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CLIMATE CHANGE AND COASTAL ZONE MANAGEMENT PROCESSES, THE GREAT LAKES, NORTH AMERICA

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ABSTRACT: The Great Lakes are the largest bodies of fresh water in the world. The majority of Canadians live within the Great Lakes drainage basins and many of our larger cities and industries are located along the shores of these lakes. The coastal zone is sensitive to climate change and all the global climate models indicate a lowering of lake levels, an increase in air and water temperatures, a change in the snow and rainfall and an increase in the severity and frequency of storm events. This will significantly affect coastal habitats and communities. Many stressors already exist on coastal ecosystems including changes in land use, pollution, the presence of non-native species such as carp (Cyprinus carpio), zebra mussels (Dressena polymorpha), mute swans (Cygnus olor) and purple loosestrife (Lythrum salicaria). Examples of recent efforts to restore degraded habitats are described in places such as Hamilton Harbour, the Toronto Waterfront and the Bay of Quinte. Major adaptation options to climate change including changes to fisheries, modification to marinas, harbours and canals, changes in power output in hydroelectric dams, changes in property boundaries and access to water are a stress on coastal wetlands that serve as habitat for a wide variety of fish and wildlife. Adaptation to a changing climate will affect the majority of Canadians. The involvement of local municipalities, conservation authorities, industry and farmers is essential in planning for a future sustainable environment in a changing environment.

Keywords: Great Lakes, climate change, coastal zone management, water

1. Introduction

The Great Lakes (Ontario, Erie, Huron, Michigan and Superior) cover an area of 244,160 square kilometres, have a total shoreline length of 17,000 kilometres and a volume of 22,684 cubic kilometres (see Figure 1) (Environment Canada, 1991). They are connected to the Atlantic Ocean by the St. Lawrence River. Dams control the water level on Lake Ontario at Cornwall on the St. Lawrence River and on Lake Superior at Sault Ste Marie. Hydroelectric power is generated at Niagara Falls and Cornwall for both Canada and the United States. The water levels on the lakes fluctuate by approximately 70 centimetres annually, though the difference between extreme high and extreme low water levels recorded during the past 150 years are as much as 200 centimetres. The majority of the Canadian population lives in the drainage basin of the Great Lakes with the majority clustered in several large and many small communities in the coastal areas. Major cities in Canada on the lakes include Toronto, Hamilton, Kingston, Windsor, Sarnia, Sault Ste Marie and Thunder Bay. The Great Lakes played a vital role in opening up the interior of North America to human settlement, industry and trade and they currently play a major role in the Canadian economy.

During the nineteenth and twentieth centuries, when the majority of industrialization and agricultural settlement occurred in the Great Lakes basin, land uses changed dramatically. The extensive forests around the southern lakes were cleared for farming; ports and harbours were established in many river mouths, and numerous wetlands along the shoreline were dyked and drained for farming. Dams were placed across most rivers to drive early saw and grist mills, for regulating water levels, and for providing hydro-electric power. Major commercial fisheries were developed on each of the lakes. During this period, many animals and plants were introduced into the Great Lakes ecosystems either on purpose or accidentally so that the ecosystems have changed radically since the first settlers appeared in the late eighteenth century.

FIGURE 1

Great Lakes Basin, North America

These communities, farms and industries have discharged many pollutants to the Great Lakes with the result that many natural biological communities have been severely degraded and altered. The International Joint Commission (IJC) of Canada and the United States has regulated water taking and water level regulation from the Great Lakes since 1909. In 1986, under the Great Lakes Water Quality Agreement, the IJC determined that 43 coastal sites were sufficiently polluted and degraded that they were designated as Areas of Concern (AoCs). Remedial Actions Plans (RAPs) were developed in each affected community and Technical and Public Advisory Committees identified the problems and developed ways in which the areas could be restored. This paper will deal with three Areas of Concern on Lake Ontario (Hamilton, Toronto and Bay of Quinte) to provide examples of management options that have been used in the past and may be used in adapting in the future.

