Helping Canadians Adapt to Climate Change in the Great Lakes Coastal Zone

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As global warming increases, Great Lakes coastal communities will be subjected to significant climatic changes driven by increasing temperature, changing precipitation and wind patterns, and a potential increase in the frequency of severe events such as windstorms and ice storms. Climate change will impact all life in every ecosystem, and people who live and work in these systems will need to adapt in a variety of ways. In response, a number of agencies and organizations have partnered to assist Great Lakes coastal communities in their efforts to identify and assess adaptation options. To date, workshops have been completed in Belleville (Lake Ontario) and Parry Sound (Lake Huron). This paper reviews some of the known and potential impacts that will result in or near Presqu'ile Provincial Park, Lake Ontario and in Sturgeon Bay, Lake Huron, and proposes a checklist of actions that could provide the basis for an adaptation protocol.

Keywords: climate change, Great Lakes, Presqu'ile Provincial Park, Sturgeon Bay

Introduction

Global warming is a complex phenomenon caused by increased additions of greenhouse gases (e.g., carbon dioxide, methane, and nitrous oxide) generated by burning fossil fuels and land use change (e.g., the conversion of forest land to urban areas). A number of models (e.g., Folland et al., 2001; Houghton et al., 2001; MaCarthy et al., 2001) indicate that natural and human-caused global warming is increasing at an unprecedented rate, elevating temperature, altering precipitation and wind patterns, and increasing the frequency of severe events such as wind or ice storms. In Ontario for example, the mean annual temperature has increased by 0.5ºC in the last hundred years and could increase another 2-5ºC in the next 50-75 years with the continued emission of greenhouse gases.

Most Canadians and millions of Americans live in coastal towns and cities in the Great Lakes basin. Climate change will impact every ecosystem and there are significant ecological, cultural, social, and economic implications to people living in towns like Parry Sound and Trenton and in cities like Toronto, Sault St. Marie and Thunder Bay. In addition to climate change, it is important to remember that continued urbanization and associated industrialization resulting in pollution, land and water modification and loss, invasive species, and over-harvesting of some species will add to the suite of eco-physiological impacts caused by global warming.

To assist Canadians in their efforts to identify and address the important questions about climate change, a number of agencies and organizations partnered in 2002 to help Great Lakes coastal communities develop climate change adaptation options. The primary objective of this project is to evaluate various climate change scenarios and to create a list of potential adaptation options for the coastal zones of the Canadian Great Lakes. The project involves:

