Report Presented to

The Clean Environment Commission

The Ecology of Coastal Wetlands around Lake Winnipeg and Vegetation Loss in Netley-Libau Marsh

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Part A – A COASTAL WETLAND PRIMER

Introduction

Wetlands are defined as having three general characteristics. First, they have shallow water up to two meters deep throughout the year but sometimes much less, possibly not visible to the eye. Second, they have persistently waterlogged soil that has low oxygen content due to the inhibition of oxygen transport by standing water. Third, they have plant species that are well-suited to environments with abundant water and low-oxygen soil, usually by having specialized underground roots and shoots that help them to transport oxygen into plant parts growing in the low-oxygen soil.

Wetlands occur on every continent except Antarctica, occupying about 6% of the global land area (Mitsch and Gosselink 2000). Manitoba is especially well endowed with wetlands, with about 40% of its land area covered by them, more than any other province or territory (Halsey et al. 1997, Rubec personal communication). Many of Manitoba's wetlands are peatlands, a special class distinguished by the presence of at least 30 centimeters of peat. Peat is organic matter produced by plants and animals which does not break down quickly due to low-oxygen conditions that impair decomposing organisms.

Coastal wetlands are those types associated with the boundaries of large water bodies. The term is sometimes thought to connote sites adjacent to salt water such as oceans but, in fact, it can be used for freshwater sites too. There are three broad classes of coastal wetlands (Keough et al. 1999, Albert et al. 2005). **Lacustrine coastal wetlands** are strongly influenced by the adjoining lake and are subject to fluctuations in lake water level, water currents, wind tides (seiches), and ice movement. Some of these wetlands are protected to an extent by barrier bars and other landforms, whereas others are fully exposed to the ferocity of lake winds and waves. **Riverine coastal wetlands** occur along the edges of rivers or streams where they flow into a body of water and usually afforded protection from wind and wave action depending on the degree of exposure of the river mouth. **Barrier-protected coastal wetlands** are, to a large extent, isolated from the lake by a barrier ridge but can be influenced by wind-driven spray and groundwater flow, so they can be affected indirectly by lake processes. Many of the coastal wetlands of the Manitoba Great Lakes (Winnipeg, Winnipegosis, and Manitoba) are marshes, a subclass which is dominated by plants that emerge from the water, such as cattails and bulrushes.

We have created an initial inventory of coastal wetlands in Manitoba using the Forest Resource Inventory (FRI) landscape classification dataset compiled using aerial photographs by the Manitoba Forest Resource Management Branch (Watchorn et al. 2012). Wetlands were defined as being coastal only if they were tangential to a lake, or protected from it by a land barrier no more than 100 meters wide. Wetlands tangential to other water bodies (such as a river, lake, or drainage ditch) which themselves were tangential to coastal wetlands or the lake were also considered to be coastal wetlands. It was necessary to select a maximum inland distance where coastal wetlands could occur, and this was set at ten kilometres based on the estimated distance that Lake Manitoba water arising from seiche activity travels inland at Delta Marsh, a major coastal wetland on that lake. This probably over-estimates the extent of coastal wetlands. We were also unsure of the extent to which a Treed Muskeg FRI class represents coastal wetland so we prepared two versions of the inventory, one excluding Treed Muskeg (Figure 1) and another including it (Figure 2). The true extent of coastal wetland lies between these values. If we use the dataset that excludes Treed Muskeg as being most conservative, these data (Table 1) show that for Lake Winnipeg, barrier-protected wetlands represent about 10% of the total while lacustrine wetlands represent about 15%. The vast majority of coastal wetlands (76%) are of the riverine type.

Our coastal wetland inventory demonstrates that the three lakes of the Manitoba Great Lakes contain an abundance of coastal wetlands, regardless whatever over-estimation may exist in the dataset. These three lakes have several times more coastal wetlands per kilometer of coastline than the much more well-studied Laurentian Great Lakes (Table 2). This abundance is due, in part, to Manitoba's generally flat topography which provides a shallow relief profile at lake shorelines where wetlands plants can develop.

There are several large, conspicuous coastal wetlands around Lake Winnipeg. Netley-Libau Marsh (Figure 3B) is the single largest coastal wetland in Manitoba, representing about 16% of all riverine wetlands around Lake Winnipeg (22,200 hectares, excluding uplands which are sometimes included in estimates elsewhere, giving values as high as 26,000 hectares). Other prominent coastal wetlands are Willow Point on the west shore south of Gimli (Figure 3D) and Grand Beach (Figure 3A).

Major Ecological Processes

A fundamental property of all wetlands, and especially so of prairie coastal wetlands such as those around Lake Winnipeg, is their resilience to—indeed, their dependence on—changes in water level. The **hydroperiod** of a wetland describes the timeframe over which its water level changes, and major types of wetlands typically differ in their hydroperiod. For example, tropical wetlands have two major seasons annually, wet and dry, punctuated by periodic storms whereas inland, temperate wetlands (such as those in much of prairie Canada) have four well-defined seasons with a pronounced wet spring caused by runoff of snow melt, gradual drainage due to evaporation and plant transpiration during the hot summer, and gradual refilling through the fall. On a longer time scale, prairie wetlands undergo droughts—during which they may be partially or fully dry—on a period ranging from a few years to a few decades.

The hydroperiod of coastal prairie wetlands are further complicated by the hydrology of the adjoining lake, so they may receive less (or no) lake water during droughts and more lake water during floods. The influence of wind tides (seiches) on coastal wetlands may also be marked, depending on the size of the lake and its orientation relative to the prevailing wind direction, the magnitude of winds, and the nature (presence/absence of channels and their size) of the connection between lake and wetland. In Delta Marsh, at the south end of the Lake Manitoba south basin, winds from the northwest can raise the water level up to 0.5 meters within a few hours, whereas the proportionately larger size of Lake Winnipeg has been known to cause water level increases of a metre or more in Netley-Libau Marsh (D. Anderson, personal communication). The hydroperiod of a coastal wetland also depends on its specific class; a barrier-protected wetland would typically have a narrower water-level range than a lacustrine or riverine wetland.

Coastal wetlands in Manitoba are typically vegetated abundantly by emergent species (which have parts above and below the water surface) and submersed species (having all parts, except possibly reproductive structures, below water). Emergent species are typically more conspicuous than submersed species, are generally perennial (whereas submersed species are usually annuals), and contribute a larger proportion of total plant abundance in the wetland. Some emergent plants common to Manitoba coastal wetlands include cattail, giant reed, and bulrush (Table 3). Marked growth responses of these plants occur during brief (one or two years) periods of low or high water. The maximum depth of colonization for most species is in the range of 1.0 to 1.5 meters. They may be able to tolerate brief periods (few days or weeks) of deeper water, such as occurs during a wind tide, but will be unable to transport sufficient oxygen to their roots when deeply covered by water for prolonged periods. For example, vast stands of hybrid cattail (*Typha X glauca*) in Delta Marsh were drowned during the 2011 flood. Ironically, the only place where cattails survived the flooding was at the deepest parts of the marsh. These cattails were not tolerant of water depth but they were in areas of new growth where they formed floating mats (e.g., Hogg and Wein 1988) so they were able to float upward into sufficiently shallow water. These living cattails formed a thin fringe around former large stands, most of which was rooted to the bottom and was thereby killed.

Recruitment of new emergent plants occurs during periods of low water. These plant germinate from seeds that occur in abundance (thousands per square meter) in most sites in coastal wetlands, and which lie dormant awaiting suitable growth conditions. During shallow water periods, seeds in these “seed banks” are exposed to greater light and oxygen conditions, which enables them to germinate and grow, and the plants typically produce new seeds that same year to resupply the seed bank in preparation for the next period of low water, perhaps years in the future. In this way, coastal wetlands are well adapted to cycles of low and high water, producing expansive new plant growth during drought and having larger expanses of open water when plants are drowned during flood. So long as water levels fluctuate, the wetland will consist of interspersed patches of open water in deeper areas and emergent plants in shallower areas. Termed a “hemi-marsh” (half-marsh) by wildlife biologists, such wetlands provide ideal habitat for animals because they provide cover amongst emergent plants where the animals can escape detection by predators and open water area where they can feed and spawn.

The responses of marsh vegetation to prolonged periods of stable water depend on the actual water level. If levels remain high, reestablishment of emergent plants cannot occur so a wetland with large areas of open water, and perhaps some submersed vegetation, will persist. On the other hand, if levels remain low, shallow water will be colonized by emergent plants and exposed mudflats will be colonized by opportunistic terrestrial “weedy” species (Shay 1999), with the result that areas of open water will diminish. There is some evidence from studies of coastal wetlands around the Laurentian Great Lakes, where low waters have persisted over several successive years, that invasive species are able to become established and thrive under these conditions (Wilcox 2012). Hybrid cattails are known to thrive in wetlands when stabilized water levels are combined with nutrient enrichment from landscape runoff (e.g., Angeloni et al. 2006, Boers et al. 2007).

Plants play a major structuring role in coastal wetlands, in that they provide habitat and food for a great diversity of invertebrates, fish, amphibians, reptiles, birds, and mammals. The ecological diversity of a wetland is generally a direct function of the extent of submersed and emergent plants (e.g., Albert and Minc 2004). The submersed surfaces of abundant plant are usually coated heavily in a living biofilm of bacteria, fungi, and algae that is metabolically reactive, and which is responsible for the uptake, storage, and transformation of natural and anthropogenic chemicals. Wetland are sometimes referred to as “nature’s kidneys” in recognition of this important role in chemical processing.

Environmental Benefits of Coastal Wetlands

Wetlands in general are widely recognized for providing numerous environmental benefits. These benefits derive from their high productivity and biodiversity, and include control of soil erosion, flood control, recharge of groundwater supplies, retention and assimilation of toxic materials, weather stabilization, support for economically important animals (hunting, fishing, etc.), supply of agricultural and aquacultural products, and provision of recreational and educational opportunities. Northern peatlands store huge quantities of carbon, thereby preventing its discharge into the atmosphere and the acceleration of global climate warming. There are six specific environmental benefits of freshwater coastal wetlands: provision of wildlife habitat, support for domestic and commercial fisheries, improvement of water quality, production of plant crops, regulation of climate including storage of carbon as an offset for climate change, and protection of coastal land (Zedler and Kercher 2005, Sierszen et al. 2012).

The importance of coastal wetlands as habitat for culturally and ecologically important birds such as waterfowl and migratory songbirds is high (e.g., Monfils et al. 2014). They also provide habitat for amphibians and reptiles, and mammals such as muskrats and beaver. The extent to which coastal wetlands are important to fish depends, in part, on the degree of connection between the lake and wetland but, where a surface connection exists, fish are usually abundant in most coastal wetlands (e.g., Kowalski et al. 2014). Coastal wetlands of the Laurentian Great Lakes are known to support diverse fish communities, providing spawning and nursery habitat for species that eventually disperse into the lakes. Therefore, the health of coastal wetlands can translate directly into health of the commercial and sport fisheries of the adjoining lake.

As the interface between the surrounding landscape, which is often intensively agricultural or industrial, and a lake, coastal wetlands are typically the initial sink for terrestrial runoff and eroded soil, as well as anthropogenic wastes including pesticides, metals, fertilizers, acids, and domestic and industrial sewage (e.g., Trebitz et al. 2007). Wetlands are where detoxification of harmful chemicals and storage (sequestration) of environment pollutants can occur (Mitsch and Gosselink 2000). The natural assimilative capacity of wetlands for these inputs reduces transport into the adjacent lake, thereby mitigating floods and improving lake water quality.

Environmental Threats to Coastal Wetlands

In Canada, agricultural activities represent by far the single-largest threat to the ecological integrity of wetlands generally (Rubec, personal communication). These threats arise from the construction of drains and dikes, encroachment, peat removal, grazing by livestock, and resource extraction (trees, fish, and other products). These threats do apply to coastal wetlands, especially ones in close proximity to agricultural land where pesticides, fertilizers, manure, and other chemicals may move from areas of application, either in surface flow or aerial drift, into nearby wetlands (e.g., Trebitz et al. 2007). However, perhaps the three largest categories of threat to coastal wetlands specifically are shoreline development and dredging, altered lake hydrology, and invasive species. Superimposed on these factors is the as-yet-unknown effect of climate change, which could alter the degree of water exchange (and associated aquatic fauna) with the lake, if the extent of connection is reduced due to greater evaporation and reduced precipitation.

At least three residential developments around the south basin of Lake Winnipeg are situated in or very near to coastal wetlands: Siglavik and Miklavik near Willow Point, south of Gimli, and Hillside Bay on the east side of the lake south of Albert Beach. Urban development of lake shorelines, especially those occupied by lacustrine wetlands or near to barrier-protected wetlands, exposes them to increased likelihood of chemical contamination; increases the potential for destruction of native plant cover (e.g., removal of emergent plants using pesticides or mechanical harvesting) in the name of beautification; promotes invasion by exotic plant and animal species; alters wetland hydrology when roads and other constructed works interrupt water flow in and out of wetlands (Drohan et al. 2006); and prevents access to wetlands by fish and other migratory animals by the construction of dikes and roads.

There are no statistics on the extent to which coastal wetlands of the Manitoba Great Lakes have been impaired by development activities. However, discrete examples can serve to illustrate the potential for harm. For example, historical dredging of channels around Lake Winnipeg has caused considerable damage to the integrity of coastal wetlands. In July 1912, the federal government arranged for its dredges to construct a channel into the isolated lagoon at Willow Point, a large barrier-protected coastal wetland south of Gimli, to provide a safe harbor during storms for tugboats and other ships of a local shipping company. Erosion of that channel has made a permanent connection between Willow Point lagoon and Lake Winnipeg, converting what was formerly a barrier-protected wetland that probably experienced minimal wind tide into a lacustrine wetland in which daily fluctuations in water level are marked.

Coastal wetland hydrology is linked to that of the adjacent lake so any change to the lake, naturally or as a result of management, will inevitably impact wetland ecological function and character. The best evidence of the connection between lake level management and coastal wetlands comes from studies of the Laurentian Great Lakes (e.g., Hudon et al. 2006, Simon and Stewart 2006, Wei and Chow-Fraser 2006, Midwood and Chow-Fraser 2012, Steinman et al. 2014).

Non-native plant species pose a threat to the health of coastal wetlands when they displace native species but do not substitute for their ecological roles. Such invasions reduce the biological diversity of the wetland ecosystem, making it less able to withstand environmental change. Four non-native emergent plants in Manitoba wetlands are hybrid cattail (*Typha X glauca*; now ubiquitous throughout southern Manitoba), purple loosestrife (*Lythrum salicaria*; with stands becoming established at Delta Marsh and Netley-Libau Marsh), reed canary grass (*Phalaris arundinacea*; now forming dense monodominant meadows at Netley-Libau Marsh), and invasive phragmites (a variant of *Phragmites australis* that grows larger and taller, and excludes the wild variant and other emergent species, found recently at sites in southern Manitoba). These exotics, and especially hybrid cattails, are favoured by prolonged low water levels and high nutrient levels (e.g., Woo and Zedler 2002, Tulbure et al. 2007, Boers and Zedler 2008, Farrell et al. 2010, Lishawa et al. 2010, Wilcox 2012).

Wetlands with explicit connections to the adjoining lake can be invaded readily by aquatic animals. The extent to which invasive animals in the Manitoba Great Lakes, such as the Spiny Water Flea, Rainbow Smelt, Rusty Crayfish, Zebra Mussel, and others, have invaded coastal wetlands is unknown. The most-studied invasive animal has been the Common Carp. Introduced to North America over 100 years ago, the robustness and adaptability of carp has allowed them to thrive in nearly all aquatic habitats in Manitoba to which they have gained access (e.g., Badiou and Goldsborough 2006). The potential access to coastal wetlands by carp can be affected by human activities, such as the construction or obstruction of channels. The degree to which the wetland is connected, either permanently or occasionally, may determine the ecological impacts of carp invasion. Abundant observational and experimental evidence shows that, where carp are present, wetland water becomes turbid and submersed plants disappear due to the combined effects of low light and physical damage (e.g., Badiou and Goldsborough 2010).

Detection of long-term vegetation change in coastal wetlands, via remote sensing, is the primary means by which the impairment of their overall ecological health can be monitored, as there are few long-term field studies at single wetland sites. The time-series analysis of maps (Gottgens et al. 1998, Owen 1999), aerial photographs (Williams and Lyon 1997, Frieswyk 2005, Farrell et al. 2010, Mitchell et al. 2011, Lishawa et al. 2013) and satellite images (e.g., Midwood and Chow-Fraser 2010) provides a means to monitor vegetation wax and wane across vastly larger geographic scales than would be possible with field measurements.

Part B – NETLEY-LIBAU MARSH

Introduction

Netley-Libau Marsh is the largest coastal wetland in Manitoba, at about 22,200 hectares, and is believed to be the largest one in North America. Situated at the confluence of the Red River into the south basin of Lake Winnipeg, behind a 25-kilometer barrier ridge along the south lakeshore, the marsh consists of a complex of shallow lakes, lagoons, and channels. Traditionally, the marsh lying west of the river has been referred to as Netley Marsh whereas the portion east of the river is the Libau Marsh. Therefore, I use the hyphenated name to refer to the entire complex.

A detailed description of the emergent plants in Netley-Libau Marsh was provided by Grosshans et al. (2004), based on analysis of marsh vegetation maps for 1979 (Hathout and Simpson 1982) and 2001 (Figure 4). The most common plants were cattail (51% of total emergents in 1979, 79% in 2001), bulrush (42% and 8%), and giant reeds (7% and 13%). Typically, the marsh consists of large, open expanses of water ranging in depth up to two metres, surrounded by emergent plants, primarily cattails as of 2001. A marked reduction in the extent of emergent plants has occurred since the early 20th century. Aerial photographs of the marsh taken in 1923 and land use maps from 1936 and 1951 (Grosshans et al. 2014) demonstrate that, at that time, most areas were in the hemi-marsh state (Figures 5, 6).

Netley-Libau Marsh has been recognized as major habitat for nesting, staging, and molting waterfowl. It has also been used for recreational activities such as hunting, fishing, boating, birdwatching, and ecotourism. The marsh has been designated internationally as an Important Bird Area (IBA). Common bird species that use the marsh for nesting or during migration include red-winged blackbird (*Agelaius phoeniceus*), yellow-headed blackbird (*Xanthocephalus xanthocephalus*), Franklin's gull (*Larus pipixcan*), western grebe (*Aechmophorus occidentalis*), black-crowned night heron (*Nycticorax nycticorax*), sandhill crane (*Grus canadensis*), and several waterfowl species. Currently, over ninety percent of the marsh is publicly owned, and includes a 1,073 hectare game bird refuge. The marsh is also thought to provide spawning, nursery and feeding habitat for fish species from Lake Winnipeg and the Red River, although there have been relatively few studies of fish populations in it.

Local residents acknowledge that the biological character of the Netley-Libau Marsh has changed radically over the past three decades. Between 1979 and 2001, the erosion of vegetated uplands between adjoining water bodies has been extensive, resulting in the amalgamation and expansion of many marsh bays and ponds. Half the entire complex (13,125 ha, 51%) was open water in 2001, compared to 35% (8,884 ha) in 1979. Waterfowl populations have declined precipitously, so much so that few recreational hunters visit the marsh now compared to the past.

An important hydraulic feature of the Netley-Libau Marsh is the Red River that passes through its centre. The river has a single channel until it breaks into three smaller channels at a site known as The Forks (Figure 7). The meandering, slow-moving river typically carries a substantial load of suspended sediment and this material is typically deposited and resuspended depending on the rate of river flow. Each year from 1884 to 1999, the federal government employed a dredge at Netley-Libau Marsh (Figure 8B) to continually remove sediment where necessary to maintain a navigable channel for commercial shipping on Lake Winnipeg. It accounted for about half of the total dredging done in Manitoba during the period from 1884 and 1925, mostly concentrated at the shallow river mouth (Figure 6; Goldsborough, unpublished data). The western-most channel was the deepest of the three channels in the period from 1884 to 1893 and was therefore the preferred route for boat traffic. However, extreme deposition of sediment at The Forks during the spring of 1893 caused the channel to become too shallow for most ships, so traffic was diverted to the eastern-most channel until about 1903. Henceforth, and continuing to the presence, most large boats use the centre channel, and a lighthouse was deployed at the mouth of this channel since at the least the 1920s (Figure 8A). Around 1911, federal engineers dredged a new channel at the mouth of the centre channel, on a northwest orientation (Figure 9), apparently in preference to the natural northeast orientation of the mouth, in hopes of reducing sedimentation of the channel mouth.

There are presently 11 openings in the barrier ridge separating the Netley-Libau Marsh from Lake Winnipeg, although these are constantly changing due to wind action and southward migration of the lake due to a faster rate of isostatic rebound at the north end of the lake basin. It is likely that, at some time before 1911, Pruden Bay at the mouth of the eastern-most river channel (Figure 9) was isolated from the lake but was connected by erosion of the barrier ridge.

In 1913, the federal government dredged a channel, referred to here at the Netley Cut (Figure 10A), that connected the Red River with the south end of Netley Lake, near the river's confluence with the Netley Creek. Initially, the Cut was less than 80 feet (24 metres) in width. The stated purposes of the Cut were two-fold. First, it was hoped to provide a means for water that had entered the marsh by wind tides on Lake Winnipeg to flow so inundated hayland used by local farmers could be drained. Second, it would provide an easier access route for residents in boats to collect drift wood that accumulated in the marsh, and to reach hay-cutting areas more easily. Widening of the channel by erosion began almost immediately and, by 1916, a small bridge that had been constructed to enable farmers to reach hayland north of the Cut, was washed away. A sheet pile wall was built between 1916 and 1917 at the riverward side of the Cut in hopes of blocking it. It was destroyed by water and ice action within five years. The hull of a former river dredge was then sunk midway along the Cut, perpendicular to the direction of water flow. It was likewise ineffective at reducing erosion. By 1924, the channel had widened to about 80 feet. It appears the government gave up its efforts to block the Cut at this point with the result that the channel widened unabated. By 2003 it was some 1,300 feet (400 metres) wide (Figure 10B) and in 2009 was 1,475 feet (450 metres) wide.

In 1999, the federal government discontinued its dredging at the mouth of the Red River, apparently as a cost-cutting measure. Since then, local boaters report that siltation has occurred at the river mouth to the extent that some feel that navigation is being impaired. The extent to which reduction in water flow at the river mouth has been reduced, and has therefore redirected water through the Netley Cut and other marsh channels, has not been measured comprehensively. Some initial data has been collected recently by Dr. Shawn Clark at the University of Manitoba. In 2009, he estimated that the Cut transmitted about 37% of the total Red River flow, ranging from 29% to 43% depending on the wind direction and other environmental factors. Clearly, a substantial proportion of Red River flow, with its associated sediment and anthropogenic chemicals, is being delivered to the Netley Lake where loss of emergent plants has been marked between 1923 and 2003 (Figure 10). Marsh mapping done in late 2010 shows clearly the large shallow area at the south end of Netley Lake by the Netley Cut (Figure 11). This area was presumably caused by deposition of sediment as water in the Red River turns westward and slows.

Since at least 2010, and possibly earlier, the provincial government has been using its flood-fighting infrastructure during the late-winter period to weaken and break Red River ice immediately south of the Netley Cut. This permits floodwater to exit the Red River into Netley Lake where it accumulates until river ice north of the Cut thaws and water can follow its natural course through the main river channel.

These activities are suspected to have exacerbated the widening of the Netley Cut but no study has been undertaken to see if the rate at which the Cut is widening correlates to the chronology of ice-breaking activities on the Red River.

Environmental Benefits of Netley-Libau Marsh

It is now accepted widely that anthropogenic discharge of phosphorus and other nutrients into Lake Winnipeg has accelerated its rate of eutrophication (e.g., EC/MWS 2011), and that changes in landscape practices will be necessary to achieve any meaningful, long-term water quality improvement. The Red River is the single-largest point source of nutrient pollution to Lake Winnipeg so the Netley-Libau Marsh, at the mouth of the river, is the last buffer against lake degradation.

Since 2006, our research has examined the nutrient accumulation in emergent plants of Netley-Libau Marsh (e.g., Grosshans 2014). Cattails (*Typha* spp.) and reed grass (*Phragmites australis*) are particularly effective in absorbing phosphorus and nitrogen from sediment and water, assimilating them into biomass. Cattails absorb a substantial amount of stored phosphorus from sediments during a single growing season.

The uptake of nutrients by marsh plants, however, would have no meaningful effect on lake pollution unless those nutrients are subsequently removed (e.g., Toet et al. 2005). Therefore, it is imperative that any effort to counteract the long-term loss of emergent plants is combined with active harvesting of those plants. Research led by Dr. Nazim Cicek at the University of Manitoba has examined the feasibility of harvesting plant biomass to prevent the return of nutrients into the wetland during natural decomposition. He has estimated that harvesting of plant biomass in Netley-Libau Marsh could remove 4 to 5% of the total phosphorus load of the Red River (Cicek et al. 2006). The removal of accumulated dead plant material removes significant stored phosphorus and stimulates plant growth in the spring. Harvested biomass provides feedstock for bioenergy production. Technologies for the conversion of biomass to energy are being examined, providing further insights on harvesting and utilization methods (Grosshans 2014).

Environmental Threats to Netley-Libau Marsh

Today, Netley-Libau Marsh resembles a shallow turbid lake more than a healthy coastal wetland. Many of the ecological goods and services (EGS, Olewiler 2004) benefits that the marsh could provide as wildlife and fisheries habitat, and in removing and storing nutrients that would otherwise enrich the lake, have been degraded or lost. Many of these benefits can be revitalized through marsh restoration and management. In 2009, the provincial government established a Provincial Wetlands Working Group focused on the restoration of Netley-Libau and Delta Marsh. Its members include representatives of provincial and federal government departments, non-governmental agencies, and academic institutions. This emphasizes the commitment and interest for the research, future management, and rehabilitation of these major coastal wetlands. To date, work has occurred primarily on Delta Marsh where, in 2012, structures were built at all the channels connecting the marsh to Lake Manitoba as a means of controlling entry to the marsh by large fish, primarily common carp, that are destructive to marsh habitat. Results from the first two years of the project (2013 and 2014) have been equivocal because the carp-excluding screens in the structures were installed slightly too late in 2013 to be completely effective at excluding carp, or were removed in 2014 when high flow in the Portage Diversion threatened the integrity of the structures. Meanwhile, in late 2013 the Lake Winnipeg Foundation organized a two-day fact-finding workshop about the deterioration of Netley-Libau Marsh.

In 2004, we published a conceptual model describing factors that we believe could be contributing to the decline of emergent plants in Netley-Libau Marsh (gray boxes, Figure 12; Grosshans et al. 2004). It shows mechanisms (shown in white boxes) by which factors on Lake Winnipeg (isostatic rebound, natural flooding, storms, and water-level regulation) could be contributing to plant loss (black box). At that time, we were especially interested in the potential role that Lake Winnipeg regulation could be playing, particularly as it may have changed: 1) the total amplitude of water-level change in the marsh (reducing the periodic low and high periods that are needed to maintain marsh health, described above), and 2) the seasonal variation of low and high periods during any given year, away from the normal pattern of high spring levels followed by gradual declines through the summer to a minimum during fall and winter. The basis for the latter change was a contention that Manitoba Hydro may be maximizing lake levels during late summer and fall to provide a large water supply for power generation during the heavy demand period of the winter. Our analysis of historical water level data for Lake Winnipeg, comparing the monthly average levels of the lake for the period from 1950 to 1974 (pre-regulation) with the monthly mean for a comparable post-regulation period (1976 to 1999) showed no difference in the seasonal pattern and, contrary to expectation, an overall average pre-regulation level that was 0.7 foot (0.2 metre) higher than during the post-regulation period. Therefore, we concluded it did not appear likely that Lake Winnipeg regulation had changed the seasonal pattern of water levels in the Netley-Libau Marsh.

On the other hand, the historical water-level dataset demonstrates clearly that the total range of levels being experienced in Netley-Libau Marsh has decreased since 1976 (Figure 13). It also shows that low-water intervals that had occurred intermittently during the 20th century (for example, in the early 1930s, early 1940s, and early 1960s) were largely absent from the post-regulation period. (Lows in the late 1970s and early 1990s did not reach values achieved during earlier periods.) An implication is that there have been few periods for recruitment of new emergent plants from seed banks in the exposed marsh sediment, and this has contributed to overall vegetation decline (Figure 12). Without plant roots to anchor soft sediments, islands and upland habitats have eroded through the effects of water flow and wind action. An exception was 2003 when remarkably low lake levels occurred as a result of regional drought. In that year, deposits of river sediment in Netley Lake were revealed (Figure 10B) and shallow areas of the marsh were rapidly colonized by hybrid cattails. An example comes from a comparison of open water area in Hardman Lake, in the north-central area of the marsh near the Red River mouth, in 2001 compared to 2003 (Figure 14). There, 285 hectares of open water was colonized by cattails in 2003.

The extent to which cattails that colonized in 2003 would survive when water levels returned to normal values has been studied, at Netley-Libau Marsh and at Delta Marsh, where similar drought and vegetation growth (by cattails as well as bulrush) occurred in 2003. At Delta, we found that expanses of bulrush in 2003 were short-lived and had mostly disappeared within two years. (Scientific literature seems to bear out the temporary nature of bulrushes following water level declines, and may explain the precipitous decrease in their abundance at Netley-Libau Marsh between 1979—after a brief period of low water, as seen in Figure 13—and 2001.) However, cattail invasions seemed more resilient and, ten years after the 2003 drought, they have mostly persisted at Delta Marsh, as they have in coastal wetlands of the Laurentian Great Lakes subject to prolonged low water (e.g., Frieswyk 2005, Tuchman et al. 2009).

Recent supporting evidence for the persistence of cattails in Netley-Libau Marsh after the 2003 low-water period comes from measurements of marsh vegetation during the last decade. Recognizing that the comparison of 1979 and 2001 vegetation was obviously limited in scope, and that it would be desirable to have data for other years, I began studies in 2014 in collaboration with Environment Canada.

The first step in this study has been to compare the results of vegetation survey obtainable using aerial photographs (1979, 2001) with much more frequently available (but lower resolution) satellite images. We have focused on a simplified classification as a basis for comparison of the two sources of information, using only the open-water area of Netley-Libau Marsh because we assumed that this area represents the part of the marsh *not* colonized by plants, and therefore it summarizes the area that *is* vegetated without attempting to subdivide it by species (our previous classification of the marsh based on aerial photography had recognized 23 distinct vegetation classes group in six marsh zones). So far, we have found the satellite-based vegetation classifications to provide useful information, and we now have data for 20 years between 1990 and 2013 (Figure 15; Watchorn, published data). They show the marked marsh-wide decrease in open-water area (due to an increase in vegetation cover) that occurred in 2003 and that there was some loss of plant cover in the first two years but it has stabilized and has been relatively constant for the eight years. This is an important finding because it suggests that single low-water events, such as occurred in 2003, may be effective at restoring vegetation long-term in Netley-Libau Marsh.

Public Perceptions

In 2008-2009, I surveyed public attitudes toward the restoration of Netley-Libau Marsh. Given the marsh's massive size, a full restoration is likely to take a long time and need substantial resources. The project had three objectives: 1) it assessed the ecological feasibility of restoration, 2) it determined if the conditions needed to permit marsh plants to thrive could be restored, and 3) it gauged the views of potential stakeholders in any restoration of the marsh. To address the first objective, I recruited two prominent wetland scientists to provide advice. Dr. Arnold van der Valk (Iowa State University at Ames) has been involved in wetland research projects all over the world, including the Marsh Ecology Research Program (MERP) at Delta Marsh in the 1980s, and he has consulted in the restoration of degraded wetlands in the Mississippi River Delta near New Orleans, and the Florida Everglades. His "wet-dry cycle" of prairie wetlands (van der Valk 2005) has been the definitive model for wetland management over the past two decades. Dr. van der Valk addressed the effect of watershed phenomena on Netley-Libau Marsh. Dr. Douglas Wilcox (New York State University College at Brockport) has spent over thirty years doing research on the coastal wetlands of the Laurentian Great Lakes (e.g., Wilcox 2004, 2012) and he was, for over twenty years, Editor-in-Chief of *Wetlands*, the leading technical journal for wetland science. Dr. Wilcox provided advice on the effect of lake hydrology on the ecological integrity of coastal wetlands. During the summer of 2008, he toured me through Metzger Marsh, along the south shore of Lake Erie. This visit provided insight on how restoration of Netley-Libau Marsh could be accomplished. Like Netley-Libau Marsh, the Metzger Marsh had lost much of its emergent vegetation. The cause was the loss of a barrier ridge that separated the wetland from the lake. In the early 1990s, the US Army Corps of Engineers successfully rebuilt the ridge and armoured it heavily using large boulders to prevent future erosion. Plant growth in the restored Metzger Marsh has been remarkable.

Lengthy discussions with Drs. van der Valk and Wilcox focused on what environmental conditions would be needed to restore Netley-Libau Marsh. My conclusion based on these meetings and the visit to Metzger Marsh was that restoration of vegetation in the Netley-Libau Marsh is ecologically feasible. Restoration might be achieved pending determination that it would be feasible to carry out two key changes. First, it would be necessary to lower the water level in the entire wetland by at least two feet (0.6 metres) for a period of not less than two years. The purpose would be to stimulate plant growth from the sediment seed bank by exposing marsh sediments. It would be difficult to manage the level of Netley-Libau Marsh independently of Lake Winnipeg because this would require extensive engineering works to isolate the wetland from the lake. (Ducks Unlimited advocated such an approach in the 1980s but abandoned it in view of the large capital expenditure and need for ongoing maintenance.) Dr. Wilcox advised, based on his extensive experience in Great Lakes coastal wetlands, that the best solution would be to permit Lake Winnipeg to undergo periodic low water levels. Second, it would be necessary to redirect some or all of the flow of the Red River that is presently passing through the Netley Cut into the western part of the marsh. I suspect that too much nutrient-laden water is passing through the marsh and the high velocity of water flow through the marsh is counter-productive to plant growth. The engineering work needed to do this is presently unknown. Restriction of water flow through the marsh may require the construction of a barrier across the Netley Cut.

Consultations with Netley-Libau Marsh stakeholders revealed a diverse range of views. In general, individuals and local organizations with an interest in the marsh or Lake Winnipeg were in favour of proceeding with hydrological modification. Representatives of the Peguis First Nation expressed a keen interest in restoring Netley-Libau Marsh as it was traditionally used by their people for hunting and gathering, and borders their Treaty Land Entitlement “initial selection” area. Members of the Netley Marsh Waterfowl Foundation and Manitoba Association of Cottage Owners, individuals who live on the shores of Lake Winnipeg and Netley-Libau Marsh, and several commercial fishermen spoke in favour of restoring the marsh. However, many expressed cynicism that the appropriate governmental agencies and crown corporations would accept any prescription for action. Other groups spoke in favour of restoring Netley-Libau Marsh in general terms, but disagreed with pursuing hydrological modifications described above. For instance, representatives of several rural municipalities and agencies feared that closing the Netley Cut would interfere with spring flood preparedness. However, contrary to this opinion, several people suggested that, in the absence of the Netley Cut, spring floodwaters would overtop the banks of the Red River north of the Cut.

Part C – CONCLUSIONS AND RECOMMENDATIONS

Lake Winnipeg Coastal Wetlands

As compared to an extensive literature on the ecology and changes in coastal wetlands of the Laurentian Great Lakes, there has been very little research on the coastal wetlands of Lake Winnipeg (e.g., Grosshans et al. 2004, Watchorn et al. 2012). Consequently, we know little about the extent to which Lake Winnipeg regulation has already had impacts on the coastal wetlands or will have impacts in the future. Just as Lake Winnipeg monitoring has become a priority of the Manitoba and Canadian governments, it would be desirable for coastal wetlands to receive greater scientific scrutiny.

An example of a study that could be undertaken is the measurement of changes in other coastal wetlands over the same period that marked changes in Netley-Libau Marsh have occurred. This would help to distinguish the relative contributions of the Red River versus Lake Winnipeg on coastal marsh ecology. In 2003, I acquired high-resolution aerial imagery of four other coastal wetlands around the south basin of Lake Winnipeg (Balsam Bay, Grand Marais, Hillside Bay, and Willow Point) as a basis for considering whether the magnitude of change in the macrophyte cover of the Netley-Libau Marsh were matched by those other wetlands. If lake hydrology is the primary factor affecting vegetation distribution in coastal wetlands such as Netley-Libau, the same changes should have occurred in other nearby wetlands. On the other hand, if the connectivity between the Netley-Libau Marsh and the Red River is the main influential variable, changes in the vegetation of Netley-Libau Marsh will not be matched by that of other coastal wetlands where the Red River influence is absent.

Netley-Libau Marsh

It is my considered opinion that Lake Winnipeg regulation has contributed to the loss of emergent plant loss in Netley-Libau Marsh, by reducing the frequency of low-water periods critical to the maintenance of healthy plant stands. However, Lake Winnipeg regulation is not solely responsible and, in fact, if acting alone, it would not have led to the magnitude of vegetation change that has been observed. I suspect the effects of water-level regulation have been exacerbated by the alteration of marsh hydrology arising from the combined effects of reduced water flow at the Red River mouth (due to elimination of dredging by the federal government) and increases in the flow potential at the Netley Cut (due to diversion of water through it by the provincial government). Management strategies to address the above may include: 1) alteration of the Lake Winnipeg regulation protocol to permit two-year, low-water periods with a frequency of roughly ten to twenty years, 2) construction of a structure at the Netley Cut to regulate flow through it; 3) resumption of dredging at the Red River mouth; and 4) encouraging retention of water on the agricultural landscape of the Red River Valley and beyond to reduce the need for catastrophic flood mitigation.

Further monitoring of the Netley-Libau Marsh should be undertaken to provide a sound scientific basis for the above statement. It would be useful, for example, to acquire and analyze all aerial photography showing the marsh. Comprehensive aerial photography of the marsh is available starting in 1948 and continues at irregular intervals to the 1970s. Oblique imagery also exists from as early as 1923. A time-series analysis of such imagery will provide data on the spatial distribution and extent of open water versus emergent vegetation. We could correlate plant growth extent to historical measurements of lake water level. This will provide a useful examination of the changes in vegetation cover relating to lake water level over a period of many decades.

A search for archival records pertaining to the construction of the Netley Cut in 1913 and its subsequent monitoring through time would provide useful background on the Cut as a factor affecting marsh hydrology. Measurements of Cut width through time, using historical aerial photographs, would allow estimates to be made of the total volume of Red River water that has flowed into Netley Lake, and the extent to which sedimentation and reduction of phosphorus loading into Lake Winnipeg has occurred. This would provide an indication of the Cut's influence on ecological integrity of Netley-Libau Marsh and could provide useful data for modelling of past, present, and future river flow via the marsh. Such studies would reveal the relative merits of restricting flow through the Netley Cut, and resumption of dredging at the Red River mouth, on the flow of water through Netley-Libau Marsh as it may be affecting plant growth.

More information is needed on the flow of Red River water (and associated anthropogenic contaminants such as phosphorus) through the marsh to evaluate the value of restricting flow at the river mouth and Netley Cut on marsh nutrient dynamics. For example, to calculate the amount of phosphorus that is presently stored in Netley-Libau Marsh, measurements should be made of phosphorus in and transfer between the water, sediment, and vegetation in the relatively well-vegetated Libau Marsh compared to the less-well-vegetated Netley Marsh, and also compared to comparable measurements at other coastal wetlands of the Lake Winnipeg south basin.

A challenge to the restoration of emergent vegetation in Netley Lake is that much of the marsh is now too deep (> 1 meters) for plants to re-establish naturally. The construction of artificial islands for plant colonization would be costly and the investment would be lost if these islands are later found not to provide suitable habitat. If they do work, the practical use of vegetation growing on these islands would require the development of amphibious equipment to harvest and transport the plants to land for processing (for biofuel and nutrient extraction benefits). In 2012, we began evaluating a new method for growing cattails on floating platforms (termed “bioplatforms”). Bioplatforms planted with cattails (using seed or portions of vegetative stock) would be deployed in the marsh and when cattails are fully grown, they would be towed back to the shoreline for harvesting of above-ground biomass that leaves the below-ground part of the plant intact to continue growth in subsequent years. Once the harvest is complete, the bioplatforms containing persistent rootstock would be returned to the marsh. The system would be in place year-round except during brief periods of harvesting. The bioplatforms could provide additional environmental benefits beyond the provision of a crop: 1) they may help to dissipate waves and promote long-term sediment accretion that enables natural re-vegetation to occur, 2) they may provide habitat for wildlife and fish in the areas of deployment, and 3) they may provide a vehicle for public education and engagement about wetland restoration, especially during harvesting periods. The technology could also be deployed elsewhere that nutrient removal is needed, such as in wastewater treatment cells, stormwater retention basins, and small land-locked prairie lakes receiving overland runoff. Initial results from bioplatforms deployed in water bodies at FortWhyte Alive in 2013 and 2014 are encouraging and we hope that testing in Netley-Libau Marsh may commence within three years, leading to what I envision could be an immense, floating “cattail farm.”

Finally, discussions with stakeholder groups suggest there is general interest in restoring the Netley-Libau Marsh. A public education campaign is needed to secure widespread support for marsh restoration, raise awareness of the factors that have contributed to its decline, and motivate changes in behaviour that will be required for its restoration. Such a campaign should presumably be consistent with the Tomorrow Now Green Plan announced by the Manitoba government in 2014 and specific provincial initiatives like the Surface Water Management Strategy. It should increase appreciation for the value of Netley-Libau Marsh within the watershed of Lake Winnipeg, but also deal more generally with wetlands in the agricultural and urban landscape of southern Manitoba and their role in fostering and preserving healthy, sustainable ecosystems.

Part D – REFERENCES (copies available on request)

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Table 1. Coastal wetland area (hectares) of the Manitoba Great Lakes, including and excluding Treed Muskeg. Source: Watchorn et al. 2012.

Coastal Wetland Class	Excluding Treed Muskeg			Including Treed Muskeg		
	Lake Winnipeg	Lake Manitoba	Lake Winnipegosis	Lake Winnipeg	Lake Manitoba	Lake Winnipegosis
Barrier-Protected	13,639	22,888	16,518	11,595	22,842	17,701
Lacustrine	20,647	17,250	14,762	38,356	17,209	13,732
Riverine	106,101	16,227	42,961	719,679	26,401	171,121
Total	140,388	56,365	74,242	769,630	66,452	202,554

Table 2. Coastal wetlands of the Manitoba Great Lakes (excluding Treed Muskeg) compared to those of the Laurentian Great Lakes (Watchorn et al. 2012). Lake shoreline data were obtained from the World Lake Database of the International Lake Environment Committee (ILEC 1999). * Data for the Laurentian Great Lakes were summed for Canadian wetlands (Ingram et al., 2004) and US wetlands (Moffett et al., 2006).

Lake	Total Coastal Wetlands (km^2)	Lake Shoreline (km)	Wetlands (km^2) per km Lake Shoreline
Winnipeg	1,404	1,750	0.802
Winnipegosis	742	927	0.800
Manitoba	564	915	0.616
Michigan *	538	2,660	0.202
Huron *	426	5,090	0.084
Erie & St. Clair *	259	1,370	0.189
Superior *	213	4,770	0.045
Ontario *	175	1,160	0.152

Table 3. Submersed and emergent plants common to coastal wetlands in Manitoba, modified from Shay (1999).

Latin name	Common name	Latin name	Common name
		EMERGENT	
Carex atherodes	Awned Sedge	*Scolochloa festucacea*	Whitetop / Spangletop
Phragmites australis	Giant Reed Grass	*Typha X glauca*	Hybrid Cattail
Schoenoplectus acutus	Hardstem Bulrush		
		SUBMERSED	
Ceratophyllum demerseum	Hornwort	*Stuckenia pectinatus*	Sago Pondweed
Myriophyllum sibiricum	Northern Watermilfoil	*Utricularia macrorhiza*	Common Bladderwort
Ruppia cirrhosa	Spiral ditchgrass	*Zannichellia palustris*	Horned Pondweed

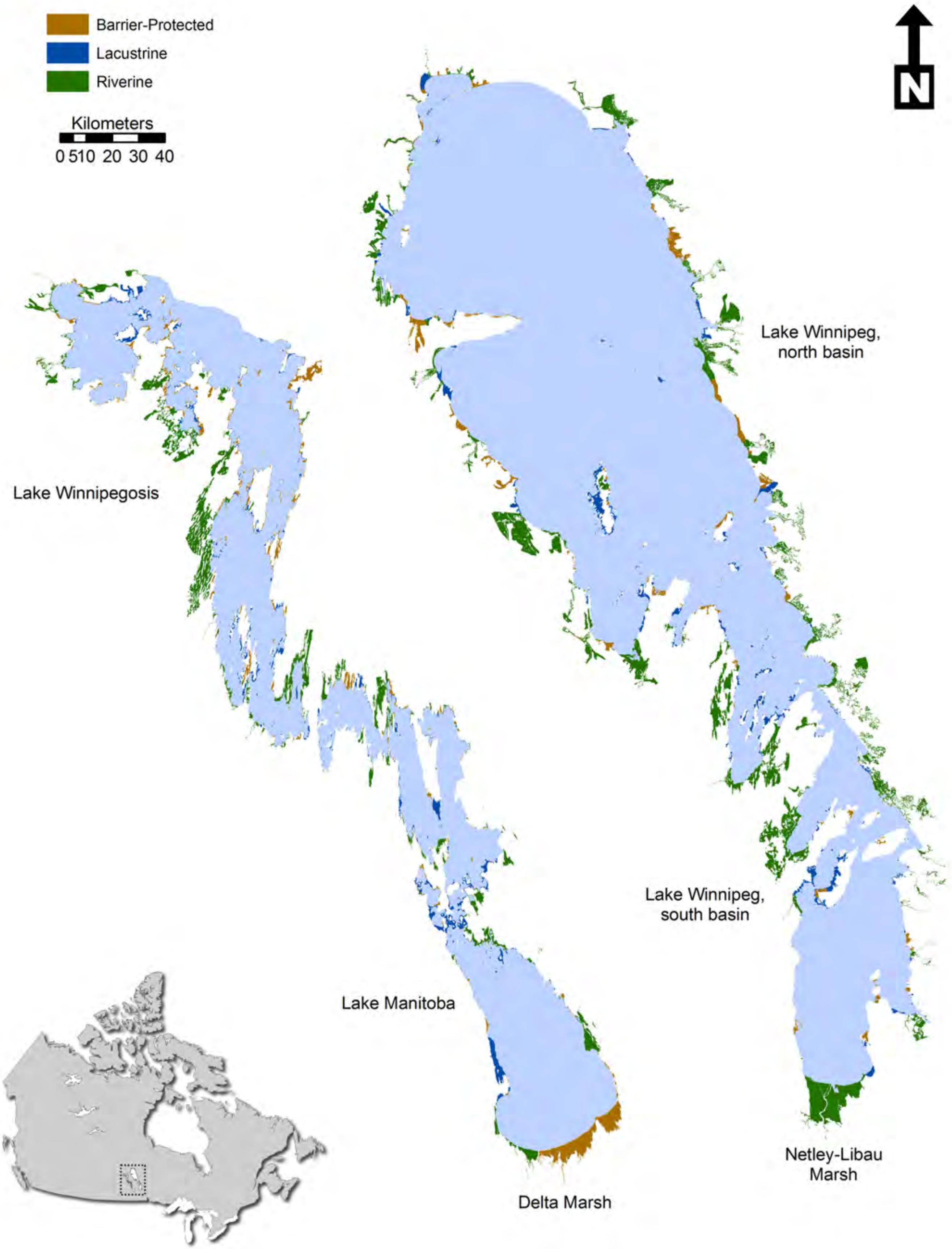

Figure 1. Inventory of the coastal wetlands of the Manitoba Great Lakes, excluding Treed Muskeg. Barrier-protected, lacustrine, and riverine classes are distinguished by color. See Table 1 for the total hectarage in each class. Source: Watchorn et al. 2012.

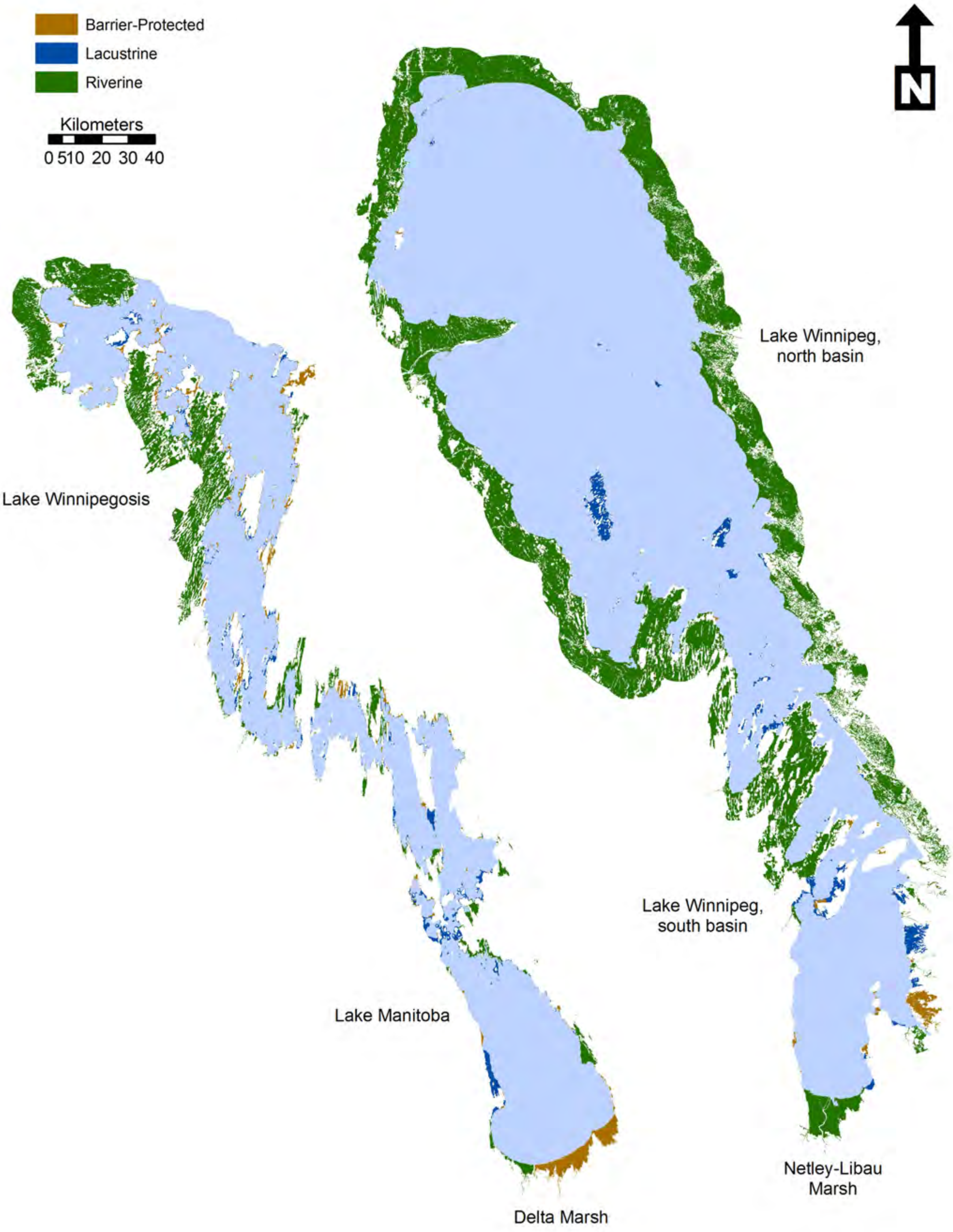

Figure 2. Inventory of the coastal wetlands of the Manitoba Great Lakes, including Treed Muskeg. Barrier-protected, lacustrine, and riverine classes are distinguished by color. See Table 1 for the total hectarage in each class. Source: Watchorn et al. 2012.

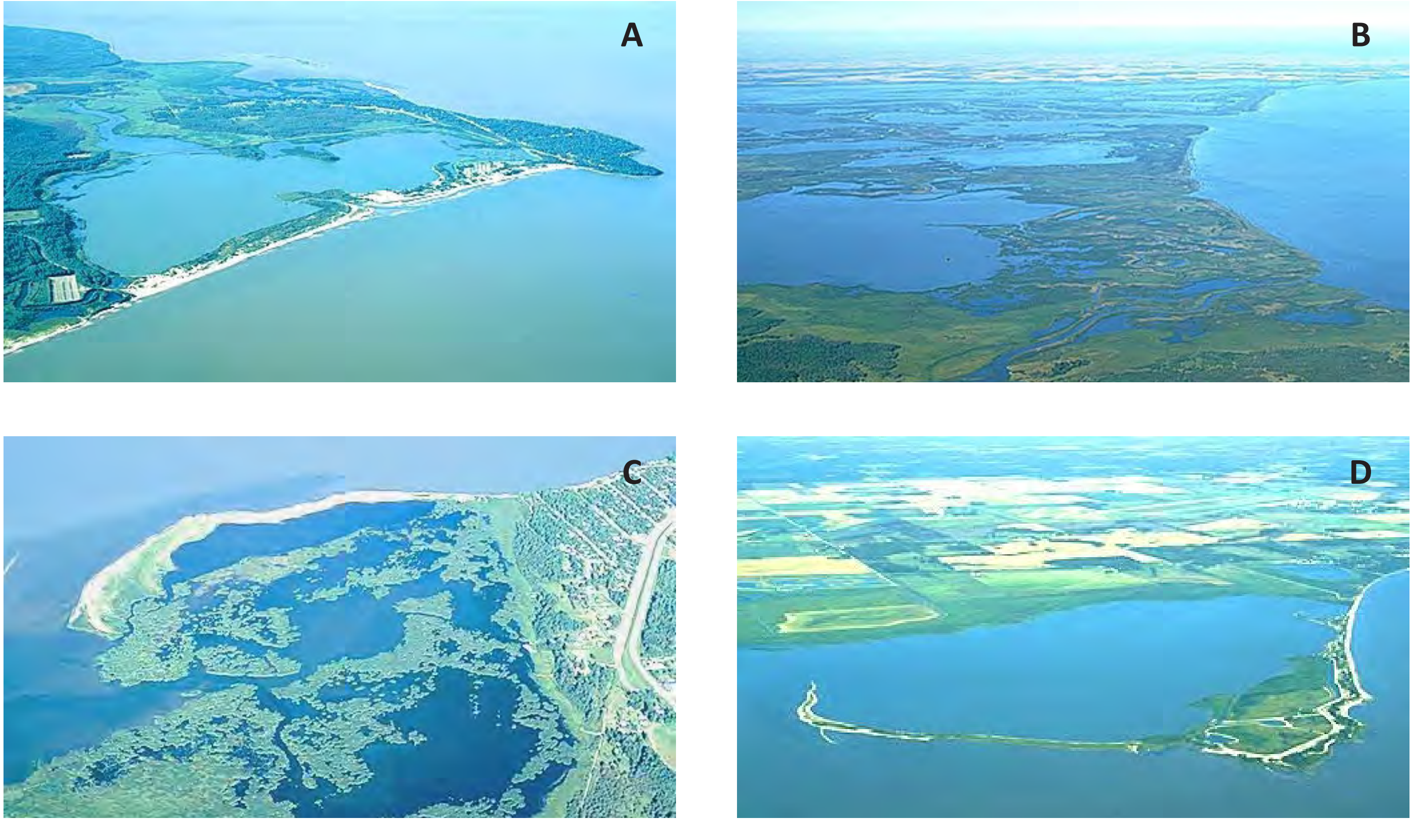

Figure 3. Examples of coastal wetlands around Lake Winnipeg. A. Barrier-beach wetland at Grand Beach. B. Netley-Libau Marsh. C. Spit at Grand Marais. D. Willow Point. Source: Harvey Thorleifson.

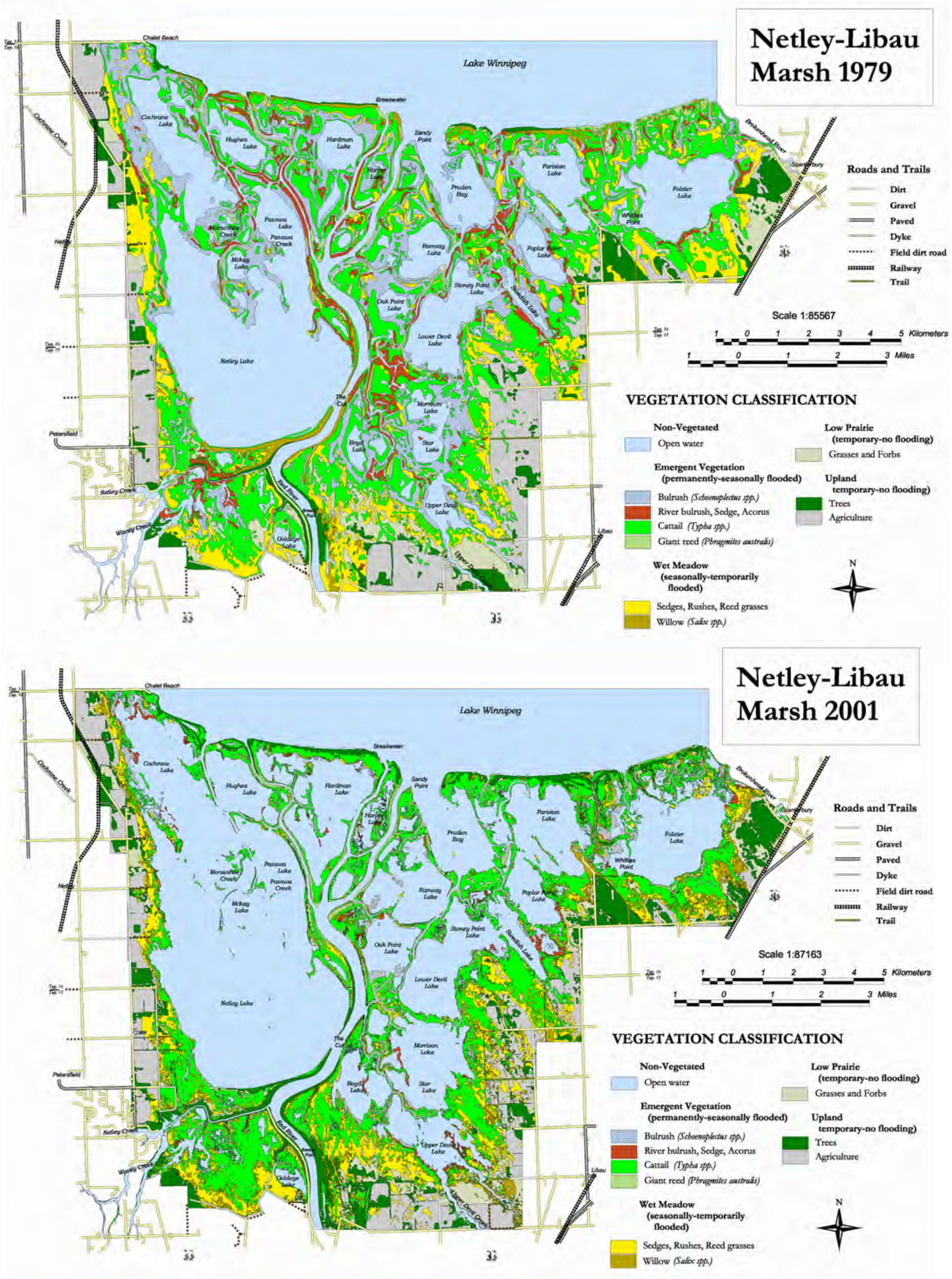

Figure 4. Maps of the emergent plants in Netley-Libau Marsh in 1979 (top) and 2001 (bottom). Source: Grosshans et al. 2004.

Figure 5. South-ward aerial views of Netley-Libau Marsh, 1923. A. The Forks and three branches of the Red River. B. Red River and south end of Netley Lake, noting hunting lodges and cut hay along the river. Source: Archives of Manitoba.

Figure 6. Mouth of the Red River at Netley-Libau Marsh, 1923. Note the abundant emergent plants at the mouth and also in the Netley unit in the background. Source: Archives of Manitoba.

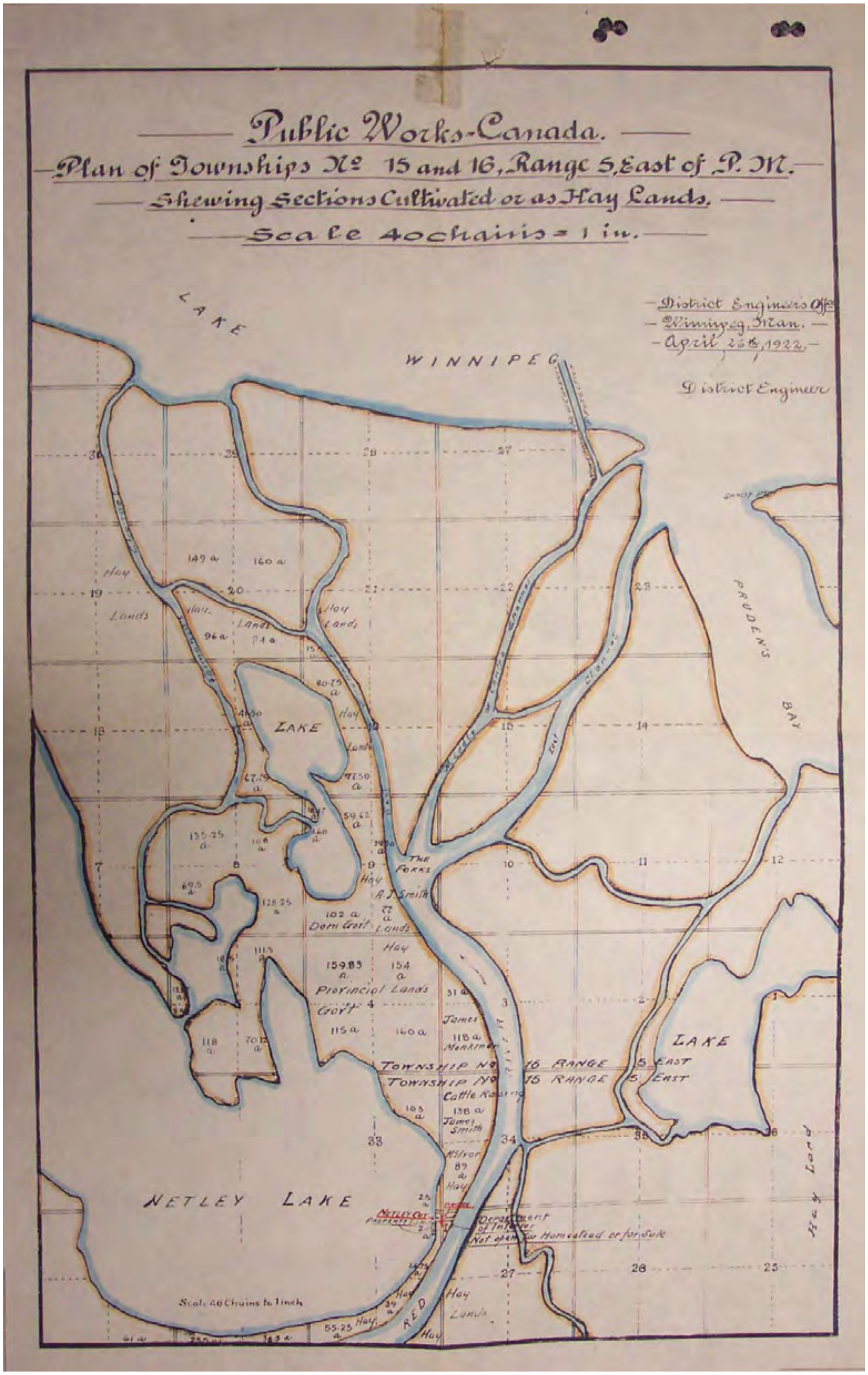

Figure 7. Map of the central unit of Netley-Libau Marsh in 1922, prior to widespread erosion of hayland in the north end of Netley Lake, west of the western channel of the Red River. Source: Library and Archives Canada.

Figure 8. Human activities at Netley-Libau Marsh, early 20th century. A. Lighthouse at the north end of the centre channel of the Red River at Lake Winnipeg, August 1923. B. Dredge "Red River" at dock in Selkirk, 1915. Source: Archives of Manitoba & Library and Archives Canada.

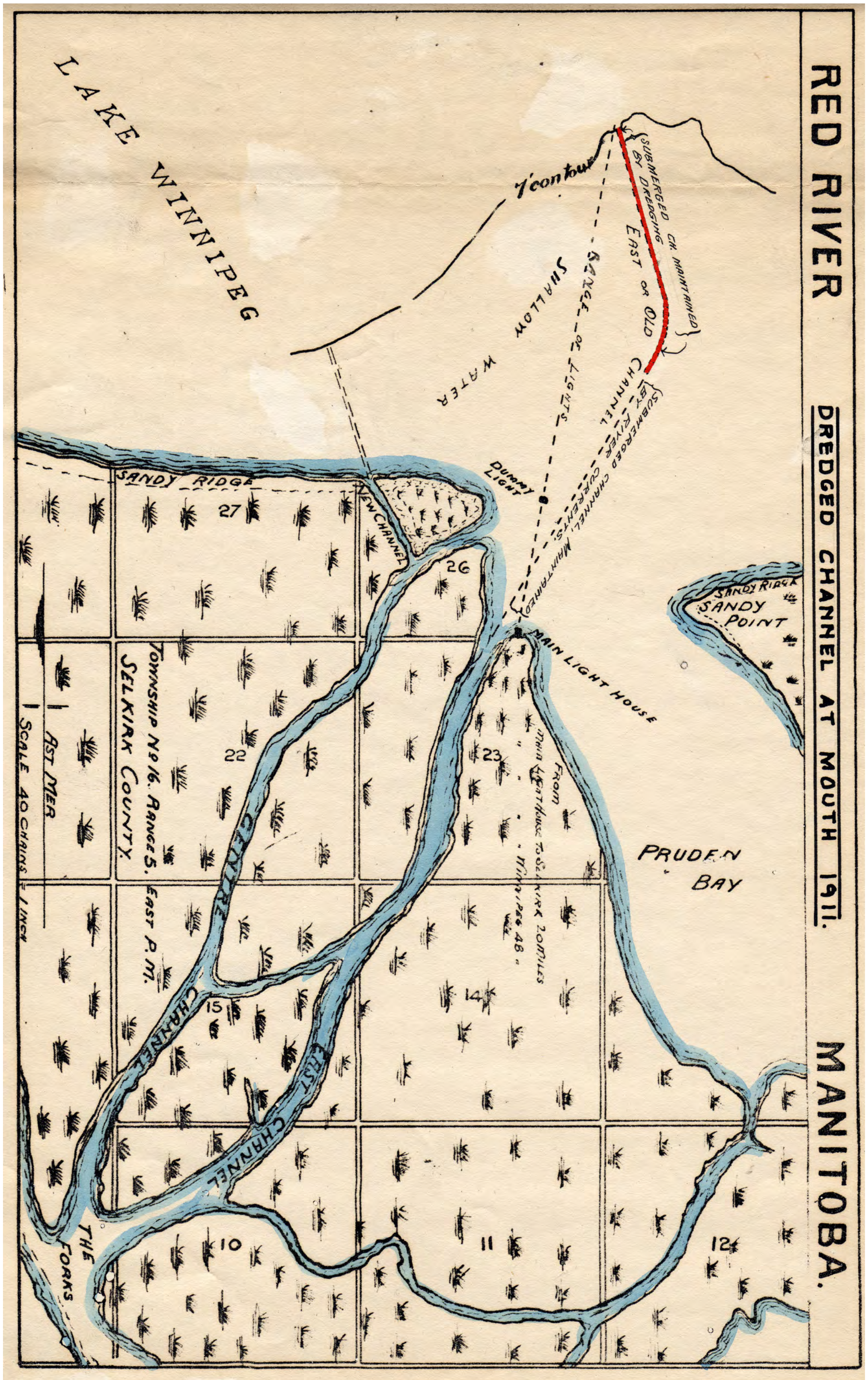

Figure 9. Map of the mouth of the Red River at Lake Winnpeg, 1911. The centre and eastern channels of the river are visible, as is the new channel dredged at the mouth of the centre channel. Compare to the 1923 photograph of the same area in Figure 5A. Source: Library and Archives Canada.

Figure 10. An aerial view of the Netley Cut in 1923 (A) and 2003 (B). The failed sheet pile dam and sunken dredge are visible in the early photo. The 2003 photo corresponded to a period of unusually low water on Lake Winnipeg, resulting in the exposure of deposited sediment in Netley Lake, seen in the lower, right corner of the photo. Source: Archives of Manitoba & Gordon Goldsborough.

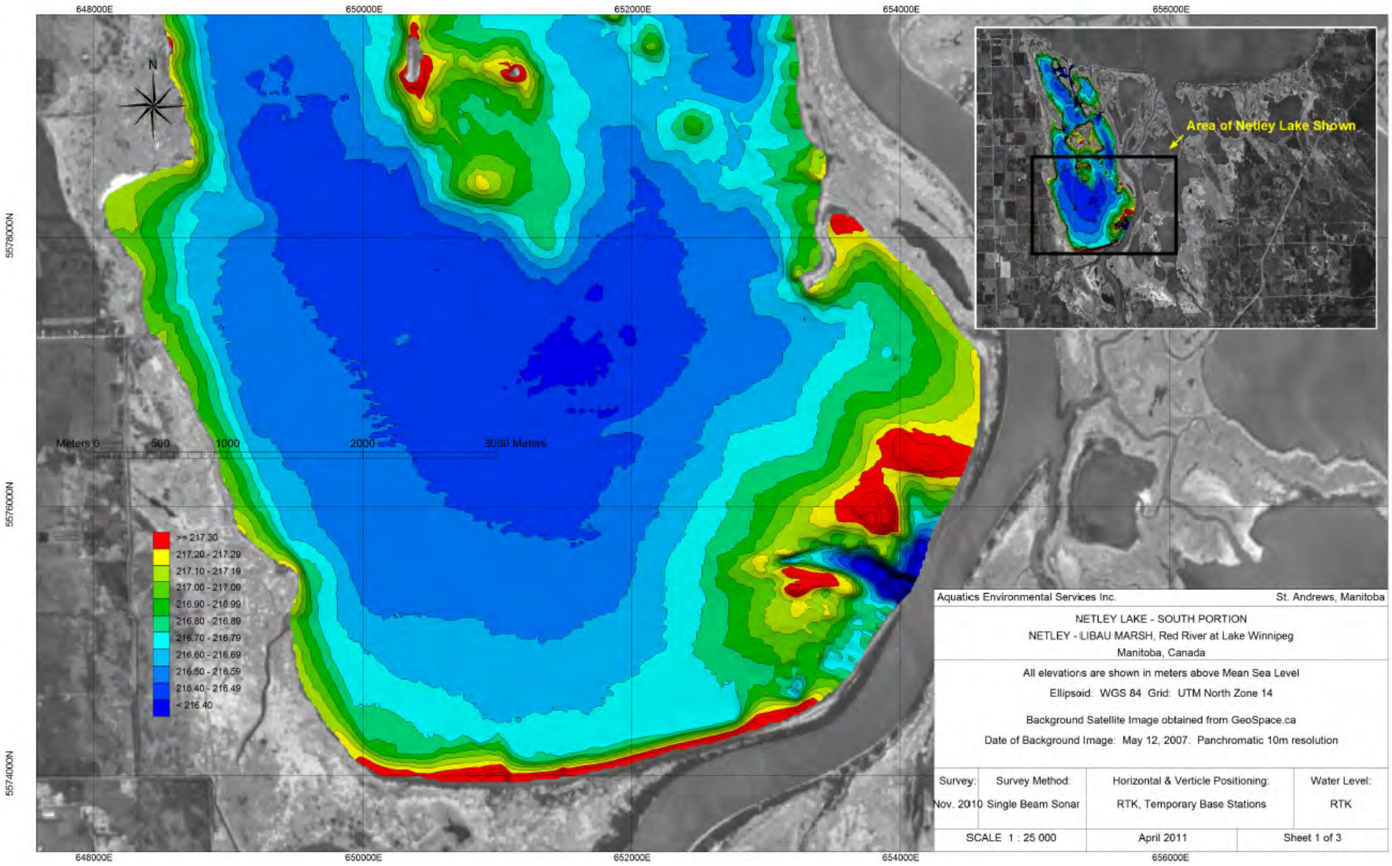

Figure 11. Bathymetric map of Netley-Libau Marsh, November 2010, where depth contours (meters above mean sea level) are represented by colours. Source: Province of Manitoba.

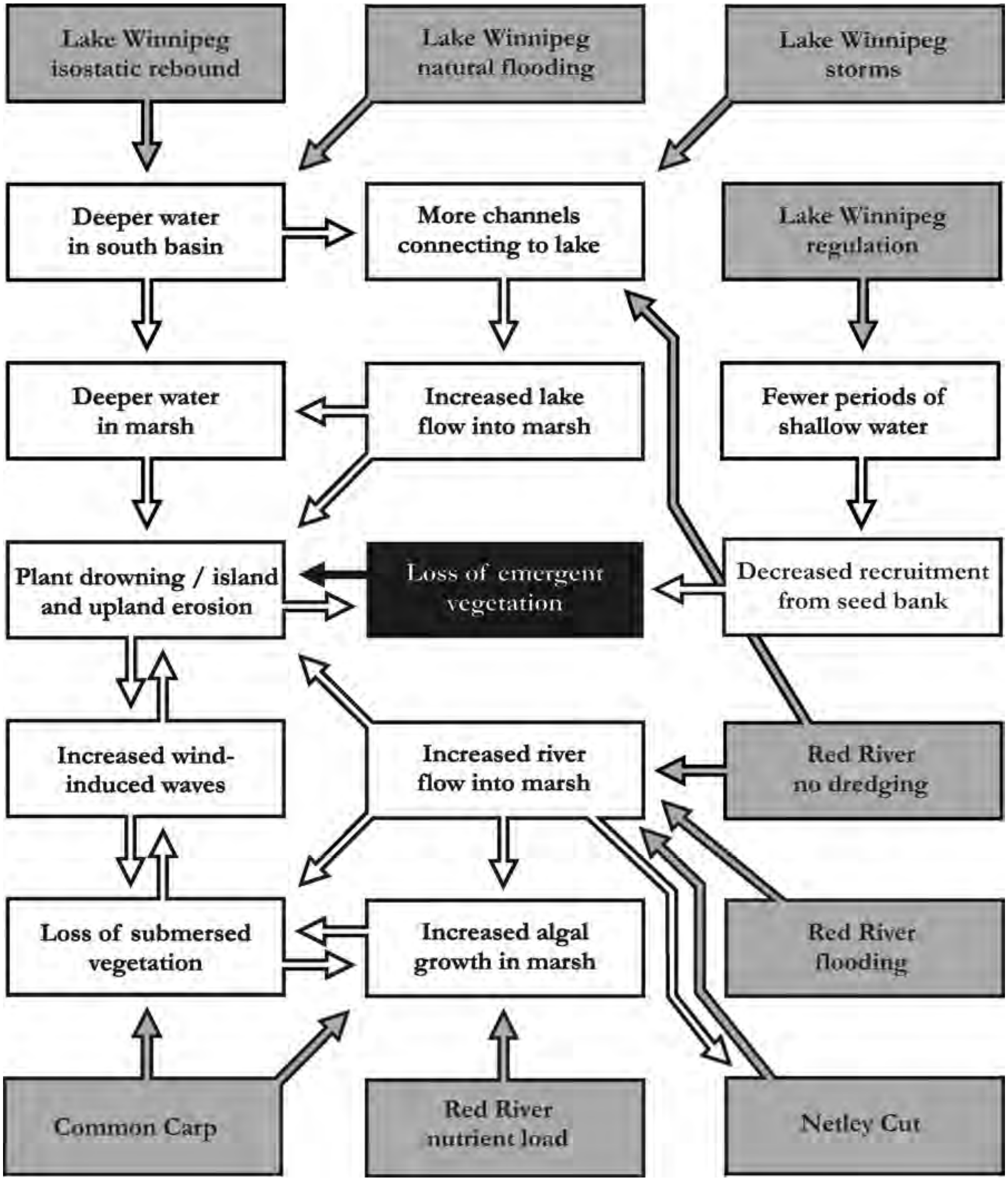

Figure 12. Conceptual diagram of some factors thought to be contributing to the decline of emergent vegetation in Netley-Libau Marsh. Shaded boxes are identified as potential primary causes of vegetation loss. Source: Grosshans et al. 2004.

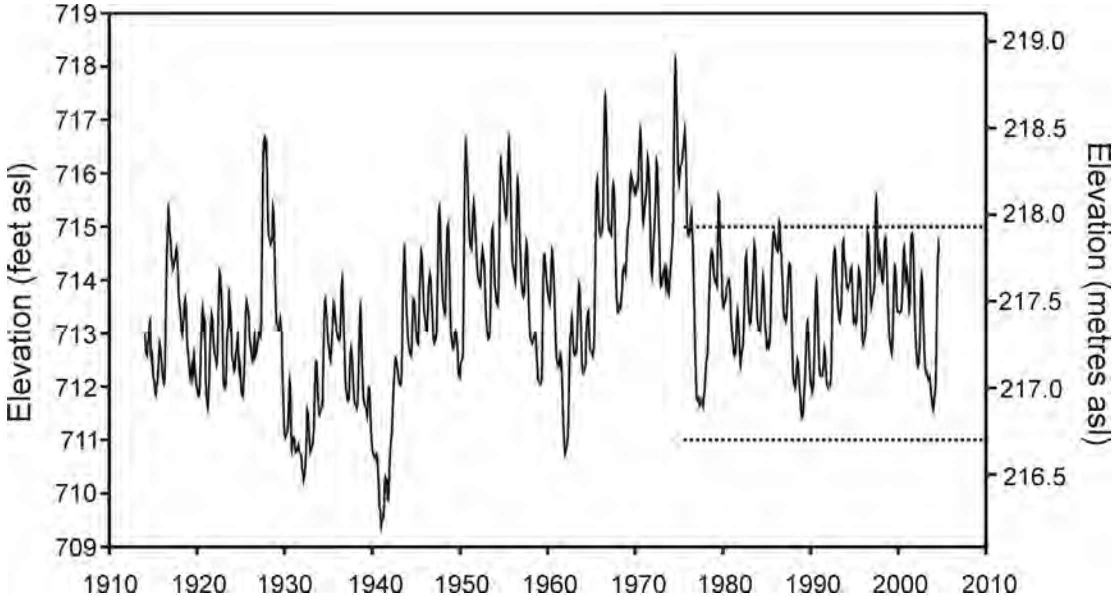

Figure 13. Monthly mean water levels for Lake Winnipeg, January 1914 to August 2004. Values are the mean of seven gauging stations around the lake, intended to eliminate the local effects of wind and therefore give a better estimate of overall lake level. Since 1975, water levels have been managed within the range of 711 feet (216.7 meters) and 715 feet (719.9 meters), as indicated by horizontal dotted lines. Source: Grosshans et al. 2004.

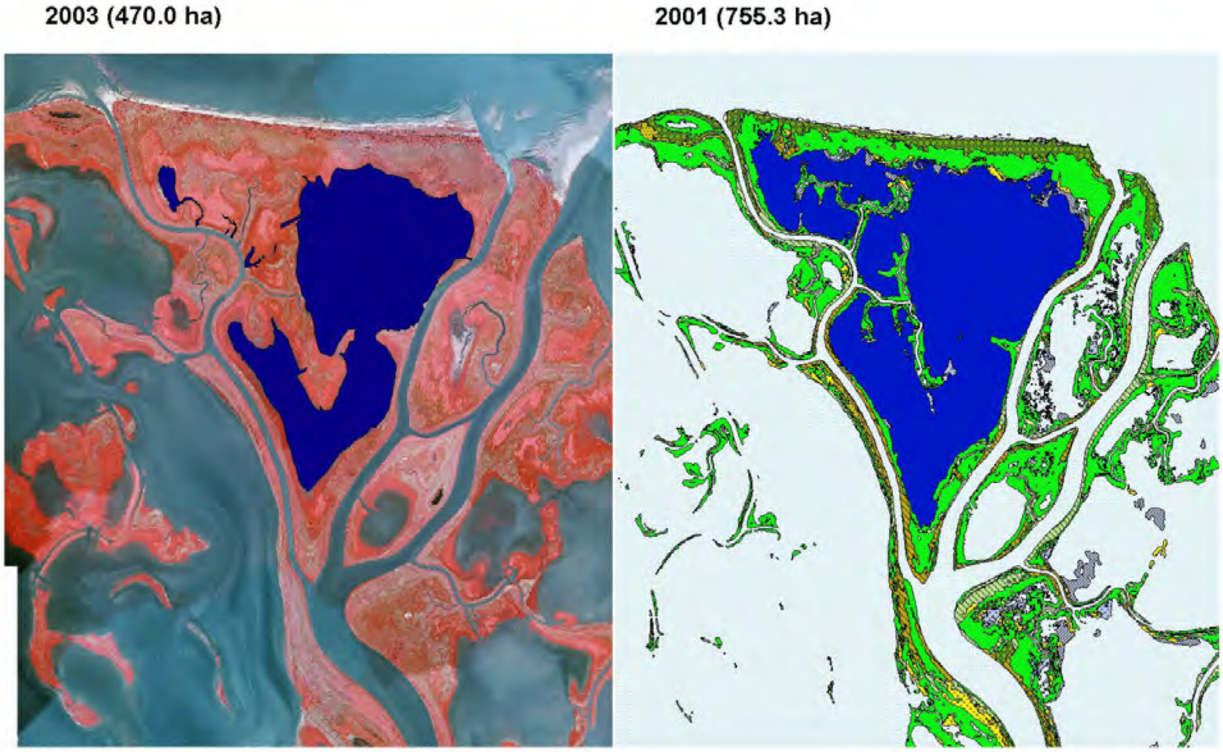

Figure 14. Comparison of the open-water area in Hardman Lake, in the central unit of Netley-Libau Marsh, in 2001 (right) and in 2003 (left) after marked cattail expansion due to low water levels. Source: Richard Grosshans, unpublished data.

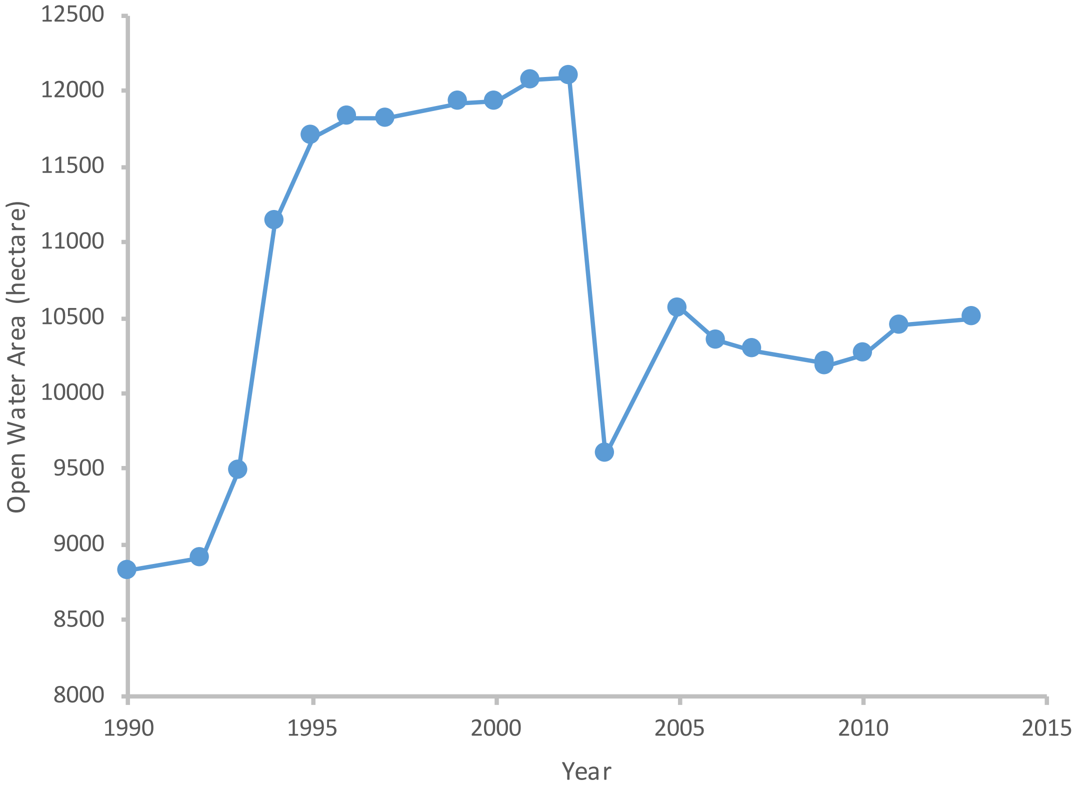

Figure 15. Changes in the open-water area of Netley-Libau Marsh between 1990 and 2013, based on analysis of satellite imagery. The precipitous drop in 2003 was due to marked growth of emergent plants during a period of drought. This revegetation was anticipated to be short-lived and a return to pre-drought conditions was anticipated. Surprisingly, although some loss of plants did occur after 2003, the vegetation has remained generally constant from 2005 to 2013. Source: Watchorn, unpublished data, 2014.

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Employment

1996 - present	**Associate Professor** Department of Biological Sciences, University of Manitoba
1996 - 2010	**Director** Delta Marsh Field Station, University of Manitoba
1996 - 2004	**Associate Professor** Environmental Science Program, University of Manitoba
1993 - 1995	**Associate Professor** Department of Botany, