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Evolution of Great Lakes coastal restoration

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Introduction

Human disturbance led to the degradation of Great Lakes coastal habitats. Various policies and programs were initiated to restore these areas. Coastal restoration efforts in the Great Lakes followed major trends in their evolution over the past 30 years. This paper highlights three case studies of restoration in Great Lakes coastal waters that demonstrate these trends. Comparing restoration projects in this context will provide insights in evaluating long-term success in consideration of the varied goals and methods used.

Background

The expansion of human settlement during the past 200 years in the Great Lakes region led to the elimination or degradation of a number of Great Lakes coastal ecosystems. Multiple factors led to this degradation. The transformation of land use in these watersheds to support agriculture, industry, and commercial and residential developments during this time influenced factors such as: the number of factories emitting toxic substances, quantity and type of upland vegetation, volume of stream flow, and influx of nutrients. At the same time, the transportation of agricultural goods and raw materials in these waterways evolved into a booming industry. This required intense modifications to natural habitats such as dredging which maintained the shipping routes. Shipping also influenced the location of water-intensive industrial operations and the settlement of large metropolitan areas to coasts of the Great Lakes (Thorp et al. 1997). Table 1 illustrates a few examples of the impacts to habitats from human activities (The Nature Conservancy 1994). Coastal wetland habitats, in particular, most frequently suffer from: drainage, filling, dredging, increased rates of sedimentation and nutrient inputs, loss of hydrological connectivity, water level regulation, introduction of non-native species, and discharges of pollutants and contaminants (Dodge and Kavetsky 1995, Maynard and Wilcox 1997). Filling and draining led to losses between 11 to 100% for coastal wetland habitats in sections of Lake Ontario, Lake Erie, Lake Michigan, and Lake St. Clair (Bedford 1990). In comparison, the most important impacts to tributaries of the Great Lakes have been: channelization, dredging, damming, sedimentation, loss of riparian vegetation, eutrophication, increased spring flooding, and toxic contamination (Dodge and Kavetsky 1995). Heightened awareness in the 1950s and 1960s that a number of Great Lakes coastal habitats were severely degraded, especially from toxic pollutants, motivated policy-makers to ban and restrict harmful substances and created momentum for the development of working groups to begin restoration activities.

Table 1. Examples of habitat impacts to ecosystems of the Great Lakes.

Group	**Example**
Chemical Changes	Toxic Chemicals
	Nutrients
	Acidification
	Salinity
Hydrologic Changes	Drainage
_	Water level management
_	Loss of hydrologic connectivity
_	Amount and fluctuation of tributary flow
Physical Process Changes	Temperature
	Sedimentation
Physical Alteration	Filling
	Dredging and channeling
Changes to Community Structure	Non-native species
	Fish stocking

The governments of the United States and Canada responded to the need for Great Lakes restoration with multiple policies and programs. One policy initiating cooperation between these two countries, the Great Lakes Water Quality Agreement, was first signed in 1972. After several revisions, the agreement was finalized in 1987, opening the door for restoration projects in the Great Lakes (International Joint Commission United States and Canada 1987). A few programs that focused even more attention on these communities include Lakewide Management Plans (LaMPs), Remedial Action Plans (RAPs) that contain Areas of Concern (AOCs), State of the Lakes Ecosystem Conferences, and the Lake Superior Zero Discharge Demonstration Program. LaMPs, developed for each of the Great Lakes except Lake Huron, include specific objectives for coastal habitat restoration (National Oceanic and Atmospheric Administration 2001). More important than the LaMPs was the identification of forty-three AOCs in Canada and the United States forming RAPs, many containing coastal habitat restoration as a main goal. As funding became available from policies and programs such as RAP, coastal restoration projects began in the Great Lakes.