2. The Present Great Lakes Environment

2.1 Climate

The present climate of the Great Lakes is characterized by frequent collisions of continental polar air masses with tropical air masses from the south (Allan et al., 1994). The Great Lakes themselves influence the otherwise continental climate in a variety of ways. Like most large bodies of water, the Great Lakes have a moderating effect on the climate of their surrounding areas, resulting in slightly cooler summers and warmer winters than adjacent inland areas. In addition to moderating temperature extremes, the lakes contribute to increased humidity and fog, increased severity of storms, increased cloud cover, and increased wind speeds (Smith and Lavender, 1998). The shape of the Great Lakes and prevailing winds also modify the distribution and amount of snowfall significantly. In the winter, moisture from the lakes is carried across the lakes by the relatively colder westerly and north-westerly winds and deposited downwind of the lakes as "lake effect snow". The lee side of the Great Lakes therefore have areas referred to as "snowbelts" since they receive a large amount of snow each winter. Areas such as Trenton and Kingston at the easterly end of Lake Ontario receive more snow that Hamilton and Toronto at the westerly end.

2.1.1. Air Temperature

The climate of the southern Great Lakes is milder than the northern, and on Lake Ontario the western end is warmer than the eastern (see Table 1). This

Table 1 Temperature Differences on Lake Ontario (MSC Climate Normals 1971-2000)			
LOCATION (CITY)	MEAN JANUARY TEMPERATURE (°C)	MEAN JULY TEMPERATURE (°C)	MEAN ANNUAL TEMPERATURE (°C)
Niagara-on-the-Lake	-4.2	22.2	9.0
Hamilton	-5.0	22.0	8.5
Toronto	-4.5	20.7	8.2
Trenton	-7.5	20.5	7.0
Kingston	-7.1	21.4	7.6

is reflected in the plant growing zones[1] which around Lake Ontario ranges from a Zone 7 in the western end around Niagara-on-the-Lake through Zone 6 around Toronto to Zone 5 in the Kingston area.

2.1.2 *Precipitation*

The precipitation in the Great Lakes basin ranges from about 550mm to 900 mm per year. Rainfall tends to be heavier at the eastern parts of the lakes (see Table 2). The high level for Niagara Falls is due to the effect of snowfall generated from Lake Erie to the west. There is considerable variability in the annual precipitation at any one location as well as considerable variation in precipitation around each of the Great Lakes.

Table 2 Precipitation at Five Sites on Lake Ontario (MSC Climate Normals 1971-2000)			
LOCATION (CITY)	TOTAL RAIN (MM)	TOTAL SNOW (MM)	TOTAL PRECIPITATION (MM)
Niagara Falls	795	148	944
Hamilton	768	126	892
Toronto	705	112	813
Trenton	759	169	893
Kingston	780	179	960

2.1.3 *Water Levels*

Water levels in the Great Lakes fluctuate seasonally as well as annually. Because Lake Ontario has its lake levels regulated by control structures at Cornwall, the historical high and low levels have now been eliminated and this has major repercussions on the ecology of the coastal areas.

1 *Plant growing zones, also known as plant hardiness zones, advise on which plants will grow in what areas based on the region's temperatures.*

2.1.4 Water Temperature

The surface water temperature in Lake Ontario ranges from freezing to about 20°C in shallow areas. Increased air temperatures will influence the temperature of surface waters of the Great Lakes as well as the depth and gradient of the thermocline. This will affect the time of Spring and Fall overturns (mixing of lake waters) and therefore affect the oxygen concentration in waters of the hypolimnion. Oveall, this may have an effect on the distribution of fish, particularly the centrarchids that are likely to be able to increase their range northwards to the detriment of cold-water salmonids.

It is expected that the ice cover on the Great Lakes will slowly decrease with climate change. The amount and timing of freezing varies significantly, but it is expected that the southern Great Lakes, particularly Lake Erie will be most affected. However, many communities on Lake Huron, particularly those on the eastern and northern shoreline will be affected in that the certainty of a solid freeze-up will change and winter access over ice will become potentially hazardous.

