikes are usually constructed to keep these areas drained. Drainage destroys the wetland and all its natural functions. Even drains that just pass through wetlands can affect water-levels, with resulting reductions in diversity and function.

Coastal wetland drainage has occurred mostly in the lower lakes basin. In the past, governments wishing to support farmers and unaware of wetland values, gave grants to encourage drainage. Between 1967 and 1982, 85 percent of southern Ontario wetland losses were to agriculture, most involving drainage (Snell, 1987). This trend also applied to coastal wetland losses in shoreline townships (Snell and Cecile Environmental Research, 1992). The rate appears to have slowed in recent years. Examples of coastal wetlands in Canada that have been greatly reduced by agricultural drainage are the St. Clair Marshes on Lake St. Clair and Pelee Marsh and Erieau Marsh on Lake Erie.

4.2.2 Filling and Dredging

The effects of filling are drastic, completely destroying wetland areas and eliminating all their functions. Filling tends to occur mostly in urban areas, where wetlands are converted to urban and industrial land uses. For example, 83 percent of the original 3900 hectares (9,637 acres) of western Lake Ontario marshland from Niagara River to Oshawa had been lost, generally to urbanization (McCullough, 1981). Some sections have lost 100 percent of coastal wetlands through filling (Whillans, 1982).

Dredging and channelling for boats, marinas and harbours occurs in many marshes. Filling often accompanies dredging, especially for harbour development. Dredging, with the accompanying filling, completely removes the marsh habitat where it takes place. The dredging itself can also raise sediment loading in the remainder of the marsh. Deepening the water adjacent to a marsh can also prevent the lakeward shift of a marsh during low water levels. Dredging reduces both the extent of the marsh and its habitat diversity, since only the drier wetland habitats remain. Dredging can also create new channels in wetlands and alter the natural flow patterns, thereby producing changes in nutrient regimes and consequent plant communities.

Dredging and channelling are localized stressors. They are likely more common in open shore and bay marshes, although historically some harbours dredged out marshes at river mouths (e.g., Oshawa Second Marsh on Lake Ontario). Dredging and channelling for boat harbours is especially evident on the lower lakes, representing a loss of significant wetland habitat (Limno-Tech, 1993).

4.2.3 Shoreline Modification

A common response to the threat of flooding and erosion along the shoreline of the Great Lakes is to construct groins, dikes, revetments or breakwalls along the shore. By reducing erosion, these structures also reduce the supply of sediments that naturally nourishes the shoreline and replaces eroded sediments. Barrier beach wetlands may thus lose the protection of a barrier beach and be impacted by waves. Hard shoreline structures also shift wave energy further downshore and may locally accelerate erosion of beaches and coastal wetlands elsewhere.

Depending on local circumstances, shoreline modification can also interfere with other sediment processes that maintain marshes. Major storms can remove large areas of marsh and, under natural conditions, the sediment gradually reaccumulates, allowing the marsh to be re-established. With shoreline modification, however, once marshes are removed following storms, the wave energy can no longer be dissipated up the shore gradient to drop sediment. Instead the energy may keep scouring away the marsh and prevent its re-establishment.

When dikes, revetments or breakwalls are constructed along the gently sloping shore of a wetland, a “backstopping” effect can also result. These shoreline structures eliminate the ability of a marsh to shift shoreward during high water levels (Wilcox, 1995). The effect is to reduce marsh extent during high levels and to reduce marsh community variability by cutting out the drier communities. These species are slower to re-establish themselves when lower levels return, since the local seed source has been erased. Waves in high water years also scour sediments from in front of the revetment, leaving an abrupt boundary between upland and deep water.

Shoreline modification can also isolate the marsh from any natural interactions with adjacent uplands, such as wildlife movement.

Shoreline modification is localized but common in the lower lakes, particularly along heavily urbanized areas, such as western Lake Ontario (McCullough, 1981). Dikes are also common in agricultural areas of the lower Great Lakes where coastal wetlands have been drained for agriculture.

4.2.4 Water-Level Regulation

Structures at the outlets of Lake Superior and Lake Ontario are presently used to regulate lake-level fluctuations and moderate the occurrence of both high and low lake levels. Low water levels create problems for the shipping, hydropower, and recreational boating industries. Conversely, high water levels create problems for lakeshore property owners and industries with structures on flood-hazard lands. Significant and competing interests exist to further regulate water levels in the Great Lakes. Regulation of water levels has deleteriously impacted coastal wetlands on the regulated lakes, Lake Superior and Lake Ontario (Busch *et al.,* 1989), and has been identified as one of the most significant human-induced stressors affecting Great Lakes coastal wetlands (The Nature Conservancy, 1994).

On Lake Superior, water levels have been regulated for much of the 20th century, but the range of fluctuations and the cyclic nature of high and low lake levels have not been altered substantially from the previous unregulated condition although there are changes in the frequency of extreme events (Wilcox *et al.*, 1993). On Lake Ontario, however, where water levels have been regulated since the St. Lawrence Seaway began operation, large changes in coastal wetlands have occurred. Prior to regulation, the range of fluctuations in Lake Ontario during the 20th century was about 2 metres (6.5 feet). With regulation, the range was reduced slightly during the period between 1960 and 1976, but low water-supply conditions in the mid-1960s and high supplies in the mid-1970s maintained much of the range. In the years following

1976, however, regulation reduced the range of water level fluctuation to about 0.9 metres (2.9 feet) (Wilcox *et al.*, 1993). This has produced a lack of alternating flooded and dewatered conditions at the upper and lower edges of these wetlands.

As described earlier, the short-term and long-term fluctuations in Great Lakes water levels are of great importance to coastal wetlands. Individual wetland plant species and vegetation communities have affinities and physiological adaptations for certain water-depth ranges. Changes in water level add a dynamic aspect to this species/depth relationship and result in shifting mosaics of vegetation types. Regulated water levels affect the natural range, frequency, timing and duration of water level-changes in coastal wetlands, and in turn reduce the extent and diversity of wetland plant communities and alter habitat quality for wetland fauna (Busch *et al.*, 1989; Busch and Patch, 1990; Keddy, 1990; Wilcox and Meeker 1991, 1992; Wilcox *et al.*, 1993; Figure 8).

Figure 8. The effects of reducing water-level fluctuations on a Great Lakes coastal wetland shoreline. The extent and diversity of wetland vegetation communities are reduced under regulated water levels (modified from Keddy 1990).

For instance, plant communities at elevations that had not been flooded for many years as a result of water-level regulation became dominated by non-wetland shrubs, grasses, and old-field plants (Wilcox, 1993). At elevations that were rarely or never dewatered, more aquatic species such as submersed and floating plants were usually dominant. The plant communities at elevations that were flooded each 10 to 20 years and dewatered for successive years between floods had the greatest diversity of wetland vegetation, including grasses, forbs, sedges, rushes, short emergent plants, and submersed aquatic vegetation. However, these more diverse communities were reduced in area compared with the natural condition with unregulated water levels.

4.2.5 Changes in Sediment Budgets

Human activities in the Great Lakes basin have substantially altered the amount and particle size of sediments flowing into the Great Lakes since European settlement, greatly affecting the sediment budgets of coastal wetlands. Volumes of sediment from some tributaries are now over a hundred times greater than natural rates of sedimentation (Morris, 1983). Elevated sediment loads are due to the reduction of vegetated cover in watersheds entering coastal wetlands and to the increases in land clearance, agricultural runoff, urbanization, construction activities, logging and erosion along stream banks subject to increased flows. In agricultural parts of the basin, the bulk of these increased sediment inputs comes from erosion from agricultural fields (Wall *et al.*, 1978). Factors such as steep slopes, bare stream edges, numerous drains, and row crops that expose the soil in some seasons encourage sediment to erode.

The excess sediment received by coastal wetlands may go far beyond that needed to replenish them after storms and to maintain their protective barriers. Excess sediment loads can prevent the germination of emergent plant species (Jurik *et al.*, 1994), and in some cases can fill marshes. They can also smother fish spawning areas and submergent vegetation critical to many forms of wildlife, reduce dissolved oxygen concentrations, and affect the survival rate of invertebrate and fish eggs. Due to physical characteristics of sediments, increases in sediment loads can also have high associated nutrient loads and can be contaminated with industrial and farm chemicals (Boto and Patrick, 1978). Furthermore, high sediment loads discourage recreation through poor aesthetics, health threats, poor wildlife habitat, and prevention of boat access.

Another effect of alterations of sediment budgets is high turbidity, which is caused by fine sediments remaining suspended in the water. Besides originating in tributaries, increased turbidity can also result from increased exposure to wave attack, which suspends sediments by mixing, and from biological action such as feeding activity by common carp (Wilcox, 1995). High turbidity reduces the availability of light to submersed plants and epiphytes, reducing photosynthesis and limiting their growth. Increased turbidity may also seriously interfere with the food-finding activities of many valuable predator fish such as northern pike (Jude and Pappas, 1992).

In some cases, human activities produce a lack of sediments in coastal wetlands. For instance, dams constructed upstream on tributary rivers can trap sediment (Williams and Wolman, 1984; Ligon *et al.*, 1995) that may be essential to the maintenance of barrier beaches protecting wetlands (e.g., Point Mouillee in Lake Erie).

Changes in sediment budgets tend to more severely affect wetlands behind barrier beaches or at river mouths. Severe sediment loading is extensive throughout the lower lakes where agricultural activity and urbanization are common, but is localized in the upper lakes.

4.2.6 Nutrient Enrichment

Wetlands become stressed by nutrient enrichment. It is also largely a result of changes in land use in watersheds upstream of coastal wetlands. Nutrient enrichment originates from point sources such as municipal sewage discharges and industrial outfalls or non-point sources such as agricultural runoff or urban stormwater runoff.

Wetland and aquatic plants can obtain nutrients from both sediments and the water column; the predominant source of nutrient uptake is species-specific. Therefore, the nutrient content of the water in a wetland can determine the species composition and productivity (Wisheu *et al*., 1990). The growth of plant species able to cope with high fertility and best able to compete for light (e.g., cattail) is enhanced by nutrient enrichment, causing a great loss of diversity and eliminating rare plant species (Wisheu *et al*., 1990). In addition, nutrient enrichment may cause excessive algal blooms that can reduce light available to macrophytes for photosynthesis. Excessive growth of macrophytes or algae can also result in depletion of dissolved oxygen when these plants die and decay. This is especially critical in shallow basins with little mixing, such as barrier beach wetlands.

Like the loss of diversity caused by the reduced range of water-level fluctuations, excess nutrients reduce the range of habitat types and their associated fish and wildlife. The low diversity of fish and wildlife together with the slimy, foul-smelling water in turn discourages recreation.

Both urban and rural areas contribute human-induced nutrient loadings to streams draining into coastal wetlands. With modern sewage treatment and restrictions on phosphorus in detergents, however, agricultural sources alone remain the biggest culprit, at least in the lower lakes basin (PLUARG, 1978; Richards and Baker, 1993). The highest contributions are from fertilizer and sediment swept off cropland by rainwater and snowmelt (Baker, 1992; Richards and Baker, 1993). In some areas, faulty septic systems can also be a problem (Hocking and Dean, 1989).

Excessive nutrient loading is a problem throughout the lower lakes but is much more localized in the upper lakes. Effects are more severe for coastal wetlands behind barrier beaches or at river mouths; bay or open shore wetlands more exposed to lake-water dilution are least affected.

4.2.7 Toxic Chemicals

Toxic chemicals can stress wetland biological systems, especially the faunal communities. They are released from industry, mining, households, forestry and agriculture, and can be carried to wetlands through the air, in waters from tributaries or the lakes, or even deposited directly, as in the case of lead shot.

Through the processes of biomagnification and bioaccumulation, the impact of toxic chemicals has been greatest on animals at the top of the food web, such as predatory birds, fish, and mammals, including humans (e.g., Aulerich *et al.*, 1973; Kubiak *et al*, 1989; Colborn, 1991; Wren, 1991; Hoffman *et al.*, 1993; Giesy *et al.*, 1994) and especially in longer lived animals such as turtles (e.g., Bishop *et al.*, 1991). Animal health and reproduction can be affected by contaminants. For instance, thinning of egg shells and deformities are well-documented among some fish-eating birds of the Great Lakes (eg., black-crowned night heron; Hoffman *et al.*, 1993). As well, high concentrations of PCBs, organochlorines and dibenzofurans in the eggs of snapping turtles near coastal wetlands of Lake Ontario and Lake Erie have been associated with lower hatching success and an increase in the rate of deformities of hatchlings (Bishop *et al.*, 1991).

Long-term effects of toxic chemicals on plants and herbivores are not well understood. Herbicides from cropland may be interfering with aquatic plant growth in wetlands. Herbicides are present in the wetlands and bays of Lake Erie at levels high enough to alter planktonic species composition and inhibit photosynthesis of algal and rooted plant communities (Dodge and Kavetsky, 1995). Recent studies on the commonly used herbicide atrazine have, however, shown that its deleterious effects on community structure in surface waters in general are usually short-term and reversible (Solomon *et al.*, 1996); but more permanent effects may be caused in wetlands receiving large quantities of agricultural runoff and not subject to large dilution factors, such as some barrier beach wetlands. Increased salinity caused by road salt runoff can also alter algal, macrophyte and faunal communities of wetlands (Wilcox 1985b).

Toxic chemicals appear extensively throughout the Great Lakes but would likely be in higher concentrations in coastal wetlands that are in Areas of Concern, near urban centres, or at river mouths. Even though stringent regulations have resulted in declines in discharges of some toxic chemicals such as PCBs, many still persist in sediments and remain available to fish and wildlife. Their effects, singly or in combination, on wetland biota or on human consumers of wetland biota are unknown (Dodge and Kavetsky, 1995).

4.2.8 Non-native Species

Species not native to the area, and aggressive species of uncertain origin that compete with native biota, are serious biological stressors affecting wetlands of the Great Lakes. Mills *et al.* (1993) documented the establishment of 139 non-indigenous aquatic organisms in the Great Lakes; many of them do not occur in wetlands or do not cause identifiable problems, but several do cause or have the potential to cause considerable problems. The species are found in coastal wetlands as a result of intentional release, deposition from ship ballast, escape from cultivated or cultured populations, and migration along travel routes such as railroads, highways, and canals. In healthy ecosystems, introductions of non-native species may not be successful. However, given the extent of wetland alteration in the Great Lakes, habitats and food webs have been sufficiently disturbed to allow many introduced species to thrive (Wilcox 1995).

Purple loosestrife (*Lythrum salicaria*) is a tall, perennial, emergent plant introduced from Eurasia into a number of port cities in the northeastern United States in the middle-to-late 1800s (Stuckey, 1980), most likely as seeds in moist ballast sands (Thompson *et al.*, 1987). It spread through the Great Lakes region via canals, railroads, and highway corridors (Thompson *et al.*, 1987; Wilcox, 1989b) and is now common to extremely abundant in wetlands. Purple loosestrife has little or no value as food or cover for wildlife (Rawinski, 1982) and forms dense clumps, often in large, monospecific stands, that choke out more beneficial native plants. It was the best competitor of 44 herbaceous wetland plant species investigated by Gaudet and Keddy (1988).

Other emergent plants that pose management problems include common reed (*Phragmites australis*) and reed canary grass (*Phalaris arundinacea*). These species may be indigenous to the Great Lakes region or other parts of North America, but became prominent as a result of human actions. They are both aggressive plants that can form solid stands and greatly reduce habitat diversity (Haslam, 1971; Apfelbaum and Sams, 1987). Stands of common reed can provide cover for wildlife when interspersed with other vegetation or open water, but impenetrable stands have little value (Cross and Fleming, 1989). Reed canary grass may provide forage for ruminants but otherwise also has little value (Apfelbaum and Sams 1987). Fluctuating water levels that include substantial flooding can be effective in controlling these species; stable water levels encourage further spread (Apfelbaum and Sams, 1987; Hellings and Gallagher 1992).

Submersed plant species can also be stressors in coastal wetlands. Eurasian water-milfoil (*Myriophyllum spicatum*) is a rapid-spreading submergent plant that produces large amounts of biomass near the water surface. It can interfere with navigation, detached fragments may interfere with water-intake structures or wash up on shore, and decomposing plants may alter water quality (Grace and Wetzel, 1978). Curly-leaved pondweed (*Potamogeton crispus*) and common waterweed (*Elodea canadensis*) may also become prevalent and serve as a stressor (Nichols and Shaw 1986).

A recent faunal invader to the Great Lakes is the zebra mussel (*Dreissena* species). Although best known for clogging water-intake structures and fouling other objects of human origin (Nalepa and Schloesser, 1992), the weight of mussels colonizing macrophytes can result in physical breakdown of the plants (Johnson, pers. com.). Studies suggest that zebra mussels show a preference for muskgrass (*Chara* species) as a substrate (Wilcox, pers. com.), and they have been observed on stems of bulrush in wetlands of Saginaw Bay (Brady, pers. com.). Zebra mussels are also known to filter great numbers of planktonic organisms from the water, thus altering food webs (MacIsaac *et al.*, 1992). In addition, they can decrease turbidity in coastal waters, thereby increasing productivity of submergent aquatic plants (Skubinna *et al.*, 1995).

Common carp (*Cyprinus carpio*) have been shown to affect wetlands by reducing the diversity and biomass of macrophytes (King and Hunt, 1967; Crivelli, 1983). Uprooting and direct consumption have had a serious impact on some plants, such as *Chara* species (King and Hunt, 1967). Other species, such as curly-leaved pondweed (*Potamogeton crispus*) and sago pondweed (*P. pectinatus*) seem to be less affected by carp. Changes in macrophyte communities may also contribute to reduced abundance of emergent insects in wetlands where common carp are abundant (McLaughlin and Harris, 1990). Although carp have been found to dominate larval fish samples from some Great Lakes marshes (Chubb and Liston, 1986; Johnson, 1989; Petering and Johnson, 1991) and are often very abundant as adults, they cause the greatest problem in diked marshes where they remain in residence year-round and are more numerous than in lake-connected wetlands (Johnson, 1989). Common carp begin to enter wetlands as early in the year as February; their numbers are greatly reduced by the end of summer, and nearly all carp have returned to the lake by autumn (Cairns, pers. com.). Common carp may cause problems in degraded coastal wetlands (Simser, 1982; Holmes 1988), but they seem to have little effect on healthy marshes.

4.2.9 Climate Change

Climate warming as a result of the doubling of global atmospheric carbon dioxide could alter the water level conditions under which the Great Lakes coastal wetlands were formed and maintained. Although consensus exists on the projected global temperature change, there is considerable uncertainty on the regional response of temperature, precipitation and other climatic elements in the Great Lakes region and their effects on the lakes (Croley, 1991; Tables 2 and 3).

Table 2. Predicted Great Lakes - St. Lawrence basin temperatures and precipitation scenarios with a doubling of global atmospheric CO_2 concentrations.

	Summer	**Winter**
Mean Annual Air Temperature	increase of 2.7 C to 8.6 C	increase of 3.4 C to 9.1 C
Annual Precipitation	change of 70% to 130%	change of 90% to 130%

Source: Croley, 1991

Table 3. Predicted characteristics of different Great Lakes basins with a doubling of global atmospheric CO_2 concentrations.

	Lake Superior	**Lake Michigan**	**Lake Huron**	**Lake Erie**	**Lake Ontario**
Change in Net Basin Water Supply	-21%	-59%	-48%	-101%	-42%
Change in Mean Lake Levels	-0.23 m	- 1.62 m	-1.62 m	-1.36 m	-1.30 m
Change in Mean Annual Surface Water Temperature	+5.1 C	+5.6 C	+5.0 C	+4.9 C	+5.4 C
Change in Ice Cover	Decrease	Decrease	Decrease	Decrease	Decrease

Source: Croley, 1991

Changes to the mean water level, the annual range of water levels, and their seasonal cycle would alter the water level regime in coastal wetlands (Mortsch and Kushida, 1996). The timing, intensity and duration of the water-level fluctuations would also be modified. For instance, if seasonal distribution of water levels are altered by a climate change, there would be shorter periods of low water in winter; earlier rises of water level in the spring, and an earlier onset of seasonal water-level decline. Increased frequency and duration of low water levels would result in higher water and air temperatures, more evapotranspiration, less runoff, and reduced ice cover. Coastal wetland vegetation and faunal communities would change substantially, although the exact changes are not known for certain (Mortsch and Kushida, 1996). The wetland biota would have to adjust to these new patterns of climate and water-level fluctuation.

4.2.10 Diking of Wetlands

Dikes are built surrounding intensively managed wetlands. Diked wetlands are believed to solve management problems under circumstances where protection from water-level change and wave action is required. However, diking also creates problems for wetlands. Isolation from the lake waters and the surrounding landscape results in the elimination or reduction of many of the functional values of wetlands, including flood conveyance, flood storage, sediment control, and improvement of water quality. Habitat for waterfowl and certain other animals may be improved by diking, but shorebirds and many less common plants and animals lose the habitat provided by a continually changing boundary between land and water. In addition, fish and invertebrates not capable of overland travel have no access to diked marshes and lose valuable habitat. Fish larvae pumped into diked wetlands during filling operations cannot leave and are thus lost to the lake population. Trapped common carp remain in diked wetlands through adulthood and cause management problems by uprooting vegetation and increasing turbidity (Wilcox 1995). Diking is more common in the flat floodplains of Lake Erie and Lake St. Clair, and is more common on the American side of the lower lakes.

4.2.11 Road Crossings

Many roads near the shorelines of the Great Lakes link coastal cities and provide access to owners of private land along the coast. Where these roadways cross coastal wetlands, they serve as stressors. A substantial percentage of the drowned river-mouth (restricted riverine) wetlands on all the lakes are crossed by roadways. The hydrology of these wetlands is altered by the constriction of the often broad, multi-channelled river to passage under a narrow bridge placed along a roadbed causeway that partially dams the river and wetland. Flood waters slowed by the causeway dam and narrowed outlet deposit excessive sediments in the wetlands and raise the elevation of the substrate. This allows invasion of plant species that would otherwise not tolerate the hydrologic regime of the wetland. Water-level changes due to seiches are also decreased by the reduced connection with the lake. Barrier beaches are also commonly used for roadbeds, with similar hydrologic impact on the wetlands behind them and added alteration of the coastal processes that create and maintain them. In addition, roadways can contaminate wetlands with by-products of combustion and with road salt in winter (Wilcox 1985a).

5.0 Indicators of Coastal Wetland Health

The above stressors, individually and in combination, affect the overall health of Great Lakes coastal wetlands. A monitoring system for coastal wetlands should be developed in order to accurately assess basin-wide health, to develop rehabilitation plans, and to monitor and judge any future progress in their conservation and restoration. The first step in the development of such a monitoring system is to identify useful indicators of wetland health.

An indicator of ecosystem health is defined as:

> "... a measurable feature which singly or in combination provides managerially and scientifically useful evidence of environmental and ecosystem quality, or reliable evidence of trends in quality." (Indicators for Evaluation Task Force, 1996).

Furthermore, a useful indicator,

> "... provides a clue to a matter of larger significance or makes perceptible a trend or phenomenon that is not immediately perceptible. It is a sign that makes something known with a reasonable degree of certainty. An indicator reveals, gives evidence. Its significance extends beyond what is actually measured to a larger phenomenon of interest." (Indicators for Evaluation Task Force, 1996).

There has been substantial progress in identifying indicators for monitoring the health of the Great Lakes basin in general (e.g., Council of Great Lakes Research Managers, 1991; Fox, 1994; Indicators for Evaluation Task Force, 1996), and for coastal wetlands more specifically (Keough and Griffin, 1994).

There are many possible indicators of coastal wetland health. They differ in terms of the information they provide and the effort required to measure them. A series of suitable indicators should be chosen to provide the most accurate, defensible, sensitive, comprehensive, time-efficient, cost-effective and pragmatic assessment of the health of coastal wetlands. Keough and Griffin (1994) compiled the responses of over thirty scientists who participated in a workshop held to discuss the most useful indicators for the monitoring of Great Lakes coastal wetlands. This forum provides a strong foundation upon which to describe suitable indicators of the health of coastal wetlands. In the section below, these useful indicators are identified and discussed.

Further work is still needed to develop the best monitoring strategy for measuring indicators of coastal wetland health. Some of these indicators are easily measured on a basin-wide basis, but do not provide enough detailed information to diagnose or predict certain problems. Conversely, other indicators provide good detailed information with high diagnostic and predictive powers, but are not practically measured across all coastal wetlands. A strategy should be developed to determine which indicators will be monitored basin-wide and which ones will be monitored at a few specific sites. If monitoring sites are to be used, the appropriate number and their locations have to be identified, and the sampling protocol has to be developed. Monitoring sites could include representative pristine wetlands, degraded wetlands, or wetlands subject to particular stressors. Areas of Concern (AOC's) may not always be suitable as monitoring sites since coastal wetlands are often not present or extensive in these areas. Any strategy to monitor coastal wetlands should be comprehensive and mutually agreed to by interested parties in both Canada and the U.S.

5.1 Physical And Chemical Indicators

Alterations of environmental conditions in Great Lakes coastal wetlands may sometimes be detected as physical or chemical changes. Specific physical and chemical measurements can therefore be useful indicators of some aspects of wetland health.

Water-level monitoring is a useful physical indicator of the health of coastal wetlands across the Great Lakes since water-level fluctuations determine many of the wetland habitat characteristics. Coupled with information on ground elevations, water-level data can be used to determine the length of time since the last flooding or de-watering of a wetland community, the duration of that event and the depth of flooding. Wilcox *et al.* (1993) used this approach to identify the effects of water-level regulation on wetland plant communities of Lake Ontario resulting from construction and operation of the St. Lawrence Seaway. Continuous water-level recorders are already in operation at numerous locations around the Great Lakes. The data can be easily accessed in annual reports issued by the National Oceanic and Atmospheric Administration (NOAA) of the U.S. Department of Commerce, in monthly reports issued by the Detroit District of the U.S. Army Corps of Engineers, and by telephone to NOAA for daily and hourly reports. Historical data are also available, allowing for a comparison of current conditions with historical conditions at different time scales.

Sediment supply characteristics can also act as physical indicators of coastal wetland health, since many coastal wetlands depend on suitable sediment supplies. As discussed earlier, excessive sediment supplies can bury wetland habitats or impede germination of plants, while reductions in sediments can cause a loss of protecting sediment bars. Sediment supply can be measured as sediment accumulation at specific locations in or near the wetlands over time. As well, sediment type and particle size determinations can provide additional information regarding the mobility of accumulated sediments. Information on fetch, exposure to wave attack, and shoreline slope can also help in determining the sediment dynamics. Sediment supply characteristics are site-specific and, therefore, not practically measured across all coastal wetlands. These indicators may best be measured at specific long-term monitoring sites, or near sites that are subject to large changes in sediment budgets.

Concentration of nutrients and toxic substances in water and sediments of wetlands are important chemical indicators of coastal wetland health. Excess nutrients promote the growth of aggressive species that reduce diversity, while toxic chemicals threaten the health of many species, especially fauna. In sediments, potential chemical constituents for analysis include the various forms of carbon, total particulate nitrogen, ammonium, nitrate-nitrite, soluble reactive phosphorus, organic contaminants, and heavy metals. In the water column, determinations of turbidity, total suspended solids, total organic carbon, total particulate carbon, ammonium, nitrate-nitrite, total phosphorus, soluble reactive phosphorus, dissolved oxygen, pH, alkalinity, conductivity, organic contaminants, and heavy metals can serve as indicators. Again, these measures are very site-specific and are not practically measured across all wetlands. They would be best suited to specific long-term monitoring sites, or sites where wetland water quality is threatened.

5.2 Individual and Population Level Indicators

Flora and fauna may be subject to multiple stressors that may not be detected by physical or chemical indicators, but may combine and act together in a synergistic manner to produce a large effect on wetland biota. Biological responses are more reliable indicators of wetland health than individual chemical or physical indicators because they integrate the independent and interactive effects of many stressors (Council of Great Lakes Research Managers, 1991). Because of the specific ecological requirements of species, the use of individuals and populations as biological indicators can provide high diagnostic and predictive powers (Council of Great Lakes Research Managers, 1991). Important indicators of wetland health that can be measured in individuals and populations of species are presented below.

Tissue concentrations of toxic chemicals or malformations in fish and wildlife are useful indicators of toxic chemicals in wetland environments. Fish and wildlife accumulate contaminants according to their place in the food web, and predators near the top of the food web, such as mink or bald eagle, tend to accumulate the most contaminants. Longer-lived wetland species, such as snapping turtles, also accumulate greater quantities of toxic chemicals due to their long lifespan. These contaminants may not be easily measured in the water column or in the sediments, but the biomagnification or additive effect of accumulation in tissues often results in measurable contaminant levels in fauna. This method provides a means to detect the presence of contaminants, and their accumulation over time, in a wetland. Biomagnification may also result in abnormalities, tumour, or lesions in fish and wildlife, allowing for a complementary assessment of toxic chemical levels in wetlands. Several coastal wetland species are presently used to assess the extent of toxic chemicals in nearshore and coastal wetland environments at some localities (Fox, 1994). These species include snapping turtle, mudpuppy (Bishop *et al.*, 1991; Environment Canada, 1995), bald eagle (Colborn, 1991), Forster's tern (Kubiak *et al.*, 1989), common tern, black-crowned night-heron (Hoffman, *et al.*, 1993) and mink (Wren, 1991; Giesy *et al.*, 1994). Since some of these species are also consumed by humans, they also provide indications of health risks to humans. Fish edibility advisories, which are available for many water bodies including parts of the Great Lakes, are another indicator of toxic chemicals in coastal wetlands, and can also act as social indicator of coastal wetland health. The most useful wetland species for monitoring purposes need to be identified, and a sampling protocol established, in order to be able to use toxic chemical biomagnification effects as useful indicators.

