State of the Lakes Ecosystem Conference 1996

Background Paper

NEARSHORE WATERS OF THE GREAT LAKES

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December 1997

ISBN 0-662-26031
EPA 905-R-97-015a
Cat. No. En40-11/35-1-1997E

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Notice To Readers

This Background Paper is part of a series of Backgournd Papers that are intended 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 greater 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 will be incorporated into the 1997 State of the Great Lakes report, which provides key information required by managers to make better environmental decisions.

Nearshore Waters
of the Great Lakes

1.0 Introduction

In October 1994, the governments of the United States and Canada convened the first State of the Lakes Ecosystem Conference (SOLEC '94). The conference was designed to further the purpose of the Great Lakes Water Quality Agreement between the United States and Canada, which aims to restore and maintain the chemical, physical, and biological integrity of the waters of the Great Lakes basin ecosystem. Background papers prepared for the conference and discussions that occurred at SOLEC '94 are summarized in a document prepared by the U.S. and Canadian governments titled "State of the Great Lakes 1995" (EC and EPA 1995). A second, follow-up conference (SOLEC '96) scheduled for fall 1996 is designed to focus more intensively on the status of the Great Lakes coastal ecosystem, which includes the coastal shorelands, coastal wetlands, and coastal or nearshore waters. A major objective of SOLEC '96 is to examine the effects of human activity—and particularly land-use practices—on the coastal ecosystem. The present paper is designed to provide background information that will facilitate discussion of the status of the nearshore waters element of Great Lakes coastal ecosystems.

2.0 The Nearshore Waters as a Significant Natural Element of the Great Lakes Basin Ecosystem

The Great Lakes basin ecosystem covers about 760,000 km^2 (USEPA and GC 1995), spans 9^o of latitude and 19^o of longitude, and lies halfway between the equator and the North Pole in a lowland corridor that extends from the Gulf of Mexico to the Arctic Ocean (Figure 1). The Great Lakes, which are the most prominent feature of this system, have a combined surface area of about 244,000 km^2, a volume of 22,700 km^3, and are the largest single collection of fresh water on the surface of the earth, excluding the polar ice caps (TNC 1994). The Great Lakes basin ecosystem has been divided into major elements by TNC (1994), Dodge and Kavetsky (1995), and Edsall (1996). These elements basically include open lake (including nearshore and offshore waters); connecting channel; wetland (including coastal and inland wetland); tributary; coastal shore; lakeplain; and terrestrial inland. This paper focuses on the Nearshore Waters as a significant element of the Great Lakes basin ecosystem.

2.1 A Definition of Nearshore Waters

The nearshore waters largely occupy a band of varying width around the perimeter of each lake between the land and the deeper offshore waters of the lake (Figure 2). The band is narrowest where the slope of the lake bed is steep and continuous. More specifically, as we define them for this paper, the nearshore waters begin at the shoreline or the lakeward edge of the coastal wetlands and extend offshore to the deepest lake-bed depth contour, where the thermocline typically intersects with the lake bed in late summer or early fall. In Lake Superior, the boundary between the nearshore and offshore waters typically

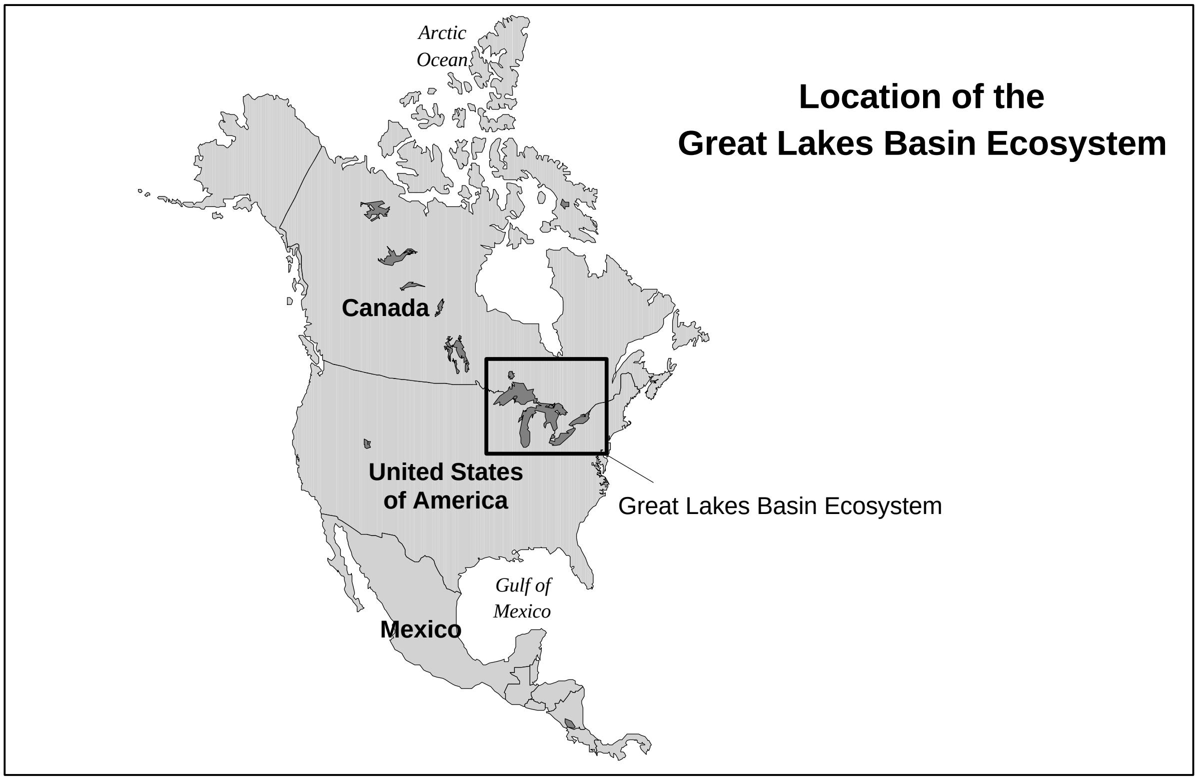


Figure 1 The Great Lakes Basin Ecosystem

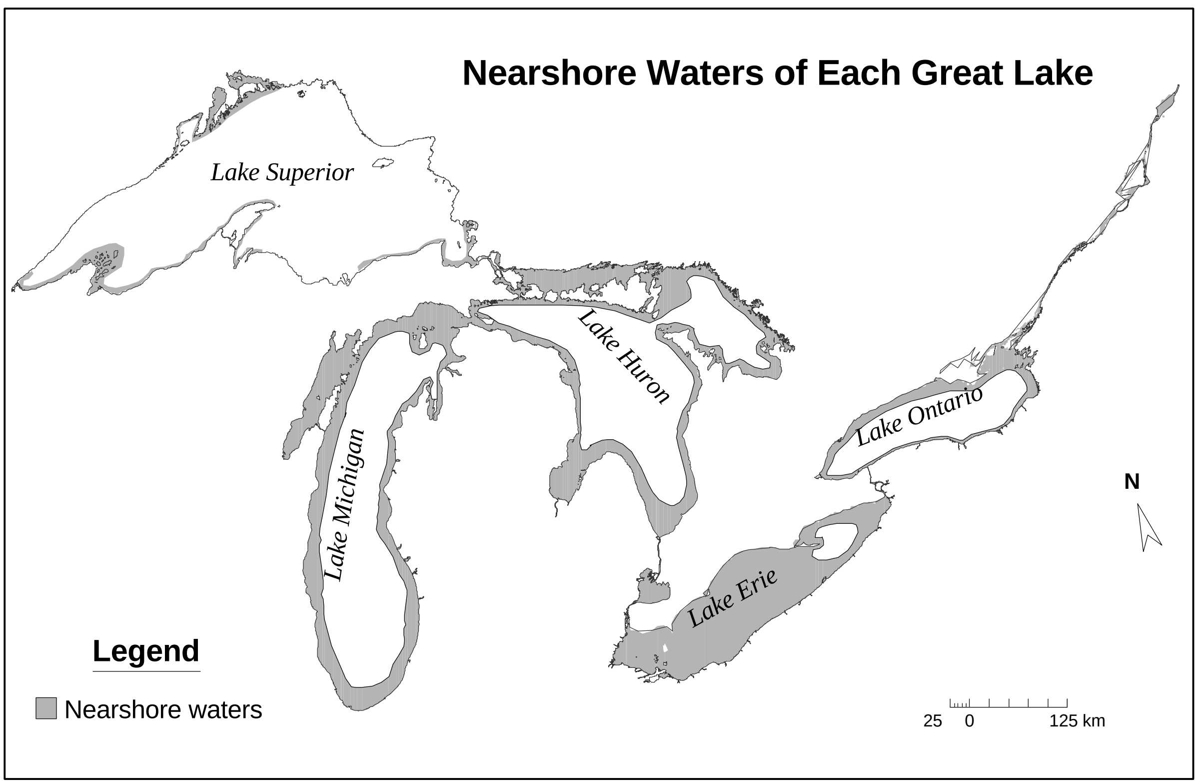


Figure 2 Nearshore Waters

occurs at about the 10-m depth contour (Bennett 1978). In the other four Great Lakes, which are farther south and display a wider range of temperatures seasonally, the boundary between the nearshore and offshore waters may occur as deep as the 30-m depth contour (Schertzer et al. 1987). In the central basin of Lake Erie, the lower limit of the thermocline is highly variable and responds to meteorological events. A detailed set of records collected in 1979 (Schertzer et al. 1987) shows that the thermocline depth in central Lake Erie increased in the May-to-September period and that the bottom of the thermocline extended to 24 m in mid-September immediately before thermal stratification ended. Thus, virtually all of Lake Erie's central basin would have been considered to be nearshore waters in 1979. The temperature of the nearshore waters at the lake bed in summer in all five lakes exceeds 15ºC and may reach 25ºC in portions of Lake Erie. In winter, the nearshore waters are typically covered with ice, and the water temperature approaches 0ºC from surface to bottom (Assel 1986; Assel et al. 1983).

Physical processes such as the lake's thermal cycle and circulation can have a pronounced influence on water-quality conditions in the Great Lakes. The major features of the thermal cycle that affect water quality include stratification characteristics such as the timing of spring and fall overturn and the temperatures of the epilimnion and hypolimnion waters, the thermal bar, the thermocline depth, and upwelling and downwelling dynamics. These thermal characteristics govern the unique circulation patterns, especially within the nearshore zone. What follows is a brief synopsis of some of the relevant characteristics of the seasonal physical processes and how they affect water-quality concerns for large lake systems.

The interaction of meteorological and hydrological factors is responsible for the seasonal thermal response of the lakes. The basic processes include radiative and turbulent heat exchanges at the air–water interface, energy storage within the lake, and net energy flowing into or out of the lake (Schertzer and Sawchuk 1990). Meteorological factors such as radiation, air temperature, precipitation, and evaporation affect the surface temperature, while winds provide the mechanical energy required to mix the heat downwards. Hydrological factors such as inflow and outflow cause local temperature changes by inducing horizontal movement and mixing of the lake waters. Solar radiation penetrates into the water column, affecting the heating of the uppermost layers.

At the temperate latitudes, the Great Lakes are subject to major seasonal changes in net heat input resulting in their going through an annual thermal cycle. The Great Lakes are dimictic—that is, they mix from top to bottom (a process called *overturn*) twice yearly, in the spring and in the fall. The timing of the overturn is closely related to the time when the surface water temperatures fluctuate through the temperature of maximum density of fresh water (i.e., 4ºC).

As a result of increased surface heating in the early spring, the nearshore littoral regions begin warming more rapidly than do the lake's deeper regions. Progressive warming results in nearshore water temperatures above 4ºC while deeper regions remain below the temperature of maximum density. The region of convergence between the two horizontal thermal regimes is referred to as the thermal bar. The thermal bar has been studied extensively in large lakes (Rodgers 1965; Tikhomirov 1963) to determine the physical dynamics and also to investigate its impact on water-quality conditions during the spring. Measurements of the thermal bar have included satellite images and detailed observation of temperature, current velocity, and optical characteristics, as well as biological and chemical characteristics. Satellite images have clearly indicated that the thermal bar is a zone of convergence not only for water masses of different temperature but also for floating debris. Of practical significance for water-quality concerns is that the sharp density front across the thermal bar effectively limits nearshore/offshore exchange of pollutants and thus affects the nearshore water quality. The proximity of the thermal bar needs to be recognized when discharge points are designed and located. Meteorological conditions such as heating and wind mixing affect the rate at which the thermal bar progresses offshore to the midlake. In the Great Lakes, this process can take as long as six weeks (Schertzer and Murthy 1994).

Figure 3 illustrates the thermal stratification cycle in Lake Ontario based on measurements made on a midlake cross-section (Simons and Schertzer 1987a). Figure 3a is a time-series of eastward wind stress. The wind stress plays a dominant role in the stratification process. Figure 3b shows isotherms along the cross-lake transect. The isotherms for May 17–18 clearly show isothermal conditions in the midlake (T less than 4^{o}C) and the development of the thermal bar on both shores. Due to topographic effects (i.e., the depth of the water and the configuration of the bottom and shoreline influence both the temperature and the circulation), the thermal bar is more developed along the shallower north shore compared to the deeper south shore. It is of interest to note the progression of the thermal bar towards the centre of the lake as the heating intensifies towards the midsummer period. Typical summer stratification occurs when the surface water temperature reaches 4^{o}C over the entire lake and the thermal bar disappears.

Summer stratification is characterized by warmer, less dense water at the surface layers and cooler, denser water in the lower layer. Progressive heating results in the development of a stable stratification and a well-defined epilimnion (warm water), mesolimnion (transition temperatures), and hypolimnion (cool water) layer. It is also interesting to note (from Figure 3b, July 16–17) that the thermocline depth is not uniform over the whole lake. The 10^{o}C isotherm is highlighted to mark the approximate depth of the thermocline in Lake Ontario.

Dynamic processes that have an impact on the temperature distribution in large lakes include upwelling and downwelling, internal waves (along the thermocline), and Kelvin waves (coastally trapped waves that propagate along the shoreline, particularly after large storms) (Simons and Schertzer 1987b). With respect to upwelling and downwelling processes, strong easterly winds along the axis of Lake Ontario will cause a surface drift to the right, which can result in tilting the thermocline. Satellite digital temperature data, along with surveillance data, has demonstrated large-scale upwelling along the north shore and downwelling along the south shore of the Lake Ontario. Figure 4 illustrates an upwelling event in Lake Ontario along the north shore, with corresponding longshore (easterly) velocity distribution. In this case, the thermocline tilting along the nearshore zone is so intense that a major “outbreak” of cold hypolimnion water has upwelled to the surface; 4^{o}C water extends 2 km from the shore. Between 2 km and 3 km offshore, there is a very intense temperature gradient, from 6^{o}C to 12^{o}C. The velocity distribution clearly shows that the upwelling event has resulted in weaker longshore

Figure 3. Thermal Stratification Cycle in Lake Ontario

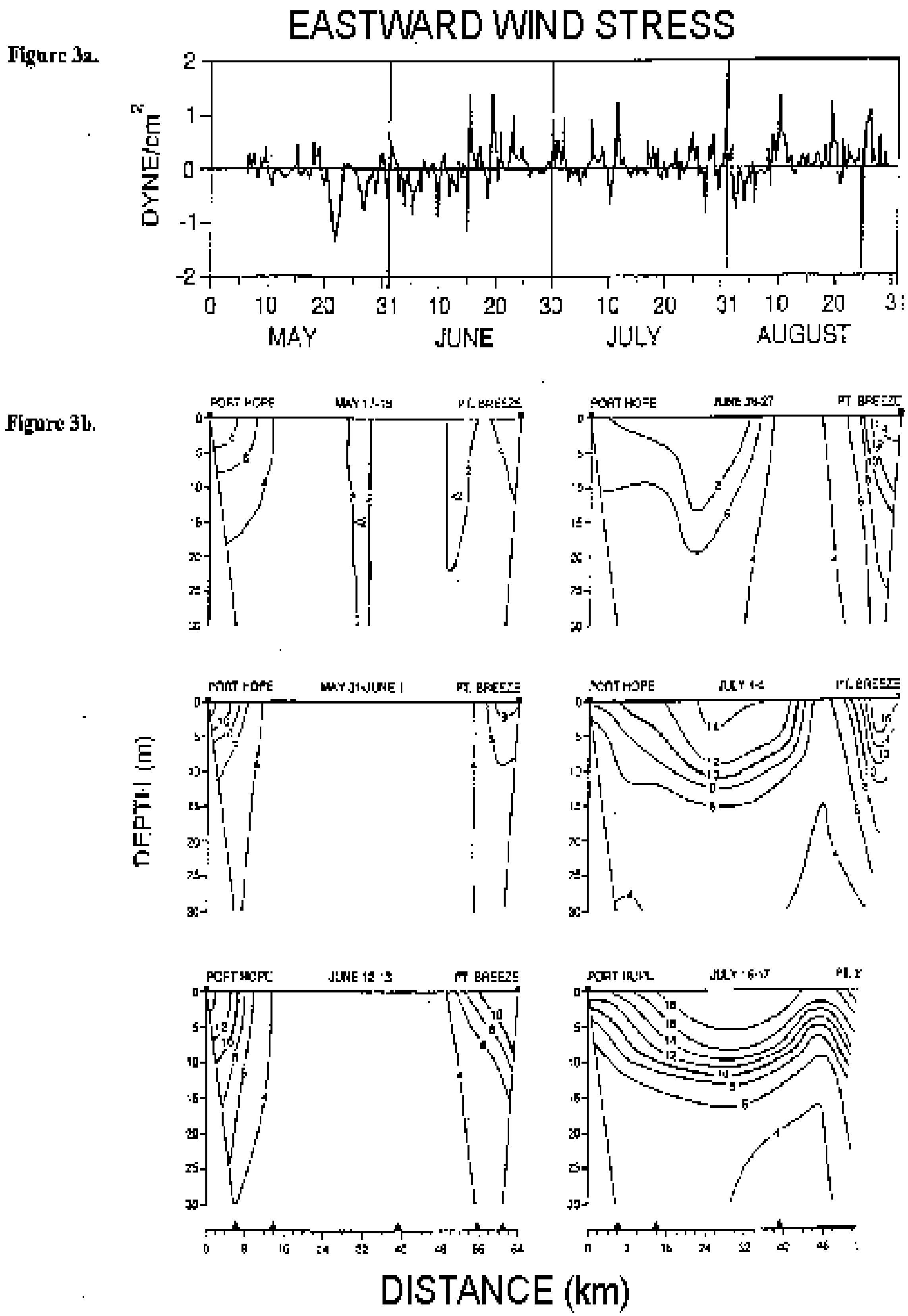
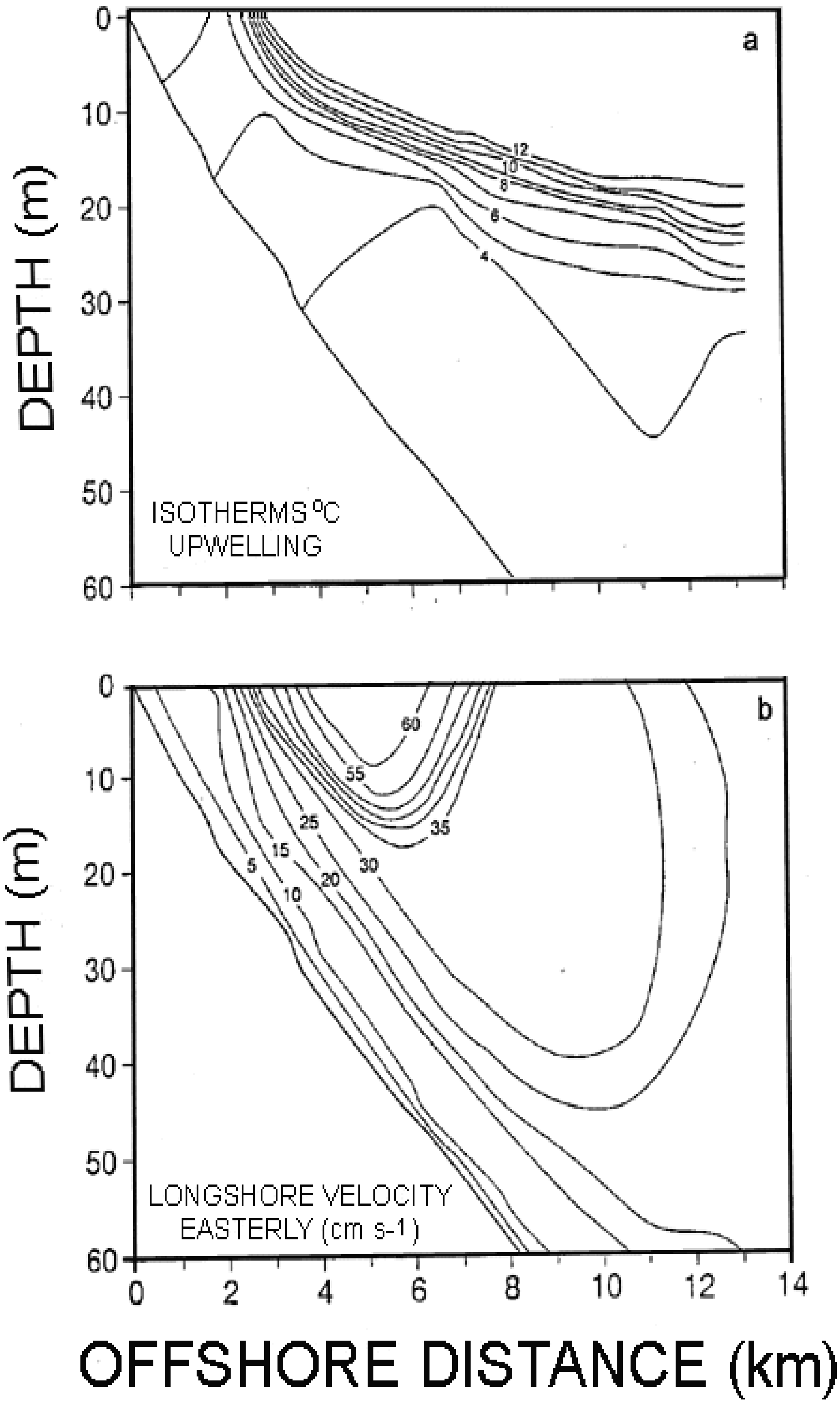


Figure 4. Upwelling in Lake Ontario with Longshore Velocity Distribution. (a) Temperature isotherms. (b) Longshore velocity contours along the coastal zone of Oshawa, Lake Ontario, following a major storm (October 1972), indicating episodes of upwelling and downwelling and the location of a coastal jet.



currents in the upwelled region closer to shore and in the formation of a “coastal jet,” with velocities ranging from 35 cm s^{-1} to 60 cm s^{-1} (Csanady and Scott 1974). The higher current speeds within the region of the coastal jet are highly effective in transporting and dispersing pollutants along the nearshore zone. The persistence of upwelling events depends on the duration of the strong wind event. During an upwelling episode, the nearshore waters are replenished with nutrient-rich hypolimnetic waters; thus, upwelling affects the nearshore water quality. Periodic upwellings can supply nutrients to the nearshore nuisance attached alga *Cladophora*.

Hydrological factors also have a significant effect on a lake’s dynamic processes and water quality. Whereas pollutants can be introduced to lakes through loading from precipitation, tributaries, and land runoff, inputs from connecting channels can play a significant role in introducing and redistributing substances in a large lake. Connecting channels among the Great Lakes include the St. Marys River, the Straits of Mackinac, the Detroit River, the Niagara River, and the St. Lawrence River. Lake Ontario, being at the downstream end of the Great Lakes, receives large inflows from the Niagara River. Water-quality analyses of the Niagara River, in the past, have shown high concentrations of toxic chemicals that are introduced into Lake Ontario. The number of toxic waste disposal sites in the area are still thought to represent a threat. Much research has been conducted to investigate the dynamics of the Niagara River inflow into Lake Ontario (Murthy and Miners 1989). The nearshore thermal structure is altered significantly by the inflow: the warmer Niagara River plume extends beyond the river mouth in excess of 10 km, after which it eventually mixes with the ambient lake water. The vertical extent of the Niagara River plume can be 8 m to 10 m, with the warmer inflowing water developing a frontal structure as it enters the lake (Murthy et al. 1986). The gradient across the thermal front depends on the time of year and therefore on the difference between the temperature of the inflowing water and the ambient lake temperatures.

Prevailing wind conditions and lake circulation patterns determine the spread of the Niagara River plume in Lake Ontario (Murthy and Schertzer 1994). In most circumstances, a plume develops from the Niagara River mouth and tends to extend eastward along the south shore of the lake. Figure 5 illustrates an example of the spatial extent of the Niagara River plume, as determined by progressively tracking the position of drifters within the current. In this example, inflowing water (bearing its load of pollutants, sediment, nutrients, plankton, exotic species, and other materials) generally flows out of the mouth to a distance of approximately 10 km. In the initial phase, horizontal velocities from the Niagara River mouth are reduced significantly, and the river water is vertically well mixed over the shallow bar area. Beyond this initial phase, the river plume is bent over in response to lakewide circulation and the prevailing winds. In most cases, the river plume is diverted to the east, and the weakly buoyant plume responds to the prevailing winds and lakewide circulation forces. Figure 5 shows that in the transition phase, a large clockwise eddy of between 10 km and 12 km in diameter is formed to the east of the Niagara River mouth. The eddy appears often and last for a few days. From a water-quality standpoint, river outflow that is entrained into this zone of low net transport is effectively isolated from the mixing effects of the main shore-parallel currents. Consequently, this nearshore area can be a zone in which fine particulate material is deposited. As shown in the inset of Figure 5, the Niagara River plume continues eastward along the south shore and around to the north shore of the lake. Considering the dynamics and characteristics of large inflows from connecting channels such as the Niagara River is significant from a water-quality standpoint, since such inflows are responsible for transporting and distributing contaminants and other pollutants over the lake.

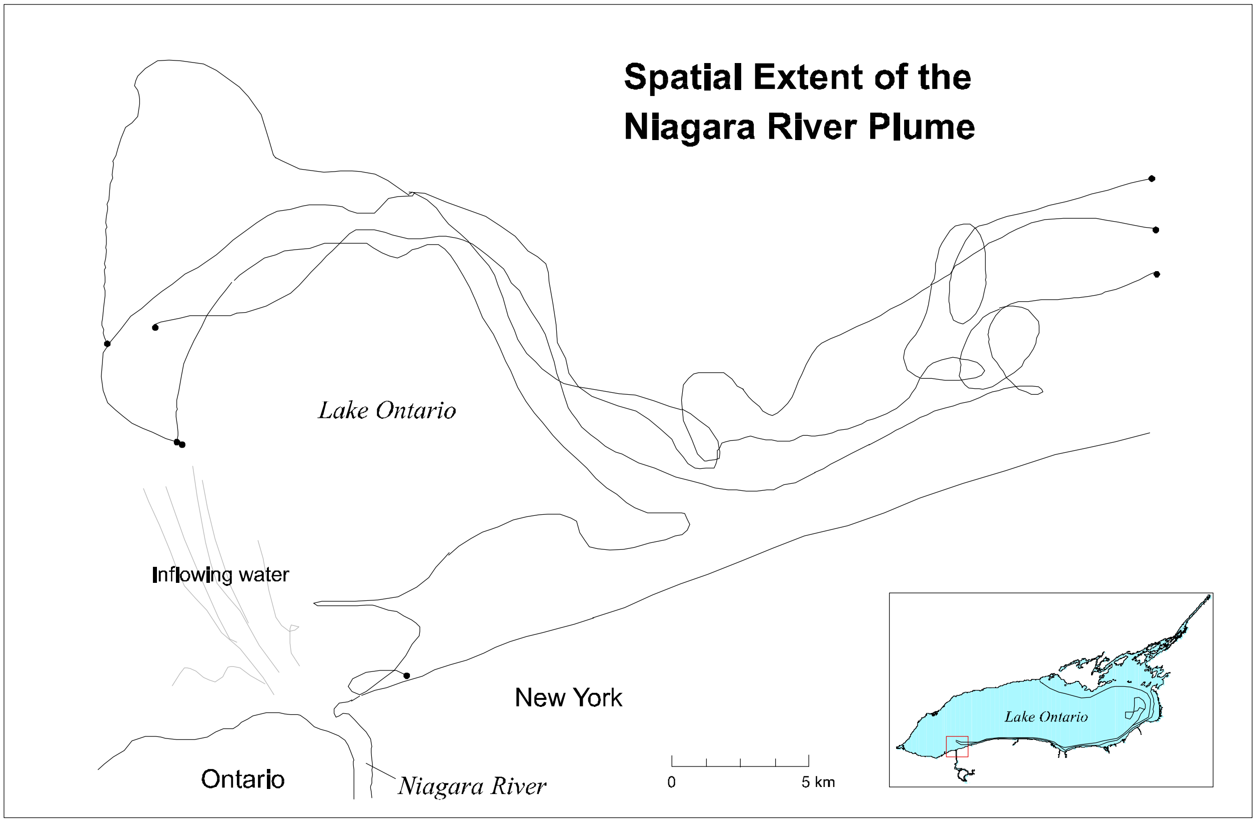
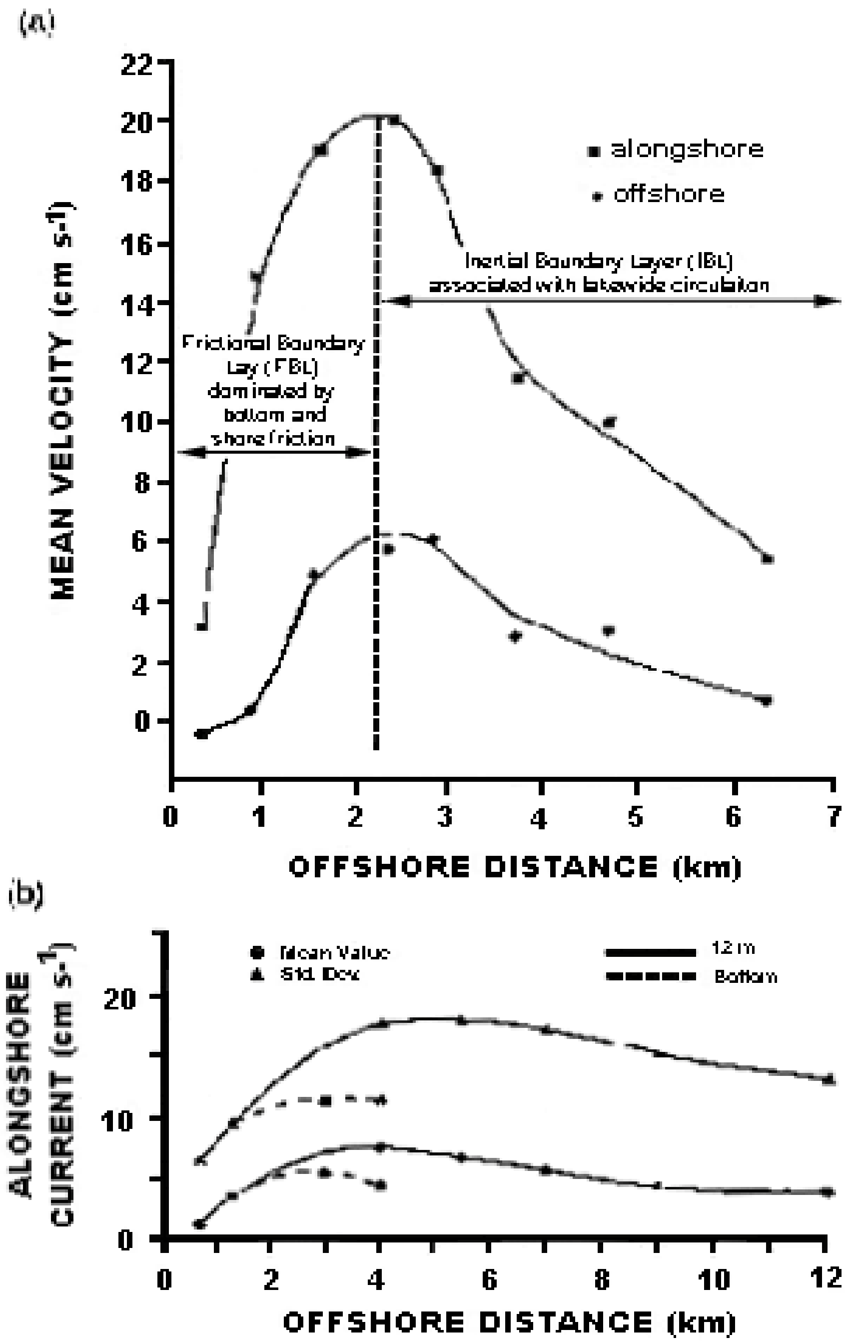


Figure 5 Niagara River Plume

Coastal boundary layer characteristics during the lake's thermally stratified period are shown in Figure 6 (from Murthy and Schertzer 1994). The alongshore component dominates the flow field, peaking at a distance of between 2 km and 3 km from the shore. This peak divides the flow field into two distinct zones. Closer to the shore, an inner boundary layer flow develops, with bottom friction gradually bringing the flow to a halt at the shoreline (frictional boundary layer). Beyond this, an outer boundary layer develops as a consequence of the adjustment of inertial oscillations to the shore-parallel flow (inertial boundary layer). Water movements within this coastal boundary layer are complex, as indicated in some of the discussion above. Knowing the extent of the coastal boundary layer is critical for understanding the impact of such activities as waste disposal through sewage outfalls, large-scale dumping operations, shore erosion, sediment transport, installation of coastal structures, land reclamation, and recreation (Murthy and Schertzer 1994). Since the dilution capability of the nearshore current regime increases in the first few kilometres of the coastal boundary layer, effective dispersal of effluents depends on the distance of the discharge from shore.

During the summer stratified period, the thermocline largely prevents the transfer of heat and particles from the epilimnion to the lower layers and thus has natural water-quality implications. A strong thermocline acts as a “diffusion floor,” suppressing vertical mixing and inhibiting the transport of mass, momentum, and heat into the hypolimnion. For a shallow lake, such as the central basin of Lake Erie, a deep thermocline with a high temperature gradient has been observed to severely limit the transfer of oxygen and materials between the upper and lower

Figure 6. Coastal boundary layer for (a) summer stratified conditions at Douglas Point, Lake Huron, and (b) winter homogenous conditions at Pickering, Lake Ontario. (Murthy and Dunbar 1981)



layers, often leading to anoxia (Schertzer et al. 1987). Vertical entrainment across thermal interfaces has also been observed after high-wind events (Boyce et al. 1989).

Towards the late summer, large lakes such as Lake Ontario attain their highest temperatures and heat storage. After the period of maximum heat storage, surface heat losses to the atmosphere occur through radiative and turbulent exchange processes (Schertzer and Sawchuk 1990). Since the heat losses are not uniform over the entire lake volume, there can be significant lags in the seasonal vertical temperature distribution. Surface heat losses and mixing processes in the fall result in decreasing the lake's mean heat content. With strong storm episodes, the depth of the mixed layer increases until the entire water column is mixed around 4ºC to 5ºC. The breakdown of thermal stratification is commonly referred to as the annual fall overturn. The period of thermal stratification varies for each Great Lake according to its latitudinal location and bathymetry. For Lake Ontario, thermal stratification generally extends from late June to October.

As a consequence of cooling coupled with wind mixing, the temperature of the main water mass continues to become more uniform, eventually attaining the temperature of maximum density. Because the rate of cooling is higher in the shallower nearshore regions, horizontal surface temperature gradients can occur and persist in winter months. During the late fall and early winter, mixing of cold inshore water with warmer offshore water may set up a thermal bar phenomenon similar to the one described earlier.

Towards the end of winter, the entire water mass cools down to below 4ºC, with the coldest water remaining close to the shore. During winter, ice begins to form in the nearshore waters of the Great Lakes in December and January and in the deeper offshore waters in February and March, reaching its greatest extent in late February or early March. Expected maximum ice covers are as follows: for Lake Erie, 90 percent; for Lake Superior, 75 percent; for Lake Huron, 68 percent; for Lake Michigan, 45 percent; and for Lake Ontario, 24 percent (Assel et al. 1983). During a severe winter, maximum ice cover can exceed 90 percent on all the Great Lakes (Assel et al. 1996); during a mild winter, maximum ice cover is usually limited to the nearshore waters (Assel 1985). The type of ice that forms in the nearshore waters includes flat shorefast ice (which forms under calm conditions); brash ice, which consists of a matrix of ice of various sizes and shapes (and which forms over several days or weeks as episodes of ice formation and breakup occur in the more exposed nearshore areas in response to high winds followed by calm); and icefoot complex (which forms as waves of freezing spray build up mounds of ice and ice ridges along lee lake shores—usually adjacent to deep waters that do not freeze until later in the winter) (Evenson and Cohn 1979; Marsh et al. 1973; O’Hara and Ayers 1972). Ice cover is an important climatic variable that affects the winter ecosystem (Vanderploeg et al. 1992), the fishery (Taylor et al. 1987), the economy (Niimi 1982), and the weather of the Great Lakes (Peace and Sykes 1966; Petterssen and Calabrese 1959). An extensive ice cover can also affect lake temperature and the length of the stratification period, since ice cover can decrease heat losses from the surface and can also affect the initial period of heating of the lake in early spring months.

Recently, there has been growing consensus among climate modelers that global air temperatures will rise with increasing concentrations of atmospheric greenhouse gases, particularly carbon dioxide, methane, nitrous oxide, and freons. There is less agreement about the magnitude of estimated temperature change, although most estimates range from 2ºC to 4ºC. Observation of thermal stratification characteristics for warm years has implied that warmer conditions may result in higher lake temperatures, lengthened stratification periods and significantly reduced ice cover (Rodgers 1987; Schertzer and Sawchuk 1990). Preliminary modelling investigations incorporating GCM model projections under steady-state, transient, and transposition scenarios have indicated that climatic warming may alter basin hydrological conditions and lake surface heat exchanges. Such changes can be expected to have an impact on the mainlake and nearshore thermal regimes of the Great Lakes. Further integrated research is required to quantify the potential physical, chemical, biological, and water-quality ramifications of climatic warming for the Great Lakes.

2.2 Areas and Volumes of the Nearshore Waters

The amount of nearshore water in each lake varies with the size and shape of the lake basin and the maximum thermocline depth (Table 1). Large, shallow embayments add substantially to the amount of nearshore water in Lakes Michigan, Huron, and Ontario, and almost all of Lake Erie is shallower than 27 m. The percentages of the total surface area and volume of each Great Lake that are considered nearshore waters vary widely (Table 1). The percentages are lowest in Lake Superior (4.7 percent of the area and 0.1 percent of the volume at the 10-m depth contour) and highest in Lake Erie (90.2 percent of the area and 60.3 percent of the volume at the 27-m depth contour). In the other three lakes, the percentages of total lake surface area and volume that occur as nearshore waters are remarkably similar to each other and are closer to the values for LakeSuperior than to those for Lake Erie.

In this paper, we also treat the Great Lakes connecting channels, which are the large rivers carrying the surface-water outflow from one Great Lake to the next (Table 2), as nearshore waters. Lake St. Clair (1,114 km^2; Bolsenga and Herdendorf 1993) is considered to be nearshore waters because it receives its inflow from Lake Huron via the St. Clair River and is so shallow (mean depth 4.4 m) that it does not develop vertical thermal stratification. Finally, we also include as nearshore waters the lower reaches of all Great Lakes tributaries, where the flow is affected by water levels in the Great Lakes, and the thermally unstratified waters reaching to the lake bed around islands and offshore shoals. The amount of nearshore water defined by these last three categories is relatively small and may not be accurately reflected in Tables 1 and 2.

Table 1. Surface Areas (km^2) and Volumes (km^3) of Great Lakes Waters between the Shoreline and the 9- and 27-m Depth Contours[a, b]

Lake	Area			Volume		
	Whole lake	0- to 9-m depth contour	0- to 27-m depth contour	Whole lake	0- to 9-m depth contour	0- to 27-m depth contour
Superior	82,329	3,845 (4.7)	8,789 (10.7)	12,287	17.3 (0.1)	118.6 (1.0)
Michigan	57,937	4,443 (7.7)	15,063 (26.0)	4,840	20.0 (0.4)	203.4 (4.2)
Huron	59,652	5,764 (9.7)	15,308 (25.7)	3,539	25.9 (0.7)	206.7 (4.2)
Erie	25,633	4,335 (16.9)	23,121 (90.2)	457	19.5 (4.3)	312.1 (60.3)
Ontario	19,309	1,731 (9.0)	4,440 (23.0)	1,652	7.7 (0.5)	59.9 (3.6)

Sources: Risti 1989;Risti and Risti 1981, 1985a, 1985b, 1989.

[a] Values in parentheses are areas and volumes of nearshore waters as a percentage of whole lake's area and volume.

[b] In Lake Superior, the nearshore waters are between the shoreline and the 9-m depth contour; in the other four Great Lakes, the nearshore waters are between the shoreline and the 27-m depth contour. See text for further explanation.

Table 2. Characteristics of the Great Lakes Connecting Channels

Characteristic	River				
	St. Marys	**St. Clair**	**Detroit**	**Niagara**	**St. Lawrence[a]**
Length (km)	121	63	41	58	150
Elevation drop (m)	6.7	1.5	1.0	99.3	1.6
Mean annual discharge (m^3/s)	2,100	5,097	5,210	5,692	7,739
Total phosphorus (ppb)	3.6	5.5	9.0	9.4	13.2
Chloride (ppm)	1.3	5.9	6.9	15.3	24.2

Sources: Edwards et al. 1989; NYSDEC 1978.