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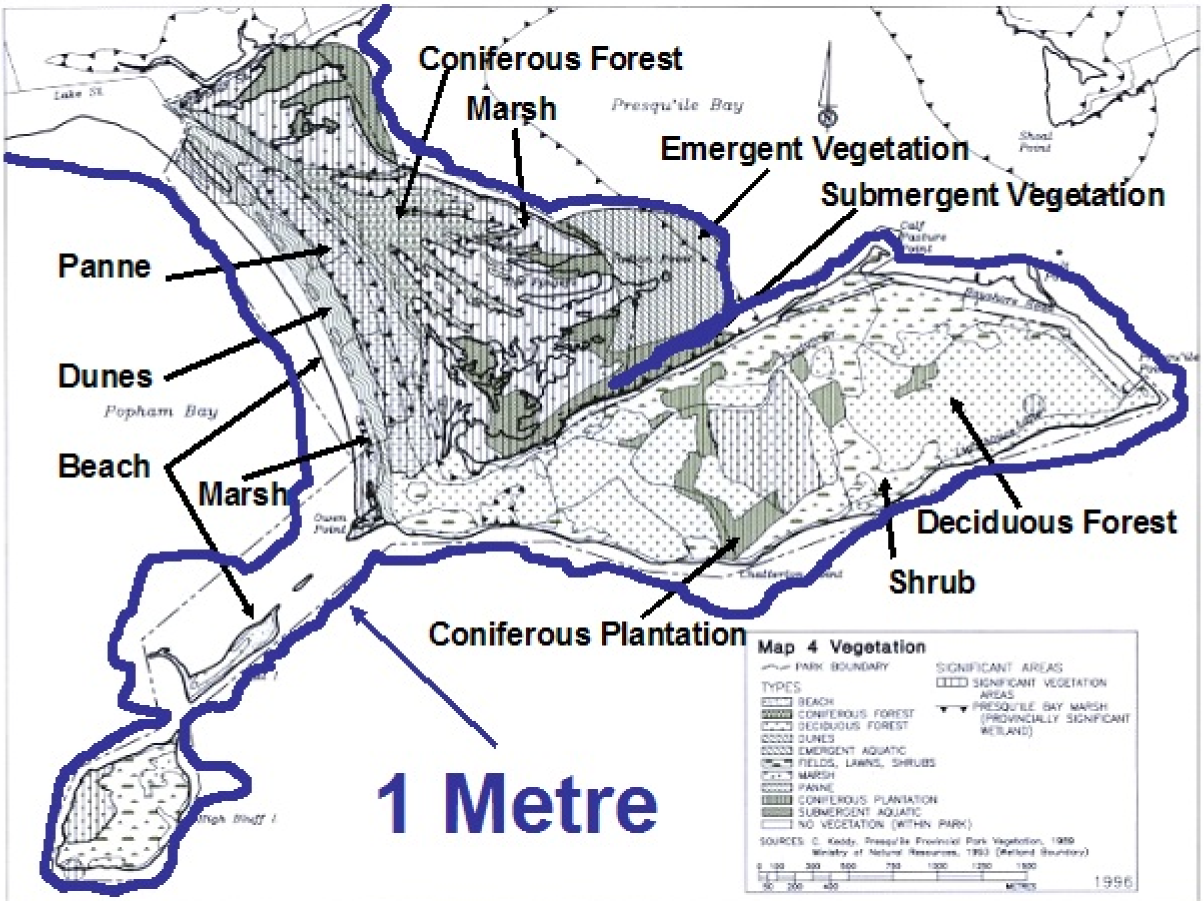

Figure 1. The extent of potential changes in Presqu'ile Provincial Park with a one-metre drop in water level. Note that the willow marsh likely will impede sand transport and dune development at the south end of the beach.

- Development of site-specific models describing future climate scenarios.
- Identification and description of potential and known impacts based on the conditions described in each of the model-generated scenarios.
- Completion of adaptation workshops in communities around the Great Lakes to identify and discuss impacts and adaptation options.
- Development of information extension and transfer tools.

To date, workshops have been held in Belleville (Lake Ontario) and Parry Sound (Lake Huron). This paper reviews some of the known and potential impacts identified in the literature and during the workshops that will result in or near Presqu'ile Provincial Park on Lake Ontario and in Sturgeon Bay, Lake Huron, and proposes a checklist of generic actions that could provide the basis of an adaptation protocol.

Season	Temperature Change (°C)	Precipitation Change (%)
Spring	+1.0-5.0	+3.0-20.0
Summer	+1.0-5.0	-18.0-+5.0
Fall	+2.0-3.0	-11.0-+5.0
Winter	+2.0-5.0	+8.0-15.0

Table 1: Projected climate change range of four scenarios based on a doubling (2x) of CO_2 for Eastern Lake Ontario (from Scott and Suffling, 2000)

The Study Area

The Great Lakes-St. Lawrence basin comprises an area of more than one million km^2 (Mortsch et al., 2000), and contains the largest single concentration of liquid freshwater on the planet (Kling et al., 2003). Most of the 40 million people living within the Great Lakes basin depend on the lakes for water supply (IJC, 2000). In addition, hundreds of thousands of smaller streams, rivers, lakes, and wetlands are connected to Great Lakes ecosystems.

The coastal zone study area boundaries are defined by the euphotic zone, the aerial extent of which changes seasonally and in response to a variety of forces and factors that shape the near-shore areas of each Great Lake. For example, the euphotic zone is defined by an area that is less than 1-metre deep in coloured and sediment-laden waters in Lake Erie to deep water ecosystems along the shores of Lake Superior. The euphotic zone in Lake Erie has increased in recent years due to the filtering ability of invasive zebra mussels, which have improved water clarity. In some areas, such as Lake Ontario's Bay of Quinte and Lake St. Clair, the coastal zone is extensive because of its shallow depth, while in other areas such as along the north shore of Lake Superior it is quite limited because of the steeply shelving bottom. Because the terrestrial part of the coastline is where people live, and is influenced by the presence of an adjacent major water body, the terrestrial component of the coastal zone is defined for the purpose of this study as extending 1 km inland.

