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September 29-30, 2014

Netley-Libau Marsh Workshop

Science Advisory Council

Lake Winnipeg Foundation

This report was prepared by the Lake Winnipeg Foundation Science Advisory Council as a record of proceedings of the Netley-Libau Marsh Restoration Workshop held September 29-30, 2014 at the University of Winnipeg. The SAC is grateful for the funding and in-kind support received from Environment Canada's Lake Winnipeg Basin Stewardship Fund, Manitoba Hydro, the University of Winnipeg, Manitoba Conservation and Water Stewardship and the Lake Winnipeg Foundation that enabled it to bring together local, national and international specialists to exchange information and ideas to guide the potential rehabilitation and restoration of Netley- Libau Marsh, Manitoba's most important wetland habitat.

Report Outline: **Page**

1. Workshop Lead-Up

The Netley Libau Marsh (NLM) is the deltaic Lake Winnipeg mouth of the Red River (RR). West of the RR is the Netley Marsh complex, which has been degraded over the past seventy years. East of the Channel is the Libau Marsh which appears to be in better condition, although there is little data to confirm this. Concerns that habitat deterioration was reducing NLM capacity to sequester nutrients contributing to Lake Winnipeg eutrophication prompted members of the Lake Winnipeg Foundation (LWF) Science Advisory Council (SAC) to ask if and how the health of NLM could be improved.

The merit of a workshop to consider NLM restoration options was initially discussed and agreed upon by Dr. Gordon Goldsborough, Dr. Harold Welch, and Alex Salki in April 2013. Broad acceptance of the concept was reached May 16, 2013 at a meeting of government and university researchers and officials (Appendix I). With Lake Winnipeg Basin Stewardship Funding (LWBSF) approval (April 2014) of the project, LWF SAC conducted a 2-day workshop September 29-30, 2014 to determine what was known about NLM, where there were deficiencies in knowledge, and to brainstorm possible approaches that might be reasonably pursued to rejuvenate the marsh (Appendix II).

We did not try to define what the final state of the marsh might be, but it was obvious from existing data and anecdotal observations that an improved marsh would include greater plant cover, better wildlife habitat, more sequestration of phosphorus (P) and sediment, and other benefits provided by a healthier marsh. Marsh and wetland protection and restoration are goals of the LWF Lake Winnipeg Health Plan guiding actions for a healthy Lake Winnipeg.

Funding for the workshop was provided by the LWBSF, Manitoba Hydro (MH), Manitoba Conservation and Water Stewardship (MCWS), University of Winnipeg (UW) and the LWF. The UW kindly provided meeting (Convocation Hall) and dining (Richardson College) facilities and LWF staff assisted in staging the event. The workshop's considerable success is entirely the product of the fifty invited participants (Appendix II).

2. Presentations and Background Materials

Before the workshop, nearly half the attendees were taken on a guided boat tour of the marsh to better inform meeting comments and discussions.

Invited presentations on historical and recent studies on NLM also assisted workshop participants in their deliberations. Examples of marsh restoration projects elsewhere – Delta (Manitoba), Coote's Paradise (Ontario), and Kis- Balaton (Hungary) helped to identify potential strategies that might be applicable to NLM (see Presentation Abstracts in Appendix III and Power Point presentations at www.lakewinnipegfoundation.org/netleylibauworkshop/).

Background reference material for the workshop was provided to participants (see at www.lakewinnipegfoundation.org/netleylibauworkshop/ and Appendix IV). In addition, a hard copy of Grosshans et al. 2004 (see references) was provided for attendees, partly because the maps helped orient participants.

3. Breakout sessions.

Participants broke out into groups to discuss specific topics provided by the workshop facilitator. Notes from all deliberations are included in Appendix V and summarized below.

3.1 A Brief Overview of What We Learned

Goldsborough presented a good introduction to the historic changes in Netley Marsh. The initial deterioration seems to have begun with the dredging of the "Cut" in 1913, which allowed direct Red River flow into and through the marsh, exiting through the Cross Channel and Salamonia Channel at the north end (Fig. 1). The marsh was still largely intact as of 1923 (Fig. 2). As the Cut widened and deepened, flow through the marsh increased. Reduction of vegetation cover and loss of above-water ground increased fetch (the length of open water available for wave formation) leading to the existing situation where most of the marsh is now Netley Lake (originally only 35% of the entire Netley Marsh). The resultant wave action has eroded marsh edges and suspended fine sediments, which appear to have been exported from the marsh downstream. The lake bottom is now largely fine sand.

The cessation of dredging at the river mouth in 1999 has probably increased RR flows through the Cut and hence Netley Marsh. Further possible negative effects are increased nutrient and sediment loads carried by the RR. The ice breaking by Amphibex could also increase spring flows through the Cut (in March 2012, Amphibex work extended about 1.6 km downstream of the Cut).

The NLM is a spawning and rearing ground for Emerald Shiners (Lysack 1987), which are a key component of lower RR and Lake Winnipeg food webs. Walleye, base of the most important commercial and sport fisheries in Manitoba, feed heavily on Emerald Shiners, although the so-called "Greenbacks" in the October run-up from Lake Winnipeg do not contain significant numbers of Shiners; virtually all have empty stomachs (Welch, pers. obs.). It is not known what effect the deterioration of Netley Marsh has had on Shiner production, although it has likely been detrimental. Janusz and O'Connor (1985) found that walleye and especially sauger used the NLM as summer rearing grounds.

NLM is designated an Important Bird Area (IBA) globally. As a Breeding Bird Survey site (http://www.ibacanada.ca/site.jsp?siteID=MB009&lang=EN), there is ongoing quantification of breeding birds in NLM, but the data are too recent to define absolute trends. Nonetheless, some critical bird species expected in the marsh are either nonexistent or confined to the relatively pristine NE part of Libau Marsh (Artuso;

MacPherson, this workshop). Certainly the Netley side holds far fewer birds than it did half a century ago. The nearly complete collapse of waterfowl hunting on the west side is further evidence of unsuitable conditions for waterfowl.

The lower RR and parts of Netley Marsh have been surveyed bathymetrically (Clark, this workshop.). The percent of Red River flow through the Cut ranges from about 11-40%, with lowest percentages in winter. During the open water season, on average about one third of the river flow goes through the Cut and Netley Lake. Since the cut is ice-covered for so long, the annual % of RR throughflow is likely < 33%. The flow and bathymetric data would provide the basis for a nutrient flow analysis if suitable nutrient concentration data existed. We can surmise that the substantial volume of RR water through the cut and Netley Lake results in little if any removal of nutrients and sediments under present conditions.