2.2 Land Use

The land use of the majority of Lake Ontario's coast is primarily agricultural and urban. The western part of the basin with the warmer and longer growing season is used for fruit growing (grapes, apples, peaches, cherries) while the eastern end of the lake supports mixed agriculture with dairy, corn and other cereals. The Greater Toronto Area (GTA) is the largest population centre in Canada and is home to approximately 4.5 million people with another million or so living in the Golden Horseshoe which extends from Niagara Falls to Oshawa. Various major industries are clustered around the lake from the major heavy industry and steel making city of Hamilton, to the automobile manufacturing cities of St. Catherines, Oakville, Toronto and Oshawa. Major generating coal, gas and nuclear generating stations occur on the shores, and the port of Hamilton serves as an important gateway for a variety of goods.

The rapid expansion of urban and industrial areas during the past hundred years has had a profound effect on water quality and this is reflected in the uptake of contaminants in fish that are still monitored annually with advisories being placed as to safe limits for human consumption. Likewise, beach closures as a result of fecal coliform contamination still occur and major efforts have been made to improve water treatment in the urban areas. The majority of forests bordering Lake Ontario were cleared in the nineteenth century, but recent efforts by many conservation authorities to revegetate riparian buffers along rivers and streams have had a major improvement on reducing flood events and sediments discharged to the lake.

3. Future Climate and Land-use around Lake Ontario

3.1 Projected Climate

In the last twelve thousand years since the last glacial period, the climatic landscape in the southern parts of Ontario has changed dramatically with the glaciers receding and slow change from tundra plant communities, to boreal forests, to deciduous forests. However, during this period there were no constraints to the movements of animals and plants, and the changes in climate were relatively slow. Now, the climatic changes are relatively rapid and only fragments of natural ecosystems remain. In the coastal zone, the majority of wetlands have been drained and there are very few coastal forest patches left in the south. This means that for those organisms with poor dispersal powers, there is little chance that they will be able to move to new locations if they cannot adapt to the changing climate. It is probable that many species will adapt, particularly the generalists, but to protect biodiversity it is necessary to provide corridors for dispersal and ensure that there are enough natural habitats to allow dispersal between patches.

3.1.1 Global Climate Change Models

Numerous reports have identified some of the projected effects of climate change on the Great Lakes clearly (Argyilan and Forman, 2003; Kling et al., 2003; Mortsch et al., 2003; Nicholls, 1999). A variety of global climate models have been developed and while they have different projections depending on the input variables, they all tend to show similar trends. For example, it is projected that air and water temperatures (see Table 3) will increase, rainfall will increase and water levels will decrease.

Table 3 Projected Great Lakes Surface Water Temperatures (modified after Mortsch 1999)

LAKE	CHANGE IN MEAN ANNUAL SURFACE WATER TEMPERATURES (°C)			
	CCCMA-II	GFDL	GISS	CCCMA –CGCMI (2050)
Superior	+5.1	+7.4	+5.6	+2.9
Huron	+5.0	+6.0	+4.7	+2.6
Erie	+4.9	+5.0	+4.4	+2.2
Ontario	+5.4	+5.9	+4.9	+2.9

3.1.2 ***Increased Air Temperature***

The primary climatic change is expected to be an increase in air temperature. This is projected to increase winter temperatures more than summer temperatures, and increase nighttime temperatures more than daytime temperatures. Because biological productivity is directly related to temperature, it is expected that productivity for terrestrial ecosystems will increase, providing that moisture levels are adequate,.

3.1.3 ***Increased Water Temperatures***

Increased air temperatures will cause increased water temperatures (from approximately 2 to 6°C) which will have a number of impacts on aquatic ecosystems. It is expected that cold water fish will retreat to the northern lakes while there will be an increase in warm water species in the southern lakes. It is also expected that the warmer southern lakes will be susceptible to range expansions and colonization by non-native species. Shallow areas may be more susceptible to oxygen depletion and the formation of "dead zones", thereby decreasing productivity. It is also expected that blue-green algae will be more common and lead to water tainting problems. There are not many management options available to limit the impacts of increased water temperatures on aquatic ecosystems. However, the options for purifying water are available and will add to infrastructure costs in the coastal zone.

The increase in winter temperatures will lead to a decrease in ice cover. This combined with an increase in the expected frequency and severity of storms will leave coastal areas more vulnerable to the effects of erosion and flooding. Management options exist that can reduce the vulnerability of some coastal areas to storms. Another impact of increased winter storms is that the near shore areas may have deeper and more frequent disturbances, which could re-suspend toxins buried in surface sediments.