[a] International section.

3.0 The Nearshore Waters as an Element of the Surface-Water Continuum

The nearshore waters are part of a “surface-water continuum” that begins in inland terrestrial settings in the basin when precipitation and groundwater collect to form surface water that discharges through tributaries into the nearshore waters of the Great Lakes. For this paper, the continuum extends downstream to the Moses-Saunders Dam at the lower end of the International section of the St. Lawrence River. This surface-water continuum provides a major pathway that allows materials and energy from the terrestrial and aquatic inland components of the ecosystem to passively enter the nearshore waters. When these resources reach the nearshore waters, they are diluted or dispersed, and then cycled through the biota. Some reach the offshore waters, where they are cycled further and where a portion may be more or less permanently buried in lake-bed sediments. Eventually some are transported downstream and out of the basin. Most of the naturally occurring materials and energy, excluding sunlight, that are needed to support food webs in the Great Lakes enter the lakes from the land via this surface-water inflow to the nearshore waters.

Material and energy incorporated into plants and animals can also be transported throughout the Great Lakes system by that biota. Plankton drift with the current, as do uprooted mats of aquatic vegetation. Strongly swimming fishes and some aquatic invertebrates can migrate upstream or downstream from one Great Lake to the next via the connecting channels. Anadromous fishes that enter Great Lakes tributaries to spawn can carry materials and energy from the nearshore waters to upstream inland areas. Birds that feed in the nearshore waters can also transport materials widely to other parts of the system, including land. Thus, the nearshore waters are physically and biologically linked with other ecosystem elements in the basin and can directly or indirectly exchange materials and energy with those elements across the basin.

4.0 The Nearshore Waters as Fish and Wildlife Habitat

Before European settlement of the basin, Great Lakes nearshore waters served primarily as habitat for fish and wildlife and for the aquatic organisms that supported fish and wildlife production. Where habitat quality has not been seriously degraded, that is still the primary natural use of Great Lakes nearshore waters. Virtually all species of Great Lakes fish use the nearshore waters for one or more critical life stages or functions. The nearshore waters are areas of permanent residence for some fishes, migratory pathways for anadromous fishes, and temporary feeding or nursery grounds for other species from the offshore waters. Only the deepwater ciscoes (members of the whitefish family) and the deepwater sculpin avoid and are rarely found in the nearshore waters. Fish species diversity and production in the nearshore waters are higher than in offshore waters; they also vary from lake to lake and are generally highest in the shallower, more enriched embayments with large tributary systems.

During the summer, the nearshore waters are occupied by aquatic plant and animal communities that are adapted to the summer thermal regime there. This adaptation, which has been studied most extensively in fish, reveals that each species has a narrow and relatively unique range of summer temperatures at which it grows best. Fish are highly mobile and actively seek that "preferred" range in summer. As a result, species with similar preferred temperature ranges generally have similar spatial distributions in summer. Three major thermal groupings or fish communities—warmwater, coolwater, and coldwater—occur in the Great Lakes. Preferred summer temperatures range from 27°C to 31°C range for warmwater fish (e.g., catfishes, basses, and sunfishes) and from 21°C to 25°C range for coolwater fish (yellow perch, walleye, and pikes); coldwater fish (trout, salmon, whitefishes, deepwater sculpin) are usually found at temperatures below 15°C (Magnuson et al. 1979).

The nearshore waters are also habitat for many other species. Great Lakes nearshore waters are critical feeding and resting habitat for ducks, geese, and swans and water birds (Herdendorf et al. 1981; Prince et al. 1992), especially during the fall and spring migrations. Aquatic mammals including muskrat, beaver, otter, and mink are common in some undisturbed, sheltered waters in the lower reaches of tributaries and near coastal wetlands (Herdendorf et al. 1981). Great Lakes nearshore waters are critical habitat for threatened or endangered species or species of special concern, including the bald eagle, osprey, and freshwater mussels (Edsall 1996; USFWS 1994). Introduced and invading (exotic) aquatic plants and animals have become established in the Great Lakes (Edsall et al. 1995; Leach 1995; Mills et al. 1993), and most are more abundant in the nearshore waters than in the deeper offshore waters.

5.0 Human Use of the Nearshore Waters

Human activities have substantially altered the Great Lakes basin landscape and the nearshore waters element of the basin ecosystem (Edsall 1996). The conversion of forests, savannahs, and wetlands to farming and agriculture was followed by industrialization and rapid human population growth. This population growth, in turn, led to the development of cities and suburban areas with high population density. Patterns of settlement, development, and population growth in the basin were influenced by climate and the distribution of natural resources in the basin. Climate and soil fertility favoured agricultural settlement in the southern portion of the basin. Surface water that could be used for drinking, manufacturing, power production, and waste disposal was also an especially important resource consideration in the settlement and development of the region. Sheltered areas where deepwater ports could be developed were important for transportation. As a result, the largest cities and areas of highest population density are clustered in the southern portion of the basin on or near Great Lakes shorelines or on the connecting channels and major tributaries. In general, the areas of high population density are the locations and sources of greatest human-mediated ecosystem stress in the basin. Thorp et al. (1996) present a more detailed discussion of the settlement and development of the Great Lakes basin and the effects of these processes on the landscape.

The nearshore waters of the Great Lakes basin are used directly by humans in a variety of ways. Some of the most common uses are process water, drinking water and, the disposal of pollutants. Most pollutants that reach Great Lakes nearshore waters enter from the land via tributaries, via shoreline discharges, or as surface runoff. These pollutants are then distributed in the surface-water continuum by processes similar to those that distribute energy and materials from natural sources. Concentrations of pollutants can be higher near tributary mouths and discharge sites until the pollutants are diluted by mixing with the nearshore waters and ultimately with the larger volumes of cleaner offshore water.

The nearshore waters are also used extensively for navigation and power production. The construction of canals, locks, hydro dams, and water-level control structures to support these uses has altered levels and flows in the Great Lakes and in their connecting channels and tributaries and has permanently converted substantial amounts of lake and river bed to other use. The dams have also fragmented the natural surface-water continuum in the St. Marys and St. Lawrence Rivers and in many tributaries, and the canals have created artificial connections between the Great Lakes drainage basin and the Hudson Bay, Mississippi River, and Hudson River drainages. Substantial volumes of nearshore water are temporarily diverted for industrial and municipal use and returned, while some is diverted and not returned. The nearshore waters were historically important for the production of fish and wildlife for use as food and to support recreational fishing and hunting. Recreational boating and bathing also occur in the nearshore waters, as do bird-watching and other non-consumptive uses. The stresses that these and other human uses place on the nearshore waters ecosystem are described in the next section of this report.

6.0 Stressors Operating in the Nearshore Waters

6.1 Definition of Stressor

Stressors are natural or human-mediated agents of stress that disturb ecosystems and favour ecosystem change. The stress can be applied directly to an individual organism—for example, by an introduced predator, pathogen, or pollutant—or indirectly to a population or community through habitat modification or loss. Human-mediated stress has markedly changed both the terrestrial and the aquatic elements of the Great Lakes basin ecosystem since settlement of the region began in the 1700s. Most major human-mediated stress that has contributed to changes in the nearshore waters has reflected use-conflicts that arose incidentally as land and water resources of the basin were developed and converted from the natural state. For example, the removal of natural vegetation to grow row crops accelerated erosion and increased turbidity in tributaries and nearshore waters. Stress was also introduced deliberately to improve or augment natural resources for human benefit. For example, Pacific salmon were introduced in Lake Michigan to produce a better recreational fishery and to prey on and thus stress the alewife population. The introduction accomplished both objectives, but also stressed native and introduced trout species that lived in tributaries and were forced to compete with the larger salmon for spawning habitat. The salmon also preyed on native fishes, stressing their populations.

The major stressors that act on Great Lakes nearshore waters fall into the following categories. Some of these stressors have obvious and direct links with observed changes in the nearshore waters ecosystem; others have less clear or less well-understood links and effects.

6.2 Power Production

The effects of power production on fish and wildlife resources are of significant concern to resource managers in the Great Lakes basin. Power is produced in thermal-electric plants (which use fossil or nuclear fuel to create steam that turns turbines and generators) and in hydropower plants (which use water to turn the turbines and generators).

6.2.1 Thermal-electric

Most of the power in the Great Lakes basin is produced in thermal-electric plants that are located either on Great Lakes shorelines or on the connecting channels and lower reaches of major tributaries. These sites were selected because the large volumes of water needed for cooling and condensing steam in the generation cycle were available there, and because coal (the fuel used in most of these thermal-electric plants) could be delivered there at low cost by boat.

About 90 thermal-electric plants draw their cooling water directly from the nearshore waters of the Great Lakes and use once-through cooling (Kelso and Milburn 1979). Water used for once-through cooling in these plants is drawn from the lake, passed through 9.5-mm (0.375-inch) screens, and then passed through the plant's heat exchangers. A temperature increase of between 4ºC and 20ºC occurs before the water is discharged into the lake. Fish are drawn into the plant with the cooling water. Fish that are too large to pass through the screens are caught (or *impinged*) on the screens and killed; smaller fish that pass through the screens (i.e., that experience *entrainment*) are killed either by collision with the screens and other surfaces in the system or by heat shock. Kelso and Milburn (1979) estimate that more than 100 million fish were killed by impingement and more than 1.28 billion by entrainment annually in the 1970s in the Great Lakes and connecting channels. More recent summaries, which include all power plants sited on the Great Lakes and connecting channels, indicate even larger fish losses. In Lake Michigan, for example, thermal-electric plants killed more than 75 billion fish eggs and larvae; a single pumped-storage hydro plant on the lake's eastern shore killed more than 400 million fish larvae and more than 100 million juvenile alewives, yellow perch, and salmon (Jensen et al. 1982; Liston et al. 1981). These losses of young fish in Lake Michigan and western Lake Erie are significant, representing between 3 percent and 10 percent of the total annual production (Manny 1984). As mitigation for the fish kills at the Lake Michigan Ludington Pumped-Storage Project, the company recently agreed to permanently operate a barrier net to reduce the entrainment mortality of fish larger than about 13 cm. They also agreed to deed about 10,000 ha of company-owned land with about 118 km of lake and river frontage to the state of Michigan. The settlement is estimated to be worth U.S. $172 million to the state of Michigan.

Advances in the development of techniques and systems to reduce the entrainment and impingement of fishes at thermal-electric plants (and at hydro-electric facilities) have been reported in publications of various government agencies and the electric power industry, and in the scientific literature. A recent publication (Ross et al. 1996) presents evidence that under certain conditions, the use of high-frequency sound drove adult alewives away from the cooling water intake of a large power plant in the New York State waters of Lake Ontario, thus significantly reducing impingement at the plant in April-July 1993. However, a permanent, fully functional system has not yet been installed at the plant. Concern has been raised by Hastings et al. (1996) about the potential damaging effects of high sound levels on the inner ear and lateral-line system of alewives, and the effect of these sound levels on other elements of the lake’s biota has not yet been reported. Systems (e.g., porous dykes) that can significantly reduce or prevent entrainment of plankton and small fish, including juvenile alewives, have not been installed on power plants in the Great Lakes, and the most effective technology employed to date seems to be the use of closed-cycle cooling, which greatly reduces the amount of lake water taken into the plants. The entrainment loss of juvenile alewives can be as serious a problem as the impingement loss of adults because the biomass of the juveniles can exceed that of the adults and because the juvenile--like the adults--are a major food of trout and salmon.

Disposal of coal ash produced in power plants sited on Great Lakes shorelines and connecting channels is a growing problem. In the 1970s, about half the coal used annually in the United States was burned in the Great Lakes basin; about 95 percent of the coal that was burned in the basin was used to produce electricity in plants sited in Great Lakes coastal areas (GLBC 1980). The ash and related solids produced in these Great Lakes coastal plants can be equal to about 50 percent by volume of the coal that they burn. The ash from this coal is typically disposed of in Great Lakes coastal areas adjacent to the facility where the coal is burned. This practice has sometimes led to the filling of coastal wetlands and adjacent nearshore waters. Leaching and aerial transport of coal ash can also result in deposition of this material in the nearshore waters. The composition of coal ash varies with the source of the coal, but metals (including selenium and mercury) are common in some ash, while radioactivity in some ash exceeds background levels in the basin. Proposals have been made to dispose of concrete-stabilized blocks of coal ash in the Great Lakes to create new fish habitat, but tests have shown that the blocks disintegrate in a relatively short time, releasing the ash to the lake. A coal ash disposal policy needs to be developed for the basin, especially for plants sited in the coastal zone or on basin tributaries, to protect nearshore waters from ash and leachate.

6.2.2 Hydropower

In the United States, hydropower production creates significant problems in many of the larger stream and river ecosystems in the region. Most of the hydropower dams were built early in the 20th century; few have fish ladders or other devices that allow fish to pass over or through the dams unharmed. Recent evaluations show that these dams fragment and substantially degrade the stream ecosystem, as well as limiting the use of the stream system by resident fishes and by anadromous fishes that migrate up Great Lakes tributaries to spawn. Most of the hydropower dams in the region were built in high-gradient stream reaches, which were areas of permanent residence for some species of fish and spawning areas for other migratory species. These high-gradient reaches were also generally sites of the groundwater inflow that was required to support coolwater and coldwater fish species. Stream fishes in the flooded areas above the dams were replaced by species better suited to a warm lake environment. Stream fishes below the dams were also adversely affected. The dams were usually operated in a daily peaking mode to supply power when it was in greatest demand, usually in the morning or evening or both. As a result, exceptionally high flows occurred once or twice a day when power was needed. Water was held back at other times. The high flows eroded the stream bed below the dam; the intervening low flows drained it. Temperatures on the exposed stream bed fell below freezing in winter and rose above air temperature on sunny days in summer, creating conditions that were lethal for aquatic bottom-dwelling organisms that occupied that portion of the stream bed.

In Michigan, there are 113 operating hydropower plants (Whelan and Houghton 1991). These plants produce only about 1.5 percent of the existing power demand, while impounding about 750 km of river bed, adversely affecting another 1,200 km of river, and blocking anadromous fish from 3,300 km of mainstream river habitat. In Wisconsin, there are 120 non–federally owned hydropower projects (Johnson 1996). In New York state, more than 322 km of the tributaries to Lake Ontario are blocked or otherwise adversely affected by hydropower production (USFWS 1995a). Although some new projects are proposed from time to time in the Great Lakes basin, they are few in number and are typically associated with developing the hydro-electric generation potential of existing dams.

Most non–federally owned hydropower dams on U.S. tributaries in the Great Lakes region are currently in the process of being relicensed by the Federal Energy Regulatory Commission. Relicensing takes place only once every 30 to 50 years on each dam. Relicensing agreements recently reached in Michigan between resource advocates and the power companies will greatly lessen the dams' adverse effects and should help set an environmentally beneficial precedent for relicensing in other states. Under these agreements, the water release patterns from the dams will closely mimic the inflow pattern to the reservoirs above the dams. In addition, effective upstream and downstream fish passage facilities will be installed in each dam, consistent with fishery management plans for the area. These changes will significantly improve habitat quality below the dams and reduce the fragmentation effect that the dams have had on the river ecosystem. The relicensing agreements also provide for dam removal when the dams are declared obsolete.

Hydropower plants are also located in the U.S. and Canadian waters of the St. Marys River between Lakes Superior and Huron, on the Niagara River between Lakes Erie and Ontario, and on the Moses-Saunders Dam on the St. Lawrence River. The effects of these plants on fish have not been fully assessed, but some loss of fish through collision with turbine blades and other internal surfaces is probably inevitable. New techniques are being developed for assessing fish mortality at hydropower dams. The results of a field test with one of these more promising new techniques (Mathur et al. 1993) indicate that mortality of juvenile American shad (*Alosa sapidissima*) at a low-head hydropower dam on the Connecticut River was less than estimated by previously by other techniques.

The hydropower dams on the St. Marys and St. Lawrence Rivers are obstacles to the upstream movement of fish. The Moses-Saunders Dam has a fish ladder designed to pass American eels. The number of eels recorded using the ladder fell from about 1.3 million in 1983 to less than 50,000 in 1990–91 and the cause of the decline is unknown (Castonguay et al. 1994). In the St. Marys River, the areal extent of the St. Marys Rapids is substantially reduced because most of the flow is diverted for power production. Historically the rapids supported a productive fishery for lake whitefish; the remaining rapids now support a valuable recreational fishery for stocked trout and salmon.

The peaking system used in some hydro generating facilities results in a low river stage, followed by a rapid increase in discharge and a subsequent return to a low river stage (Curry et al. 1994). The fluctuating water levels and velocities can create unstable habitats, which can in turn reduce the reproductive success, survival, and growth of biota. As part of the Remedial Action Plan (RAP) of the north shore of Lake Superior, a Water Management Plan that accommodates the needs both of the fish community and of Ontario Hydro has been developed for the Nipigon River and Lake Nipigon (Atria Engineering Hydraulics Inc. 1994).

6.3 Marine Transportation and Recreational Boating

Marine transportation and recreational boating interests in the basin are supported by a wide variety of activities and developments, all of which can act as stressors in the nearshore waters. Some of these activities and developments also serve power production interests. Recreational boating is an important and growing industry; about 1 million boats operate each year, with a direct spending impact of about U.S. $2 billion (EC and EPA 1995). Recreational boating activities can stress migrating waterfowl; fishing and hunting from recreational boats remove fish and wildlife from the system and, if not properly regulated, both activities can significantly stress fish and wildlife populations (see Section 6.7).

6.3.1 Vessel Passage Effects

The effect of passage of large commercial vessels on Great Lakes nearshore water habitat and biota has not been extensively studied, but the areas of greatest concern are sections of the connecting channels where the vessels follow a dredged channel that occupies a large portion of the cross-sectional area of the connecting channel. In these areas, the larger vessels fill much of the channel; as they pass, they sharply disrupt the normal water level and flow conditions. The change can be easily seen by watching the movement of water at the shoreline while a vessel passes. As the vessel approaches, its propellers cause a drawdown, pulling water towards the channel and dewatering shallow shoreline areas; then as the vessel passes, it creates a shoreward surge of water that floods the shoreline. During this drawdown and surge process, the direction of water flow at the shoreline rotates 360^{o} (Alger 1979). This water movement is believed to uproot or fragment submersed aquatic plants and to erode the low-density substrates that provide attachment for these plants (Haslam 1978; Schloesser and Manny 1989; Westlake 1975). A study in the St. Clair and Detroit Rivers (Schloesser and Manny 1989) revealed that the density and diversity of submersed aquatic plants was lower in the channels used by large commercial vessels than in the adjacent channels that were not used by such vessels.

Vessel passage in the connecting channels during the period of solid ice cover creates stronger drawdown and surge effects and stronger rotation of flow direction than during the ice-free period and can substantially increase the amount of living plants, decaying plants, and benthic invertebrates that are swept from the shallow nearshore portions of the river bed into the main channel and then moved rapidly downstream as “drift” (Jude et al. 1986; Poe and Edsall 1982; Poe et al. 1980). The accelerated transport of this material through the connecting channels in winter, when natural production of aquatic plants and animals approaches the annual minimum, represents a considerable loss of materials and energy that would otherwise be recycled in summer to produce useful plants and animals in these portions of the ecosystem.

Vessel passage in winter also destroys ice bridges used by mammals, including wolves and moose, to cross the St. Marys River from Ontario to Michigan; it also closes natural open pools in the ice field where bald eagles capture fish in winter (Duffy et al. 1987). The effects of vessel passage in winter on the incubation and survival of lake herring eggs spawned in the river just before ice cover forms in early winter may be less than feared (Savino et al. 1994).

Lake St. Clair, portions of the connecting channels, and certain other sheltered portions of the Great Lakes nearshore waters are important resting and feeding areas for migrating waterfowl (Duffy et al. 1987; Edsall et al. 1988; Manny et al. 1988; Prince et al. 1992). Recreational boaters can flush and otherwise disturb flocks of resting and feeding birds, causing them to unnecessarily expend energy needed for migration, survival, and reproduction. They can also force them to seek less favourable feeding and resting habitat or to alter their migratory schedules. To help relieve this stress, recreational boating is restricted seasonally in substantial portions of Lake St. Clair, which have been declared refuges for migrating waterfowl.

6.3.2 Level and Flow Regulation

Water levels and flows in the Great Lakes and connecting channels are of considerable importance to hydropower, commercial navigation, and recreational boating interests, as well as to owners of residential or commercial property in low-lying coastal areas. Water levels and outflows are regulated in Lakes Superior and Ontario, respectively, by dams in the St. Marys and St. Lawrence Rivers. Recent proposals to further regulate levels and flows in the system to benefit navigation and hydropower interests and to reduce flooding and shoreline erosion in commercial and residential areas during high-water years have been rejected. The decision not to further regulate the system expressly recognized the ecological importance of retaining the natural fluctuations in levels and flows in the system.

The most adverse direct ecological effect of level and flow regulation would be felt in coastal wetlands. These wetlands are adapted to short-term flooding and draining by storm tides (seiches) and to seasonal and longer-term changes (i.e., changes that occur over years or decades) in lake level, which limit the invasion of woody vegetation and rejuvenate the wetland vegetation. A more detailed description of this process is presented in the Coastal Wetlands report (Maynard and Wilcox 1996).

The impoundment of the International section of the St. Lawrence River, which was completed with the closing of the Moses-Saunders Dam in 1958, provides a relatively recent case history and database from which to evaluate the effects of dams and altered water levels and flows on fish habitat and on the fish community in Great Lakes connecting channels. An intensive mapping project completed on the river before and after flooding (Patch and Busch 1984) revealed that the greatest effects of impoundment on habitat were in the section between the Iroquois Dam and the Moses-Saunders Dam, where the fall of the river had been greatest and the narrow, rapidly flowing river was transformed into a lake. The largest quantified change in habitat observed in 1962, four years after impoundment, was a nearly 20 percent increase in nearshore water habitat and a 2 percent increase in coastal wetland habitat. In 1979, 20 years after impoundment, the amount of nearshore water habitat was unchanged, but the coastal wetland habitat had decreased by about 7 percent.

The significance of these habitat changes is difficult to assess because of a lack of pre- and post-impoundment data on the fish community. However, it is clear that northern pike, sunfish and bass, and brown bullhead still spawn successfully and thrive in the St. Lawrence River above the dams, while muskellunge may have declined (Patch and Busch 1984). Catches of muskellunge in trapnets declined in the early to middle 1950s and have remained low since then; however, no current measure exists to quantify trends in the status of the population (LaPan and Penney 1991).

Lake sturgeon have declined, probably due to loss of spawning habitat, blockage of migration routes, or both (GLFC 1994; Patch and Busch 1984). The historical range of lake sturgeon in New York state waters of the Great Lakes basin is poorly understood because exploitation and population decline occurred before 1950 (Carlson 1995). Joliff and Eckert (1971) found few lake sturgeon remained in the St. Lawrence River's Thousand Islands region; the only self-sustaining population occurred below the Moses-Saunders Dam. There are no fish passage facilities at the Iroquois Dam, which remains open most of the year; the fish ladder on the Moses-Saunders Dam is not designed to pass lake sturgeon. There are also older dams on all of the major tributaries to the International section of the St. Lawrence River; these dams may have contributed to the early decline of the area's lake sturgeon. Efforts are under way to re-establish lake sturgeon in the U.S. tributaries to the St. Lawrence River and to assess the potential for restoring the population in the St. Lawrence River above and below the Moses-Saunders Dam (LaPan et al. 1994).

Walleye were historically common in the St. Lawrence River (Greeley and Greene 1931), but their numbers declined sharply following the construction of the St. Lawrence Seaway and Power Project in 1958, probably due to the inundation of the rapids and rocky whitewater areas that were their preferred spawning habitat (LaPan and Klindt 1994; Patch and Busch 1984). The population is showing signs of recovery (LaPan and Klindt 1994), and index netting indicates that abundance has increased irregularly from 1983 to 1993 (Bendig 1994).

6.3.3 Dredging and Disposal of Dredged Material

Navigation-related dredging and dredge material disposal in the U.S. nearshore waters of the Great Lakes probably began soon after European settlement of the basin, but early records of quantities dredged and disposed of are fragmentary or non-existent (Raphael et al. 1974). In Lake Michigan, removal of sediments from public harbours began in the middle 1800s, but dredging records kept by the U.S. Army Corps of Engineers extend back only to 1918. In Lake Superior, dredging activity dates from the early 1900s; records are available from 1937. Dredging has occurred for decades in the other Great Lakes: quantitative records are available from 1930 for Lake Huron and Lake St. Clair and from 1951 for Lakes Erie and Ontario (Table 3). The total recorded amount of material dredged from all five lakes through 1972 was 357.2 million m^3 (Table 3). In the 1970s and 1980s, navigation-related dredging and dredged material disposal in the Great Lakes were the subjects of intensive deliberation by both the U.S. and the Canadian governments. The revised Water Quality Agreement signed by the two governments in 1978 called for the establishment of a Dredging Subcommittee under the auspices of the International Joint Commission's (IJC) Water Quality Board; it also required the maintenance of a register of significant dredging projects being undertaken in the Great Lakes system, together with information needed for the assessment of the environmental effects of the projects (IJC 1982). The register, which is maintained at the IJC Regional Office in Windsor, Ontario, contains information on about 95 percent of the dredging in the Great Lakes basin during the 1975 through 1979 period (IJC 1982). Records provided by the U.S. Army Corps of Engineers (D. Raven, North Central District, personal communication) revealed that total volume dredged in 1983 was about 4.0 million m^3, while the estimated volume for 1984 was 4.3 million m^3. These volumes were slightly lower than the historical annual average for Lake Erie alone (4.9 million m^3; see Table 3), but were similar to the 1975–79 annual average for all lakes combined (3.5 million m^3) as described by the IJC (1982).

Table 3. Historical Dredging Quantities (millions of m^3) in U.S. Waters of the Great Lakes

Lake	Period	Total by Lake for Period	Annual Average for Period
Superior	1937–72	68.7	2
Michigan	1918–72	90.8	1.7
Huron and St. Clair	1930–72	88.2	2
Erie	1951–72	102.8	4.9
Ontario	1951–72	6.7	0.3
Total all lakes	1918–72	357.2	

Source: Raphael et al. 1974.

In 1985–1989, more than 15.8 million m^3 of sediment were dredged from the Great Lakes (IJC 1991a). About 87 percent of the total was from Lake Erie. The United States removed 13.7 million m^3, and Canada about 2.0 million m^3. Most of the dredging projects were either very small (less than 25,000 m^3) or very large (more than 100,000 m^3). Dredging activities were dominated by small projects in Lakes Michigan and Ontario and by large projects in Lake Erie.

The disposal methods for dredged material include upland disposal, confined disposal, open-water disposal, beach disposal, and reuse disposal (IJC 1990). Upland sites are terrestrial areas that are situated away from the lakeshore. Confined disposal facilities (CDFs) are extensions of the shoreline or artificial islands created by diking portions of the nearshore waters; the dredged material is deposited inside the diked area. Open-water disposal occurs largely in the nearshore waters. Beach disposal usually occurs on beaches near the dredging site. Reuse involves depositing dredged materials to create revetments, to stabilize shoreline structures, and for similar uses.

Confined disposal was the dominant disposal method by volume in all but Lake Ontario. No confined disposal occurred in the U.S. portion of Lake Ontario. Beach disposal accounted for little of the total quantity of material. The greatest use of beach disposal was in Lake Michigan, where most dredging projects involved fewer than 25,000 m^3. Open-water disposal occurred in all lakes except Lake Michigan. Most of the open-water disposal occurred in Lake Erie. Open-water disposal accounted for the greatest volume of material disposed of in Canadian projects in Lake Ontario and was the only method practised on the U.S. side of the lake. Upland and reuse disposal accounted for minor portions of the total. Upland disposal occurred in each of the lakes and reuse occurred only in Lake Huron.

Quantitative comparison of the 1985–1989 and 1975–1979 (IJC 1982) information is problematic due to inconsistencies in reporting (IJC 1991b). However, a qualitative comparison of the 1985–1989 and the 1980–1984 (IJC 1990) data reveals that the most significant difference between the two periods is the substantial decrease both in the number of projects and in the quantity of dredged and disposed-of material (IJC 1991b). There was also a consistent decrease in the total volume and number of projects during the

1980–1989 period. This decrease probably reflects (1) reduced sediment delivered to harbour and navigational channel areas; (2) higher water levels, temporarily creating deeper navigational channels; (3) reduced shipping activity and the closing of some ports; and (4) a higher incidence of contaminated sediments. The contaminated sediments limit disposal options, increase disposal costs, cause more selective use of dredging, and contribute to closing some ports or areas of harbours.

Due to high costs, difficulties in disposing of contaminated sediments, and the limitation of available space, few CDFs are being constructed; a decrease in the use of confined disposal has been predicted (IJC 1990). There was a substantial decline in the overall number of projects (43 in 1980; 12 in 1989) and in the volume of material (4 million m^3 in 1980; 712,998 m^3 in 1989) disposed of in CDFs over the 10-year period. This decline exceeded the total decrease in dredged quantities and projects: confined disposal accounted for 52 percent of all disposal projects in the 1980–1984 period but for only 34 percent of all disposal projects in 1985–1989. Such projects accounted for 72 percent of the volume in the 1980–1984 period, but represented only percent of the volume in the 1985–1989 period.

The major dredging-related concerns focus on contaminated sediments and on the precautionary measures needed for excavating and disposing of them safely without adversely affecting water quality or the biota. When the dredged sediment contains high contaminant concentrations, it must usually be placed into a confined disposal facility (CDF) to prevent more widespread contamination of the environment. Dredging restrictions occur at many of the 43 Areas of Concern in the Great Lakes. Although CDFs remove the contaminated sediments from the water, they still can pose significant hazards to fish and wildlife unless they are properly managed (USFWS 1994). For example, the federally owned CDF in lower Saginaw Bay, Lake Huron, hosts significant concentrations of nesting terns, gulls, and other birds, and requires continuing Service coordination to ensure that the provisions of the Migratory Bird Treaty Act are upheld. To date, attempts to prevent birds from using the CDF have been unsuccessful. The U.S. Fish and Wildlife Service, the U.S. Army Detroit District Corps of Engineers, the Michigan Department of Natural Resources, and local counties are working together to develop a 20-year Dredged Material Management Plan to deal with maintenance dredging on the Saginaw River and in Saginaw Bay. The plan investigates disposal options on uplands, in a new or expanded CDF, and in open water (USFWS 1995b).

Studies by the U.S. Army Corps of Engineers and others address the physical effects of dredging, and of the open-lake disposal of clean dredge spoils, on fish and wildlife and their habitat in the Great Lakes (IJC 1982; USACE 1979). The available evidence suggests that dredging of uncontaminated sediments and the open-lake disposal of these sediments may have only temporary or minor adverse impacts on fish and wildlife habitat. Concerns addressed in such an evaluation should include the loss of benthic organisms in the dredged area during dredging operations, as well as the possibility that future use of the dredged area may be prevented if the remaining substrates are unsuitable for habitation; similar concerns should be addressed regarding open-lake disposal areas where uncontaminated materials are deposited. Care should be taken to avoid depositing this material on or near fish spawning grounds or in areas and at times that would interfere with spawning migrations. Disposal of dredged materials on a reef used for spawning by lake trout in Thunder Bay, Lake Huron, was recently documented (Edsall and Kennedy 1995).

Dredging activities can also interfere with habitat use by avian wildlife. The U.S. Fish and Wildlife Service, the U.S. Army Corps of Engineers, the Michigan Department of Natural Resources, the Holland Township Planning Commission, and the public worked together for several years to ensure that the channel dredging and disposal plan for Holland Harbor on Lake Michigan did not interfere with the use of the area by bald eagles. Of major concern was the proximity of the navigation channel to a bald eagle nest. The problem was resolved by scheduling dredging to occur outside the nesting season. Similar conflicts can be expected between dredging activities and use of the Great Lakes nearshore waters by other water-oriented birds, including ospreys, double-crested cormorants, Canada geese, and the white pelican, a new arrival to Green Bay (Dave Best, personal communication). Research is needed to assess the effects of dredging activities on these species so that adverse effects can be avoided or minimized by better implementation and enforcement of existing authorities. Adverse effects of dredging could be further minimized if (1) heavily polluted sediments were dredged with no overflow, decontaminated, and disposed of appropriately in acceptable CDFs on land; and (2) CDFs shown not to be toxic to plants and animals were managed as fish and wildlife habitat.

6.4 Shoreline Modification

Urban, commercial, and recreational developments in Great Lakes coastal areas have resulted in significant losses of valuable wetland habitat (Jaworski and Raphael 1978; Herdendorf et al. 1981). The magnitude of these losses relative to specific land-use practices or developments is not well documented, but they are apparently most severe near urban centres. In Michigan, coastal wetland losses are relatively well documented, and the impact of urban, commercial, and recreational development has been examined. Losses that occurred between the earliest period of record (from the middle 1800s to the early 1900s) and in the relatively recent past (1958 to 1973) exceeded 16,500 ha (41,000 acres)—or about 70 percent of the total wetlands present—during the earliest period of record. Most of the losses in Michigan occurred in major coastal wetland areas along the Lake Erie and Detroit Rivers, Lake St. Clair, Saginaw Bay, and Bay de Noc. These losses were attributed to urban, commercial, or recreational developments; however, in some areas wetlands were converted to agricultural use first, and then later the same lands were converted to the other uses. A more detailed accounting of Great Lakes coastal wetland losses is presented by Maynard and Wilcox (1996).

Associated with these wetland losses, and even less well documented, is the loss of shallow nearshore water habitat because of dredging, bulkheading, and filling. For example, much of the Detroit River shoreline has been permanently altered by dredging, bulkheading, and backfilling, but the amount of shallow nearshore water habitat lost in the process probably cannot be easily quantified because reliable early records showing the unmodified shoreline are lacking. Most of these losses of shallow nearshore water habitat occurred near human population centres in the sheltered coastal areas—including tributary mouths, bays, and the connecting channels, where development was most intense.

6.5 Sand and Gravel Mining

Mining of underwater deposits of sand and gravel occurs at a number of locations throughout the Great Lakes (IJC 1982). More than 1 million m^3 were mined in 1975, the last year for which records were published. This practice is not generally viewed as an important stress on the ecosystem, and we were unable to find published reports describing its effects on fish habitat in the Great Lakes. However, it is clear that removal of gravel would affect some species. For example, lake whitefish require gravelly substrates for spawning and fry production, and lake sturgeon require gravel and coarser rocky materials (Goodyear et al. 1982); extraction of these substrate materials would render sites unattractive for spawning by these important species. A mined area at the head of the St. Clair River was historically a spawning area for lake sturgeon (Goodyear et al. 1982). Major deposits of sand and gravel have been identified in Lake Ontario near Niagara, Hamilton, Toronto, and Wellington, and mining has occurred on the Niagara Bar at the mouth of the Niagara River, a nursery area for at least one species of fish (Goodyear et al. 1982). Interest was expressed recently in extracting gravel from the Canadian waters of the upper St. Marys River, in an area identified by Goodyear et al. (1982) as a spawning ground for lake whitefish.

The most far-reaching physical effect of underwater mining in the Great Lakes occurred as a result of sand and gravel extraction at the head of the St. Clair River between 1908 and 1925, followed by channel dredging there in 1939 and 1962. Together these actions lowered the outlet of Lake Huron by about 0.3 m, with a corresponding lowering of the water level in Lakes Michigan and Huron (Derecki 1982). The volume of water lost by a 0.3-m fall in lake levels was probably about 35 km^3, which is the equivalent of about 0.04 percent of the present combined volume of both lakes. This lowering of lake levels was probably most sharply registered in the shallow, productive nearshore waters, whose volume was proportionally reduced more than that of the deeper offshore waters. The permanent lowering of lake level must also have adversely affected coastal wetlands, displacing them lakeward from their historical locations. Increased channel and harbour dredging to accommodate commercial vessels in Lakes Michigan and Huron was also undoubtedly required as a result of the lower lake level. A closer examination of the local and lakewide effects of underwater sand and gravel mining on aquatic habitat and on adjacent elements of the ecosystem is needed to more adequately evaluate and regulate the practice.

6.6 Pollution

6.6.1 Discharges and Spills

Pollution has severely degraded portions of the Great Lakes system. While treatment systems now in place have resulted in improvements, and most municipal and industrial dischargers have operated within their permit limits, in some cases, major embayments and other portions of the system have become overly enriched or impacted. These discharges—together with spills and frequent discharges of raw sewage into storm-water drains that flush into tributaries or directly into the Great Lakes—are still problems in many municipal areas. Aerial inputs of some contaminants are also significant. Organochlorine compounds have reached unacceptably high levels in Lakes Michigan and Ontario; these and other industrial pollutants, including oils and metals, are also at high levels in sediments in some areas in the connecting channels and in certain harbours throughout the system (EC and EPA 1988). The IJC has identified 43 such Areas of Concern in the Great Lakes system—each is an area where the beneficial uses of the system have been substantially degraded by pollution. Remedial Action Plans are being developed to reduce the amount of incoming pollutants and restore the affected areas to good ecological health.

6.6.2 Agricultural Runoff

Sediment input to the Great Lakes nearshore waters has occurred since the lakes were formed. Inputs occur from shoreline erosion and tributaries. Tributary inputs increased in the 19th century when the forest cover in the basin was removed for lumber or to permit farming. Agricultural activities and construction in urban areas continue to facilitate soil erosion and cause accelerated sediment input to Great Lakes nearshore waters. Sediment inputs are of concern because they decrease water clarity and light penetration into the water, thereby limiting the growth of the aquatic plants that form the base of the food chain in the Great Lakes. High turbidity can also limit feeding by desirable sight-feeding fishes and favour introduced species like common carp, which can feed by taste and smell in highly turbid water. Sedimentation can also bury fish spawning areas and other critical bottom habitat in nearshore waters. Sediment is also of concern because of its ability to bind with and transport phosphorus, heavy metals, pesticides, and other organic compounds. Sediment can also act as a "sink" for some pollutants, carrying them to offshore deepwater areas of the Great Lakes, where they are permanently buried. In Lake Erie, for example, the deep eastern basin acts as a sink for sediments from the rest of the lake. The zebra mussel, which has recently invaded the Great Lakes, has been shown to reduce the amount of suspended solids in the water (see Section 7.2.2) and may create sediment sinks in the shallow nearshore waters where none existed before. The effect of such shallow-water sediment, nutrient, and contaminant sinks on the nearshore ecosystem is unknown.

Annual loadings of suspended solids and sediments to the Great Lakes total 60 million metric tons; about 80 percent of that amount is derived from erosion of Great Lakes shorelines, and the rest comes from tributary inputs (IJC 1978). Total loadings vary from about 2.8 million metric tons in Lake Huron to about 22.5 million metric tons in Lake Michigan. Annual tributary loadings (suspended solids) are about 707,000 metric tons in Lake Michigan; 1.1 million to 1.6 million metric tons for Lakes Superior, Huron, and Ontario; and 6.5 million metric tons for Lake Erie.

Annual tributary loadings vary widely among tributaries, depending on their land use and soil type. Loading data for the periods 1975–78 and 1982–94 (WQL 1995) indicates that the Maumee River contributes 20 percent of the tributary sediment that enters Lake Erie each year.

Monitoring-based estimates of loading rates of pesticides into the Great Lakes are virtually absent from the published literature (Richards 1996). Knowledge of these loads in the Great Lakes is needed for (1) developing and refining lakewide management plans (LAMPs), (2) predicting equilibrium concentrations of herbicides in the Great Lakes and interpreting their effects on human and ecosystem health, and (3) providing a basis for assessing the status of agricultural pollution on regional and national scales.

Annual loadings of the herbicides atrazine, alachlor, cyanazine, metolachlor, and metribuzin were calculated for the period 1983–93 for the Raisin, Maumee, Sandusky, Cuyahoga, and Grand Rivers (Richards 1996). Variability in the annual loads of these U.S. tributaries to Lake Erie was large and was linked to annual differences in rainfall and river discharge, particularly for the several months following herbicide application in the spring. The highest annual loads exceeded the lowest by up to 60-fold. The Sandusky and Maumee Rivers had the highest unit area loads, due to row crop agriculture and fine-grained soils, which favoured greater surface runoff. In these two rivers, atrazine and metolachlor loads were typically 2 g/yr and 5 g/yr, but occasionally reached the 9 g/yr to 12 g/yr range; alachlor loads were generally 1 g/yr to 2 g/yr and did not exceed 4 g/yr; and cyanazine and metribuzin loads were typically less than 1.5 g/yr and did not exceed 2 g/yr.

In the Cuyahoga and Raisin Rivers, loads were typically less than 1 g/yr. Atrazine loads were highest—typically about 1 g/yr, sometimes reaching 3 g/yr. Herbicides were infrequently detected in the Grand River; loads there were low, and estimates had considerable error. These loadings from U.S. tributaries to Lake Erie were comparable to those reported elsewhere for basins of similar size and land use. These herbicides must be present in high concentrations to be toxic to animals, but can affect aquatic plants at lower levels (Richards and Baker 1993). Direct toxicity due to short exposures at high concentration would be more likely to occur in headwater reaches; effects due to chronic exposure would be more likely in the lower reaches and in the nearshore waters.