The Impacts of a Changing Climate on Great Lakes Coastal Ecosystems

Air temperature over the Great Lakes will increase during the 21st Century. For example, using four climate change scenarios Scott and Suffling (2000) report a 1-5°C mean annual increase in air temperature over eastern Lake Ontario (Table 1). Air temperature influences ecosystem composition, structure, and function in many ways, including biological productivity. For example, air

Lake	Range of Mean Monthly Water Temperatures (°C)	Annual Average Water Temperature (°C)	Annual Average Precipitation (mm)
Lake Superior	1-12	2.3	712.0
Lake Huron	0-20	6.9	858.0
Lake Erie	1-22	8.6	985.2
Lake Ontario	2-20	7.9	763.7

Table 2: Average annual temperature and precipitation rates in the Canadian Great Lakes. (data from Allan, 1998).

temperature is a dominant factor affecting the distribution and abundance of flora and fauna. In addition, warmer and shorter winters will impact recreational activities such as snowmobiling, skiing, and ice fishing. Longer summer and shoulder seasons could increase boating and camping opportunities.

Lake	Lake level changes (differences from base in metres)									
	Recent transient results (with aerosols)						Older 2x CO_2 (no aerosols)			
	CGCM1			UK HadCM2			CCCC	US GFDL	US GISS	US OSU
	2030	2050	2090	2030	2050	2090				
Superior	-0.22	-0.31	-0.42	+0.04	-0.01	+0.11	-0.23	------	-0.46	-0.47
Michigan-Huron	-0.72	-1.01	-1.38	+0.14	+0.03	+0.35	-1.62	-2.48	-1.31	-0.99
Erie	-0.60	-0.83	-1.13	+0.11	+0.04	+0.27	-1.36	-1.91	-1.16	-0.87
Ontario	-0.35	-0.53	-0.99	+0.25	+0.04	+0.01	-1.30	-----	-----	-----

Table 3: GCM climate change scenario impacts on mean water level – changes from reference level (from Mortsch et al., 2003).

In addition to water depth and the thermocline gradient, air temperature influences water temperature. For example, the average annual water temperatures in southern Great Lakes can be as much as 5°C higher than in northern Great Lakes (Table 2). As air temperatures continue to warm, the bio-physical functioning of lakes will change. Warmer water will affect spring and fall lake water mixing regimes, which will in turn affect the oxygen concentration in the hypolimnion.

Increased air and water temperatures will contribute to a change in aquatic species composition, distribution, and abundance. For example, as lake and river waters warm, cool water and cold water fish species will disappear (Casselman, 2002; Casselman et al., 2002; Kling et al., 2003; Shuter and Lester, 2003). In some rivers and lakes there will be a significant increase in the distribution and abundance of warm water fish species. In fact, it has been suggested (Magnuson et al., 1997) that warming associated with a doubling of atmospheric CO_2 could result in a 500-600 km northward shift in the zoogeographical boundary of freshwater fish species. In addition, most Ponto-Caspian invasive species originate in warmer waters, which provide them a competitive advantage over cool and cold water species inhabiting the Great Lakes (Schindler, 2001).

Comparable northwards changes in distribution are also expected for terrestrial plants (Malcolm and Pitelka, 2000) and examples can be viewed at the University of Toronto Forestry website http://www.forestry.utoronto.ca/treeatlas/mainpage/main_page.htm.