3.1.4 ***Increased Precipitation***

Most of the climate models forecast an increase in precipitation. More of this will fall as rain rather than as snow. There may well be an increase in the number of ice storms in parts of the Great Lakes. It is expected that precipitation will be greater in the fall and winter months and generally less in the summer, leading to an increased frequency of drought conditions during the late summer months. This may well impact wetlands and other natural habitats as well as farming activities.

3.1.5 Lower Water Levels

While precipitation is expected to increase, the combined increase in evaporation and evapotranspiration caused by higher temperatures is expected to lead to an overall reduction in Great Lakes water levels. Water management structures have been built to deal with the variability of water levels in the present climate, though whether they are sufficient to deal adequately with future climates is not known. Levees have been built to withstand flood events and dams and reservoirs have also been built to manage water flow in streams and rivers (Deloe and Kreutzwiser, 2000). One adaptive response that has been proposed to deal with projected lower lake levels is to regulate water levels with further control structures and diversions.

Changing water levels are expected to be one of the most significant impacts on the coastal environment. Mean annual water levels are expected to decline to below historic levels because of increased evaporation and evapotranspiration in the region. Based on the results of the Canadian Global Climate Model CGCMI 2050 scenario, the mean Great Lakes water levels are expected to drop from 0.3 to 1.0 metre (Mortsch, 1999).

4. Examples of Management Options in the Great Lakes Coastal Zone

Some methods of management on Lake Ontario may also be used in managing the impacts of climate change. Several authors (Mortsch and Mills, 1996; DeLoe and Kreutzwiser, 2000) agree that various factors should be considered when considering possible climate change management options. They are:

- **Economic feasibility and efficiency**: Is this option affordable? Who will pay? Who will benefit? Will there be an economic risk? Will resources be allocated and used efficiently?
- **Technical feasibility:** Is the technology available or can it be developed? How much time will it take to develop and or implement it?
- **Social acceptability:** Does society want it? Who will benefit from it? Who will be affected? Does it reflect society's needs, values and goals?
- **Legal acceptability:** Are there any laws, regulations or policies that would prevent implementation?
- **Political realism and acceptability:** Do the politicians and the electorate support the measure? Can existing institutions implement it?

- **Environmental sustainability:** Will the environment be impaired to the detriment of future generations? Will the complexity and resilience of ecosystems be maintained?
- **Flexibility:** Does this option allow for future corrective actions? Does a wide range of alternative actions remain available?

It is important to note that many constraints exist to the implementation and use of successful management options. If an option is economically and technically feasible, it may still be constrained by perception or attitudes. It is also important to note that the issue of scale is relevant to adoption of management options.

4.1 Fisheries & Adaptation

The fish community of Lake Ontario has changed dramatically since European settlement of the area in the late 16th Century. Early settlers exploited large populations of sturgeon, salmon, lake trout and herring. The commercial fisheries rapidly expanded to utilize this seemingly limitless resource. But decade-by-decade, the fish community and many species that were once so prolific such as Lake Trout, Herring and Whitefish became rare (Regier et al., 1988). Together with the loss of the larger predatory fish came introductions of other fish. Pacific Salmon (Coho and Chinook) were introduced, alewives came in with the construction of navigation channels. Wetlands were drained and dyked reducing the available nursery habitats. Pollution had major impacts on algal growth and oxygen levels particularly in the shallow protected areas such as the Bay of Quinte. It is expected that cold water species will become restricted to the Upper Great Lakes and centrarchids will displace salmonids in Lake Ontario. However, fisherman will adapt to the available fish populations with adjustments in nets and equipment, timing of fishing seasons, and species caught. There has been a major increase in the recreational fishery on Lake Ontario which was worth at least $200 million in 1989 and is increasing annually.

Climate change is likely to exacerbate the already growing problem of invasive species in the Great Lakes region. Warmer water temperatures will likely allow the expansion of warm water species to the north. Invasive species which are often brought into the Great Lakes from the Ponto Caspian region in ship's ballast water, will find it easier to establish themselves in a warming climate. The recent expansion of the Round Goby in Ontario with its relationship to type e botulism and the death of many waterbirds has been reported in recent years.