6.7 Extraction of Renewable Resources

Commercial fishing has significantly changed the fish community in the Great Lakes. Blue pike and several species of deepwater ciscoes or whitefishes (coregonines) that were once abundant in portions of the Great Lakes ecosystem and were selectively fished by the commercial fishery are now extinct. The abundance of other species of high commercial value has been severely depressed (e.g., lake whitefish) by the intensive fishing; local extinctions have occurred (e.g., lake trout). Some of these changes in abundance are detailed in Section 7.2.3.

Separating the effects of overfishing from those of habitat degradation and the introduction of exotic species is difficult or impossible in many cases, because all three factors often operated simultaneously in the environment. However, the effect of overfishing on the walleye in Lake Erie is clear. Commercial catches declined from between 2.3 million kg and 2.8 million kg in the late 1950s to about 25,000 kg in 1971. Commercial fishing interests blamed the decline on deteriorated habitat. However, when high mercury levels were detected in walleye and the fishery was closed to protect human consumers, walleye abundance almost immediately rebounded to near historic levels. With more stringent catch regulations in place, the walleye now supports a valuable, self-sustaining fishery that is shared by recreational and commercial interests.

A detailed and interesting case for the effects of overfishing in the collapse of the economically important fish community in Lake Huron is presented by Spangler and Peters (1995). They argue that commercial fishing of lake trout, whitefishes, and percids (e.g., walleye) in the 19th century greatly exceeded the sustainable capacity of the stocks and that improvements in fishing technology in the 20th century permitted overfishing of many of the remaining native species. This overfishing destabilized the native community and permitted introduced species like the alewife and rainbow smelt, which arrived later and are only marginally suited to living in the Great Lakes, to become rapidly established and further contribute to the decline of the native fish community. This argument for the destabilizing effect of overfishing on the native fish community and the subsequent establishment of nuisance or destructive exotic fish species could apply throughout the Great Lakes ecosystem. Additional discussion of the effects of exotic species follows in Section 6.8.

Waterfowl that nested in the Great Lakes region—or migrated through it and used the nearshore waters for feeding and resting areas—were sharply reduced by market hunting and habitat destruction (Prince et al. 1992). Hunting regulations are currently designed to ensure the sustainability of the waterfowl community.

6.8 Exotic Species

Global transfer of exotic organisms is one of the most pervasive and perhaps least recognized effects of humans on the world's aquatic ecosystems (Edsall et al. 1995; Leach 1995; Mills et al. 1993). Such transfers to new environments may lead to loss of species diversity and to the extensive alteration of the native (or pre-invasion) community. These changes may in turn have broad economic and social effects on the human communities that rely on the system for food, as a water supply, or for recreation.

Since the early 1800s, at least 139 new aquatic organisms have become established in the Great Lakes (Mills et al. 1993). Most of these species are plants (42 percent), fishes (18 percent), and algae (17 percent). Introduced species of molluscs, oligochaetes, crustaceans, flatworms, bryozoans, cnidarians, and disease pathogens combined represent 22 percent of the total. These organisms entered the Great Lakes basin by five major mechanisms or routes. *Shipping activities* alone brought 41 exotic species to the Great Lakes, of which 63 percent arrived in ballast water, 31 percent with solid ballast, and 6 percent on ship hulls. *Unintentional releases* established 40 new species in the Great Lakes: 30 percent of these were plants that escaped from cultivation. Unintentional releases also include accidental releases from fish culture activities (19 percent) and aquarium holdings (17 percent). Seventeen organisms entered the Great Lakes through human-made canals, along railroads or highways, or as deliberate releases. Entry vectors are unknown for 14 species, and multiple entry mechanisms are suspected for 27. The exact locations of most of these introductions are unknown, but most probably occurred in Great Lakes tributaries, canals, and nearshore waters.

The rate of introduction of exotic species increased markedly after the 1800s, as human activity in the Great Lakes basin increased. Almost one-third of the introductions to the Great Lakes have been reported in the past 30 years. The first introductions of aquatic plants occurred when ships discharged solid ballast in the late 1800s. The opening of the St. Lawrence Seaway in 1959 greatly increased the number of oceangoing vessels entering the Great Lakes and dramatically increased the entry of exotic species via ships. Deliberate releases declined after the 1800s; entry by canal increased slightly through 1959; entry by railroad and highway occurred mostly in the 1800s; and unintentional releases have been consistently high since the late 1800s.

At least 25 non-native fishes have become established in the Great Lakes since European settlement of the region; nearly half of them have had substantial ecological and economic effects on the region (Bailey and Smith 1981; Edsall et al. 1995; Leach 1995; Mills et al. 1993). The sea lamprey, a marine species, contributed to the loss of native Atlantic salmon and lake trout in Lake Ontario. The sea lamprey probably entered Lake Ontario from the Hudson River via the Erie Canal. The canal, which was opened to barge traffic in 1819, connects the Hudson River and Lake Ontario drainages via Lake Oneida. The sea lamprey later moved into the upper four Great Lakes, probably through the Welland Canal, which carries shipping around Niagara Falls, or through the Erie Canal, which connects the Hudson River and Lake Erie drainages. In the upper four Great Lakes, the sea lamprey contributed directly to the decline of the lake trout and to that of several other large species of fish that had supported the sport and commercial fisheries of those lakes. Millions of dollars are now spent annually on sea lamprey control in an effort to restore the damaged fish populations.

The alewife is another marine species that has become established in the Great Lakes. It was present in Lake Ontario in 1873, having probably entered the lake and spread throughout the rest of the basin following the same route used by the sea lamprey. It reached Lake Michigan in 1949 (Smith 1972) and by the 1960s had caused major changes in the plankton community (Wells 1970). The alewife may also have suppressed several native fishes, including whitefishes, yellow perch, emerald shiner, deepwater sculpin, and spoonhead sculpin, probably through preying on the youngest life stages and competing with all life stages (Potter and Fleischer 1992). The alewife also may have suppressed the rainbow smelt, a marine forage species that had been deliberately introduced into the Great Lakes system in the early 1900s to provide forage for trout and salmon. It is generally believed that the alewife would not have reached such high levels of abundance and dominated the fish community in any of the Great Lakes if large, predatory native fish had not been destroyed by overfishing and by the sea lamprey's predation on them. Eventually the alewife became a major prey for trout and Pacific salmon; it came to be considered a beneficial addition to the forage base. However, recent information (Fisher et al. 1995a, 1995b, 1996) shows that an enzyme carried by the alewife destroys vitamin B_1 in Atlantic salmon that eat alewives. Female Atlantic salmon that feed extensively on alewives become B_1 deficient; as a result, the fry that hatch from their eggs die when they are only a few weeks old. Thus, the invasion of the Lake Ontario drainage by the alewife is implicated in the extinction of the remnant native populations of Atlantic salmon in the drainage in the late 1800s. The alewife can also cause B_1 deficiency in lake trout and may therefore have contributed to the general failure of stocked lake trout to reproduce in Lakes Michigan, Erie, and Ontario, where the alewife is a major food source for lake trout.

The blueback herring, a marine species closely related to the alewife, is one of the newest additions to the fish fauna of the Great Lakes. This species was recently documented entering the Lake Ontario drainage from the Hudson River via the Erie Canal (L.R. Wedge, New York Department of Environmental Conservation, personal communication)—the same entry route postulated for the sea lamprey and the alewife. Its effect on the Great Lakes fishes and ecosystems is expected to be similar to that of the alewife, which it closely resembles.

The ruffe, a small perch-like fish from Eurasia, is another recent addition the Great Lakes. It reached the St. Louis River estuary in Lake Superior in ballast water in the early to middle 1980s (Pratt et al. 1992; Simon and Vondruska 1991). Ruffe abundance increased sharply in 1993, and the species spread to other parts of the lake. Yellow perch numbers in the St. Louis River estuary declined markedly between 1988 and 1991 as ruffe abundance increased; there is concern that similar declines could occur elsewhere in the Great Lakes if the ruffe expands its range and competes with yellow perch for thermal habitat (Edsall et al. 1993) and food (Ogle et al. 1995). The ruffe has the potential to occupy nearly 7 million ha of habitat in the Great Lakes that is currently suitable for use by yellow perch (Edsall et al. 1993). Two ruffe were captured in August 1995 in Thunder Bay, Lake Huron, near Alpena, Michigan; there are also unconfirmed sightings from the Detroit River ("Ruffe spreads..." 1995).

Round and tubenosed gobies are also among the recent ballast-water additions to the Great Lakes. They were first reported from the St. Clair River in 1990 (Jude et al. 1995). They are expected to compete strongly with native sculpins and other small bottom-feeding fishes and are considered highly undesirable additions to the region. A round goby was found in the Duluth–Superior harbour in July 1995 ("First goby..." 1995).

The successful stockings of Pacific salmon, rainbow trout, and brown trout in the Great Lakes during the 20th century have had profound and largely beneficial economic effects on the region. These species are large predators that feed extensively on the introduced alewife and rainbow smelt. They also support popular fisheries that contribute significantly to the total Great Lakes fishery, which is valued at more than $4 billion annually. There are self-sustaining populations of these fish in some areas, but in most areas stocking substantially augments the naturally produced fish.

Of the fish pathogens introduced into the Great Lakes, *Glugea*, a protozoan, caused extensive mortality in rainbow smelt in Lakes Erie and Ontario in the 1960s and 1970s. A second pathogen, which causes bacterial kidney disease, has been implicated in the massive mortalities of Pacific salmon in Lake Michigan in the 1988–1994 period. Other introduced pathogens cause salmon whirling disease and furunculosis, mainly in fish hatcheries, where crowding makes fish vulnerable to outbreaks of disease. A more detailed accounting of the fish pathogens in the Great Lakes is contained in the records of the Fish Health Committee, Great Lakes Fishery Commission, Ann Arbor, MI, and in Hnath (1993).

The arrival of the zebra mussel in Lake Erie in 1986 set the stage for long-term changes in the structure of pelagic and benthic communities in the Great Lakes and in the economic and social future of lake users. The zebra mussel, which feeds by filtering particles from the water, may cause substantial changes in the food chain by removing most of the phytoplankton and the smaller zooplankton, along with other suspended materials, from the water and depositing them on the bottom. This process greatly reduces the plankton community and the amount of food available to planktivorous fish that feed above the bottom, and greatly increases the food supply for benthic communities and bottom-feeding fish. As a result, the overall production of fish in the Great Lakes will probably be reduced. There is concern that the zebra mussel may change the nitrogen-to-phosphorus ratio in Great Lakes nearshore waters so much that the production of noxious blue-green algae will be favoured over that of the more desirable species of green algae, which are an important component of the food chain. Zebra mussel fouling on vessel hulls and the deposition of zebra mussel shells on beaches may also negatively affect those who boat or swim in the Great Lakes. The zebra mussel is also the major fouling organism of water intakes and navigation structures in the Great Lakes; $120 million was spent in the 1989–1994 period to maintain these structures in operating condition (ZMU 1996). The zebra mussel has already spread—presumably from populations established in the Great Lakes—to Southern Ontario in Canada. Its westward range extension in 1995 included the Mississippi River (intermittently from its headwaters near St. Paul, Minnesota, to its mouth at New Orleans, Louisiana) and westward into the lower and middle reaches of the Arkansas River. The environmental tolerances and requirements of zebra mussel larvae (Table 4) and adults (Table 5) suggest that it will do well in Great Lakes nearshore waters, except perhaps in Lake Superior. Additional discussion of the zebra mussel is presented in Section 7.2.2.

Table 4. Environmental Conditions Affecting Survival of Zebra Mussel Larvae

Condition	Range	Optimum
Water temperature	12–24 C	18 C
pH	7.4–9.4	8.5
Dissolved calcium	> 40 mg/L	unknown
Salinity	0–3 ppt	0
Colonization substrates	Soft mud, rocks, wood, aquatic plants, etc.	Hard, calcareous

Source: Adapted from Sprung 1993.

Introduced plant species outnumber all other groups of introduced organisms, but the effect of only a few of these are known (Mills et al. 1993). Purple loosestrife has spread throughout the Great Lakes basin; it is replacing the cattail and other native wetland plants and is making wetlands less suitable as wildlife habitat. Eurasian water milfoil is also increasing its range in the Lake St. Clair ecosystem (Schloesser et al. 1996). Massive beds of the plant can make boating and swimming impossible and can reduce fish and invertebrate populations. Some introduced species of algae have become dominant members of the algal community of the Great Lakes. Their ecological impacts are generally unknown, but one, *Stephanodiscus,* has caused water-quality problems on several occasions.

Table 5. Colonization Potential of Zebra Mussels under Various Environmental Conditions

Variable	High	Moderate	Low	Very low
Calcium (mg/L)	25–125	20–25	9–20	< 9
Dissolved oxygen (ppm)	8–10	6–8	4–6	< 4
pH	7.4–8.5	7.0–7.4 8.5–9.0	6.5–7.0	< 6.5 > 9.0
Salinity	0–1	1–4	4–10	10–35
Turbidity (cm secchi disk)	40–200	20–30	10–20 200–250	< 10 > 250
Water velocity (m/sec)	0.5–0.7	0.1–0.5 0.7–1.0	1–2	> 2

Source: C. O’Neill, New York Sea Grant.

The ecological effects of the introduced crustaceans, oligochaetes, bryozoans, cnidarians, and flatworms are largely unknown. Historically, the ecological and economic risks associated with these groups have not been as high as those posed by other plants and animals. The recently introduced spiny water flea, a predatory zooplankter, has undergone rapid expansion in the Great Lakes. Its ecological effect may not be great, but its establishment in Lake Michigan coincided with changes in the zooplankton community characteristic of those caused by an invertebrate predator.

In summary, the collective ecological, social, and economic effects of exotic species in the Great Lakes are enormous. Most introduced species have not been thoroughly studied to determine their effects on the ecosystem, but some have clearly had serious adverse effects. Introduced species exist at almost every level in the food chain, and their effects must certainly pervade the entire Great Lakes aquatic community. We conclude that as long as human-mediated transfer mechanisms persist, and as long as habitat alterations and other factors that stress native aquatic communities are allowed to occur, the Great Lakes ecosystem will be at substantial risk from new, undesirable, exotic species. Clearly, guidelines to prevent introductions should be enforced and efforts to reverse and remediate habitat damage should continue.

7.0 Status and Trends

7.1 Fish and Wildlife Habitat

The nearshore areas of the Great Lakes are diverse physical habitats, exhibiting a range of morphometric features, current velocities, substrates, and aquatic vegetation. These features, combined with seasonal fluctuations in temperature, provide conditions optimum to most species of fish in the Great Lakes for at least a portion of their life cycle. Of 139 Great Lakes fish species reviewed by Lane et al. (1996a), all but five species—the deepwater ciscoes (*Coregonus hoyi*, *C. johannae*, *C. nigripinnis*, *C. reighardi*, *C. zenithicus*) and deepwater sculpin (*Myxocephalus thompsoni*)—typically use waters less than 10 m deep as nursery habitat; and even the latter has been captured from shallows in the St. Clair River delta (Leslie and Timmins 1991a). Adults of many species occur over a range of depths, but 80 percent of fish species in the Great Lakes use nearshore areas for at least part of the year (Lane et al. 1996b). It is therefore not surprising that species diversity and biomass of fish are higher in the nearshore than in the offshore and profundal areas of the Great Lakes. Steedman and Regier (1987) noted that areas that provide the essential conditions for specific activities, such as reproduction, are far more ecologically significant than their small size would suggest. In addition, a disproportionately large number of these critical areas, which they term "centres of organization," occur in shallow nearshore areas.

Nearshore areas are also locations of greatest human interaction with the Lakes. This concentrated activity has resulted in the degradation of water quality and also in a significant loss of nearshore habitat around the Great Lakes. Loss of fish and wildlife habitat has been identified as a beneficial-use impairment at 11 of the 17 Areas of Concern identified on the Canadian side of the Great Lakes, and has also occurred at many locations outside of Areas of Concern (Kelso and Minns 1996). In most locations the habitat losses are primarily, if not exclusively, in nearshore habitats. Randall et al. (1993) have correlated degradation of nearshore habitats with reductions in the proportion of fish biomass contributed by piscivores and with increased spatial variability in species richness and biomass.

7.1.1 Fish Habitat Features of the Nearshore

7.1.1.1 Depth

By definition, shallow habitats are found only in the nearshore waters. Depth has direct effects on fish distributions; smaller individuals can occupy shallower depths. Thus, the shallows provide a refuge for small fish, including young-of-the-year. In addition to depth per se, fish distributions are influenced by other factors, individually or in combination, which are related to depth. The most significant of these—water temperature, substrate, and aquatic vegetation—are discussed below.

7.1.1.2 Temperature

Temperature influences physiological processes, which affect the growth, reproduction, and survival of fishes, and can also act as a proximate factor through its influence on food supply, competition, and predation (Reynolds 1977). Preferred and/or optimum temperatures differ between species, with younger individuals of some species, such as alewife (*Alosa pseudoharengus*), preferring higher temperatures than the adults of those species do (Brandt 1980). Consequently, habitat partitioning among and within species is affected by temperature, and the amount of habitat available at different temperatures has a profound influence on fish community composition.

In the spring, solar radiation causes water temperatures in the Great Lakes to increase. Water temperature increases most rapidly in sheltered, shallow habitats, where wind-induced mixing is least. As the warming continues, a band of warmer water forms along the shore; this “thermal bar” gradually expands towards the centre of the lake until the lake becomes thermally stratified. During the spring, many coldwater species (such as lake trout) inhabit shallow, warmer water where temperatures are closer to their thermal optimum. As water temperature increases, these species migrate to deeper water. In Hamilton Harbour, Lake Ontario, gill net catches have indicated that warmwater species such as carp (*Cyprinus carpio*) and brown bullheads (*Ameiurus nebulosus*) are concentrated in the shallow, sheltered inner harbour (Cootes Paradise) during early spring, when water temperatures there were higher than in the outer harbour. As temperatures in the outer harbour increased, these species dispersed (Portt et al. unpublished). For species that are near the northern limit of their range, such as largemouth bass (*Micropterus salmoides*), the availability of shallow, sheltered habitats that warm early in the spring is probably essential for survival. For other species, such as lake trout, using warmer nearshore areas effectively increases the growing season and may significantly increase production.

7.1.1.3 Vegetation

Of the 133 species examined by Lane et al. (1996a), the young-of-the-year of 77 are moderately to strongly associated with aquatic vegetation; more species are associated with submergent than with emergent vegetation (Table 6). Wetlands provide critical spawning and nursery habitats for many Great Lakes fish species, and several authors have reported high species richness of young fishes from wetland habitats. Chubb and Liston (1986) identified larvae of 18 fish species in Pentwater Marsh, a coastal wetland on Lake Michigan. Stephenson (1990) found juveniles of 31 fish species in one or more of five coastal marshes in the Toronto area of Lake Ontario, with the number of species at individual sites ranging from 12 to 25. Young-of-the-year of 19 species were present in Second Marsh, Lake Ontario (OMNR 1980).

Table 6. Numbers of Great Lakes Fish Species Exhibiting Various Strengths of Association with Submergent and Emergent Aquatic Vegetation as Young-of-the-year and as Adults

Life Stage	Vegetation Type	Strength of Association			
		Strong	Moderate	Low	None
adult	submergent	42	21	21	49
	emergent	33	9	18	73
young-of-the-year	submergent	36	27	22	42
	emergent	27	14	15	71

Sources: Lane et al. 1996a, 1996b.

The abundance of young-of-the-year fishes is also often higher in vegetated than in non-vegetated habitats (Chubb and Liston 1986; Holland and Huston 1984; Leslie and Timmins 1994; Keast et al. 1978). Chubb and Liston (1986) reported that larval fish densities were usually 10 times to 100 times more abundant in the vegetated bayou of Pentwater Marsh, Lake Michigan, than in adjacent unvegetated bayou mouths or river channels.

Vegetation is also an important component of adult habitat. Adults of nearly one-third of the fish species in the Great Lakes are strongly associated with submergent vegetation, while adults of one-quarter of the species are strongly associated with emergent vegetation (Table 6).

7.1.1.4 Substrate

Table 7 indicates the wide diversity of substrates used by both adult and young-of-the-year fish species of the Great Lakes. Gravel, sand, and silt are the most preferred materials, with more than three-quarters of young-of-the-year fish species and two-thirds of adult species using at least one of them. These substrate types are often found within vegetated habitat, and the strong association is certainly related. Coarse substrates such as rubble and cobble also provide important nursery and adult habitat (Lane et al. 1996a, 1996b). In addition, many species of Great Lakes fishes—such as lake trout, lake whitefish, walleye, bass, and most sunfish—spawn on gravel, cobble, and rubble. In the nearshore, many features are actively forming at present lake levels, the continued extension of Long Point, Lake Erie, being one example.

Glacial, glaciolacustrine, and lag or relict beach deposits have been described over a wide range of depths at many locations in the Great Lakes (Sly and Prior 1974; Sly and Sandilands 1988; Thomas et al. 1976). These deposits can be subject to degradation due to infilling and/or burial by finer sediments and/or particulate organic material. In the nearshore, wind-generated currents determine the size distribution of particles that are transported. In some areas, accretion of fine sediments occurs; in others, these materials accumulate. This accumulation leads to a diversity of substrates that is not found in the deeper portions of the Lakes.

Table 7. Numbers of Great Lakes Fish Species Exhibiting Various Strengths of Association with Substrate Types as Young-of-the-year and as Adults

Life Stage	Substrate Type	Strength of Association			
		Strong	Moderate	Low	None
Adult	boulder	8	12	5	108
	cobble	12	13	3	105
	rubble	24	24	7	78
	gravel	68	26	12	27
	sand	90	18	6	19
	silt	71	16	6	40
	clay	6	9	8	110
Young-of-the-year	boulder	11	2	1	113
	cobble	12	2	3	110
	rubble	19	9	5	94
	gravel	43	25	2	57
	sand	84	17	3	23
	silt	65	15	5	42
	clay	10	14	2	101

Sources: Lane et al. 1996a, 1996b.

7.1.2 The Significance of Water-level Fluctuations

Variation in Great Lakes water levels is generally identified at three temporal scales, which we define here as short-term, seasonal, and year-to-year. Short-term cyclical fluctuations—with periods measured in hours, and amplitudes typically measured in centimetres or tens of centimetres—occur due to seiche activity. Occasionally, larger short-term fluctuations—with amplitudes in excess of 1 m—occur as a result of cells of low barometric pressure and/or high winds. Seasonal changes in water levels occur largely in response to seasonal patterns of precipitation and temperature in the drainage basin. The amplitude of these seasonal fluctuations varies between the lakes, as does the time of maximum and minimum levels. On average, water levels rise during a five-month period in the spring and early summer and recede during the remaining seven months of the year. The annual minimum and maximum occur approximately two months earlier in Lake Ontario (where they occur in late January and mid-June, respectively) than in Lake Superior (where they occur in mid-March and late August, respectively).

Superimposed on the seasonal cycles are year-to-year fluctuations in water levels, which occur primarily as a result of year-to-year variation in precipitation within the drainage basin. These fluctuations can cause substantial deviations from the “normal” seasonal pattern. The amplitude of the year-to-year variations differs between the lakes. The extreme highs and lows for the period of record differ by approximately 2.0 m in Lake Ontario and Lake St. Clair; 1.8 m for Lakes Michigan, Huron, and Erie; and 1.2 m for Lake Superior. The locations of the “shoreline,” depth contours, and the thermocline vary over time because of these water-level fluctuations. Where bottom slopes are gentle, the migrations can be large. Such changes illustrate the dynamics of nearshore habitats and the direct influence they have on the fish community.

Maynard and Wilcox (1996) discuss the well-documented importance of water-level fluctuations for healthy wetlands. Effects on other fish habitats has not been researched as extensively; however, Henderson (1985) showed that yellow perch reproduction improved in high-water years in South Bay, Lake Huron. He attributed this improvement to the increased availability of vegetation along the shoreline. Strong year classes of northern pike have been attributed to rising water levels that have flooded vegetation in impoundments (Bodaly and Lesack 1984; Nelson 1978). Similar effects would be expected in Great Lakes wetlands.

7.1.3 Types of Nearshore Habitats

The nearshore waters have been defined as including the portion of the lakes from the shore, or the outer edge of coastal wetlands where these are present, to the intersection of the late-summer thermocline with the bottom. Also included are the connecting channels, as well as tributaries upstream to the point where lake levels affect flow. These habitats can be divided into five general categories: wetlands, embayments, connecting channels, tributaries, and exposed coastline and offshore shoals.

7.1.3.1 Wetlands

Wetlands are defined as areas that are covered by shallow water, either seasonally or permanently, as well as areas where the water table is at or near the surface (OMNR 1992). Wetlands comprise different types of ecosystems and serve a number of functions, including maintaining and improving water quality, providing erosion and flood protection, and providing fish and wildlife habitat (Maynard and Wilcox unpublished). Along the Great Lakes shoreline, coastal wetlands provide an important link between aquatic and terrestrial systems. These wetlands differ from inland wetlands in a number ways. Water levels in coastal wetlands are dependent on lake water levels, which fluctuate over a period of years. Because of this long-term fluctuation, coastal wetlands do not exhibit the gradual senescence that occurs with inland wetlands (Herdendorf et al. 1986).

Coastal wetlands are formed by a diversity of landforms, including barrier bars, deltas, lagoons, and natural levees (Jude and Pappas 1992). These characteristics provide the extensive zonation that results in diverse habitat structures. These areas, in turn, promote the formation of complex food webs and diverse community structure.

The role of coastal wetlands in fish production relates primarily to providing both nursery and spawning habitat (Stephenson 1990). The fundamental prerequisites for nursery habitat of virtually all larval fish species are abundant food supply and protection from predators. The proliferation of aquatic macrophytes in coastal wetlands provides microhabitat for both eggs and larvae, the necessary cover from predator species, and the storage and release of nutrients (Petering and Johnson 1991). In addition, higher water temperatures promote higher growth rates for larvae, as well as providing favourable conditions for all life phases of certain warmwater fish species.

Another result of the profile of favourable characteristics common to wetlands is the species diversity found in both pristine and degraded areas. Stephenson (1990) found 31 species of juvenile fish in the combined sampling sites of marshes around the Toronto area. Individual marshes supported 18 taxa, a similar number to that found by Chubb and Liston (1986) in their study of Pentwater Marsh on Lake Michigan. Species abundance, however, tends to be lower in degraded wetlands, with one species—often carp—being dominant (Chubb and Liston 1986).

7.1.3.2 Embayments

Embayments represent another diverse array of sheltered habitats for fish species in the nearshore areas of the Great Lakes. Although many embayments contain wetlands (abundant submergent and emergent vegetation are typically present), they also include areas of open water. Often they represent a transition between open water and riverine habitats. The Bay of Quinte (Lake Ontario), Long Point Bay (Lake Erie), and Saginaw Bay (Lake Michigan) are examples of embayments. Field studies in Muscote Bay, Bay of Quinte (Leslie and Moore 1985), and Hog Bay, Severn Sound (Leslie and Timmins 1995), both Areas of Concern, showed 24 and 31 taxa, respectively.

7.1.3.3 Connecting Channels

The Great Lakes connecting channels are also important spawning and nursery habitats. Leslie and Timmins (1991a) captured 21 species of fish larvae in the St. Clair River proper, but captured more than 60 species in waters connected to and adjacent to the river. Young-of-the-year of 48 species were captured in tributaries of the St. Clair River (Leslie and Timmins 1991b). Liston and McNabb (1986) reported larvae of 33 species and juveniles of 27 from Munuscong Bay on the St. Marys River. The St. Marys River, downstream from the dam at Sault Ste. Marie, and the Niagara River provide spawning habitat for Pacific salmon and for rainbow trout, which also spawn in many of the tributaries of the Great Lakes.

Connecting channels also have an important role in the transport of water, sediments, nutrients, and contaminants (Sparks 1995).

7.1.3.4 Tributaries

The principal spawning and nursery habitats for one-third of the fishes in the Great Lakes are located in the tributaries (Lane et al. 1996a). Many of these species spawn further upstream than the area that has been defined as nearshore habitat (the furthest distance upstream that water levels are affected by lake levels). Other species, however, spawn within the lower reaches of the tributaries. Temperatures sufficiently high to trigger spawning often occur in streams before they occur in lakes, thus providing a longer growing season. For example, spottail shiners spawned one month earlier in a tributary to Lake Michigan than they did in the lake (Mansfield 1984). Productivity also tends to be higher in streams than in pelagic lake areas, probably as a result of the allochthonous input from terrestrial areas (Mansfield 1984).

Floodplains also enhance productivity and maintain diversity. At drawdown, nutrients are mineralized and accumulation occurs; during flooding, the nutrients are dissolved and high primary production and decomposition rates occur (Bayley 1995). The result is a high turnover rate and optimum conditions for spawning and nursery grounds for many species of fish.

7.1.3.5 Exposed Coastline and Offshore Shoals

Exposed coastline and offshore shoals have been the subject of less sampling effort in the Great Lakes than have the other nearshore habitats. This neglect is probably due both to the fact that such areas are perceived as being less important in terms of fish habitat than are most other nearshore habitats and to the fact that they are more difficult to sample. Macrophytes are typically not present, with the exception of deeper beds in some locations. Wave-induced mixing inhibits thermal stratification, and upwelling of water from the hypolimnion occurs in many areas. Although total fish numbers are generally lower than in sheltered habitats, these areas present unique features that are optimum for certain species, particularly those adapted to turbulent environments. Upwelling also affords coldwater species with periodic access to shallow littoral habitats.

7.1.4 Problems and Issues

Fish habitat problems related to power production, dredging, transportation, and boating have been mentioned earlier in this report. This section covers problems associated with other types of activities.

7.1.4.1 Shoreline Modification

Portions of the Great Lakes shoreline have been modified during the course of industrial, commercial, and residential development. Except where diking of coastal areas for agricultural purposes has occurred (primarily along the shores of Lakes Erie and St. Clair), the extent of these modifications is roughly proportional to the population along the shoreline. Shoreline modifications range from simply infilling the shallows to erecting sheet steel and concrete walls. In Hamilton Harbour, a major industrial port, filling the nearshore areas, along with straightening and hardening the shoreline, reduced the shoreline's length by 36 percent between 1808 and 1992. Only about 6 percent of the original shoreline remains in an unaltered state. In Severn Sound, which represents an intermediate case, 15 percent of the 325 km of shoreline that has been inventoried has been altered. The alterations include nearly 9.7 km of concrete walls and 3.4 km of sheet steel piling. Not surprisingly, the modifications are concentrated in sheltered embayments that are surrounded by the most intense development. Along the north shore of Lake Superior, where there are relatively few communities, most of the shoreline is still in its natural state.

Hardening the shoreline eliminates the migration of the nearshore with changing water levels. Indeed, such modifications are often motivated by the desire to eliminate such migration. Their effect, however, is to reduce the amount of fish habitat available, especially in relation to what would be available during high-water years. Usually, such modifications also straighten the shoreline. Because irregularities in the shoreline cause local variations in alongshore currents, which in turn cause local variation in substrate, straightening results in a loss of habitat diversity.

Other examples of shoreline modification are accumulations of wood fibre and bark near some pulp mills and accumulations of wood scraps from lumber operations in Penetang Harbour.

7.1.4.2 Water-quality Degradation

The impaired beneficial uses of many of the 17 Areas of Concern in the Canadian waters of the Great Lakes all relate in some way to eutrophication. The cycle of eutrophication begins with the enrichment of water as a result of nutrient loading and, subsequently, increased algal blooms. Eutrophication causes a shift in community to a species profile that can better tolerate the conditions of impaired visibility and variations in dissolved oxygen (Severn Sound RAP Team 1993). Often these species are less desirable—for example, carp (*Cyprinus carpio*), alewife (*Alosa pseudoharengus*) and brown bullhead (*Ameiurus nebulosus*). Sewage plants, septic systems, urban storm water, and agricultural sources—both livestock and crops—all contribute to the eutrophication problem in the Severn Sound AOC (Severn Sound RAP Team 1993). In the Bay of Quinte AOC, six municipal sewage treatment plants bordering the area are mainly responsible for phosphorus loadings (Bay of Quinte RAP 1996). Discharges from the Domtar liner-board mill on Nipigon Bay and from the two local sewage treatment plants are responsible for eutrophication problems in that AOC (Nipigon Bay RAP Team 1995).

7.1.5 Fish Habitat Policy and Current Initiatives

7.1.5.1 Department of Fisheries and Oceans (Canada) Policy for the Management of Fish Habitat

The habitat protection provision of the Canadian Fisheries Act provides the legislative mandate for the management of fish habitat in Canada. This Act prohibits any work or undertaking that is likely to result in the harmful alteration, disruption, or destruction (HADD) of fish habitat without the implementation of compensatory measures. The Department of Fisheries and Oceans (DFO) policy for the management of fish habitat establishes an overall objective: to "increase the natural productive capacity of habitats for the nation’s fisheries resources, to benefit present and future generations of Canadians” (DFO 1986). The first goal of this policy is to maintain the current productive capacity of fish habitats. The guiding principle for achieving this objective is no net loss of the productive capacity of habitats. Simply stated, the DFO will seek to balance any unavoidable habitat loss with habitat replacement on a project-by-project basis (DFO 1986). Other goals include rehabilitating the productive capacity of fish habitats in selected areas where economic or social benefits can be achieved through the fisheries resource, and improving and creating fish habitats in selected areas where the production of fisheries resources can be increased for the social or economic benefit of Canadians.

In Ontario, the DFO and the Ontario Ministry of Natural Resources (OMNR) work together to protect fish habitat. The provincial agency is responsible for enforcing the habitat protection provisions of the Fisheries Act. Applications for activities that will affect fish habitat are reviewed by OMNR field offices. If a HADD is anticipated, the project is normally referred to the DFO for authorization. The major decision criteria for the authorization of a HADD are the significance of the habitat and the possibility of compensation. Typically, the creation of new habitat or the modification of existing habitat that will increase fish productive capacity is considered acceptable. Table 8 provides information on some projects assessed by the DFO under the “no net loss” policy. Less than 5 percent of the shoreline referrals were dedicated to restoration. Close to 50 percent of the projects affect between 0 m and 1,000 m of shoreline each, yet the cumulative effect of these projects is significant. The development of long-range habitat management plans that deal effectively with these issues is essential.

Table 8. Summary of 127 Shoreline Projects Referred to the Canadian Department of Fisheries and Oceans, Central Region

Variable		Count (Number of Projects)	Percent
Project	Marina	27	21.2
	Dock	9	7.0
	Water Intake	3	2.3
	Industrial Wastewater	9	7.0
	Storm Sewer	3	2.3
	Sewage Treatment	4	3.1
	Water Course Diversion	3	2.3
	Armourment	16	12.5
	Restoration/Cleanup	5	3.9
	Infilling	16	12.5
	Dredging	11	8.6
	Other	21	16.2
Shore Affected (m)	0	16	12.5
	> 0–10	9	7.0
	10–100	29	22.8
	100–1,000	27	21.2
	1,000–10,000	15	11.8
	> 10,000	2	1.5
	Unknown	29	22.8
Area Affected (m^2)	0	10	7.8
	> 0–10	1	0.7
	10–100	8	6.2
	100–1000	37	29.1
	1000–10,000	20	15.7
	> 10,000	25	19.6
	Unknown	26	20.4
Effects	Construction	7	5.5
	Permanent	13	10.2
	Both	90	70.8
	None	7	5.5
	Unknown	10	7.8

Source: Minns et al. 1995.

7.1.5.2 Current Initiatives

The ecosystem approach to nearshore fish habitat management has been adopted for the Canadian waters of the Great Lakes. In this approach, which recognizes the link between the natural ecosystem and human activity, the effects of shoreline development are assessed with respect to their impact on fish habitat (Minns et al. 1995). A problem exists based on the lack of a protocol that would allow the consistent and quantitative assessment of fish habitat in its pre- and post-development stages. Current methods do not consider cumulative impacts, the direct and indirect effects of development, or the habitat needs of fish (e.g., individuals, communities, proximity of spawning, and nursery habitats). There is a need for a common approach to evaluating the effects of habitat modification on fish productive capacity.

Development of Methods for Pre- and Post-Development Assessment of Fish Habitat

A prototype methodology has been developed for use with nearshore fish habitat of the Great Lakes that provides the ability to assess fish community objectives with respect to proposed development (Minns et al. 1995). The proposed methodology estimates (1) total habitat area that will be affected, either directly or indirectly, by the development; (2) pre- and post-development fish community productivity area; and (3) suitable area for special habitat (e.g., spawning habitat for coldwater piscivores) for pre- and post-development. These estimations are based on information compiled regarding life history, life stage, ecology, and fish community objectives. The result is a pair of scores—one each for pre-development status and post-development status. The difference between the two scores is an estimate of the net change in fish productivity that will result from the proposed development. Refinements to the methodology are ongoing.

Incorporating Fish Habitat Concerns into Land-use Planning

It is increasingly recognized that fish habitat protection must be incorporated into traditional land-use planning to be effective. In Ontario, recent amendments to the Land Use Planning and Protection Act require that fish habitat be addressed with other natural features in a Natural Heritage Policy. Management agencies require ways of providing ecologically sound information, in a form that can be readily used by planners and other non-fisheries professionals, for effective habitat management planning.

Initiatives aimed at developing habitat classification systems for littoral habitats are under way in two Great Lakes Areas of Concern, the Bay of Quinte (Lake Ontario) and Severn Sound (Lake Huron), as part of their Remedial Action Plans. Both use Geographical Information System (GIS) software to integrate habitat data (substrate, depth, vegetation) with biological information. In the Bay of Quinte, fish sampling data have been used to calculate an Index of Biotic Integrity or IBI (Minns et al. 1994) for the various littoral habitats. The IBI scores, in combination with a rating of spawning suitability, were used to calculate a community habitat suitability score for each identified habitat type (MacLeod et al. 1995). In Severn Sound, knowledge of the habitat requirements of Great Lakes fishes is being used to predict fish utilization of different littoral habitats. These results will subsequently be evaluated by comparing them to field collection data. Making this information available to planners, developers, and other agencies will ensure a proactive rather than a reactive approach to development. Projects will be redirected away from sensitive habitats before damage occurs and before large amounts of time and money are invested.

Integration of Coastal Processes and Fish Habitat Management

Nearshore areas of the Great Lakes are highly diverse and are subject to constant change with respect to both natural and human forces. Wave action, sediment transport, deposition, and erosion are some of the factors that induce changes in surficial substrate, macrophytes, and water depth. Changes in the amount and quality of fish habitat result. Modelling techniques are currently being developed that will enable the prediction of wave action and circulation patterns, along with prediction of the changes in habitat that may occur as a result (W.F. Baird and Associates 1996). These techniques are based on documentation of existing morphology, evaluation of wave dynamics, and current models. Once the techniques have been applied, the findings can be interpreted to determine changes in key habitat characteristics (W.F. Baird and Associates 1996). These advancements clear the way for Coastal Zone Management planning to expand from its traditional area of flood/erosion control towards the Fish Habitat Management Planning process envisioned in the Department of Fisheries and Oceans policy.

Canadian Airborne Spectral Imagery Project (CASI)

The purpose of the CASI project is to develop a digital inventory of habitat types for Lake Erie. An atlas of digital maps will be compiled using data collected with CASI along with digital georeferenced data from other sources. The maps will show nearshore aquatic and terrestrial habitat components on Long Point Bay, Lake Erie. The atlas will provide an improved technique for assessing aquatic habitat suitability and influences of terrestrial activity on aquatic habitats in a consistent and reliable manner. Such a tool will be key in helping the agencies responsible for making land-use and resource management decisions.

7.1.5.3 New Initiatives for Improving Management

The Lake Superior Bi-national Program provides a more broad-scale approach to restoration and management planning. The overall objective of this program is to achieve the designation of Lake Superior as a zero-discharge area for nine designated pollutants. The need to inventory existing habitat and to initiate activities aimed at protecting or restoring habitat resources is also included in the broader program to restore and protect the Lake Superior ecosystem. More specifically, the Habitat Committee was established to address issues that relate directly to wetland, aquatic, and terrestrial habitat. Its direct responsibilities include (1) developing criteria for identifying areas of important habitat and identifying sites that meet those criteria; (2) promoting partnerships aimed at integrating the inventory, restoration, and maintenance of habitat; (3) developing a system of ranking habitat restoration and maintenance—a system that involves all potentially affected individuals at all levels; (4) integrating long-term habitat inventory, assessment, and restoration efforts (Lake Superior RAP unpublished).

7.1.5.4 Restoration Examples

In recent years, numerous projects aimed at restoring fish and wildlife habitat have been undertaken in nearshore areas of the Great Lakes. Currently, approximately 58 habitat restoration projects are being supported, in part, by the Great Lakes 2000 Cleanup Fund. Some examples are discussed below.

Hamilton Harbour and Cootes Paradise Habitat Restoration

This fish and wildlife project, currently the most ambitious on the Canadian side of the Great Lakes, is coordinated by the Department of Fisheries and Oceans and is supported by a broad partnership of government and private organizations. Project activities include the creation of islands, shoals, and reefs; the naturalization of shoreline; and the restoration of wetlands. The project's overall aim is to restructure the fish community so that instead of being dominated by carp (as it is now), it becomes a more diverse community dominated by top-order predators. The projected total cost of this project is more than Cdn $31 million.