The *population characteristics of economically or socially valuable wetland species* is another indicator of coastal wetland health. Suitable species may include charismatic species such as the bald eagle, wetland-dependent recreational and commercial fish species, and waterfowl. Many species of waterfowl and recreational and commercial fish are already monitored to some degree, and the recovery of bald eagle populations in the lower Great Lakes has been closely monitored (Colborn, 1991). The status of these species could also act as social indicators of wetland health.

The *presence of characteristic species with narrow environmental tolerances* can be a useful measure of wetland health and degradation. The presence of species typical of pristine habitats indicates that the critical environmental conditions remain intact, and that little degradation has occurred. Rare species are often included in this category. Conversely, the presence of indicator species typical of degraded habitats can indicate degraded conditions. For instance, some wetland plants require specific hydrologic, water chemistry or sediment conditions to survive or flourish. Reductions in their population may indicate more subtle stresses to the wetland that are not obvious by examining physical and chemical characteristics alone. Population and biomass studies of plant production for these species may be needed to determine the stability of their populations. Many fish and wildlife species are also sensitive to physical and chemical disturbances, or have low tolerance for changes in environmental conditions; their presence, absence, relative abundance, and condition can sometimes be used to detect habitat degradation. This is especially true for fauna that are not highly mobile. For instance, many fish species require certain wetland habitats in one or more of their life history stages; the absence of these species in a wetland can be an indicator of habitat loss or degradation. Other species of fauna can be used to detect degraded conditions (e.g., populations of carp). The most suitable indicator species of flora and fauna have to be identified, and a sampling protocol must be established, in order to use these indicators effectively.

The *presence and abundance of invasive species* is another indicator of coastal wetland health; their presence indicates degraded conditions. Many invasive plants, including native and introduced species, require disturbance in order to create open habitat where they can become established. The mere presence of these plant species in a wetland can be an indication that a disturbance has taken place, and the expansion or spread of invasive species usually indicates that degraded conditions persist. Invasive or exotic fish and wildlife species may also indicate a stressed ecosystem. For example, zebra mussels, which sometimes occur in wetlands, do not thrive in nutrient-poor, oligotrophic waters because they lack sufficient food. Thus, abundant zebra mussel populations are indicative of more nutrient-rich, eutrophic waters. Common carp is another example of an invasive and destructive species that can be used as an indicator. In most cases, “rough” fish, such as carp, are less competitive in pristine areas, but can tolerate degraded conditions better than other species, giving them a competitive advantage in those areas. Thus, the percentage of rough fish can also serve as an indicator of wetland health. A sampling protocol for invasive species must be established in order to use these as indicators.

5.3 Wetland Community Indicators

Certain characteristics of wetland habitats and communities can also provide useful indicators of wetland health. These indicators integrate the impacts of stressors even further than individual species, with more possible synergistic effects. They can be more reliable than individual species as general indicators of wetland health, although they tend to have less diagnostic or early-warning potential (Council of Great Lakes Research Managers, 1991).

Changes in area of habitats or vegetation types over time can be useful indicators of wetland health. Vegetation mapping from air photos, with ground-truthing, can provide information on the long-term changes in areal extent and percentage of each major vegetation type in a coastal wetland. Interspersion of vegetation and open water, another critical habitat factor for many species, can also be determined by this process. Areal extent of certain vegetation or habitat features could also be coupled with the habitat requirements of sensitive or key wildlife species to determine areal changes in their available habitat.

Biodiversity measurements can also be used as measurements of coastal wetland health. Wetlands with high biological diversity have high levels of stability (resistance to disturbance), and the ability to recover from disturbance (resilience). Possible measurements include the number of species (species richness) in different taxonomic groups (e.g., algae, fungi, macrophytes, invertebrates, or vertebrates) in a unit area of wetland, the number of individuals of different species, or more complex diversity indices. The species richness in the various vegetation types or the wetland as a whole is a useful descriptor of the overall health of a wetland and its value as faunal habitat. Some biodiversity measurements require detailed knowledge of specific groups in order to identify species. Other accurate methods can be performed by non-specialists, requiring the separation of morphologically different taxa, but not requiring their identification (e.g., Oliver and Beattie, 1993). These methods are effort intensive and, depending on the methods used, can require specialized knowledge. These measurements would be most useful at specific monitoring sites.

Changes in plant community characteristics can be useful indicators of wetland health. Information on the dominance of plant species in communities can be valuable in identifying wetlands that have been altered or degraded. The growth form of plant communities (e.g., submersed, floating, small stature emergent, large stature emergent or woody plants) can often be used to determine disturbance history in a wetland, particularly from hydrologic alterations. Growth form, as well as presence of detrital plant material, can also be interpreted in view of habitat requirements for various fish and wildlife species (e.g., spawning habitat for fish). These measures are effort-intensive and consequently would be most practical at specific monitoring sites.

Changes in faunal community characteristics are also potential indicators of wetland health. The stability of a faunal community, its productivity (e.g., as measured in biomass of fish or emergence rate of aquatic insects), and ratios of guilds or traits (e.g., pelagic vs. benthic fish ratio, predator vs. prey ratio) are potential indicators. Again, these measures are effort-intensive and would be most practical at specific monitoring sites.

Biotic community indices based on different groups of organisms can also be reliable and, in many cases, diagnostic tools for assessing the health of Great Lakes coastal wetlands. These indices typically use the presence and abundance of organisms in a certain community to assess different aspects of ecosystem health (e.g., water quality). For instance, many biotic indices have used attached algae communities to assess changes in water quality in streams and rivers (e.g., McCormick and Cairns, 1994; Whitton and Kelly, 1995). These indices may be modified for coastal wetlands and used to indicate changes in water quality. A number of indices based on aquatic invertebrate communities also exist. For instance, the diversity of species of adult caddisflies, and the presence/absence of certain sensitive species, show promise as indicators in coastal wetlands (Armitage, 1995). Similar measurements can be applied to other wildlife and fish. These measures are also effort-intensive and consequently would best be used at specific monitoring sites.

5.4 Landscape Indicators

Many stressors affecting Great Lakes coastal wetlands are large-scale problems, perceptible at the scale of the landscape. Aerial photos and satellite imagery can be used to accurately determine many aspects of coastal wetlands in a relatively cost-effective and time-efficient manner. Remote sensing and landscape ecology are, therefore, powerful tools for the assessment of the health of Great Lakes coastal wetlands. Since there are archival aerial photos of many coastal areas going back 40-60 years, they also provide a powerful tool to determine historic trends (Wilcox, 1995). The use of a Geographic Information System (GIS) makes such assessments easier.

The *size, position and number of Great Lakes coastal wetlands* can be assessed accurately using remote sensing. The existence of historical aerial photography allows for a determination of trends in their size and number. Remote sensing could also provide data on the changes in wetland size in response to between-year water-level fluctuations (e.g., Williams and Lyon, 1991). The ratio of the area of wetlands to their perimeter can be measured to provide information on its fragmentation, and the susceptibility of a wetland to threats along its border. Determinations of wetland size and number exist for many parts of the Great

Lakes, as detailed in section 6, but methodologies are diverse and not standardized, making it difficult to determine trends. A standardized methodology would be required for these measures.

Land-use characteristics in the vicinity of coastal wetlands are also important in determining the health and extent of coastal wetlands. Many human-induced stressors are a result of land use, and trends in their extent can be assessed by remote sensing. For instance, the drainage, filling, and dredging of wetlands for conversion to agricultural, urban, and industrial land uses can be monitored. The extent of breakwalls, dikes, and revetments can also be used to determine the trends in shoreline modification and its impacts on wetlands. The number of roads in and near wetlands can also be monitored.

Land use changes upstream in the watersheds of coastal wetlands with inflowing tributaries, can also be monitored through the use of remote sensing. These include the extent of agricultural, urban and industrial development on upland areas, changes in agricultural practices, deforestation, changes in road density, dam construction on tributaries, and other hydrologic alterations. This data would provide important information on potential changes in hydrology, and in sediment, nutrient, and toxic chemical loads entering coastal wetlands.

Other examples of landscape-scale indicators of potential stress on wetlands that can be monitored using remote sensing include: changes in the status of protective barriers such as sand spits and barrier beaches, proximity to navigable channels and recreational boating activity, and hydrologic connectivity with the lake as determined by the presence of dike structures or continuous natural barriers.

5.5 Social and Economic Indicators

Any assessment of the health of coastal wetlands must also consider that humans are part of the ecosystem. Social, economic and human health indicators must, therefore, be included with other ecosystem indicators in any monitoring strategy. These indicators would all best be monitored in the vicinity of coastal wetlands with high human use.

Fish consumption advisories for wetland-dependent species are important indicators of the presence of toxic chemicals in the wetland environment. Many areas in or near Great Lakes coastal wetlands have fish consumption guidelines that are updated every few years. Historical data is also available for many classes of toxic chemicals in many wetlands.

Certain health problems can be monitored in communities with high consumption rates of plants, fish or wildlife from coastal wetlands and be used as an indicator of toxic chemicals in coastal wetlands. Several First Nation communities in particular rely heavily on plant, fish, and wildlife from coastal wetlands for their diet.

Commercial fish catches of wetland-dependent species is a useful indicator of the health or degradation of wetland-dependent fish populations. It also provides a good measure of the local wetland-dependant economies.

Recreational opportunities for anglers, hunters, bird-watchers or other recreationalists can be useful indicators of local wetland-dependent economies. These can be measured in many ways, such as surveys, outfitter numbers and revenues, number of boats in wetlands, and number of visits. They would also serve as indicators of the human stress in wetlands.

Number of employed persons in activities directly or indirectly related to coastal wetlands may also be used to measure the degree of reliance of local economies on coastal wetlands.

6.0 Status of Coastal Wetlands

6.1 Lake Superior

6.1.1 Setting

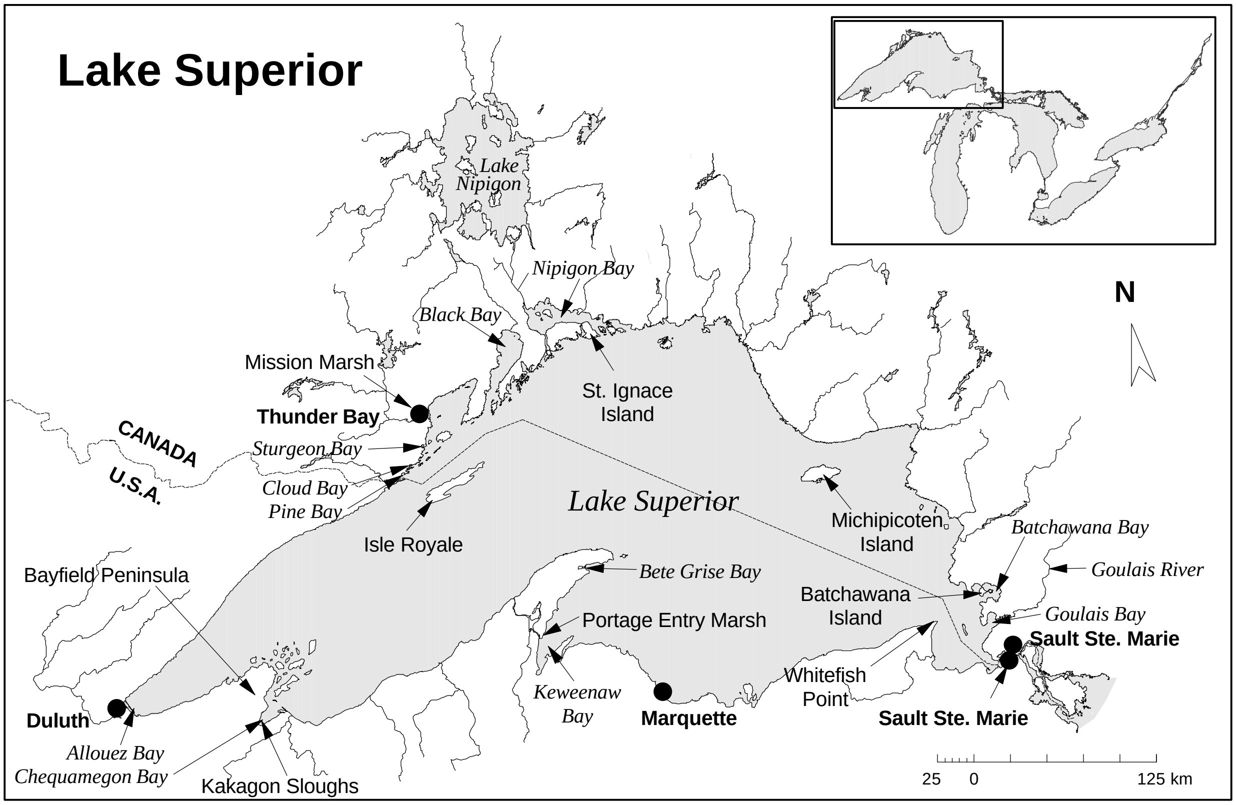


Figure 9. Map of Lake Superior

Lake Superior is the largest and deepest of the Great Lakes (Figure 7). Its surface area is 82,100 km^2 and the shoreline extends 5,105 km (International Joint Commission, 1993). Many islands are present in Lake Superior with Isle Royale in Michigan and St. Ignace Island and Michipicoten Island in Ontario being the largest. Its drainage basin is 138,586 km^2 in size and is mostly forested (95%) with very small areas of agricultural land (1%), urban and industrial area (0.1%) and other land uses (4%) (PLUARG, 1978).

The north shore of Lake Superior is a high energy environment with few areas of sediment deposition. Wetlands are rare here and restricted to the large sheltered embayments of Goulais Bay and Batchawana Bay in the northeast, and Thunder Bay, Black Bay and Nipigon Bay in the northwest. Due to their rarity, those that do exist are particularly important to fish and wildlife populations. Small lacustrine marshes are the most dominant wetland type, however there are also some large swamps and peatlands (eg. Black Bay, Goulais River). The number and area of coastal wetlands along the north shore are not known. There are at least 21 coastal wetlands (Environment Canada, 1993), but only 10 of these have been evaluated by the Ontario Ministry of Natural Resources, mostly along the northwestern shoreline. They total 915 ha and range in size from 5 ha to 429 ha (K. Bray, pers. com.; S. Suke, pers. com.; A. Kalas pers. com.). At least 3,500 ha of coastal wetland remains to be evaluated, including several large wetlands such as the Goulais River Wetland complex and the Black Bay Wetland (K. Cullis, pers. com.; A. Dupont, pers. com.). The large Goulais River Wetland complex is probably the most significant wetland on the north shore of Lake Superior (H. Ball, pers. com.).

Wetlands along the southern shore of Lake Superior are larger and more numerous than those of the north shore. The shoreline is more complex with many river mouths, providing shelter from wind and wave action, allowing wetlands to develop. Herdendorf (1981e) identified 272 wetlands totalling 21,357 ha along the south shore of Lake Superior. The largest wetlands are the palustrine wetlands of western Lake Superior. Chequamegon Wetland (3,850 ha) and Fish Creek Wetland (320 ha) in Chequamegon Bay, and Portage Entry Marsh (3,300 ha) in Keweenaw Bay constitute 25% of U.S. coastal wetlands of Lake Superior (Prince *et al.*, 1992).

6.1.2 Significant Features

Several significant plant species are found in Lake Superior wetlands such as awlwort (*Subularia aquatica*) and water-starwort (*Callitriche heterophylla*) in shallow water marshes, black sedge (*Carex atratiformis*) in swamps and spike-rush (*Eleocharis nitida*) in coastal meadow marshes (W. Bakowsky, pers. com.).

Forty-one fish species have been identified in coastal wetlands of Lake Superior; they use them as spawning, nursery and feeding habitats (Jude and Pappas, 1992; Ball and Tost, 1992; Entwistle, 1986). In wetlands along the south shore of Lake Superior, black bullhead, white perch, log perch and freshwater drum are the most common permanent residents while many other species utilize the wetlands on a temporary basis for spawning, nursery, shelter and feeding (Jude and Pappas, 1992). Northern pike, walleye and yellow perch are the primary sportfish that use Lake Superior coastal wetlands. The only muskellunge populations along the north shore are found at the large wetlands at the mouth of the Goulais River (Ontario Ministry of Natural Resources, 1991). No rare fish species have been identified in north shore Lake Superior coastal wetlands (Sutherland, 1994, Mandrak and Crossman, 1992).

Little is known about the amphibian and reptile populations utilizing Lake Superior marshes. Snapping turtles and bullfrogs are present in all Thunder Bay marshes (Entwistle, 1986). The central newt (*Notophthalmus viridescens louisianensis*), a rare amphibian in Ontario, is found in some coastal wetlands along the north shore of Lake Superior (D. Sutherland, pers. com.).

Lake Superior coastal wetlands provide important breeding and migratory habitat for waterfowl. Along the southern shore of Lake Superior, wetlands in Chequamegon Bay and the Portage Entry Marsh have been identified as significant areas of waterfowl production in the Great Lakes (Prince *et al.*, 1992). Canada geese and dabbling ducks including mallard, black duck, American widgeon and teal species are the most common waterfowl species. Portage Entry has one of the highest densities of breeding pairs of dabbling ducks in the Great Lakes (Prince *et al.*, 1992). Sea ducks and ruddy ducks which seldom nest in other Great Lakes coastal marshes, utilize Lake Superior marshes for breeding (Prince *et al.* 1992). Along the north shore of the lake, many migrating waterfowl use the wetlands along the shores of Batchawana Island and the Goulais River Wetland complex in the southeast and Mission Marsh in Thunder Bay in the northwest (Smith, 1987). Tens of thousands waterfowl and other water birds pass through the Thunder Bay Harbour marshes during spring and fall migration (Entwistle, 1986). The most abundant migratory waterfowl include Canada geese, scaup, other diving ducks and dabbling ducks.

Colonial birds such as the great blue heron, double-crested cormorant and American bittern are common summer residents in these coastal wetlands and breed in Thunder Bay marshes (Entwistle, 1986). Large numbers of great blue herons utilize the wetlands on the shores of Batchawana Island (Environment Canada, 1993), and the sandhill crane breeds in the Goulais River Wetland complex in Goulais Bay (Environment Canada, 1993). Rare bird species reported to utilize Lake Superior coastal wetlands during breeding season include bald eagle, peregrine falcon and short-eared owl, while yellow-headed blackbird uses them during migration (Entwistle, 1986).

6.1.3 Wetland Status

There are no comprehensive estimates of coastal wetland losses for Lake Superior. Along the north shore, large scale losses have not occurred because the shoreline is remote and sparsely populated. The only reported wetland loss has occurred in Northern Wood Preservers Marsh in Thunder Bay Harbour as a result of shoreline modification and urban encroachment (K. Bray, pers. com.). None of the wetlands outside the city of Thunder Bay have suffered significant wetland loss (S. Suke, pers. com.).

Coastal wetlands along Lake Superior are comparatively less affected by human stressors than those of the other Great Lakes. Water level regulation is the most widespread stressor and many other stressors affect wetlands on a site-specific basis.

Water level regulation has affected all coastal wetlands in Lake Superior. Water levels on Lake Superior have been regulated for much of the 20th century as a result of the locks at Sault Ste. Marie. The natural range of water levels is less than in other lakes. This range of fluctuations and the cyclic nature of high and low lake levels have not been altered substantially. However, the extreme low water conditions during the typical high summertime periods are not frequent enough to allow cyclic, regenerative processes to occur over a large enough range of elevations (Wilcox, *et al.*, 1993).

Nutrient enrichment and toxic contamination of waters and sediments in coastal wetlands is a site specific stressor of some coastal wetlands. Four Areas of Concern are located along the Canadian shore and three are located along the U.S. shore. In Canada, only Thunder Bay harbour has significant areas of coastal wetland which are potentially affected. Adjacent industrial land use in the harbour have been reported to stress these wetlands (K. Bray, pers. com.).

Along the northwest shore, other site specific stresses on coastal wetlands include recreational use, cottaging and the associated roads, especially in Cloud Bay, Pine Bay and Sturgeon Bay to the west of Thunder Bay; they may result in incremental loss of wetland area (S. Suke, pers. com.). Similarly, ongoing recreational use and cottage development along the northeast shore continually exerts pressure on coastal wetlands (K. Bray, pers. com.)

In U.S. coastal wetlands, site-specific stresses include harbour and marina development, shoreline development and road construction. Watershed runoff of sediments, especially from logging activity, can dramatically increase sediment inputs into tributaries which can also affect coastal wetlands near river mouths, especially in western Lake Superior where watersheds are dominated by fine clay soils (Johnston, 1992).

6.2 St. Marys River

6.2.1 Setting

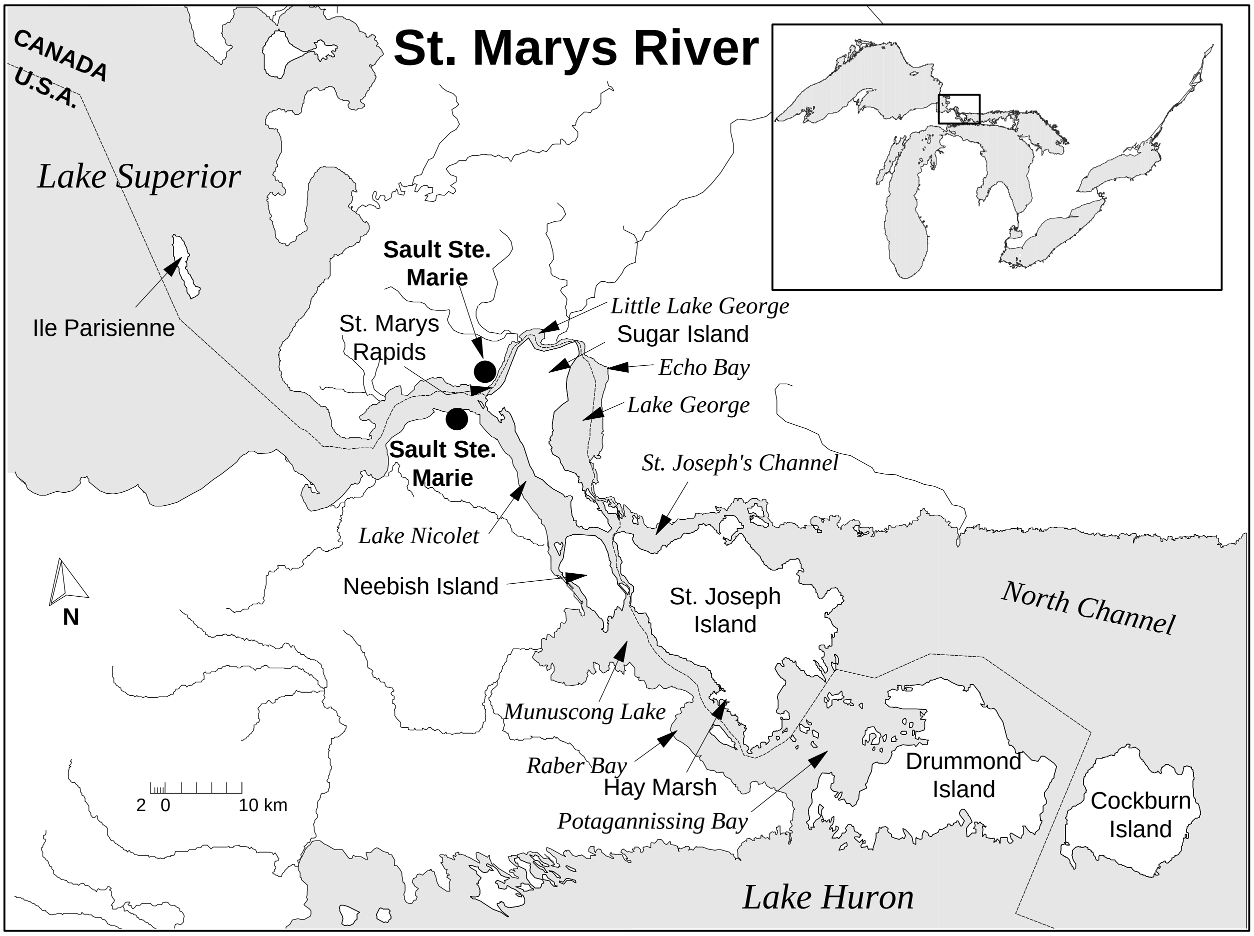


Figure 10. Map of the St. Marys River

The St. Marys River extends 112 km, draining Lake Superior into Lake Huron (Figure 8). It drops 6.7 m along its length, mostly at the 1.2 km long St. Marys Rapids in Sault Ste. Marie (Duffy *et al.*, 1987). Several islands occur in the river, including the large Sugar Island, Neebish Island, St. Joseph Island and Drummond Island. The river flows through several channels around these islands and through several large lakes including Lake Nicolet, Lake George and Munuscong Lake. Its shoreline stretches 292 km on the Canadian side and 390 km on the U.S. side (International Joint Commission, 1993). The river itself has several tributaries, draining a watershed of 2,830 km^2, but the water entering from these tributaries is only a small fraction of the drainage from Lake Superior (Kauss, 1991). Most of this watershed is forested (95%) (Kauss, 1991); the small urban and industrial areas are concentrated in Sault Ste. Marie, Ontario and Sault Ste. Marie, Michigan.

The upper river above the St. Marys Rapids has sandy and rocky shores, with emergent wetlands occurring only in protected areas (Duffy *et al.*, 1987). The lower river is bordered by extensive emergent marshes in shallow areas of the large lakes, bays and islands (Duffy *et al.*, 1987; Kauss, 1991). These are exposed to the river and often grade inland to palustrine wetlands, mostly marshes and swamps. Along the U.S. shore of the lower river, it is not uncommon for emergent wetlands to extend uninterrupted for 3-5 km along the shores (Duffy *et al.*, 1987). These wetlands are found especially along the shores of Lake George, Lake

Nicolet, Munuscong Lake, Potagannissing Bay and several of the larger islands including Sugar Island, Neebish Island, St. Joseph Island and Drummond Island.

In the U.S., 76 wetlands with 5,384 ha have been identified along the St. Marys River (Herdendorf, 1981e). Major wetlands on the U.S. side include the Sugar Island wetland complex (1,316 ha), Neebish Island wetland complex (812 ha) and the West Munuscong Lake complex (747 ha) and Rabber Bay wetland (644 ha) (Herdendorf, 1981e).

On the Canadian side, 8 wetlands have been evaluated totalling 3,705 ha and ranging from 42 ha to 2,275 ha, but at least 130 other wetlands greater than 2 ha have yet be evaluated in the lower river (S. Jones, pers. com.; A. Dupont, pers. com.). The largest evaluated wetlands include Hay Marsh along the southwest shore of St. Joseph Island (2,275 ha) and Echo Bay in Lake St. George (710 ha) (A. Dupont, pers. com.).

6.2.2 Significant Features

The emergent wetland areas of the St. Marys River serve as spawning, nursery and feeding habitat for 44 fish species (Duffy *et al.*, 1987). Sportfish such as northern pike, muskellunge, smallmouth bass, largemouth bass, yellow perch, and walleye are highly dependent on these marshes (Bray, 1993). Twelve species of reptiles and amphibians also depend on these wetlands, including the rare eastern massassauga which reaches the northern limit of its range along the southern edge of the St. Marys River in the U.S. (Duffy *et al.*, 1987).

The St. Marys River wetlands have been identified as a significant area of waterfowl production in the Great Lakes basin (Prince *et al.*, 1992). Common breeding species are Canada geese, mallard, blue-winged teal, black duck and common merganser (Duffy *et al.*, 1987). The wetlands are also important migratory staging areas, especially for diving ducks such as ring-neck duck, redhead and scaup species (Duffy *et al.*, 1987; Prince *et al.*, 1992). In terms of other birds, significant species breeding or using these wetlands include bald eagle, sandhill crane, short-eared owl and black tern (Duffy *et al.*, 1987; D. Sutherland, pers. com.).

6.2.3 Wetland Status

Historically, wetlands along the Canadian and U.S. shoreline have not suffered significant loss due to human influence (Bray, 1992; Williams and Lyon, 1991). There has been site-specific loss of wetland area along the shoreline of the city of Sault Ste. Marie from dredging, filling and sediment contamination (Bray, 1992). Most of the evaluated wetlands on the Canadian side have also suffered some recent loss, primarily from shoreline modification, dredging, filling, channelization and cottage development (S. Jones, pers. com.; A. Dupont, pers. com.).

The extent of human stressors affecting St. Marys River wetlands is not clearly understood, but these wetlands appear in general to be less impacted than other connecting channels downstream. These stressors are mostly site-specific in extent.

The entire river has been declared an Area of Concern due to elevated concentrations of contaminants in the water, localized contaminants of the sediments, the presence of fish tumours, localized impairment of the benthos and localized high bacterial counts (Hartig and Thomas, 1988). These impacts are especially heavy along the Canadian shore, downstream of Sault Ste. Marie, Ontario to Little Lake St. George (Kauss, 1991; Nichols *et al*,. 1991; Burt *et al.*, 1991). Local wetlands in these areas are therefore stressed to some degree from contaminants in the sediments, but the extent of these impacts are not clear.

Commercial shipping continues to produce stresses for wetlands in the St. Marys River. The passing of large commercial vessels in the shipping channels causes increased current speed, greater wave action, more erosion and more turbidity in these coastal wetlands, affecting plant rooting and growth and associated invertebrates and fauna (Manny *et al.*, 1987; Kauss, 1991). Dredging of the river also would affect the currents and sediment deposition patterns in the river, but the impacts on the sediment supply to coastal wetlands and their functioning are not clear. Tributaries to the St. Marys River can also produce excessive turbidity in nearshore areas during major runoff events as a result of the fine clay soils in their watersheds, especially in Munuscong Lake in the lower river (Kauss, 1991). The excessive turbidity negatively impacts coastal wetlands by reducing water clarity, plant growth and faunal interactions.

Cottaging also produces site-specific stresses on coastal wetlands. These stresses are associated with dredging and channelization for boat slips and marinas and the hardening of the shoreline (A. Dupont, pers. com.).

6.3 Lake Michigan

6.3.1 Setting

Lake Michigan, the only lake entirely in the U.S., covers a surface area of 57,800 km^2 and has a volume of 4,920 km^3. Its 118,000 km^2 drainage area includes parts of four states. The shoreline spans 2,633 km, including the shoreline of its islands. It has three major island groups, all in the northern portion of the lake: the Beaver Islands, the Fox Islands, and the Manitou Islands.

Land use within the lake's drainage area includes the largest urban area in the Great Lakes basin at the southern end of the lake, cropland and woodland over much of the western and eastern regions, and forested land in the most northern reaches. The coastal wetlands are concentrated along the rivers emptying into the lake along Michigan's western shore, in Green Bay, and embayments in the northern part of the lake.

In total, 411 wetlands covering almost 49,000 ha have been identified along the shores of Lake Michigan (Herdendorf *et al.*, 1981a). There are 61 wetlands larger than 100 ha, with 13 of these being over 1000 ha. The eight largest, which exceed 2,000 ha, are Big Bay de Noc (3,867 ha), Oconto Marsh (3,792 ha), Manistee River (3,705 ha), Sturgeon River (2,710 ha), and Pere Marquette River (2,532 ha), Muskegon River (2,449 ha), Seul Choix Point Complex (2,361 ha), and Peshtigo River (2,040 ha) (Figure 11).

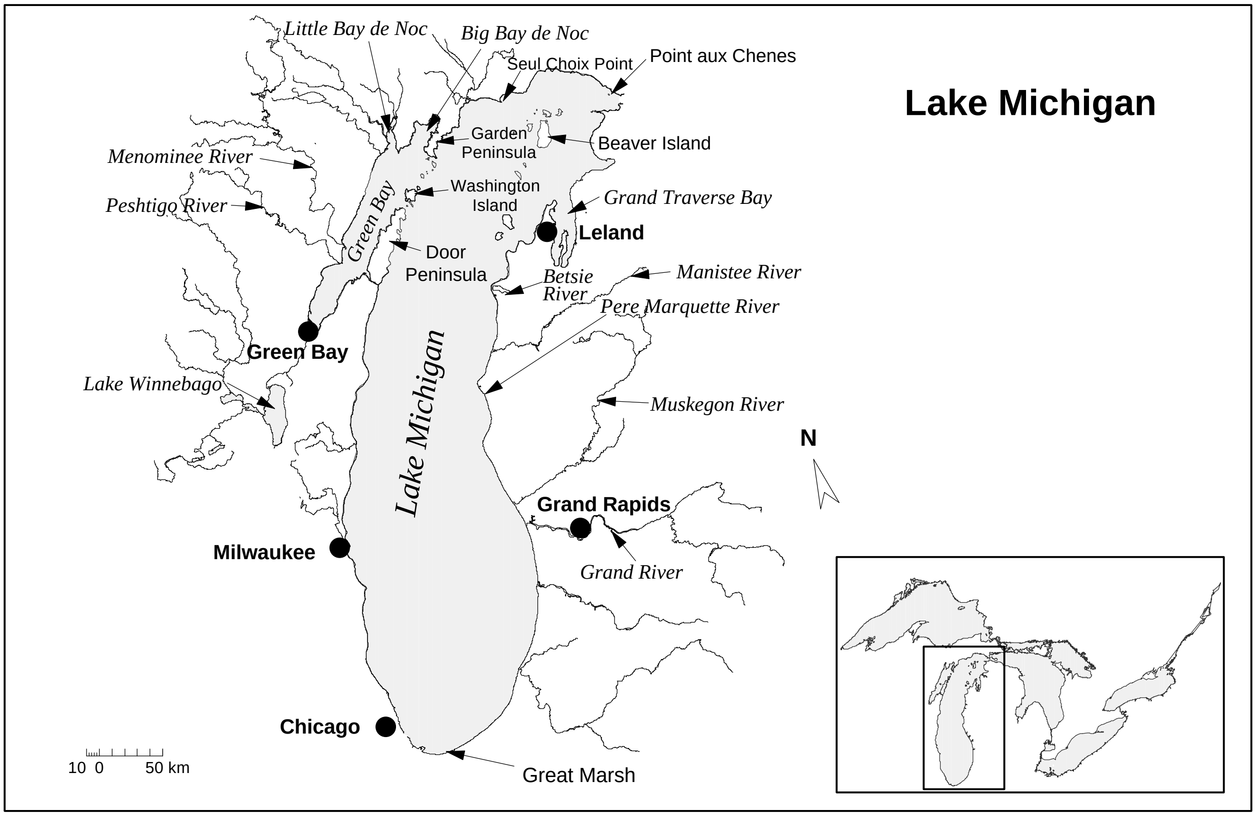


Figure 11. Map of Lake Michigan

As with the other Great Lakes, Lake Michigan owes its existence to recent periods of glacial advances and retreats. As the glaciers melted and retreated northward, the area that is today Lake Michigan was first uncovered at the southern end and drained southward into the Mississippi drainage. As the glaciers receded and relieved the land of their tremendous weight, isostatic rebound and the creation of other outlets at southern Lake Huron closed the southern outlet and Lake Michigan became connected with Lake Huron.

For several thousand years, the two lakes stood at approximately 184.4 meters, then fell in stages over a few more thousand years to about 181.4 meters (Door and Eschman, 1970). As the lake level fell, it left distinctive beach ridges parallel to the shore in embayments where sands had accumulated during short-term periods of high lake levels. Both lakes have averaged 176.3 meters (1985 Datum) from 1900 to 1992. Successive parallel berms are fairly common along the northern Lake Michigan shore. Between them, wetland swales have become established.

During lake-level recession, steep banks were exposed along the Wisconsin shore and the dune building process of accretion and closure of river mouths continued on the Michigan shore. Isostatic rebound also caused the southern shore to decrease in elevation with respect to the northern shore. Along the river valleys, behind the main dune lines, many river mouths were drowned as the land surface decreased in elevation. Where major rivers fed these lakes, outlets were maintained to Lake Michigan, and lake-connected wetlands developed in the upstream and shallow margins of these drowned river mouths. While marinas and urbanization this century have heavily encroached upon the drowned river mouth wetlands, they remain some of the largest extant tracts of coastal wetlands in the entire basin, with a fascinating history of constant transformation.

6.3.2 Significant Features

The shores of Lake Michigan run the gamut from high erodible banks to low lakeplains to rocky cliffs and stone beaches; thus each stretch has its characteristic features and associated wetland types.

Green Bay's western and northern shore has low sand banks fronted with low beach ridges and numerous fringe wetlands. Huge bulrush beds flank the shore in Big and Little Bay de Noc and other protected bays. Behind the active beach barrier, inactive beach ridges may exist which in turn flank large lagoons and interior marshes of cattails, open water, sedge meadows and shrub zones. Some of the finest examples of Great Lakes marshes are in northern Green Bay and along the eastern side of the Door Peninsula.

From northern Indiana and continuing northeasterly into Michigan, the most colossal shore feature in all the Great Lakes becomes apparent. These are the massive coastal dunes which flank the shore for about 370 km. These dunes run without interruption, except for river valleys, some cities, and roads along the entire shore to heights of 100 meters and breadths to more than a kilometer (usually less than 350 meters). They are extensively urbanized with summer homes and permanent residences in many stretches, often very close to the shore.

Ancient high lake levels of Lake Michigan began forming these dunes as beach ridges, and as the lake receded from the 189-meter stage (Door and Eschman, 1970) to the present day level of about 176.3 meters, the prevailing on-shore winds continued to blow beach sand up the slopes overtopping the crest to form running, active dune fields inland. There are no littoral marshes along this shore of Lake Michigan, but there are some extensive interdunal wetlands between the dune ridges, small intradunal wetlands in depressions within the dunes, and considerable wetlands tucked into and up every tributary. These are large "drowned river mouth" marshes that formed as lake levels rose from a lower previous level. Some are very extensive and all have been severely modified in their lower reaches due to marina, condominium development, housing, and other commercial enterprises.

A typical marsh system would be similar to that of the Betsie River. A narrow, short channel separates Betsie Lake from Lake Michigan. The dune fields are thus interrupted by the river valley, and Betsie Lake has had most its shoreline wetlands eliminated by bulkheads or shore maintenance. Betsie Lake then narrows in its upper reaches and merges within the Betsie River and its associated floodplain. Large tracts of floodplain wetlands then characterize the river for many kilometers, becoming narrower upstream. As Lake Michigan trends higher in some years, the wetlands near the channel recede to the floodplain and shore terraces because the water near the channel becomes too deep. When levels are low, mudflats often become exposed, quickly being colonized by new hydrophytes, and the wetlands expand to the channel margins. Thus, the diversity of the wetland vegetation is greatly enhanced by the natural fluctuations of the lake level.

North of Leland, through the Traverse Bays, and continuing north to the Straits of Mackinac, the shore of Lake Michigan changes again into rocky cliffs and bluffs, cobble beaches and occasional embayed wetlands of small size. The high relief shores preclude any opportunity for lakeplain wetland development and the actual shoreline is under constant wave attack from deep water. Along the offshore islands (Manitou, Fox, Beaver, etc) the situation is similar although a few do exist as lagoon wetlands protected from the main lake.

From the Straits westerly, the Michigan shore becomes distinct again, with low relief, multiple sand ridges being interrupted by shallow, sheltered bays. Many of these bays have large shoreline wetlands which intergrade into beach swales, wet meadows, and shrub thickets before the more upland plants become apparent. All along this stretch, the forest dune and swale complex is well developed, being leftover from ancient higher lake levels. These plants and features have recently been cataloged by Comer and Albert (1993). Where the major rivers or small creeks empty, riverine and lagoon wetlands flourish upstream, with good examples at practically every outlet. Along the Garden Peninsula, many embayed wetlands remain untouched, fronting on low relief uplands or tucked between large limestone cliffs.

It could be said the Lake Michigan is the most diverse of any of the lakes. Its shoreline changes continuously from one major landform to another, with each major type extending for hundreds of kilometers. It has lakeplains, high clay bluffs, low erodible bluffs, vast dune fields, rocky cliffs, glacial drift bluffs, sand ridge shores, and clay/pebble embayments flanked by ancient ridges. Its wetlands are equally diverse. The most common are the embayed, barrier beach, and riverine. Deltaic formation only occurs weakly at some Green Bay sites, because in all other situations the shore currents quickly carry away any alluvium or detrital accumulations.

The establishment of these diverse coastal wetland plant communities in turn provides habitat for numerous species of wildlife dependent on wetlands. Many insects have an aquatic larval stage. Amphibians also depend on wet conditions, at least during the larval stage. Many reptiles spend their entire lives in or near these coastal wetlands. Coastal wetlands provide important habitat for small fish, due to the abundant food supply and relative safety from predators. A great variety of birdlife uses coastal wetlands for foraging, resting, and breeding. Mammals too are an important part of the coastal wetland community.

It is because of the interactions between the various wetland plants and animals that each species is able to survive and flourish. The location of these coastal wetlands, with access both to the open lake and inland terrestrial systems, constantly augments the food chain and enhances the value of these wetlands as a refuge for a greater diversity of plant and animal life.

6.3.3 Wetland Status

South of Sturgeon Bay, all the way to Chicago, wetland development has been very limited because most of the shore is high bluffs with narrow, high energy beaches, and few unmodified river mouths. The rivers have small watersheds, thus limited sediment loads, and at all river mouths, urbanization has eliminated the wetlands. South of Chicago and around the bottom of Lake Michigan are many smaller and remnant wetlands and larger interdunal wetlands left from the heavy industrialization of the area. Some of these in the Calumet area are being restored and reconnected to the lake water table. The Green Bay area, however, has also suffered from severe losses and degradation of its wetlands. The drowned river mouth wetlands of the Michigan shoreline have had their hydrology altered by road crossings, thus increasing sediment deposition, and have been affected by ditching, agricultural practices, and colonization by invasive plant species. In the more unpopulated, northern extent of the lake, many of the wetlands remain intact.

6.4 Lake Huron

6.4.1 Setting

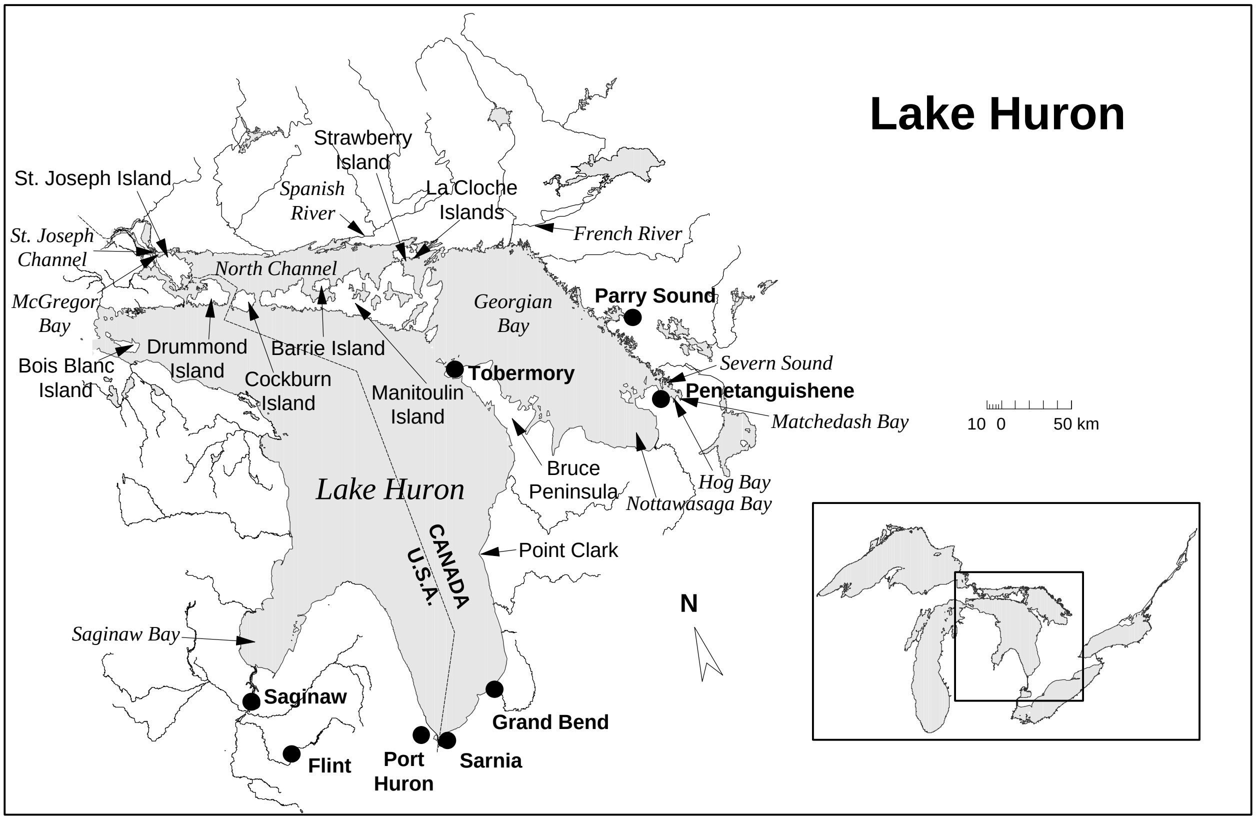


Figure 12. Map of Lake Huron

Lake Huron is the second largest Great Lake (Figure 9). Its surface area is 59,500 km^2, and the shoreline extends 6,373 km (International Joint Commission, 1989, 1993). It has many islands, ranging from large ones such as Manitoulin Island, St. Joseph Island, Cockburn Island, Bois Blanc Island and Drummond Island, to the many small islets of eastern Georgian Bay. Its drainage basin is 128,863 km^2 and is predominantly forested (66%), especially on the Canadian side, with lesser amounts of agricultural land (22%), residential and industrial land (10%) and other land uses (2%) (PLUARG, 1978).

Wetlands along the Canadian shore of Lake Huron are common in the sheltered environments of embayments and creek mouths and in the lee of large islands (Environment Canada, 1994). However, an accurate estimate of wetland area along the Canadian shore of Lake Huron has not been determined. Forty-three wetlands have been evaluated by the Ontario Ministry of Natural Resources in Lake Huron totalling

7,159 ha of wetlands and ranging in size from 5 ha to 807 ha. More than 100 wetlands greater than 2 ha in size still need to be evaluated, especially in the North Channel, along Manitoulin Island and in Georgian Bay (H. Ball, pers. com.). Bookhout *et al.* (1989) estimated that 12,600 ha of wetlands occurred in Georgian Bay alone. Wetlands of Lake Huron are generally smaller but more numerous than those in the southern Great Lakes and over half are wetland complexes. Marshes and swamps are equally dominant, and many have significant fen components.

Only six small coastal wetlands occur between Sarnia and Point Clark along the southeast Canadian coast as a result of high energy shoreline environments; they are predominantly swamps and total 341 ha (D. Hector, pers. com.; M. Malhiot, pers. com.). From Point Clark to the base of the Bruce Peninsula, the shoreline is mostly exposed, but 4 large wetlands totalling 885 ha are found in sheltered bays. They are mostly palustrine swamp and fen wetland complexes extending back from the shore (A. Murray, pers. com).

The western shore of the Bruce Peninsula and southern shore of Manitoulin Island have exposed irregular shorelines, with wide and shallow, boulder-strewn, limestone bedrock shelfs, many small islands and reefs and many sheltered bays. The irregular coast and islands provide many sheltered, low energy and bay environments where wetlands can develop (Environment Canada, 1994). Ten wetlands have been evaluated on the western side of the Bruce Peninsula, primarily large wetland complexes with swamp, marsh and fen components, totalling 1653 ha (A. Murray, pers. com.). At least 17 unevaluated wetlands also occur on the southern shore of Manitoulin Island which appear to possess similar characteristics to those of the western side of the Bruce Peninsula (Environment Canada, 1994; Natural Heritage Information Centre, 1995).

The eastern shoreline of the Bruce Peninsula in Georgian Bay is rugged with steep nearshore slopes, preventing the development of extensive wetlands. The long mostly sandy shore of Nottawasaga Bay also lacks wetlands except in interdunal areas, a few harbours and river mouths. Southern Georgian Bay is rocky, but some sheltered embayments occur where a number of shoreline marshes have developed (eg. Matchedash Bay) (Environment Canada, 1994). Twenty-two wetlands totalling 3,978 ha have been evaluated between Tobermory and the French River (G. Allen, pers. com.; R. Black, pers. com.). They are primarily lacustrine wetlands and some palustrine marshes with large swamp components. A few of these wetlands also have minor bog and fen components.

The shoreline of the north channel and northern Georgian Bay is extremely complex with bedrock outcrops, islands and bays. The mainland coast is very sheltered from wind and wave action due to numerous islands, headlands and embayments (Environment Canada, 1994). Wetlands develop in the protected embayments of the islands and the mainland. There are at least 60 wetlands in this area (H. Ball, pers. com.), but only one has been evaluated, at the mouth of the Spanish River (305 ha) (W. Sellinger, pers. com.). Unevaluated wetlands occur primarily in the protected bays of St Joseph's Channel, along the north shore of Manitoulin Island, near Barrie Island, Strawberry Island, La Cloche Islands and in McGregor Bay (Environment Canada, 1994).

6.4.2 Significant Features

Wetlands in Lake Huron have more complex vegetation communities than those in the southern Great Lakes. The large amount of fen and swamp habitat, the diversity of wetland types, the variations in geomorphology and the calcareous soils all contribute to this complexity (Smith *et al.*, 1991). The fens which commonly occur in Lake Huron and Georgian Bay wetlands, also known as shoreline meadow marshes, have been identified by the Nature Conservancy as globally imperiled communities (Natural Heritage Information Centre, 1995). Over 40 species of rare plants have been found in coastal wetlands of Lake Huron (Wilcox, 1995). For example, the coastal meadow marshes of Lake Huron and Georgian Bay support some of Ontario's rarest plant species, including Spike-rush (*Eleocharis geniculata*), Bluehearts (*Buchnera americana*), Three-awn (*Aristida longespica*), Rigid Sedge (*Carex tetanica*), Yellow Cyperus (*Cyperus flavescens*), and Stiff Yellow Flax (*Linum medium* var. *medium*) (Natural Heritage Information Centre, 1995).

Fifty-nine fish species utilize the coastal wetlands of Lake Huron (Prince *et al.*, 1992; Severn Sound Remedial Action Plan, 1993a). Over half are permanent residents while the remainder use them on a temporary basis for feeding, shelter, spawning, nursery, dispersal of young and migratory wandering. Largemouth bass, rock bass, bluntnose minnow, pumpkinseed and banded killifish are the most common permanent residents (Severn Sound Remedial Action Plan, 1993a). Sportfish such as northern pike, walleye, muskellunge and smallmouth bass also depend on these wetlands along with many species of bait fish. Eleven rare fish species use these coastal wetlands (Sutherland, 1994; Mandrak and Crossman, 1992); permanent residents include pugnose shiner, striped shiner, quillback, lake chubsucker, river redhorse, grass pickerel, green sunfish, and longear sunfish, while species that use the wetlands on a temporary basis include the golden redhorse, stonecat and brook silverside.

Lake Huron wetlands also provide important habitat for amphibians and reptiles. The amphibians use them for spawning, nursery and feeding. Reptiles nest on uplands, but many species spend the remainder of their life cycle in these wetlands. Five significant reptile species have been found in the coastal wetlands of Lake Huron and Georgian Bay, including wood turtle, spotted turtle, eastern spiny softshell, queen snake and eastern massassaga (Wilcox, 1995; D. Sutherland pers com).

Prince *et al.* (1992) identified the marshes of Georgian Bay and Saginaw Bay as significant areas of waterfowl production in the Great Lakes. At least 2,100 and 4,400 pairs of dabbling ducks nest in Georgian Bay wetlands and Saginaw Bay wetlands respectively (Prince *et al.*,1992). The wetlands of Lake Huron are also important during migration for significant species such as the red-necked grebe, northern shoveler, and redhead duck. In terms of other birds, 14 significant species use Lake Huron coastal wetlands for breeding, feeding or during migration (D. Sutherland, pers. com.). These include breeding sites for great egret, least bittern, black-crowned night heron, northern shoveler, redhead, ruddy duck, little gull, black tern, Forster's tern and red-shouldered hawk.

Lake Huron wetlands provide habitat for many fur-bearing mammals including mink, beaver, river otter, raccoon, red fox and muskrat. In south and central Lake Huron, the coastal swamps provide significant winter cover for white-tailed deer. Moose occur in the wetlands along the north shore of Georgian Bay.

6.4.3 Wetland Status

Along the Canadian shore of Lake Huron, no comprehensive estimates of coastal wetland loss are available. Loss of wetland habitat on a large scale has not occurred because most of the shoreline is sparsely populated and remote. Most losses tend to be concentrated around the small urban centres that dot the shore. Within the last 10 years, there has been incremental and site-specific loss of wetland area from agricultural encroachment and cottage development. More than half of the wetlands along the central coast, the western coast of the Bruce Peninsula and southern Georgian Bay have suffered recent loss of acreage (A. Murray, pers. com.; G. Allen, pers. com.; R. Black, pers. com.). A study of wetland loss in Severn Sound in southern Georgian Bay indicated that wetland habitats have decreased by 68% and 18% in Penetanguishene and Hog Bay respectively since 1951 (V. Cairns pers. com. in Severn Sound Remedial Action Plan, 1993b). The main causes for these wetland losses are shoreline modification, road construction, filling for urban and cottage development and dredging and channelization associated with marina development (Severn Sound Remedial Action Plan, 1993a). The wetlands along shoreline of the North Channel and northern Georgian Bay have only suffered small losses, however cottaging, marina and subdivision development continually puts pressure on these coastal wetlands through dredging and modification of the shoreline (W. Selinger, pers. com.).

Along the Canadian shore, remaining wetlands do not appear to be as impacted by human stresses as compared to the southern lakes. Stresses appear to be site-specific and localized in extent.

Besides causing wetland loss, urban encroachment, cottaging and marinas cause multiple stresses on remnant wetlands. On the western Bruce Peninsula and southern Georgian Bay, these stresses include shoreline modification, road crossings, dredging and channelization. Shoreline modification prevents the landward migration of remnant wetlands during high water periods. Road crossings alter their hydrology and, along with dredging, filling and channelization, fragment the remaining wetland habitat.

Wetlands in the bays of southeastern Georgian Bay are affected by nutrient and sediment loading from watersheds. Excessive phosphate inputs to these bays originate from point and non-point sources associated with urban areas and agriculture (Severn Sound Remedial Action Plan, 1993a). Excess sediment loadings originate mostly from non-point source inputs, mainly agricultural runoff (Severn Sound Remedial Action Plan, 1993a).

Non-indigenous species including purple loosestrife, carp and zebra mussels are also localized stressors in Georgian Bay. Purple loosestrife is especially a problem in southern Georgian Bay (G. Allen, pers. com.).

6.5 St. Clair River

6.5.1 Setting

The St. Clair River drains Lake Huron into Lake St. Clair. It forms a large bird-foot delta with many distribution channels and wetlands where it meets the lake. This delta is a transitional environment between the river and the lake. For the sake of clarity, the delta and its coastal wetlands are covered under the assessment of wetlands of Lake St. Clair. The first 43 km of the St. Clair River are considered here, between Lake Huron at Sarnia-Port Huron and the first distribution channel of the delta, Chenal Ecarté across from Algonac.

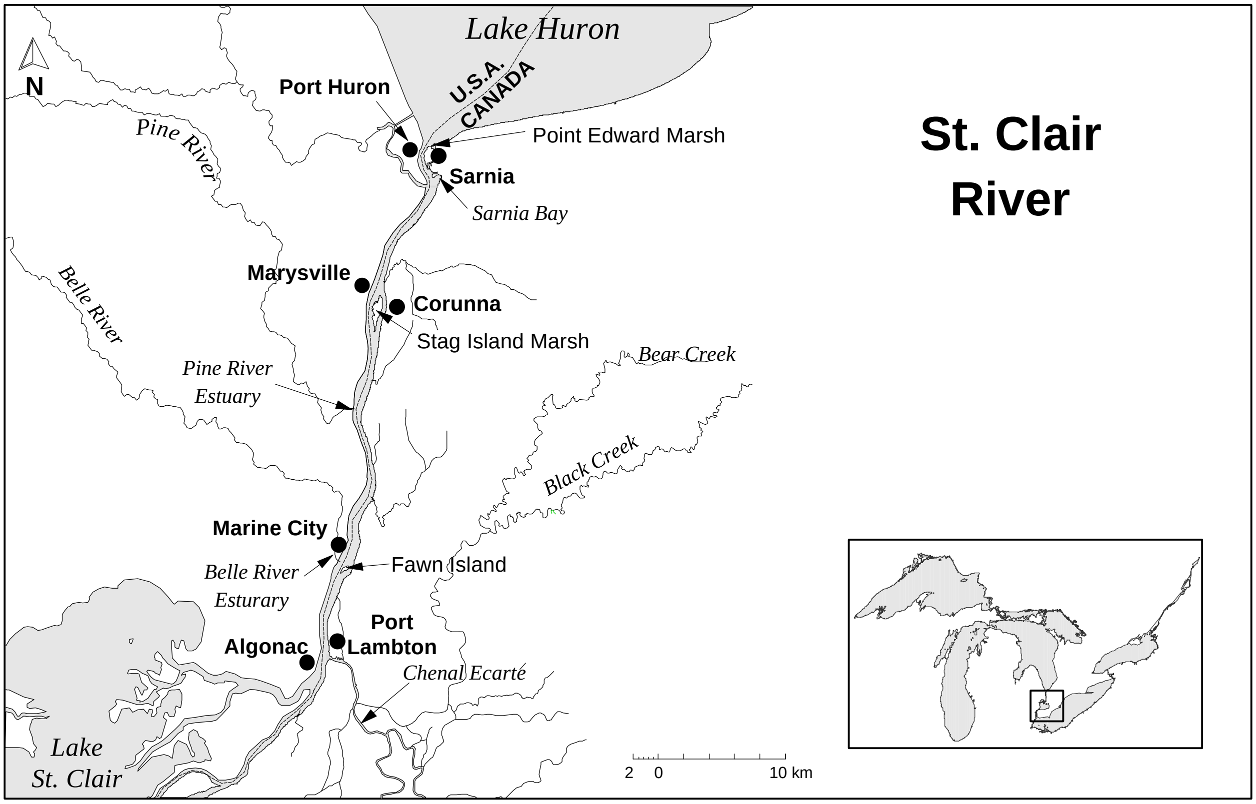


Figure 13. Map of the St. Clair River

The river above the delta is a uniform channel with very few bends or meanders, no cutoff channels or oxbow lakes and only two islands, Stag Island and Fawn Island (Edsall *et al.*, 1988). The river drops only 1.4 m between Lake Huron and the beginning of the delta at Chenal Ecarté, but it has relatively high flows, with an average flow velocity reaching 3.2 km/hr. The natural shoreline has a bank of 1.5-5 m high (International Joint Commission, 1989), but most of this shoreline is now artificial, especially on the U.S. side (Ontario Ministry of the Environment and Michigan Department of Natural Resources, 1991).