Manitoba Hydro lake level regulation since 1976 has resulted in almost no change in *average* water level, but extreme highs, and to a lesser extent lows have been dampened (Hutchison, this workshop). This probably has had some effect on NLM. The almost 40 year period since regulation began has been wetter in the basin than the preceding period.There has been a 37% increase in water flow (inputs from the Lake Winnipeg drainage basin) in the past ten years. A simulation of "without LWR" water levels shows the lake level would rarely have dropped below elevation 715 over the past 10 years, and flood peaks of 2005, 2011 and 2014 would have been 2 feet or more higher. During periods of high precipitation in the basin, inflows from the many tributaries to Lake Winnipeg can far exceed even the enhanced outflow capacity available through Manitoba Hydro's Lake Winnipeg Regulation Project. The result is that Manitoba Hydro can only influence the lake level, not control it.

Runoff from the Lake Winnipeg drainage has increased recently because of increased rainfall, which is likely to continue if climate change continues on its predicted course (McCullough, this workshop). Because soils are now mostly saturated, incremental runoff from a given increase in precipitation is higher than it is when soils are under-saturated. Phosphorus concentrations in runoff are also higher during peak flow, so we can expect the higher phosphorus loading of the past decade or so to continue with continued high runoff. Prolonged periods of low water to facilitate marsh re-vegetation are therefore unlikely without considerable hydraulic engineering within the marsh.

Satellite imagery indicates that, while much of the NLM is losing emergent vegetation, some parts are actually gaining (McCullough, this workshop). Quantification of these changes is an obvious direction for research.

The Province of Manitoba has considerable data on water levels and flows throughout the Manitoba portion of the RR basin, including the lower RR (Bin Luo, this workshop). This can be used to predict water flows through NLM, although it has not yet been used to do this. The data are primarily used for flood prediction and protection. In that regard, any manipulation of water level and flow changes must consider flooding aspects upstream of NLM. In general RR flows are now higher and faster than would be expected historically from the same precipitation on the watershed.

Marshes in general sequester nutrients and sediment from inflowing water. Grosshans (this workshop) provided some approximate figures that are useful for calculating the effects of both a deteriorating and a rebuilding marsh. A mature stand of cattails holds about 150 kg/ha P, most of it in the sediment. Cattails don't take up P directly from the water, but from the roots. Sedimentation, facilitated by submerged vegetation, may drive the sequestration of P in the marsh. A rejuvenated marsh would remove about 100 kg P/ha in the process of regrowth. Harvesting cattails removes on the order of 20-60 kg/ha P, and could improve habitat for nesting birds as well (Megyer, this workshop). Cattail production could therefore be used both as source of biomass energy, and nutrient recycling through agriculture.

Wrubleski (this workshop) summarized the current state of affairs on Delta Marsh at the south end of Lake Manitoba, another marsh of great historical and practical importance. That marsh, like NLM, is also largely driven by seiches (the wind-driven sloshing of lake water back and forth in the basin, much like the wave you set up in your bathtub). Facilitated by a multi-partner initiative, corrective measures are being tried on Delta Marsh, starting with control of the common carp. In Delta Marsh, carp destroy submerged vegetation and with it critical marsh habitat, as demonstrated by experimental carp exclosure experiments. Carp control structures have been installed and the marsh is being monitored to determine the effects.

Chow-Fraser presented the work on Cootes Paradise marsh upstream of Burlington Harbour (Lake Ontario), a good example of partial marsh regeneration, not to its original state, but much improved from its degraded state. She emphasized that an ecosystem approach was essential, and trying to correct the problem piecemeal does not work on something as complex and dynamic as a marsh. It is also important to involve all interested parties, not only to ensure their individual desires are considered, but to generate enthusiasm and funding for such a long term project.

Megyer presented a summary of the Kis-Balaton marsh, a cleansing and recreational ecosystem at the head of Lake Balaton in Hungary. An important message for this

workshop was the need to be flexible and to be able to change direction a bit now and then, depending upon results, opposition, and facilitation. He also emphasized how difficult it was to constructively change such a dynamic and complex ecosystem, and how important it was to bring all stakeholders on board.

3.2 Highlight Results of Breakout Sessions

Note: This is a summary more or less in priority order of session notes (see Appendix 5 for details). Keep in mind that not all pertinent issues were raised and discussed. To some extent these notes reflect the knowledge and bias of individual participants and should not be considered as proven facts. Some information summarized under speakers (above), is not duplicated here.

<u>Breakout Session 1</u>: Lessons and Insights. What we learned from presentations.

- No clear definition of what we consider to be a "healthy marsh". What are we restoring it to and why? Reasons to restore include birds, fish, nutrient and sediment sequestration, improved Lake Winnipeg water quality, plant cover, hunting, birding, ecotourism, it is part of a healthy lake, the delta acts as a filter and sponge for the Red River, and simply because we should.
- Doing nothing is an option, although this will result in continuing degradation. How much do we actually need to know before embarking on an action plan?
- Marsh, especially Netley side, is changing very rapidly, documented by decreasing plant cover, increasing lake size, decreasing bird populations, and increasing water flow. Why do some parts of NLM appear to be growing and others shrinking?
- Upstream effects (e.g. dams, ditching) affect the marsh.
- NLM is a nursery for baitfish, and hence is important to top predators (including birds) to some unknown degree.
- NLM might not be such an Important Bird Area anymore.
- A healthy marsh provides economic and environmental benefits.
- Water levels are primarily controlled by watershed runoff and winds/atmospheric pressure on Lake Winnipeg. Climate change suggests a continuation of high runoff.
- Multiple stakeholders must be engaged; what are the interests, who owns what, what are potential costs, who might pay for it?
- Bathymetric map exists.
- Isostatic rebound is slowly sinking NLM, probably influencing southward progression of marsh.
- The marsh is a very complex, dynamic, large system and therefore study results

may not be entirely predictable. Harness natural processes and don't fight what we can't control. Highs and lows are required for a healthy system. Economic impacts (e.g. Manitoba Hydro, flooding) will be important considerations for any proposed marsh alterations.

- River flows provide the raw materials to the marsh and vary seasonally. However, flooding, sediment and nutrient removal, and subsequent ebbing of clarified water occurs over a period of one to a few days. It is this dynamic which appears to drive the marsh at present.

<u>Breakout Session 2:</u> Knowledge Gaps.