Penetang Harbour

About 63 percent of Penetang Bay wetland has been lost through development (filling). Wood debris from lumber operations along a portion of the shoreline at the bay's south end prevented the growth of aquatic plants; in doing so, it impaired habitat for water-based wildlife. Removal of wood debris from the bottom (4 ha) has allowed colonization by aquatic vegetation. Two hectares of parkland, which had been created by filling the bay, were recontoured to create two wetlands containing small, spring-fed watercourses. Steel half-culverts that had contained two other small streams were removed to allow these channels to revert to a more natural condition. The projected total cost of this project is Cdn $260,000.

Restorations of Natural Habitat Structure, Toronto Waterfront

Underwater structural complexity was re-created along the Toronto waterfront, reducing the extent of habitat impairment caused by shoreline modifications. This activity will help restore self-sustaining fish and wildlife populations to the area.

In summary, the nearshore habitats of the Great Lakes have been significantly affected since 1800, when colonization of North America expanded. The rate and magnitude of change accelerated greatly with the increases in population and the increases in agricultural and industrial development that followed. No comprehensive documentation of the recent changes in the amount and quality of nearshore habitats is available, but it is clear that with the adoption of the "no net loss" policy and with the efforts directed at habitat restoration, a net gain in the amount and quality of nearshore habitats has been realized in recent years. Though the current restoration efforts are improving aquatic habitat, much of the damage is irreversible. For example, restoration estimates for northern pike (*Esox lucius*) habitat in Hamilton Harbour indicate that 20 percent of the harbour will provide suitable habitat. In its original state, nearly 50 percent of Hamilton Harbour provided some degree of pike habitat (Minns et al. 1993). In addition, the degradation in one area significantly affects our ability to improve fish and wildlife populations in adjacent areas. Pressures on nearshore habitat will continue as the population of the Great Lakes basin increases. Subsequently, demand for water increases as well, along with demand for sewage disposal, food, housing, recreation, transportation, and a range of other human needs and wants that threaten aquatic habitats, especially the nearshore. Recognizing the unfortunate history of habitat destruction and degradation and the lost opportunities that have resulted, and recognizing the high cost of restoration, inspires a commitment to anticipate future human-induced stressors and to develop strategies to prevent us from repeating the mistakes of the past.

7.1.6 Nutrient Enrichment and Algae

Nutrient trends and Great Lakes ecosystem responses to nutrient loadings and concentrations were reviewed for SOLEC '94 (Neilson et al. 1995). Targeted phosphorus loading reductions were exceeded in Lakes Superior, Huron, and Michigan and were reached or nearly reached in Lakes Erie and Ontario (Neilson et al. 1995). Phosphorus concentrations in lake water followed trends in nutrient loadings and reached expected levels except in western Lake Erie, where the expected level was sometimes exceeded. Trends in soluble reactive phosphorus (the biologically available form, abbreviated SRP) generally followed those of total phosphorus. As a result, the growth of *Cladophora*, a filamentous alga, was reduced in nearshore waters, and chlorophyll *a* was reduced in offshore waters. Nitrogen (nitrate–nitrite) levels seem to be increasing, particularly in Lake Ontario. This increase, coupled with a reduction in phosphorus levels, has reduced the total quantity of algae in the water and has shifted the species composition away from nuisance blue-green algae and towards the more desirable diatoms, which were historically dominant. These changes indicate that the open waters of the three upper lakes have remained oligotrophic and that Lake Ontario is tending in that direction. Phosphorus loading reductions have not been sufficient to permit re-establishing year-round aerobic conditions in the hypolimnion in central Lake Erie.

The return of the Great Lakes to a more oligotrophic condition—as evidenced by a reduction in the abundance of blue-green algae and by a reduction in the annual occurrence of anoxic conditions in the bottom waters of central Lake Erie—is certainly desirable from a water-quality management perspective and is also desirable from a fisheries management perspective, as long as increasing oligotrophy does not result in a substantial reduction in fish production. Fisheries and water-quality management strategies for the Great Lakes have evolved more or less independently; although the two types of management strategies have generally benefited the environment, they do not have identical goals or approaches. In the future, a more ecologically oriented approach that considers both fisheries and water-quality management goals and that better integrates management activities should be aimed for.

7.1.7 Nearshore Nutrients

Nutrients important to algal growth (phosphorus and nitrogen) are added to the lakes in the nearshore zone through combined sewer overflows (CSOs), sewage treatment plants (STPs), and rivers. The Ecosystem Health Division of the Environmental Conservation Branch of Environment Canada's Ontario Region is responsible for conducting the Great Lakes Surveillance Program. Since 1967, open-lake cruises have been conducted on the Great Lakes to assess transboundary pollution, and to fulfil Canada's obligations under the Canada–U.S. Great Lakes Water Quality Agreement. The surveillance program now focuses on one lake each year (except Michigan), conducting multiple water sampling cruises for organics, nutrients, and physical parameters. The program's objectives are to ensure compliance with water-quality objectives, evaluate trends, identify emerging issues, and support the development of LAMPs.

Although the surveillance program is an *offshore* monitoring program, some of the stations routinely sampled fall within the SOLEC definition of "nearshore" (i.e., less than 10 m in Lake Superior, less than 30 m in all other Great Lakes). None of the Great Lakes Surveillance stations on Lake Superior meet the criteria. Conversely, almost all the Surveillance stations on Lake Erie are within the 90 percent of the lake classified as "nearshore" according to the criteria used in Table 1. For Lakes Huron and Ontario, only the stations closest to the shoreline are within the 30-m contour.

Using the most recent surveillance data (1991 for Lake Superior; 1994 for Lake Huron; 1995 for Lake Erie; 1993 for Lake Ontario), surface distribution maps of spring total phosphorus (Figure 7), spring soluble reactive phosphorus (Figure 8), spring filtered nitrate-plus-nitrite (Figure 9), and summer chlorophyll *a* (Figure 10) were constructed to illustrate nearshore–offshore gradients. Although the stations that fall within the SOLEC definition of "nearshore" are still, in general, 1 km to 2 km from shore, elevated concentrations of phosphorus and nitrate-plus-nitrite, as well as the highest concentrations of chlorophyll *a*, are observed. In Lake Ontario, where the spring phosphorus guideline is 0.010 ppm, exceedances are observed within these “nearshore” stations. Similarly, in Lake Erie, where the total phosphorus guideline is basin-specific (0.015 ppm for the Western basin, 0.010 ppm for the Central and Eastern basins), exceedances are also observed, both at stations that meet the “nearshore” criteria and offshore. Algae and macrophytes require nutrients for growth.

An overabundance of nutrients leads to nuisance algal populations in the water and also leads to algae attaching themselves to rocks and structures. Nutrients stored in sediment stimulate macrophytes, which may cause navigation problems for recreational boaters in shallow-water areas. Figure 10 shows that chlorophyll, the algal indicator in this case, tends to follow the total phosphorus concentrations in the nearshore of the lower lakes. Thus, the nutrient sources are bioavailable. This is consistent with STP sources of nutrients rather than less available nutrient forms in natural soils, which may be in suspension nearshore.

Clearly, the ubiquitous STP outfalls and CSOs still influence nearshore water quality near population centres. Though sewage plants reduce the phosphorus in sewage, they do not eliminate phosphorus. Many STPs operate with effluents in the range of 1000 g P/L, which is 100 times the desired concentration in Lake Ontario. Thus, nearshore–offshore gradients are to be expected. Experiments conducted in 1991 by M.N. Charlton (unpublished data) between Burlington and Toronto are typified by the results shown in Figure 11 (Charlton Nearshore TP Gradient). The nutrients are introduced to the lake at the shore side of the shore boundary layer both by sewage sources and by rivers. Thus, relatively high concentrations can occur locally even though control programs have caused low concentrations generally in the lake.

In the late 1960s, the Ontario Water Resources Commission began monitoring planktonic algae in samples collected weekly from a number of municipal water-supply intakes in the province, including several on the Great Lakes. The program was expanded in 1976, when the (then) Water Resources

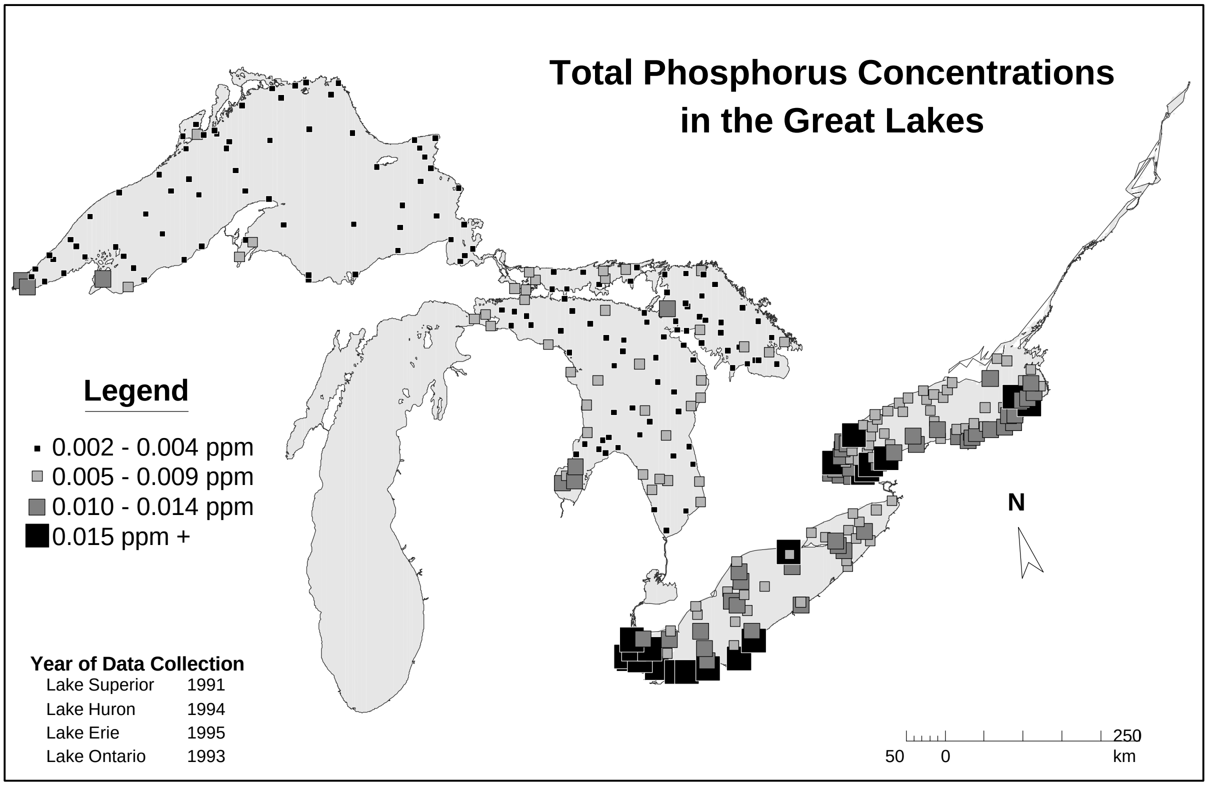


Figure 7 Surface Distribution of Phosphorus Concentrations

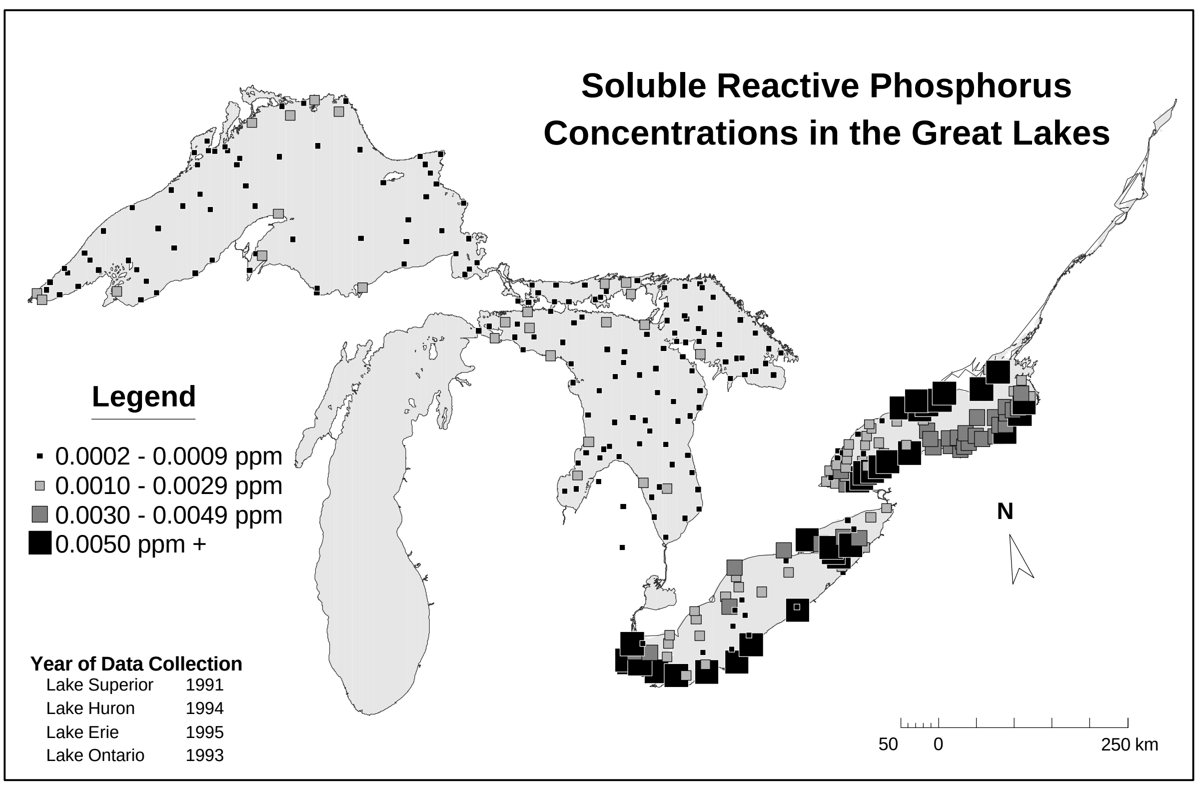


Figure 8 Surface Distribution of Soluble Reactive Phosphorus Concentrations

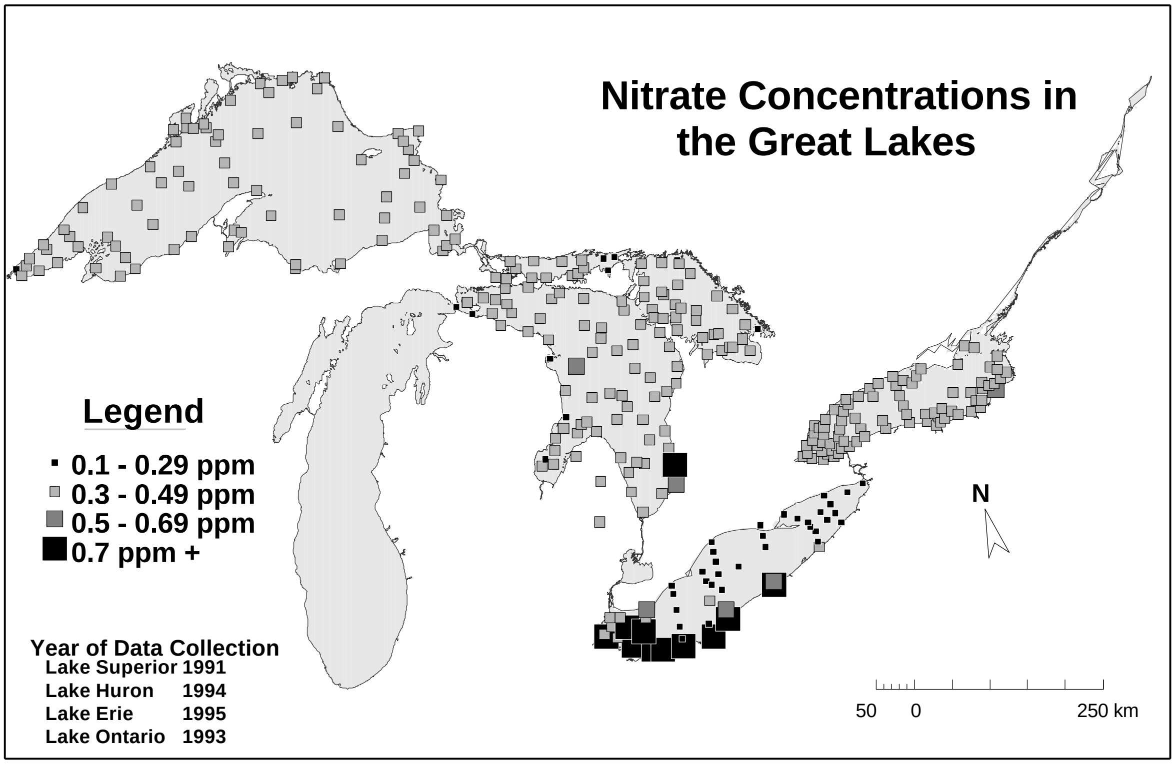


Figure 9 Surface Distribution of Spring Filtered Nitrate-plus-nitrite

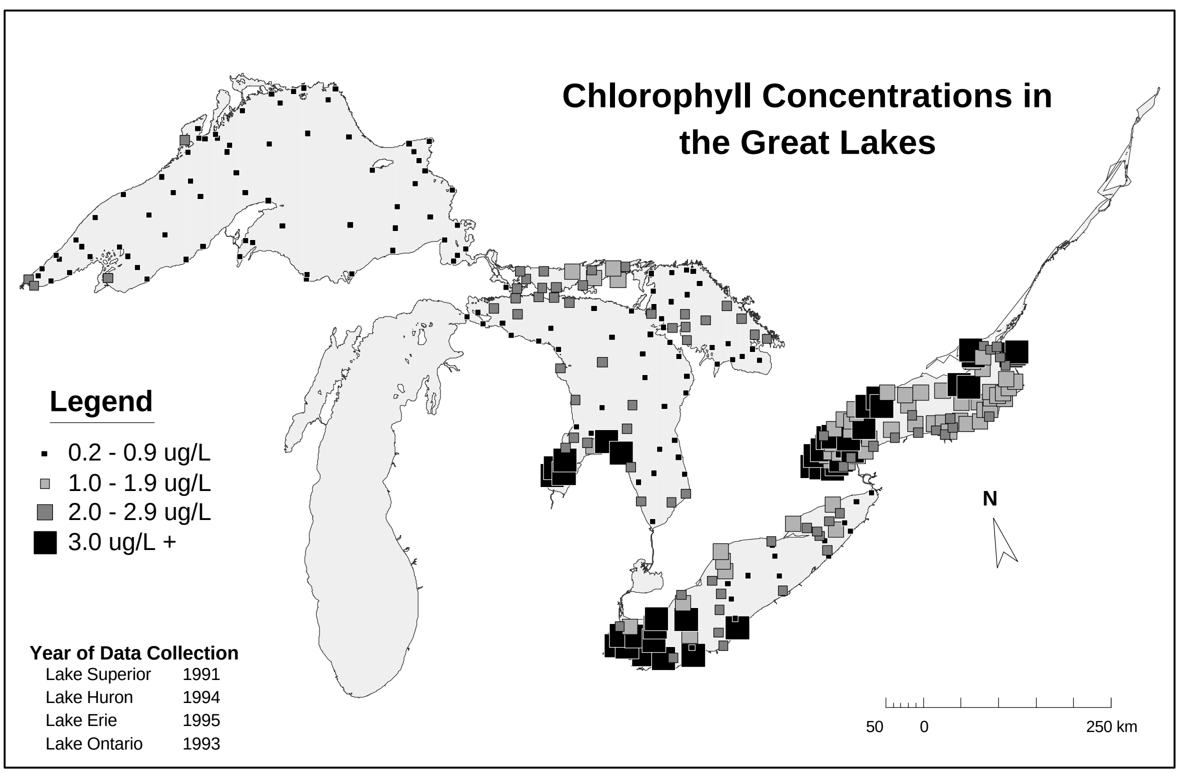


Figure 10 Surface Distribution of Chlorophyll *a* Concentrations

Branch of the Ontario Ministry of the Environment increased the number of Great Lakes sampling locations to 13 and began measuring several trophic state variables, including nitrogen, phosphorus, silica, and chlorophyll. Five additional intake sampling locations were added between 1978 and 1985. Data from this program have been useful for measuring the response of the nearshore Great Lakes to the international phosphorus control program (Nicholls et al. 1980) and are essential for the fulfilment of terms of the Great Lakes Water Quality Agreement (IJC 1988). More recently, the data have proven useful in demonstrating some water-quality effects of the zebra/quagga mussel invasion relative to phosphorus management (Holland 1993; Holland et al. 1995; Johengen et al. 1995; Nicholls 1996; Nicholls and Hopkins 1993; Nicholls and Standke 1996). The following is a brief synopsis of some of the recent Ontario findings.

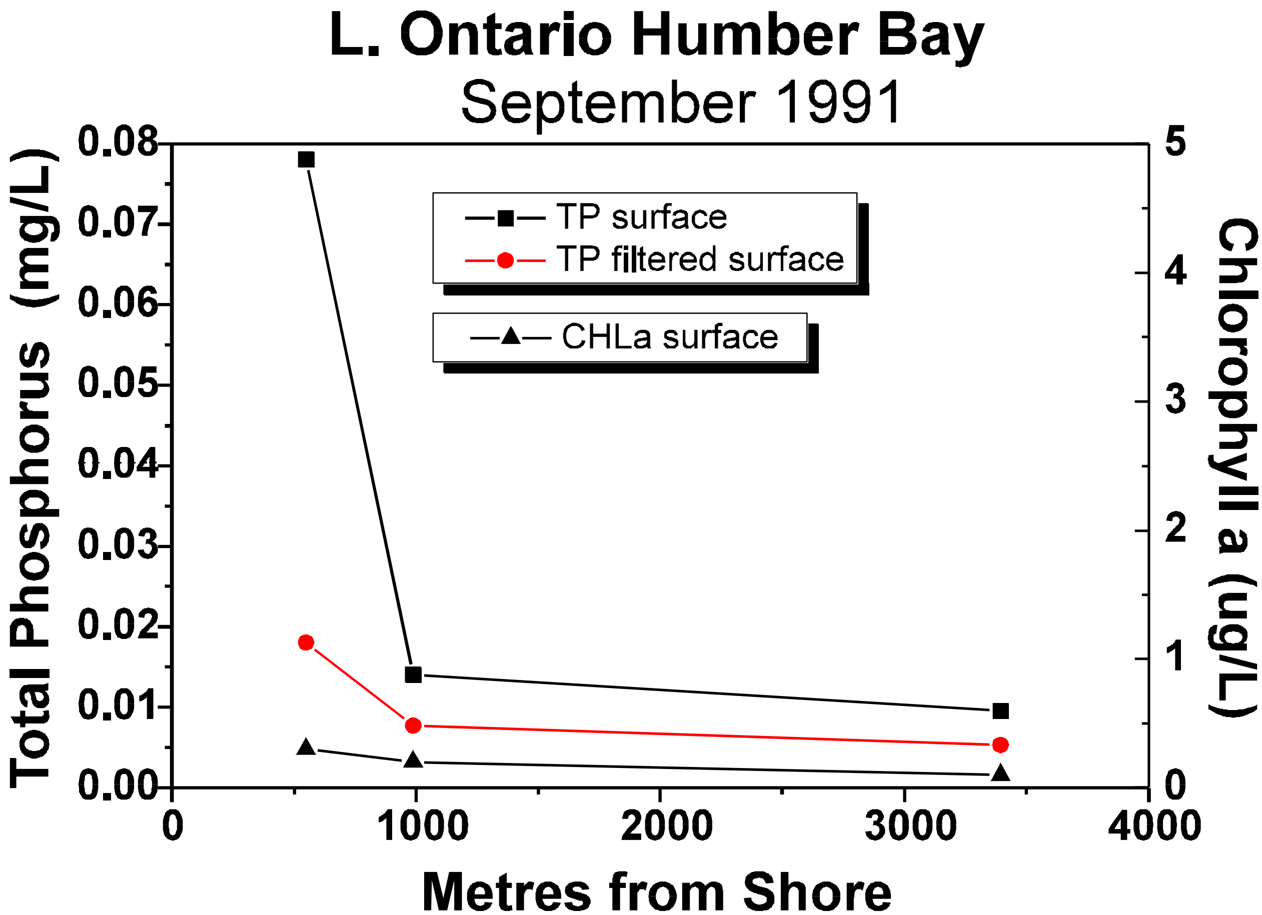


Figure 11 Phosphorus Gradient in Lake Ontario

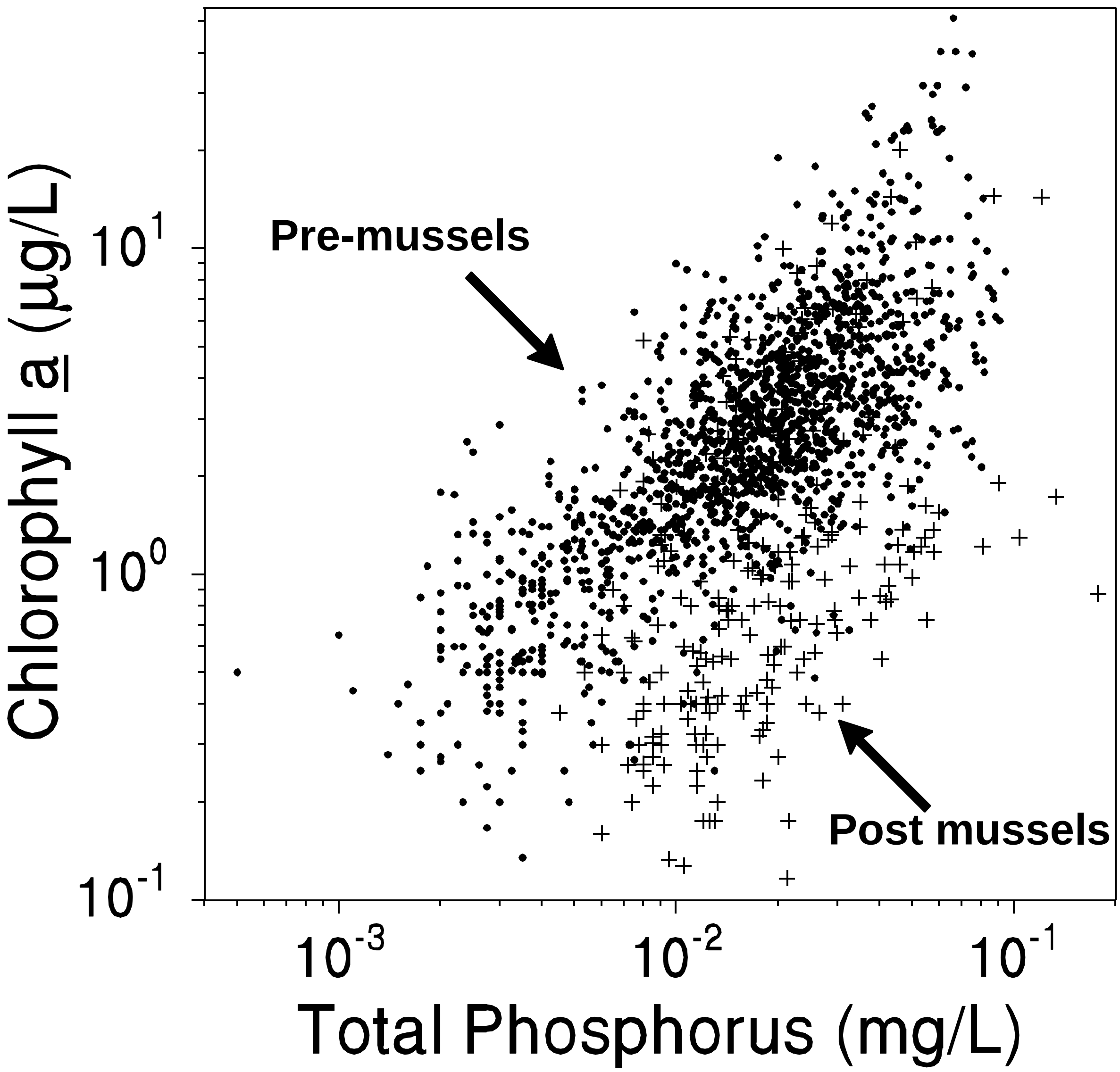


Figure 12 Total Phosphorus (TP) and Chlorophyll *a* Concentrations

Total phosphorus (TP) and chlorophyll concentrations ranged from the lower limits of analytical detection (0.001 mg P/L or 1 g P/L, and 0.2 g chl/L) in many of the Lake Superior samples to maximum concentrations two orders of magnitude higher in the Bay of Quinte. For the May through November periods of all years, the relationship between monthly mean TP and chlorophyll *a* was well defined for the pre–zebra/quagga mussel years (Figure 12). The invading mussels remove chlorophyll at a higher rate than they remove total phosphorus; this removal-rate difference has led to a decrease in the summer chlorophyll-to-TP ratio of more than 60 percent (Nicholls and Standke 1996; Figure 12).

Long-term declines in total phosphorus are evident in all of the Great Lakes, but considerable variability has characterized many of the sampling locations. It is apparent that many years of data are needed to identify trends, which are best defined in western Lake Erie and eastern Lake Ontario (Figure 13). At the Union location in western Lake Erie, TP concentrations rose steadily from 1976 to 1983 and then declined at a rate of about 0.003 mg/L per year through 1994. The rate of decline of TP at the Kingston and Brockville locations was about three times higher, averaging about 0.010 mg/L per year between the middle 1970s and the middle to late 1980s. No further declines have been apparent so far during the 1990s at any of the Lake Ontario locations (Figure 13).

Long-term chlorophyll data from all locations are highly variable; only after 1988–89 in Lake Erie is there a major reduction (Figure 14), which is attributed to the establishment of zebra/quagga mussels. A reduction of between 30 percent and 50 percent at the Grand Bend location in 1993–94 (Figure 14) is consistent with the delayed establishment of mussels in parts of Lake Huron (Johengen et al. 1995). Similarly, large recent reductions in chlorophyll at Kingston and Brockville are consistent with the establishment of invading mussels in eastern Lake Ontario and the Bay of Quinte in 1992–94.

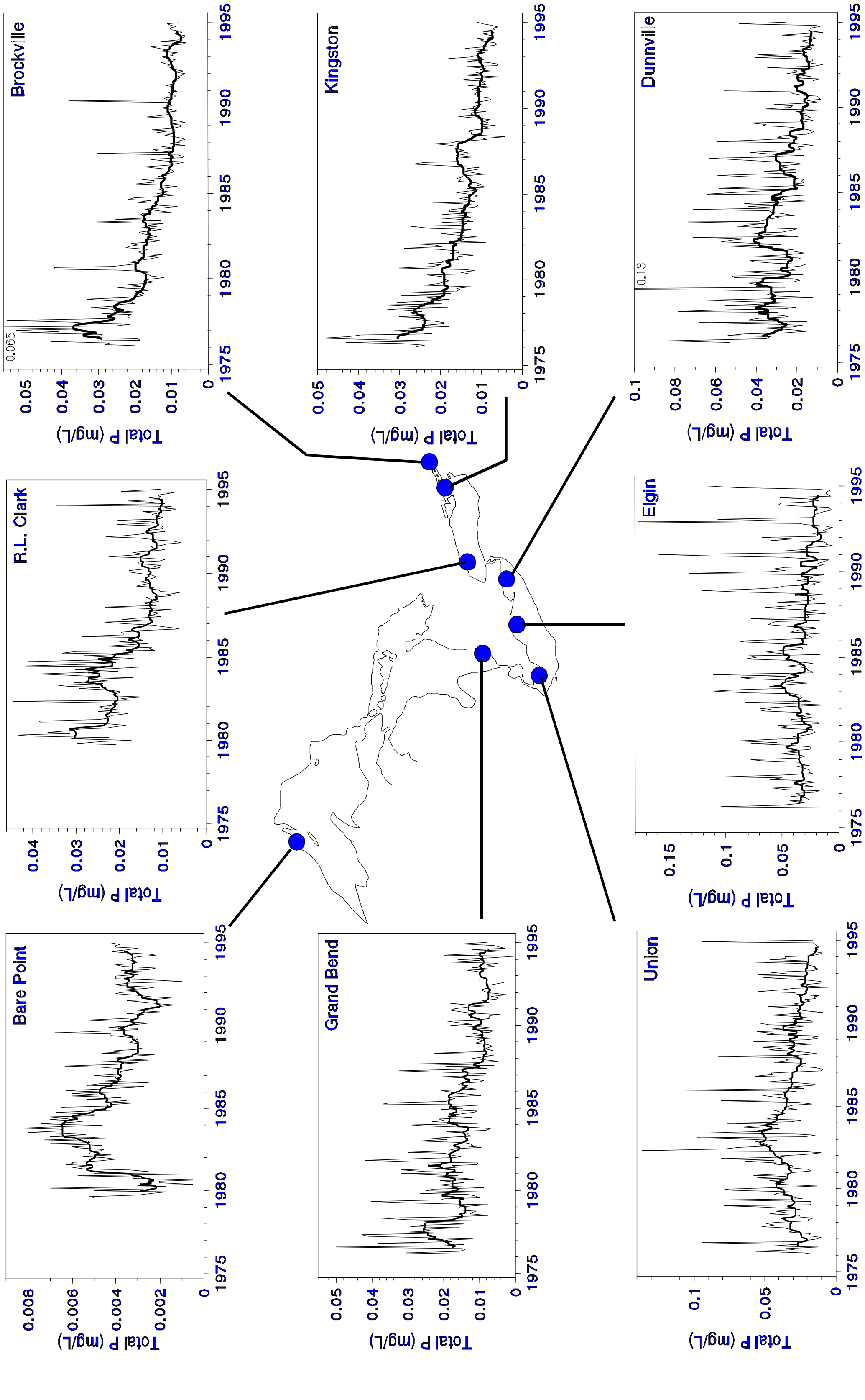


Figure 13 Long Term Trend in Total Phosphorus Concentrations in the Great Lakes

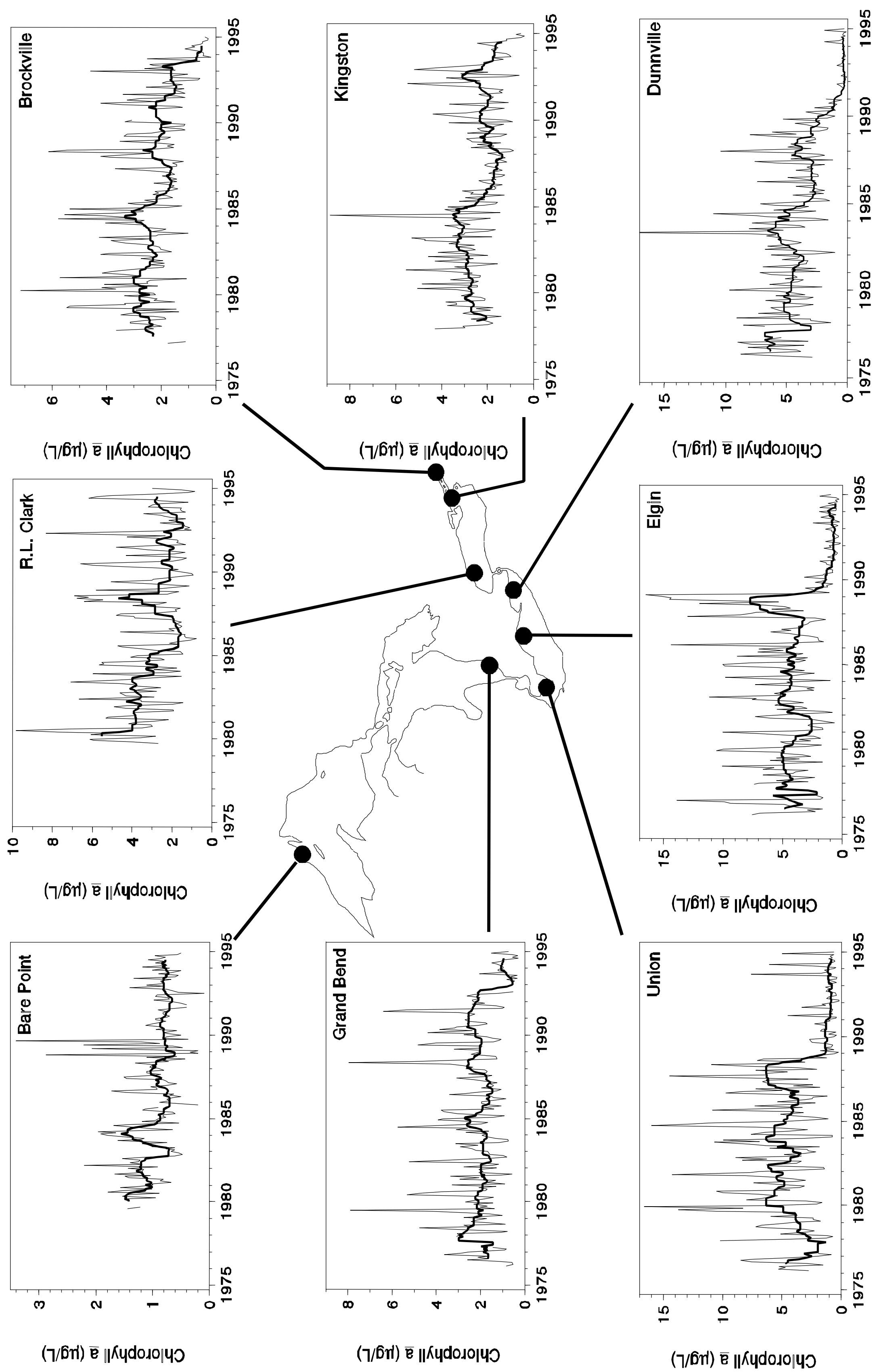


Figure 14 Long Term Trend for Chlorophyll *a* Concentrations in the Great Lakes

In the short term (10 years), the zebra mussel affected Lake Erie planktonic algae dramatically in all three basins of the lake (Figures 15 and 16a). In the western basin, however, a longer-term view of the data (30 years) provides a very different perspective relative to the phosphorus loading control effects. Over a three-decade period, the declines in chlorophyte plankton (including several "weedy" species of the genera *Pediastrum* and *Scenedesmus*) that occurred during the 1970s and 1980s were of much greater importance than the decline experienced in 1988 attributable to zebra mussels (Figure 16b). By the late 1980s (before the mussel invasion), total chlorophyte density was only 6 percent of late 1960s–early 1970s levels, so further reductions brought about by invading mussels were relatively minor. This was not the case in the lake's central and eastern basins, where phosphorus loading controls have apparently been less effective (as evidenced by relatively unimportant declines in algae before the mussels invaded during the 1988–90 period). The decline in western Lake Erie phytoplankton was well under way by the time the chlorophyll sampling started in 1976. As well, the phytoplankton data demonstrate a continuing decline through the 1980s, apparently in response to decreasing phosphorus loads (Figure 16), while chlorophyll levels remained fairly constant at about 5 g/L (Figure 15, Union

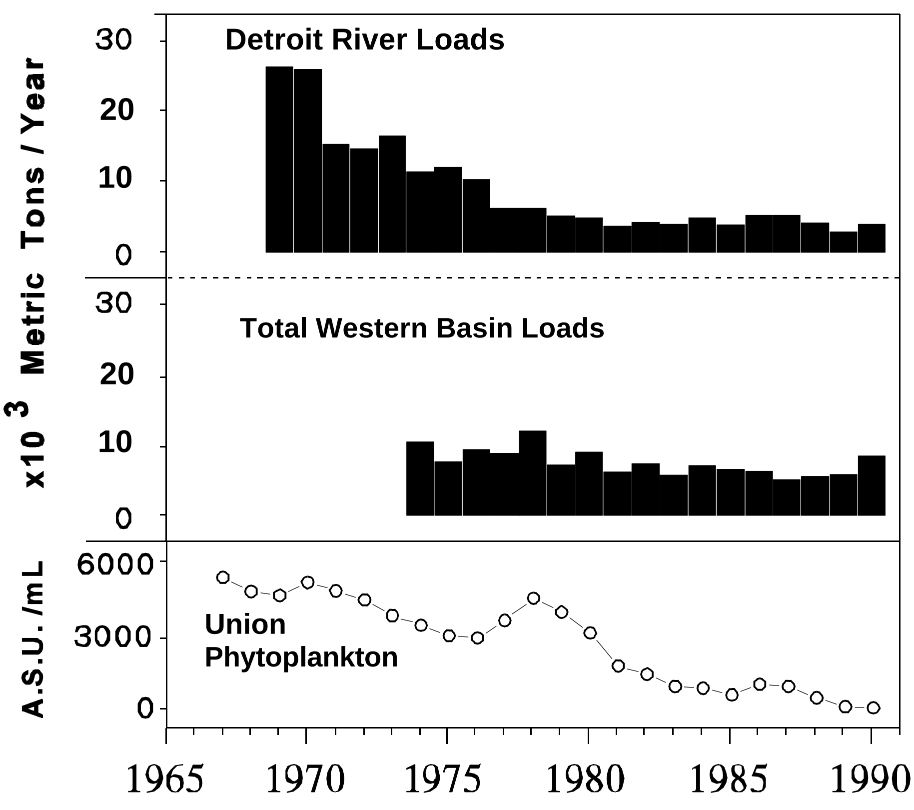


Figure 15 Algal Response to Phosphorus Loading in Western Basin of Lake Erie

data). This apparent discrepancy may relate to the changing chlorophyll contents of algal cells—a change that would result from a shift from N limitation to P limitation brought on by phosphorus loading controls and by rising nitrate concentrations through the 1970s and 1980s (Figure 18). Because cells' chlorophyll contents depend on the availability of inorganic nitrogen as well as on other factors, greater care may be needed in interpreting long-term chlorophyll data than in interpreting data on phytoplankton biovolume and density.