Several small tributaries drain into the river, mostly from the U.S. side, including Black River, Pine River and Belle River (Ontario Ministry of the Environment and Michigan Department of Natural Resources, 1991). However, the overwhelming majority of the flow in the river comes from Lake Huron. Including the delta, the drainage basin of the river is 3,368 km^2 and is mostly agricultural (69%). The urban areas are concentrated in a narrow zone along the river with the larger centres being Sarnia in Ontario and Port Huron, Michigan. Much of the industry is concentrated in Ontario in the first 14 km of the river between Sarnia and Corunna, a stretch of shoreline known as 'Chemical Valley'.

The lack of shoreline complexity, along with the fast current, the depth of the river and wave forces generated by the passage of large commercial vessels limits wetland development along the banks of the river (Edsall *et al.*, 1988; Bookhout *et al.*, 1989). Wetlands occur primarily on the shallow submerged shoals of the river and tributary channels and consist mostly of submergent macrophyte beds (Edsall *et al.*, 1988; Griffiths *et al*., 1991).

There is no clear estimate of the area of coastal wetland in the St. Clair River above the delta. Edsall *et al.*, (1988) identified 550 ha of coastal wetlands in the entire St. Clair River based on navigation charts and topographic maps, but do not provide the location and size of individual wetlands. Conversely, Bookhout *et al.* (1989) only identify 96 ha of coastal wetland, all along the Ontario shore. Extensive submergent macrophyte beds are known to occur in Sarnia Bay, around Stag and Fawn Islands and along the Canadian shoreline near these islands (Griffiths *et al.*, 1991). In Ontario, only 13 ha of wetlands have been evaluated along the river, namely the Stag Island Marsh and the Point Edward Marsh. Along the U.S. shoreline four small wetlands occur at Port Huron, Marysville, Pine River Estuary and the Belle River Estuary (Herdendorf *et al.*, 1986). All these estimates indicate that wetlands are now uncommon habitats in the St. Clair River above the delta. The remaining wetlands are therefore particularly important habitats for plants, fish and wildlife in the river.

6.5.2 Significant Features

Wetlands in the St. Clair River are primarily composed of submersed species, but emergent macrophytes also occur (Edsall *et al.*, 1988; Griffiths *et al*., 1991). Four rare plant species have been found in the shallow water and meadow marshes, including four-angled spikerush (*Eleocharis quadrangulata*), winged loosestrife (*Lythrum alatum*), many-fruited false loosestrife (*Ludwiga alternifolia*) and Walter's barnyard grass (*Echinochloa walteri*) (W. Bakowsky, pers. com.).

Unlike Lake St. Clair and the delta of the river, the river above the delta are not important breeding sites or migration corridors for waterfowl (Bookhout *et al.*, 1989). Waterfowl do winter in wetlands in the river when nearby marshes with less current are frozen since thermal pollution and current keep the river open. Common species are common merganser, redhead, canvasback, American widgeon, mallard and scaup. In terms of other birds, a few significant species breed in the wetlands of the St. Clair River including least bittern, ruddy duck, American coot and Forster's Tern (Austen *et al.*, 1994).

Forty-five species of fish have been recorded using the wetlands of the St. Clair River (Edsall *et al.* 1988; Mandrak and Crossman, 1992). Over half of these are permanent residents, with brown bullhead, common carp and white perch being the most abundant. Other species use the wetlands on a temporary basis for spawning, nursery and feeding; the most abundant species include the white sucker, alewife, rainbow smelt, gizzard shad and rockbass. Several important sport fish also use the wetlands on a temporary basis including northern pike, muskellunge, walleye, yellow perch, smallmouth bass and largemouth bass (Edsall *et al.*, 1988). Four significant fish species also inhabit the St. Clair River wetlands, including pugnose minnow, green sunfish, stonecat and brook silverside (Mandrak and Crossman, 1992; Sutherland, 1994).

Many species of amphibians and reptiles, including salamanders, frogs, toads, snakes, lizards and turtles, also occur in these wetland habitats (Edsall et al. 1988). Two significant reptiles inhabit St. Clair River wetlands, namely the eastern spiny softshell and the eastern fox snake (D. Sutherland, pers. com.).

Mammals commonly found in the coastal wetlands of the St. Clair River include the Virginia opossum, eastern cottontail rabbit, muskrat, striped skunk and white-tailed deer (Edsall *et al.*, 1988).

6.5.3 Wetland Status

Some wetland loss appears to have occurred along the shores of the St. Clair River above the delta, but there is no comprehensive estimate of the extent of loss. In Ontario, there are known wetland losses of 3 ha at Point Edward and 40 ha at Stag Island.

Almost all of the U.S. shoreline and most of the Canadian shoreline consists of residential, recreational and industrial developments and has been extensively modified (Edsall *et al.*, 1988). The river is also an important port. As such, wetland loss in the river appears to be largely related to extensive bulkheading, shoreline hardening, filling, channelization and dredging along the shores of the river. These activities also fragment the few remaining wetlands along the river. Urban encroachment continues to cause wetland loss and impairment on the Canadian side (D. Hector, pers. com.).

Several other human activities stress remnant wetlands along the river. The river is a busy seaway and port. Ship wakes from large commercial vessels are an important stressor to shoreline habitats, including remnant coastal wetlands, by eroding the shoreline and hampering the establishment of aquatic macrophytes.

The St. Clair River was declared an Area of Concern (AOC) as a result of the excessive levels of toxic substances in the water, contaminated sediments, impaired benthos and bacterial contamination (Hartig and Thomas, 1988). Industry is the main source, but municipal sewage treatment plants, other point sources and nonpoint sources are also concerns (St. Clair River Remedial Action Plan, 1995). Although progress has been made in cleaning up the river, impaired benthos still indicates contaminated sediments downstream of industrial outfalls, mainly along the Canadian shoreline (Griffiths, 1991; St. Clair River Remedial Action Plan, 1995). Remnant wetlands are particularly vulnerable to contamination by toxic chemicals since they are located in sediment accumulation zones along the shore.

6.6 Lake St. Clair

6.6.1 Setting

Lake St. Clair is a shallow productive lake located between the St. Clair River and the Detroit River. Where the St. Clair River meets Lake St. Clair, an expansive bird-foot delta has formed which has many distribution channels, islands and wetlands. This delta is included here in the assessment of the wetlands of Lake St. Clair.

Lake St. Clair is heart-shaped with a surface area of 1,115 km^2 (Edsall *et al.*, 1988). The basin is very shallow and has a maximum natural depth of 6.5 m, although a commercial shipping channel has been dug across the lake to a depth of 8.5 m. The shoreline, excluding the distributary channels in the delta, extends

272 km (Edsall *et al.*, 1988). Several large tributaries flow into the lake including the Sydenham River and the Thames River in Ontario and the Clinton River in the U.S.. Together they drain a basin of 12,616 km^2, and agricultural land uses predominate (Edsall *et al.*, 1988). These tributaries only contribute 2% of the flow to the lake; the remainder flows from the St. Clair River.

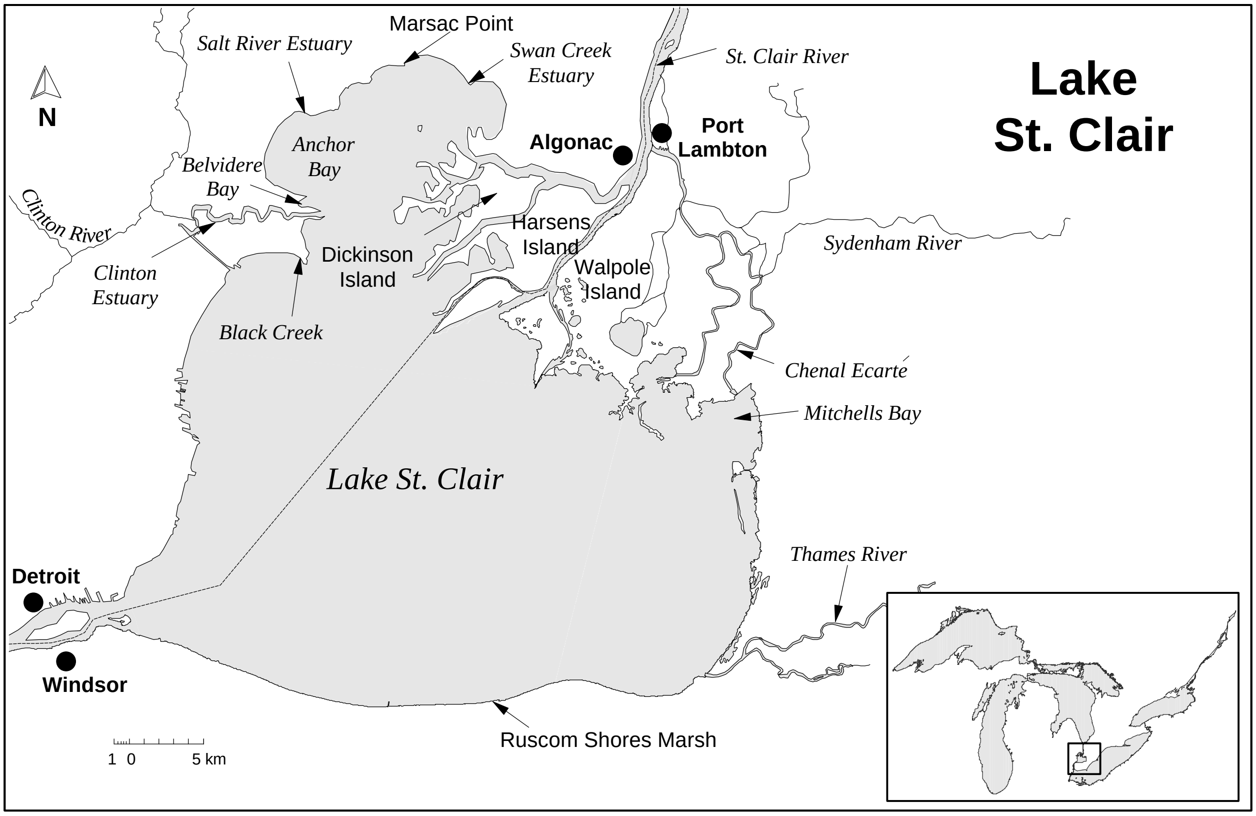


Figure 14. Map of Lake St. Clair

The St. Clair River enters the lake in the northeast forming a large delta. The topography is very flat and the river drops only 0.2 m over 17 km through the delta (Edsall *et al.*, 1988). There are numerous distribution channels, but the majority of the flow (92%) passes through the western half of the delta through the North, Middle and South Channels. This delta is the product of long-term geological and riverine processes; its development is linked to the deposition of sediments as the river slows to meet the lake. Sediments which continue to feed this delta originate from the nearshore areas of southern Lake Huron (Edsall *et al.*, 1988).

Lake St. Clair and the St. Clair Delta contain some of the largest coastal wetlands in the Great Lakes. There are many estimates of the aerial extent of these wetlands. However, since the topography surrounding much of the lake and especially in the delta is almost flat, water level fluctuations greatly affect their extent and position. Large changes in wetland area are especially great between years of high and low water levels (Herdendorf *et al.*, 1986). While these changes are important for the diversity of habitat, they make it difficult to compare different estimates of wetland extent in the lake.

The largest wetlands in the lake are found in the St. Clair Delta, which harbours a vast complex of lacustrine, riverine and palustrine wetlands. On the Canadian side of the St. Clair Delta, there are at least 12,769 ha of coastal wetlands (D. Hector, pers. com.). The major wetlands lie in the Walpole Island Indian Reserve (10,360 ha) and have not been evaluated. Four other wetlands have been evaluated on the Canadian side of the delta ranging from 3 ha to 2,335 ha, the largest being the St. Clair Marshes Complex in Mitchell's Bay (2,335 ha). Of these wetlands, around a third have been diked for intensive waterfowl management (Bookhout *et al.*, 1989).

On the U.S. side of the delta, there are around 3,500 ha of wetlands (Herdendorf, 1992). The major coastal wetlands include St. Johns Marsh (445 ha), Dickinson Island (2,023 ha) and Harsens Island (1,053 ha) (Bookhout *et al.*, 1989). Large parts of Harsens Island wetlands and all of St. Johns Marsh are diked; the former is diked for intensive waterfowl management while the latter is effectively diked by roads and housing developments, but is not managed specifically for waterfowl (Herdendorf *et al.*, 1986).

Outside the delta, remnant lacustrine marshes occur primarily near mouths of rivers and creeks along the northern and eastern shores of the lake. Very few wetlands occur along the highly developed southern and western shores. In Ontario, four wetlands are located along the eastern shore totalling 159 ha and ranging from 4-131 ha; the largest occurs at the mouth of the Thames River (131 ha) (D. Hector, pers. com). Many of these wetlands are diked (Herdendorf *et al.*, 1986). Only one small wetland, Ruscom Shores Marsh (29 ha) is found on the southern shore. In the U.S., six wetlands are located in Anchor Bay and near the mouth of the Clinton River along the northwest shores of the lake (Edsall, *et al*., 1988). They include the Clinton River Estuary, Black Creek (196 ha), Belvidere Bay (40 ha), Salt River Estuary, Marsac Point (2 ha) and the Swan Creek Estuary (31 ha) (Herdendorf *et al.*, 1981c; Edsall *et al.*, 1988).

6.6.2 Significant Features

Herdendorf *et al.* (1986) identify twelve different wetland habitats in Lake St. Clair and the delta, each with different vegetation and environmental characteristics. As a result of this diversity of habitats and the size of the wetlands, Lake St. Clair has some of the most diverse wetlands in the Great Lakes for plants, fish and wildlife. These wetlands provide habitat for many common species, but also and provide some of the most important habitat for rare flora and fauna.

Fourteen significant plant species have been found in the coastal wetlands of Lake St. Clair (W. Bakowsky, pers. com.). For example, these include the very rare four-angled spikerush (*Eleocharis quadrangulata*), as well as southern tickseed (*Bidens coronata*), Emory's sedge (*Carex emoryi*), honey locust (*Gledistsia triacanthos*), tapered rush (*Juncus acuminatus*), swamp rose mallow (*Hibiscus moscheutos*), American lotus (*Nelumbo lutea*), many-fruited false loosestrife (*Ludwiga alternifolia*) and prairie fringed orchid (*Platanthera leucophaea*).

The Lake St. Clair marshes provide habitat for more than 65 species of fish (Edsall *et al.*, 1988; Mandrak and Crossman, 1992). Two-thirds of the fish species are permanent residents; the most common species are rock bass, bluegill, black bullhead, yellow bullhead, channel catfish, alewife, white perch and common carp. Other fish use the wetlands on a temporary basis for spawning, nursery, shelter or feeding; common species include white sucker, rainbow smelt and alewife. Several sportfish also commonly use these wetlands including northern pike, muskellunge, walleye, yellow perch, smallmouth bass, crappie and sunfish species (Edsall *et al.*, 1988; Pappas and Jude, 1992). Lake St. Clair is one of only two sites with large muskellunge populations in the Great Lakes (Edsall *et al.*, 1988). The only large spawning area for muskellunge left in Lake St. Clair is in Anchor Bay, Michigan, while the shallow marshes of the delta are the only known nursery areas for muskellunge in the entire St. Clair River, Lake St. Clair and Detroit River system (Edsall *et al.*, 1988).

Many species of amphibians and reptiles also occur in the wetland habitats of Lake St. Clair, including salamanders, frogs, toads, snakes, lizards and turtles (Edsall *et al.*, 1988). Five significant reptiles inhabit Lake St. Clair wetlands, including eastern fox snake, queen snake, spotted turtle and eastern spiny softshell turtle (D. Sutherland, pers. com.).

The St. Clair River Delta has been identified as one of the most significant areas for waterfowl production, staging and migration in the Great Lakes (Prince *et al.*, 1992; Bookhout *et al.*, 1989). Approximately 16% of all the Great Lakes coastal wetlands of importance to waterfowl are found in the St. Clair Delta (Prince *et al.*, 1992). In terms of breeding waterfowl, the highest densities of mallard, black duck, blue-winged teal and green-winged teal in the Great Lakes basin are found in the wetlands of the St. Clair Delta. Redheads are the only species of diving duck that breeds regularly in the Great Lakes, and the St. Clair Delta wetlands produce up to 4,000 redheads annually (Prince *et al.*, 1992). The delta wetlands also provide nesting habitat for Canada geese and ruddy duck. The St. Clair Delta also lies on major migration corridors of both dabbling and diving ducks (Bookhout *et al.*, 1989). They provide one of the most important staging and feeding grounds for postbreeding and migratory Canada geese, tundra swan and dabbling ducks on the Great Lakes. The delta is also one of the major fall staging areas in North America for canvasbacks and redheads (Prince *et al.*, 1992).

The wetlands provide habitat for many other species of birds. American coot, herring gull, common tern, red-tailed hawk and northern harrier are commonly observed in Lake St. Clair marshes (Herdendorf, 1992). Waterbirds such as great blue heron, American bittern, least bittern, great egret and black-crowned night heron breed here. Large nesting colonies of great blue heron and black-crowned night heron occur in the marshes of Walpole Island (Smith *et al*., 1987). Walpole Island marshes also support the largest number of nesting pairs of Forster's tern on the Great Lakes and provide nesting habitat for the black tern (Smith *et al*., 1991). Other rare birds breed here including bald eagle, king rail, white-eyed vireo, Louisiana waterthrush and the yellow-headed blackbird (D. Sutherland, pers. com.).

More than a dozen species of mammals use the Lake St. Clair wetlands. The Virginia opossum, eastern cottontail rabbit, muskrat, striped skunk and white-tailed deer are common (Edsall *et al.*, 1988). Muskrat and raccoon are important furbearers and are extensively trapped in the region.

6.6.3 Wetland Status

Lake St. Clair and the St. Clair Delta have been extensively studied in terms of wetland loss. Overall, these wetlands were reduced by 9,139 ha or by 41% between 1868 and 1973. The most extensive losses have occurred at the mouth of the Clinton River, in the St. Clair Delta and along the eastern shore of the lake (Herdendorf *et al.*, 1986).

On the Michigan side of the lake and delta, 4,375 ha or 51% of the wetlands have been lost between 1873 and 1968 (Edsall *et al.*, 1988). These losses occurred mostly in the St. Clair Delta, along Anchor Bay and near the mouth of the Clinton River. For instance, the Clinton River had over 1295 ha of wetlands in 1868, but by 1973, it had been reduced to 221 ha (Edsall *et al.*, 1988). Agriculture and urban and recreational development are the major causes of wetland loss (Herdendorf *et al.*1986). Most of the U.S. shoreline is now developed with marinas, urban or cottage developments; wetland loss from urban and recreational encroachment is still a problem (Edsall *et al.*, 1988).

Along the Ontario shoreline, 4,764 ha or 34% of coastal wetlands have been lost in the delta and the lake between 1873 and 1968 (Edsall et al, 1988). In 1873, the wetlands along the eastern shoreline of the lake were approximately 2.5 km wide, but by 1968, wetlands were reduced in width to around 0. 8 km wide. Much of this loss is due to large scale conversion of wetlands to agriculture. More recently, wetlands along the east shore of the lake, from the mouth of the Thames River to Chenal Ecarté, further dwindled by 1064 ha between 1965 and 1984 (McCullough, 1985). This loss was mostly a result of agricultural drainage (89%), but some loss was due to marina and cottage development (11%). The wetlands on the Ontario side of the St. Clair Delta are intact in many places, but shoreline development, dredging and placement of dredge spoils have taken their toll. Between 1965 and 1978, 508 ha or 4.5% of the wetlands on Walpole Island were lost (McCullough, 1982). Recently, wetland loss to agricultural and urban development has continued in the lake and delta, albeit at a slower pace (D. Hector, pers. com.).

Urban, recreational and agricultural encroachment not only cause wetland loss but also stress remaining wetlands. In many cases, shoreline hardening such as bulkheading and diking associated with urban areas and agriculture restrict the landward migration of wetland communities during high water periods. This causes a backstopping effect which reduces the size and diversity of wetland communities. Recreational and urban developments also fragment the remaining wetland area.

Another major stress is the diking of wetlands. About half of the wetlands in Lake St. Clair and the St. Clair Delta have been diked (Bookhout *et al*., 1989). They are managed mainly for waterfowl hunting at the expense of other wetland functions (Herdendorf, et al., 1986; Jude and Pappas 1991). Diking isolates these wetlands from the upland and lake environments, and many wetland functions are impaired. Their use by fish for spawning, nursery or feeding are impeded or cannot take place. Many of the fish species in the lake are dependent on wetlands for part of their life cycle (Edsall *et al*., 1988). Diking also disrupts the food chain of the remainder of the lake by reducing organic material inputs into the lake (Herdendorf et al., 1986). Furthermore, the diversity of wetland habitats are decreased since water level controls are used to maintain particular vegetation and environmental conditions (Herdendorf *et al.*, 1986).

Other stresses to these wetlands include sediment and nutrient loading from tributaries and invasive species such as reed canary grass (*Phalaris arundinacea*) and purple loosestrife (*Lythrum salicaria*) (D. Hector, pers. com.).

6.7 Detroit River

6.7.1 Setting

The Detroit River connects Lake St. Clair to Lake Erie. It is 51 km long and drops only 0.9 m along its length (Manny *et al.*, 1988; Figure 10). The shoreline stretches 107 km on the Canadian side and 127 km on the U.S. side (International Joint Commission, 1989). Several islands occur in the river, with the largest, Grosse Ile, near its mouth. Around 95% of the total flow in the river enters from Lake St. Clair (Manny *et al.*, 1988), and the remainder flows from tributaries and sewer systems, draining a watershed of 1844 km^2 (Manny and Kenaga, 1991). The Canadian portion of this watershed is largely agricultural (90%), and the remaining consists of urban, residential and industrial lands, centred around Windsor in the northern reaches of the river (Manny and Kenaga, 1991). The U.S. portion of the watershed is only 30% agricultural, while the remainder is residential (30%), urban (30%), and industrial (10%) (Manny and Kenaga, 1991). Over 5 million people live in the Detroit River watershed. The natural shoreline consists of clay banks, but 87% of the U.S. shoreline and 20% of the Canadian shoreline is now artificial with revetments and other shoreline hardening structures (Manny and Kenaga, 1991; International Joint Commission, 1993).

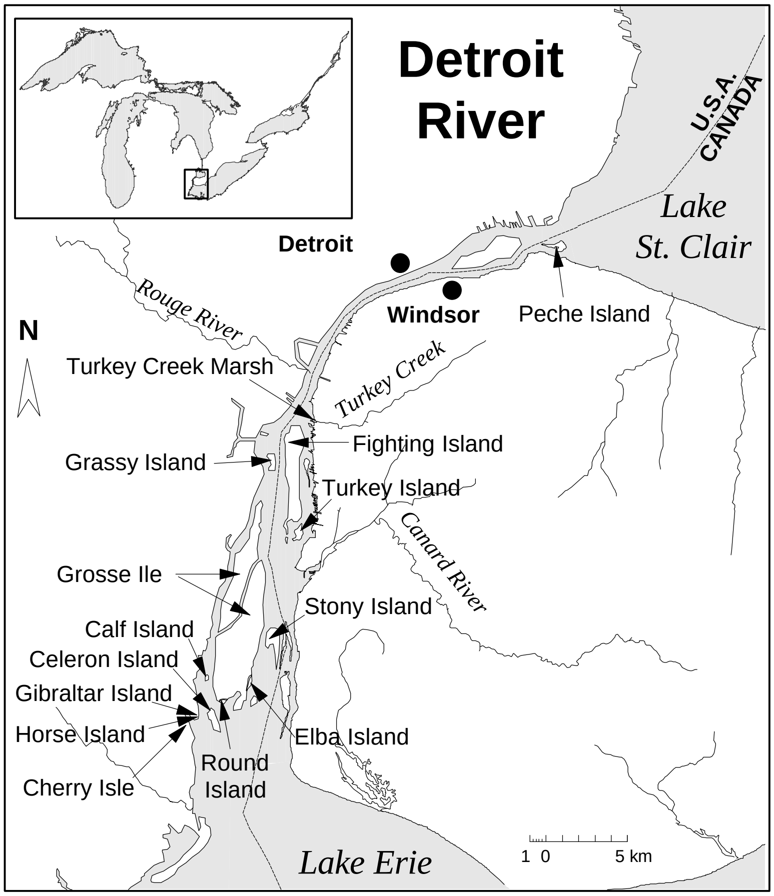


Figure 15. Map of the Detroit River

Along the Canadian shore, 5 coastal wetlands have been evaluated by the Ontario Ministry of Natural Resources, primarily in the middle reaches of the river; they total 1,136 ha and range in size from 32-575 ha (D. Hector, pers. com.). The Detroit River Marshes near Fighting Island represent the largest wetland complex (575 ha). Two smaller wetlands are found on Fighting Island and Peche Island, and the remaining wetlands are associated with tributaries entering the river, including the large Canard River wetland complex (416 ha) and the Turkey Creek Marsh (32 ha). Around half of the Canard River wetland is diked for intensive waterfowl management (Manny *et al.*, 1988).

On the U.S. side of the river, Manny *et al.* (1988) identified 16 coastal wetlands and large submersed macrophyte beds based on 1:130,000 Landsat imagery, totalling 1,382 ha (Manny *et al.*, 1988). They are mostly restricted to islands in the lower reaches of the river as a result of the extensive shoreline modification along the U.S. shore. They occur along Gibraltar Island, Cherry Isle, Celeron Island, Horse Island, Round Island, Elba Island, Calf Island, Stony Island, Grassy Island and Grosse Ile (Herdendorf, 1992; Manny *et al.*, 1988).

6.7.2 Significant Features

In general, wetlands along the Detroit River are typically riverine and river-mouth marshes, sometimes with a small swamp component (Smith *et al.*, 1991). They are often dominated by submergent macrophyte communities (Manny *et al.*, 1988). Fifteen significant plants have been found, including the rare sedge (*Carex suberecta*) which in Canada is only found in the coastal wetlands of the Detroit River (W. Bakowsky, pers. com.).

At least 45 species of fish inhabit the Detroit River marshes, 21 of which are permanent residents (Herdendorf, 1992; Mandrak and Crossman, 1992). The most abundant species are northern pike, gizzard shad, bowfin, common carp, goldfish, carp-goldfish hybrids, golden shiner, blacknose shiner, white sucker, brook silverside, rock bass, pumpkinseed, black crappie and yellow perch (Herdendorf, 1992). Other species which use these wetlands for spawning include lake sturgeon, muskellunge, carp, channel catfish, largemouth bass, smallmouth bass, bluegill and walleye (Herdendorf, 1992). Four species of rare fish in Ontario also use the wetlands, including the striped shiner, pugnose minnow, spotted sucker and green sunfish (Mandrak and Crossman, 1992; Sutherland, 1994).

Many species of reptiles and amphibians inhabit Detroit River wetlands. These coastal wetlands offer especially important habitat since the surrounding landscape has been dramatically altered. Four rare species of reptiles have been identified in these wetlands including the eastern fox snake, eastern massassauga, queen snake and the eastern spiny softshell turtle (D. Sutherland, pers. com.).

The wetlands of the Detroit River are significant in the Great Lakes for waterfowl production (Prince *et al.*, 1992; Bookhout *et al.*, 1989). The marshes provide important resting and feeding grounds for post-breeding and migratory Canada geese, tundra swan and dabbling ducks. They are especially attracted to the diked wetlands of the Canard River along the Canadian shore where there are large areas of emergent wetlands with controlled water levels and adjacent agricultural fields. Many waterfowl winter in wetlands of the Detroit River because they remain open from commercial navigation and thermal pollution (Manny *et al.*, 1988). For instance, about 11,700 and 4,500 ducks wintered in the wetlands of the Detroit River in 1980 and 1981, respectively (Bookhout *et al.*, 1989). The wetlands also provide habitat for many other bird species. Significant bird species which breed in these wetlands include least bittern, northern shoveler, ruddy duck, Forster's tern, white-eyed vireo and yellow-headed blackbird (D. Sutherland, pers. com.).