- Good data is scarce. Participants noted knowledge gaps in nearly every aspect of NLM. An important step is to summarize and interpret existing information and determine what important pieces are missing. Noted gaps included:

  - Gaps in marsh history and probable causes
  - Bird population trends and causes
  - Fish abundance, dependence upon the marsh, effects on fisheries
  - Pre-1979 conditions; general antecedent marsh conditions
  - Dynamics of nutrient and sediment removal by marsh (interaction with lake and river)
  - Comparison of Netley with Libau
  - Effects of lake level regulation
  - Ice/water dynamics relative to dredging and lake regulation
  - Effects of invasive species
  - Result of river mouth dredging
  - Clarify hydraulic forces that drive the marsh
  - Can marsh be rejuvenated without closing the Cut?
  - Impacts of spring flooding and general river dynamics, especially during high water
  - Importance of NLM to various stakeholders
  - Importance of degrading marsh to stakeholders over time (e.g. hunters)
  - Roles of emergent and submerged vegetation on sequestration of P
  - Importance of carp
  - Effects of cattail harvesting
  - What has worked for other marsh restoration efforts
  - Who pays
  - How are sediments transported around the marsh
  - Role and amount of sedimentation in NLM

- How various regulations control what we could do
- Return on investment for various stakeholders

<u>Breakout Session 3:</u> Most feasible strategies to rejuvenate NLM and next steps to be taken.

Note: There was considerable overlap, plus diversity, of strategies suggested, plus they overlap with steps to be taken. They are listed below in no particular order, with the idea that they will inform the next steps to be taken. Some of those steps are also summarized below.

- Collect all available pertinent information and summarize it in a referenced report that will serve as the starting point for all considerations.
- Establish a web-based portal for knowledge accumulation and dissemination [Preference to use existing repository of Lake Winnipeg and watershed information at the University of Manitoba - Lake Winnipeg Information Network]
- Establish some form or forms of "champion". A small steering committee of knowledgeable and influential players would be a good start, possibly under the auspices of the LWF or DUC. "Science" and "Communications" teams might be useful. A single person driving the process would be good. A small field station wherein people could work would be good but probably not a first step.
- Establish stakeholders, money and equipment sources. Some of these are already available at little cost.
- Apply for grants and try for secure funding
- Acquire a "jon boat" as a working skiff for people wishing to visit, observe, or sample the marsh.
- Acquire a camera drone to monitor vegetation changes in selected locations.
- Raise public awareness; build a "success story" than will enhance public involvement and education.
- Treat Netley and Libau marshes separately and learn what we can from Libau
- Close the Cut; Don't close the Cut (!).
- Resume dredging at river mouth.
- Rebuild beach ridge
- Have periodic draw down
- Harvest cattails and possibly try floating rafts of vegetation; assess results
- Set goals and priorities
- Start where access is easiest
- Measure progress and demonstrate results and successes
- Use Amphibex for bottom work

- Monetize value of solutions, not just costs.
- Build small cells to test strategies
- Research priorities include:
    - effects of marsh on nutrients and sediments,
    - calculation of benefits of marsh renewal on an areal basis,
    - changes in vegetation (remote sensing, ground truthing),
    - measurements of water flow in and out of selected channels as a function of lake seiche,
    - continuation of breeding bird surveys,
    - use of high quality and degraded marshes as fish habitat.

4. Figures

1. Map of Netley-Libau Marsh Area (Grosshans et al 2004)
   (a) 1979 (b) 2001
2. Red River – Netley-Marsh 1923 (Goldsborough from Manitoba Archives)

Figure 1(a) Netley-Libau Marsh 1979

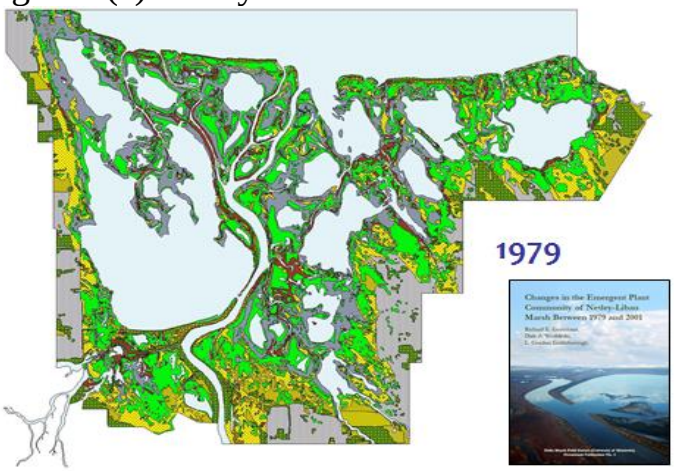

Figure 1(b) Netley-Libau Marsh 2001

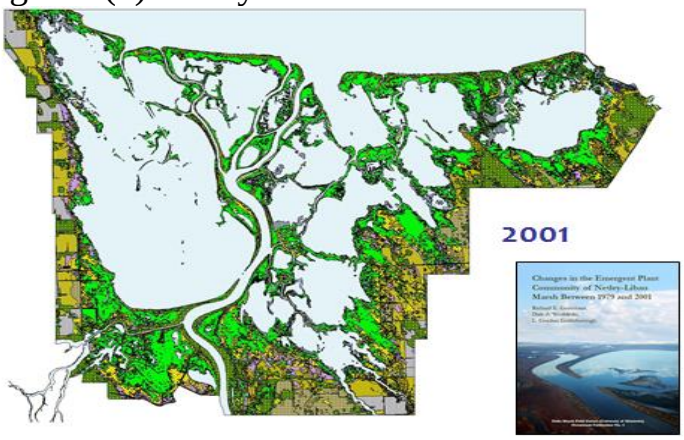

Figure 2. Netley Libau – Red River mouth area 1923

Appendix 1: Attendees at Building Consensus for NLMW, May 16/13

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Appendix II: NLM Workshop Agenda and List of Attendees

AGENDA
NETLEY LIBAU MARSH WORKSHOP
SEPTEMBER 29 – 30, 2014
UNIVERSITY OF WINNIPEG
CONVOCATION HALL

Monday September 29

Opening 8:30 – 9:00

8:30 – 8:40 Introductory remarks, Workshop Funders – SAC Chair Alex Salki
8:40 – 8:45 Official Welcome - University of Winnipeg President Dr. Annette Trimbee
8:45 – 8:55 Lake Winnipeg Foundation - President Roger Mollot
8:55 – 9:00 Meeting Structure & Process – Facilitator Cate Watrous

Netley Libau Presentations 9:00 – 10:30

9:00 - Gordon Goldsborough: Cut and (not) dried: An historical context for the decline of Netley-Libau Marsh
9:20 – Walt Lysack: Emerald Shiner dynamics in vegetated and non-vegetated shorelines of Netley Libau Marsh and the Red River in the 1980s
9:35 - Christian Artuso: Changes in regional bird populations
9:50 – Shawn Clark: Physical and Hydraulic Characteristics of Netley Libau Marsh
10:10 – Dale Hutchinson: Lake Water Level Dynamics and Lake Winnipeg Regulation

Coffee 10:30

Netley Libau Presentations 10:50 – 12:00

10:50 – Greg McCullough: Climate, hydrology and the Netley-Libau Marsh
11:10 – Bin Luo: Flood Frequency Dynamics in Netley Libau Marsh
11:30 – Richard Grosshans: Nutrient Sequestration of Netley-Libau Marsh: Novel Ecological Biomass in a Watershed-Based Bioeconomy

Lunch 12:00 – 1:30 Convocation Hall

Facilitated Sessions 1:30 – 3:00

1:30 – 2:15 - Breakout Topic 1: What lessons/insights do presentations/background materials provide for a NLM restoration strategy

2:15 – 3:00 - Breakout Topic 2: What do we still need to know for a rehabilitation strategy?

Coffee 3:00

Facilitated Plenary 3:20 – 4:00 - Sharing Ideas from Breakout Group Topics

Marsh Restoration Project Examples – Local to Global

4:00 – 4:30 Dale Wrubleski: Delta Marsh (Manitoba): The Long Road to Restoration

Monday Dinner: Richardson College for the Environment, Atrium – (599 Portage, 5 minute walk west of Wesley Hall)

5:30 - Cash Bar Open
6:00 – 8:00 – Buffet Dinner

Tuesday September 30 Convocation Hall

Marsh Restoration Project Examples – Local, **National**, International
9:00 – The Cootes Paradise (Ontario) Marsh Restoration Project – Patricia Chow-Fraser,

Coffee 10:15

Marsh Restoration Project Examples – Local, National, **International**
10:45 - The Kis-Balaton (Hungary) Marsh Rehabilitation Project – Csaba Megyer

Lunch 12:00 – 1:30 Convocation Hall

Facilitated Breakouts and Plenary 1:30 Next Steps for moving forward

Workshop Wrap-up 3:00

Attendees NLMW September 29-30, 2014

1	Bourne	Alexandra	MCWS
2	Goldsborough	Gordon	UM
3	Grey	Bruce	MCWS
4	Grosshans	Richard	IISD
5	Hann	Brenda	UM/LWF SAC
6	Hutchison	Dale	MB HYDRO
7	Loadman	Nancy	UW/SAC
8	MacPherson	Charlie	NLM
9	McCullough	Greg	LWF SAC
10	Salki	Alex	LWF SAC
11	Salki	Cathy	LWF SAC
12	Swanson	Gary	MB HYDRO
13	Welch	Harold	LWF SAC
14	Wong	Charles	UW/SAC
15	McDougal	Rhonda	MCWS
16	Hanson	Mark	UM/SAC
17	Meuckon	Cam	MCWS
18	Wrubleski	Dale	DUC
19	Kling	Hedy	AT&E/LWF SAC
20	Chow-Fraser	Patricia	McMaster U
21	Megyar	Csaba	Lake Balaton
22	Paterson	Mike	IISD
23	Artuso	Christian	Manitoba Naturalists
24	Clark	Shawn	U of Manitoba
25	Mollot	Roger	LWF
26	Hudon	Christiane	EC Montreal
27	Watchhorn	Elise	MCWS

28	Page	Bryan	DUC
29	Brezinski	Ken	U of W student
30	Brown	Alistair	U of W student
31	Kowal	Paige	U of M student
32	Lumb	Chelsey	MCWS
33	Watrous	Cate	facilitator
34	Earl McCorrister	Kirsten	LWF
35	Bluesky	Gord	Brokenhead FN (absent)
36	Penner	Wes	Manitoba Hydro
37	Anderson	Dennis	President Brandon U (retired)
38	Scheider-Vieira	Friederike	North South consultants
39	Zacharias	Allison	MB HYDRO
40	Luo	Bin	MCWS
41	lysack	walt	retired MCWS fisheries
42	Sigmundson	DJ	RM St. Clements
43	Belanger	Armande	East Interlake CD
44	Badiou	Pascal	DUC
45	Sugget	Glen	MCWS
46	Rutherford	Les	EC
47	Armstrong	Nicole	MCWS
48	Ali	Genevieve	U of M
49	Venema	Hank	IISD (absent)
50	McLeod	Sheldon	LWF Board
51	Stoll	Nicole	U of M student
52	Smith	Carl	Brokenhead FN (absent)
53	Stainton	Mike	LWF SAC
54	Tesarski	Ian	RM St. Andrews
55	Trimbee	Annette	U of W President

Appendix III: Speaker abstracts

Cut and (Not) Dried: An Historical Context for the Decline of Netley-Libau Marsh

Gordon Goldsborough
Department of Biological Sciences, University of Manitoba

There have been at least four factors contributing to a marked decline in the emergent macrophyte cover of Netley-Libau Marsh over the past 100 years. In 1913, the Canadian government dredged a channel from the Red River into the south end of Netley Lake. Marked erosion of this channel, dubbed the Netley Cut, has increased the quantity of fast-flowing water into the marsh, eroding the bottom and deepening the marsh beyond the tolerance of macrophyte taxa. Water quality has worsened due to the high influent load of suspended solids and nutrients from the Red River. Two changes in the last 15 years have increased the impact of the Netley Cut on the marsh. First, the stoppage of dredging at the Red River mouth in 1999, and the resulting accumulation of sediment, has encouraged greater flow through the Cut. Second, flood mitigation

work by the Manitoba government has included ice-breaking on the Red River immediately south of the Netley Cut to facilitate inflow into Netley Lake. Finally, a reduction in the frequency of low-water periods on Lake Winnipeg, due to lake regulation by Manitoba Hydro, has affected the extent of plant recruitment from the seed bank.

Emerald Shiner Dynamics in Vegetated and Non-vegetated Shorelines of Netley Libau Marsh and the Red River in 1983 – 1984.

Walter Lysack
Fisheries Biologist (retired) Manitoba Conservation

Densities in vegetated and non-vegetated shoreline areas and in mid-stream areas at Lockport, Selkirk, and Netley-Libau tended to be high in spring, decline during summer and increase in the fall.
Young of the year, yearling, and two year old shiners dominated the catches in both years. The mean length at 50% maturity was about 67mm.
Commercial fishing effort was highest in spring and declined steadily until autumn. Commercial catch per unit of effort was high from May to July, decreased in late July to August and increased in September. Commercial catches are heavily culled.
Adult shiners move into the marshes to spawn. Newly-hatched shiners remain in the marsh to feed and are flushed into the river in autumn as dissolved oxygen concentrations decline. This coincides with the autumnal walleye run.

Physical and Hydraulic Characteristics of Netley-Libau Marsh

Shawn Clark
University of Manitoba

Since 2009 a reasonable amount of data regarding the physical and hydraulic characteristics of Netley-Libau Marsh has been acquired. Most significantly, bathymetric data for all of the various lakes within the marsh was quantified in 2010 and 2011. Recently acquired bathymetric observations at two key locations suggest some possible changes have occurred. Occasional discharge measurements in the region near Netley Cut as well as some of the channels within the marsh have been acquired since 2009. In 2010 and 2011 a fairly comprehensive monitoring program was established on the marsh. Water velocity measurements were taken from moored acoustic instruments placed in several of the channels. Water levels and temperature were recorded throughout the marsh for the open water season. When combined, these measurements can help us to understand how water levels and flows within the marsh respond to wind events.