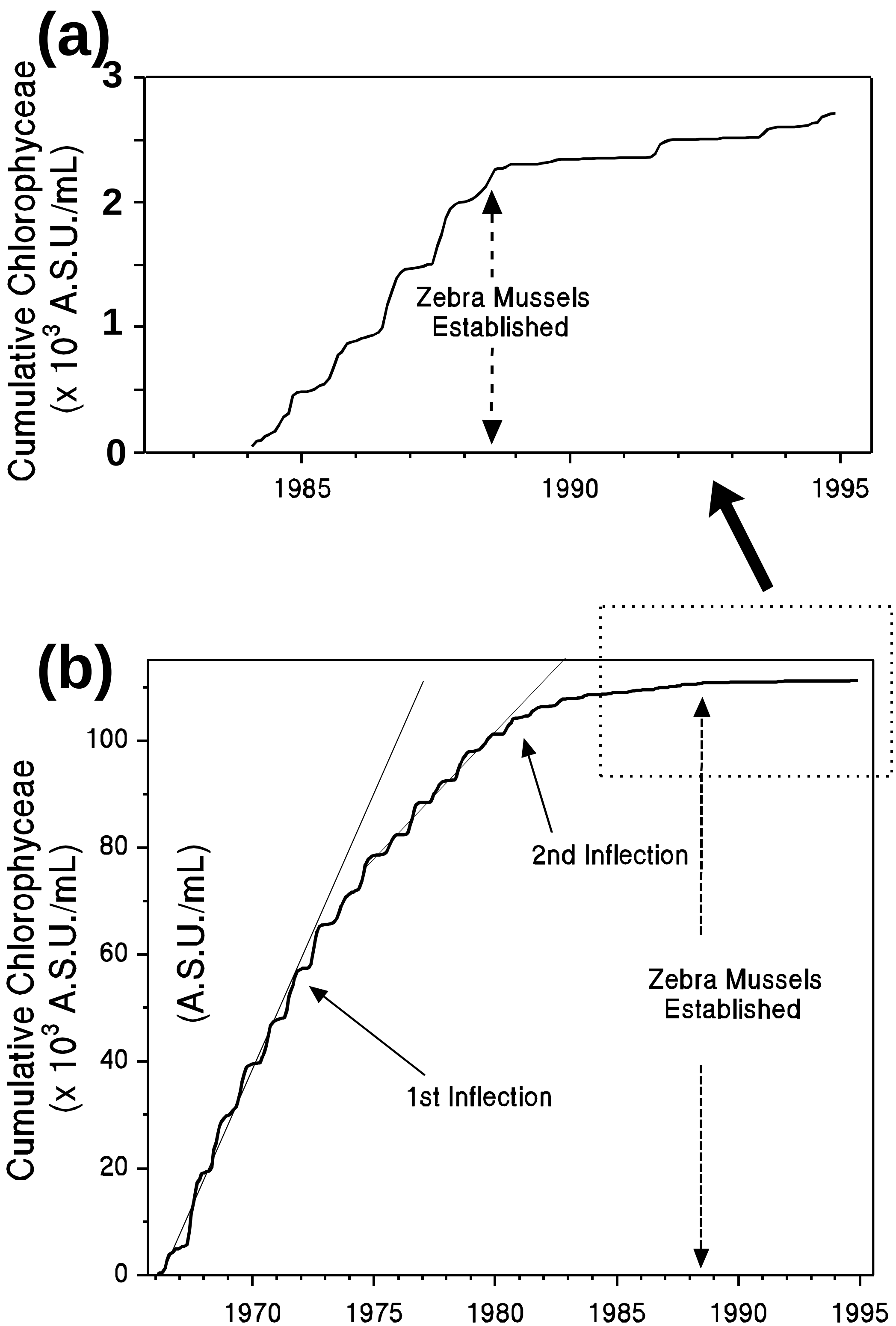


Figure 16 Cumulative Decline of Algal Populations in Western Lake Erie

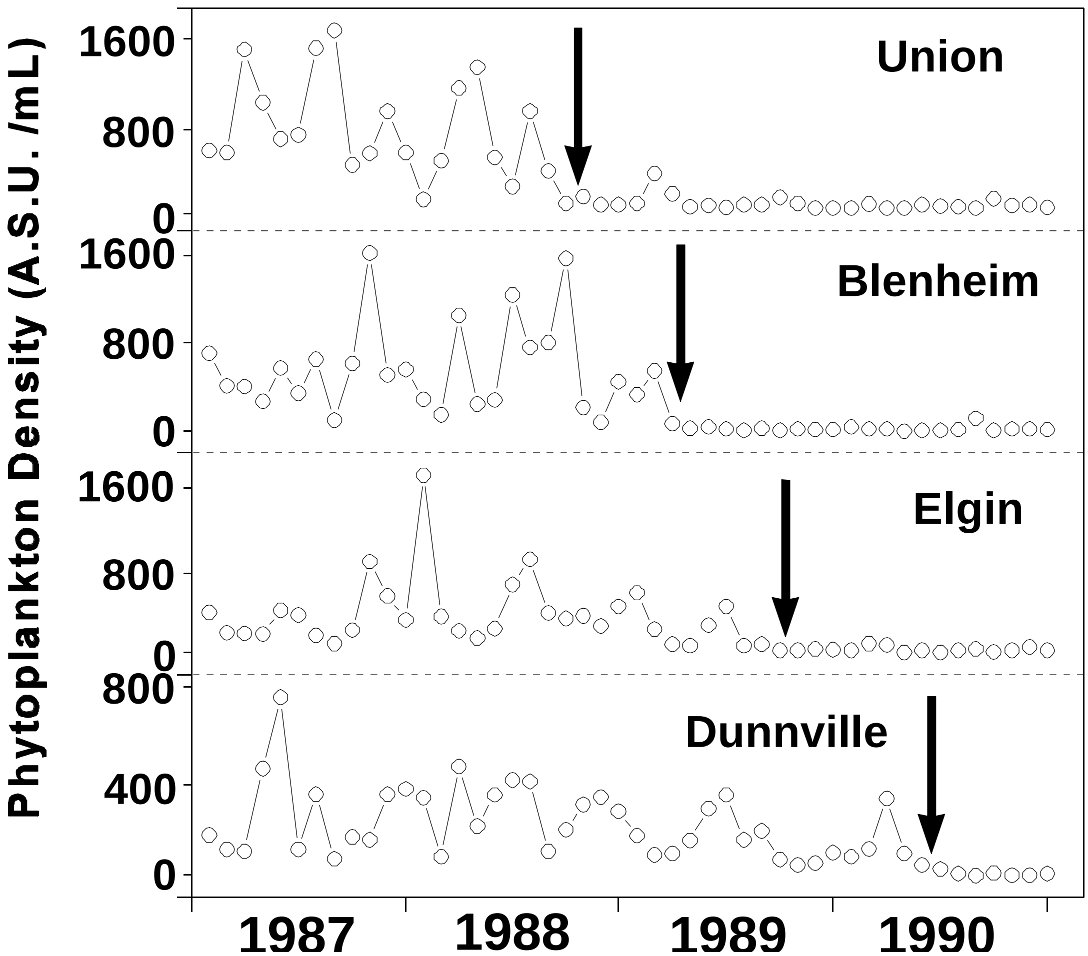


Figure 17 Phytoplankton Density in Lake Erie

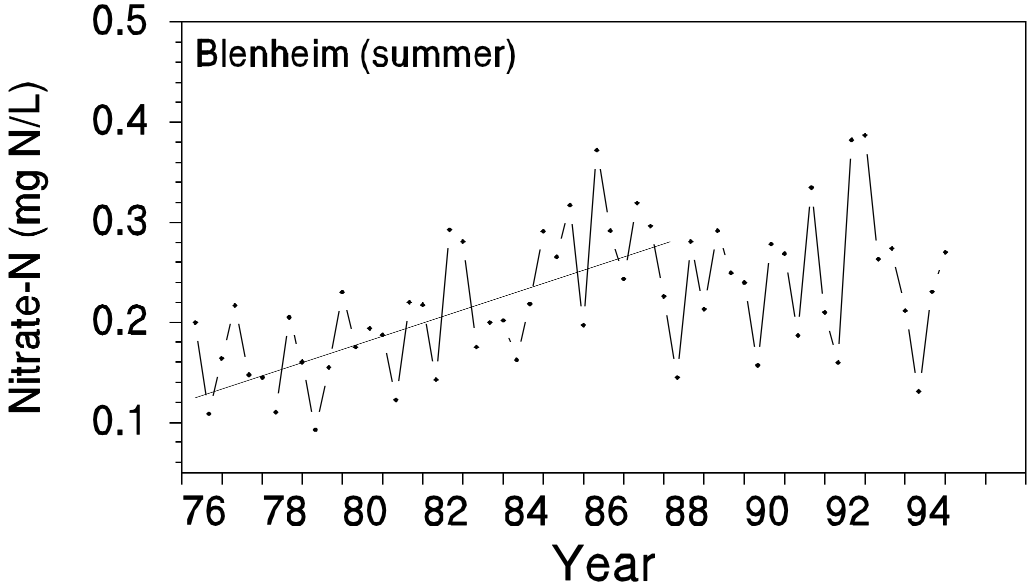


Figure 18 Nitrate Trend in Central Basin of Lake Erie

The Bay of Quinte Remedial Action Plan (RAP) has set an interim phosphorus concentration objective of 0.030 mg P/L for the upper Bay of Quinte. Significant declines in phosphorus concentrations have occurred in the Bay of Quinte since 1977 (Figure 19a), mainly in response to optimized secondary sewage treatment and phosphorus removal at municipal sewage treatment plants discharging to the Bay of Quinte. A few more years of data will likely be required to be certain that concentrations at Station B in the upper bay are (after 1995) consistently below this target concentration. Declines in phytoplankton biomass have generally followed the decreasing phosphorus concentrations (Figure 19b) and have been reflected in improved water quality in the upper bay for drinking-water supply and recreational uses.

Nutrient loads to the lakes have been reduced, not eliminated. The problems caused by nutrients, therefore, may be reduced but are still present. For example, the attached alga *Cladophora* grows on rocky bottom areas in shallow water. Formerly, the growths, when they broke off and drifted to shore, created widespread problems by their unsightliness and unpleasant odour. During July 1995, a survey of Lake Erie's east basin that was conducted by the Ontario Ministry of Environment and Energy found shoreline fouling at four areas. In addition, growth still attached to the bottom was abundant at 16 locations between Fort Erie and Port Dover. The reason for the widespread abundance of *Cladophora* in the shallow littoral zone in July 1995 is unclear. The minimum phosphorus concentrations predicted to sustain growth are relatively low (Jackson and Hamdy 1982). Neilson et al. (1995) predicted that SRP concentrations in Lake Erie's nearshore were sufficient to sustain *Cladophora* growth. Several studies have shown that *Cladophora* growth responds to phosphorus concentration variations in the range of concentrations now found in the lakes. Thus, intermittent loads or even small sources can stimulate this nuisance. Local shoreline or tributary inputs of nutrients to the littoral zone probably contributed to the greater-than-average abundance of *Cladophora* in some areas. But the extent to which local sources of nutrients were a factor in the overall abundance of *Cladophora* is not known. Increased water clarity in the eastern basin may also contribute to the observed abundance of *Cladophora* by reducing the degree of light limitation on growth. A more speculative question is whether *Cladophora* benefits from the presence of dreissenid mussels by scavenging nutrients released from the mussels' waste products (faeces and pseudofaeces).

To identify areas of concern and monitor contaminant trends over time, the Ontario Ministry of Environment and Energy initiated a contaminant surveillance program using juvenile fish as biomonitors in the nearshore waters of the Great Lakes in 1975. This program's findings have been widely reported (Suns et al. 1991).

A variety of organochlorine contaminants and metals are known to bioaccumulate in fish. Contaminants that are often undetectable in ambient water samples may be detected in young-of-the-year forage fish. Because fish integrate spatial and temporal changes in water quality and in contaminant availability, body burdens provide a good basis for assessing environmental change. A common forage fish, the spottail shiner (*Notropis hudsonius*), was selected as the principal biomonitor (Suns and Rees 1978) for assessing temporal trends in contaminant levels in nearshore waters, determining the spatial extent of pollution throughout the Great Lakes, identifying sources of contamination, and assessing the effectiveness of pollution control. Among the criteria used in selecting spottail shiners were its limited range in its first year of life, its undifferentiated food habits in early life stages, its importance as a forage fish (Scott and Crossman 1973), and its presence throughout the Great Lakes. Forage fish also provide an important link in assessing contaminant transfer to higher trophic levels (e.g., fish-eating birds, mammals).

The significance of the contaminant levels in the forage fish is assessed using wildlife protection guidelines. Specifically, the Forage Fish Contaminant Index (FFCI) developed by Suns et al. (1991) assesses risk to piscivorous wildlife for 7 organochlorine compounds. The FFCI is calculated as the sum of individual contaminant concentrations divided by individual wildlife protection guidelines or objectives. The concept of additivity inherent in the FFCI has been used by the USEPA (1989) to establish risk factors for chlorinated dibenzo-p-dioxins and dibenzofurans. Bishop (1989) has shown that the sum of total organochlorine body burdens, rather than specific compounds, was related to biological effects.

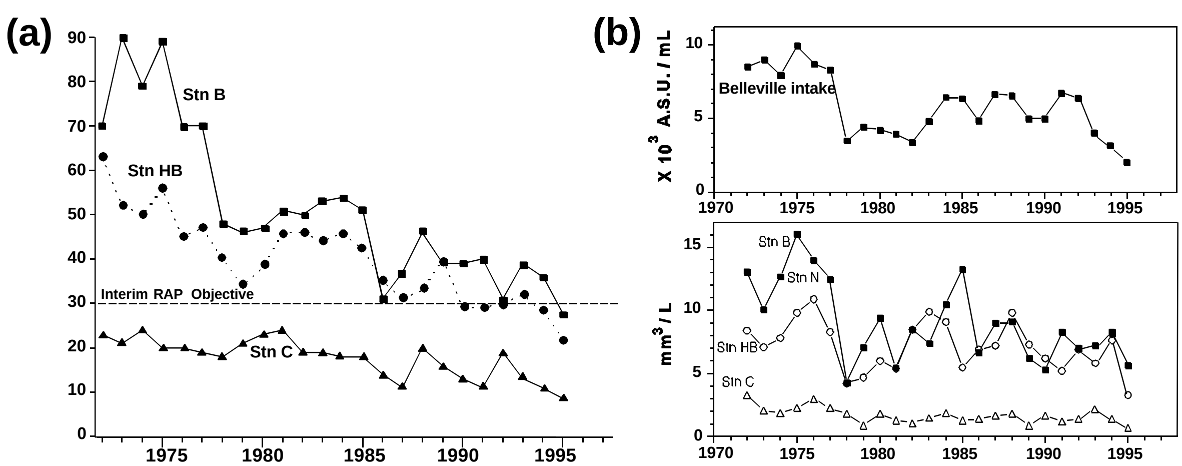


Figure 19 Phosphorus Concentrations in the Bay of Quinte

Guidelines used for calculating the FFCI were the most stringent available and included the IJC Aquatic Life Guideline (GLWQA 1978) and the NYSDEC Fish Flesh Criteria (Newell et al. 1987) for the protection of piscivorous wildlife. Contaminants and guidelines used were polychlorinated biphenyls (PCBs) (100 ng/g), dichlorodiphenyl trichloroethane (DDT) (200 ng/g), hexachlorocyclohexane (BHC) (100 ng/g), hexachlorobenzene (HCB) (330 ng/g), octachlorostyrene (OCS) (20 ng/g), and chlordane (500 ng/g). Because the mirex guideline is below detection limits, a value of 1 ng/g was used in calculations.

7.1.8 Persistant Toxic Contaminants in Water, Sediment, and Biota

7.1.8.1 Status

Spottail shiners were collected at 44 sites throughout the Great Lakes in September 1993 or 1994. Five to seven 10-fish composites were measured for total length (mm), wrapped in hexane rinsed aluminum foil, and frozen at –20 C until analysed for PCBs and organochlorines at the MOEE Laboratory (Ontario Ministry of Environment and Energy 1994a).

Calculated FFCI values, concentrations of total PCBs, and DDT are shown in Figure 20. An index value of 1 is designated as the Wildlife Risk Level. Higher values represent greater risk for piscivorous wildlife. Higher index values were generally more frequent in the lower Great Lakes, with the maximum observed values noted at the Grass R and Reynolds Aluminum sites in the St. Lawrence River and at the Welland Canal.

PCB contributions to the index were generally high at most of the sampled sites. PCB residues were present in spottail shiners at 31 of the 44 sites sampled in 1993 or 1994 (70 percent), exceeding the IJC Aquatic Life Guideline of 100 ng/g at 13 sites (30 percent) (Figure 22). PCBs generally accounted for the largest component of the FFCI at most locations, with the exception of octachlorostyrene in the St. Clair River at Lambton Generating Station (15 ± 2 ng/g) and in Lake St. Clair (less than 5 ng/g), where a localized source contributed to the index. PCBs at Lambton Generating Station were below detection limits in 1994, a significant decrease from 1992 and 1993 (when the levels ranged from 131 ng/g to 168 ng/g). Unusually high localized PCB residues in forage fish on the U.S. side of the St. Lawrence River—in the Grass River and at Reynolds Aluminum—remain above 2500 ng/g. PCB residues in the Welland River just west of the Chippawa Power Canal (220 ± 39 ng/g) reflect upstream impacts. PCBs remain elevated on the U.S. side of the Niagara River downstream of the 102nd Street waste site (158 ± 20 ng/g). It is not known whether the continued declines at the Search and Rescue Station (244 ± 53 ng/g) are related to remedial measures (sediment removal) at Gill Creek in 1992. While PCB bioavailability at several sites in the Humber River watershed continue to fluctuate above the IJC guideline, concentrations remain elevated at the mouth of the river (174 ± 17 ng/g).

Total DDT concentrations in young-of-the-year spottail shiners were well below established guidelines (200 ng/g) at all sites.

BHC (Hexachlorocyclohexane) was elevated to 1985 levels at Cayuga Creek in 1994 (33 ± 11 ng/g). Four other occurrences in the Niagara River and Lake Ontario were less than 6 ng/g.

Chlordane was present at four sites—one at Fort Erie and three in Lake Ontario. Concentrations in spottail shiners did not exceed 12 ng/g.

HCB (hexachlorobenzene) residues have declined since the middle 1980s at Lambton Generating Station (the 1985 levels were 60 ± 13 ng/g; those in 1994 were 3 ± 1 ng/g). HCB did not exceed 1 ng/g in Lake St. Clair or the Detroit River in 1993 or 1994.

OCS (octachlorostyrene) was generally confined to the St. Clair River, Lake St. Clair, and the Detroit River. Levels have declined since the middle 1980s at Lambton Generating Station (having once been as high as 104 ng/g), but still persist in 1994 (15 ± 2 ng/g). OCS residues in juvenile fish declined downstream (less than 5 ng/g) to the mouth of the Detroit River (where none were detected).

Chemical industry activities in Sarnia were identified in the mid 1980's as the source of HCB and OCS releases (DOE/MOE 1986). Process changes and abatement measures instituted by the major contributor had actually been started in the 1970's. These changes significantly reduced releases. In 1994, the processes responsible for the production of most of these byproduct chemicals were permenently shut down. As a result, the releases from this source ended.

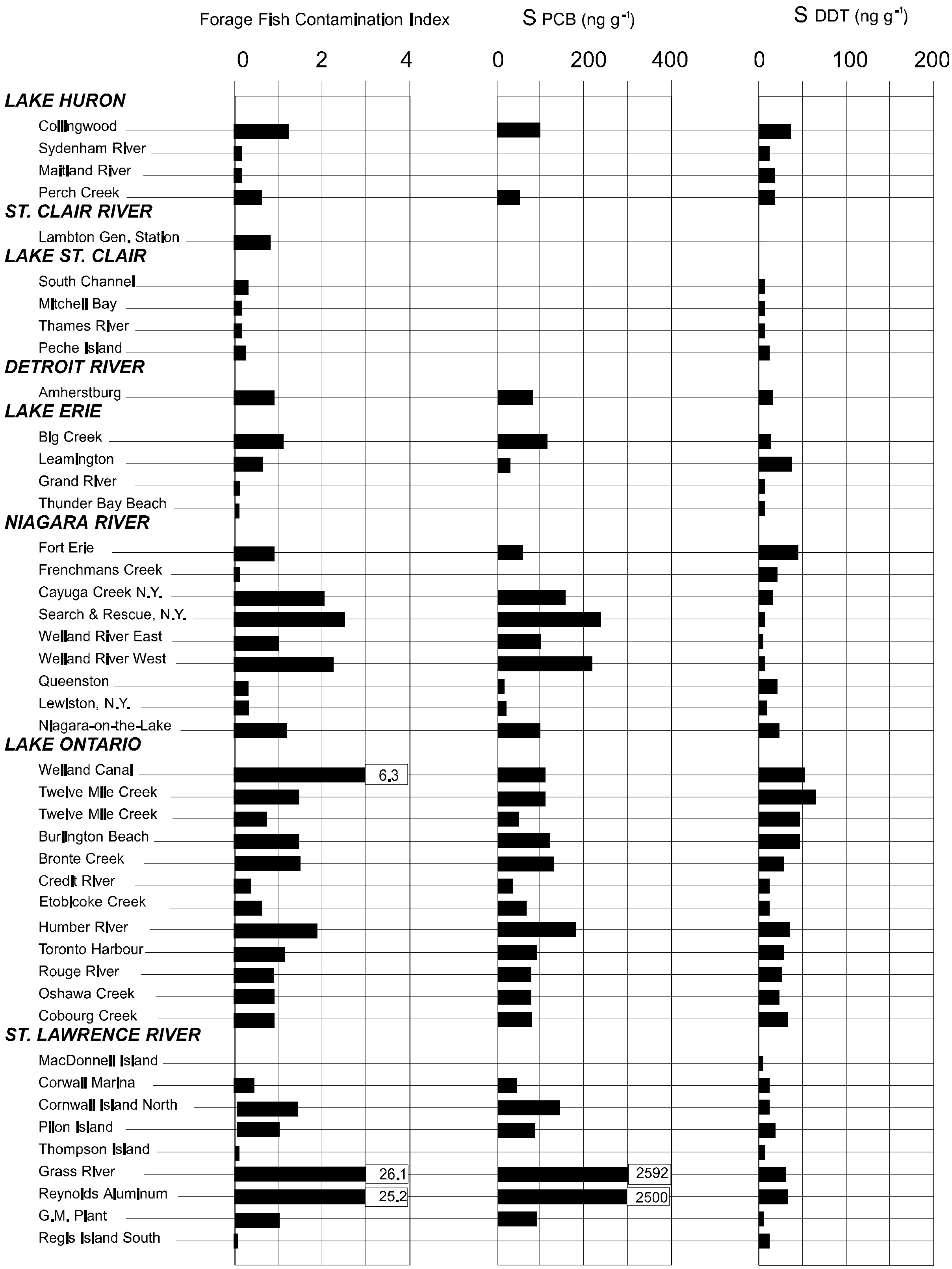


Figure 20 Forage Fish Contamination Index (FFCI) for young-of-the-year spottail shiners in the Great Lakes in 1993 or 1994, with relative contributions from PCBs and DDT.
Wildlife Risk Level =1.

Elevated concentrations of trichlorobenzene (89 ± 49 ng/g), tetrachlorobenzene (681 ± 338 ng/g), pentachlorobenzene (232 ± 95 ng/g), hexachlorobenzene (34 ± 6 ng/g), and BHC (51 ± 28 ng/g) were found in sand shiners just downstream of 102nd Street in the Niagara River. Although sand shiners may not be directly comparable to spottail shiners (for which comparable data are unavailable), these results indicate that leachate from several chemical disposal sites in the area, and contaminated river sediments near 102nd Street, may still be influencing contaminant levels in juvenile fish downstream.

Mirex was present only at the mouth of the Welland Canal (5 ± 3 ng/g).

Raw, log-transformed, and lipid-normalized contaminant values were used for temporal trend analysis. Since results were similar, only raw wet-weight–based values are shown graphically.

Temporal trends of PCBs are illustrated in Figure 21. Values are means with ± 95 percent confidence limits. Lines indicate significant correlations with time ($p < 0.05$). Total PCB concentrations in spottail shiners were negatively correlated with time at 12 of the 16 long-term sampling sites. Trend data indicate that PCB availability in the nearshore waters of the Great Lakes continues to decrease at most sites where contaminant inputs are low. Further containment of watershed inputs and point-sources of PCBs are required to reduce contaminant levels to acceptable levels at all sites.

7.2 Fish and Wildlife

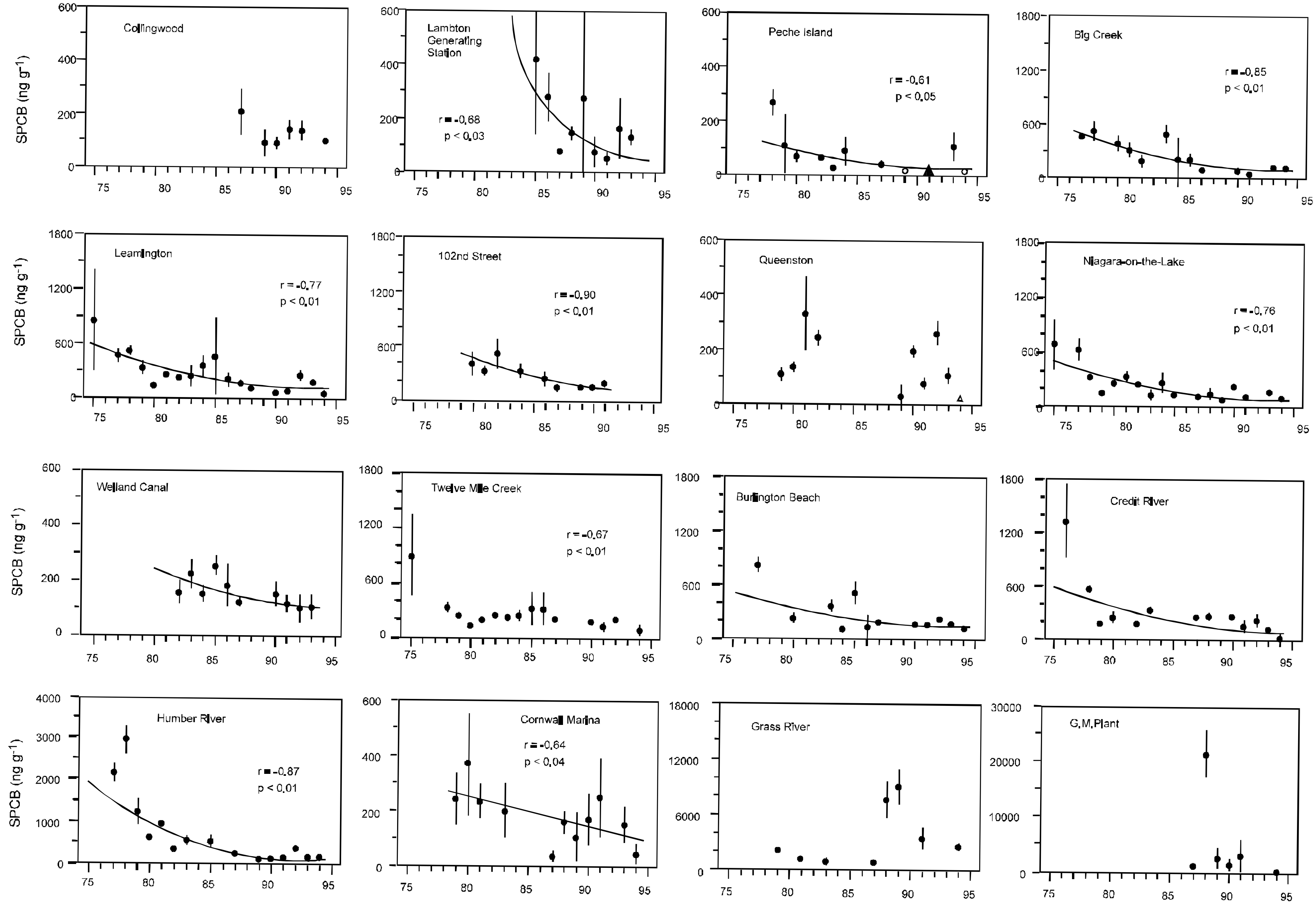
7.2.1 Zooplankton

Zooplankton are the secondary producers of the aquatic food chain. They filter and eat the algae; their growth provides energy and nutrients in a form usable by fish. Populations of zooplankton cycle up and down seasonally in response to temperature and food availability as well as to predation by fish. The degree of predation can be related to fish stocking: predatory fish consume the smaller fish, which feed on zooplankton. Some introduced fish species, such as alewives, are subject to population variations due to temperature fluctuations; these variations may be reflected in zooplankton numbers. Zooplankton studies are difficult, because sampling must be frequent and identification and taxonomy are tedious and demanding specialties.

Studies in Lake Erie since the late 1920s have shown that zooplankton increase with eutrophication and then decline as nutrient pollution is controlled. Most studies have been conducted in the west basin. Two additional exotic species were noticed in the 1960s. In the 1980s, the spiny water flea *Bythotrephes* appeared; this is cause for concern.

Bythotrephes is more abundant in the offshore than in the nearshore, probably due to temperature preference or perhaps predation by alewife and gizzard shad. When alewife abundances are particularly low in Lake Ontario—as has been true in 1987, 1994, and 1995 (O. Johannsson, Department of Fisheries and Oceans Canada, personal communication)—*Bythotrephes* is able to increase its numbers. *Bythotrephes* eats other zooplankton and therefore competes directly against young-of-the-year fish. Preliminary studies indicate that between 10 percent and 40 percent of zooplankton production can be consumed by *Bythotrephes*. *Bythotrephes* is not a preferred prey for many fish. Thus, this new addition to

Figure 21 Temporal trends of total PCB concentrations of young-of-the-year spottail shiners in the Great Lakes from 1975 to 1994. Values are +/-95% confidence limits. Lines indicate significant correlations with time. (= not detected, = trace).



the fauna is at best an extra trophic level between algae and fish; this means more inefficiency on energy transfer. At worst, *Bythotrephes* is an energy sink from the standpoint of fish production.

Zebra mussels seem to have affected zooplankton. The mussels, which spend most of their life attached to the lake bottom, divert energy to the benthic system and away from the plankton system that many fish have depended on. The mussels' immature planktonic stages can at times be as abundant as native zooplankton once were. Zooplankton abundance has decreased in Lake Erie's east basin, where there is the most extensive shallow-water substrate for zebra mussels. Changes in the biomass of zooplankton in the lake's west and central basins are less clear.

To some extent, the challenges to the zooplankton community seen in the lower lakes are present in all the lakes. In the last 13 years, the introduced species have changed the trophic relations in the lakes. Expectations of fish yield based on previous trophic structure may therefore not be realized.

7.2.2 Benthic Invertebrates

The benthic habitats in Great Lakes nearshore waters are complex and diverse. These habitats include bays, harbours, shallow basins, connecting channels, tributary mouths, and coastal wetlands. Benthic invertebrate communities in these habitats are often highly variable, diverse, and patchy by nature. Yet for similar substrates and water depths, assemblages can also be remarkably consistent between habitats, making recognizable patterns in community structure. Thus, if the historical changes in benthic community structure relative to anthropogenic stresses and if the tolerances of individual species to those stresses are known, an assessment of the present status of the nearshore benthic community can provide a consistent, precise indicator of environmental quality in the nearshore region.

Extensive surveys and subsequent assessments of benthic invertebrate communities within the nearshore zone of the Great Lakes have been rather limited over the past several decades. Most recent surveys that have compared past and present communities, however, have shown that dramatic changes in community structure have occurred over broad areas in the nearshore zone. These changes have been attributed to changes in water quality and in sediment quality resulting from nutrient and other pollution abatement programs, and to ecological changes induced by the zebra mussel.

Studies of benthic communities in Lake Erie, the Bay of Quinte, and the Detroit and St. Clair Rivers conducted in the early 1980s (before the establishment of the zebra mussel) found changes in community structure consistent with improved water quality when compared to communities in the 1960s. One index often used to assess the relative health of the benthic community is the abundance and composition of oligochaete worms. Oligochaete abundances vary directly with the degree of organic enrichment. In areas of western Lake Erie nearest major river mouths, and in the Bay of Quinte, a significant decline in oligochaete numbers suggests that a decline in organic enrichment occurred over the period (Johnson and McNeil 1986; Schloesser et al. 1995). Also, declines in numbers were accompanied by shifts in species composition: species that tolerate polluted conditions gave way to species that are more pollution-sensitive. In areas farther offshore in the western basin, however, changes in community structure were not as readily discerned, indicating perhaps that the community was in the state of transition in the early 1980s. Another recent study in the nearshore waters of Lake Erie similarly indicated improved conditions (Kreiger and Ross 1993). Near Cleveland Harbor, there was an increase in number of taxa, a reduction in the proportion of oligochaetes, and widespread distribution of pollution-sensitive forms not observed the 1970s. In the Detroit and St. Clair Rivers, pollution-sensitive species other than oligochaetes (e.g., mayflies and caddisflies) increased over a two-decade period, with most of the changes occurring along the Canadian shoreline (Davis et al. 1991; Thornley 1985).

The increase in abundance and distribution of the burrowing mayfly provides dramatic evidence of improved conditions in Lake Erie western basin. This organism was historically abundant in the western basin, but a gradual increase in productivity of the basin over time, along with a period of calm weather in the middle 1950s, resulted in a severe decline in oxygen concentrations that virtually eliminated the population. A small increase in the population was noted near the mouth of the Detroit River in 1980 (Thornley 1985), but it was not until 1991 that the population increased to any extent. By 1995, burrowing mayflies were found throughout the western half of the basin and in much of the eastern half (Kreiger et al. 1996). Not all studies that examined changes in the benthic community between the 1960s and 1980s indicated improved conditions in the nearshore zone. In the southern end of Lake Michigan, oligochaete abundances actually increased twofold over the period (Nalepa 1987). However, the increase in abundance was not accompanied by the usual shift from pollution-sensitive species to pollution-tolerant ones, indicating perhaps that only mild enrichment occurred. Also, studies have shown that a severely degraded community is evident in many local harbours and bays, including the U.S. side of the Detroit River (Day et al. 1995; Rosiu et al. 1989). Other studies of the burrowing mayfly in the upper Great Lakes connecting channels (the St. Marys, St. Clair, and Detroit Rivers and Lake St. Clair) in 1985–86 revealed areas of exceptionally high abundance and production in clean habitats and other areas of low production where burrowing mayfly populations had apparently been stressed or extirpated by contamination of the lake-bed and river-bed sediments with oil, grease, and heavy metals (Edsall et al. 1991; Schloesser et al. 1991). In other areas, historical records of the benthic community exist, but recent information is not available with which to assess community status. Important areas that need to be reassessed are Green Bay, the St. Marys River, and Lake Ontario’s southern shoreline, particularly near the Niagara River mouth.

MOEE sampled Lake Ontario to compare benthos populations between 1981 and 1991. In 1981, benthic invertebrates were collected from 25 areas along Lake Ontario’s north shore. The collections were used to make biologically based inferences about environmental conditions and to examine the relationships between natural environmental factors and the composition of benthic invertebrate communities. Benthic communities described at the time suggested that areas near the mouths of the Niagara and Humber Rivers, along with areas at the lake's far eastern part (near Prince Edward Point), were eutrophic (Barton 1986). In the lake's central and northeastern parts (from eastern Scarborough to Ostrander Point), the results suggested that the effects of exposure and upwelling caused low standing stocks of chironomids and other insects. The majority of stations were located in areas away from major point-sources of pollutants and outside of locations known to be heavily affected by anthropogenic activity. The stations, on the whole, represented background conditions along the nearshore of Lake Ontario's Canadian shoreline.

Since the early 1980s, there have been improvements in a variety of aspects of Lake Ontario's water quality (e.g., De Vault et al. 1994; Neilson et al. 1995). In 1991, parts of the 1981 survey of benthic invertebrates were duplicated to determine whether changes in benthic invertebrate communities suggested improvement in water quality over the 10-year period. The 1981 survey included sampling at multiple depths (2 m, 5 m, 10 m, and 20 m) over the prevailing types of lake bottom. The 1981 data suggested that most of the substrate and depth-related variation in composition could be represented by results from the 5-m and 20-m depths alone. The original 5-m and 20-m stations were revisited in the late summer of 1991.

The differences in the composition of benthic invertebrates observed between 1981 and 1991 suggested that changes in water quality had occurred. Changes were more obvious from the 5-m communities than from the 20-m communities. At 5 m, changes suggestive of improvements in water quality were generally widespread and demonstrated by increases in taxonomic richness and by increased numbers of insects (Ephemeroptera, Chironomidae) and gastropods. At 20 m, communities along the lake's north shore exhibited changes that also suggested improvements in water quality, with increased numbers of lumbriculid worms, gastropods, and sphaeriid clams. Along the Niagara–Hamilton corridor, a reduction in the numbers of chironomids at 20 m was observed. There was no obvious explanation for the change. Because of subtle differences in the methods and timing of surveys between 1981 and 1991, however, interpreting the results is subject to a degree of uncertainty.

Of those habitat factors studied, depth had the most obvious effects on community structure. In general, 5-m communities were characterized by epibenthic fauna such as gastropods and insects (chironomids, Ephemeroptera, Trichoptera). In contrast, 20-m communities were characterized by infaunal groups such as sphaeriid clams and oligochaete worms. During 1981, the 5-m community was more similar to the 20-m community because of a higher proportion of worms, which was attributed to the more nutrient-enriched conditions at that time. In 1991, after improvements in water quality, gastropods and insects were more abundant at 5 m.

As of 1991, the presence of zebra mussels at 5 m between Niagara and Hamilton did not appear to cause changes in community composition at the level of major taxonomic groups. But there was some suggestion that the abundance of several gastropod species was related to the presence of zebra mussels. Density of zebra mussels in Lake Ontario's western end during 1991 varied from 611 per m^2 at Bronte to more than 24,000 per m^2 at Niagara-on-the-Lake. Based on knowledge of growth rates, samples indicated that zebra mussels entered and settled along the shoreline between Stoney Creek and Oakville in the fall of 1990, and between Niagara-on-the-Lake and Beamsville during the spring of 1991. Quagga mussels (*Dreissena bugensis*) were found between Niagara-on-the-Lake and Beamsville, and at Oakville. The presence of large mussels at Beamsville suggested that settlement occurred sometime in 1990.

In the late 1980s and early 1990s, the zebra mussel became widespread and abundant in almost all nearshore regions in the Great Lakes except those in Lake Superior, particularly in areas with hard substrates. Because of their filter-feeding activities and because they occur in dense clumps, zebra mussels have generally benefited most benthic taxa. Material filtered from the water and biodeposited on the bottom as waste is used as food by many other benthic forms. Zebra mussel clumps also increase substrate complexity and structure. In nearshore regions with hard substrates in both Lakes Erie and Ontario, the abundance of all benthic taxa increased, and more taxa were collected after zebra mussels became established (Dermott et al. 1993; Stewart and Haynes 1994). In Lake St. Clair, the benthic community in the portion of the lake with an established zebra mussel population changed to a community more indicative of improved water quality; that is, pollution-sensitive forms became more abundant after the zebra mussel became established (Griffiths 1993). The implications of these zebra mussel–induced changes in the nearshore zone are clear: we can no longer assume that changes in the abundance and diversity of the benthic invertebrate community are directly related to human-induced changes in water quality. This is true not only for areas with high zebra mussel abundances, but also for areas without high abundances that are located in well-mixed, partially confined regions in close proximity to zebra mussel–infested areas. For example, in Saginaw Bay, zebra mussels are abundant on hard substrates but not on soft substrates. Yet the number of oligochaetes in soft-substrate areas have declined dramatically since the zebra mussel became established (T. Nalepa, NOAA, Michigan, personal communication). Although the zebra mussel has had a mostly positive impact on benthic community diversity in the nearshore zone, one native taxonomic group, the *Unionidae* (large freshwater clams), has declined substantially and has been virtually extirpated from large regions. The Lake St. Clair–western Lake Erie corridor once had the richest and most diverse assemblages of unionids in North America (Goodrich and van der Schalie 1932). The relatively shallow depth and high flushing rate (river–lake habitat) in this region provided conditions that were highly favourable to unionid populations. Within 6 years after the discovery of the zebra mussel in this region, unionid populations in the region declined to almost zero (Nalepa 1994; Schloesser and Nalepa 1994). The population in western Lake Erie had been steadily declining before the zebra mussel became established, but the population in Lake St. Clair had remained virtually unchanged since the turn of the century. While the unionid population declined, the zebra mussel population continued to expand. Biodiversity has declined sharply as the functional community has basically shifted from a stable, slow-growing, multispecies unionid community with minor influence on the ecosystem to a single-taxon population of zebra mussels with a relatively high turnover rate that strongly affects ecosystem dynamics.