6.7.3 Wetland Status

No comprehensive estimate exists on the extent of wetland loss along the shores of the Detroit River. From depth surveys of the river in the 1870's, wetlands and large submergent macrophyte beds were nearly continuous along the shores of the river in historic times. A fringe of emergent vegetation occurred all along the shores of the river in waters 0.3 m to 2.0 m deep (Manny *et al.*, 1988). Emergent marshes extended inland from these depths and were sometimes over 1 km wide, especially near the mouths of tributaries such as the Rouge River. Today, around 87% of the U.S. shoreline of the Detroit River has been filled and bulkheaded (Manny and Kenaga, 1991), and more than 20% of the Canadian shoreline is artificial with revetments and other hardened shorelines, especially in the northern sections of the river in Windsor (International Joint Commission, 1993). Consequently, many of the historic coastal wetlands have been lost through dredging, bulkheading and/or backfilling. The remaining wetlands mostly occur on islands in the river. In recent years, loss of wetland along the shores has diminished, but incremental loss from agricultural conversion, shoreline modification, marina development and urban encroachment is still a concern (D. Hector, pers. com.).

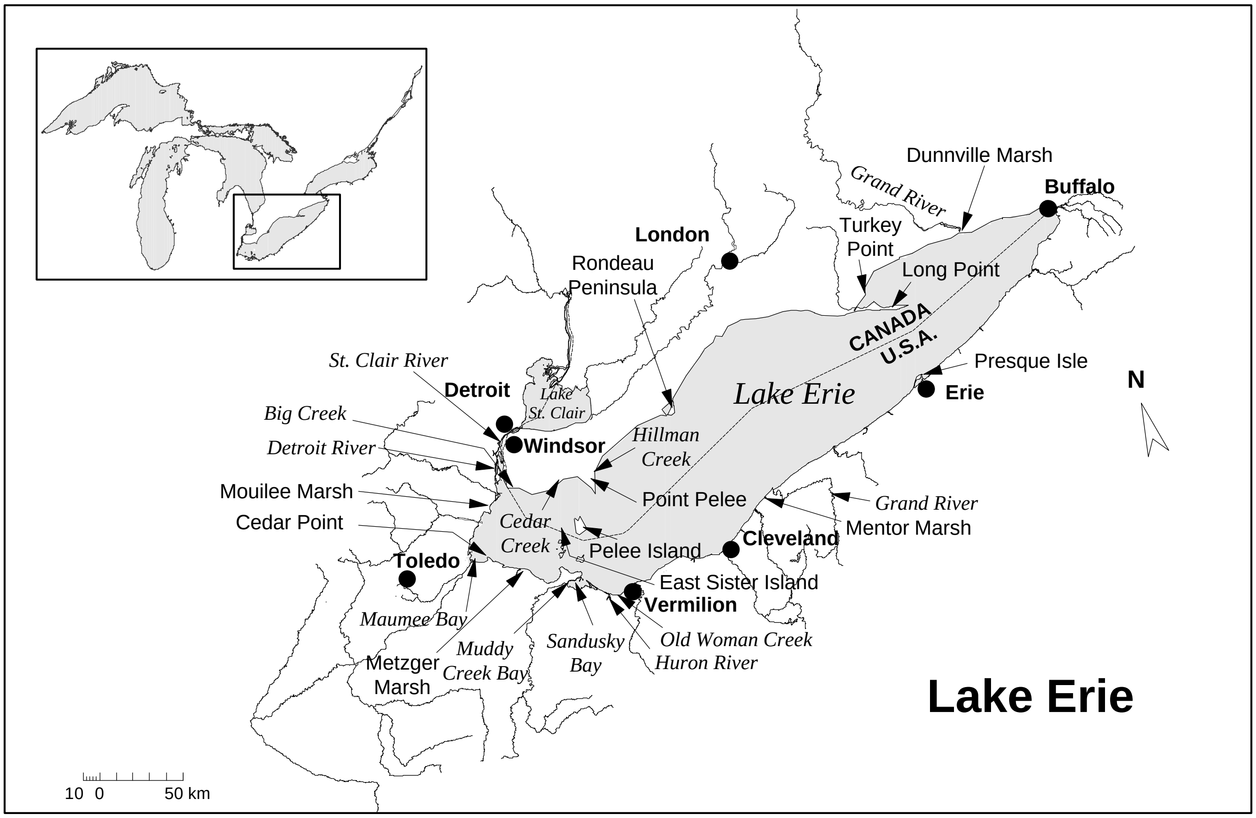
Many human stressors continue to impact remaining wetlands, including erosion from shipping, shoreline modification, dredging and channelization, excess nutrients, contamination of water and sediments with toxic chemicals, agricultural and urban encroachment and invasive non-indigenous species (Manny *et al.*, 1988; Manny and Kenaga, 1991; D. Hector, pers. com.).

The Detroit River is the busiest port in the Great Lakes. Commercial and recreational vessels cause excess wave action, changes in shoreline currents and erosion of wetlands along the shores (Manny *et al.*, 1988). Shoreline hardening is the common solution to this erosion. Where this hardening occurs adjacent to remaining wetlands, it restricts their connection to upland habitats and prevents their upslope migration during high water periods, greatly reducing the diversity of habitats.

The shipping channel is dredged each year for navigation, substantially changing the river morphology (Manny *et al.*, 1988). Sediment dynamics in the river are changed, but it is not known how these changes affect the distribution and status of wetlands. Dredging and channelization associated with the numerous smaller marinas, canals and boat slips also stresses remaining wetland areas through wetland loss, fragmentation, changes in sediment dynamics and increased erosion from wave action (D. Hector, pers. com.).

The busy nature of the port, the large urban areas and the numerous industries contribute to the pollution of the river and its wetlands. The Detroit River and the Rouge River have both been identified as Areas of Concern (Hartig and Thomas, 1988). Excessive phosphates from combined sewers and other sources causes the eutrophication of wetland communities which reduces plant and wildlife diversity. As well, sediments in many stretches of the river are contaminated with heavy metals, oils and PCBs, especially along the U.S. side of the river (Manny *et al.* 1991; Nichols *et al.*, 1991). Wetlands and other nearshore habitats are especially vulnerable to toxic substances since they are deposition zones for sediments (Manny *et al.*, 1988). Submergent plants have been found to concentrate these contaminants (Manny *et al.*, 1991) and are used as food sources for fauna, including waterfowl. Toxic effects and bioaccumulation are therefore important stressors to wetlands in the Detroit River.

Several exotic species are present in the Detroit River wetlands and affect the composition and structure of wetland communities. Invasive plant species of concern include Eurasian water milfoil (*Myriophyllum spicatum*) and curled pondweed (*Potamogeton crispus*) (Manny *et al.*, 1988). Large populations of carp are also now established in the river, and destroy submergent macrophyte beds, increase turbidity and displace native fish species (Manny *et al.*, 1988).



The diking of wetlands, such as parts of the Canard River wetlands, provide high quality habitat for waterfowl and other fauna, but unfortunately also isolate them from the river, reducing their function in the river ecosystem (Manny *et al.*, 1988).

6.8 Lake Erie

6.8.1 Setting

Figure 16. Map of Lake Erie

Lake Erie has a surface area of 25,657 km^2 and a shoreline that extends 1,402 km (Herdendorf, 1992). Several large sand spits project into the lake, including Long Point, Turkey Point, Rondeau Peninsula, Point Pelee and Presque Isle, and a series of small islands occurs in the western part of the lake (Figure 11). The lake basin can be naturally divided into three sub-basins: the western basin to the west of Point Pelee, the central basin between Point Pelee and Long Point, and the eastern basin to the east of Long Point. Lake Erie is also the shallowest of the Great Lakes, and is particularly subject to the effects of storms, wind tides and seiches (Bedford, 1992).

Lake Erie, together with the St. Clair River, Lake St. Clair, and the Detroit River, has a watershed of 78,769 km^2 (PLUARG, 1978). Most of this watershed is agricultural (59%), and the remaining land is forested (17%), residential or industrial (15%) or under other land uses (9%) (PLUARG, 1978). Only around 10% of the flow entering the lake comes from tributaries, while the remainder flows from the Detroit River (Herdendorf, 1987).

A large number of coastal wetlands fringe the low lying shorelines and estuaries of western Lake Erie in Michigan and Ohio (Herdendorf, 1992), and fewer but more extensive wetlands are nestled behind large sandspits along the north shore of Lake Erie in Ontario. Wetlands of Lake Erie are predominantly lagoon, embayed and drowned river mouth emergent marshes. Many have barrier beaches, but several have been diked for increased shoreline protection and intensive wetland management.

Along the Canadian shoreline, extensive coastal wetlands have developed behind the large sand spits and at river and creek mouths. In total, 31 wetlands occur here covering nearly 18,866 ha, and ranging in size from 3 ha to 13,465 ha (H. Ball, pers. com.). Over half are wetland complexes, consisting mostly of marshes with some swamp and rare fen and bog components. Beginning in the western basin of the lake, there are 10 wetlands covering 3,033 ha (D. Hector, pers. com.). The largest are barrier beach marshes at Point Pelee (1,175 ha) and the drowned river mouths marshes at Big Creek (1,000 ha), Cedar Creek (250 ha) and Hillman Creek (362 ha). Smaller wetlands are also found on Pelee Island and East Sister Island. In the central basin, 5 wetlands totalling 1,286 ha are found along the Canadian shoreline, with the marsh and swamp in Rondeau Bay (930 ha) being the largest (D. Hector, pers. com.). In the eastern basin of the lake, there are 16 wetlands along the Canadian shoreline, totalling 14,547 ha (R. Thompson, pers. com.; G. Birch, pers. com.; P. Hunter, pers. com.). The most important wetlands of the eastern basin are the wet meadows, forested swamps, deep-water cattail marshes and shallow-water grass and sedge marshes and ponds protected by Long Point (Prince *et al.* 1992). These Long Point wetlands encompass 13,465 ha and include more than 70% of the total wetland area along the north shore of Lake Erie (R. Thompson, pers. com.). The remaining wetlands along the eastern basin occur primarily at river and creek mouths, including the Dunnville Marsh complex (518 ha) at the mouth of the Grand River (G. Birch, pers. com).

Along the U.S. shoreline of Lake Erie there are 87 wetlands, encompassing more than 7,937 ha (Herdendorf *et al.*, 1981b). Most of the wetlands have been diked and are hydrologically isolated from the lake. The shallow western basin of the lake from the mouth of the Detroit River to Sandusky Bay, Ohio has the largest concentration of marshes (Herdendorf, 1992). The natural shoreline consists of low-lying emergent marshes protected by sandspits and barrier beaches, most of which are now diked. The largest coastal wetlands of western Lake Erie are Mouillee Marsh (550 ha), the Maumee Bay wetland complex (570 ha), the wetland complexes flanking Locust Point (3,500 ha) and wetlands in Sandusky Bay including Muddy Creek Bay Wetland (1,260 ha) and Bay View Wetland (260 ha) (Herdendorf *et al.*, 1981b). The

U.S. islands in western Lake Erie only have wetlands in small embayments on some larger islands (Herdendorf, 1992). In the central basin of the lake, low bluffs occur along the shoreline, and wetlands are limited to drowned river mouths such as at Huron River and Old Woman Creek (Herdendorf, 1992). The largest wetland along the U.S. shore of the central basin is a primarily forested wetland at Mentor Marsh (3,500 ha), in the abandoned valley and delta of the Grand River (Herdendorf, 1992). In the eastern basin, the U.S. shoreline consists predominantly of bluffs, precluding wetland development except at Presque Isle, a 10 km-long sand spit with numerous lagoon wetlands (162 ha) (Bookhout *et al.,* 1989).

6.8.2 Significant Features

The coastal wetlands of Lake Erie support the largest diversity of plant and wildlife species in the Great Lakes. The moderated climate of Lake Erie and its more southern latitude allow for many species not found along the northern Great Lakes. For instance, over 300 species of plants have been identified in the aquatic and wetland habitats of western Lake Erie (Herdendorf, 1992). In the open water of the lake and larger bays, submersed species predominate, including several species important to wildlife, such as wild celery (*Valisneria americana*), and sago pondweed (*Potamogeton pectinatus*) (Herdendorf, 1992). Water lilies such as the white water lily (*Nymphaea odorata*), yellow water lily (*Nuphar advena*) and the American lotus (*Nelumbo lutea*) are not common, but where they do grow they form extensive colonies. Emergent species line the edges of coastal lagoons often in segregated zones, and other species grow in the drier fringes of the marshes.

As a result of this diversity, coastal wetlands of Lake Erie provide habitat for many rare species of flora. Rare wetland communities such as coastal meadow marsh (shoreline fen) occur at several locations including Long Point. At least 37 significant plant species are found in the coastal wetlands of Lake Erie (W. Bakowsky, pers. com.). The rare and endangered Pennsylvania smartweed (*Polygonum pensylvanicum* var. *eglandulosum*) is endemic to the Erie Islands in western Lake Erie (Herdendorf, 1987). Other examples include horsetail spike-rush (*Eleocharis equisetoides*), grass-leaved arrowhead (*Sagittaria cristatata*), American lotus (*Nelumbo lutea*), Emory's sedge (*Carex emoryi*), swamp rose mallow (*Hibiscus moscheutos*) and prairie fringed orchid (*Platanthera leucophaea*).

Wetlands of Lake Erie are important to fish production because they provide spawning and nursery habitat for many wetland dependent species, cover for juvenile and forage fish, and feeding areas for predator fish. Many are important recreational or commercial fish species. Forty-six species of fish have been captured in Lake Erie wetlands and an additional 18 species captured in open water are known to use them during some part of their life (Jude and Pappas, 1992). The most abundant permanent residents of Lake Erie coastal wetlands are white crappie, gizzard shad, black bullhead, white perch, white bass, log perch and freshwater drum. Other species such as while white sucker, common carp, emerald shiner, spottail shiner and yellow perch are abundant temporary residents (Jude and Pappas, 1992). Many fish species in these wetlands are rare in the Great Lakes, including spotted gar, striped shiner, quillback, lake chubsucker, golden redhorse, stonecat, brindled madtom, grass pickerel, green sunfish, longear sunfish, orange-spotted sunfish brook silverside and warmouth (Mandrak and Crossman, 1992; Sutherland, 1994).

Many species of snakes, turtles, frogs and salamanders are dependent on Lake Erie wetlands. Twenty-eight species of amphibians and twenty-seven species of reptiles inhabit the Lake Erie region, most of which are found in coastal wetlands for part of their life cycle (Herdendorf, 1992). Four rare amphibians are found in Lake Erie coastal wetlands, including Jefferson's salamander, smallmouth salamander, Fowler's toad, Blanchard's cricket frog (Herdendorf, 1992; D. Sutherland, pers. com.); the last three species are restricted in Canada to the shores of Lake Erie. Several species of rare reptiles have also been found including spotted turtle, spiny softshell turtle, queen snake, eastern fox snake, Lake Erie water snake and eastern massassauga (D. Sutherland, pers. com.). The Lake Erie water snake is confined in Canada to the western shores of the lake, and is predominantly found in coastal wetlands.

Wetlands of Lake Erie support a diversity of bird life. Waterfowl, wading birds, shore birds, gulls and terns, raptors and perching birds use Lake Erie wetlands for migration, nesting and feeding. The wetlands in western Lake Erie from the mouth of the Detroit River to Sandusky Bay, and those at Point Pelee, Rondeau Bay and Long Point have been identified as some of the most important waterfowl habitat complexes in the Great Lakes (Prince *et al.*, 1992). For instance, large numbers of post-breeding dabbling ducks and Canada geese, and thousands of tundra swans stop annually in southwestern Lake Erie coastal wetlands (Prince *et al.*, 1992). As well, Long Point is one of the major staging areas in North America for canvasback and redhead ducks. Wetlands of southwestern Lake Erie and Long Point also provide a major stop over point for sea ducks such as migrating bufflehead, common goldeneye, red-breasted merganser, common mergansers and ruddy duck (Prince *et al.*, 1992).

In terms of other bird species, wetlands adjacent to the large sand spits such as Point Pelee, Rondeau and Long Point attract many migratory many species which cross the lake. Several rare bird species also occur in Lake Erie coastal wetlands. Bald eagles nest near these wetlands, feed in them and also use them during migration. The swampy woodlands associated with the marshes also support rare species such as least bittern, great egret and black-crowned night heron. Other rare birds nesting in Lake Erie wetlands include Wilson's phalarope, king rail, little gull, Forster's tern, black tern, short-eared owl, acadian flycatcher, white-eyed vireo, prothonotary warbler, louisiana waterthrush and yellow-headed blackbird (D. Sutherland, pers. com.).

About 20 species of mammals that utilize Lake Erie marshes (Herdendorf, 1992). Furbearers such as raccoon and mink can be found near the marshes where they feed, and muskrats are common throughout. Deer are common around the upland edges of many of these wetlands.

6.8.3 Wetland Status

Along the U.S. shore of Lake Erie, large areas of coastal wetlands have been lost over the past century and a half, especially in western basin of the lake. Prior to 1850, an extensive coastal marsh and swamp system covered an area of approximately 122,000 ha between Vermilion, Ohio and the mouth of the Detroit River, Michigan, extending up the valley of the Maumee River (Bookhout *et al.*, 1989). This was part of the Black Swamp, a vast wetland complex 160 km long and 40 km wide on the fine textured soils of the lake plain which extended inland almost 70 m above the current lake level (Herdendorf, 1987). Prior to 1900, these wetlands were largely cleared, drained, filled and diked to provide agricultural land. Most wetlands were lost except for some of the river mouth and coastal marshes (Bookhout *et al.*, 1989). Between 1900 and 1951, the loss of the remaining marshlands continued, and by 1951, only 12,407 ha remained in the western basin (Bookhout *et al.*, 1989). During this period, wealthy sportsmen purchased the remaining marshland around western Lake Erie to preserve quality waterfowl hunting, and many of these were enclosed by dikes (Herdendorf, 1992). Since 1951, wetland losses have continued. Between 1972 and 1987 about 6,600 ha of Ohio's coastal marshes were destroyed, and only 5,300 ha now remain (Bookhout *et al.*, 1989). These losses have been attributed to continued drainage and fill, and to encroachment by Lake Erie as a result of record high water levels in 1973 (Herdendorf, 1987). Along the Michigan shore, coastal wetlands have been reduced from 2,154 ha in 1916 to 827 ha in the late 1960's early 1970's, a reduction of 62% (Herdendorf, 1987). The development of the city of Monroe, Michigan has had a particularly significant impact on coastal wetlands at the mouth of the Raisin River. Only about 100 ha remain physically unaltered today in an area where 70 years ago the marshes were 10 times more extensive (Herdendorf, 1987). Site specific incremental loss is still occurring from dredging and filling, especially near harbours, marinas and waterfront developments.

Estimates of the loss of coastal wetlands along the Canadian side of Lake Erie are not comprehensive. Losses of coastal wetland area has mostly occurred in the vicinity of the large sand spits such as Point Pelee. Agricultural land drainage has been identified as the most significant factor in the decline of these wetlands (Lynch-Stewart, 1983). For instance, the area of Point Pelee Marsh declined by 71%, from 3,878 ha in 1880 to 1,126 ha in the mid-1970's (Rutherford, 1979). The bulk of wetland drainage occurred in the 1890's when 50% of Pelee Marsh was converted into agricultural lands. Large portions of the remaining shoreline marshes are either parks or are privately-owned and managed for waterfowl hunting. Although wetland loss has slowed in recent decades, site-specific incremental loss is still a concern.

In addition to actual loss of coastal wetland acreage along the shores of Lake Erie, the quality of many remaining wetlands has been degraded by numerous stressors, especially excessive loadings of sediments and nutrients, contaminants, shoreline modification, changes in sediment budgets, exotic species and diking of wetlands.

Turbidity and excessive suspended solids are significant stressors to coastal wetlands of Lake Erie (Herdendorf, 1987, 1992; Jude and Pappas, 1992; D. Hector, pers. com., G. Birch, pers. com.). The waters of marshes and many bays along the U.S. shore of western Lake Erie have become turbid in the last century as a result of erosion from agriculture, the dredging, diking and drainage of many large wetlands, shoreline modification and the introduction of carp (Herdendorf, 1987). Many tributaries of western Lake Erie have watersheds dominated by clay soils; the western basin is consequently more turbid than the waters of the rest of the lake (Herdendorf, 1987). Although there have been efforts at reducing suspended solid inputs from tributaries especially in western Lake Erie, they have not declined significantly in the last two decades (Richards and Baker, 1993).

Excessive nutrient loading is common stressors in Lake Erie coastal wetlands in the U.S. and Canada (Herdendorf, 1987; D. Hector, pers. com., G. Birch, pers. com.). Excess phosphorus is associated with the excess inputs of suspended solids. Loadings of phosphorus to the watershed from point and non-point sources have reduced over the last two decades due to control measures (Dolan, 1993; Richards and Baker, 1993). However, nitrogen loadings from non-point sources, mainly agricultural runoff have increased in several watersheds (Richards and Baker, 1992). Wetlands with inflowing tributaries and barrier beaches are particularly prone to stresses from excess nutrients.

Pesticide loading from agricultural runoff has been identified as an important stressor (Herdendorf, 1987), however, the impacts on coastal wetlands are not clear. As with phosphorus, they are associated with the suspended sediment load. Coastal wetlands with inflowing tributaries and barrier beaches are also especially vulnerable.

Many stretches of the U.S. shoreline in western Lake Erie have shallow slopes and have been modified with dikes, revetments or other shoreline structures for protection of built-up areas and agricultural fields against periodic high water levels and potential for flooding, erosion and property damage (Herdendorf, 1987). Shoreline modification is a site-specific stressor adjacent to wetlands along the north shore of Lake Erie, mostly associated with urban encroachment and cottaging (D. Hector, pers. com.; R. Thompson, pers. com. G. Birch, pers. com.). Remaining wetlands suffer a backstopping effect from these revetments and dikes since the wetland communities cannot migrate upslope during high water years. This reduces wetland area during high water years and can also reduce extent and long-term diversity of wetland communities. Storms during high water years can aggravate this problem by removing large areas of remaining wetland.

The extensive use of revetments, groins and other structures which protect shoreline properties has also limited the supply of sediments in the littoral drift in western Lake Erie. Barrier beaches protecting wetlands must be replenished with these sediments. The few remaining natural wetlands with barrier beaches and sand spits are now losing this protection, as losses to erosion cannot be replenished from littoral sediment drift. As a result, these wetlands are becoming increasingly exposed to wave erosion. Examples occur along Cedar Point in Ohio and Woodtick Peninsula in Michigan.

Most of the remaining marshland along the U.S. shoreline is encompassed by dikes, while on the Canadian side, relatively few are diked. While diking allows for more intensive management of waterfowl and other fauna, it also isolates it from the lake, impairing many wetland functions. For instance, many fish species, such as northern pike, which require wetlands for part of their life cycle can no longer access these wetlands. Methods of restoring these wetlands include the innovative Metzger Marsh Restoration Project which attempts to reconnect the diked wetlands with the lake, thereby restoring multiple wetland functions.

One of the most common stresses in wetlands along the shore of Lake Erie are invasive non-indigenous species (R. Thompson, pers. com.; D. Hector, pers. com.). Important species include purple loosestrife, zebra mussels and carp.

6.9 Niagara River

6.9.1 Setting

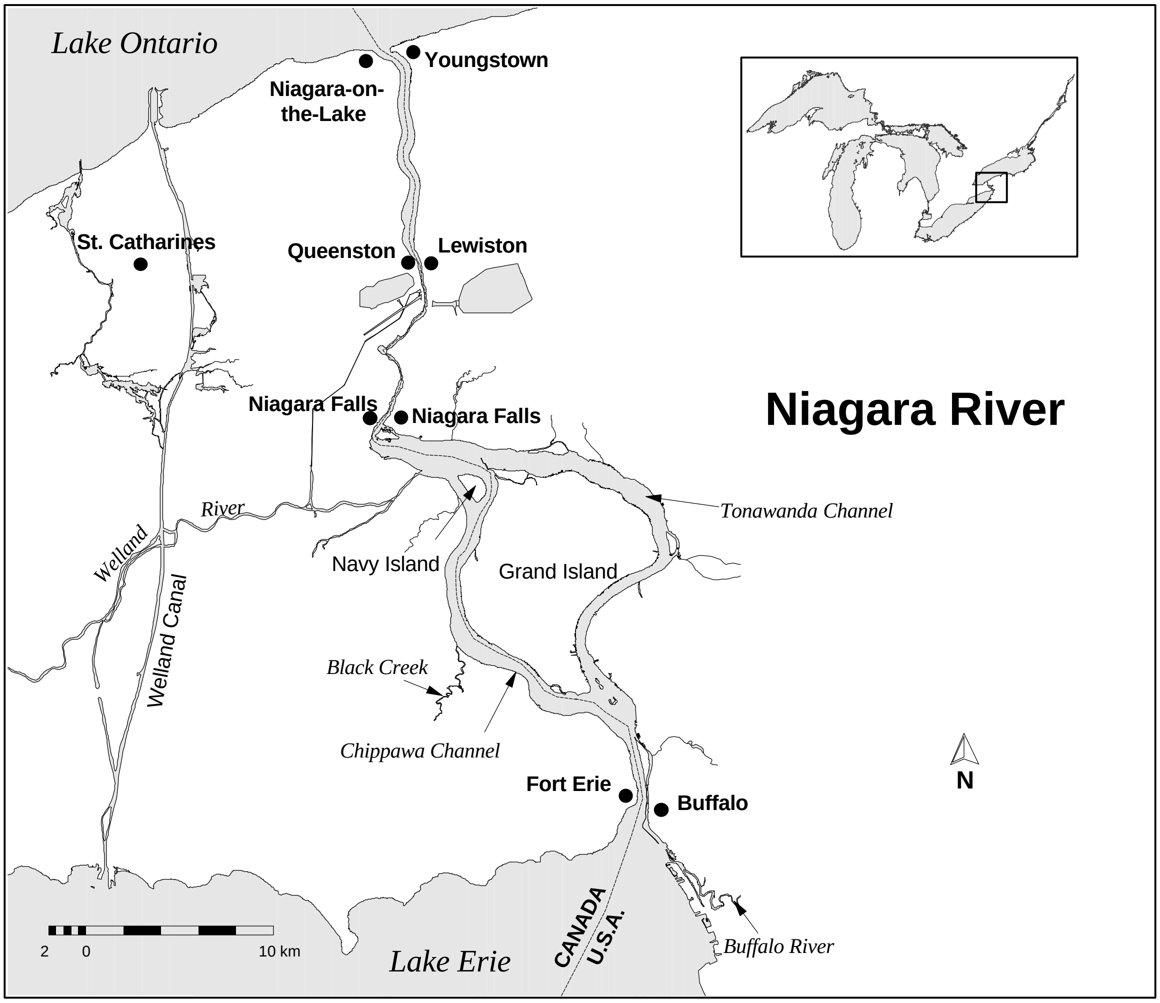


Figure 17. Map of the Niagara River

The Niagara River drains Lake Erie into Lake Ontario. The river is 56 km long and drops 100 m along its course, most of which is at Niagara Falls. Its shoreline extends 60 km on the Canadian side and is much longer on the U.S. side, extending 112 km, as a result of the shoreline along Grand Island (International Joint Commission, 1993). The natural shoreline of the river consists of low banks in the upper portion of the river and a deep gorge cut through sedimentary deposits in the lower river below Niagara Falls.

Several tributaries flow into the river from the U.S. and Canada, draining a watershed of 3,251 km^2 (Envirosearch, 1992; New York State Department of Environmental Conservation, 1994), but they contribute only a small fraction of flow to the river. On the Canadian side, land uses are dominated by agriculture (32%), abandoned agricultural land (23%), urban land (23%) and forests (16%) (Envirosearch, 1992). On the U.S. side, farmland and forests are found in the upper parts of the watershed, but the lower parts are predominantly urban (New York State Department of Environmental Conservation, 1994). Large urban centres along the river include Fort Erie and Niagara Falls in Ontario and Buffalo and Niagara Falls in New York.

The fast flow of the river has precluded the development of wetlands in many reaches of the river. A few wetlands and beds of submergent macrophytes are however present in the upper reaches of the river (Herdendorf, 1992; G. Birch, pers. com.). Nine wetlands are located along the U.S. shores in the upper reaches of the river totalling 158 ha (Herdendorf *et al.*, 1981b). They are mainly marshes associated with the low sandy shores of the river islands, particularly Grand Island (Herdendorf, 1992). Most are separated from the river by a barrier beach or ridge that provides protection from the fast current, while others are open shoreline wetlands fringing the shore (International Joint Commission, 1993).

On the Canadian side, wetlands are also restricted to the upper reaches of the Niagara River. There are four small wetlands totalling 85 ha, ranging in size from 5 to 37 ha (G. Birch, pers. com.). They are riverine in nature, sometimes with large palustrine components, and all but the Navy Island Marsh are associated with creek mouths. All have swamp and marsh components. The largest wetlands are the marshes on Navy Island (26 ha) and at Black Creek (37 ha).

6.9.2 Significant Features

Most of the significant plant species found in the Niagara River are associated with these wetlands. Examples include arrow arum (*Peltandra virginica*), red-rooted cyperus (*Cyperus erythrorhizos*), Smith's club-rush (*Scirpus smithii*), honey locust (*Gleditsia triacanthos*), swamp-rose mallow (*Hibiscus moscheutos*) and strange cinquefoil (*Potentilla paradoxa*) (W. Bakowsky, pers. com.).