While average precipitation is expected to increase across Canada, it is projected to decline in Great Lakes and St. Lawrence River ecosystems (Mortsch et al., 2000). This decline will be characterized by decreased snowfall and increased rainfall. This overall decline, in conjunction with seasonal changes in precipitation patterns, will affect the timing of spring run-off and maximum flows in streams and rivers (Table 1). Mean annual water depths are expected to decline to below historic levels because of increased evaporation and evapotranspiration in the region (Lofgren et al., 2000; Kling et al., 2003; Mortsch et al., 2000, 2003). Mortsch et al. (2000) suggest that water levels could drop by 0.3-1.0 m by 2050 (Table 3).

Fluctuating water levels are important natural phenomena of the Great Lakes. Between 1918 and 1998, for example, lake levels fluctuated by 1.19 m in Lake Superior and 2.02 m in Lake Ontario (Moulton and Cuthbert, 2000). These fluctuations will likely continue as the climate changes but they will occur around lower mean water levels.Lower water levels will exert some of the most significant impacts on terrestrial and aquatic coastal ecosystems. For example, reduced water levels will modify or eliminate wetlands that function to maintain shoreline integrity, reduce erosion, filter contaminants, absorb excess storm water, and provide fish and wildlife habitat (Branfireum et al., 1999; Devito et al., 1999; Lemmen and

Warren, 2004; Mortsch, 1998) because coastal wetlands function as important staging, breeding, and wintering habitat for waterfowl (TWS, 2004) and breeding and nursery areas for many fish (Whillans 1990).Lower water levels in conjunction with increased algal growth will likely cause supply, odour, and taste problems in communities with shallow water intakes or pipelines designed for historical water levels (Nicholls, 1999; Schindler, 1998). Decreased water quality and an associated impact on human health is also a concern (Bruce et al., 2000). Great Lakes infrastructure is also at risk. For example, lower water levels will reduce the ability of existing hydroelectric stations to generate power (IJC, 2000), reduce boat access to existing docks and facilities, and increase navigational hazards (Lemmen and Warren, 2004). While warmer temperatures will result in a longer ice free season, the benefits of an extended shipping season may be offset by losses with lower water levels (Lemmen and Warren, 2004). In addition, some communities may need to undertake costly harbour, lake, and channel dredging projects (Lemmen and Warren, 2004).

Case Studies Presqu'ile Provincial Park, Lake Ontario

Presqu'ile Provincial Park encompasses 974 ha at the eastern end of Lake Ontario and includes the Presqu'ile Peninsula (except the Bayshore Road residential area) and the islands off Owen Point near the Town of Brighton (Figure. 1). The park has 22.3 km of road, 394 campsites, 10 group campsites, a park store, parking for about 1,200 cars, a boat launch, interpretative trails and an interpretative centre at the lighthouse (MNR, 1996).The shoreline consists of a rocky headland with offshore reefs that caused many shipwrecks in early colonial days. To the west of Owen Point lie High Bluff Island and Gull Island, which are separated from the mainland by a shallow bar and beyond them an extensive beach system with a flat, very gently

Figure 2. Examples of impacts to Presqu'ile Provincial Park with a one-metre drop in water level.

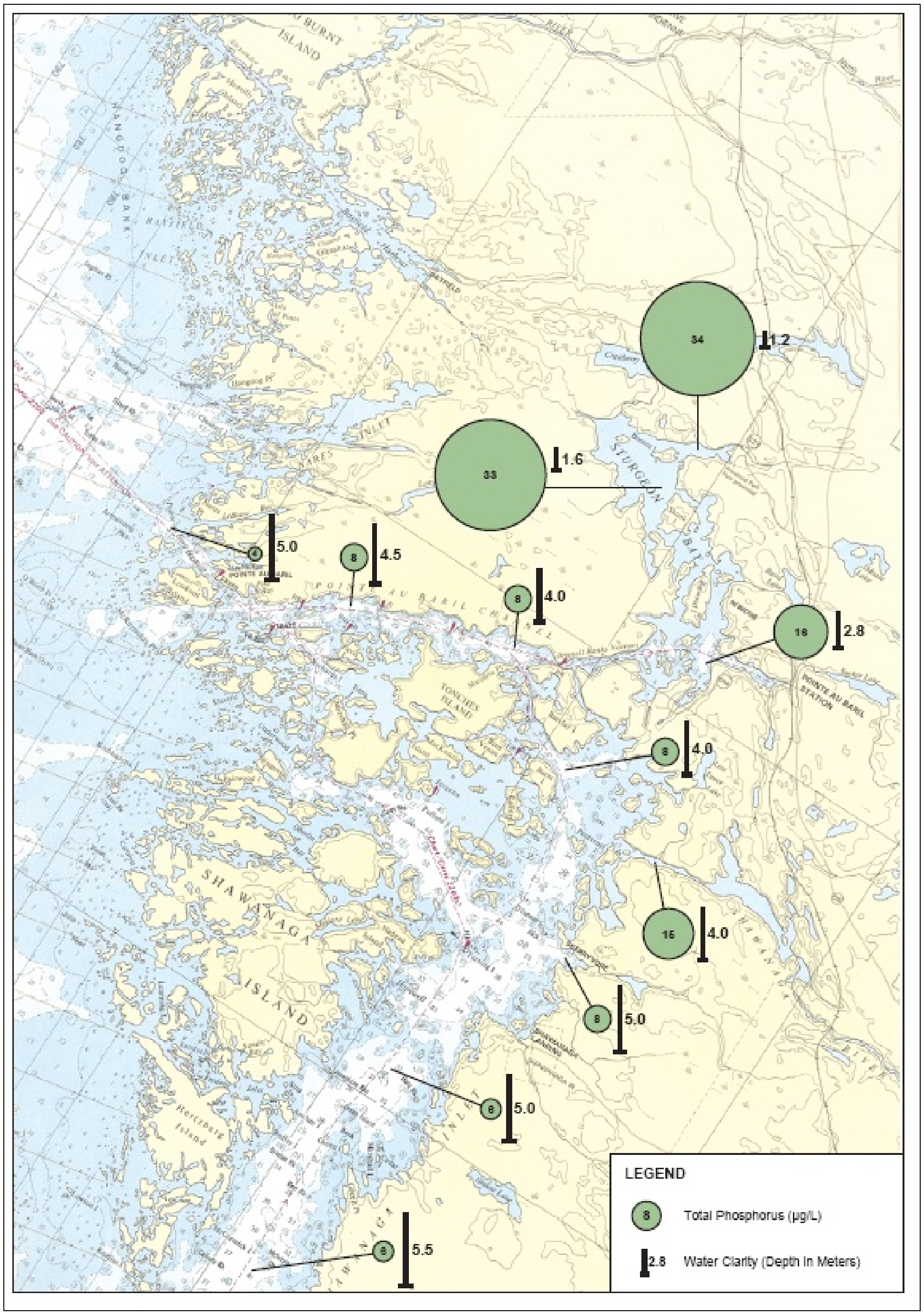

Figure 3. Total Phosphorous and Water Clarity in the Sturgeon Bay and Pointe au Baril Area of Georgian Bay, 06 September 2001.

sloping topography into Popham Bay. The park is comprised of many ecosystems characterized by dunes, pannes, marsh, deciduous, mixed and coniferous forest, and alvar features (Figure 1). A warmer climate and a drop in lake water levels will result in a number of changes. Presqu'ile's landforms are dynamic, and include an active tombola system that constantly changes the shoreline. The westerly movement of sand has created an active dune system with characteristic dune vegetation. A one-metre drop in water levels will result in additional beach area in the west. This may provide a much larger beach area for recreational activities depending upon the rate at which dunes form in the back beach zone. In the past, dune vegetation restoration programs have been successful, and it is likely that dune vegetation management will be required in future as well.

Many of Presqu'ile's vegetation species and plant associations reflect soil and climatic conditions and human impacts. Much of the park's area was cleared in the 19th century for a townsite that was never