There is considerable variability in the status of zebra mussel populations in the Great Lakes, and predicting the future of zebra mussel populations is difficult. In some areas, particularly eastern Lake Erie, zebra mussel populations have declined dramatically in recent years, perhaps due to a reduced food supply (S.J. Nichols, NBS–Great Lakes Science Center, personal communication). In other areas where food supplies have not been depleted, populations either have remained stable or are increasing. Areas with stable or increasing populations of zebra mussels include those near river mouths in Thunder Bay on Lake Huron (D. Reid, GLERL, NOAA, unpublished data), and near the mouth of the Raisin River in western Lake Erie (W. Kovalak, Detroit Edison Company, unpublished data). The discovery in Lake Erie of the quagga mussel, a second species closely related to and resembling the zebra mussel, further complicates monitoring and predicting this exotic group's future status of in the Great Lakes.

In summary, benthic community structure has generally improved over broad areas in the nearshore zone within the past few decades. Diversity has increased, and forms considered to be pollution-sensitive have become more dominant. Degraded communities are still evident, however, in many local harbours and bays. Broad changes in communities reflect an improved trophic status resulting from anthropogenic abatement programs that were in place before the establishment of the zebra mussel. Large numbers of zebra mussels now present in the nearshore zone have also brought about broad changes in benthic community structure. Many of these changes resemble those resulting from abatement programs. The challenge for the future is to interpret benthic community changes relative to the appropriate causative agent.

7.2.2.1 Nearshore Benthic Communities of the Great Lakes

From 1991 to 1993, reference nearshore locations were visited in the Great Lakes to establish a reference database describing natural invertebrate community assemblages. The primary purpose of this database was to establish benthic invertebrate community targets for fine-grained sediment for the nearshore. Such targets are proposed as an objective method for assessing degraded conditions—specifically, impairment of benthic communities.

As far as possible, sites were evenly stratified throughout the lakes based on ecodistricts (24). A total of 345 sites were visited. The actual number of sites per lake was as follows:

Ontario	Erie	St Clair	Huron	Georgian Bay	North Channel	Michigan	Superior
30	47	1	17	71	44	38	36

The database comprises site location information, invertebrate community structure data (162 species or genera from 40 families), sediment chemistry data (30 variables) and water chemistry data (4 variables). A subset of sites were visited annually for two years (17 sites) or three years (a further 17 sites), and four sites were visited monthly for two years. The total number of site visits was 429. Based on the biological data, 252 sites are initially considered as acceptable reference sites, each representing an area in the lakes that is relatively unaffected by pollution.

To describe natural community assemblages, the matrix of 252 sites and 162 taxa was classified using mathematical techniques into six distinguishable community types. Of the 162 taxa, 12 are significantly correlated with the structure observed in the data (Table 9).

Table 9. Mean Number (s.d.) per 35 cm^2 of 12 Taxa in Great Lakes Community Assemblages

Taxa	Comm. 1	Comm. 2	Comm. 3	Comm. 4	Comm. 5	Comm. 6
Chironomus spp.	5.7 (5.8)	(3.1)	(1.3)	(1.8)	0.0	(0.4)
Heterotrissocladius spp.	0.2 (1.1)	0.8 (2.5)	0.0	(0.7)	(1.7)	(1.8)
Procladius spp.	(1.9)	(2.3)	(2.7)	(1.4)	(0.3)	(0.6)
Diaporeia hoyi	0.0	(6.2)	(0.9)	0.0	(41.8)	(5.1)
Amnicola limosa	(0.3)	(1.2)	0.0	(0.7)	0.0	0.0
Valvata tricarinata	(0.4)	0.7 (1.9)	(0.2)	(2.0)	0.0	0.0
Dreissenia polymorpha	(7.7)	(1.0)	(0.6)	(78.1)	0.0	(0.7)
Dreissenia bugensis	(7.2)	0.0	0.0	(181.2)	0.0	0.0
Pisisdium casertanum	(2.8)	(8.7)	(1.8)	(0.8)	(8.4)	(1.1)
Stylodrilus heringianus	0.0	(1.8)	0.0	0.0	(8.9)	(3.8)
Aulodrilus pigueti	(0.7)	0.2 (0.6)	(0.7)	(0.4)	0.0	0.0
Helobdella stagnalis	0.2 (0.3)	0.0	0.0	0.3 (0.3)	0.0	0.0

Communities 1 and 4 largely represent sites in Lake Erie. Community 1 is characterized by chironomid midges, primarily *Chironomus*, and by the presence of *Dreissenia*. Community 4, which is represented by only nine Lake Erie sites, is dominated by zebra mussels (*Dreissenia* spp.).

Communities 2 and 3 are characterized by the sphaerid (fingernail) clam *Pisidium*; in Community 2, it is associated with the amphipod *Diaporeia hoyi*, and in Community 3 with the predatory midge *Procladius*. Communities 2 and 3 include the majority of Georgian Bay sites, together with sites from the North Channel, Lake Ontario, and Lake Erie. Communities 5 and 6 are both *Diaporeia hoyi* and *Stylodrilus heringianus* dominated. The primary difference between the two is quantitative: much larger numbers are found in Community 5 (which characterizes Lake Michigan) than in Community 6 (largely represents Lake Superior sites). These data show a strong spatial signal in the occurrence of communities at a large scale; however, each community occurs in a number of the lakes (Table 10), and there is no certainty of determining the assemblage of organisms expected at a site based on the lake. The overall correlation of habitat variables with community structure showed the following variables to relate to community structure: depth, latitude, longitude, alkalinity (overlying water), calcium oxide (sediment), total nitrogen (sediment), and total organic carbon (sediment). From these relationships, it is possible to develop models to predict the community expected at a site based on the site's environmental attributes.

Table 10. Occurrence of Six Community Types among 252 Great Lakes Reference Sites, and Number of Sites Representing Each Community

Lake	**Community 1**	**Community 2**	**Community 3**	**Community 4**	**Community 5**	**Community 6**
Erie	17	3	11	9	1	0
Ontario	7	6	9	0	2	4
St Clair	1	0	0	0	0	0
Huron	2	4	1	0	6	4
Georgian Bay	0	11	32	0	0	18
North Channel	2	8	11	0	1	14
Michigan	0	7	0	0	22	8
Superior	0	0	0	0	2	29

To use these data to establish impairment, it is necessary to know what type of community would be expected to occur at any site. This expected community type, based on the reference sites, can then be compared with the actual species occurring at a site to establish whether the predicted group of organisms is actually present. Because it is important to know what organisms would occur at a site if it were unaffected, it is necessary to use only certain environmental variables—those that would not be modified by anthropogenic activity. Accordingly, although they were measured at each site, we have not included nutrients, metals, or organic contaminants as potential predictors. A total of 26 variables have been examined for their ability to predict community assemblages, including major elements, particle size and organic content of the sediment, water depth and alkalinity, and site location (latitude and longitude).

Stepwise discriminant analysis shows that 11 variables can discriminate sites between the six community types with an error rate of 32.4 percent, predicting 162 of the 252 sites correctly. To verify this predictive model, 20 sites were removed from the reference data set; the model was then rebuilt using the 232 remaining sites. Using the 11 predictor variables identified by discriminant analysis, 16 of the 20 sites (80 percent) were correctly predicted (Table 11).

Table 11. Accuracy of Predicting Community Types at 20 Sites

Site membership	**Predicted to**					
	Comm. 1	**Comm. 2**	**Comm. 3**	**Comm. 4**	**Comm. 5**	**Comm. 6**
Comm 1	2	0	0	0	0	0
Comm 2	0	3	0	0	0	0
Comm 3	1	2	3	0	0	0
Comm 4	0	0	0	1	0	0
Comm 5	0	0	0	0	3	0
Comm 6	0	0	0	1	1	4

7.2.3 Fish

The native fish fauna of the Great Lakes basin comprise 153 species—in 64 genera and 25 families—and is relatively large and diverse (Bailey and Smith 1981). Status and trend information are available for a number of fishes commonly found in the Great Lakes. The longest set of records is for fish species that were of commercial value and that entered the commercial catch. The commercial fishery in the Great Lakes dates back to the 1700s in some areas; regular reporting of the fishery began in 1867 in Canada and in 1879 in the United States (Baldwin et al. 1979). Because the records do not report the amount of fishing effort expended to catch the fish, or the amounts of some fish species that were caught but not brought to land for sale, they must be interpreted carefully. The records for the high-value, intensively fished species such as lake whitefish probably do reflect the trends in abundance, whereas records for low-value species such as freshwater drum do not. Freshwater drum were often taken incidentally in large numbers in nets set for other high-value species such as yellow perch and walleye. The market price for freshwater drum and the size of the catch of high-value species made by the individual fisherman on any given day probably determined how many freshwater drum were brought ashore for sale and how many were simply dumped back into the lake. Thus, the records for freshwater drum and other low-value species are generally not good indicators of trends in abundance. However, if the catch data are interpreted carefully, the history of the early commercial fishery in the Great Lakes can be seen to be one of intensive, selective fishing that eventually caused stocks of high-value species to decline and in some cases to become extinct. A more detailed discussion of the use of commercial catch data to examine the dynamics of commercially harvested Great Lakes fish is available elsewhere (USFWS 1995b).

Catch records for the lake sturgeon, blue pike, and walleye that inhabited the nearshore waters illustrate the effects of overfishing on coolwater species. The lake sturgeon, which does not reproduce until it is about 25 years old, was one of the first species to approach extinction in the Great Lakes. Annual catches in Lake Erie's U.S. waters fell from an all-time high of 2.1 million kg in 1885 to about 13,000 kg in 1917. Thereafter, reported catches never exceeded 10,000 kg, and after 1966 the catch fell to zero. Early in the fishery, the lake sturgeon was considered a nuisance species: it destroyed nets set for other smaller fish. Later, as markets developed, it became a sought-after species. The construction of dams that denied the lake sturgeon access to its spawning grounds in Great Lakes tributaries also helped accelerate its decline. The blue pike, a high-value species that reproduced at about age 4, became extinct because of overfishing. Annual catches as high as 9 million kg were made in the middle 1930s in Lake Erie's U.S. waters, but by the early 1960s the species had been fished to extinction. The walleye, a closely related species, was also severely overfished in Lake Erie. Catches declined from highs of about 2.3 million kg to 2.8 million kg annually in the late 1940s through the late 1950s, and to about 25,000 kg in 1971. Commercial fishing interests generally attributed the decline to deteriorated environmental conditions. However, closure of the fishery due to mercury contamination in the early 1970s followed by the imposition of more stringent catch regulations allowed walleye numbers to rapidly increase; now, the species again supports a healthy, self-sustaining, high-value fishery.

High-value coldwater fishes that use the nearshore waters during the colder months of the year declined to virtual extinction in all or some of the Great Lakes; these species include the lake trout, lake whitefish, and lake herring. Native populations of lake trout were nearly extinguished in the Great Lakes as a combined result of overfishing and predation by the introduced sea lamprey. The native lake trout populations in Lakes Michigan, Erie, and Ontario were lost; only a small population survived in a remote area of Lake Huron's Georgian Bay. In Lake Superior, the nearshore populations of native fish were sharply reduced by the late 1950s, when commercial fishing ended and the sea lamprey was controlled. Lake whitefish populations reached record lows in the 1950 and 1960s in Lake Huron, and in the 1950s in Lake Michigan, but have since recovered. In Lake Erie, for example, the U.S. catch fell gradually from a high of 17.8 million kg in the late 1800s to zero in the early 1960s, but a recovery may have begun in the late 1980s. Catches also fell to record lows in Lake Superior in the 1970s. These declines in the lake herring populations have been attributed to overfishing and to predation on young lake herring by rainbow smelt.

Overfishing has also contributed to a loss in the genetic diversity of the native fish fauna of the Great Lakes. This shift includes the loss associated with the extinction of several native species, including the blue pike and some deepwater ciscoes (whitefishes), as well as the loss of genetic diversity resulting from the extirpation of local stocks of native fishes by overfishing, together with habitat loss and the introduction of exotic species. Although the loss due to species extinctions is relatively obvious and unequivocal, the loss due to the extirpation of local stocks is less so. Perhaps the best examples can be seen among the whitefishes and lake trout, which were major elements of the native coldwater fish fauna of the Great Lakes.

At the time of European settlement, whitefishes were abundant and ecologically important as food for lake trout and burbot and as human food. As many as 40 species and subspecies of ciscoes (whitefishes most closely related to the lake herring) were identified by biologists working in the basin. Most of the group probably evolved locally, because there are no records for any of them, other than the lake herring, from outside the basin. Bailey and Smith (1981) present evidence that the reproductive isolation (absence of interbreeding) that had developed among these species and subspecies over a 10,000-year period was unstable and that it broke down as populations were reduced by commercial fishing and predation by the sea lamprey. Interbreeding among the survivors then caused their offspring to become more alike genetically. Today the ciscoes are represented only by the lake herring and by one to three other closely related species or subspecies that are extinct, are approaching extinction, or are simply merging their genetic identities by interbreeding.

Differences were historically recognized among stocks of native lake trout by aboriginal people, explorers, and missionaries, and later by naturalists and biologists (Krueger and Ihssen 1995); the evolution of subspecies was postulated for lake trout in the Finger Lakes in the Lake Ontario drainage of New York State (Royce 1951) and in the Great Lakes proper (Brown et al. 1981; Goodier 1981; Goodyear et al. 1982). Most of the native stocks recognized historically in Lake Superior and all of those in the four lower Great Lakes, except for two small relict native stocks in Lake Huron, were lost before they could be examined for genetic differences. However, genetic differences have been demonstrated among the native lean, humper, and siscowet lake trout groups that survive in Lake Superior (Krueger and Ihssen 1995); similar differences must have occurred in the other Great Lakes, where lake trout occupied a diversity of habitats.

The loss of native genetic diversity affects the status of the Great Lakes ecosystem irreversibly. Left unoccupied were habitats, particularly those in deep water, that were occupied productively by native species and stocks that had become adapted to them following the retreat of the glaciers from the basin about 10,000 years ago. Other vacated habitats in shallower water were left open to invasion by undesirable exotic species that had gained access to the basin as a result of human activities. The full and productive use of the diverse array of habitats in the Great Lakes nearshore waters requires that the genetic diversity of the remaining native species be protected by actions taken to perpetuate all recognized stocks of these species.

Contemporary information on the status and trends of Great Lakes fish populations is now compiled annually for each of the lakes by committees that comprise biologists and managers from the Great Lakes states, the province of Ontario, Canada’s Department of Fisheries and Oceans, the National Biological Service, and the Indian tribes that have treaty fishing rights. These reports reveal the following major trends.

In Lake Superior, the lake trout fishery is currently maintained by stocking and by natural reproduction from wild fish (Hansen 1994). Introduced species of trout and salmon support a stable fishery, whereas brook trout and lake sturgeon populations have not recovered from earlier declines and are still at low levels. Lake herring numbers are recovering strongly, and rainbow smelt are reduced from earlier levels of peak abundance. Lake whitefish are abundant and support a productive fishery. The sea lamprey is reduced to about 10 percent of its former peak abundance, and the ruffe is increasing in abundance.

In Lake Huron, the fish community is recovering, but remains unstable after decades of overharvest and the effects of introduced species (Ebener et al. 1995). Modest numbers of stocked lake trout are once again reproducing in the lake, and populations of whitefish are more abundant than at any other time in the century. Walleye and yellow perch are once again abundant. Rainbow smelt and alewife populations are stable but have been reduced compared to former peak levels in the 1970s. In the 1980s, the sea lamprey increased in abundance in the northern end of the lake, imposing high mortality on lake trout and reversing recent gains in lake trout restoration in that area.

In Lake Michigan, substantial numbers of stocked, breeding-age lake trout are present in lake trout refuges at several locations throughout the lake (Holey et al. 1995). Spawning and fry production by stocked fish have been recorded at several locations in the lake; wild yearling and older lake trout have also been found in the lake, but substantial numbers of adult wild fish have not been produced. Pacific salmon abundance is sharply reduced compared to the peak levels reached in the 1970s to the middle 1980s. The causes for that decline are complex and not fully understood. Mortality of coho salmon fry soon after hatching has been observed. This mortality can be alleviated by treatment with vitamin B_1, suggesting that there is a vitamin B_1 deficiency in the female parent that causes mortality in the fry. Mortality of adult Pacific salmon in the lake is correlated with an incidence of bacterial kidney disease, a pathogen that has been introduced to the Lake Michigan basin. A linkage between the pathogen’s virulence and the salmon’s nutritional status is being investigated. The biomass (a measure of abundance expressed as weight) of each of the three major prey fishes in Lake Michigan has changed significantly since the early 1970s (National Biological Service, unpublished data). Alewives constituted more than 80 percent of the biomass in catches in the 1970s but declined to about 10 percent in the middle 1980s through the 1990s. The biomass of rainbow smelt decreased from between 15 percent and 20 percent in the 1970s and early 1980s to less than 10 percent in the middle 1980s and 1990s. Slimy sculpin abundance peaked in the late 1970s, but declined in the 1980s and 1990s to less than 20 percent of peak 1970s levels, probably in response to predation by trout, salmon, and burbot.

In Lake Erie, lake trout restoration goals are being met, and lake whitefish are showing signs of a recovery (GLFC 1995a). Walleye and yellow perch are intensively managed to provide productive recreational and commercial fisheries in the United States and Canada (GLFC 1995b). The abundance of the major forage fish species in Lake Erie—rainbow smelt, spottail shiners, emerald shiners, gizzard shad, and alewives—may be declining.

In Lake Ontario, the fish community has improved considerably from a low point in the 1960s (Kerr and LeTendre 1991; OMNR and NYSDEC 1994). Alewife and rainbow smelt abundance declined in the 1980s in response to (a) trout and salmon predation and (b) reduced nutrient input to the lake; in the 1990s, stocking of trout and salmon was reduced to bring them into better balance with their food supply. Some native fishes are recovering from low levels observed in the 1960s. For example, lake whitefish, which typically were most abundant in the eastern end of the lake, were nearly absent there in the catch in the 1970s, began increasing in 1980s, and were 30- to 40-fold more abundant there in the 1990s.

Fish from Great Lakes nearshore waters in areas where the sediment is contaminated sometimes exhibit tumours (Baumann et al. 1996). These tumours fall into two general classes: benign (or harmless) and malignant (or cancerous). It is generally believed that tumour production may be a response to degraded habitat. Tumour outbreaks in the Great Lakes have been found in populations of benthic species, including brown bullhead, white sucker, common carp, bowfin, and freshwater drum. Common carp—and particularly common carp × goldfish hybrids—primarily exhibit gonadal tumours; freshwater drum primarily have neural (chromatophore) tumours that are externally visible. Bowfin liver neoplasms (newly formed tumours that may or may not become cancerous and that are not readily seen as a lump or bump) have been documented in fish taken from the Detroit River. White sucker and brown bullhead both exhibit skin and liver neoplasms. These species have been more studied than the others in the Great Lakes. The white sucker has been used as an indicator organism for a series of contaminant studies in Canada. Similarly, the brown bullhead has been used as an indicator organism for a variety of studies in the United States. Many of the locations in which tumour outbreaks in these species were documented have subsequently been designated as Areas of Concern by the International Joint Commission.

Epidermal (skin) papillomas (tumours that appear as raised lumps or bumps and will become cancerous), particularly on the lips, are the most commonly observed neoplasm in white sucker. Recent experimental work by Premdas and Metcalf (1996) has proven that papillomas can be induced in white suckers by exposing them to a cell-free filtrate obtained from enlarging papillomas. This result indicates that a virus is involved in producing these tumours. Widespread surveys in Canada (Figure 22 and Table 12) revealed the presence of skin neoplasms in white sucker populations throughout the Great Lakes. However, a high prevalence (more than 20 percent) of lip papillomas occurred only in populations from the lower Great Lakes, and an especially high prevalence of oral papillomas was found only in such locations as Hamilton Harbour and Oakville Creek, Ontario, where the sediment was polluted with industrial wastes. Thus, epidermal papillomas may result from both virus and chemical carcinogens in the sediment.

Epidermal papillomas are also found on brown bullhead in a number of Great Lakes locations (Figure 23 and Table 13). The greatest incidence of such tumours was in populations from Hamilton Harbour and Presque Isle Bay, where frequencies exceeded 50 percent—more than double the next highest values (Obert 1994; Smith et al. 1989). Populations in the Buffalo and Black Rivers formed a second cluster, with papilloma prevalence of about 25 percent. The four sites just mentioned are all locations with elevated levels of PAH in the sediment; all have also been designated as Areas of Concern. Other Great Lakes locations surveyed had bullhead populations with papilloma incidence ranging from 2 percent to 16 percent. These included a mixture of contaminated sites (e.g., Ohio’s Ashtabula River, at 16 percent) and uncontaminated sites (e.g., Ontario’s Long Point Bay, at 15 percent). The percentage of squamous carcinomas (malignant skin cancers) was seldom determined; Presque Isle Bay, however, had an extremely high prevalence of these, with fish from the Cuyahoga River and Hamilton Harbour also having elevated frequencies. Though a virus may be involved in producing these cancers, no experimental evidence supports such a conclusion at this time. Sediment carcinogens do seem to have a role in producing these cancers.

Table 12. Prevalence of Lip and Body Papillomas Reported in White Sucker Populations in Ontario Waters of the Great Lakes and in Surrounding Areas

Location	Collection Date	N	Neoplasms (%)	Reference[a]
Hamilton Harbour[b]	1972–75	—	30	1
	1981–83	168	39	2
	1986	225	43	3
Oakville Ck.[b]	1982-83	612	62	2
	1986	482	46	3
Bay of Quinte[b]	1982–83	148	5	2
Keefers Ck.[b, c]	1986	81	11	3
Whites Ck.., L.[b, c]	1986	71	16	3
Thunder Bay	1986	199	2.5	4
Jackfish Bay	1987	300	7.6	4
St. Marys River	1988	185	9.1	4
Black Bay[c]	1986	232	3.4	4
Mountain Bay[c]	1987	304	3.6	4
Batchawana Bay[c]	1988	231	8.6	4
Ganaraska River[b]	1992–93	356	46	5
Squaw River[b, c]	1992–93	239	5	5

Source: Adapted from Baumann et al. 1996.

[a] Key to References in Column 5: (1) Sonstegard et al. 1977; (2) Cairns and Fitzsimons 1988; (3) Smith et al. 1989a; (4) Smith, unpublished; (5) Premdas et al. 1995.

[b] Only data for lip papillomas are reported.

[c] Reference site from a relatively pristine area.

Table 13. Prevalence of External Tumours Reported in Brown Bullhead Populations in U.S. and Canadian Waters of the Great Lakes Basin

Location	Collection Date	*N*	Neoplasms (%)	Malignancies(%)	Reference[a]
Ashtabula River, OH	1991	97	16.0	NA[b]	1
Black River, OH	1993	104	25.0	NA	2
Buffalo River, NY	1988	100	23.0	NA	2
Plum Creek, MI	1985	57	7.0	NA	2
Cuyahoga River, OH	1984	90	8.9	5.5	3
Menominee R., WI and MI	1984	47	2.1	NA	3
Fox River, WI	1984	52	7.7	1.9	3
Detroit River, MI	1985–87	449	10.0	NA	4
Hamilton Harbour, ON	1985	176	55.0	7.0	5
Presque Isle Bay, PA	1992	102	56.0	33.0	6
Long Point Bay, ON[c]	1985	53	15.0	NA	5
Munuscong Bay, MI[c]	1984	63	3.2	NA	3
Old Woman Ck., OH[c]	1984–85	120	2.5	NA	2

Source: Adapted from Baumann et al. 1996.

[a] Key to References in Column 5: (1) Mueller and Mac 1994; (2) Baumann, unpublished; (3) Baumann et al. 1991; (4) Maccubbin and Ersing 1991; (5) Smith et al. 1989a; (6) Obert 1994.

[b] "NA" means that brown bullheads from that site have not been analysed histologically for malignancies.

[c] Reference site in relatively pristine area.

Though white suckers from 19 different locations in Canada were examined for liver tumours, no population had an incidence as great as 10 percent (Table 14 and Figure 22). White suckers in five of seven relatively pristine reference sites had a liver tumour prevalence of less than 0.5 percent. However, white suckers from nine Areas of Concern sampled had an average prevalence of 5.3 percent. Lake Superior's Batchawana Bay (Ontario) was the only relatively pristine reference location where bullhead had a tumour prevalence (8.6 percent) that exceeded 3 percent; this high prevalence may reflect the advanced age (up to 26 years) of the suckers that were examined from the bay. A high incidence of liver tumours occurred among suckers older than age 15 (23 percent) from this location. The cause of liver tumours in white sucker is probably associated with exposure to carcinogenic contaminants; tumour prevalence of 5 percent or greater should be viewed as an indication of such exposure.

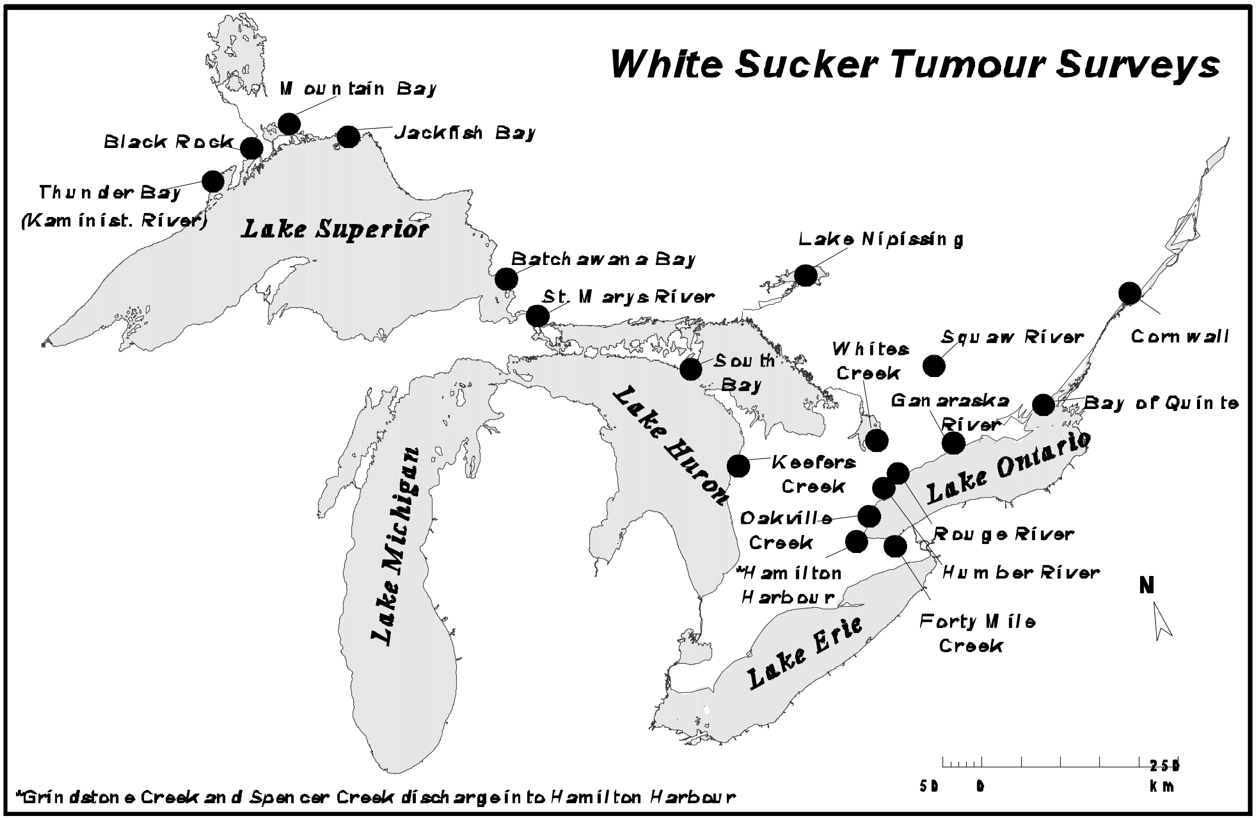


Figure 23 White Sucker Tumour Surveys

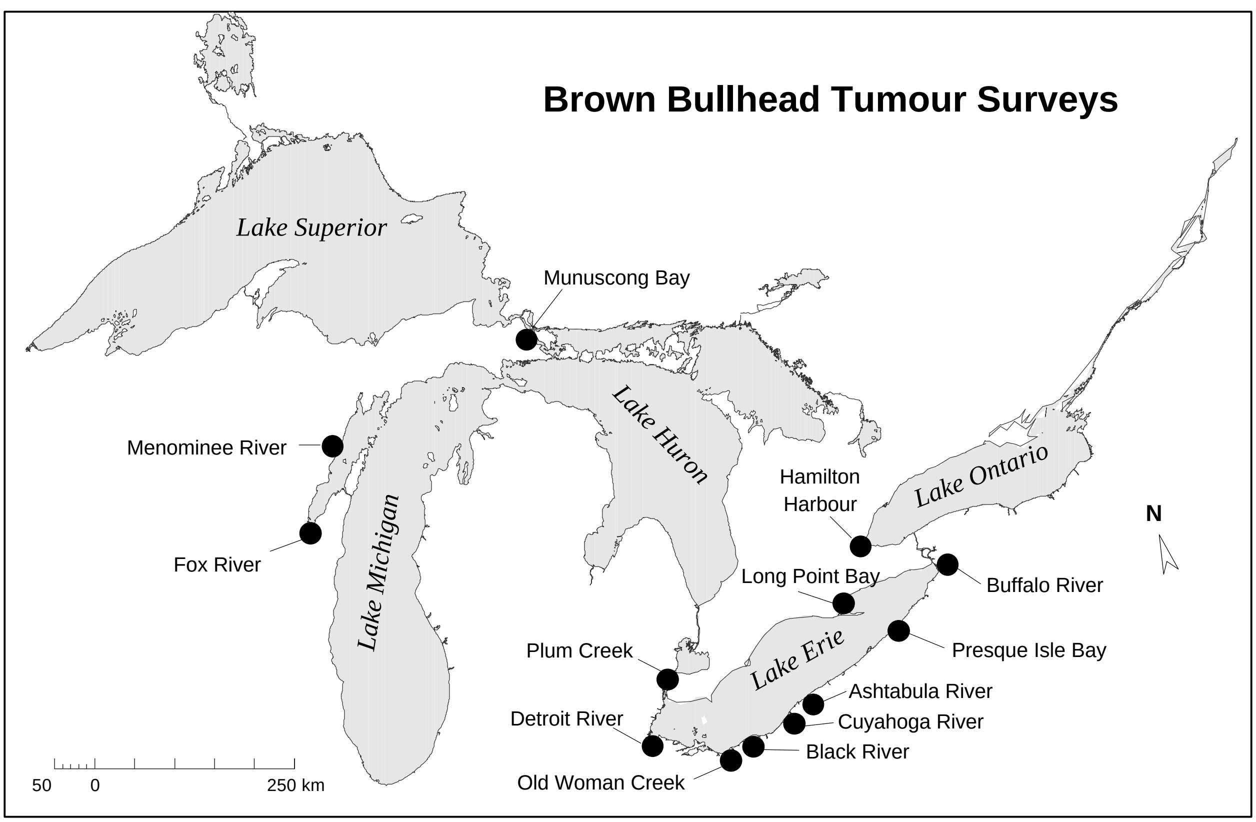


Figure 22 Brown Bullhead Tumour Surveys

Table 14. Prevalence of Combined Cholangiocytic (Bile-duct) and Hepatocytic (Liver-cell) Liver Tumours Reported in White Sucker Populations at Remedial Action Plan (RAP) Sites and Reference Sites in Canadian Waters of the Great Lakes, and from Sites in Surrounding Areas

Location	Collection Date	*N*	Neoplasms (%)	Reference[a]
Hamilton Harbour[b]	1982–83	168	1.2	1,2,4
(Grindstone Ck.)	1985–90	119	5.8	3,4
Oakville Ck.	1982–83	612	7.4	1,2,4
	1985–90	306	8.1	3,4
Spencer Ck.[b]	1982–83	174	3.4	2,4
Forty Mile Ck.	1982–83	133	0	2,4
Rouge River	1982–83	199	3.5	2,4
Humber River[b]	1982–83	192	4.7	2,4
Bay of Quinte[b]	1982–83	148	0.7	1,2,4
	1985–90	91	0	4
Ganaraska River[b]	1982–83	116	6.0	2,4
Cornwall[b]	1985–90	178	6.1	4
South Bay[c]	1982–83	228	0	1,2,4
Lake Nipissing[c]	1985–90	231	0.4	4
Whites Ck.[c]	1985–90	24	0	3,4
Keefers Ck.[c]	1985–90	37	0	3,4
Jackfish Bay[b]	1985–90	194	7.1	4
Kaministiquia[b]	1985–90	112	7.1	4
St. Marys River[b]	1985–90	184	9.2	4
Black Bay[c]	1985–90	231	0	4
Mountain Bay[c]	1985–90	75	2.4	4
Batchawana Bay[c]	1985–90	230	8.6	4

Source: Adapted from Baumann et al. 1996.

[a] Key to References in Column 5: (1) Cairns and Fitzsimons 1988; (2) Canada 1991; (3) Hayes et al. 1990; (4) Smith et al. 1995.

[b] RAP site on Great Lakes.

[c] Reference site from a relatively pristine area.

Brown bullhead collected from a series of locations with industrial contamination had liver tumours (Table 15 and Figure 23). Bullhead from two relatively uncontaminated sites had a liver tumour prevalence that was greater than 5 percent, though these populations had a greater percentage of older fish(age 5 and up) than the industrial sites (Baumann et al. 1996). Bullhead from the Cuyahoga and Detroit Rivers had tumour prevalence of between 8 percent and 10 percent, while those from the Buffalo River and Presque Isle Bay had about 20 percent. All four of these river systems have elevated levels of polynuclear aromatic hydrocarbons (PAH) in at least some portions of their sediment. In 1982, when a coking facility associated with a steel plant on Ohio’s Black River was operational, the bullhead population had a liver cancer prevalence of 38.5 percent (Table 14). The coking facility closed in l983, and by l987 PAH concentrations in surficial river sediment had declined to 0.4 percent of the concentration in 1980 (Baumann and Harshbarger 1995). By 1987, the cancer frequency in the bullhead population had also declined—to about one-fourth of that seen in l982. Areas of sediment most contaminated with PAH were subsequently dredged from the river in 1990, and two years later the cancer incidence in bullhead exceeded that in 1982 (Table 14). This Black River case history indicates that natural, unassisted remediation can be effective in reducing the incidence of cancer in bullheads in some systems; it also shows that dredging using traditional methodology can result in at least a temporary increase in cancer incidence and degradation of the health of native species (Baumann and Harshbarger 1995). Collectively, these data show that bullhead liver tumours track PAH levels in natural systems, making them a good biomarker for exposure of benthic fish to carcinogens in sediment.

Joint Canada–U.S. studies of benthic fishes in a gradient of polluted to pristine Great Lakes locations using standardized methodology would greatly enhance our knowledge of the etiology of tumours and their usefulness as indicators.

Table 15. Prevalences of Liver Tumours Reported in Brown Bullhead Populations in U.S. and Canadian Waters of the Great Lakes Basin

Location	Collection Date	N	Neoplasms (%)	Malignancies (%)	Reference[a]
Ashtabula River, OH	1991	97	6.2	3.1	1
Black River, OH	1982	124	60.0	38.5	2
	1987	80	32.5	10.0	2
	1992	97	58.0	48.0	3
Buffalo River, NY	1988	100	19.0	5.0	3
Cuyahoga River, OH	1984	85	9.4[b]	NA	4
Detroit River, MI	1985–87	306	8.8	NA	5
Hamilton Harbour, ON	1984	124	1.6	1.6	6
Presque Isle Bay, PA	1992	102	22.0	6.9	7
Old Woman Ck., OH[c]	1992–93	125	5.6	3.2	3

Munuscong Bay, Mi[c]	1984	63	5.9	2.9	4

Source: Adapted from Baumann et al. 1996.

[a] Key to References in Column 5: (1) Mueller and Mac 1994; (2) Baumann and Harshbarger 1995; (3) Baumann, unpublished; (4) Baumann et al. 1991; (5) Maccubbin and Ersing 1991; (6) Smith et al. 1989a; (7) Obert 1994.

[b] Conservative value based on a combination of gross observations and a limited histopathological survey.

[c] Reference site in relatively pristine area.

7.2.4 Birds

Nearshore waters are used periodically by a variety of waterfowl species from late summer until migratory flights the following spring are complete. Groups of dabbling ducks begin to use areas adjacent to coastal wetlands as resting and refuge sites in August and September. Sites with open water in the winter can become important to wintering flocks of mallards as resting areas (Reed 1971).

Major use of nearshore waters for feeding and resting is done by five species of diving ducks (lesser scaup, canvasback, redhead, ring-necked duck, and greater scaup, listed in order of importance) and by six species of sea ducks (common goldeneye, bufflehead, oldsquaw, hooded merganser, red-breasted merganser, and common merganser). Seeds, tubers, rootstocks, and vegetative parts of submersed plants, benthic organisms, and fish are eaten in accordance with availability and with each duck species' food preferences. Diving ducks are most abundant group of waterfowl: flocks of hundreds and even thousands of birds are associated with the 15 major waterfowl habitat complexes in the Great Lakes that have been identified by Prince et al. (1992).

Documented responses of migrating ducks, especially lesser scaup, to abundant supplies of zebra mussels are beginning to appear in the literature. If this trend continues, an increased use of nearshore waters during the October–November and March–April periods can be expected. Evaluation of the dynamics of waterfowl use of zebra mussels should be monitored. Diving ducks (common goldeneye and common merganser) are often attracted for feeding and resting to ice-free nearshore waters kept open by heated water discharges or by mechanical means in the winter (Padding 1993). Each new ice-free area resulting from expanded human activity needs an ecological evaluation in this context.

7.2.4.1 The Importance of the Nearshore Aquatic Zone for Wildlife on the Canadian waters of the Great Lakes

The Canadian Nearshore Aquatic Zone (NAZ) does not provide a great variety of habitat to non-fish wildlife species. Birds are the main wildlife species in this area, but amphibians and reptiles, as well as selected species of mammals, do make heavy use of wetlands.

This section poses three questions to guide the reader through a consideration of the NAZ's importance. Each question is discussed in the light of colonial waterbirds, aquatic raptors, and waterfowl. All references to the Great Lakes in this section refer to the Canadian waters of the

Great Lakes (unless otherwise stated); no attempt is made here to evaluate the NAZ's importance for wildlife in the U.S. waters of the Great Lakes.

Why Is the Nearshore Aquatic Zone So Important for Wildlife? What Are We Trying to Protect beyond Wetlands?

Importance for nesting and feeding during the breeding season: In addition to wetlands, the other habitat that is exceedingly important to wildlife in the NAZ is islands. Most of the islands in the Great Lakes occur in the NAZ—i.e., in water that is less than 30 m deep. On the Canadian Great Lakes, islands provide nesting habitat for more than 105 species of aquatic birds—including colonially nesting gulls, terns, herons, cormorants, etc.; waterfowl; and aquatic raptors—as well as several species of reptiles and amphibians.

The colonial waterbirds that breed on the Great Lakes include the following: ring-billed gulls, herring gulls, great black-backed gulls, and little gulls (see Appendix A for Latin names); common terns, caspian terns, black terns, and forster's terns; double-crested cormorants; black-crowned night-herons; great blue herons; and great egrets.

The first three gull species are generalists when it comes to nesting habitat. They will nest on barren, rocky, grassy, or treed islands that are either close to shore (less than 100 m) or at much greater distances offshore (12 km to 60 km). In Southern Ontario, they will also nest at mainland sites where access is restricted—e.g., Toronto's Tommy Thompson Park, Hamilton's Eastport facility, or Port Colborne's Canada Furnace property. Common and caspian terns often nest in association with herring and ring-billed gulls but usually in areas of specific microhabitat—e.g., places with gravel of a specific size, etc. Their breeding areas are therefore often unique to specific sites. Great blue herons and great egrets require tall trees and often nest at the same site. The night-herons nest at low elevations in mature trees or in shrubs and bushes of various species. Cormorants nests in trees at mainland sites and in trees or on the ground on insular sites. Little gulls, black terns, and forster's terns are marsh or wetland nesters; they will nest in wetlands that are located on islands. Of the above-mentioned species, great egrets, little gulls, black terns, and forster's terns are quite restricted in their nesting range on the Great Lakes: forster's terns are known to nest at only one site, and little gulls are not known to have nested since the late 1980s or early 1990s.

A census in 1980 of all nesting sites of five predominant species of colonial waterbirds estimated that more than 300,000 pairs of birds (600,000 individual birds) were nesting on the Canadian Great Lakes at that time. Approximately 40 percent of these birds occurred on the lower Great Lakes, where all islands are within the NAZ; most of the remaining birds occurred in Lake Huron (where most, though not all, islands occur in the NAZ). Hence, the Nearshore Aquatic Zone—and particularly its islands—serves as home to nearly all the colonial waterbirds that occur on the Great Lakes.

The waterfowl species that breed regularly on the Great Lakes and that would use the NAZ include the following: mute swan; Canada goose; wood duck; green-winged teal; American black duck; mallard; northern pintail; blue-winged teal; northern shoveller; gadwall; American wigeon; canvasback; redhead; ring-necked duck; lesser scaup; goldeneye; hooded merganser, common merganser, and red-breasted merganser; and ruddy duck. Common loons also breed on the Great Lakes and are included here, but are not considered a waterfowl species.

The shoreline and NAZ of the Great Lakes are not great areas for breeding waterfowl. There are no large concentrated breeding areas; water-level fluctuations may cause problems for breeding waterfowl; and isolated pairs of most of the above species can be found on some islands or near wetlands. Red-breasted mergansers breed on some, and maybe most, of the islands in the northern lakes, and their total numbers may be considerable. Loons and diving ducks breed in specific and well-known areas, but their overall populations are probably small.

Ospreys and bald eagles are the two aquatic raptors that breed on the Great Lakes. Historically, both these species nested along the shoreline of the Great Lakes and on offshore islands. On Lake Erie, only the eagle has recolonized the shoreline (mainland) sites. Neither species has returned to nest on islands there, nor are any eagles or ospreys nesting on Lake Ontario, though suitable habitat exists on both the mainland and the islands. In Lakes Huron and Superior, eagles are making a slow recovery, primarily on island sites, while ospreys have responded very well to artificial nesting platforms and other human-made structures. There are good numbers of ospreys in Lake Huron's Georgian Bay and in the St. Marys River.

Importance for feeding and resting during migrational staging: The migrational staging areas of most colonial waterbirds on the Great Lakes are not very well known. Western Lake Erie is a known area for common terns (Courtney and Blokpoel 1983) and cormorants (D.V. Weseloh, personal observation) in autumn. Cormorants also gather on islands in eastern Lake Ontario at that time of year. Long Point Bay, on Lake Erie's north shore, may be an important staging area for little gulls: more than 300 have been observed at one time there. The Long Point peninsula is certainly an important area for summering immature gulls and may also be important for migrational staging. The Niagara River is an important area for gulls from late autumn through the winter, when there are huge daily movements up and down the river (D.V. Weseloh, personal observation), and may also be important for migrant gulls. The St. Clair River (at Sarnia) is known to be a migrational route for several species of resident and transient colonial waterbirds, but they do not appear to do any staging in the area. Except for this information on specific sites, however, very little species-specific information is known on a Great Lakes–wide basis. For example, nothing is known about staging areas for the other three species of terns, for any herons, or for night-herons. There is virtually no information on staging during spring migration for colonial nesters. Presumably, the Great Lakes are important areas for these birds as they move north, waiting for those areas to “open up” (i.e., thaw).

The Great Lakes, particularly the NAZ, are an extremely important area for migrating and staging waterfowl, especially the diving and sea ducks. In spring and autumn, sites such as Lake St. Clair, Long Point (Lake Erie), Presqu’Ile Provincial Park (Lake Ontario), and Prince Edward County and Wolfe Island (at Lake Ontario’s eastern end) are of international importance for tundra swans, canvasbacks, redheads, greater scaups, lesser scaups, common goldeneyes, common mergansers, and red-breasted mergansers. Use of the NAZ, which is greatest in the autumn, is more concentrated in the spring because of the limited amount of open water that is available. These sites, where ice thaws first and, presumably, food is first available, may be more critical or limiting in the spring.

Raptors do not generally migrate over large or even moderately sized expanses of water; in fact, they avoid them. Migration of raptors, including aquatic raptors, in Ontario is very structured so that they can avoid travelling over open water. The main avenue of migration in the spring is westward along the Niagara Escarpment between Lakes Erie and Ontario, and then northward. In the autumn, raptors migrate southwestward along the north shores of Lakes Ontario and Erie, crossing into the United States over the very narrow Detroit River. In the north, raptors move westward along the north shore of Lake Superior, passing south at the lake’s west end, at Duluth, Minnesota.

Importance for feeding while overwintering: Most species of colonial waterbirds are absent from the Great Lakes during winter, having migrated in September and October. Adult herring gulls remain in the Great Lakes: they do not migrate. Great black-backed gulls migrate into the Great Lakes from the Atlantic; several species of Arctic nesting gulls migrate to the Great Lakes in small numbers; most ring-billed gulls also migrate out of the Great Lakes. For those gulls that occur on the Great Lakes in winter, the Niagara River is the major staging and congregating area. Observations suggest that the large number of fish that go through the hydro turbines and then back into the River and the abundant shallow water above the Falls provide excellent feeding habitat for gulls in this area.

Gulls need open water to feed in the winter, so any such areas have the potential to attract them. Gaps between otherwise frozen expanses of water in Lake Erie and ice edges in Lake Ontario are known to attract gulls (D.V. Weseloh, personal observation); the same may be true for the upper lakes. These areas may usually be outside the NAZ.

Among waterfowl, there are overwintering populations of canvasback, scaup, common goldeneye, and common merganser in the Detroit, St. Clair, Niagara, and St. Lawrence Rivers. Lake Ontario and Lake Erie provide overwintering habitat for sea-ducks such as white-winged scoters and oldsquaw; for example, as many as 40,000 oldsquaw ducks have been recorded in the

Kingston basin on a single survey. Recently, the invasion of zebra mussels has affected the migratory and wintering distribution of scaup and other molluscivorous ducks in Lake Erie (Wormington and Leach 1992) and Lake Ontario.

The only known overwintering population of aquatic raptors occurs along the St. Lawrence River, from Gananoque to Mallorytown, Ontario. This portion of the river is mostly open all winter; the bald eagles feed on ducks and deer carcasses, most of the latter being intentionally provided by humans (Ewins and Andress 1995).

What needs protection: For colonial waterbirds, the most critical factor is breeding habitat. Preservation of traditional sites that have large and varied nesting populations is a must if the diversity is to be protected, especially in the lower lakes, where demand for developmental lands is high. Preservation of such sites as Pigeon Island, the islands of Presqu'Ile Provincial Park (Gull and High Bluff Islands), Tommy Thompson Park, and Eastport and its associated islands in Lake Ontario, and of Middle, East Sister, and Middle Sister Islands and Port Colborne in Lake Erie, is essential. In the upper lakes, where there are many more islands and nesting colonies, specific sites may not be as critical; however, the Limestone Islands, the Cousin Islands, the Watcher Islands in Lake Huron ,and other islands with Caspian Terns on them (these islands always have other colonials nesting on them) are good candidates for protection.

For colonial waterbirds, an adequate population of small to medium-sized fish as a food supply is also essential, but at present that does not seem to be a problem.

For waterfowl, it is more a question of protected sites for unique feeding opportunities during migration that is critical. Large underwater beds of vegetation, such as those found at Long Point Bay, are essential for Canvasbacks and Redheads. Areas with high densities of snails are crucial for several waterfowl species (e.g., scaup at Wolfe Island and in Prince Edward County). The recent introduction of zebra mussels may have provided a gala winter boost for the duck species that feed on molluscs.

Aquatic raptors require the maintenance (or creation) of nesting sites (super-canopy trees and artificial platforms) and accessible open water in winter at nearshore situations. For example, if the St. Lawrence River froze over at Gananoque–Mallorytown, the overwintering eagles there would almost certainly leave.

What Is the Population Status of Wildlife in the Nearshore Aquatic Zone? (Bad and increasing? Bad and getting worse? Stable?)

Colonial waterbirds can be grouped into four categories for the purpose of evaluating their status. The categories and the species that occur in each category are listed below.

Common to abundant, populations stable or increasing

Ring-billed and herring gulls

Double-crested cormorant

Caspian tern

Great blue heron

Uncommon, populations stable or increasing, species at edge of range

Great egret

Great black-backed gull

Common but populations under some pressure from various sources

Common tern

Black-crowned night-heron

Uncommon, populations declining (or, where marked by an asterisk, at edge of range)

Black tern

Forster's tern

Little gull*

Waterfowl are more easily grouped according to species and then evaluated. They are listed by species group below.

Dabblers and geese: Stable

Bay ducks (scaup, redhead, canvasback, ring-necked duck): Numbers are stable but variable; availability of zebra mussels may cause redistribution of bay duck numbers in some areas.

Mergansers and goldeneye: Reasonably stable.

Sea ducks: Increased numbers overwintering because of zebra mussels.

Aquatic raptors are dealt with on a species-by-species basis below:

Osprey: Relatively common in eastern Georgian Bay and the St. Marys River; slowly returning and increasing in other areas because of the placement of artificial nesting platforms.

Bald eagle: Well-established and reasonably numerous breeding population present on western Lake Erie; smaller numbers in northern Lake Huron and Lake Superior. Not yet breeding on the shores of Lake Ontario, but did breed within that lake's basin in 1996.

What Are the Problems for the Various Species and What Management Actions Are Needed?

Colonials:

Double-crested cormorant: No problems other than perhaps excessive numbers. Controls may be needed now or in the near future to safeguard rare trees and to reduce competition with black-crowned night-herons.

Black-crowned night-heron: Competition for nest sites with and fouling by cormorants; protection of colonies of more than 100 nests is required.

Herring gull, great black-backed gull, and great blue heron: No problems; no management actions required.

Ring-billed gull: Excessive numbers in some areas. Control needed to help common terns (e.g., in Port Colborne).

Great egret: Few nesting sites; protection of the few existing colonies is required.

Black tern and forster's tern: Deterioration of nesting habitat due to disturbance and unknown other factors; surveys are needed to determine trends. If populations are declining, ecological studies are needed to find out why and to arrive at conservation options. Meanwhile, protection of all important colonies (for black terns, colonies of more than 50 nests; for forster's terns, all nesting sites) is required.

Little gull: Marginal nesting habitat; protect any colony if found nesting again.

Caspian tern: Few problems (perhaps disturbance); protect all long-standing colonies of more than 100 nests.

Common tern: Competition and predation from ring-billed and herring gulls, as well as disturbance from humans; protect all colonies of more than 100 nests.

Waterfowl:

Dabblers and geese: Disturbance at roosting sites; protection at and/or of roosting sites.

Divers—Bay Ducks: Quiet shallow water is needed for feeding; bay ducks are more susceptible to disturbance than are other ducks; protected areas are needed.

Divers—Sea Ducks: Few problems, because they use more offshore waters than do other ducks.

Aquatic Raptors:

Osprey: Lack of suitable natural nesting habitat and absence of local nesting population; erect nesting platforms.

Bald eagles: Lack of suitable natural nesting habitat; contaminants may be a problem in some areas (e.g., Lake Ontario); disturbance by humans. Erect platforms in specific areas for specific pairs; continue current restrictions (and impose new ones if needed) on contaminants; and restrict access to all nest sites, especially any new ones.

7.2.5 Mammals

Few species of mammals use the nearshore waters. River otters, minks, beavers, muskrats, and raccoons occur in sheltered parts of the system, including embayments, tributaries, and the connecting channels. Larger mammals, including deer and moose, and carnivores, including wolves and coyotes, use the ice bridges in nearshore waters as migration routes.

8.0 Human Health

8.1 Infectious Organisms as Health Hazards

During the 20th century, waterborne infectious illnesses have become rare in the Great Lakes basin (Health Canada 1995a, 1995b, 1995c; Health and Welfare Canada 1980) because of effective environmental hygiene measures, especially drinking-water and sewage disinfection, and because of vaccinations. But some major Ontario cities introduced drinking-water filtration and disinfection only in the early 1930s; until then, a single outbreak of waterborne typhoid fever could affect nearly 1,000 people and kill nearly 100 in a population of 100,000 (Calamai 1995). Great Lakes waters of the nearshore zone, like wilderness waters, cannot be considered safe for recreational use unless their microbial quality is carefully monitored, and should not be used for human consumption without treatment (Health and Welfare Canada and Environment Canada 1991). Even modern water treatment plants have weaknesses. In 1993, human error in operating a water treatment plant led about 400,000 inhabitants of Milwaukee to become infected by a protozoan parasite (*Cryptosporidium*); about 4,000 of those who were affected had to be hospitalized (MMWR SS 93). This outbreak attracted the attention of news media (Beil 1995), as well as that of public health and water treatment professionals (Blair 1994; Otterholm 1994; Robertson and Sullivan 1994). A smaller outbreak of cryptosporidiosis occurred in the Ontario city of Kitchener–Waterloo, with more than 200 confirmed cases and perhaps as many as one-third of all households experiencing diarrheal illness (Welker 1995). In 1996, another outbreak of illnesses associated with *Cryptosporidium* occurred in Collingwood, Ontario (“Parasites invade...” 1996). Drinking water contaminated with this parasite (or with bacteria) can be rendered safe by boiling it (“Is the public getting...?” 1996).

Many people who bathe in the lakes and streams of the Great Lakes basin suffer the discomfort of “swimmer’s itch,” a condition caused by tiny worm larvae that normally infect waterfowl but that will also burrow into the skin of humans (Chandler and Read 1961; Ontario Ministry of Environment 1986). A water-quality problem that has received little attention in the Great Lakes region but that is common in the Prairie region is the growth of certain cyanobacteria (blue-green algae) in sources of drinking water. These algae can contain or secrete toxic chemicals and may thus affect water quality (Kotak et al. 1993).

Table 16 contains a list of some of the pathogenic viruses, bacteria, protozoa, and other parasites commonly found in North America, including in the nearshore waters of the Great Lakes, especially in areas polluted by agricultural runoff, sewage discharges, and wildlife excrement. The types of microbes identified as causing recent waterborne diseases in Canada in the 1990–94 period were summarized in a Canadian Public Health Association survey report commissioned by Health Canada’s Environmental Health Directorate (CPHA 1995); however, often the causative agent was not identified. These statistics indicate that the trend observed in the data for 1974–87 continued through 1990–94 (Health Canada 1995b). Most of the people who became sick (cases) were infected by a kind of bacterium that had received little attention until recently—namely, *Campylobacter jejuni* (Robertson 1995). Thus, both *Cryptosporidium* and *Campylobacter* seem to be “emerging pathogens.”

Table 16: Organisms That Cause Waterborne Diseases

Viruses	**Bacteria**	**Protozoa**	**Algae**	**Yeasts, Fungi**	**Worms**
Hepatitis A	*Escherichia coli*	*Entamoeba*	*Cyclospora*	*Candida*	Schistosomes
Norwalk	*Leptospira*	*Cryptosporidium*	*Microcystis*		
Rota	*Legionella*	*Giardia*			
Adeno	Coliforms	*Naegleria*			
Entero	*Salmonella*	*Toxoplasma*			
Reo	*Aeromonas*				
	Pseudomonas				
	Shigella				
	Staphylococcus				

Sources: Baker 1995; Burns and Reffle 1995; Health and Welfare Canada 1980, 1983a, 1983b; Jekel 1995; Stotts et al. 1993.

In many locations within and beyond the official Areas of Concern, the nearshore waters have become so polluted that they can no longer be used safely without special precautions. In addition to natural pollutants, which are found everywhere and which are not attributable to humans, the nearshore waters of the Great Lakes basin contain some disease-causing organisms—such as viruses, bacteria, protozoa, and worms—that use humans as their "home environment." Many of these organisms can also thrive in wild and domestic animals such as amphibians, reptiles, aquatic birds, and mammals (including beaver, moose, and cattle) that live, forage, or swim in lakes and streams or that otherwise frequently come into contact with water. The parasites or their cysts or eggs are then discharged into the nearshore waters in excreta or sewage. Although encountered only sporadically, some potentially fatal waterborne diseases (such as amoebiasis, hepatitis, salmonellosis, shigellosis, and Norwalk virus), as well as infectious "nuisance diseases" (such as swimmer's itch), occur in the Great Lakes basin (Health Canada 1995b).

The large human population in the Great Lakes basin produces a large amount of liquid wastes (sewage), which must be rendered harmless by mechanical, physical, and chemical processes in sewage treatment plants. In 1989, about 400 sewage treatment plants discharged effluents into surface waters in Ontario; about a quarter of these plants exceeded Ontario's effluent-quality guidelines. Fifty plants had failed to meet the guidelines for three successive years, but most of them had improvements planned or under way. In 1992, 120 of the 490 treatment plants did not comply with Ontario guidelines. In the late 1980s, the Ontario waste treatment plants discharged about 8 million m^3 of untreated (bypass) wastes annually—that is, about 3 percent of the total annual effluent volume (which is about 230 million m^3). Some sewage treatment plant discharges are not disinfected before release, and thus contribute to the nearshore waters' pathogen load (Ontario Ministry of Environment 1991; Payne and Sumi 1994). In addition, some sewage plant effluents, especially those carrying industrial wastes, are toxic to algae and probably also to other aquatic organisms (Wong et al. 1995). Other effluents, such as urban storm water and agricultural runoff, also contain toxic chemicals (Pitt et al. 1995). The chemical disinfectants used to kill pathogens in sewage and in drinking water also can create toxic by-products (Cotruvo 1985; Dunnick and Melnick 1993). These toxins are in addition to those found naturally in surface waters. In densely settled and heavily used areas, such as the St. Clair–Detroit River channel, the numbers and kinds of toxic chemicals found even in treated waters can be considerable (Roberts et al. 1986). The leaching of components of the materials used for water distribution and storage systems can further contribute to the mix of chemicals in the water (Health and Welfare Canada 1983a).

Recreational use of nearshore waters for purposes such as bathing, boating, windsurfing, and fishing may result in exposure to microbial pathogens. The pathogens in Canadian recreational waters and the health concerns associated with them, as well as relevant epidemiological data, were reviewed by Health Canada in 1978 and 1980 (Health and Welfare Canada 1978, 1980). A preliminary and now outdated Canadian study of illnesses among 479 swimmers and 39 non-swimmers at public beaches on Lakes Erie, Huron, and Ontario found only an insignificant difference in the incidence of illnesses (18.6 percent vs. 12.8 percent) between these two groups—mainly eye, ear, nose, respiratory, and gastrointestinal ailments. Illnesses in the last two categories were more common among non-swimmers (Health and Welfare Canada 1980). A more recent study was carried out by Seyfried et al. (1985a, 1985b). There is a need for more studies of this kind.

One of the most important microbial and chemical stressors of the Great Lakes nearshore waters is sewage. The population in the Great Lakes basin and the recreational use of nearshore waters have increased considerably during the past 15 years; at the same time, the construction and maintenance of wastewater and drinking-water treatment plants has been adversely affected by the continuing economic crisis in this region (Payne and Sumi 1994). The public therefore needs to be better educated about the potential hazards of using polluted waters for recreation. Health Canada reviewed the problems of municipal wastewater disinfection in Canada more than 10 years ago (Health and Welfare Canada 1984).

It is still difficult and costly to reliably identify pathogenic bacteria, viruses, and other pathogens in water samples (Baker 1995; Bitton et al. 1995); this fact probably explains in part the scarcity of statistics on the occurrence of pathogens in Great Lakes basin waters. Similarly, very little information exists about the relationship between (a) the presence of pathogens in recreational and drinking water and (b) illnesses caused by those pathogens. It is thus not possible to cite appropriate health effects indicators in the form of adequate epidemiological studies, as recommended by the Council of Great Lakes Research Managers (IJC 1991a). In Canada, the prevalence of some waterborne diseases, such as toxoplasmosis, is still unknown, though one Canadian study found antibodies to this parasite in more than a quarter of adults tested ("Outbreak..." 1995). But some indirect indicators related to the microbial quality of nearshore waters are available—for example, counts of *E. coli* or of faecal coliform bacteria (both of which are thermotolerant) in recreational waters and counts of concomitant beach closures.

8.2 Beach Closures

Many Great Lakes beaches are used extensively for bathing from June through August. But the water along some stretches of shoreline has become polluted, rendering beaches there unfit for bathing. In Canada, the microbial quality of public Great Lakes beaches is regularly assessed during the bathing season by public health authorities, who determine the numbers of the bacterium *Escherichia coli* (*E. coli*) or of similar (faecal coliform) bacteria in the waters near public beaches. Beach closures can therefore serve as an indirect indicator of excessive bacterial contamination of nearshore waters near beaches. But water sampling and microbiological testing procedures have not yet been standardized across the Great Lakes. There are many different kinds of beaches, and the kinds and levels of microbes found at a given beach vary with local sources of contamination (e.g., storm-sewer outfalls, agricultural wastes), with the water currents and water temperature, with nutrient levels, with the numbers of beach users, and with other factors. It is therefore not yet possible to be sure of patterns or trends in the microbial quality of nearshore waters at public beaches across the Great Lakes, or even at any given beach. In addition, the "safe" (guideline) levels for microbially "safe" recreational water have changed over the years; these guidelines may also vary among different jurisdictions. Therefore, the methods used to assess the microbial quality of public beaches need to be standardized.

In Canada, the microbiological and chemical requirements for ensuring safe recreational and drinking water are laid down in *Guidelines for Canadian Recreational Water Quality* (Health and Welfare Canada 1992) and in *Guidelines for Canadian Drinking Water Quality* (Health Canada 1996). Corresponding federal guidelines apply in the U.S. portion of the Great Lakes basin.

Public health units in Ontario now use a mean level of 100 *E. coli* per 100 mL of water as a guideline for determining whether recreational water is "safe." The Canadian federal guideline uses a level of 200 *E. coli* per 100 mL. Counts at both federal and provincial levels are mean values based on at least five samples. There are no guidelines for viruses. If the guideline level is exceeded at a beach, warnings are posted and the affected beach is considered "closed" until the water quality improves. The terms *beach posting*, *beach closing*, and *beach advisory* are often used interchangeably; each indicates that an advisory sign has been posted at a beach to inform users that a microbial or chemical hazard exists. At some beaches, such warnings are posted permanently—for example, when it is not feasible to determine when the water-quality impairments will no longer exist.

New procedures are needed to decrease the time required to assess the quality of beach water, improve public health protection and minimize unnecessary beach closures. The Rapid Beach Detection Study for the Greater Grand Bend Region (Ontario) is field testing a rapid (1-6 hr.) *E. coli* detection method. Health Canada has a major funding role in the partnership which includes the Village of Grand Bend, Town of Bosanquet, Township of Stephen, Ausable Bayfield Conservation Authority, Environmental Youth Corps, Ontario Ministry of Environment and Energy, and the Greater Grand Band Economic Development Office.

The numbers in Table 17 suggest that the use of recreational waters at public beaches on the north shores of Lakes Erie and Ontario—and, to a lesser extent, on the north shore of Lake Huron—has been significantly impaired by bacterial contamination in recent years.

Table 17: Closures of Great Lakes Beaches in Ontario (Chiefly Because of Microbial Contamination), 1986–1994

Lake	Total Number of Beaches on the Lake	Number of Beaches on the Lake with "Closure Notices"	Percentage of Beaches on the Lake with "Closure Notices"
	1986–1994		
Superior	15	1	7
Huron	156	33	21
Erie	86	38	44
Ontario	112	89	79
Total	369	161	44

Public beaches on rivers that empty into the Great Lakes are also affected. A 1993 study of 18 beaches on the Thames River that were used by residents of London, Ontario, showed that 10 of the 18 sites studied exceeded geometric mean counts of 100 *E. coli* per 100 mL up to fivefold; levels at 3 of the sites were grossly above this standard, with counts of up to 3,330 *E. coli* per 100 mL (Burns and Reffle 1995). The authors concluded that none of the 8 locations within the London city limits were suitable for sustained public recreation, given the presence of 250 sanitary and storm-sewer outfalls directing wastes into the Thames River system.

In the United States, each of the states monitors a portion of the bathing beaches within its jurisdiction to help ensure that bathers are protected from contact with polluted water. In 1981–94, the U.S. Environmental Protection Agency's Great Lakes National Program Office (USEPA-GLNPO 1995) collected information about Great Lakes bathing beaches from state, county, and city health departments that were responsible for overseeing beaches. This information, which covered most of the beaches used by the public for bathing both now and in the past, forms the basis for this discussion.

The total number of recognized U.S. Great Lakes bathing beaches rose gradually over the period in question, from 491 in 1981 to 585 in 1994. The increase reflects the reporting authorities' recognition that bathing occurs at beaches other than those officially designated as bathing beaches. Part of the increase can also be attributed to the subdividing of large beaches into smaller, named sections for operational purposes. The number of recognized bathing beaches that were monitored to determine their suitability for use by the public was 300 in 1981, averaged about 336 in 1982–87, rose to 395 in 1988, and then declined irregularly to 276 in 1994. The number of monitored beaches that were closed or use-restricted one or more times a year averaged 76 in 1981–83, dropped to 16 in 1984, and then varied without trend (averaging about 55) in 1984–94. In some cases, the changes reflect the cessation of monitoring at beaches that consistently showed no pollution problems. In other cases, some beaches that were continuously polluted were permanently closed and no longer monitored.

There are 83 U.S. counties represented in the USEPA-GLNPO survey. In 1981–94, 42 of these counties reported that they had had no beach closings due to pollution. Beach closings in the other 41 counties varied widely (Table 18). Only 2 of the 15 counties bordering Lake Superior reported pollution problems; similarly, 17 of the 33 counties bordering Lake Michigan, 6 of the 13 counties bordering Lake Huron, 2 of the 2 bordering Lake St. Clair, 11 of the 13 bordering Lake Erie, and 4 of the 8 bordering Lake Ontario reported closings. Closings were generally fewer in northern counties, where human population density was low and there was little industrial development; conversely, more closings occurred in southern counties, where the shoreline was more intensively developed, population density was high, and there was extensive industrial development.

Table 18: Status of Bathing Beaches in U.S. Waters of the Great Lakes, 1981–1994

Lake	State	County	Present condition						Comment
			Good	Mixed	Poor	Restored	Improving	Deteriorating	
Superior	MI	Alger		x					CSO; one of five beaches closed 1981-84; no closings 1985-89; no beaches now monitored.
	WI	Ashland		x					Two of six beaches monitored; both monitored beaches closed by pollution in 1994.
Michigan	IL	Cook	x				x		Thirty-six beaches; CSOs; Chicago sanitary canal lock opening to Lake Michigan; remediated.
		Lake			x				AOC (Waukegan Harbor); Chicago sanitary canal locks opening to Lake Michigan; industrial area.
	IN	Lake			x				AOC (Gd. Calumet River-Indiana Harbor Ship Cana); industrial pollution and permanent closings.
		La Porte		x			x		Both beaches relatively free of pollution; no closings in 1992-1994.
		Porter		x				x	Four of eight beaches frequently closed; frequency of closing increasing.
	MI	Berrien	x			x			Sewage lagoon discharge closed 1 of 26 beaches in 1986.
		Charlevoix	x			x			Bunker oil closed only beach for two days in 1985.
		Gd. Traverse	x			x			One of 14 beaches closed in 1992-93 due to pollution.
		Oceana	x			x			Medical waste; all six beaches closed one day in 1988; no monitoring.
		Ottawa		x			x		CSOs in Grand Rapids; retention basin built in 1991; four CSO overflows and closings in 1994.
		Van Buren	x						One of two beaches closed for one day in 1993 and 1994; cause unknown; no monitoring.

Lake	State	County	Present condition						Comment
			Good	Mixed	Poor	Restored	Improving	Deteriorating	
	WI	Brown			x				AOC (lower Green Bay and Fox River); only beach closed since 1944 by pollution; no monitoring after 1992.
		Kenosha			x				CSOs; all five beaches closed for 48 hours after heavy rain for 13 of 14 years.
		Milwaukee		x				x	AOC (Milwaukee estuary); eight beaches; pollution closed beaches in early 1980s and in 1992-94.
		Oconto	x						No monitoring; one beach closed in 1989.
		Racine			x				All beaches closed annually by pollution in 1990-94.
Mi-Huron	MI	Mackinac		x					One of six beaches closed since 1990 due to ruptured sewer line.
Huron	MI	Alpena	x			x			Algae on one of five beaches in 1981-82.
		Bay	x			x			AOC (Saginaw River and Bay); three of six beaches closed by pollution in 1989; some algae.
		Cheboygan	x			x			No monitoring after 1987; one beach closed in 1994.
		St. Clair	x			x			AOC (St.Clair and Clinton rivers); two of five beaches closed for high fecal coliform levels in 1982.
		Sanilac		x				x	Sewage lagoon dumping; major spill of cow manure; no monitoring.
St. Clair	MI	Macomb		x				x	AOC (Clinton River); all four beaches frequently closed by industrial pollution in St. Clair River.
		Wayne		x				x	AOC (Rouge and Detroit rivers); high fecal coliform; two or three of four beaches closed in 1992-94.
Erie	MI	Monroe	x			x			AOC (Raisin River); one of eight beaches closed in 1988; limited monitoring.
	NY	Chatauqua	x			x			One of 18 beaches closed in 1983.

Lake	State	County	Present condition						Comment
			Good	Mixed	Poor	Restored	Improving	Deteriorating	
		Erie	x						AOC (Buffalo and Niagara rivers); closings for high (storm) turbidity; medical wastes in 1988-89.
	OH	Ashtabula		x				x	AOC (Ashtabula River); all five beaches closed following heavy rains in 1992-93; three closed in 1994.
		Cuyahoga		x				x	One of four beaches closed for six years in 1980s; all four closed by pollution in 1993-94.
		Erie	x			x			Thirteen of 29 beaches closed in 1983; problems at 16 in 1984 no closings reported in 1989-94.
		Lake		x				x	All five beaches closed in 1992-94.
		Lorain			x				AOC (Black River basin); pollution problems at all beaches in 1992-94.
		Lucas			x				AOC (Maumee River); pollution closed both beaches several times in 1992-94.
		Ottawa		x				x	Pollution from waste water treatment plant closed one beach; other sources affect other beaches.
	PA	Erie		x				x	AOC (Presque Isle Bay); 18 of 24 beaches have had pollution problems and closings in 1981-94.
Ontario	NY	Jefferson	x						One of four beaches closed once due to waste discharge from ship.
		Monroe			x				AOC (Rochester embayment); the one beach is closed periodically by storm runoff or algae blooms.
		Oswego	x						AOC (Oswego River Harbor); one of seven beaches closed once in 14 years.
		St. Lawrence	x						Sewer eruption closed one of seven beaches in 1987.

Source: W. Jacobson, USEPA-GLNPO, Chicago, Illinios

Present conditions at U.S. bathing beaches that have records of closings range from good to poor; some beaches have been restored from earlier polluted conditions, some are improving, and others are deteriorating (Table 18). On Lake Superior, conditions in two counties were mixed. On Lake Michigan, beach conditions were good in seven counties, mixed in seven, and poor in five; four had been restored, three were improving, and two were deteriorating. On Lake Huron, four were good and two were mixed; four were restored and one was deteriorating. On Lake St. Clair, two were mixed and deteriorating. On Lake Erie, four were good, five were mixed, and two were poor; three had been restored and five were deteriorating. On Lake Ontario, three were good and one was poor.

Sewage and industrial pollution are the most common causes of beach closings (Table 18). Combined sewer overflows (CSOs) are a common source of sewage. High faecal coliform levels were reported as a problem in some areas. Spills or discharges from ships occurred infrequently, as did dumping of medical wastes. High turbidity following storms was responsible for closings in one county. Closings occurred frequently in Areas of Concern (AOCs). These areas are under scrutiny; plans are being developed and actions taken to remediate or restore them.

An unusual and reasonably well-documented beach closing occurred at Metropolitan Beach on Lake St. Clair in 1994. The beach was closed for much of the summer in 1994 because large amounts of submersed aquatic vegetation had become stranded there and on adjacent portions of the Michigan shoreline in late spring and early summer. The stranded and floating mats of plants reduced circulation in the nearshore areas, and coliform bacteria reached high levels in these areas. Waterweed was the principal plant stranded on the Michigan shoreline. A similar plant-stranding problem occurred on Lake Ontario's shoreline in summer 1994. There, naiad was the main problem plant. Waterweed and naiad were among the most abundant plants in the lake in 1995 (Edsall et al. 1996; Schloesser et al. 1996). The Michigan strandings were attributed to higher-than-normal water clarity and to an excess of nutrients; both conditions promoted greater-than-normal plant growth. The higher water clarity was attributed to the recent colonization of the lake by the zebra mussel, which feeds by filtering particles from the water; this process makes the water clearer and lets light penetrate to greater depths, thus promoting more widespread plant growth. A recent lakewide survey (Schloesser et al. 1996) shows that water clarity is high and that submersed plants are now more abundant in Lake St. Clair than in 1978; plants are now present almost everywhere in the lake where light reaches the lake bed. Nitrogen and phosphorus were higher near Metropolitan Beach and the adjacent mouth of the Clinton River Cutoff channel than elsewhere in Michigan waters of the lake (Edsall et al. 1996). The Clinton River is an IJC Area of Concern. Leaking septic tanks and CSOs in the river basin contribute nutrients to the river. No major plant strandings or beach closings occurred in Michigan waters of the lake in 1995, and plant biomass in April-July 1996 was low—probably due to cold spring weather (T. Edsall, unpublished data).

8.3 Drinking Water

This section will focus on problems related to toxic contaminants created during drinking-water disinfection, especially as a result of chlorination.

A comprehensive survey of the status of Great Lakes drinking water was carried out in 1984 and published by the Canadian Public Health Association two years later (CPHA 1986). The authors concluded that treated and tap waters met microbial standards and objectives, and that while chlorination led to increased concentrations of chloroform and other chlorination by-products in tap water, it also reduced the numbers of bacteria essentially to zero for *Escherichia coli* and coliform bacteria. Noting that there were significant data gaps for radiological and organic water-quality parameters, the report recommended that these data gaps should be filled; it also stated that there was a need to ensure a consistent level of water-quality testing effort (CPHA 1986).

Sewage water and drinking water are usually disinfected through the use of such chemicals as chlorine (as Cl_2 gas or chloramine, alone or in combination with ozone). These chemicals, which are very reactive, will attack not only microbes but also any other organic materials in the water (Bunce 1990). The resulting chemical reactions can produce a great variety of toxic chemicals from naturally occurring precursors such as humic and fulvic acids; the products vary with the types and amounts of organic materials present, as well as with the water temperature and with other seasonal factors. It is therefore very difficult to predict the kinds and amounts of by-products (Thomas et al. 1995). Small amounts of some of these chemicals can also be formed in nature; in some groundwaters, they may persist for many years (Asplund et al. 1989). The best-known of these by-products are chloroform, other halomethanes, and haloacetic acids. Though some of the disinfection by-products may occur only in minute quantities, even those tiny amounts may be very toxic. For instance, 3-chloro-4-dichloromethyl-5-hydroxy-2(5H)-furanone may account for only 0.01 percent of the by-products, but may be responsible for 50 percent of the mutagenic activity (Kronberg et al. 1990; Thomas et al. 1995).

Health Canada carried out its first comprehensive survey of halomethanes in drinking water in 1977 (Health and Welfare Canada 1977). The survey showed that the concentration of these chemicals increased within the drinking-water distribution system from the treatment plant to the consumers and that chloroform concentrations reached up to 121 g/L. Since then, several other such surveys have been performed with similar results.

Chloroform is the most common trihalomethane; it can cause cancer and possibly also slows fetal growth (Dunnick and Melnick 1993; Kramer et al. 1992). The World Health Organization has set its guideline for chloroform at 200 g/L, which still ensures proper disinfection of the water (WHO 1993). The U.S. Environmental Protection Agency set a standard of 100 g/L, based on animal studies (Henshaw et al. 1993). The latest Canadian drinking-water guidelines (Health

Canada 1996) set an interim maximum acceptable concentration of 100 g/L for total trihalomethanes (THMs).

A list of chlorination by-products found in 1993 in Canadian drinking water that had been disinfected with chlorine or with chlorine-releasing chemicals is shown in Table 19 (Williams et al. 1996). Chloroform, dichloroacetic acid, and trichloroacetic acid—the major contaminants found—generally occurred in the highest concentrations and were found in all treated-water samples; haloacetic acid concentrations often equalled or exceeded total trihalomethane concentrations. In addition, trihalomethane concentrations were higher during the summer than during the winter regardless of the chlorination process used, and tended to increase as the water moved along the distribution system. Until recently, only trihalomethanes and related compounds were thought to be of concern among the by-products of water disinfection. But these and other recent findings point out the need for further studies to clarify regional and seasonal variations in the levels of water disinfection by-products.

Maximum acceptable concentrations (MACs) for some of these contaminants in drinking water have been published by the World Health Organization (WHO 1993), and updated Canadian national guidelines will be published soon (Health Canada 1996). Water disinfection by-products are also addressed in the 1994 *Ontario Drinking Water Objectives* (Ontario Ministry of Environment and Energy 1994b). The effects of drinking-water disinfection on disease outbreaks, and the complex issues involved in regulating drinking-water disinfectants and disinfection by-products, have been reviewed by Orme et al. (1991) and by Sonich-Mullen and Papa (1991).

Some of the by-products of drinking-water chlorination are mutagenic and carcinogenic (Koivusalo et al. 1995; Wigle et al. 1986). For this reason, the organic by-products of chlorination are the chemicals of greatest concern in the assessment of the carcinogenic potential of chlorinated water (Dunnick and Melnick 1993; U.S. Department of Health and Human Services 1994). Velema (1987) reviews the possible carcinogenic effects of a wide range of drinking-water contaminants.

More than a dozen epidemiological studies have been carried out in North America and Europe to determine whether the consumption of water that contains chlorination by-products, especially trihalomethanes, might lead to an increased risk of cancer. The most recent of these was a case-control study carried out in Ontario; this study found that long-term consumption of chlorinated surface water with trihalomethane concentrations above 50 g/L was associated with an increased risk of bladder cancer and possibly also with an increased risk of colon cancer (Health Canada 1995c; Marrett and King 1995). The results suggest that up to 15 percent of bladder cancers that occur in Ontario may be due to chlorination by-products in drinking water. This proportion would amount to about 200 cases and about 70 deaths per year. In addition, about 350 cases of—and about 70 deaths from—colon cancer may occur annually in Ontario due to the by-products of drinking-water chlorination. Combining the estimates for the two types of cancer produces about 550 cases and about 140 deaths per year (Marrett and King 1995). Reduction of trihalomethane levels in Ontario's drinking water might therefore help reduce the incidence both of bladder cancer and of colon cancer in the province. Consumption of groundwater appears to result in lower rates of bladder cancer than does consumption of surface water. Consumers' use of carbon filters (a relatively recent phenomenon) did not appear to affect the results. Water treatment processes would therefore have to be altered at the treatment plants in order to reduce the levels of chlorination by-products and the risk of bladder and colon cancer. Some water treatment plants in Ontario have apparently already changed their treatment procedures in order to reduce trihalomethane levels in drinking water (Williams et al. 1996).

Many people living in the Great Lakes basin do not seem to think that municipal water treatment plants provide sufficiently pure drinking water: a recent study found that 18.7 percent of Ontario households surveyed used drinking-water filters or purifiers (Statistics Canada 1992). The odours and discolouration present in some public drinking-water supplies may be partly responsible for a lack of confidence in the quality of the drinking water and for the widespread use of domestic water filters. But Lévesque et al. (1994) found that three types of pathogenic bacteria (*Staphylococcus aureus*, *Pseudomonas aeruginosa*, and *Aeromonas* spp.) occurred significantly more often in water dispensers than in tap water. Unless they are properly maintained, water coolers and water filters may thus actually worsen the microbial and chemical quality of tap water.

Table 19: Chlorination By-products Found in Canadian Drinking Water

Chemical	Concentration g/L (= ppb)	Percentage of Samples That Were Positive	Guideline g/L
Halomethanes			
Bromodichloromethane	0.5–3.9	–	60 (WHO)
Bromoform	< 0.1–3.3	–	100 (WHO)
Chloral hydrate	< 0.1–22.5	94	10 (WHO)
Chlorodibromomethane	< 0.1–2.9	–	100 (WHO)
Chloroform	0.5–15.5	100	200 (WHO)
Haloacetic acids			
Bromoacetic acid	< 0.01–9.2	31	
Chloroacetic acid	0.3–9.7	100	
Dibromoacetic acid	< 0.01–1.9	62	
Dichloroacetic acid	0.2–163.3	100	50 (WHO)
Trichloroacetic acid	0.1–273.2	100	100 (WHO)
Haloacetonitriles			
Bromochloroacetonitrile	< 0.1–0.9	92	
Dibromoacetonitrile	< 0.1–1.2	57	
Dichloroacetonitrile	< 0.1–12.6	97	90 (WHO)
Trichloroacetonitrile	< 0.1	9	
Other			
Dichloropropanone	< 0.1–3.7	93	
Trichloronitromethane	< 0.1–2.5	73	
Trichloropropanone	< 0.1–10.4	91	

Source: Williams et al. 1996.

8.4 Fish Consumption Advisories

Fish from contaminated sites may contain high levels of toxic bioaccumulating contaminants, and may show elevated levels of abnormalities, including tumours (see Tables 12 through 15 of this paper, and Dawe et al. 1991). These levels of toxins and abnormalities, along with a variety of striking abnormalities that have been observed in fish-eating birds and mammals, have raised concerns that eating Great Lakes fish may lead to health effects in people who eat large amounts of such fish. Provincial governments and state governments in the Great Lakes region have therefore issued sportfish consumption guidelines such as the 1995–96 *Guide to Eating Ontario Sport Fish* (Ontario Ministry of Environment and Energy 1995).

The human health studies that have looked at the levels of exposure of anglers and other people who eat Great Lakes fish to toxic bioaccumulating contaminants found in such fish or in game were reviewed in a recent report (USEPA-GLNPO 1995). This report points out that populations in the Great Lakes basin rely on the nearshore waters for numerous residential, commercial, and recreational uses, and that most of the data available on human exposure to toxic substances in the Great Lakes come from analyses of contaminant levels in drinking water and in sport fish. Only very limited information is available about the health risks associated with exposure to such contaminants.