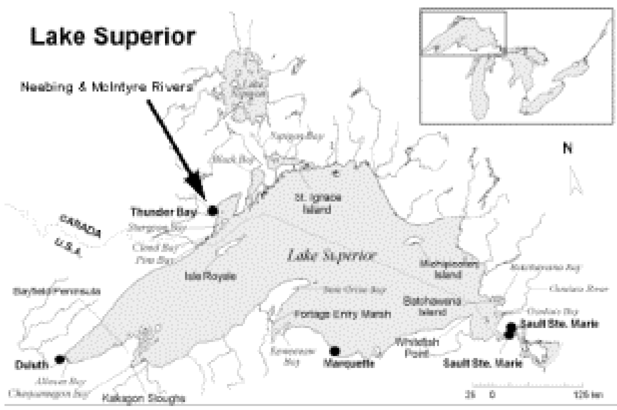
Coastal restoration trends in the Great Lakes progressed from early attempts that primarily provided a few ecosystem services to larger strategies which attempted to restore degraded systems to historic conditions. The earliest restoration trend in the Great Lakes discussed in the published literature focused on lake-wide populations, such as *Salvelinus namaycush* (lake trout), which impacted commercial fisheries. These species-specific projects led the way for the next trend of coastal restoration that centered on the enhancement or creation of habitat for waterfowl and fish communities. One reclamation technique commonly used especially in areas with severe physical alterations from channelization and dredging was island creation (Geiling 1995, Monds 1995). Breakwall and dike construction techniques providing sheltered fish habitat also fall into this category (Reutter 1995, International Joint Commission United States and Canada 1998). The Neebing and McIntryre Rivers case study clearly illustrates habitat enhancement by the addition of habitat structures for fish in channelized Great Lakes tributaries. The next stage of coastal restoration in the Great Lakes was dominated by small-scale pilot projects attempting to bridge the gap in understanding which techniques could be used successfully, especially in coastal wetlands (Dushenko 1990). A number of these attempts met at times with limited success (G. Hill, personal communication). These successes and failures produced an environment for innovative approaches of coastal restoration as shown by the case study of Irondequoit Bay, which addresses nutrient cycling and oxygen demands in a degraded bay of Lake Ontario. The third case study, Metzger Marsh illustrates a more comprehensive approach that restores a degraded coastal wetland close to historic conditions by revitalizing the natural ecosystem structure and functions. Coastal restoration continued to evolve in the past ten years including projects which place an increasing emphasis on multiple scales (Wilcox and Whillans 1999, J. Hall, personal communication), community involvement and education (Rodriguez 2001), and GPS/GIS technologies. Recognizing restoration efforts in the context of these trends assists in differentiating the varied levels of goals and successes of projects in the Great Lakes.

Case studies

Neebing and McIntryre Rivers case study

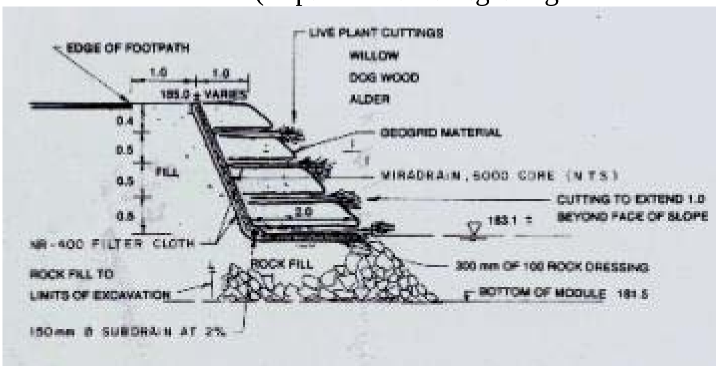
The first trend of coastal restoration, illustrated in the Neebing and McIntyre Rivers project, focuses on habitat enhancement and creation. Historically, the Neebing and McIntryre Rivers flowed separately into the northwest section of Lake Superior in the Thunder Bay Harbor of Ontario, Canada (Figure 1). At that time, these meandering rivers had both vegetated banks and littoral zones which provided habitat for spawning *Oncorhynchus mykiss* (rainbow trout) and residential populations of *Salvelinus fontinalis* (brook trout), *Stizostedion vitreum* (walleye), and *Perca flavescens* (yellow perch) (Cullis 1995). Humans physically altered this habitat in 1983 to mitigate flooding in residential areas. The lower portions of the tributaries were filled and then combined into a single, straight, 4-kilometer (2.5-mile) long channel lacking instream structure (Cullis 1995). Representatives from the North Shore of Lake Superior Remedial Action Plan (including Environment Canada, the Great Lakes Cleanup Fund, Ontario Ministries of Natural Resources) and the Great Lakes Laboratory for Fisheries and Aquatic Sciences in the Department of Fisheries and Oceans collaborated in 1991 to restore some ecosystem services. The necessity of maintaining both the flood control structure and a channel for small boat navigation limited the level of restoration in the Neebing-McIntryre channel that could be accomplished. These circumstances influenced their restoration goal, which was to provide habitat structures benefiting immigrating spawning and emigrating juvenile fish.

Figure 1. Location of Neebing-McIntryre channel. Modified image courtesy of the Environmental Protection Agency and Environment Canada's 1996 State of the Lakes Ecosystem Conference (http://www.epa.gov/glnpo/solec/96/coastal/).



Neebing-McIntryre project managers initially added embayment structures, wood pilings, log mats, and boulder piles in order to provide diverse fish habitat in this channel. The embayment structures were constructed at 100-meter intervals in four sections along the bank to increase littoral habitat and reduce stream flow. The first step involved the excavation of approximately 7x2 meter sections of soil from the bank providing a place for structures to be added (Figure 2). The next phase of construction was the addition of rock fill at the bottom of this space primarily below the water line. Two meters of layered rock and earth fill, geogrid, and live plant cuttings covered this fill above the water line. Geotextile fabric with plastic tubing enclosed for drainage separated this layered material from the rock fill at the water level and on the bank side. Managers also placed granite boulders on the outside edges of these structures perpendicular to water flow to reduce discharge. Aquatic vegetation was also planted around these boulders. In addition to these embayment structures, managers also added eight clusters of boulder piles (geotextile and rock fill in excavated areas), wood pilings (poplar driven into substrate), and log mats (wood logs arranged horizontal amongst the tops of wood pilings) to the edges of the channel. No recurrent management activities to maintain or adjust these habitat structures were recorded.

Figure 2. Example of an embayment structure used in the Neebing-McIntyre project. Image courtesy of Environment Canada (http://www.on.ec.gc.ca/glimr/data/habitat-rehabilitation).



Neebing and McIntyre managers monitored the success of providing habitat structure in the channel through a variety of methods, specifically interested in noting an increase in fish quantity and abundance. They collected fish by applying electric currents to the water, which attracts them (electrofishing), and by using large nets either placed in the channel (seining) or dragged along the bottom (trawling). This data was used to determine if the new structures did indeed create additional fish habitat. They did note an increased abundance and diversity of fish populations in the channel, specifically rises in the number of surviving emigrating juvenile fish (Cullis 1995). Additional results suggest that waterfowl also extensively used these created habitats (Monds 1995). Overall, this project faced some success in enhancing 210 meters of the channel with a demonstrated increase in the use by fish and bird species. It is interesting to note that an alternative explanation to changes in fisheries data could also result from a rise in the overall abundance of these populations outside the channel which could limit the usefulness of this data (Kelso and Hartig 1995). Data monitoring the planting success of aquatic vegetation along with up-to-date fish monitoring data would have provided useful information for managers performing similar habitat enhancement activities. Lack of long-term monitoring data, common in these early restorations, is often due to funding constraints. A full ecosystem recovery could not be expected, nor was it the intent of this the Neebing-McIntyre Rivers project, but illustrates a level of success for coastal habitat rehabilitation in areas with severe physical alterations.

Irondequoit Bay case study

The next stage of coastal restoration in the Great Lakes improved upon the early habitat creation projects by using more holistic approaches in recovering ecosystem processes. Most often, innovative methods were used which addressed multiple scales of the ecosystem in the project goals. This coastal restoration trend improved the potential for long-term success as demonstrated by the Irondequoit Bay case study. Irondequoit Bay located on the south shore of Lake Ontario near Rochester, New York faced degraded water quality conditions since the early 1900s (Figure 3). Inputs of nutrients from wastewater and urban runoff shifted the 1648-acre (667-hectare) bay from a mesotrophic (moderately productive) to a eutrophic (very biologically productive) state. This produced foul odors and floating mats of algae and vegetation. In the late 1970s, total phosphorus values even reached levels of about 300 mg/L which most likely triggered high measurements of chlorophyll-a (70-80 mg/m^3), an estimator of algal biomass (Brown 2001). These conditions depleted the amount of dissolved oxygen in the metalimnion which is the middle zone that lies between the upper and lower layers of a stratified water body to less than 0.2 mg/L (Brown 2001). This limited the amount of time top-predator fish species such as *Stizostedion vitreum* (walleye) and*Oncorhynchus mykiss* (rainbow trout) could survive in Irondequoit Bay. Restoration actions led by the Monroe County Environmental Health Laboratory in collaboration with the New York State Department of Environmental Conservation, Bay Border Towns, New York State Department of Transportation, Praxair, Cornell biological field station, and Limnofix began in 1993 to address these degraded water quality conditions. The goal for Irondequoit Bay restoration was to return it to a stable mesotrophic state as indicated by chlorophyll-a measurements between 5-10 mg/m^3 (Brown 2001).

Figure 3. Map showing the location of Irondequoit Bay. Modified image courtesy of the Environmental Protection Agency and Environment Canada's 1996 State of the Lakes Ecosystem Conference (http://www.epa.gov/glnpo/solec/96/coastal/).

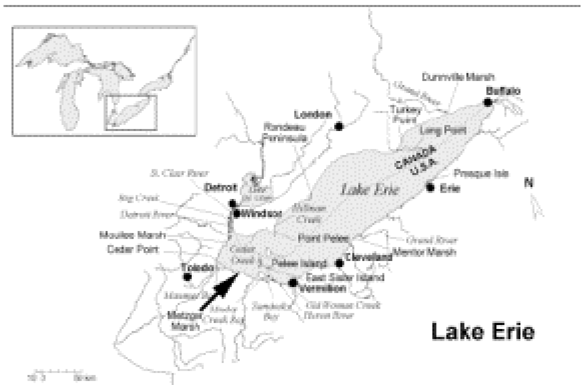
Irondequoit Bay project managers started accomplishing their restoration goal through a variety of methods. First, point source pollution such as wastewater was diverted and treated by a sewage plant in the 1970s and sewer overflows were reduced by 1986 (Brown 2001). In 1986, managers applied alum to regions of the bay where the water depth was six meters or greater. Alum binds to phosphorus in the sediments making it unavailable for algal growth. This treatment lowered internal phosphorus levels by 60-70%. Project partners then decided that in order for internal phosphorus inputs to remain low, the next management tool would be the oxygenation of the hypolimnion, which is the bottom layer of a stratified water body. Increased oxygen levels in a water body provide an environment where phosphorus particles can adsorb to iron oxides. This precipitate reduces the amount of phosphorus available for algal growth and improves the oxygen conditions for zooplankton populations. Zooplankton, tiny aquatic animals, can then survive and graze the abundant algae. Seven sites in the bottom of the bay were infused with 100-180 tons of oxygen per year from 1993 to 2000 using a Liquid Injection System. Originally, the goal for this part of the project was to provide 4-5 ppm of oxygen in the metalimnion, a costly task. Cornell researchers discovered during this phase of the project, however, that only 0.5-1.5 ppm of oxygen were needed for optimal growth conditions for *Daphnia*, a zooplankton, to thrive (Brown 2001). This mid-course correction in the management of Irondequoit Bay now drives the start of oxygen release in the summer when levels fall below 1.5 ppm of dissolved oxygen. Irondequoit Bay managers also wanted to lessen the external inputs of phosphorus from stormwater runoff. In 1997, a weir was constructed in wetlands that drain into Irondequoit Bay to hold the water for a longer period of time. This resulted in an increased nutrient uptake by plants.

The assortment of management techniques used for the restoration of Irondequoit Bay thus far has met with a moderately high success. Evidence for this success is the decrease in chlorophyll-a from 70-80 mg/m^3 in the late 1970s to 9-18 mg/m^3 in the late 1990s. Irondequoit Bay managers attained part of their restoration goal in 1999 with a chlorophyll-a reading that fell between 5-10 mg/m^3. They predict oxygen supplementation will be needed each year until 2010 for the bay to a reach a stable mesotrophic state, which is their complete restoration goal (Brown 2001). The presence of *Stizostedion vitreum*year round in Irondequoit Bay provides a further indication of the success in restoring this ecosystem (G. Brown, personal communication). One element that could complicate the interpretation of the findings was the introduction and expansion of *Dreissena polymorpha* (zebra mussels). *Dreissena polymorpha* can filter large amounts of algae from the water, which could confound the chlorophyll-a results. No methods to control zebra mussel populations in an environmentally friendly manner are currently available so this stressor will continue to impact the bay. Even in light of this information, the trends show significant improvements of water quality in Irondequoit Bay that could not be due to the infestation of zebra mussels alone. One key factor for the success of this project was the amount of monitoring data collected each year, especially as a management tool for oxygen supplementation. Overall, the partial recovery of Irondequoit Bay to a mesotrophic state can be attributed to the innovative, multiple-scale approaches used.

Metzger Marsh case study

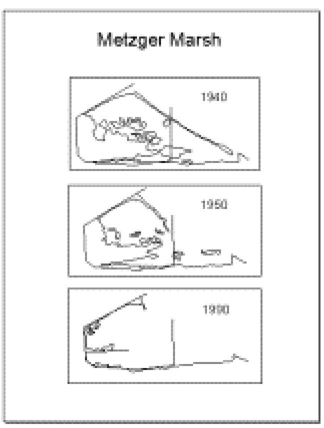
The most recent trend in coastal restoration in the Great Lakes focuses on revitalizing natural ecosystem structure and functions close to historical conditions. Metzger Marsh, located about 11 miles (18 km) east of Toledo, Ohio on the southwestern shore of Lake Erie, is an example of this trend (Figure 4). Historically, a barrier beach on the eastern side of this 907-acre (367-ha) coastal wetland protected the sedge and grass dominated vegetative community (Kowalski and Wilcox 1999, Figure 5). Since the beginning of European settlement, Metzger Marsh faced disturbance in the form of dikes, drainage, and rerouting of a major stream source (Wilcox and Whillans 1999). By 1973, wave action took its toll on this disturbed system and the last remnants of the barrier beach were lost to high water levels. Loss of this protective beach over the next 20 years caused the site to transform from an emergent marsh with 58% diverse vegetative cover to an open embayment with 10% vegetative cover with a low plant diversity (Wilcox and Whillans 1999, Figure 5). Managers from the U.S. Fish and Wildlife Service (USFWS) and the Ohio Department of Natural Resources (DNR) Division of Wildlife in collaboration with Ducks Unlimited, Maumee Bay Audubon, Lake Erie Wildfowlers, Ohio Decoy Carvers, and the Wolf Creek Sportsmen's Club procured funding in 1993 for restoration and management of Metzger Marsh. Returning the degraded wetland to a vegetated, hydrologically connected coastal marsh that could provide multiple functions and values was their goal (Wilcox and Whillans 1999). First, the USFWS and Ohio DNR managers started pre-restoration monitoring to document the plant, fish, and wildlife communities. This information assisted them in considering multiple options for restoration. At the same time, data showing the current and historic vegetated and barrier beach areas of the wetland were collected and interpreted (Kowalski and Wilcox 1999). Using this information, it was decided that the reestablishment of a barrier beach was too difficult because of inadequate sediment supply and unpredictable lake levels (Kowalski and Wilcox 1999). The original goal of this restoration project proposed the creation of a dike that would completely close this wetland from the wave action of Lake Erie. This dike could provide conditions conducive for wetland vegetation reestablishment. As the planning process advanced, managers adjusted their goal to hydrologically connect Metzger Marsh with Lake Erie, mimicking historical conditions more closely (D. Risley, personal communication). This connection was established by including five 2-meter wide experimental water-control structures in the dike. Designers included vertical bars in these structures allowing for the movement of small fish. Electronic fish baskets installed in outside channels enabled managers to transfer desired large fish between Metzger Marsh and Lake Erie, restoring yet another historic connection (French et al. 1999). The different fish management devices were primarily used to exclude *Cyprinus Carpio* (common carp) which disturb sediments as they forage, uprooting numerous aquatic plants (Moss et al. 1996).

Figure 4. Map showing the location of Metzger Marsh. Modified image courtesy of the Environmental Protection Agency and Environment Canada's 1996 State of the Lakes Ecosystem Conference



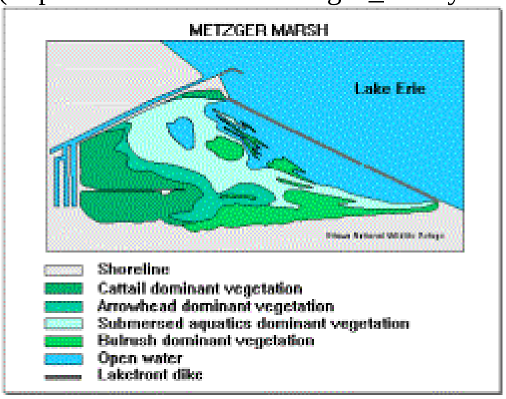
(http://www.epa.gov/glnpo/solec/96/coastal/).

Figure 5. Map demonstrates the loss of the barrier beach and decrease in wetland vegetation in Metzger Marsh from 1940-1990. Image courtesy of the Ohio Department of Natural Resources Division of Geological Survey (http://www.dnr.state.oh.us/geo_survey/lakeerie/metzger.htm).



The Ohio Department of Natural Resources and U.S. Fish and Wildlife Service performed numerous management actions following the completion of dike construction in Metzger Marsh. They conducted a draw down of the wetland in 1996 and 1997 to replicate low water levels and promote revegetation of wetland plants. Managers also added rotenone, a pesticide used in fish eradication, during the drawn down for controlling *Cyprinus Carpio*. Metzger Marsh was reflooded in 1998, and water control structures were opened in 1999. During 1996-1998, a dramatic response to these management techniques was observed when 72-82% of the historically vegetated area of Metzger Marsh once again contained a diverse array of wetland plants (Wilcox and Whillans 1999, Figure 6). This plant community, however, also contained undesirable tree and shrub species and *Lythrum salicaria* (purple loosestrife), an invasive, exotic wetland plant that responded well to the low water levels. Attempts were made to control these populations by spraying *Lythrum salicaria* with glyphosate in 1997 and cutting and spraying (2,4-D) the tree and shrub species between the years of 1997-1999. Currently, two stressors inhibit the successful establishment of a stable plant community that could mirror historic vegetative populations in Metzger Marsh. First, low water levels in the Great Lakes continue to provide suitable conditions for the encroachment and establishment of unwanted plant species (D. Risley, personal communication). Secondly *Cyprinus Carpio* continues to stress wetland plant communities in spite of the control techniques performed (D. Risley, personal communication). Despite these challenges, the restoration of Metzger Marsh can be considered a success as the creation of an open-dike system simulates the historic barrier beach allowing both revegetation of wetland species and a hydrologic connection with Lake Erie.

Figure 6. Map showing the dike and vegetation of Metzger Marsh. Image courtesy of the Ohio Department of Natural Resources Division of Geological Survey (http://www.dnr.state.oh.us/geo_survey/lakeerie/metzger.htm).



Conclusion

Trends in Great Lakes coastal restoration provide a context for insight about long-term success of particular projects. The goals of the earliest restoration attempts focused on enhancement and creation of habitat for waterfowl and fish communities. Projects in this category evaluated success based on short-term monitoring or qualitative results of a few ecosystem services such as increased abundance of fish species. Most often, the efforts were successful in improving upon severely altered habitats. Data are limited, however, and do not represent entire ecosystem factors when evaluated. Efforts improved upon this problem in the next stage of coastal restoration with innovative projects encompassing multiple scales. The level of monitoring data collected also increased allowing for adaptive management, which produced even more successful outcomes. The most recent trend includes projects devised for the restoration of degraded sites to historic conditions. Pre-restoration activities involving intensive data gathering and monitoring promoted adaptive management in the goal-setting stage. The direction of future restoration efforts in the Great Lakes should expend more energy on pre-restoration activities and post-restoration monitoring. These factors promote appropriate goal setting and opportunities for adaptive management leading to an increased potential for long-term success. Another component of Great Lakes coastal restoration worth considering in the goal-setting stage is the identification of potential stressors with realistic management plans.

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