Carp were introduced in the nineteenth century into millponds in Ontario and for many decades they were only a minor component of the southern Great Lakes fish community (Scott and Crossman 1973). In the past century they have multiplied extensively, particularly in the southern Great Lakes and have become a particular problem, reducing biodiversity and destroying many sensitive wetland areas. As part of the Hamilton Harbour Remedial Action Plan, and in an effort to restore the once prolific and diverse wetland area called Cootes Paradise, a fishway was constructed in the Desjardines Canal between Cootes Paradise and Hamilton Harbour in the spring of 1995. The fishway prevents carp from entering the marsh while providing both upstream and downstream access for other species of fish such as pike, walleye and bass. All large fish are caught in a series of traps that are lifted twice daily during the spring and fall migration movements and carp are returned to the harbour while the other species are allowed to move into the wetland and into the spawning streams. The carp control has been very successful with reduced numbers in the wetland and there has been a major improvement of biodiversity in this large wetland. The water level of Lake Superior is controlled at Sault Ste Marie primarily for navigation purposes.

4.2 Water Quality Improvement

Numerous pollutants have entered the Great Lakes during the past two hundred years. Some of these are relatively short-lived within the ecosystem and others are long lived. During the mid-1960s, major fish kills occurred in Lake Erie and it was found that the lake was dying due to eutrophication caused by algal growth growing on an abundance of nutrients, particularly phosphorus. In 1972, Canada and the United States signed the Great Lakes Water Quality Agreement to begin a binational Great Lakes cleanup that emphasized the reduction of phosphorus entering the lakes.

The high levels of phosphates in the lakes were the result of phosphates in washing detergents and from agricultural fertilizers. Water treatment plants now remove phosphates from urban wastewater and there have been substantial improvements to water quality. However, further reductions are necessary from non-point sources such as the agricultural use of fertilizers, particularly in southern Ontario. Major advances have been made in many watersheds and the enclosed Bay of Quinte has seen substantial improvements in water quality from improvements to agricultural practices and the protection of water sources.

However, further north in the Georgian Bay area of Lake Huron, there are an increasing number of cottagers living along the shores of the many islands and channels. Because of inadequate sewage treatment, the nature of the coastal region, low water levels and warmer summers, there are now major impacts to the costal zone. Major blue-green algal blooms have occurred in recent years, and the once pristine coastal inlets are polluted. While there may be solutions to improving the technology of wastewater treatment, low water levels have meant water access to many houses is now difficult for some summer months and solutions are being sought. These various issues must be addressed now, as with the projected changes in the coastal zone due to climate change, land use should be changed to sustainable levels. The tax base of some municipalities is declining as property values decrease and the options for adaptation are limited. The tasks are enormous and so extensive in some areas that governments cannot reasonably undertake them. Therefore there is a desperate need for public communication and a restriction on the numbers of people living in the coastal zone.

4.3 Wetlands and Water Quality Improvement

Natural wetlands perform many functions. Besides providing habitat for a great many species, they also provide valuable water cleansing functions as well as helping provide a steady base flow to many streams and rivers (Hammer and Bastian 1989). The loss of wetlands has reduced the capability of watersheds to perform many ecosystem functions that are critical to the larger lake ecosystem. In some cases it is still possible to protect watersheds and wetlands and ensure that watercourses are clean by providing adequate riparian buffers, and if they are degraded, revegetating them. In many urbanised areas, this is no longer possible and end of pipe solutions must be used. In the Toronto Area of Concern, an end of pipe system developed by Karl Dunkers was built to improve water quality. It consists of a series of cells in which water from the combined water discharge flows is recycled, allowing contaminants and sediments to settle out before water is discharged to Lake Ontario.