There is sufficient evidence that consumption of contaminated sport fish and wildlife can significantly increase human exposure to Great Lakes pollutants. A spectrum of major contaminants have been identified in cooked Great Lakes fish, and methods have been recommended for reducing the amounts of contaminants by judiciously preparing and cooking the fish (Skea et al. 1979; Voiland et al. 1991; Zabik and Zabik 1995; Zabik et al. 1995). Investigators have demonstrated that blood serum levels of these contaminants are significantly increased in consumers of Great Lakes sport fish as compared with the levels in non-fisheaters (Humphrey 1983a, 1983b; Jacobson et al. 1989; Kearney et al. 1995). Also, several investigators have shown that exposure from fish far outweighs exposure from atmospheric, terrestrial, or water-column sources (Humphrey 1983b; Swain 1983). The exposure patterns associated with the different pathways may vary for different populations, especially those living in the vicinity of industrial sites, such as refineries or smelters.

Several epidemiological studies have investigated the association between water pollutants in the Great Lakes and the health of residents who live on or near the lakes. The following studies have demonstrated increased tissue levels of toxic substances (body burdens) that may be associated with reproductive, developmental, behavioural, neurological, endocrinological, and immunological effects:

Michigan Maternal and Infant Study (Fein et al. 1983)

Michigan Sports Fisherman Study (Humphrey 1976)

Minnesota Ecologic Epidemiologic Study (Schuman et al. 1982)

New York Ecologic Epidemiologic Study (Kagey and Stark 1992)

Dar's Wisconsin Maternal and Infant Study (Dar et al. 1992)

Wisconsin Sports Fish-Consumers Study (Fiore et al. 1989; Sonzongni et al. 1991)

Smith's Wisconsin Maternal and Infant Study (Smith 1984)

Other epidemiological studies of mothers exposed to toxic substances similar to those identified in Great Lakes fish showed either reproductive and developmental or neurobehavioural effects in their children. These studies include the following:

Japan and Taiwan PCBs Studies (Hsu et al. 1985)

The North Carolina Breast Milk and Formula Project (Rogan et al. 1986)

Occupationally Exposed Female Capacitor Workers (Taylor et al. 1989)

The limitations of these human health studies have been documented. They include concerns about laboratory techniques and sensitivity in some studies; concerns about sample size, non-random sampling techniques, recall bias, and uncontrolled confounders were noted in other studies. Despite such limitations, epidemiological studies of exposed human populations provide the most convincing evidence of human health effects.

The most direct evidence for adverse human health effects from environmental pollution is found in a series of studies linking PCB exposure to consumption of contaminated fish (Fein et al. 1984; Jacobson and Jacobson 1988; Jacobson et al. 1984a, 1984b, 1984c). Replicating and continuing these types of epidemiological studies should provide the most relevant and convincing evidence regarding the status of human health following exposure to Great Lakes pollutants.

More recent ongoing human health studies in the United States and Canada were designed to build on and extend these earlier studies. Further, the later studies were designed to control various limitations that had hampered the previous health studies in the Great Lakes. Most of these studies were begun just a few years ago and are not yet complete. Preliminary findings do support earlier reports of an association between the consumption of contaminated Great Lakes fish and body burdens of persistent toxic substances, including PCBs, other organochlorines, heavy metals such as mercury and lead, and PAHs. The body burdens for such substances that have been identified in the fluids and tissues of fish consumers are three- to fourfold higher than those in the general population. Additionally, some preliminary data support the earlier observations of both neurobehavioural and developmental deficits associated with the consumption of contaminated fish.

Most of these more recent human health studies target populations that are presumed to be particularly susceptible—that is, Native North Americans, sport anglers, the urban poor, pregnant women, and fetuses and nursing infants of mothers who consume contaminated Great Lakes fish. Focusing our efforts on such at-risk populations offers the best opportunity to address the important public health questions that remain unanswered regarding exposure to chemical contaminants in the basin. Results from the following studies are not yet available:

> An Assessment of a Human Population at Risk: The Impact of Consuming Contaminated Great Lakes Fish on Native American Communities (University of Wisconsin–Superior & Milwaukee)
>
> Cognitive and Motor Effects of PCB Exposure in Older People from the Michigan Fisheater Cohort: Emphasis on the Role of Ortho-Substituted Congeners (University of Illinois at Urbana-Champaign)
>
> Consortium for the Health Assessment of Great Lakes Sport Fish Consumption (Wisconsin Department of Health and Social Services)
>
> Contribution of Nursing to Behavioral Changes in Children of Mothers Who Consumed Lake Ontario Fish: Two Methodological Approaches (State University of New York at Oswego)
>
> Great Lakes Fish as a Source of Maternal and Fetal Exposure to Chlorinated Hydrocarbons (University of Illinois at Chicago)
>
> Health Risks from Consumption of Great Lakes Fish (Michigan State University)
>
> The New York State Angler Study: Exposure Characterization and Reproductive and Developmental Effects (State University of New York at Buffalo)
>
> PCB and DDE Exposure among Native American Men from Contaminated Great Lakes Fish and Wildlife (New York State Department of Health)

In 1992–93, Health Canada carried out an exposure study on 176 adult men and women from Mississauga, Ontario, and Cornwall, Ontario. Many of these people had been eating fish from Lake Ontario or from the St. Lawrence River for many years. They were compared to 56 men and women who ate no Great Lakes fish (the controls) (Kearney et al. 1995). Analysis of blood samples showed that most of the fisheaters had PCB levels in blood plasma that were well below those seen in other fisheater studies; only four participants slightly exceeded Health Canada guidance levels of 20 g/L. Mean blood plasma levels of organochlorine pesticides were lower than mean levels seen in other studies of fisheaters. Levels of chlorinated dibenzofurans and dibenzodioxins were also low, and appeared to be strongly correlated with age—that is, older people generally had higher blood plasma levels than did younger people. Total blood mercury and methylmercury levels were also low and below Health Canada's guideline value. Blood cadmium levels reflected mainly tobacco consumption levels. No relationships were found between fish consumption and liver plasma enzyme levels, thyroid hormones, urinary porphyrins, or urinary d-glucaric acid levels. Urinary cotinine was an effective biomarker for tobacco-smoking status. The small differences between fisheaters and controls did not warrant further health studies of fisheaters in the study areas.

Health Canada is currently conducting a pilot dietary and fish consumption study on Asian immigrants in the Toronto area (a group thought to have a high level of fish consumption), as well as a shoreline angler survey in the Toronto–Hamilton, Niagara, and Windsor areas. These studies may provide further insight into the fish consumption habits of various population groups and into the possible benefits and risks of eating fish from the Great Lakes.

In Canada, the Ontario Ministry of the Environment and Energy's Sport Fish Contaminant Monitoring Program has measured contaminant concentrations in fish from the Ontario nearshore waters of the Great Lakes for more than 20 years. The results have been used to provide consumption advice to the public.

Most fish are collected by the Ministry of Natural Resources. When possible, researchers catch 20 fish of each species with lengths and weights representative of the size range of the species in the location being tested. The length, weight, and sex of each fish are recorded and a skinless, boneless fillet of the dorsal muscle is removed from the fish, packaged, and frozen for shipment to MOEE laboratories for analysis. This sample portion provides the most consistent test results and is also the best edible portion of the sport fish.

All fish are analysed for mercury. Depending on the location being studied, analyses may also be done for PCBs; pesticides (including DDT and toxaphene); mirex; dioxins and furans; metals (such as lead); PAHs; chlorinated phenols; and chlorinated benzenes.

The consumption advice provided to the public in the *Guide to Eating Ontario Sport Fish* (Ontario Ministry of Environment and Energy 1995) is based on the health protection guidelines developed by Health Canada. The advice is phrased as a maximum number of recommended meals per month; consumption categories are eight meals, four meals, two meals, one meal, and no meals per month. Consumption advice specifies the species of the fish, the length of the fish, and the location where the fish is caught.

The *Guide*'s advice is designed to apply to anglers who consume moderate amounts of fish. The consumption advice will protect individuals who follow the *Guide*'s advice and consume no more than eight sportfish meals per month. Health Canada guidelines have been developed to protect the health of the most sensitive individuals, generally considered to be children and pregnant women. But as an added precaution, the *Guide* recommends that women of childbearing age and children under 15 avoid consuming any fish that falls into the one-meal-per-month category as well as any fish in the restricted category.

For the Great Lakes, consumption advice is provided for blocks or regions of each lake. Contaminant levels for all fish of a given size and species should be similar throughout a block. The blocks' boundaries were established in consultation with fisheries biologists who are familiar with local fish populations and after comparing contaminant levels in fish from several adjacent locations.

Consumption advice is provided on a wide variety of sport fish species. For the purposes of this paper, lake trout were chosen as an indicator species for the coldwater fishery because of their distribution across all Great Lakes. Additionally, because of their high fat levels, lake trout are particularly useful as monitors of organic contaminants such as PCBs, mirex, and toxaphene. Lake trout in a size class (55–65 cm) that would typically be kept and consumed by anglers were selected for this assessment.

A summary of the 1995–96 consumption advisories for 55-cm to 65-cm lake trout in the Canadian waters of the Great Lakes is given in Figure 24. The consumption categories of four meals, two meals, and one meal per month are shown as "limited" consumption. The eight-meal-per-month category is shown as "not restricted." Table 20 identifies the contaminant or contaminants causing the consumption restrictions.

In Lake Superior, lake trout in the 55-cm to 65-cm size class are safe to consume in limited amounts in the western end of the lake. In the eastern end of the lake, in the open waters from Sewell Point to Batchawana Bay, as well as in the waters of Thunder Bay's outer harbour, consumption of 55-cm to 65-cm lake trout is not advised. The principal contaminant causing these consumption restrictions is toxaphene. Dioxins are a concern in specific locations, such as Jackfish Bay, as well (Table 20).

In Lake Huron, 55-cm to 65-cm lake trout are not restricted for consumption in the North Channel, in the open waters south of Manitoulin Island, and in Georgian Bay. Where data exist, "limited" consumption restrictions are in place for lake trout down the length of the eastern shore of Lake Huron, from Fitzwilliam Island to north of Grand Bend (blocks H2 and H4 in Figure 24). PCB is the principal contaminant of concern causing these consumption restrictions.

In Lake Erie, information on contaminants in lake trout is limited to the eastern end of the lake. A "limited" consumption advisory is in place for lake trout from Long Point Bay and in Lake Erie east of Long Point Bay (Figure 24). Again, PCB is the contaminant causing the consumption restrictions.

At all locations in Lake Ontario and the Niagara River for which information is available, a “limited” consumption advisory is in effect for 55-cm to 65-cm lake trout (Figure 24). PCB is the principal contaminant of concern causing the consumption advisories, with levels of mirex and dioxin also of concern in certain locations (Table 20).

No single species of fish is suitable as an indicator of the warmwater/coolwater fishery because none are distributed across all locations in the Great Lakes. Consequently, for the purposes of this paper, smallmouth bass (30 cm to 35 cm), walleye (35 cm to 45 cm), and yellow perch (20 cm to 25 cm) were chosen as indicators. Fish from these size classes were chosen for assessment as being representative of sizes of fish that would typically be kept and consumed by an angler.

A summary of the 1995–96 consumption advisories for 30-cm to 35-cm smallmouth bass, 35-cm to 45-cm walleye, and 20-cm to 25-cm yellow perch in the Canadian waters of the Great Lakes is given in Figure 25. Where information on more than one of the species is available, the most restrictive consumption advisory is given. In this figure, the consumption categories of four meals, two meals, and one meal per month are shown as “limited” consumption. The eight-meal-per-month category is shown as “not restricted.” Table 20 identifies the contaminant or contaminants causing the consumption restrictions.

Table 20. Consumption Advisories for Selected Great Lakes Fish

Lake	Zone[1]	Coldwater Consumption Advisory[2]	Reason for Advisory	Warmwater Consumption Advisory[3]	Reason for Advisory
L. Superior	1	limited	toxaphene	not restricted	—
	2	not advised	toxaphene	not restricted	—
	3	no data	—	not restricted	—
	4	no data	—	no data	—
	5	limited	toxaphene	no data	—
	6	limited	toxaphene	not restricted	—
	7	limited	toxaphene	limited	Hg
	8	limited	dioxin	no data	—
	8a	limited	toxaphene	no data	—
	9	not advised	toxaphene	no data	—
	10	not advised	toxaphene	no data	—
	11	no data	—	not restricted	—
St. Marys R.		no data	—	not restricted	—
L. Huron	NC1	not restricted	—	not restricted	—
	NC2	not restricted	—	not restricted	—
	GB1	no data	—	no data	—
	GB2	no data	—	no data	—
	GB3	not restricted	—	not restricted	—
	GB4	no data	—	not restricted	—
	H1	not restricted	—	not restricted	—
	H2	limited	PCB	no data	—
	H3	no data	—	limited	Hg
	H4	limited	PCB	no data	—
	H5	not restricted	—	not restricted	—
St. Clair R.	7a	no data	—	not restricted	—
	7b	no data	—	not restricted	—
	7c	no data	—	not restricted	—
Lake St. Clair	6	no data	—	not restricted	—
Detroit R.	5a	no data	—	limited	PCB
	5b	no data	—	not restricted	—
L. Erie	1	no data	—	not restricted	—
	2	no data	—	not restricted	—

Lake	Zone[1]	Coldwater Consumption Advisory[2]	Reason for Advisory	Warmwater Consumption Advisory[3]	Reason for Advisory
	2a	no data	—	not restricted	—
	3	limited	PCB	not restricted	—
	4	limited	PCB	not restricted	—
Niagara R.	1a	no data	—	not restricted	—
	1b	limited	PCB	not restricted	—
L. Ontario	2	limited	PCB	not restricted	—
	3	no data	—	not restricted	—
	4	limited	PCB/mirex/dioxin	not restricted	—
	4a	no data	—	not restricted	—
	5	no data	—	no data	—
	6	limited	mirex	limited	Hg
	6a	no data	—	no data	—
	6b	no data	—	no data	—
	7	limited	PCB	no data	—
	8	limited	mirex	not restricted	—
	9	no data	—	not restricted	—
	10	no data	—	not restricted	—
	11	limited	PCB	not restricted	—
St. Lawrence R.	12	N/A	—	not restricted	—
	13	N/A	—	not restricted	—
	14	N/A	—	not restricted	—
	15	N/A	—	not restricted	—
	16	N/A	—	not restricted	—

[1]Zones refer to Figure 24 and Figure 25.

[2]55-cm to 65-cm lake trout, 30-cm to 35-cm smallmouth bass, 35-cm to 45-cm walleye

[3]20-cm to 25-cm yellow perch, 35-cm to 45-cm walleye, 30-cm to 35-cm smallmouth bass

N/A Not Applicable

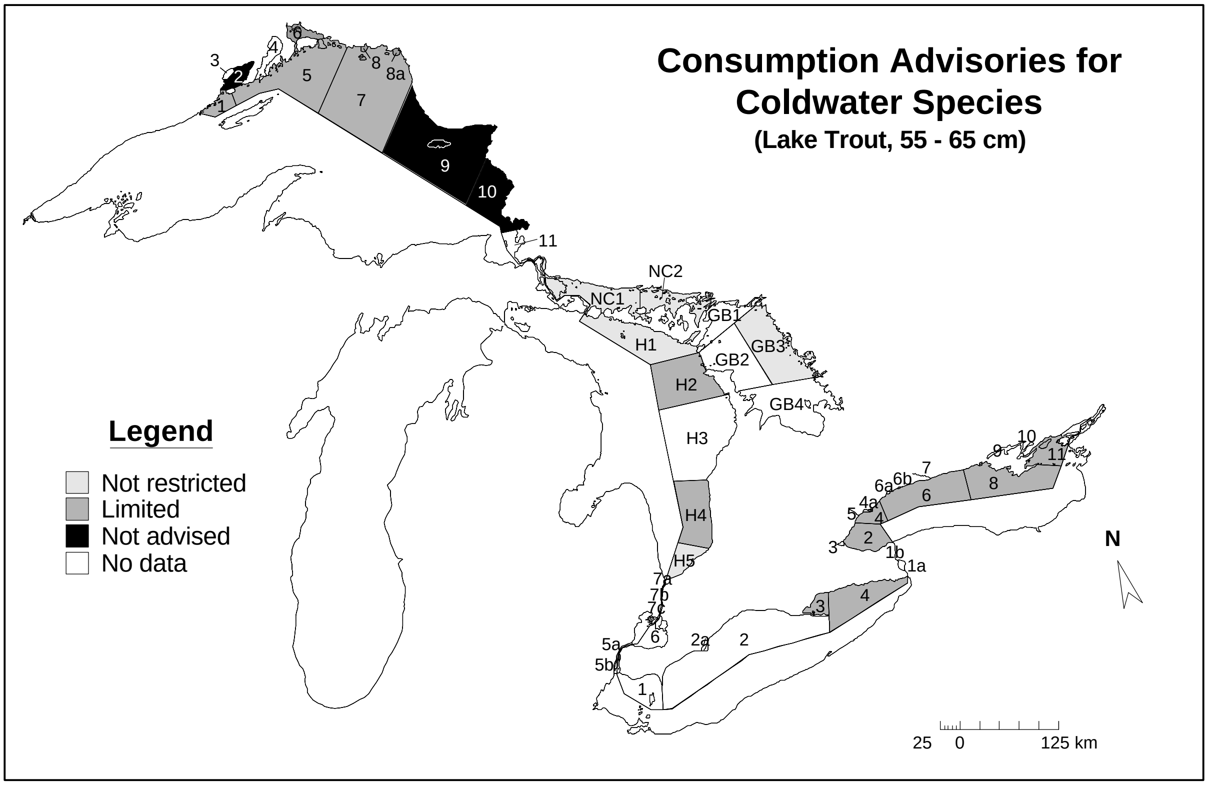


Figure 24 Fish Consumption Advisories for Coldwater Species

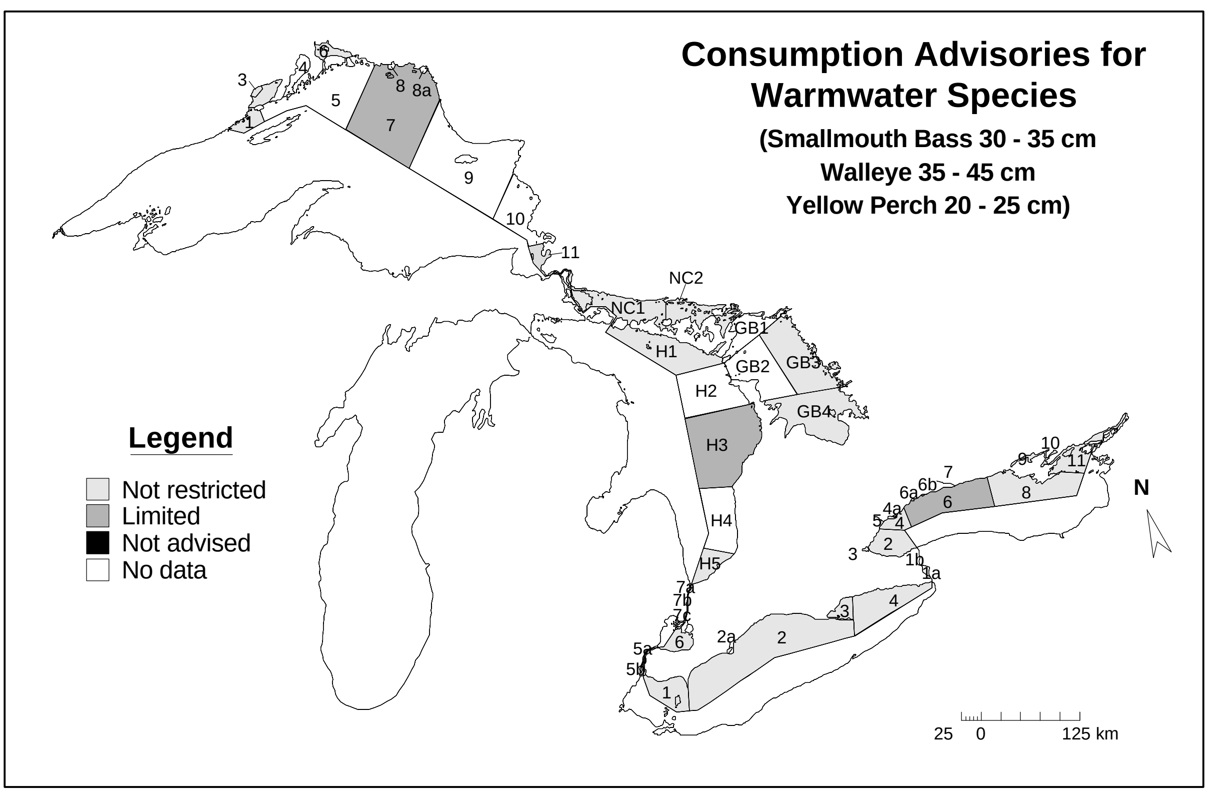


Figure 25 Fish Consumption Advisories for Warmwater Species

For Lake Superior, information on contaminants in these warmwater/coolwater indicator species exists for limited sites only. In the waters around Pie Island, Thunder Bay harbour, Nipigon Bay, and Goulais Bay, no consumption restrictions are in place for these fish species at the sizes noted. “Limited” consumption of 35-cm to 45-cm walleye in the waters from Shreiber Point to Sewell Point is advised. The contaminant of concern causing the consumption restriction is mercury (Hg).

In Lake Huron, no consumption restrictions on the indicator species in the sizes noted are in effect for the North Channel, Georgian Bay, the waters south of Manitoulin Island, or from Grand Bend to Pt. Edward. Only smallmouth bass in the waters from Stokes Bay to Point Clark (H3 in Figure 25) have a “limited” consumption advisory in place. The advisory is due to mercury.

No consumption restrictions are in effect for any of the warmwater/coolwater indicator fish species/sizes in Lake St. Clair or Lake Erie. A “limited” consumption advisory is in effect for 20-cm to 25-cm yellow perch from the upper Detroit River due to PCB.

In Lake Ontario and the St. Lawrence River, there are no consumption restrictions in effect for any of the warmwater/coolwater indicator species/sizes, except for 30-cm to 35-cm smallmouth bass caught in waters east of the Scarborough Bluffs to Colborne (Block 6 in Figure 25). The principal contaminant of concern causing the consumption restriction is mercury.

Trends in contaminant concentrations vs. time are plotted in Figure 26, focusing in each lake on the contaminants causing the current consumption restrictions in the coldwater and warmwater indicator species. Data plotted are mean measured concentrations of a contaminant for a given species across all size classes collected in a specific location vs. year of collection.

Trend information on toxaphene in Lake Superior lake trout is limited, with four observations from 1986 to 1992. No temporal trend can be identified from this information. No information is available to identify trends in mercury, the principal contaminant of concern in the warmwater indicator species.

Concentrations of PCBs in lake trout from southern Lake Huron declined from 2.6 ppm in 1976 to 0.67 ppm in 1994. Mean mercury levels in walleye in southern Lake Huron varied from 0.26 to 0.47 ppm over the period 1981 to 1992 but show no trend vs. time.

No trend information is available for the contaminant of concern (PCB) in either the coldwater or warmwater indicator species for Lake St. Clair or Lake Erie.

In Lake Ontario, good long-term trend information is available for both PCB and mirex in rainbow trout at the Ganaraska River. In both cases, concentrations declined between 1976 and the middle to late 1980s and have shown no clear trend since then. PCBs declined from 3.9 ppm in 1976 to 0.65 ppm in 1994, and mirex concentrations dropped from 0.26 ppm in 1976 to 0.06 ppm in 1994. Mean mercury concentrations in walleye in eastern Lake Ontario varied between 0.19 ppm and 0.43 ppm over the period 1981 to 1994, with no clear trend over time.

Figure 26. Trends in Contaminant Concentrations

In the United States, most Great Lakes states have been monitoring contaminants in fish and issuing fish consumption advisories since the middle 1970s. At one time, the FDA (Food and Drug Administration) action levels were the most common criteria by which the advisories were issued. As programs expanded and risk analysis became more common, the states began to re-evaluate their advisory criteria and, at times, to deviate from the FDA–action-level approach.

Because of the differences among states in criteria for issuing advice (Table 21), the states created a group known as the Great Lakes Fish Advisory Task Force. This group, which comprised health and environmental officials from each of the Great Lakes states, was charged with creating a uniform fish advisory protocol for the region. The group delivered a proposed protocol to the Council of Great Lakes Governors in September 1993. The protocol has undergone considerable debate since that time. Minnesota and Indiana have adopted the protocol for their Great Lakes waters, and Ohio has adopted a version of the protocol. The other five states continue to debate the issue.

Polychlorinated biphenyls (PCBs) are by far the most common reason for the issuance of advisories for U.S. Great Lakes fish. Several states have also issued advisories for other contaminants, including chlordane, dioxin, and mirex.

The advisories have changed with time, so that an exact basinwide accounting is not available. But more sites and species have probably been added to the fish advisories over the years than have been taken off. For example, Wisconsin has not removed any sites from the advisory; Michigan has removed some but added others—particularly near harbours or tributaries where contaminant concentrations are higher than in the associated lake as a whole. Indeed, if there has been an increase in the listings, it probably reflects more intensive monitoring over time rather than further degradation of the environment. The 80 percent decrease in contaminant levels (primarily PCBs) observed in Great Lakes fish since 1980 supports this interpretation.

Table 21. Summary of Existing Sport Fish Consumption Advisory Programs and Criteria Related to the Great Lakes Basin, 1989

State or Province	Lead Agency for Advisory Criteria	Lead Agency for Advisory Issuance	Apply Federal Action Levels	Have Trigger Levels Different from U.S. Federal Govt.	Apply Risk Assessment as Basis for Advisories	Compensate for Multiple Contaminants	Concentration Allowed for Unlimited Consumption	Concentration Resulting in Restricted Consumption Advisory	Concentration Resulting in "Do Not Eat" Advisory
New York	NYS DOH	NYS DOH	YES	TCDD 10 ppt PCDD/PCDF Eq. Tumours	TCDD, Cd	YES	N.A.[a]	Generic—1 m/wk 1.0 × AL[b]— 1 m/mo using ACGIH Model (exc. metals)	> 3 × AL
Pennsylvania	Pa DOH	Pa DER	YES	NO	NO	NO	x < AL	N.A.	x AL
Ohio	ODH	ODH	YES	YES Tumours/PCB	YES	NO	x < AL 0.05ppm PCB	>0.05ppm PCB	x AL>1.9ppm PCB
Indiana	ISBH	ISBH	YES	YES	NO	NO	0–10% > AL	11–49% > AL	50% AL
Illinois	IDPH	IDPH	YES	NO	NO	NO[c]	0–10% > AL	11–49% > AL	50% AL
Michigan	MDPH	MDPH	YES	Tumours Hg - 0.5 ppm TCDD - 10 ppt	Hg, TCDD	NO	0–10% > AL	11–49% > AL, 1 m/wk Hg - 0.5–1.49 ppm	50% AL Hg 1.5 ppm

State or Province	Lead Agency for Advisory Criteria	Lead Agency for Advisory Issuance	Apply Federal Action Levels	Have Trigger Levels Different from U.S. Federal Govt.	Apply Risk Assessment as Basis for Advisories	Compensate for Multiple Contaminants	Concentration Allowed for Unlimited Consumption	Concentration Resulting in Restricted Consumption Advisory	Concentration Resulting in “Do Not Eat” Advisory
Wisconsin	WI DOH	WI DNR WI DOH	YES	Hg - 0.5 ppm	Hg only	NO	0–10% > AL	11–49% > AL Hg (3 groups)	50% AL Hg > 1 ppm
Minnesota	MnDPH	MnDPH	NO	Hg - 0.16 ppm PCB-LOD[d] (0.05 ppm) TCDD-LOD (0.6 ppt)	Hg only	NO	Hg < 0.16 ppm PCB/TCDD <LOD	Hg - 0.16–0.65 ppm, 1 m/wk; 0.66–2.81 ppm, 1 m/mo. PCB/TCDD > LOD, 1 m/mo.	Hg > 2.81 ppm
Ontario	H&W-C	OMOE	YES	Hg - 0.5 ppm TCDD-20 ppt	Hg, PCB, TCDD	NO	<AL	Hg - 0.5–1.49 ppm Organics > AL	Hg 1.5 ppm

Table 21 (continued): Summary of Existing Sport Fish Consumption Advisory Programs and Criteria Related to the Great Lakes Basin, 1989

State or Province	Special Cautions for Women and Children	Advice on Preparation and Cooking	How Published	Advisory Update Date(s)	Comments
New York	YES	YES	Pamphlet, fishing guide, news release	Yearly, May–June	Will issue mid-year advisories if significant conditions are detected; “significant” not defined. Start reviewing data in January for April deadline.
Pennsylvania	YES	YES	News releases	No specific date	Interagency agreement between DOH, DER, Fishery Commission; no designated budget for fish monitoring. Uses composite samples of skin-on fillets rather than individual fillets.
Ohio	YES	YES	News Releases, Pamphlet Fishing Guide	Site-specific, when data available	Interagency fish tissue monitoring group. Uses composite samples of skin-on fillets rather than individual fillets.
Indiana	YES	YES	Pamphlet, fishing guide	Yearly, March–April	Yearly sampling, but not of all waters.
Illinois	YES	YES	Pamphlet, fishing guide	Yearly	Interagency agreement within Illinois; now coordinating with states to south and southwest. Uses composite samples of skin-on fillets rather than individual fillets. Half of Mississippi River stations collected every year.

Michigan	YES	YES	Fishing guide, news releases	Yearly, late January	Interagency agreement between MDPH, MDA, MDNR; draft policy awaiting Great Lakes Fish Advisory Task Force decisions.
Wisconsin	YES	YES	Pamphlet, news releases, fishing guide	Twice yearly, April and October	Has not released an advisory since April 1994, pending a decision regarding Great Lakes protocol.
Minnesota	YES	YES	Fishing guide, news releases, booklet	Every two years	Interagency program. Analyses routinely only for Hg, PCB, and TCDD. Uses composite samples of skin-on fillets rather than individual fillets.
Ontario	YES	YES	Large guidebook, news releases, bulletins	Yearly, May	Sample type different from other jurisdictions—uses a skinless dorsal section of the fillet, rather than untrimmed skin-on fillets.

Sources: After Hesse 1990; updated in 1996 by J. Amrhein, Wisconsin DNR.

[a] N.A. = Not Applicable

[b] AL = Action Level

[c] If several contaminants present just below guideline threshold, list species.

[d] LOD = Analytical level of detection (value in parentheses, when specified, applies to row).

9.0 Emerging Challenges

9.1 Sewage Treatment

The recognition of cultural eutrophication as a threat to the lakes resulted in the Great Lakes Water Quality Agreement between Canada and the United States of America. The agreed-upon method for reducing nutrient loads was to limit phosphorus in detergents and to limit phosphorus in effluent at most of the STPs to no more than 1 mg/L. Eventually, the nutrient loads decreased by about 50 percent in Lakes Ontario and Erie (SOLEC 1994). Concentrations of phosphorus declined about 50 percent in the west basin of Lake Erie and in Lake Ontario. The decreased phosphorus load was brought about both by building STPs and by using phosphorus precipitation chemistry at the STPs. As the human population continues to grow, the 1 mg P/L limit will allow the nutrient load to grow. Thus, to maintain the low loads now in place and to avoid reversing hard-won progress, sewage treatment will have to become more and more stringent. In addition, the problem of untreated sewage discharges by combined sewer overflows is being and must be addressed in many large cities. There is a tendency to perceive eutrophication as a “mature issue” that requires no further effort. In reality, control of sewage effluents has just begun. Human sewage effluent in the lakes will be a management issue for the foreseeable future. Optimization of existing infrastructure and construction of the necessary technologies at STPs are needed steadily if a trend to worsening conditions is to be avoided.

9.2 Aquaculture

The use of cages in open waters has emerged recently as a fish culture technology that meets the needs of the industry for large-volume water supplies at temperatures appropriate to the needs of coldwater-loving species. Because the cages’ structure makes them vulnerable to storm damage, many concerns have been expressed about the impact of escaped fish on natural biodiversity and on the integrity of the wild gene pools. Further, unlike the relatively sterile groundwaters used for most fish hatcheries, the cages’ natural environments expose the fish to natural pathogens that must be routinely treated with therapeutants and prophylactics—which in turn are harmful to other elements of the natural biota. But the most worrisome potential effect of cage aquaculture on wild fish production is the nutrient enrichment of the surrounding waters via faeces and surplus food. Unlike wastes produced by onshore feedlots and hatcheries (and cities), these wastes cannot be harvested from the effluents. The conversion efficiency of fish food to fish is roughly 50 percent. Thus for every tonne of fish produced, there will be about a tonne of waste. If the caged fish are fed on netted lake fish, there may be an effect on natural populations. If the caged fish are fed on prepared food, the waste produced represents a new nutrient load to the system. The phosphorus output from a salmonid cage facility producing 100 tonnes of fish in the most efficient way is the equivalent of the raw sewage effluent from a community of 850 people. Since the industry will seek out relatively sheltered sites, the list of concerns includes losses of aesthetic and recreational values, contamination of bottom sediments, and the potential for rising drinking-water costs.

10.0 Summary and Conclusions

There is little doubt that the nearshore environment of the Great Lakes has been altered physically, chemically, and biotically by anthropogenic effects. Beginning about 25 years ago, however, the trend to worsening conditions began to slow down and reverse. This shift was largely due to the Great Lakes Water Quality Agreement (GLWQA) between the two sharing nations. On a lakewide basis, the GLWQA resulted in massive reductions in nutrient loads—reductions that in turn are the foundation for future protection initiatives. Toxic chemical loadings were reduced, resulting in decreased concentrations in biota. The GLWQA's ecosystem concept has brought about a more comprehensive view of environmental management, along with increased public awareness and participation. For example, the Great Lakes Action Plan and the Great Lakes 2000 Cleanup Fund have begun remediation of sediment contamination and habitat damage at more than 50 sites. Funding has been almost evenly distributed between projects on habitat, contaminated sediment, sewage treatment, urban drainage, and non-point sources. These remedial actions—which are occurring in both Canada and the United States—were agreed to in principle during the most recent iterations of the GLWQA, which named the 43 remaining worst polluted areas and instigated Remedial Action Plans to begin remedial activities. Similarly, the binational Lakewide Management Plan process seeks to develop a consensus and plan for the future restoration, maintenance, and use of the lake ecosystems. The progress is largely built on scientific capital accumulated over the last 20 years. Development and maintenance of this scientific capital has been slowing in the recent economic climate. Maintenance of scientific expertise is needed to efficiently delineate what can be expected from remediation. For example, a recent report (Fox et al. 1996) showed that contrary to expectations, the pollution of Lake Ontario by PCBs and PAHs from the Hamilton Harbour AOC was small relative to loadings from the atmosphere and the Niagara River. Thus, though there is a locally significant sediment PAH hotspot in Hamilton Harbour, the research points elsewhere for major gains in Lake Ontario's status. Further research of this type seems necessary to ensure that reasonable expectations prevail and that problems can be prioritized.

In conclusion, the nearshore waters face continued challenges from the effects of human population growth. Much of the damage to physical habitat is permanent, but means of prevention and mitigation are now in place. Water- and sediment-quality problems, which are mostly reversible, are under control. Continued vigilance is needed to prevent repetition of past problems.

11.0 Acknowledgments

We thank the following, who provided information or draft material for incorporation into this report:

J. Amrhein; A. Ballert; P. Baumann; T. Bushian; W. Cibulas, Jr.; J. Christie; D. Dolan; T. Howell; W. Jacobson; O. Johannsson; R. Kavetsky; D. Klemans; R. Murthy; T. Nalepa; M. Neilson; K. Nichols; S.J. Nichols; C. Portt; H. Prince; T. Reynoldson; R.P. Richards; D. Riedel; R. Rossman; W. Scheider; W. Schertzer; S. Stoddard; D.V. Weseloh; A. Zimmerman.

12.0 Glossary

Species—The species is the fundamental unit of biological organization. Members of a species are genetically similar and normally mate only with other members of the same species, thus preserving that genetic similarity.

Community—The community is a more complex level of organization. Typically, the geographic distributions or ranges of many species overlap. This overlapping suggests either that these species are competing with each other for the space, food, and other resources needed for them to grow and reproduce, or that each is using the resources differently in the area of overlap. Plant or animal species with overlapping ranges that are tolerant of each other and derive some mutual benefit from associating with each other generally occur in assemblages called communities.

Ecosystem—The most complex level of organization is the ecosystem. An ecosystem includes the plant and animal communities in an area together with the non-living physical environment that supports them. Ecosystems have physically defined boundaries, but they are also dynamic: their boundaries and constituents can change over time. They can import and export materials and energy and thus can interact with and influence other ecosystems. They can also vary widely in size. A small pond or patch of woodland can be an ecosystem, as can the entire Great Lakes region, or the biosphere of the earth with its human component.

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15.0 List of Tables and Figures

Appendix A: Common and Scientific Names of Plants and Animals Mentioned in This Report

	Common name	**Scientific name**
Algae	Stephanodiscus	*Stephanodiscus binderanus*
Vascular plants	Common cattail	*Typha latifolia*
	Eurasian watermilfoil	*Myriophyllum spicatum*
	Naiad	*Najas flexilis*
	Purple loosestrife	*Lythrum salicaria*
	Waterweed	*Elodea canadensis*
Protozoans	Glugea	*Glugea hertwigi*
Zooplankton	Spiny water flea	*Bythrotrephes cederstroemi*
Mussels	Quagga mussel	*Dreissena bugensis*
	Zebra mussel	*Dreissena polymorpha*
Benthic invertebrates	Burrowing mayfly	*Hexagenia* spp.
Fish	Alewife	*Alosa pseudoharengus*
	American eel	*Anguilla rostrata*
	Blueback herring	*Alosa aestivalis*
	Blue pike	*Stizostedion v. glaucum*

Bowfin	*Amia calva*
Brown bullhead	*Ameiurus nebulosus*
Burbot	*Lota lota*
Common carp	*Cyprinus carpio*
Catfishes	*Ictaluridae*
Coho salmon	*Oncorhynchus kisutch*
Deepwater ciscoes	*Coregonus* spp.
Deepwater sculpin	*Myxocephalus thompsoni*
Emerald shiners	*Notropis atherinoides*
Freshwater drum	*Aplodinotus grunniens*
Goldfish	*Carassius auratus*
Gizzard shad	*Dorosoma cepedianum*
Lake herring	*Coregonus artedi*
Lake sturgeon	*Acipenser fulvescens*
Lake trout	*Salvelinus namaycush*
Lake whitefish	*Coregonus clupeaformis*
Largemouth bass	*Micropterus salmoides*
Pacific salmon	*Oncorhynchus* spp.
Pikes	*Esocidae*
Rainbow smelt	*Osmerus mordax*
Round goby	*Neogobious melanostomus*
Ruffe	*Gymnocephalus cernus*
Sea lamprey	*Petromyzon marinus*
Slimy sculpin	*Cottus cognatus*
Spottail shiners	*Notropis hudsonius*
Sunfishes	*Centrarchidae*
Tubenose goby	*Proterorhinus marmoratus*

	Walleye	*Stizostedion vitreum*
	White sucker	*Catostomus commersoni*
	Yellow perch	*Perca flavescens*
Birds	American black duck	*Anas rubripes*
	American wigeon	*Anas americana*
	Bald eagle	*Haliaeetus leucocephalus*
	Black-crowned night-heron	*Nycticorax nycticorax*
	Black tern	*Childonias niger*
	Blue-winged teal	*Anas discors*
	Bufflehead	*Bucephala albeola*
	Canada goose	*Branta canadensis*
	Canvasback	*Athaya valisneria*
	Caspian tern	*Sterna caspia*
	Common goldeneye	*Bucephala clangula*
	Common loon	*Gavia immer*
	Common merganser	*Mergus merganser*
	Common tern	*Sterna hirundo*
	Double-crested cormorant	*Phalacrocorax auritus*
	Forster's tern	*Sterna forsteri*
	Gadwall	*Anas strepera*
	Great black-backed gull	*Larus marinus*
	Great blue heron	*Ardea herodias*
	Great egret	*Casmerodius albus*
	Greater scaup	*Athaya marila*
	Green-winged teal	*Anas crecca*
	Herring gull	*Larus argentatus*

	Hooded merganser	*Lyphodytes cucullatus*
	Lesser scaup	*Athaya affinis*
	Little gull	*Larus minutus*
	Mallard	*Anas platyrhynchos*
	Mute swan	*Cygnus olor*
	Northern pintail	*Anas acuta*
	Northern shoveler	*Anas clypeata*
	Oldsquaw	*Clangula hyemalis*
	Osprey	*Pandion haliaetus*
	Red-breasted merganser	*Mergus serrator*
	Redhead	*Athaya americana*
	Ring-billed gull	*Larus delawarensis*
	Ring-necked duck	*Athaya collaris*
	Ruddy duck	*Oxyura jamaicensis*
	Tundra swan	*Cygnus columbianus*
	White pelican	*Pelecanus erythrorhynchos*
	White-winged scoter	*Melanitta fusca*
	Wood duck	*Aix sponsa*
Aquatic mammals	Beaver	*Castor canadensis*
	Mink	*Mustela vision*
	Muskrat	*Ondatra zibethica*
	Raccoon	*Procyon lotor*
	River otter	*Lutra canadensis*