Lake Water Level Dynamics and Lake Winnipeg Regulation

Dale Hutchison
Manitoba Hydro

The presentation describes Lake Winnipeg hydrology and examines two key questions: (i) How has the Lake Winnipeg Regulation Project (LWR) affected the Lake Winnipeg water regime? And (ii) Can LWR be used to create a more favourable water regime for the Netley-Libau Marsh?
The Lake Winnipeg water regime has been influenced by a variety of factors since LWR was put in place in 1976. To remove influences attributable to changes in hydro-climatic conditions, upstream regulation and land use, Manitoba Hydro constructed a model to simulate “without LWR” water levels for the period from 1976 to

present. These simulated water levels are compared to water level data from before and after LWR. The results indicate that: water levels continue to follow a typical seasonal pattern; regulation has lowered peak water levels, has not increased the average water level; and water residence times are similar to natural conditions.
To address the second question Manitoba Hydro examined two factors: the limitations of LWR to control Lake water level (and by extension marsh water level); and the effects of reducing the operating range for power production on Lake Winnipeg by one foot. This examination shows that in addition to significant financial costs, the reduction in operating range results in increased downstream flooding, reduced energy reliability, and limited additional reduction to peak water levels on Lake Winnipeg.

Climate, hydrology, nutrient loading and the Netley-Libau marshes

Greg McCullough
University of Manitoba

Climate may affect the Netley-Libau marshes in many ways. Here, I limit myself to aspects of climate-driven runoff, wind, and runoff-driven nutrient loading. Variability in runoff from the Lake Winnipeg basin, and the runoff-evaporation balance, are the major determinants of interdecadal variability in thelevel of Lake Winnipeg, and hence, of the Netley-Libau marshes. The seasonality of runoff has historically determined seasonal level variability, although this is now altered by regulation of the lake's outflow. However, short-term water level variability in the marshes is largely determined by another aspect of climate: winds, which set up lake levels and force level fluctuations in the marshes at sub-diurnal scale. Less directly, to the extent that nutrient concentrations and loading from the Red River are determined by flooding (and to the extent that flooding is determined by climate), climate has a large effect on nutrient loading to the marshes. This occurs both in spring when Red River flood flow typically exceeds the marshes' volume many times over, and also during larger set-up events which result in significant exchanges of lake and marsh water. In this talk, I examine these aspects of climate effects on the Netley-Libau marshes in the context of regional climate history and predicted climate change.

Flood Frequency Dynamics of Netley Libau Marsh in Lake Winnipeg-Red River System

Bin Luo and Steve Topping
Hydrologic Forecasting & Water Management
Manitoba Infrastructure and Transportation

Establishing proper water level frequencies at the Netley Libau marsh in the Lake Winnipeg - Red River system is important for flood protection, land easement, and water hazards assessment. Flood levels at the Netley marsh are governed by both Lake Winnipeg water level and Red River inflow and further complicated by wind action on the lake, river and lake ice condition, and regulation from water control structures on Red/Assiniboine River and Lake Winnipeg. This presentation explains the determination of peak water level frequencies on Lake Winnipeg and flood-discharge frequencies on Red River at James Avenue. It also examines the dynamics of flood levels at the Netley Libau marsh and further reveals the challenges in determining the flood level frequencies in the study area.

Nutrient Sequestration of Netley-Libau Marsh: Novel Ecological Biomass in a Watershed-Based Bioeconomy

Richard Grosshans
International Institute for Sustainable Development

Netley-Libau Marsh has undergone significant changes resulting in a loss of plant communities, erosion of channels and islands, and expansion of open water. The extensive loss of plant communities and organic sediment layers resulted in a significant decrease in the nutrient capture and filtration capacity of this coastal marsh system. Many benefits that it could provide in removing and storing nutrients that would otherwise enrich the lake have been degraded or lost. A survey was conducted in 2009 and 2010 to measure current average total P and N content of the plant communities and organic litter, and to evaluate potential additional uptake capacity with 25% restoration. In addition, research from 2006 to 2010 demonstrated that harvesting the large emergent plant cattail (Typha spp.), one of the dominant plant communities in NLM, permanently removes P and N, and harvested biomass can be utilized for bioenergy and bioproducts. Cattails yields 15 to 20 T (DM)/Ha, with 20 to 60 kg/Ha of P captured during harvesting. Nutrients taken up during growth are locked in harvested biomass and prevented from being released via decomposition. Calorific heat value is 17 to 20 Mj/kg with excellent densification and combustion properties. Ash content 5 to 6% and phosphorus is recovered in ash following combustion. Pilot scale harvesting from 2012 to 2014 has demonstrated commercial and economic viability for watershed nutrient management. By harvesting novel ecological biomass that effectively absorbs nutrients we're gaining additional environmental and economic co-benefits: creating a supply of sustainable renewable biomass for industry, displacing fossil fuel use for energy, removing nutrients that can be recycled, and improving habitat.

Delta Marsh: The Long Road to Restoration

Dale Wrubleski
Ducks Unlimited Canada

Delta Marsh is one of the largest and most well-known freshwater coastal wetlands in North America, and it is a wetland of international and regional importance. From the late 1800s, the marsh was known as an important waterfowl hunting area, and attracted many local residents, as well as royalty and the rich and famous from around the world. However, over the last four to five decades, Delta Marsh has seen many changes. Hybrid cattails have taken over large parts of the marsh, filling in smaller isolated ponds. In the large bays, islands and stands of emergent vegetation have been lost to erosion. Water quality has deteriorated, becoming murky, and algae blooms now occur annually. Submersed aquatic plants have declined in abundance and diversity, and have all but disappeared from much of the marsh. Waterfowl production is almost nonexistent, and its role as a molting and staging marsh has also been greatly reduced. Several factors are thought to be contributing to the decline, including stabilized water levels, eutrophication and common carp. After several earlier attempts to initiate restoration/management plans, a ten-year project was started in 2012. Delta Marsh – Restoring the Tradition is a multi-partner initiative struck to reverse the deterioration of Delta Marsh. Phase 1 of the restoration effort is the exclusion of common carp from the marsh, along with a five-year monitoring program to assess the impacts of carp exclusion, and to provide additional information on bathymetry, land use, hydraulics, hydrology, and ecology of the marsh and watershed area. This new information will then be used to initiate additional restoration measures.

Highs and lows of restoring Cootes Paradise Marsh: water levels, native biodiversity, expectations, frustrations and effectiveness of monitoring programs

Patricia Chow-Fraser
McMaster University

People have destroyed or severely degraded most of the coastal wetlands in Lakes Erie and Ontario. In the 1990s, the Hamilton Harbour Remedial Action Plan initiated plans to restore one the largest remaining coastal marshes of Lake Ontario, Cootes Paradise Marsh. In this talk, I will present information on the planning process leading to implementation of a marsh-wide carp exclusion as a restoration strategy, establishment of the effectiveness monitoring program, and use of ecological indicators based on water-quality, zooplankton, macrophyte and fish information to assess the effectiveness of the carp exclusion. There has been significant improvements in water quality and re-establishment of some native plant and fish taxa, but decline in water level has also allowed non-native invasive species (notably manna grass (Glyceria maxima) and the common reed, (Phragmites australis australis)) to become established at the expense of the native species of cattail (Typha latifolia). Compared to a coastal marsh in another Area of Concern that was delisted in 2002 (Matchedash Bay in Georgian Bay, Lake Huron), it is still more degraded in all aspects studied. The high nutrient levels in the sediment and runoff from the watershed as well as high turbidity from wind re-suspension are preventing progression of the "restored" marsh to a clear-water, macrophyte-dominated system. Successful attempts to restore a "novel ecosystem" to its original biotic and abiotic conditions will take a very long time, and those who wish to initiate a similar restoration must be ready for many frustrations and surprises.

The Kis-Balaton (Hungary) Marsh Rehabilitation Project

Csaba Megyer
Balaton Uplands National Park Directorate

The project targeting the completion of the Kis-Balaton Water Management System Phase II started in 2011 after a 4-year-long preparatory period and will be finished in October 2014. 85 % of the budget of the project is financed by the European Commission. The main objectives are: improvement of the ecological status of the area, further support of the good water quality of Lake Balaton and the expansion of the flood-control function of the Kis-Balaton. Management of the nature conservation in this area belongs to the Balaton Uplands National Park Directorate. We took part both in the preparatory and in the implementation periods as advisors, consultants and conducted professional inspection as well.

The most important results of nature reservation are: apart from the flexible flow regulation, the seasonal variation of the water conditions are able to manifest. The system contains many different possibilities of the operation: the water can flow round or through different parts of the area with operating the sluices of the bypass system. It already makes better conditions not only for the waterfowl, but (opened the dam with two fish-ladders) also enables the successful reproduction of the native fish species.

Finally, an abandoned borrow pit area was modified and transformed to a new shallow-watered wetland complex. After removing the surface of the soil, different ground levels and water depth have evolved. The marsh vegetation appeared quickly in this new wetland area. Besides reaching better ecological conditions, it can be utilized in eco-tourism of the Kis-Balaton.

Appendix IV: Workshop Reference Materials

Essential References

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Selected Reference Abstracts

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Guest editorial

Setting ecological restoration goals for technical feasibility and scientific validity

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Abstract

Major ecological restoration will not be undertaken unless human society approves the goals and objectives of restoration. In addition, restoration will not persist unless human society has sufficient esteem for the restored ecosystem to protect its integrity. Linking ecological restoration to sustainable use of the planet seems a promising way to foster society's interest in and acknowledgment of human dependence on natural systems. An increase in environmental and ecological literacy is essential to achieving this end, as is an awareness of the goals and conditions of sustainability. If the science and technology underlying ecological restoration are not understood by the general public, implementation will fail for lack of public support. Ecosystem services, those functions of natural systems perceived as beneficial to human society, are likely to be understood and accepted if their value in the life support system of human society is explained. Emphasis in ecological restoration must shift from reestablishing a naturalistic community of plants and animals in the damaged ecosystems to restoring ecological functions, particularly those perceived as ecosystem services. Most restoration projects thus far have emphasized structure rather than function, although both are doubtless important to sustainable use of the planet. Nevertheless, support for ecological restoration may be enhanced by emphasizing the restoration of ecological services. An essential third consideration beyond technically feasible and scientifically valid goals is whether the goals are socially feasible. This manuscript will explore aspects of social feasibility because neither technically feasible goals nor scientifically valid goals will be possible in the absence of societal acceptance.

Percentage land use in the watershed determines the water and sediment quality of 22 marshes in the Great Lakes basin

Barb Crosbie and Patricia Chow-Fraser

Abstract: Data from 22 Ontario marshes were used to test the hypothesis that distribution of forested, agricultural, and urban land in the watershed determines the water and sediment quality of Great Lakes wetlands. The first three components of the principal components analysis explained 82% of the overall variation. PC1 ordinated wetlands along a trophic gradient; species richness of submergent vegetation decreased with PC1 scores. PC2 reflected the content of inorganic solids and phosphorus in sediment and the ionic strength of the water. Both PC1 and PC2 scores were positively correlated with percent agricultural land, whereas PC1 scores were negatively correlated with forested land. Correlation between PC1 and agricultural land improved when best-management practices were considered. Accounting for common carp (*Cyprinus carpio*) disturbance did not confound the relationship between land use and water quality. PC3, driven by soluble reactive phosphorus and nitrate nitrogen concentration in the water, was not correlated with land use. Concentrations of polycyclic aromatic hydrocarbons and Metolachlor were correlated with urban and agricultural land, respectively, and may be useful as land use surrogates. Watershed management favouring the retention of forested land, or creation of buffer strips to trap agricultural runoff in the drainage basin, should help maintain aquatic plant diversity in coastal wetlands.

Can Constructed Wetlands Reduce the Diffuse Phosphorus Loads to Eutrophic Water in Cold Temperate Regions?

B. C. Braskerud,* K. S. Tonderski, B. Wedding, R. Bakke, A.-G. B. Blankenberg, B. Ulén, and J. Koskiaho

Construction of wetlands is a possible supplement to best management practices (BMP) at the field level to mitigate phosphorus (P) pollution from agricultural areas. In this paper, annual results from 17 intensively studied wetlands in the cold temperate or boreal climatic zone are reported and analyzed. Surface areas varied from 0.007 to 8.7% of the catchment area. The average total phosphorus (TP) retention varied from 1 to 88%, and the dissolved reactive phosphorus (DRP) retention from −19 to 89%. Retention varied substantially from site to site, indicating the existence of site-specific factors in the catchment and wetlands that influenced the P removal. Factors important for P retention in wetlands were evaluated through multiple statistical analyses by dividing P into two fractions: particulate phosphorus (PP) and DRP. Both *relative* (%) PP and DRP retention increased with wetland surface area. However, PP retention was not as sensitive as DRP in terms of wetland size and retention: *specific* PP retention (gram P retention per m^2 and year) decreased as wetland area (A_w) increased, suggesting the existence of a site-specific optimal wetland to catchment area (A_c) ratio. Particulate P retention decreased with increasing DRP to TP ratio, while the opposite was found for DRP. Dissolved reactive P retention was higher in new than in old wetlands, while increasing age did not influence PP retention negatively. Effective BMP in the catchment is important to keep the P loss low, because the outlet concentration of P from wetlands is often positively correlated to the input concentration. However, wetlands act as the last buffer in a catchment, since the retention often increases as the P concentration in streams increases.

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Chemical characteristics of soils and pore waters of three wetland sites dominated by *Phragmites australis*: relation to vegetation composition and reed performance

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Abstract

Chemical characteristics of soils and soil pore waters, plant species composition and horizontal stand structure were investigated for three reed stands in the Třeboň Basin (Czech Republic): Branná sand pit and two littoral stands of Rožmberk fishpond (Rožmberk East and Rožmberk West). *Phragmites* stands were expanding, stable and retreating at the three sites, respectively. The elemental soil composition (especially of C, N, P, and K) indicated the lowest trophic conditions at Branná, intermediate at Rožmberk East and the highest at Rožmberk West. This corresponded well also with concentrations of ammonium nitrogen, dissolved reactive phosphate and total phosphorus in the soil pore water. In contrast, Branná had by far the highest level of total nitrogen, determined by nitrate nitrogen (20 mg l^{-1}), and the highest level of total dissolved solids (concentrations of NO_3^-, SO_4^{2-}, Ca^{2+} and Mg^{2+}) of all three sites. No conspicuous differences were found among the three stands in biomass and its allocation. The vegetation composition corresponded more closely to elemental soil composition than to total nitrogen or total dissolved solids in the pore water. It is concluded that Branná provides an example of a site subjected to an initiating but dramatic and fast eutrophication while conditions at the two Rožmberk sites indicate a slower

but longer lasting eutrophication. Owing to continuous heavy organic loading, Rožmberk West represents a hypertrophic site characterised by the highest levels of organic matter and associated characteristics (soil C, N, P, K, dissolved P), but also by the most severe lack of oxygen of the three sites.

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Guest editorial

Restoration of coastal habitats: expectation and reality

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Abstract

Restoration today must satisfy a wide array of societal goals. In the past, success or failure of a project was dependent on minimal, measurable criteria. Simplistic designs and compliance criteria are being replaced by technically sophisticated projects and design goals that have variable criteria for success. Instead of a being static target, success criteria can be altered through a process termed Adaptive Management. Natural resource damage can be assessed accurately through a Habitat Equivalency Analysis. Acceptable progress toward compliance criteria is best measured by trends approaching a desired end point. An approach using natural variation of similar habitats also shows promise as a means of assessing compliance. Large-scale restoration projects are underway, directly and indirectly underwritten by the public. If the public is to continue support for restoration it must be a part of the decision-making process. This can be best accomplished through landscape management plans with clear objectives and goals that the public understands and that benefit the public at large. Technical problems in accomplishing and evaluating restoration projects will be solved if the experience gained at each site is used in future projects.

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Hydrological forcing of a recent trophic surge in Lake Winnipeg

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ABSTRACT

Nutrient enrichment leading to eutrophication of lakes is frequently attributed to increasing anthropogenic loading to the watershed. We use a phosphorus mass balance model to demonstrate that a discharge increase in a major tributary contributed more than increased anthropogenic loading to a recent sudden doubling of total phosphorus (TP) and a shift to a cyanobacteria-dominated plankton population in Lake Winnipeg. Runoff from the Red River watershed rose abruptly during the mid-1990s. The decadal mean discharge has since been more than 50% higher than for any previous decade in the century-long record. Widespread spring flooding has become common. TP concentration roughly doubles during floods, magnifying the effect of higher runoff on downstream phosphorus loading. Concentrations of both dissolved and particulate phases are raised by flooding. Over 90% of dissolved phosphorus downstream of flooded farm land in one tributary was in the form of highly bio-available orthophosphate. From 1994 to 1999, TP in the lake rose from less than 30 to more than 50 mg m^{-3}. It has since remained over 50% higher than before the mid-1990s. We use the phosphorus model to demonstrate that the change in Red River discharge alone would have caused a sustained 32% increase compared to when phosphorus was first routinely monitored in the 1970s, while direct increases in the rate of anthropogenic loading alone would have caused only a 14% increase. It required both increased loading to the land and higher runoff to produce the observed increase in TP in the lake.

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HYDROGEOMORPHIC FACTORS AND ECOSYSTEM RESPONSES IN COASTAL WETLANDS OF THE GREAT LAKES

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Abstract: Gauging the impact of manipulative activities, such as rehabilitation or management, on wetlands requires having a notion of the unmanipulated condition as a reference. An understanding of the reference condition requires knowledge of dominant factors influencing ecosystem processes and biological communities. In this paper, we focus on natural physical factors (conditions and processes) that drive coastal wetland ecosystems of the Laurentian Great Lakes. Great Lakes coastal wetlands develop under conditions of large-lake hydrology and disturbance imposed at a hierarchy of spatial and temporal scales and contain biotic communities adapted to unstable and unpredictable conditions. Coastal wetlands are configured along a continuum of hydrogeomorphic types: open coastal wetlands, drowned river mouth and flooded delta wetlands, and protected wetlands, each developing distinct ecosystem properties and biotic communities. Hydrogeomorphic factors associated with the lake and watershed operate at a hierarchy of scales: a) local and short-term (seiches and ice action), b) watershed / lakewide / annual (seasonal water- level change), and c) larger or year-to-year and longer (regional and/or greater than one-year). Other physical factors include the unique water quality features of each lake. The aim of this paper is to provide scientists and managers with a framework for considering regional and site-specific geomorphometry and a hierarchy of physical processes in planning management and conservation projects.

Predictions on the effect of common carp (*Cyprinus carpio*) exclusion on water quality, zooplankton, and submergent macrophytes in a Great Lakes wetland

Vanessa L. Lougheed, Barb Crosbie, and Patricia Chow-Fraser

Abstract: We conducted a study to examine the relationship between common carp (*Cyprinus carpio*) exclusion, water quality, zooplankton, and submergent macrophytes. Twelve 50-m^2 in situ experimental enclosures were installed in degraded Cootes Paradise Marsh during the carp spawning period in 1995. Enclosures were stocked with two or three carp of similar size, ranging from 13 to 59 cm and in total biomass from 23 to 2100 kg/ha. Turbidity, total phosphorus, and total ammonia concentrations increased predictably with total carp biomass in the enclosures. Although carp had no direct effect on zooplankton community structure, increased turbidity and nutrient load associated with carp activity resulted in reduced total zooplankton biomass. We developed a relationship between species richness and water turbidity for 19 wetlands in the Great Lakes basin which indicated that above an apparent threshold of 20 NTU, there were less than five species of submergent plants, while a more diverse community existed in less turbid systems. We predict that water turbidity in Cootes Paradise Marsh may not be reduced below this threshold value of 20 NTU following carp exclusion. We emphasize the need to consider other factors that may contribute to increases in water turbidity and nutrient concentrations, including wind resuspension and substrate characteristics.

Can. J. Fish. Aquat. Sci. **55**: 1189–1197 (1998).

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Large-scale coastal wetland restoration on the Laurentian Great Lakes: Determining the potential for water quality improvement

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Abstract

Coastal wetlands around the Laurentian Great Lakes, estimated to cover 1290 km^2 in the USA after extensive losses in the past 200 years, are rarely restored for water quality enhancement of the Great Lakes, despite the need for minimizing phosphorus and other pollutant inputs to the lakes. A simulation model, developed and validated for a series of created experimental marshes in northeastern Illinois, was aggregated and simplified to estimate the nutrient retention capacity of hypothetical large-scale coastal wetland restoration in Michigan and Ohio. Restoration of 31.2 km^2 of wetlands on agricultural land along Saginaw Bay, Michigan, would retain 25 metric tons-P $year^{-1}$ (53% of the phosphorus flow from the upstream watershed). Hydrologic restoration of 17.3 km^2 of mostly diked wetlands in Sandusky Bay, Ohio, would retain 38 metric tons $year^{-1}$ (12% of the phosphorus flow from the upstream watershed). A wetland distribution model developed for the Saginaw Bay site illustrated a technique for identifying sites that have high potential for being transition zones between open water and upland and thus logical locations for wetland restoration.

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Lake Winnipeg coastal submergence over the last three centuries *

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Key words: large lakes, coastal recession, submerged trees, beach ridges, barrier beaches, water levels

Abstract

Radiocarbon dating of marsh facies peat and drowned trees along the barrier beaches at the south end of Lake Winnipeg, indicates water levels are presently rising. Lagoonal sediment and associated trees are being buried as the barrier islands move landward in response to rising water levels. Estimates based on radiocarbon dating suggest the water level has been rising 20 cm/century over the last three hundred years. This estimate is consistent with lake level records and models of isostatic uplift which suggest the level of the lake should be rising between 6.7 and 12 cm/century along the south shore. However, additional radiocarbon dates on submerged trees from Observation Point, at the north end of South Basin, and the Spider Islands, near the northern outlet, indicate that at least part of the water-level rise is basin wide.

Southward transgression of Lake Winnipeg, throughout the Holocene, is believed to be the result of isostatic tilting of the basin, whereas the recent basin-wide water-level rise is more likely the result of a combination of isostatic tilting and increased precipitation associated with climate change.

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Review

The rapid eutrophication of Lake Winnipeg: Greening under global change

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ABSTRACT

Nuisance blooms of heterocystous Cyanobacteria in Lake Winnipeg have nearly doubled in size since the mid 1990s. The increases are the result of a recent rapid increase in loading and concentration of phosphorus. The rapid increase in phosphorus is largely the result of two factors. The first factor is the result of rapidly increased livestock production and use of synthetic fertilizer in the Red River Valley, with smaller contributions of phosphorus from the city of Winnipeg and other human development in the Red and Winnipeg river basins. The second factor is the increased frequency and intensity of spring floods in the Red River watershed in recent years, which have greatly enhanced the transfer of phosphorus from the landscape to the lake, as well as slower increases in nitrogen. Because the low ratio of nitrogen to phosphorus in the increased inputs favors nitrogen fixing species of Cyanobacteria, these nuisance forms account for most of the increase in phytoplankton. Recovery of the lake will require reducing both agricultural and major urban sources of phosphorus and, if possible, the frequency and intensity of flooding in the Red River watershed. Flooding will be increasingly difficult to control if modeled predictions for increased precipitation under climate warming materialize. Even with targeted reductions in phosphorus inputs of 50% and measures to control flooding, recovery of the lake is expected to be slow because of phosphorus recycled from sediments and the climatic sensitivity of this shallow lake and the flooding of the Red River.

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Detecting changes in ecosystem quality following long-term restoration efforts in Cootes Paradise Marsh

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ABSTRACT

Cootes Paradise Marsh is a large urban wetland of western Lake Ontario that has undergone major restoration as part of the Hamilton Harbour Remedial Action Plan. A key component of the restoration plan is exclusion of common carp (*Cyprinus carpio*) via construction of the Cootes Paradise Fishway that became operational in 1997. Here, we evaluate the response of the marsh community to carp exclusion using three approaches. First of all we analyze changes in water quality parameters and the community composition of zooplankton, macrophytes and fish. Secondly, we use ecological indices based on water quality, zooplankton, macrophytes and fish communities to track changes in quality. Lastly, we evaluate changes in the wetland quality of Cootes Paradise over the past decade in comparison with two other coastal wetlands of the Laurentian Great Lakes for which long-term data exist (Matchedash Bay of Lake Huron and Long Point Marsh of Lake Erie). Our results show that there has been variable improvement in wetland quality at Cootes Paradise, but compared to the two other wetlands, it is still the most degraded in all aspects studied. The overall trend towards moderately better water quality conditions in Cootes Paradise over the past decade is not directly reflected in the zooplankton, macrophyte and fish communities. We believe that high nutrient levels and high turbidity are preventing the progression to a clear-water macrophyte dominated system. This is one of few long-term studies that tracks the progress of restoration in a degraded marsh. It underscores the difficulty in trying to restore a 'novel ecosystem' to its original biotic and abiotic characteristics.

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A hydrogeomorphic inventory of coastal wetlands of the Manitoba Great Lakes: Lakes Winnipeg, Manitoba, and Winnipegosis

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ABSTRACT

We compiled an GIS-based inventory of coastal wetlands associated with the Manitoba Great Lakes—Lakes Winnipeg, Manitoba, and Winnipegosis—using a hydrogeomorphic classification system, orthophotography, satellite imagery, and digital habitat maps. The lakes have six times more wetlands per km of shoreline than the Laurentian Great Lakes: Lake Winnipeg has 1404 km^2 (0.8 km^2/km), Lake Manitoba has 564 km^2 (0.6 km^2/km), and Lake Winnipegosis has 742 km^2 (0.8 km^2/km). Riverine wetlands are the most common class on Lakes Winnipeg and Winnipegosis whereas barrier-protected wetlands are the most common class on Lake Manitoba. The totals for Lakes Winnipeg and Winnipegosis are greater by 548% and 273%, respectively, if Treed Muskeg habitat in the northern regions of the watersheds is included in the inventory, whereas the total for more southerly Lake Manitoba is greater by only 18%. Netley-Libau Marsh (222 km^2) on Lake Winnipeg and Delta Marsh (139 km^2) on Lake Manitoba are among the largest coastal wetlands on the North American continent. These baseline data can be used to identify ecologically important wetlands warranting further study or remediation.