Many stakeholder groups have spent considerable hours and efforts in reclaiming abandoned sites and improving habitats around the Great Lakes. There have been major efforts to restore habitats for fish, amphibians, reptiles, birds and mammals. Pollution reduction and habitat creation and protection have meant that a number of species such as Otters and Bald Eagles are returning to Lake Ontario. In Hamilton Harbour, for example, the shoreline has been recreated to provide islands for nesting colonial waterbirds such as Caspian and Common Terns; beaches, pools and wetlands created for amphibians and turtles to breed; and off shore reefs constructed for fish nursery habitat. The projects were undertaken in a series of stages with input from many stakeholder groups and government agencies. Final plans were completed and construction undertaken in the mid 1990s. The colonial waterbirds, for example, have largely moved from the heavily contaminated areas of the harbour to new island habitats.

5. Policy and Public Involvement in a Changing Environment

The public is generally very aware of the environment and some 85 percent of Canadians participate regularly in nature-related activities such as hiking, bird-watching and fishing. The majority of Canadians are concerned about the environment and 98 percent view nature in all its variety as being essential to human survival (Boyd 2003). Many volunteer groups have become involved in restoring shoreline habitats around the Great Lakes. This can take many forms of activity. Cleaning up garbage from natural areas is an activity that is done on a regular basis by many groups while restoring habitats through planting trees, shrubs and wild flowers is another. Some groups are involved in stream restoration, stabilizing banks with shrubs and root balls while others are involved in removing non-native vegetation such as Purple Loosestrife or Garlic Mustard. Many local newsletters and guided walks serve to transmit information from knowledgeable people to those interested, and help bring about a more informed public.

However, many environmental issues are relatively low on the government's agenda. The laws protecting the environment and the coastal zone were introduced many years ago, long before climate change became an issue. There are many factors that assume the environment is relatively static, that shorelines are not moving and that the climate we know today is the one that will occur in the future. However, many factors such as changing shorelines, or changing the frequency of major rainfall events, are likely to have impacts on properties, on infrastructure and on ecosystems around the Great Lakes.

It will be necessary to harmonize the many laws and regulations to ensure that truly sustainable environments are protected for the long term. This should be measured in hundreds of years rather than the four or five years that most elected governments are in office.

The laws and regulations in Canada are divided between several layers of government; the federal, provincial, regional and municipal levels and many responsibilities overlap. The federal government has provided funding for many restoration efforts in Areas of Concern, and in some cases, the provincial government has been involved as a partner. The Conservation Authorities have played a relatively active role in undertaking restoration initiatives at the local level and provide the expertise not available to many municipalities. However, funding at the local level is very limited because of their revenue source that is primarily dependant on property taxes. A major problem with the current situation is that the federal and provincial governments develop large scale plans regarding the protection of the natural environment but in most cases do not provide funding for the area municipalities and Conservation Authorities that are likely to undertake the work. This is a major disconnect and requires to be remedied before comprehensive coastal protection and restoration can be undertaken. Changes in municipal Official Plans and the responsibilities of Conservation Authorities and Regional Governments to manage the coastal resources in a sustainable manner are currently lacking.

6. Conclusions

Climate change is already affecting the coastal zone of the Great Lakes. Lower water levels, increasing water temperature, changes in the ice cover regime, changes in the frequency and intensity of rain events will all impact coastal processes. The key to dealing with climate change in the coastal zone will be to balance the competing demands of biological systems and society’s needs to ensure sustainability of all species and ecosystems. Many of these features are interconnected and while some of these projected changes can be adapted to, others cannot. It is essential to recognize the importance of natural ecosystems and the values they provide which may not be fully costed in terms of the benefits they provide. To protect coastal ecosystems in the long-term requires that an ecosystem approach be undertaken to coastal and landuse management. While it may be possible to adapt to some changes in the coastal zone, many of these adaptations are costly and are not proven to be sustainable in the long term.

Therefore it is imperative that reasonable long-term land use plans be developed in which all components of the environment are addressed. This requires that policies and laws be developed for all levels of government that are rational and harmonized. One reason for involving local stakeholders is that adaptation options should be developed by the people who are most familiar with the problems, as solutions will generally be implemented at the community level, tailored to specific regions and sectors and actively involve those who live and work there (Smith et al., 2001). In areas where there are a number of competing interests, it is especially important to involve local stakeholders from a number of sectors, so that a range of interests are represented. The people of Canada and the United States must realize that natural resources are limited and that over-exploitation in the short-term may lead to the extinction of species and the loss of valuable resources for future generations.

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