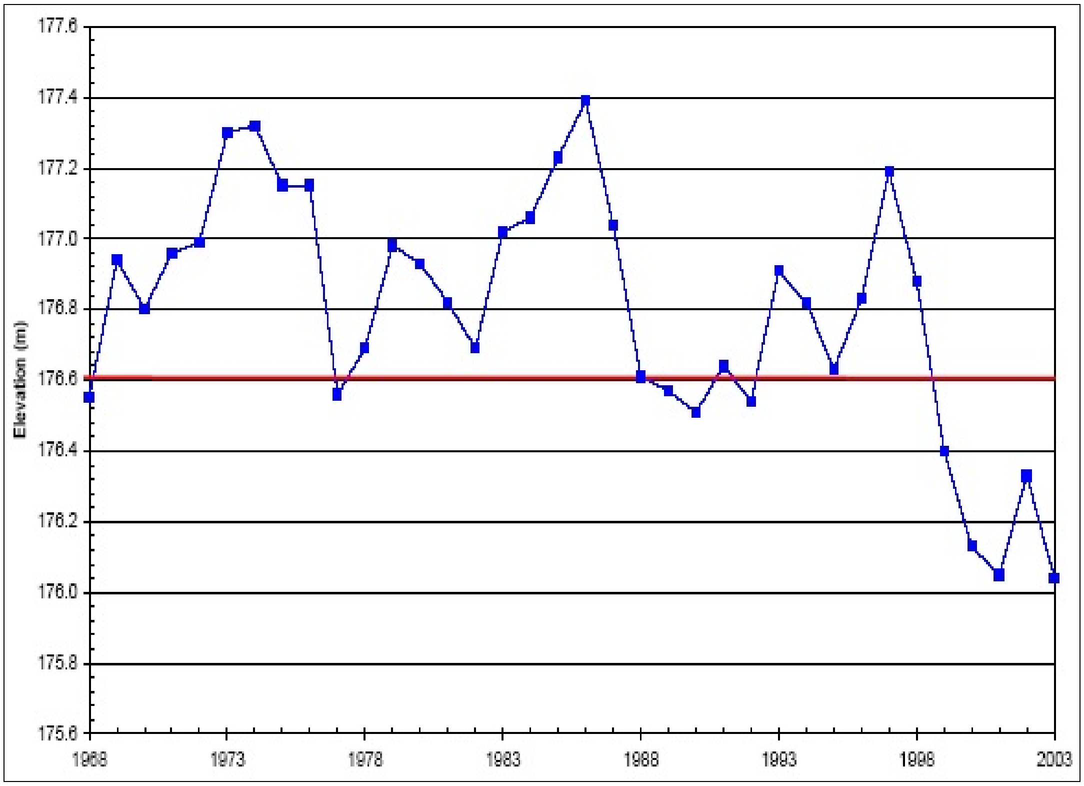

Figure. 4. Mean July Water Levels – Lake Huron/Georgian Bay, 1968-2003.

developed, and natural vegetation has recolonised many of the cleared areas. Conifers were planted in some areas, while the calcareous bedrock areas (alvars) provide habitat for some meadow species and cedar and hawthorn shrubs. As the temperature continues to warm and summer precipitation rates decline during the 21st century, it is likely that permanent alvars will dominate the calcareous bedrock habitats. A number of Presqu'ile's plant species and species associations are northern in character because of the cooling effect of Lake Ontario, where the 'Fingers' support a natural coniferous forest with many boreal characteristics and where the mixed forest growing on the 'Foot' of the park is dominated by tree species commonly found further north in the Algonquin area (Figure 1). Increased air and water temperatures likely will provide more suitable ambient conditions for southern species. In response, some northern tree species may disappear and southern, Carolinian species may successfully establish in the park. The loss of northern plant species may impact bird species such as the white-throated sparrow and yellow-rumped warbler found in the park. Conversely, more southerly species such as the tufted titmouse, mockingbird, and Carolina wren may become more common in the area. The northern boundary of the Park includes extensive marshes that provide bird nesting habitat (e.g., black tern colony), important fish spawning and nursery areas, and habitats for many other species. In the event of a one-metre drop in water levels, for example, the in-shore side of the marsh will dry out and the out-shore side of the marsh likely will extend further into Presqu'ile Bay. It is expected that the marsh species will remain relatively the same although the distribution and abundance of marsh vegetation is expected to change. If water level reductions are significant enough to re-connect the two islands to the mainland, it will place one of the largest Great Lakes colonial waterbird colonies in jeopardy, because once connected, ground and tree nesting species will be more susceptible to predators such as skunks and raccoons (Figure 2).There are a number of socio-economic issues as well. For example, private homes have been constructed along the north shore towards Salt Point and an increase in the area of shoreline resulting from lower water levels will result in land and water access issues. The warming trend of the last decade has reduced cross-country skiing opportunities in the park, and under increased warming trends, it is expected to disappear. In addition, warmer air temperatures during the spring and fall shoulder seasons may result in an increased demand for park services such as camping.