Fifty-nine species of fish which use coastal wetlands on a permanent or temporary basis have been reported from the Niagara River (Mandrak and Crossman, 1992). The submerged vegetation of the wetlands in the upper river provides important spawning and nursery grounds for sportfish such as muskellunge, northern pike, and smallmouth bass (Herdendorf, 1992). The Niagara River wetlands also provide year-round habitat for several significant fish species, including striped shiner, quillback and lake chubsucker; the rare golden redhorse and stonecat use them on a temporary basis for spawning nursery or feeding (Mandrak and Crossman, 1992; Sutherland, 1994).

Coastal wetlands of the Niagara River also provide habitat for a wide range of amphibians, reptiles, birds and mammals. The only reported site in Ontario for the northern dusky salamander is found in these wetlands (D. Sutherland, pers. com.).

Wetlands in the upper river are not heavily used by waterfowl for breeding or migration, but waterfowl numbers increase as winter approaches, when other wetlands in Lake Erie and Lake Ontario freeze (Bookhout, *et al.*, 1989). The dominant waterfowl include merganser species, canvasback, common goldeneye, scaup species, bufflehead, mallard and black duck (Bookhout *et al.*, 1989; Herdendorf, 1992). In terms of other birds, the wetlands also provide important nesting habitat for the black-crowned night heron.

6.9.3 Wetland Status

There have been no specific studies on wetland loss in the Niagara River, however many wetlands have been reduced in size or lost. A large portion of the U.S. shoreline is developed, especially in the Buffalo area where extensive filling has occurred. For instance, the Tifft Street area in Buffalo was formerly the largest emergent marsh on the eastern end of Lake Erie; it was fragmented and largely filled for industrial and railroad development (New York State Department of Environmental Conservation, 1994). Similarly, the marsh and submergent macrophyte beds around Rattlesnake Island and in small embayments in the Tonawanda Channel have been filled or dredged for residential or marina developments (New York State Department of Environmental Conservation, 1994). On the Canadian side of the river, there is no comprehensive information on wetland loss. Recent loss has been reported from one location, the Black Creek Wetland as a result of urban development (G. Birch, pers. com.). Loss and stress of wetlands from shoreline modification and urban encroachment continue to be concerns (G. Birch, pers. com.).

Several other human stressors affect remaining wetlands. The Niagara River and a tributary, the Buffalo River have been declared Areas of Concern (AOCs) as a result of excessive toxic chemicals in the water, sediment contamination, fish edibility restrictions, the incidence of tumours in fish, degraded benthos and elevated phosphorus levels (Hartig and Thomas, 1988). Sources include industry outfalls, sewage treatment plants, other point sources and non-point sources (Hartig and Thomas, 1988; Envirosearch, 1992; New York State Department of Environmental Conservation, 1994). Wetlands near these sources are vulnerable to eutrophication and contamination with toxic chemicals. Nearshore areas, including wetlands, are deposition zones for sediments in the river (New York State Department of Environmental Conservation, 1994) and are therefore especially susceptible to sediment contamination. Some areas such as wetlands in the Tifft Street area in Buffalo are known to have toxic sediments, although wildlife still use them (New York State Department of Environmental Conservation, 1994).

Water taking is another stress to coastal wetlands. More than half of the flow of the Niagara River is diverted for power production, causing dewatering of some marsh areas (New York State Department of Environmental Conservation, 1994; G. Birch, pers. com.). This is exacerbated in some areas by road crossings of wetlands which restrict their hydrology.

6.10 Lake Ontario

6.10.1 Setting

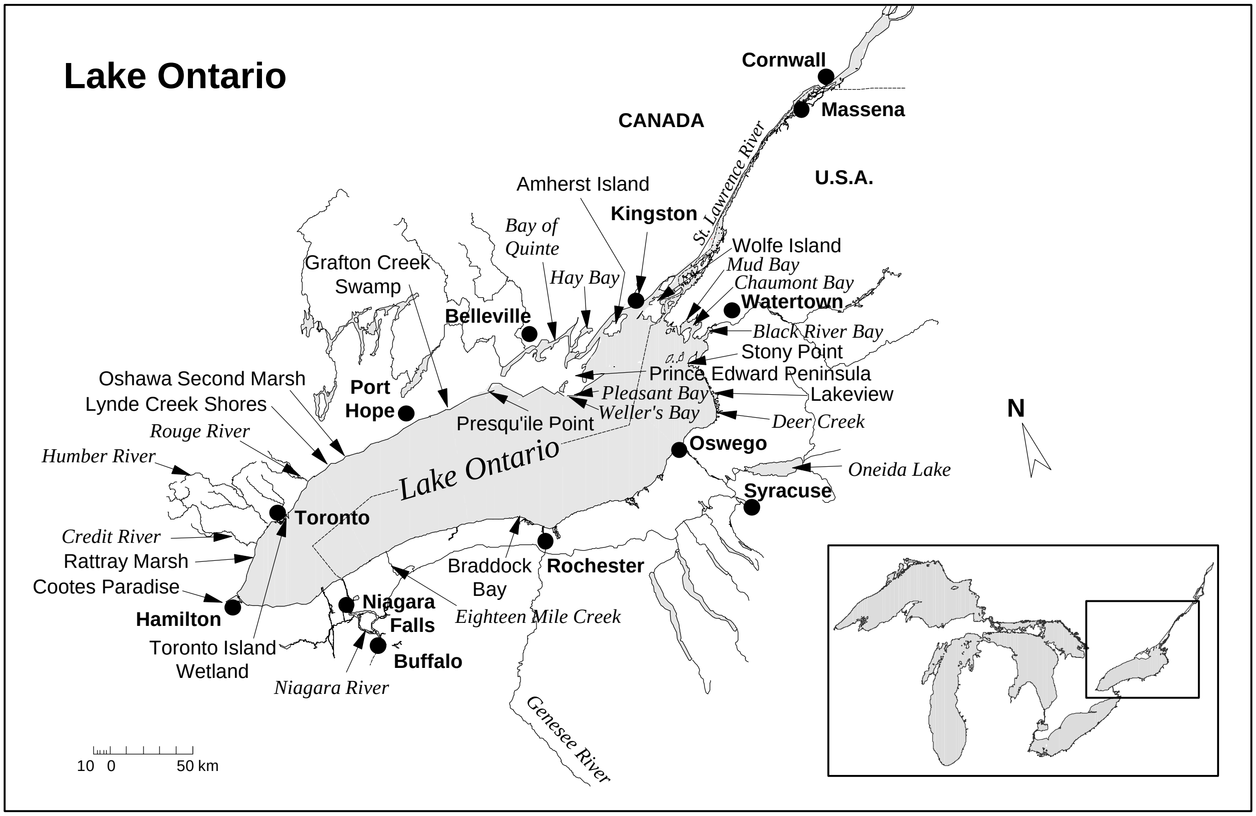


Figure 18. Map of Lake Ontario

Lake Ontario is the smallest of the Great Lakes with a surface area of 18,960 km^2. However, it is relatively deep, and its average depth is second only to Lake Superior. The shoreline extends for 1,168 km and is particularly complex in the eastern third of the lake, with many embayments and peninsulas. The only islands occur in the eastern end of the lake, near its outlet. Its drainage basin is 60,600 km^2 (Fuller *et al.*, 1995) and is dominated by forests and agriculture, with lesser amounts of urban area and other land uses (PLUARG, 1978). Large urban centres occur in the western end of the lake around Toronto and Hamilton and at Rochester. Water levels of the lake are controlled by dams and locks in the St. Lawrence Seaway along the St. Lawrence River.

In total, 255 wetlands covering 17,067 ha have been identified along the shores of Lake Ontario (Herdendorf *et al.*, 1981a; H. Ball, pers. com.). Wetlands are most abundant in the eastern portions of the lake. They occur at river mouths, nestled in embayments and behind bars and barrier beaches. Wetlands are typically emergent and submergent marshes with a swamp or scrub-shrub component along the upland margins.

Along the Canadian shoreline, 87 coastal wetlands have been evaluated under the Ontario wetland evaluation system, totalling 11,538 ha (H. Ball, pers. com.). Wetland distribution varies with shoreline geomorphology. From Niagara to Toronto, the shoreline consists mostly of bluffs and low cliffs except in the Hamilton area which has low-lying beaches (International Joint Commission, 1989). Coastal wetlands are restricted here to protected locations behind barrier beaches and in drowned mouths of rivers and creeks (Whillans *et al.*, 1992). Cootes Paradise in Hamilton is the largest wetland of western Lake Ontario, covering 250 ha. Many wetlands in western Lake Ontario have suffered from extensive filling and loss, especially around Toronto (Whillans, 1982). Remaining wetlands in the Toronto region include the Credit River Marshes (14 ha), Humber River Marshes (26 ha) and Rouge River Marshes at river mouths and Rattray Marsh (10 ha) and the Toronto Island Wetland (22 ha) behind barrier beaches.

East of Toronto to Presqu'ile Point, the shore is steep with few wetlands; those that are present are also mostly found at river mouths and behind barrier beaches. Typical river mouth wetlands in this stretch of shoreline are Grafton Creek Swamp (62 ha) and Lynde Creek Shores (110 ha); the Oshawa Second Marsh (104 ha) and Cranberry Marsh (32 ha) are examples of barrier beaches wetlands.

From Presqu'ile Point to the mouth of the St. Lawrence River, the shoreline is complex with several channels, embayments, headlands and islands. As a result, there are many protected sites suitable for wetlands. Thirty-eight wetlands totalling 9,736 ha are found here, not including Wolfe Island; this is 85% of the wetland area along the Canadian shore of the lake. The wetland along Presqu'ile Point (970 ha) is especially diverse, consisting mostly of marsh with some swamp and a small coastal meadow marsh (shoreline fen). The southwest shores of Prince Edward Peninsula are dominated by large marshes that are protected by bay mouth bars and are connected landward to lagoons. The largest include Wellers Bay Complex (185 ha), Pleasant Bay (299 ha), Hucycks Bay (245 ha), West Lake (706 ha) and East Lake (230 ha). Bay of Quinte along the north and east side of the peninsula has a very complex shoreline, and extensive marshes have developed in the many sheltered bays, around islands and at creek mouths. The most notable are Sawguin Creek (2,093 ha), Hay Bay Marsh (1,335 ha), Big Island Marsh (858 ha), Big Marsh (400 ha), Dead Creek Marsh (359 ha) and Pleasant Bay Marsh (299 ha). Amherst Island to the east also harbours a large wetland complex (472 ha) with marshes nestled in bays along the south shore. Some of these coastal wetlands also include large palustrine components.

In the U.S., a total of 168 wetlands covering 5,529 ha are present (Herdendorf *et al.*, 1981a). Barrier beach wetlands and embayment wetlands are the most common type. The southern shore of the lake from the outlet of the Niagara River to Rochester consists mostly of bluffs with only a few small marshes. The highest concentration of wetlands in this stretch of shoreline occurs around Braddock Point; the largest are Braddock Bay Wetland (159 ha) and Buck Pond Wetland (143 ha).

The largest number of wetlands along the U.S. shoreline occur between Rochester and Stony Point, making up 70% of the wetland area along the U.S. shore. Wetlands in this area are large and typically protected by barrier beaches. The Sterling Creek Wetland Complex (368 ha), East Bay Wetland (506 ha) and Deer Creek Wetland Complex (545 ha) are larger examples of these barrier beach wetlands. The eastern shoreline from Stony Point to the mouth of the St. Lawrence River consists of rock outcrops. Pockets of marsh have developed in protected embayments, the largest being the Black River Bay Wetland Complex (314 ha), Mud Bay Marsh (94 ha) and Chaumont Bay Wetland (76 ha).

6.10.2 Significant Features

Coastal wetland of Lake Ontario consist mostly of submergent and emergent marshes, but there are also some swamps and a few of the rare coastal meadow marsh (shoreline fen) communities (Herdendorf *et al.*, 1981a; Smith *et al.*, 1991; Natural Heritage Information Centre, 1995). In many marsh, wet meadow or submergent habitats, dominant plants are often introduced or native invasive species, such as purple loosestrife (*Lythrum salicaria*), eurasian water-milfoil (*Myriophyllum spicatum*), reed canary grass (*Phalaris arundinacea*) and hybrid cattail (*Typha* X *glauca*) (International Joint Commission, 1993; Wilcox *et al.*, 1993). Despite these problems, seventeen rare species of plants have been found in Lake Ontario's coastal wetlands (W. Bakowsky, pers. com.). For instance, arrow arum (*Peltandra virginia*), twin-scaped bladderwort (*Utricularia geminiscapa*), winged loosestrife (*Lythrum alatum*) and yellow pond lily (*Nuphar advena*) occur in certain marsh habitats. Historically, mosquito fern (*Azolla caroliniana*) was also found in shallow water marshes, but has not been found in recent years (Herdendorf *et al.*, 1981a). Other significant species such as bushy aster (*Aster dumosus* var. *strictior*), low nut rush (*Scleria verticillata*) and Smith's club rush (*Scirpus smithii*) are found in the few coastal meadow marshes along Lake Ontario (W. Bakowsky, pers. com.).

Sixty-eight species of fish use coastal wetlands of Lake Ontario, two thirds of which are permanent residents (Stephenson, 1990; Jude and Pappas, 1992). Gizzard shad, white perch and freshwater drum are the most abundant permanent residents, while alewife, rainbow smelt, white sucker, smallmouth bass, spottail shiner, johnny darter, trout-perch, walleye and yellow perch are common species which use them on a temporary basis for spawning, nursery or feeding. Several important sportfish also use these wetlands including carp, northern pike, muskellunge, pumpkinseed, bluegill, black crappie, white crappie, largemouth bass, smallmouth bass, walleye, yellow perch and white bass (Herdendorf *et al.*, 1981a; Glooshenko *et al.*, 1987). Several species of fish in these coastal wetlands are considered as rare in Ontario or New York including eastern silvery minnow, pugnose shiner, striped shiner, blackchin shiner, blacknose shiner, quillback, grass pickerel, green sunfish, Iowa darter, tadpole madtom, stonecat and brook silverside.

The coastal wetlands provide important habitat for reptiles and amphibians. Bullfrog, green frog, northern leopard frog, spring peeper and grey tree frog are common frogs which inhabit coastal marshes and swamps (Herdendorf *et al.*, 1981a; M. Oldham, pers.com.). The mudpuppy and red-spotted newt are other amphibians commonly found in submersed macrophyte beds in coastal wetlands. Common reptiles include snapping turtle, midland painted turtle, northern water snake, eastern garter snake and eastern milk snake. As well, several rare species of reptiles have also been found, including wood turtle, spotted turtle, eastern spiny softshell and eastern fox snake.

Coastal wetlands along the south-central coast of Lake Ontario and the northeast coast around Prince Edward Peninsula have been identified as important areas for waterfowl in the Great Lakes (Prince *et al.*, 1992). Prince Edward Peninsula in particular is the third most significant region for waterfowl in Ontario, after Long Point and the St. Clair Delta (Bookhout *et al.*, 1989). Their importance is mostly linked to providing staging habitats during spring and fall migration. Large numbers of diving ducks, especially scaup and merganser species, are attracted to these wetlands in the fall (Prince *et al.*, 1992). Northern shoveler, canvasback and redhead can also be found in fair numbers in the marshes and bays along the Prince Edward Peninsula. Wetlands in western Lake Ontario near Toronto have largely disappeared, but concentrations of dabbling ducks, diving ducks and Canada geese still are present along the shoreline during fall migration. Coastal wetlands of Lake Ontario are of lesser importance for breeding waterfowl, but many dabbling ducks do nest in them, including mallard, black duck, blue-winged teal and wood duck (Bookhout *et al.,* 1989; Prince *et al.*, 1992).

Coastal wetlands of Lake Ontario provide feeding, nesting or migration habitats for many other bird species. For instance, several raptors nest or migrate through these coastal wetlands including peregrine falcon, bald eagle, sharp-shinned hawk, cooper's hawk, red-shouldered hawk and northern harrier (Herdendorf *et al.*, 1981a; D. Sutherland, pers. com.). Several species of waterbirds occur, such as double-crested cormorant, great blue heron, American bittern and green-backed heron are common waterbirds (Glooshenko *et al.*, 1987; Herdendorf *et al.*, 1981a). Common terns regularly breed in north shore wetlands, but are uncommon along the south shore. Caspian terns are also common in wetlands along the northeast shore. Rare species of colonial birds nest and feed in these wetlands, including least bittern, black-crowned night heron and black tern. Others significant species also breed in these wetlands, namely short-eared owl and white-eyed vireo (D. Sutherland, pers. com.).

The coastal wetlands of Lake Ontario are important habitats for many mammals. More than 20 mammal species have been found in wetlands along the U.S. shoreline (Herdendorf *et al.*, 1981a). Beaver, muskrat, mink and otter are highly dependent on these wetlands (Herdendorf *et al.*, 1981a; Glooshenko *et al*., 1987). White-tailed deer, red fox, short-tailed weasel, raccoon, coyote are examples of other species using Lake Ontario wetlands.

6.10.3 Wetland Status

Wetlands of Lake Ontario have suffered severe loss over the last two centuries (McCullough, 1982; Whillans, 1982; Lynch-Stewart, 1983; International Joint Commission, 1989). Main causes are agricultural drainage and urban encroachment. Between 1789 and 1979, Whillans (1982) estimated the loss of coastal marsh along the Canadian shore west of the Bay of Quinte to be 1,920 ha or 43% of the original marsh area. Similar estimates were found by McCullough (1982). This loss was greatest from Toronto to the Niagara River where an estimated 1,518 ha of coastal marsh have been lost; this is 73% to 100% of the original marsh along these shores (Whillans, 1982). The greatest losses occurred in the late 1800s and early 1900s when large marshes were filled and dredged for shipping, industrial and urban uses. East of Toronto, less marsh area has been lost. Between Toronto and Presqu'ile, 646 ha or 32% of the original marsh has been lost, while from Presqu'ile to the Bay of Quinte, only 347 ha or 7.5% has been lost. Large losses have occurred in the Bay of Quinte. Around 12,008 ha of wooded and emergent wetlands have been lost prior to the 1960's within a 3.2 km strip inland from the bay, mainly due to agricultural drainage (Ontario Ministry of the Environment *et al*., 1990). Between 1967 and 1982, a further 412 ha of coastal wetland were lost in this area, but since 1967, 542 ha have been reclaimed from agricultural use and restored to wetland. Wetland loss along the Canadian shores continues to be a concern as a result of urban encroachment (K. Hartley, pers. com.; B. Snider, pers. com.; M. Heaton, pers. com.; K. Tuininga, pers. com.) or agricultural encroachment (K. Hartley, pers. com.; G. Birch, pers. com.).

Along the entire U.S. shore, wetland losses have been estimated to be near 60% (Busch *et al*., 1993). Most of the losses are associated with the heavily populated areas surrounding Oswego and Rochester. Small-scale wetland loss continues along the U.S. shore as a result of shoreline development, especially around large barrier beaches and near larger cities, and dredging and filling associated with harbours, marinas and waterfront developments.

Remaining wetlands are affected by several other human stressors. A major stressor to all coastal wetlands in Lake Ontario is water level regulation. Water levels have been regulated in the lake since construction of the St. Lawrence Seaway in 1959. Regulation of water levels seeks to reduce the occurrence of both high and low lake levels. Prior to regulation, the range of water level fluctuations during the 20th century was about 2 m (6.5 ft). Following regulation, this range was reduced slightly between 1960 and 1976 and was reduced to about 0.9 m (2.9 ft) after 1976 (Wilcox *et al.*, 1993). Regulation also prevented water levels from reaching record highs in 1986 as they did on all other lakes. The lack of alternating flooded and dewatered conditions at the upper and lower edges of the wetlands decreased wetland area and the decreased the diversity of plant and wildlife communities (Busch *et al.*, 1990; Wilcox *et al.*, 1993). Upland species became more prevalent along the upper edges of the wetlands. Emergent communities declined in area, and aquatic macrophyte beds increased. As well, invasive plants began to dominate wetland communities. Extensive stands of cattail are now established in these wetlands, and many areas are dominated by purple loosestrife, reed canary grass, and various shrubs (Wilcox *et al.*, 1993; N. MacLean, pers. com.; M. Heaton, pers. com.; K.Tuininga, pers. com.; G. Birch, pers. com.).

High sediment loads and excess turbidity has been noted as a stressor in several coastal wetlands. Examples include Cootes Paradise in Hamilton (Simser, 1979; Painter et al., 1989), Oshawa Second Marsh (Cecile, 1983; Morris, 1983) and wetlands of the Bay of Quinte (Crowder and Bristow, 1988). Sources are site-specific but are mostly related to urban and agricultural runoff. Carp are also a serious related problem in Lake Ontario by resuspending sediments, increasing turbidity and destroying aquatic macrophytes (Painter *et al.*, 1989).

Turbidity problems are compounded by excess nutrients which encourage algae which in turn decrease water clarity (Painter et al., 1989). Excess nutrients has also caused the eutrophication of wetland communities, reducing the diversity of wetland vegetation in some areas. These stressors are especially evident in the Bay of Quinte (Crowder and Bristow, 1986).

Contaminants are site-specific stressors to coastal wetlands. Several sites around Lake Ontario have been declared Areas of Concern including Hamilton Harbour, Toronto, Port Hope, Bay of Quinte in Ontario and Eighteen Mile Creek, Rochester and Oswego in New York (Hartig and Thomas, 1988). Of the Canadian sites, Cootes Paradise in Hamilton and the Bay of Quinte have large areas of coastal wetlands so are especially susceptible to contamination with toxic chemicals. Both these areas are known to have contaminated sediments or bioaccumulation problems in their biota (Crowder *et al.*, 1989; Bishop *et al.*, 1991, 1995).

Shoreline modification is another site-specific concern (N. MacLean, pers. com.; K. Hartley, pers. com.; M. Heaton, pers. com.; G. Birch, pers. com.). Dikes or revetments not only can fill wetlands but can prevent the migration of remaining wetland communities as a response to fluctuating water levels.

6.11 St. Lawrence River

6.11.1 Setting

The St. Lawrence River is the outlet of the Great Lakes system draining Lake Ontario. It extends 870 km in length from Lake Ontario to the Gulf of St. Lawrence (Grant, 1995). The focus of this report is the 186 km section of the river from Wolfe Island at the outlet of Lake Ontario to the Quebec border. This includes the international section of the river and the Ontario shore of Lake St. Francis. Other studies examine the state of the river and its wetlands through Quebec to the Gulf of St. Lawrence (Centre St. Laurent, 1996a,b).

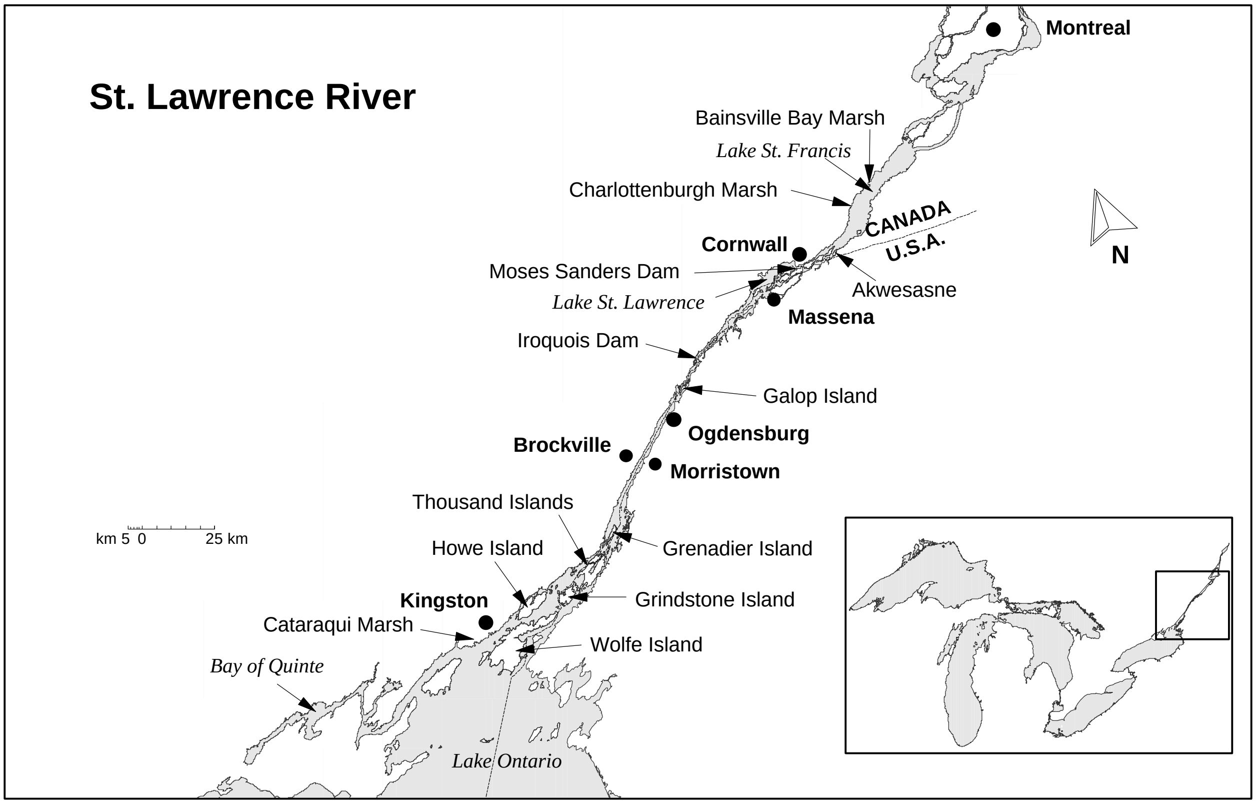


Figure 19. Map of the St. Lawrence River

Water level and flows have been regulated in this section of the St. Lawrence River since the construction of the St. Lawrence Seaway in 1959. Since then, dams and water control structures have greatly changed the character of the river and its wetlands. This section of the St. Lawrence River can now be divided into four distinct sections, each displaying different physical and biological characteristics: the Thousand Islands, Middle Corridor, Lake St. Lawrence and Lake St. Francis (Busch and Patch, 1990; Grant, 1995). The Thousand Islands section lies in the uppermost reach of the river. It has a rocky shoreline and many islands, bays, shoals and quiescent areas with extensive wetlands. The Middle Corridor extends a distance of 49 km from just west of Brockville/Morristown downstream to the Iroquois Control Dam. This is the most riverine section of the St. Lawrence, with of a single deep, wide channel and a relatively uniform shoreline. Currents are very strong and wetlands are restricted to small bays, shoreline indentations and tributary mouths. At Iroquois, the water is shallower and there are some extensive vegetated shallow areas.

Lake St. Lawrence occurs in the lower reach of the international section of the river, extending from the Iroquois Dam to the Moses-Saunders Dam near Cornwall. This area was changed completely from riverine environment to a lacustrine environment following the construction of the Seaway. It has numerous islands and shoals. Wetlands are relatively common in this section, however the extent of marshes is quite small compared to that of the Thousand Island region. Below the Moses-Saunders Dam, there is a short stretch of river with fast current leading to Lake St. Francis. Lake St. Francis is a lacustrine environment with extensive wetlands located at creek mouths, in embayments and surrounding islands (Grant, 1995).

Along the Ontario shoreline, there are 38 evaluated wetlands totalling 7,062 ha (N. MacLean, pers. com.; R. Cholmondeley, pers. com.; R. Grant, pers. com.; M. Eckersley, pers. com.). The wetlands along the Ontario shoreline range in size from 4 ha to 1,398 ha. They are primarily riverine marshes (84%) with relatively small swamp components. More than 60% of the wetlands both in number and area are found in the Thousand Islands section of the river. The largest wetlands in this reach include the Wolfe Island Complex (1,398 ha), Grenadier Island Complex (868 ha) and the Cataraqui Marsh (505 ha). The Wolfe Island Complex has a large bog component, one of only two in the lower Great Lakes. The Morrisburg Swamp (391 ha) and Upper Canada Migratory Bird Sanctuary are large wetlands in the Lake St. Lawrence Section. The Morrisburg Swamp is the only swamp found along the Ontario St. Lawrence River shoreline. Along the Ontario shores of Lake St. Francis, Charlottenburgh Marsh (851 ha) and Bainsville Bay Marsh (407 ha) are large representative wetlands.

6.11.2 Significant Features

The wetlands of the St. Lawrence River are predominantly cattail marshes with areas of submergents and floating plants such as water lilies and occasional swamp components, mostly dominated by willow (Smith *et al.*, 1991). Five provincially significant plants are found in St. Lawrence River wetlands (W. Bakowsky, pers. com.). For instance, arrow arum (*Peltandra virginica*), narrow-leaved water-plantain (*Alisma gramineum*) and Smith's club-rush (*Scirpus smithii*) are found in the shallow water marshes and adjacent wet beaches of the St Lawrence. Historically, the mosquito fern (*Azolla caroliniana*) was also found in the St. Lawrence River, but it has not been recorded in the last 20 years.

At least 64 species of fish inhabit wetlands of the St. Lawrence River, 42 of which are permanent residents (Patch and Busch, 1984; Jude and Pappas, 1992; Mandrak and Crossman, 1992). The major recreational fisheries are muskellunge, northern pike, brown bullhead, smallmouth bass, yellow perch, walleye and a variety of panfishes (Grant, 1995). Wetlands in the St. Lawrence River support one of only a few large self-sustaining populations of muskellunge in North America (Grant, 1995). Three provincially significant species also depend on these wetlands to provide habitat on a permanent basis including the eastern silvery minnow, pugnose shiner and grass pickerel (Sutherland, 1994; Mandrak and Crossman 1992).

The shoreline wetlands of the St. Lawrence River are of primary importance as migration and staging habitat for waterfowl. The St. Lawrence Lowlands have been identified in the North American Waterfowl Management Plan as an important waterfowl staging area. Wolfe Island in the Thousand Island section of the river is strategically located on the northwest-southeast migration route, and is surrounded by abundant shallow water areas with submerged vegetation. Large numbers of waterfowl, primarily scaup and teal are found during spring and fall migration in this area (Ross, 1984). The Wolfe Island area is also an important staging area for the Canada Goose. Significant waterfowl species such as northern shoveler, redhead and ruddy duck also breed in St. Lawrence River wetlands (Sutherland, pers. com.). In terms of other birds, the St. Lawrence River wetlands provide important nesting habitat for many colonial waterbirds. Several rare bird species breed here including least bittern, black-crowned night-heron, American coot, Wilson's phalarope, black tern and short-eared owl (Austen *et al.*, 1994).

Many reptiles and amphibians use wetlands along the St. Lawrence River for nesting and spawning, nursery and/or feeding sites. However, only one rare species, the spotted turtle, has been recorded (Oldham, pers. com.). A variety of mammal species are found in St. Lawrence River wetlands including muskrat, mink, red fox and coyote. Several wetlands also provide regionally significant winter habitat for deer.

6.11.3 Wetland Status

The St. Lawrence River has experienced a wide variety of environmental disturbances since the first channel modifications in the late 18th century (Grant, 1995). The largest disturbance was associated with the construction and operation of the St. Lawrence Seaway. Prior to the construction of the Seaway, the river resembled a large riverine estuary in the Thousand Island section. The middle and lower sections down to Cornwall were part of a riverine system with many islands and shoals, and many rapids in the lower reaches of the international section (Busch and Patch, 1990). The creation of Lake St. Lawrence and the dredging for navigation and power production greatly altered these habitats. These changes have been monitored best along the U.S. side (Patch and Busch, 1984; Busch and Patch, 1990).

After the initial opening of the Seaway, relatively little change occurred along the U.S. shore in the Thousand Island section of the river, but changes became apparent at Galop Island in the middle section of the River and were most dramatic in the lower section in Lake St. Lawrence. Numerous islands and shoals were flooded along with several major rapids, and there were large increases in deepwater and littoral habitat. Wetland habitats changed greatly. By 1962, shortly after the construction of the Seaway, there was a decline in wetland area of 11.4% along the U.S. shore (Patch and Busch, 1984). However by 1988, wetland area had increased by 106 ha (9%) along the U.S. shoreline as compared to the pre-Seaway condition (Busch and Patch, 1990). Between 1955 and 1988, there were losses of 174 ha (-18%) and 10 ha (-40%) along the U.S. shoreline in the Thousand Islands and Middle Corridor, respectively, but an increase of 448 ha (+64%) in the U.S. side of Lake St. Lawrence. There were also large changes in wetland community structure as compared to the Pre-Seaway condition as a result of the regulation and stabilization of water levels. Emergent wetlands decreased in area to the benefit of broad-leaved forested and scrub/shrub wetlands. In Lake St. Lawrence, wetlands are relatively common, but emergent wetland area is small, primarily due to the regulation of water levels.

Changes in wetland area and stressors due to other human activities now tend to be smaller scale and site-specific. Beginning in the Thousand Islands section of the river, recreational activities dominate with many cottages, picnic and camping areas and marinas. Along the Canadian side of the river, shoreline modification from these activities has historically resulted in irretrievable direct losses of wetland habitat, although these losses have greatly reduced over the last 5-6 years (R. Cholmondeley pers. com.). Recent loss has been limited to development of occasional shoreline protection structures, although some illegal dredging still occurs. Pressures from these activities are however ongoing, as marinas try to expand or dredge deeper to allow for bigger boats or to compensate for fluctuating water levels. Recreational boats also stress remaining wetlands by creating wakes which disturb and erode emergent and submergent vegetation.

Wetland losses in the Canadian shore of Thousand Island section of the river have also resulted from the construction of roads such as the St. Lawrence Parkway as well as numerous access roads to cottages (R. Cholmondeley pers. com.). Not only is there wetland loss from filling of the roadbed, but many segments of wetlands are cut off from the river and have their hydrology altered.

Other stressors affect remaining wetlands in the Thousand Island section. They suffer to some extent from water level regulation which draws down water levels in the fall, leading to plant freeze out or ice scour; the vegetation has been dramatically affected (R. Cholmondeley pers. com.). Nutrient and sediment loading from tributary creeks also acts as a local stress on wetlands in the Thousand Islands. Additionally, non indigenous species have taken their toll on wetlands. For instance, zebra mussels have increased water clarity, but there appears to be a consequent reduction in aquatic plant growth and an increase in filamentous algae (R. Cholmondeley, pers. com.).

The Middle Corridor has been substantially altered by dredging and filling which accompanied the construction of the Iroquois Control dam, locks and the Seaway navigational channel in 1954-1959 (Busch and Patch, 1990; Grant, 1995). Although few wetlands remain in this reach, residential and industrial developments are common along the Canadian shoreline. Dredging and filling have been associated with these activities, resulting in direct loss in the past and concerns remain regarding future losses (R. Grant, pers. com.). These activities have also stressed remaining wetlands through sediment and nutrient loading (R. Grant pers. com).

In Lake St. Lawrence, the greatest stresses relate to the construction and operation of the Moses-Saunders Dam, as detailed above. Stresses on existing wetlands in this area are site specific, and are primarily related to industrial, commercial, residential and recreational development (M. Eckersley, pers. com).

In Lake St. Francis, modifications to the hydrological regime have resulted in an increase of 36 cm in the mean water level, and there are no longer any annual water level fluctuations (Jean and Bouchard, 1991). The stable water levels mean spring flooding does not occur in many wetlands (M. Eckersley, pers. com.). Over the past 40 years, wetlands of Lake St. Francis have been subject to extensive urban, recreational and agricultural development (Jean and Bouchard 1991; M. Eckersley, pers. com.). As a whole, only 7% of wetlands disappeared between 1946 and 1983, however wetlands in certain areas have been reduced as much as 41% through conversion primarily to urban lands (Jean and Bouchard 1991).

The section of the St. Lawrence River downstream of Cornwall, ON and Massena, NY has contaminant problems of concerns for coastal wetlands. This section of the river has been declared an Area of Concern as a result of excessive toxic substances in the water, contaminated sediments at Cornwall and at the mouth of the Grass River near Massena, fish consumption advisories, tumours in fish along Cornwall, degraded benthos, elevated fecal coliform bacteria counts and eutrophication from elevated phosphorus downstream of Cornwall. Bioaccumulation of PCBs have been observed to be very high in red-winged blackbirds and tree swallows from coastal wetlands in Akwesasne downstream of Cornwall/Massena (Bishop *et al.*, 1995).

7.0 Summary

7.1 Wetland Ecology and Science

1) Water-level fluctuations are integral to the dynamics, integrity, and existence of Great Lakes coastal wetlands. These wetlands have evolved as a result of, and are adapted to these long and short-term changes in water levels.

2) Coastal wetlands filter incoming water by removing and trapping nutrients and sediment, thereby improving water quality in the receiving lake or connecting channel. Several mechanisms are involved. Roots and stems of emergent and submergent plants trap sediment.
   Wetland vegetation and microbes also remove, transform, and store nutrients and release these nutrients in a less harmful form.

3) Wetland vegetation helps to stabilize the shoreline. This vegetation buffers wave and wind action and moderates the impacts of ice scour. This function is especially important during storm events and high surface runoff.

4) Coastal wetlands provide critical habitat for commercial and sport fisheries of the Great Lakes.

5) Substantial local, regional, social and economic benefits can be attributed to Great Lakes coastal wetlands. These include tourism, sport and commercial fisheries, hunting, bird-watching, nature enjoyment, aesthetic and cultural values.

7.2 Wetland Stressors

1) Great Lakes coastal wetlands are by nature, stress-driven ecosystems. Water level changes, both historic and seasonal, as well as storm events all contribute to the size, geographic distribution, diversity of plant and animal species, and productivity of Great Lakes coastal wetlands. Other natural stressors such as sediment, ice, storms, natural pests, and disease all contribute to wetland processes and functions. Coastal wetlands require these natural stressors to maintain their resilience, integrity, size, geographic distribution, and diversity.

2) Humans add additional stressors to which coastal wetlands are not naturally adapted to.

3) Historically, large-scale drainage and filling have been the most significant human-induced stressors, resulting in extensive wetland loss and degradation. Conversion of wetlands to agriculture has been the most significant cause of wetland loss, but shoreline urbanization and industrial, recreational and cottage developments have also been important.

4) Conversion of wetlands to other land uses through draining, filling, and shoreline modification is not as extensive as it was historically but continues on a smaller scale today. Policies and programs are in

place to prevent large scale loss, however degradation and conversion of coastal wetlands continue. As a result, wetlands are often fragmented and their ability to perform functions such as water quality improvement, critical habitat, shore stabilization and buffering, and providing viable diverse seedbanks are impaired. Although there is no comprehensive data, localized research suggests that drainage and filling continue at a much slower rate and scale.

5) Water-level control and regulation, such as implemented on Lake Ontario and Lake Superior, reduce the range of natural water levels, reducing the occurrence of extreme high and low levels. This regulation reduces the extent, diversity, function, and value of wetlands in the nearshore.

6) Shoreline modification from groins, revetments, breakwaters or other structures has reduced the sediment supply feeding natural protective structures such as sand spits and barrier beaches. Their loss threatens coastal wetlands with erosion from wave action. Shoreline modification also reduces area and diversity of wetlands in the nearshore and impairs their function.

7) Sedimentation of wetlands from upstream sources and shoreline modification are two significant stressors responsible for recent coastal wetland degradation and loss.

7.3 Wetland Status and Indicators

1) Evaluations of wetland status, and trends in status, have typically been based on the number and size of wetlands, often on a regional or local scale. However, there is no comprehensive inventory and evaluation of Great Lakes coastal or even inland wetlands.

   Along the Canadian shoreline, the most complete inventory and evaluation of coastal wetlands is based on the Evaluation System for Wetlands of Ontario South of the Precambrian Shield (Ontario Ministry of Natural Resources 1984,1993). These results are based on field assessments of wetlands greater than 2 ha in size. The majority of coastal wetlands in Ontario have been inventoried and evaluated. However, several sections of shoreline have extensive wetlands, notably along the northern shore of Lake Huron, Georgian Bay, St. Mary's River, and northeast shore of Lake Superior that have not been inventoried or evaluated.

   Along the United States shoreline, the most comprehensive inventory and description of coastal wetlands is Herdendorf et al. (1981a-e). 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.

   While wetland size, number, type, and distribution are useful indicators at the landscape scale, these variables are not strong indicators of wetland functions and processes. Other indicators are required for monitoring and assessing the status of Great Lakes coastal wetlands.

2) Coastal wetlands are variable ecosystems, making monitoring and assessment difficult. They vary in terms of geographic distribution, size, climate, vegetation, hydrology, water levels and flows, shore slope, substrate, and adjacent land use. Furthermore, wetlands are dynamic systems over time and are

dependent on change. Thus, the use of indicators to detect and monitor change is by necessity complex and site specific.

3) 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. There is general agreement that field-based indicators are most useful, and any monitoring program using these indicators should be regionally-based.

4) Coastal wetland restoration efforts provide a valuable opportunity to further develop indicators. Process and function based evaluations should be conducted for past, present, and future coastal wetland restoration projects. This will assist land managers, governments, municipalities, and decision makers to design projects and manage wetlands to meet the required or desired functions, and enable managers to use financial resources wisely and efficiently.

5) Successful restoration and long-term protection and management of Great Lakes coastal wetlands is most likely to result from efforts to return to, or mimic the natural landscape functions and processes.

8.0 Sources of Information

Allen, G. 1996. Personal communication. Midhurst District Office, Ontario Ministry of Natural Resources, Midhurst, Ontario.

Angel, J.R. 1995. Large scale storm damage on the U.S. shores of the Great Lakes. *Journal of Great Lakes Research* **21**, 287-293.

Apfelbaum, S.I., and C.E. Sams. 1987. Ecology and control of reed-canary grass (*Phalaris arundinacea* L.). *Natural Areas Journal* **7**, 69-74.

Armitage, B.J. 1995. *Evaluation of Six Wetlands in Lake Superior Employing Adult Caddisflies (Insecta: Trichoptera)*. Report to National Biological Service, Great Lakes Science Center, Ann Arbor, Michigan.

Aulerich, R.J., Ringer, R.K., and S. Iwamoto. 1973. Reproductive failure and mortality in mink fed on Great Lakes fish. *Journal of Reproduction and Fertility (Supplement)* **19**, 365-376.

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

Baedke, S.J. and T.A. Thompson. 1993. *Preliminary Report of Late Holocene Lake-level Variation in Northern Lake Michigan: Part 1*. Indiana Geological Survey, Open File Report 93-4, Indiana University.

Baedke, S.J. and T.A. Thompson. 1995. *Preliminary Report of Late Holocene Lake-level Variation in Northern Lake Michigan: Part 3.* Indiana Geological Survey, Open File Report 95-111, Indiana University.

Baker, L.A. 1992. Introduction to nonpoint source pollution in the United States and prospects for wetland use. *Ecological Engineering* **1**, 1-26.

Bakowsky, W. 1996. Personal communication, Natural Heritage Information Centre, Ontario Ministry of Natural Resources, Peterborough, Ontario.

Ball, H. 1996. Personal communication. Contributing author, SOLEC '96. Peterborough, Ontario.

Ball, H. and J. Tost. 1992. *Summary of Small Fish Surveys Conducted in Rivers Entering Thunder Bay Harbour, 1990*. Technical Report #11, North shore of Lake Superior Remedial Action Plans.

Barnes, P.W., Kempema, E.W., Reimnitz, E., and M. McCormick. 1994. The influence of ice on southern Lake Michigan coastal erosion. *Journal of Great Lakes Research* **20**, 179-195.

Batterson, T., McNabb, C., and F. Payne. 1991. Influence of water level changes on distribution of primary producers in emergent wetlands in Saginaw Bay. *Michigan Academemician* **23**, 149-160.

Bedford, K.W. 1992. The physical effects of the Great Lakes on tributaries and wetlands, a summary. *Journal of Great Lakes Research* **18**, 571-589.

Birch, G. 1996. Personal communication. Fonthill Area Office, Ontario Ministry of Natural Resources, Fonthill, Ontario.

Bishop, C.A., Brooks, C.N., Carey, J.H., Ng, P., Nostrom, R.J., and D.R.S. Lean. 1991. The case for a cause-effect linkage between environmental contamination and development in eggs of the common snapping turtle *Chelydra serpentina serpentina* from Ontario. *Canadian Journal of Toxicology and Environmental Health* **33**, 521-548

Bishop, C.A., Koster, M.D., Chek, A.A., Hussell, D.J.T., and K. Jock. 1995. Chlorinated hydrocarbons and mercury in sediments, red-winged blackbirds (*Agelaius phoeniceus*) and tree swallows (*Tachycineta bicolor*) from wetlands in the Great Lakes-St. Lawrence River Basin. *Environmental Toxicology and Chemistry* **14**, 401-501.

Black, R. 1996. Personal communication. Parry Sound District Office, Ontario Ministry of Natural Resources, Parry Sound, Ontario.

Bond, W.K., Cox, K.W., Heberlein, T., Manning, E.W., Witty, D.R., and D.A. Young. 1992. *Wetland Evaluation Guide: Final Report of the Wetlands Are Not Wastelands Project*. Sustaining Wetlands Issues Paper No. 1992-1, North American Wetlands Conservation Council (Canada), Ottawa, Ontario.

Bookhout, T.A., Bednarik, K.E., and R.W. Kroll. 1989. The Great Lakes marshes. In: Smith, L.M., Pederson, R.L., Kaminski, R.M., *Habitat Management for Migrating and Wintering Waterfowl in North America*. pp. 131-156. Texas Tech University Press, Lubbock, Texas.

Boto, K.G., and H. Patrick, Jr. 1978. Role of wetlands in the removal of suspended sediments. In: Greeson, P.E., Clark, J.R., Clark, J.E., *Wetland Functions and Values: the State of Our Understanding*. pp. 479-489. American Water Resources Association, Minneapolis, Minnesota.

Brady, V.J. 1992. *The Invertebrates of a Great Lakes Coastal Marsh*. MS thesis. Michigan State University, Lansing, Michigan.

Bray, K. 1992. *Changes to Fish Habitat of the St. Marys River: a Retrospective Analysis.* M.Sc. Thesis, Trent University, Peterborough, Ontario.

Bray, K. 1993. *Preliminary Inventory and Evaluation of Littoral Habitat in the St. Marys River Area of Concern.* St. Marys River Remedial Action Plan Report.

Bray, K. 1996. Personal communication. Lake Superior Remedial Action Plan Program Office, Thunder Bay, Ontario.

Burt, A.J., McKee, P.M., Hart, D.R., and P.B. Kauss. 1991. Effects of pollution on benthic invertebrate communities of the St. Marys River, 1985. *Hydrobiologia* **219**, 63-81.

Busch, W.-D.N., Kavetsky, R., and G. McCullough. 1989. *Water Level Criteria for Great Lakes Wetlands*. Summary of January 1989 workshop, Water Levels Reference Study, Functional Group 2, Canadian Centre of Inland Waters, Burlington, Ontario.

Busch, W.-D.N., Lazeration, M., Smith M., and M. Scharf. 1993. *1992 Inventory of Lake Ontario Aquatic Habitat Information*. U.S. Environmental Protection Agency.

Busch, W.-D.N., Osborn, R.O., and G.T. Auble. 1990. The effects of water levels on two Lake Ontario wetlands. In: Kusler, J., Smardon, R. (eds.) *Proceedings: International Symposium on Wetlands of the Great Lakes*. pp. 92-96, Association of State Wetland Managers, Niagara Falls, N.Y.

Busch, W.-D.N., and S. Patch. 1990. Human-Caused Habitat Changes in the International Section of the St. Lawrence River. In: Kusler, J, Smardon, R. *Proceedings: International Wetlands Symposium - Wetlands of the Great Lakes,* pp. 141-155. The Association of State Wetland Managers, Niagara Falls, N.Y.

Cairns, Victor, date, Personal communication.

Carpenter, S. R. And D.M. Lodge. 1986. Effects of submersed macrophytes on ecosystem processes. *Aquatic Botany* **26**, 341-370.

Cecile, C. P. 1983. *Oshawa Second Marsh Baseline Study, Final Report.* Environment Canada.

Centre St. Laurent. 1996a. *The State of the Environment Report on the St. Lawrence River, Vol. 1: The St. Lawrence Ecosystem.* Environment Canada & Editions MultiMondes, Montreal, Quebec.

Centre St. Laurent. 1996b. *The State of the Environment Report on the St. Lawrence River, Vol. 2: The State of the Saint Lawrence*. Environment Canada & Editions MultiMondes, Montreal, Quebec.

Chabot, A. 1996. Preliminary results from the Marsh Monitoring Program in 1995. *Great Lakes Wetlands* **7**, 7-11.

Cholmondeley, R. 1996. Personal communication. Brockville Area Office, Ontario Ministry of Natural Resources, Brockville, Ontario.

Chubb, S. L. and C.R. Liston. 1986. Density and distribution of larval fishes in Pentwater Marsh, a coastal wetland on Lake Michigan. *Journal of Great Lakes Research* **12**, 332-343.

Colborn, T. 1991. Epidemiology of Great Lakes bald eagles. *Journal of Toxicology and Environmental Health* **33**, 395-454.

Comer, P. And D. Albert. 1993. A survey of Wooded Dune and Swale Complexes in Michigan. Michigan natural Features Inventory.

Council of Great Lakes Research Managers. 1991. *A Proposed Framework for Developing Indicators of Ecosystem Health for the Great Lakes Region*. International Joint Commission.

Cowardin, L.M., Carter, V., Golet, F.C., and E.T. LaRoe. 1979. *Classification of Wetlands and Deep Water Habitats of the United States.* Fish and Wildlife Service, U.S. Department of the Interior, Washington, D.C.

Craig, B.E. 1993. *Fisheries of Lake Erie and the Long Point Area: Past and Present.* Long Point Environmental Folio Publication Series, Technical Paper 4, Heritage Resource Centre, University of Waterloo, Waterloo, Ontario.

Craig, R. 1996. Personal communication. Midhurst District Office, Ontario Ministry of Natural Resources, Midhurst, Ontario.

Crivelli, A.J. 1983. The destruction of aquatic vegetation by carp. *Hydrobiologia* **106**, 37-41.

Croley, T.E. II. 1990. "Laurentian Great Lakes double -CO_2 climate change hydrological impacts", Climate Change, 17:27-47.

Croley, T.E. II. 1991. *CCC GCM 2x*CO_2 *Hydrological Impacts on the Great Lakes*. Task Group 2, Working Committee 3, International Joint Commission, Water Levels Reference Study.

Croley, T.E. II. 1992. CCC GCM 2xCO_2 Hydrological Impacts on the Great Lakes. in Climate , Climate Change, water level forecasting and frequency analysis, Supporting documents, Vol. 1 Water supply scenarios. Task Group 2, Working Committee 3, IJC, Levels Reference Study, Phase II.

Cross, D.H. and K.L. Fleming. 1989. *Control of Phragmites or Common Reed.* USFWS Fish and Wildlife Leaflet 13.4.12.

Crowder, A.A. and J.M. Bristow. 1988. The future of waterfowl habitats in the Canadian lower Great Lakes wetlands. *Journal of Great Lakes Research* **14**, 115-127.

Crowder, A., Dushenko, W.T., Greig, J., and J.S. Poland. 1989. Metal contamination in sediments and biota of the Bay of Quinte, Lake Ontario, Canada. *Hydrobiologia* **188/189**, 337-343.

Crowder, A. and D.S. Painter. 1991. Submerged macrophytes in Lake Ontario: current knowledge, importance, threats to stability, and research needs. *Canadian Journal of Fisheries and Aquatic Sciences* **48**, 1539-1545.

Cullis, K. 1996. Personal communication. Lake Superior RAP Program Office, Thunder Bay, Ontario.

Dean, R.G. 1978. Effects of vegetation on shoreline erosional processes. In: Greeson, P.E., Clark, J.R., Clark, J.E. (eds.). *Wetland Functions and Values: The State of Our Understanding*. pp. 415-426. American Water Resources Association, Minneapolis, Minnesota.

Dennis, D.G., McCullough, G.B., North, N.R., and N.K. Ross. 1984. An updated assessment of migrant waterfowl use of the Ontario shorelines of the southern Great Lakes. In Curtis, S.G., Dennis, D.G., Boyd, H. (eds.) *Waterfowl Studies in Ontario, 1973-1981*. Canadian Wildlife Service Occasional Paper 54.

Dodge, D. and R. Kavetsky. 1995. *Aquatic Habitat and Wetlands of the Great Lakes.* 1994 State of the Lakes Ecosystem Conference (SOLEC) Background Paper. Environment Canada and United States Environmental Protection Agency EPA 905-R-95-014.

Dolan, D. M. 1993. Point source loadings of phosphorus to Lake Erie: 1986-1990. *Journal of Great Lakes Research* **19**, 212-223.

Dorr, J.A., Jr., and D.F. Eschman. 1970. Geology of Michigan. University of Michigan Press, Ann Arbor.

Duffy, W.G., Batterson, T.R., and C.D. McNabb. 1987. The St. Marys River, Michigan: An Ecological Profile. U.S. Fish and Wildlife Service, Biological Report 85 (7.10).

Dupont, A. 1996. Personal communication, Sault Ste. Marie District Office, Ontario Ministry of Natural Resources, Sault Ste. Marie, Ontario.

Engel, S. 1985. *Aquatic Community Interactions of Submersed Macrophytes.* Wisconsin Department of Natural Resources Technical Bulletin No. 156. Madison, Wisconsin.

Entwistle, J. 1986. *Thunder Bay Marshes Study, Summary Report 1982-1985.* Lakehead Region Conservation Authority Report, Thunder Bay, Ontario.

Environment Canada. 1993. *Environmental Sensitivity Atlas for Lake Superior's Canadian Shoreline.* Environment Canada.

Environment Canada. 1994. *Environmental Sensitivity Atlas Lake Huron's Canadian Shoreline*. Environment Canada.

Environment Canada. 1995. *Amphibians and Reptiles in Great Lakes Wetlands: Threats and Conservation*. Environment Canada, 12 p.

Envirosearch Limited (ed.). 1992. *Niagara River Remedial Action Plan, Stage 1: Environmental Conditions and Problem Definition*. Ontario Ministry of the Environment, Environment Canada, Ontario Ministry of Natural Resources, Fisheries and Oceans Canada.

Farber, S. and R. Costanza. 1987. The economic value of wetland systems. *Journal of Environmental Management* **24**, 41-51.

Farney, R.A. and T.A. Bookhout. 1982. Vegetation changes in a Lake Erie marsh (Winous Point, Ottawa County, Ohio) during high water years. *Ohio Journal of Science* **82**, 103-107.

Fox, G.A. (ed.). 1994. *Bioindicators as a Measure of Success for Virtual Elimination of Persistent Toxic Substances.* Report to the Virtual Elimination Task Force. International Joint Commission. Windsor, Ontario.

Fuller, K., Shear, H., and J. Wittig. (eds.). 1995. *The Great Lakes: An Environmental Atlas and Resource Book*. Government of Canada and United States Protection Agency.

Gaudet, C.L. and P.A. Keddy. 1988. A comparative approach to predicting competitive ability from plant traits. *Nature* **334**, 242-243.

Geis, J.W. 1985. Environmental influences on the distribution and composition of wetlands in the Great Lakes basin. In: Prince, H.H., D'Itri, F.M. (eds.) *Coastal Wetlands*. pp. 15-31. Lewis Publishers, Chelsea, Michigan.

Giesy, J.P., *et al.* 1994. Contamination in fishes from Great Lakes influenced sections and above dams of three Michigan rivers. II. Implications for the health of mink. *Archives of Environmental Contamination and Toxicology* **27**, 213-223.

Glooschenko, V., Parker, B., Coo, L., Kent, R., Wedeles, C., Mason, A., Dawson, J., Herman, D., and P. Smith. 1987. *Provincially and Regionally Significant Wetlands in Southern Ontario.* Interim Report, Wildlife Branch, Ontario Ministry of Natural Resources, Toronto, Ontario.

Grace, J.B. and R.G. Wetzel. 1978. The production biology of Eurasian watermilfoil (*Myriophyllum spicatum* L.): a review. *Journal of Aquatic Plant Management* **16**, 1-11.

Grant, R. 1996. Personal communication. Brockville Area Office, Ontario Ministry of Natural Resources, Brockville, Ontario.

Grant, R.E. 1995. *Canada Ports Corporation 1994 Fisheries Act Violation, Port of Prescott*. Ontario Ministry of Natural Resources, Brockville, Ontario.

Griffiths, R.W. 1991. Environmental quality assessment of the St. Clair River as reflected by the distribution of benthic macroinvertebrates in 1985. *Hydrobiologia* **219**, 143-164.

Griffiths, R.W., Thornley, S., and T.A. Edsall. 1991. Limnological aspects of the St. Clair River. *Hydrobiologia* **219**, 97-123.

Harris, H.J., Fewless, G., Milligan, M., and W. Jownson. 1981. Recovery processes and habitat quality in a freshwater coastal marsh following a natural disturbance. In: Richardson, B. (ed.) *Selected Proceedings of the Midwest Conference on Wetland Values and Management.* pp. 363-379. St. Paul, Minnesota.

Hartig, J.H. and R.L. Thomas. 1988. Development of plans to restore degraded areas in the Great Lakes. *Environmental Management* **12**, 327-347.

Hartley, K. 1996. Personal communication. Moira Conservation Authority, Belleville, Ontario.

Hartmann, H.C. 1990. Climate Change Impacts on Laurentian Great Lakes Levels. *Climatic Change, 17:49-68.*

Haslam, S.M. 1971. Community regulation in *Phragmites communis* Trin. I. mono-dominant stands. *Journal of Ecology* **59**, 65-73.

Heath, R.T. 1992. Nutrient dynamics in Great Lakes coastal wetlands: future directions. *Journal of Great Lakes Research* **18**, 590-602.

Heaton, M. 1996. Personal communication. Greater Toronto Area, Maple, ON.

Hector, D. 1996. Personal communication. Chatham Area Office, Ontario Ministry of Natural Resources, Chatham, Ontario.

Helling, S.E. and J.L. Gallagher. 1992. The effects of salinity and flooding on *Phragmites australis*. *Journal of Applied Ecology* **29**, 41-49.

Herdendorf, C.E., Hartley, S.M., and M.D. Barnes (eds.). 1981a. *Fish and Wildlife Resources of the Great Lakes Coastal Wetlands within the United States, Vol. 2: Lake Ontario.* U.S. Fish and Wildlife Service, FWS/OBS-81/02-v2.