Sturgeon Bay, Lake Huron

Sturgeon Bay is typical of many bays along the Georgian Bay coast. It provides protection from Lake Huron storms, is road accessible, and extensively developed with cottages, houses, resorts, a marina, and a provincial park. Although connected to Lake Huron by a long, narrow and navigable channel (Figure 3), and impacted by Lake Huron water levels, the Bay's aquatic ecosystems are discrete and unique. Sturgeon Bay is supplied with water from a relatively small watershed and from seiche effects in Georgian Bay. For example, a strong west wind will temporarily raise water levels along the eastern coast of Georgian Bay and push water into the southern end of Sturgeon Bay. Conversely, a strong east wind will push water out of Sturgeon Bay. Flushing rates are low, however, because of the relatively small flow of water from the watershed. Water in the deeper northern basin of Sturgeon Bay has an average residence time of approximately 1.4 years (Schiefer, 2003). This long residence time reduces the rate of contaminant and nutrient discharge rate from the Bay.

The mean July water level from 1969-1999 was 177.0 m, and from 2000-2004 dropped to 176.2 m (Figure 4). This drop of almost 1 m significantly reduced the water exchange flows between Georgian Bay and Sturgeon Bay because it eliminated 25-30% of water volume in Sturgeon Bay. A reduction of this magnitude significantly reduces the capacity of Sturgeon Bay to dilute introduced nutrients and other materials and flush them into Lake Huron. If water levels continue to drop beyond historical levels, eutrophication impacts will increase.

The limnology of lakes is strongly influenced by summer thermal stratification and dissolved oxygen levels in the hypolimnion. Climate change will significantly alter thermal stratification regimes and oxygen levels in Sturgeon Bay because:

- With longer, warmer summers, thermal stratification begins earlier in the spring and continues further into the fall. This increases the total period of summer thermal stratification and isolation of the hypolimnion.
- Warmer summers have the effect of lowering the thermocline as the volume of warm surface waters increase. This reduces the volume of the hypolimnion and the dissolved oxygen reservoir within it.
- Lower water levels compound this effect, resulting in a smaller late summer hypolimnion water volume because the thermocline is deeper.

Thermal stratification combined with the high phosphorus levels in Sturgeon Bay results in rapid and complete depletion of dissolved oxygen in the hypolimnetic waters. This process is often responsible for the loss of coldwater fish species such as lake trout and whitefish. These species no longer exist in Sturgeon Bay and are being reduced or eliminated in other similar bays along the Lake Huron coast.

Reduced dilution, flushing, water exchange, and the degree of thermal stratification are important factors in eutrophication in Sturgeon Bay. Lakeshore development combined with the poor suitability of this granite bedrock landscape for septic systems has resulted in exceptionally high phosphorus levels (34 mg/L) in Sturgeon Bay compared to Georgian Bay where total phosphorus seldom exceeds 6 to 8 mg/L (see Figure 3). In addition to causing rapid oxygen depletion below the thermocline, high phosphorous levels provide nutrients for surface plankton, resulting in algal growth and low water clarity.

In recent years, eutrophication has caused large blooms of blue-green algae in Sturgeon Bay (Fig. 5). Because of the toxins often produced by these algae, public health warnings have been issued. This has had a negative impact on residents, cottagers, and the tourism industry. Changes in temperature and water levels in the Great Lakes are not the primary cause of eutrophication and algal blooms in Sturgeon Bay, but they accelerate the process and increase the impact.

Fish populations and communities in the middle Great Lakes have changed significantly in the last 100 years. In addition to habitat degradation and loss, native species have been over-fished, parasitized and predated (e.g., lamprey) by invasive species. Invasive species continue to

Figure 5. Location of Houses and Roads Around Sturgeon Bay and Blue-Green Algal Blooms.

enter the Great Lakes through bilge-water discharge by ocean-going ships on the St. Lawrence Seaway, through the Chicago Canal, which is linked to the Mississippi watershed, through the Erie Canal, and by accidental and deliberate releases of baitfish and other species. These species have invaded every trophic level and in many cases have emerged as dominant species in many habitats. For example, smelt, alewife, carp, goby, ruffe and Pacific salmon are now significant components of the Great Lakes ecosystems.

Climate change exacerbates the invasive species problem. For example, many invasive species prefer more temperate, eutrophic habitats than historically found in most of the Great Lakes. With the exception of Lake Erie, the Great Lakes functioned as cold, clear, oligotrophic ecosystems until the 20th Century. These cold ecosystems favoured native salmonid and corregonid species in deeper waters, and walleye, northern pike, and perch in the cool-water littoral zones. In addition, many of the warmwater centrarchid species, including largemouth and smallmouth bass, reached the northern limit of their natural range in Great Lakes waters.

With climate change-induced warmer summer surface waters and a shortened ice cover period, shallow water habitats in many of the Great Lakes have become more suited for invasive species. Increased eutrophication has contributed to these conditions, for example, carp, round goby, and zebra mussel have successfully invaded Great Lakes habitats and many North American warmwater species (e.g., sunfish) have extended their range north into the lakes. The Asian grass carp, now established in the Mississippi watershed, could invade through the Chicago Canal and survive in the Great Lakes if water temperatures continue to increase and electric barriers are breached.

The coldwater fish community of Lake Huron provides an excellent example of how climate-related factors can profoundly impact fish populations. Over-fishing and predation by lamprey, smelt, and alewife decimated the native lake trout fisheries. These forage species achieved large populations in the absence of a coldwater predator such as the lake trout. To create a new food chain equilibrium and sport fishery in Lake Huron, Chinook and Coho salmon were stocked in the 1980s and 1990s. These species adapted well to Great Lakes habitats, and are now the foundation of a very successful and important sports fishery. Winters were relatively mild in the 1990s and alewife populations flourished in Lake Huron. But the long, cold winter of 2002 significantly reduced alewife populations, the primary food of salmon. Consequently, the salmon populations declined, which in turn impacted the sport fishery.

The Basis for an Impact Response Protocol

Many suggestions were made at the workshops, including the need to understand climate change, to mitigate the impacts of climate change, and to help people and communities adapt to climate change. Accordingly we anticipate the need for community-based programs that respond to an adaptation protocol organized around the need to:

1. Understand the impacts of climate change through science and experience. Effective data and information gathering and management programs (such as research, inventory, monitoring and assessment) to advance knowledge of climate change is critical to successful identification and implementation of solutions.

2. Mitigate the impacts of climate change using an integrated suite of tools that include commitment, partnership, policy based on the principles of adaptive management, strategic planning, and on-site management:

- The importance of commitment to address the short- and long-term impacts of climate change cannot be overstated. Agencies and organizations must strive to ensure that their staff and partners are equipped with the tools and techniques to adaptively manage for climate change.

- Partnership is necessary to engage all sectors of society in decision-making. Partnership can be used to engage people who are interested and capable of developing and implementing community-based solutions.

- Communities will need to adopt a strategic approach to climate change impact identification and management. A strategic approach requires that communities constantly identify impacts and solutions and revisit and revise programs accordingly.

- Policy solutions must be adaptive, where they are based on a commitment to continually assess success.

- On-site management and emergency planning will likely require a combination of initiatives directed at changing human behaviour and/or implementing technological solutions. An emergency response capability will remain important in all coastal communities. For example, federal government now requires that major new projects consider climate change in their planning and the Ontario Emergency Readiness Act (Bill 148) requires that municipalities plan for extreme events and emergencies.

3. Help Ontarians adapt through education, extension, and training programs. Knowledge dissemination through life-long learning opportunities that are accessible and current (education, extension, and training programs) are critical to any program designed to manage for climate change.

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