Herdendorf, C.E., Hartley, S.M., and M.D. Barnes (eds.). 1981b. *Fish and Wildlife Resources of the Great Lakes Coastal Wetlands within the United States, Vol. 3: Lake Erie.* U.S. Fish and Wildlife Service, FWS/OBS-81/02-v3.

Herdendorf, C.E., Hartley, S.M., and M.D. Barnes (eds.). 1981c. *Fish and Wildlife Resources of the Great Lakes Coastal Wetlands within the United States, Vol. 4: Lake Huron.* U.S. Fish and Wildlife Service, FWS/OBS-81/02-v4.

Herdendorf, C.E., Hartley, S.M., and M.D. Barnes (eds.). 1981d. *Fish and Wildlife Resources of the Great Lakes Coastal Wetlands within the United States, Vol. 5: Lake Michigan.* U.S. Fish and Wildlife Service, FWS/OBS-81/02-v5.

Herdendorf, C.E., Hartley, S.M., and M.D. Barnes (eds.). 1981e. *Fish and Wildlife Resources of the Great Lakes Coastal Wetlands within the United States, Vol. 6: Lake Superior.* U.S. Fish and Wildlife Service, FWS/OBS-81/02-v6.

Herdendorf, C.E., Raphael, C.N., and W.G. Duffy. 1986. *The Ecology of Lake St. Clair Wetlands: A Community Profile*. National Wetlands Research Center, Fish and Wildlife Service, U.S. Department of the Interior, Washington, D.C.

Herdendorf, C.E. 1987. *The Ecology of the Coastal Marshes of Western Lake Erie: A Community Profile*. U.S. Fish and Wildlife Service, Biological Report 85(7.9).

Herdendorf, C.E. 1992. Lake Erie coastal wetlands: an overview. *Journal of Great Lakes Research* **18**, 533-551.

Hocking, D. and D. Dean. 1989. *Ausable-Bayfield Conservation Authority Clean Up Rural beaches (CURB) Plan.* Ausable-Bayfield Conservation Authority. Owen Sound, Ontario.

Hoffman, D.J., Smith, G.J., and B.A. Rattner. 1993. Biomarkers of contaminant exposure in common terns and black-crowned night herons in the Great Lakes. *Environmental Toxicology and Chemistry* **12**, 1095-1103.

Holmes, J.A. 1988. Potential for fisheries rehabilitation in the Hamilton Harbour-Cootes Paradise ecosystem of Lake Ontario. *Journal of Great Lakes Research* **14**, 131-141.

Hunter, P. 1996. Personal communication. Aylmer Area Office, Ontario Ministry of Natural Resources, Aylmer, Ontario.

Indicators for Evaluation Task Force. 1996. *Indicators to Evaluate Progress under the Great Lakes Water Quality Agreement*. International Joint Commission.

International Joint Commission. 1989. *Living With the Lakes: Challenges and Opportunities. Annex B. Environmental Features, Processes and Impacts: An Ecosystem Perspective on the Great Lakes - St. Lawrence River System.* Functional Group 2, International Joint Commission, Water Levels Reference Study.

International Joint Commission. 1993. *Levels Reference Study, Great Lakes St. Lawrence River Basin. Annex 2. Landuse and Management*. International Joint Commission.

International Lake Erie Regulation Study Board. 1981. *Lake Erie Water Level Study*. International Joint Commission. Windsor, Ontario.

Jackson, S.T., Futyma, R.P., and D.A. Wilcox. 1988. A paleoecological test of a classical hydrosere in the Lake Michigan dunes. *Ecology* **69**, 928-936.

Jean, M. and A. Bouchard. 1991. Temporal changes in wetland landscapes of a section of the St. Lawrence River, Canada. *Environmental Management* **15**, 241-250.

Johnson, D.L. 1989. Lake Erie wetlands: fisheries considerations. In: Krieger, K.A. (ed.) *Lake Erie Estuarine Systems: Issues, Resources and Management*. pp.257-274. National Oceanic and Atmospheric Administration, Seminar Series 14. NOAA Estuarine Programs Office. Washington, D.C.

Johnson, Ladd. date. Personal communication.

Johnston, C.A. 1991. Sediment and nutrient retention by freshwater wetlands: effects on surface water quality. *Critical Reviews in Environmental Control* **21**, 491-565.

Johnston, C.A. 1992. Land-use activities and western Lake Superior water quality. In: Vander Wal, J., Watts, P.D. (eds.) *Making a Great Lake Superior.* pp 145-162. Lakehead University, Centre for Northern Studies, Occasional Paper No. 9. Thunder Bay, Ontario.

Jones, S. 1996. Personal communication. Sault Ste. Marie District Office, Ontario Ministry of Natural Resources, Sault Ste. Marie, Ontario.

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

Jurik, T.W., Wang, S.-C., and A.G. van der Valk. 1994. Effects of sediment load on seedling emergence from wetland seed banks. *Wetlands* **14**, 159-165.

Kalas, A. 1996. Personal communication. Thunder Bay District Office, Ontario Ministry of Natural Resources, Thunder Bay, Ontario.

Kauss, P.B. 1991. Biota of the St. Marys River: habitat evaluation and environmental assessment. *Hydrobiologia* **219**, 1-35.

Keddy, P.A. 1990. Water level fluctuations and wetland conservation. In: Kusler, J., Smardon, R. (eds.) *Proceedings: International Symposium on Wetlands of the Great Lakes*. pp. 79-91, Association of State Wetland Managers, Niagara Falls, N.Y.

Keddy, P.A. and A.A. Reznicek. 1986. Great Lakes vegetation dynamics: the role of fluctuating water levels and buried seed. *Journal of Great Lakes Research* **12**, 25-36.

Keough, J.R. and J. Griffin. 1994. *Technical Workshop on EMAP Indicators for Great Lakes Coastal Wetlands.* Report to U.S. Environmental Protection Agency, Duluth, Minnesota.

King, D.R. and G.S. Hunt. 1967. Effect of carp on vegetation in a Lake Erie marsh. *Journal of Wildlife Management*. **31**, 181-188.

Kreutzwiser, R.D. 1981. The economic significance of the Long Point Marsh, Lake Erie, as a recreational resource. *Journal of Great Lakes Research* **7**, 105-110.

Kreutzwiser, R.D. and A.O. Gabriel. 1992. Ontario's Great Lakes flood history. J*ournal of Great Lakes Research* **18**, 194-198.

Krieger, K.A. 1992. The ecology of invertebrates in Great Lakes coastal wetlands: current knowledge and research needs. *Journal of Great Lakes Research* **18**, 634-650.

Kubiak, T.J., Harris, H.J., Smith, L.M., Schwartz, T.R., Stalling, J.A., Trick, J.A., Sileo, L., Docherty, D.E., and T.C. Erdman. 1989. Microcontaminants and reproductive impairment of the Forster's tern on Green Bay, Lake Michigan. 1983. *Archives of Environmental Contamination and Toxicology* **18**, 706-727.

Lawrence, P. and G. Nelson. 1994. *Shoreline Flooding and Erosion Hazards in the Long Point Area*. Long Point Environmental Publication Series, Working Paper 1, Heritage Resource Centre, University of Waterloo, Waterloo, Ontario.

Leach, J.H. 1991. Biota of Lake St. Clair: habitat evaluation and environmental assessment. *Hydrobiologia* **219**, 187-202.

Ligon, F.K., Dietrich, W.E., and W.J. Trush. 1995. Downstream ecological effects of dams, a geomorphic perspective. *BioScience* **45**, 183- 192.

Limno-Tech. 1993. *Great Lakes Environmental Assessment*. National Council of the Paper Industry for Air and Stream Improvement. Michigan.

LMSOFT. 1995. *Valuing the Economic Benefit of Wetlands in Ontario: Case Studies in Ontario*. unpublished report for: Canada Centre of Inland Waters, Environment Canada, Burlington, Ontario.

Lynch-Stewart, P. 1983. *Land Use Change on Wetlands in Southern Canada: Review and Bibliography*. Working Paper No. 26, Lands Directorate, Environment Canada. Ottawa, Ontario.

MacIsaac, H.J., Sprules, W.G., Johanasson, O.E., and J.H. Leach. 1992. Filtering impacts of larval and sessile zebra mussels (*Dreissena polymorpha*) in western Lake Erie. *Oceologia* **92**, 30-39.

MacLean, N. 1996. Personal communication. Ontario Ministry of Natural Resources, Napanee Area Office, Napanee, Ontario.

Malhiot, M. 1996. Personal communication. Wingham Office, Ontario Ministry of Natural Resources, Wingham, Ontario.

Mandrak, N. and E.J. Crossman. 1992. *A Checklist of Ontario Freshwater Fishes.* Royal Ontario Museum, Toronto, Ontario.

Manny, B.A., Edsall, T.A., and E. Jaworski. 1988. *The Detroit River, Michigan: an Ecological Profile.* U.S. Fish and Wildlife Service Biological Report 85(7.17).

Manny, B.A. and D. Kenaga. 1991. The Detroit River: effects of contaminants and human activities on aquatic plants and animals and their habitats. *Hydrobiologia* **219**, 269-279.

Manny, B.A., Nichols, S.J. and D.W. Schoesser. 1991. Heavy metals in aquatic macrophytes drifting in a large river. *Hydrobiologia* **219**, 333-344.

Matisoff, G. and J.P. Eaker. 1992. Summary of sediment chemistry research at Old Woman Creek, Ohio. *Journal of Great Lakes Research* **18**, 603-621.

McCormick, P. and J. Cairns, Jr. 1994. Algae as indicators of environmental change. *Journal of Applied Phycology* **6**, 509-526.

McCullough, G.B. 1981. Wetland losses in Lake St. Clair and Lake Ontario. In: A. Champagne (ed.) *Proceedings of the Ontario Wetlands Conference*. pp. 81-89. Federation of Ontario Naturalists and Ryerson Polytechnical Institute, Toronto, Ontario.

McCullough, G.B. and F.G. Thornton. 1981. *Inventory of Ontario's Lower Great Lakes Wetlands.* Canadian Wildlife Service Report Series.

McCullough, G.B. 1982. Wetland losses in Lake St. Clair and Lake Ontario. In: Champagne, E. (ed), *Proceedings of the Ontario Wetlands Conference*. Federation of Ontario Naturalists, Don Mills, Ontario.

McCullough, G.B. 1985. Wetland threats and losses in Lake St. Clair. In: Prince, H. P, D'Itri, F.M. *Coastal Wetlands*. pp. 201-208. Lewis Publishing. Co. Chelsea, Michigan.

McDonald, M.E. 1955. Cause and effects of a die-off of emergent vegetation. *Journal of Wildlife Management* **19**, 24-35.

McLaughlin, D.B. and H.J. Harris. 1990. Aquatic insect emergence in two Great Lakes marshes. *Wetlands Ecology and Management* **1**, 111-121.

McPherson, B. 1996. Personal communication. Hamilton Region Conservation Authority, Ancaster, Ontario.

Merendino, M.T., Smith, L.M., Murkin, H.R., and R.L. Peterson. 1990. The response of prairie wetland vegetation to seasonality of drawdown. *Wildlife Society Bulletin* **18**, 245-251.

Meeker, J.E. 1996. Wild rice and sedimentation processes in a Lake Superior coastal wetland. *Wetlands* **16**, 219-231.

Mills, E.L., Leach, J.H., Carlton, J.T., and C.L. Secor. 1993. Exotic species in the Great Lakes: a history of biotic crises and anthropogenic introductions. *Journal of Great Lakes Research*. **19**, 1-54.

Mitsch, W.J. 1992. Combining ecosystem and landscape approaches to Great Lakes wetlands. *Journal of Great Lakes Research* **18**, 552-570.

Mitsch, W.J. and J.G. Gosselink. 1993. *Wetlands, 2nd Edition*. Van Nostrand Reinhold, N.Y.

Mitsch, W.J. and B.C. Reeder. 1992. Nutrient and hydrologic budgets of a Great Lakes coastal wetland during a drought year. *Wetlands Ecology and Management* **1**: 211-223.

Morris, R. 1983. *Erosion and Sedimentation Processes Throughout the Oshawa Second Marsh Watershed.* Lands Directorate, Environment Canada, Burlington, Ontario.

Mortsch, L. and G. Koshida. 1996. "Effects of fluctuating water levels on Great Lakes Coastal Wetlands" Mortsch, L.D. and B.N. Mills (eds) Great Lakes - St. Lawrence Basin Projects Progress Report #1 Adapting to the Impacts of Climate Change and Variability. Environment Canada, Atmospheric Environment Service, Burlington, Ontario pp 98-103.

Mortsch, L.D. and H.F. Quinn. 1996. Climate scenarios for Great Lakes ecosystem Studies, Limnology and Oceanography. 41(5):903-911.

Murray, A. 1996. Personal communication. Owen Sound Area Office, Ontario Ministry of Natural Resources, Owen Sound, Ontario.

Nalepa, T.F. and D.W. Schloesser (eds.). 1992. *Zebra Mussels: Biology, Impacts, and Control*. Lewis Publishers, Ann Arbor, Michigan.

National Oceanic and Atmospheric Administration. 1992. *Great Lakes Water Levels, 1860-1990.* National Ocean Service, Rockville, Maryland.

National Wetlands Working Group. 1988. *Wetlands of Canada*. Ecological Land Classification Series, No. 24. Sustainable Development Branch, Environment Canada, Ottawa and Polyscience Publications, Montreal, Quebec.

Natural Heritage Information Centre. 1995. Rare communities of Ontario: Great Lakes coastal meadow marshes. *Ontario Natural Heritage Information Centre Newsletter* **2**, 4-5.

Neilson, M., L'Italien, S. Glumac, V., Williams, D., and P. Bertram. 1995. *Nutrients: Trends and System Response*. 1994 State of the Lakes Ecosystem Conference (SOLEC) Background Paper. Environment Canada and United States Environmental Protection Agency EPA 905-R-95-015.

Nichols, S.A. and B.H. Shaw. 1986. Ecological life histories of the three aquatic nuisance plants, *Myriophyllum spicatum, Potamogeton crispus* and *Elodea canadensis*. *Hydrobiologia* **131**, 3-21.

Nichols, S.J., Manny, B.A., Schloesser, D.W., and T.A. Edsall. 1991. Heavy metal concentrations of sediments in the upper connecting channels of the Great Lakes. *Hydrobiologia* **219**, 307-315.

New York State Department of Environmental Conservation. 1994. *Niagara River Remedial Action Plan, Summary*. Division of Water, New York State Department of Environmental Conservation, Buffalo, N.Y.

Oliver, I. and A.J. Beattie. 1993. A possible method for the rapid assessment of biodiversity. *Conservation Biology* **7**, 562-568.

Ontario Ministry of Natural Resources. 1991. *Sault Ste. Marie District Shoreline Management Plan, 1991-2000*. Ontario Ministry of Natural Resources, Sault Ste. Marie, Ontario.

Ontario Ministry of Natural Resources. 1993. *Ontario Wetland Evaluation System Southern Manual, Third Edition.* Toronto, Ontario.

Ontario Ministry of the Environment, Michigan Department of Natural Resources. 1991. *The St. Clair River Area of Concern Environmental Conditions and Problem Definitions,* Stage 1 Remedial Action Plan.

Ontario Ministry of the Environment, Environment Canada, Department of Fisheries and Oceans, Ontario Ministry of Natural Resources, Ontario Ministry of Agriculture and Food. 1990. *Bay of Quinte RAP Stage I: Environmental Setting and Problem Definition*. Belleville, Ontario.

Painter, D.S., McCabe, K.J., and W.L. Simser. 1989. *Past and Present Limnological Conditions in Cootes Paradise Affecting Aquatic Vegetation*. Technical Bulletin No. 13. Royal Botanical Gardens, Hamilton, Ontario.

Patch, S.P. and W.-D.N. Busch. 1984. *The St. Lawrence River-Past and Present: A Review of Historical Natural Resource Information and Habitat Changes in the International Section of the St. Lawrence River.* U.S. Fish and Wildlife Service, Cortland, N.Y.

Petering, R.W. and D.L. Johnson. 1991. Distribution of fish larvae among artificial vegetation in a diked Lake Erie wetland. *Wetlands* **11**, 123-138.

PLUARG. 1978. *Environmental Management Strategy for the Great Lakes System.* International Reference Group on Great Lakes Pollution from Land Use Activities, International Joint Commission, Windsor, Ontario.

Prince, H.H., Padding, P.I., and R.W. Knapton. 1992. Waterfowl use of the Laurentian Great Lakes. *Journal of Great Lakes Research* **18**, 673-699.

Raphael, C.N. and E. Jaworski. 1979. Economic value of fish, wildlife and recreation in Michigan's coastal wetlands. *Coastal Zone Management Journal* **5**, 181-194.

Rawinski, T.J. 1982. *The Ecology and Management of Purple Loosestrife (Lythrum salicaria* L.*) in Central New York.* MS thesis. Cornell University, Ithaca, N.Y.

Renman, G. 1989. Distribution of littoral macrophytes in a north Swedish riverside lagoon in relation to bottom freezing. *Aquatic Botany* **33**, 243-256.

Richards, R.P. and D.B. Baker. 1993. Trends in nutrient and suspended sediment concentrations in Lake Erie tributaries, 1975-1990. *Journal of Great Lakes Research* **19**, 200-211.

Ross, R.K. 1984. Migrant waterfowl use of major shorelines of eastern Ontario. In: Curtis, S.G., Dennis, D.G., Boyd, H. (eds.). *Waterfowl studies in Ontario, 1973-1981.* pp. 53-62. Occasional Paper No. 54, Canadian Wildlife Service, Environment Canada, Ottawa, Ontario.

Rutherford, L.A. 1979. *The Decline of Wetlands in Southern Ontario*. Unpublished B.E.S. thesis. Department of Environmental Studies. University of Waterloo, Waterloo, Ontario.

Sager, P.E., Richman, S., Harris, H.J., and G. Fewless. 1985. Preliminary observations on the seiche-induced flux of carbon, nitrogen and phosphorus in a Great Lakes coastal marsh. In: Prince, H.H., D'Itri, F.M. *Coastal Wetlands*, pp. 59-68. Lewis Publishers, Chelsea, Michigan.

Selinger, C. 1996. Personal communication. Espanola Area Office, Ontario Ministry of Natural Resources, Espanola, Ontario.

Selinger, W. 1996. Personal communication, Espanola Area Office, Ontario Ministry of Natural Resources, Espanola, Ontario.

Severn Sound Remedial Action Plan. 1993a. *Severn Sound Remedial Action Plan Stage 2 Report.*

Severn Sound Remedial Action Plan. 1993b. *An Interim Fish Habitat Management Plan for the Severn Sound*.

Simser, W.L. 1982. *Changes in Aquatic Biota of Cootes Paradise Marsh*. Technical Bulletin No. 12. Royal Botanical Gardens. Hamilton, Ontario.

Simser, W.L. 1979. *Changes in Aquatic Biota of Cootes Paradise Marsh*. Technical Bulletin No. 12. Royal Botanical Gardens, Hamilton, Ontario.

Singer, D.K., Jackson, S.T., Madsen, B.J., and D.A. Wilcox. 1996. Differentiating climatic and successional influences on long-term development of a marsh. *Ecology*. In press.

Skubinna, J.P., Coon, T.G., and T.R. Batterson. 1995. Increased abundance and depth of submersed macrophytes in response to decreased turbidity in Saginaw Bay, Lake Huron. *Journal of Great Lakes Research* **21**, 476-488.

Smith, P. 1987. *Towards the Protection of Great Lakes Natural Heritage Areas.* Technical Paper, Heritage Resources Centre, University of Waterloo, Waterloo, Ontario.

Smith, P.G.R., Glooschenko, V., and D.A. Hagen. 1991. Coastal wetlands of the three Canadian Great Lakes: inventory, current conservation initiatives and patterns of variation. *Canadian Journal of Fisheries and Aquatic Sciences* **48**, 1581- 1594.

Snell, E.A. 1987. *Wetland Distribution and Conversion in Southern Ontario.* Canada Land Use Monitoring Program. Working Paper No. 48. Inland Waters and Lands Directorate, Environment Canada.

Snell and Cecile Environmental Research. 1992. *A Spatial Planning Study of Southern Ontario Using Wetland, Agricultural Land Use and Waterfowl Data to Assist Development of the North American Waterfowl Management Plan - Eastern Habitat Joint Venture.* unpublished report submitted to Ducks Unlimited Canada, Barrie, Ontario.

Solomon, K.R., Baker, D.B., Richards, R.P., Dixon, K.R., Klaine, S.J., La Point, T.W., Kendall, R.J., Weisskopf, C.P., Giddings, J.M., Giesy, J.P., Hall, L.W.Jr., and W.M. Williams. 1996. Ecological risk assessment of atrazine in North American surface waters. *Environmental Toxicology and Chemistry* **15**, 31-76.

St. Clair River Remedial Action Plan. 1995. *The St. Clair River Area of Concern: Water Use Goals, Remedial Measures and Implementation Strategy*. Ontario Ministry of Environment and Energy, Michigan Department of Natural Resources. Sarnia, Ontario and Lansing, Michigan.

Stephenson, T.D. 1990. Fish reproductive utilization of coastal marshes of Lake Ontario near Toronto. *Journal of Great Lakes Research* **16**, 71-81.

Stuckey, R.L. 1980. Distributional history of *Lythrum salicaria* (purple loosestrife) in North America. *Bartonia* **47**, 3-21.

Suke, S. 1996. Personal communication. Lakehead Region Conservation Authority, Thunder Bay, Ontario.

Sutherland, D.A. 1994. *Natural Heritage Resources of Ontario: Freshwater Fishes.* Natural Heritage Information Centre. Peterborough, Ontario.

Sutherland, D.A. 1996. Personal communication. Natural Heritage Information Centre, Ontario Ministry of Natural Resources, Peterborough, Ontario.

The Conservation Foundation. 1988. *Protecting America's Wetlands: An Action Agenda.* The Conservation Foundation, Washington, D.C.

The Nature Conservancy. 1994. *The Conservation of Biological Diversity in the Great Lakes Ecosystem: Issues and Opportunities*. The Nature Conservancy Great Lakes Program. Chicago, Illinois.

Thompson, R. 1996. Personal communication. Long Point Area Office, Ontario Ministry of Natural Resources, Simcoe, Ontario.

Thompson, T.A. 1992. Beach-ridge development and lake-level variation in southern Lake Michigan. *Sedimentary Geology* **80**, 305-318.

Thompson, T.A. and S.J. Baedke. 1995. Beach-ridge development in Lake Michigan: shoreline behaviour in response to quasi-periodic lake-level events. *Marine Geology* **129**, 163-174.

Thompson, T.A., Fraser, G.S., and N.C. Hester. 1991. *Lake-level variation in southern Lake Michigan: magnitude and timing of fluctuations over the past 4,000 years.* Indiana Geological Survey Report, Bloomington, Indiana.

Thompson, D.Q., Stuckey, R.L., and E.B. Thompson. 1987. *Spread, Impact and Control of Purple Loosestrife (Lythrum salicaria) in North American Wetlands.* United States Fish and Wildlife Service, United States Department of Interior, Washington, D.C.

Tuininga, K. 1996. Personal communication. Greater Toronto Area, Maple, Ontario.

Wall, G.J., van Vliet, L.J.P., and W.T. Dickinson. 1978. *Contribution of Sediments to the Great Lakes from Agricultural Activities in Ontario.* Task C (Canadian Section), Pollution form Land Use Activities Reference Group (PLUARG).

Weller, M.W. 1987. *Freshwater Marshes Ecology and Wildlife Management, Second Edition*. University of Minnesota Press, Minneapolis, Minnesota.

Weller, M.W. and C.E. Spatcher. 1965. *Role of Habitat in the Distribution and Abundance of Marsh Birds*. Iowa State University Agricultural and Home Economics Experimental Station Special Report No. 43. Ames, Iowa

Wetzel, R.G. 1992. Wetlands as metabolic gates. *Journal of Great Lakes Research* **18**, 529-532.

Whillans, T.H. 1982. Changes in marsh area along the Canadian shore of Lake Ontario. *Journal of Great Lakes Research* **8**, 570-577.

Whillans, T.H. 1987. Wetlands and aquatic resources. In: M.C. Healey and R.R. Wallace (eds.), *Canadian Aquatic Resources*, *Canadian Bulletin of Fisheries and Aquatic Sciences* **215**, 321-356.

Whillans, T.H. 1990. Assessing threats to fishery values of Great Lakes wetlands. In: Kusler, J., Smardon, R. (eds.) *Proceedings: International Wetland Symposium - Wetlands of the Great Lakes*, pp. 156-164. The Association of State Wetland Managers, Niagara Falls, N.Y.

Whillans, T.H., Smardon, R.C., and W.-D.N. Busch. 1992. *Status of Lake Ontario Wetlands*. Great Lakes Research Consortium.

Williams, D.C. and J.G. Lyon. 1991. Use of a Geographic System Database to Measure and Evaluate Wetland Changes in the St. Mary's River, Michigan. *Hydrobiologia* **219**, 83-95.

Whitton, B.A. and M.G. Kelly. 1995. The use of algae and other plants for monitoring rivers. *Australian Journal of Ecology* **20**, 45-56.

Wilcox, D.A. 1985a. The effects of deicing salts on water chemistry in Pinhook Bog, Indiana. *Water Resources Bulletin* **22**, 57-65.

Wilcox, D.A. 1985b. The effects of deicing salts on vegetation in Pinhook Bog, Indiana. *Canadian Journal of Botany* **64**, 865-874.

Wilcox, D.A. 1989a. Responses of selected Great Lakes wetlands to water level fluctuations. Appendix B in: Busch, W.-D.N., Kavetsky, R., McCullough, G. *Water Level Criteria for Great Lakes Wetlands*. International Joint Commission Water Levels Reference Functional Group 2.

Wilcox, D.A. 1989b. Migration and control of purple loosestrife (*Lythrum salicaria*) along highway corridors. *Environmental Management* **13**, 365-370.

Wilcox, D.A. 1993. Effects of water level regulation on wetlands of the Great Lakes. *Great Lakes Wetlands* **4**, 1-2,11.

Wilcox, D.A. 1995. The role of wetlands as nearshore habitat in Lake Huron. In: Munawar, M., Edsall, T., Leach, J. (eds.), *The Lake Huron Ecosystem: Ecology, Fisheries and Management*. pp. 223-245. SPB Academic Publishing, Amsterdam, The Netherlands.

Wilcox, D.A., Apfelbaum, S.I., and R.D. Hiebert. 1984. Cattail invasion of sedge meadows following hydrologic disturbance in the Cowles Bog Wetland Complex, Indiana Dunes National Lakeshore. *Wetlands* **4**, 115-128.

Wilcox, D.A. and J.E. Meeker. 1991. Disturbance effects on aquatic vegetation in regulated and unregulated lakes in northern Minnesota. *Canadian Journal of Botany* **69**, 1542-1551.

Wilcox, D.A. and J.E. Meeker. 1992. Implications for faunal habitat related to altered structure in regulated lakes in northern Minnesota. *Wetlands* **12**, 192-203.

Wilcox, D.A., Meeker, J.E., and J. Elias. 1993. *Impacts of Water-level Regulation on Wetlands of the Great Lakes.* Phase 2 Report to Working Committee 2, International Joint Commission, Great Lakes Water Levels Reference Study.

Wilcox, D.A. and J.E. Meeker. 1995. Wetlands in regulated Great Lakes. In: LaRoe, E.T., Farris, G.S., Puckett, C.E., Doran, P.D., Mac, M.J. (eds.) *Our Living Resources: A Report to the Nation on the Distribution, Abundance, and Health of U.S. Plants, Animals, and Ecosystems.* pp. 247-249. U.S. Department of the Interior, National Biological Service, Washington, D.C.

Wilcox, D.A. and H.A. Simonin. 1987. A chronosequence of aquatic macrophyte communities in dune ponds. *Aquatic Botany* **28**, 227-242.

Wilcox, J. date. Personal communication.

Wilcox, S.A. 1994. *Local Economies of the Long Area*. Long Point Environmental Publication Series, Working Paper 1, Heritage Resource Centre, University of Waterloo, Waterloo, Ontario.

Wilcox, S.A. 1995. *Bird and Nature Conservation Planning: A Financial and Human Ecological Approach, the Case of Long Point.* M.A. thesis. School of Urban and Regional Planning. University of Waterloo, Waterloo, Ontario.

Williams, D.C. and J.G. Lyon. 1991. Use of geographic information system data to measure and evaluate changes in the St. Marys River, Michigan. *Hydrobiologia* **219**, 83-95.

Williams, G.P. and M.G. Wolman. 1984. *Downstream Effects of Dams on Alluvial Rivers*. U.S. Geological Survey Professional Paper 1286, USGS, Washington, D.C..

Wisheu, I.C., Keddy, P.A., Moore, D.R.J., McCanny, S.J., and C.L. Gaudet. 1990. Effects of Eutrophication on Wetland Vegetation. In: Kusler, J., Smardon, R. (eds.) *Proceedings: International Wetland Symposium - Wetlands of the Great Lakes*, pp. 112-121. The Association of State Wetland Managers, Niagara Falls, N.Y.

Wren, C.D. Date. Cause-effect linkages between chemicals and populations of mink (*Mustella vison*) and otter (*Lutra canadensis*) in the Great Lakes basin. *Journal of Toxicology and Environmental Health* **33**, 549-586.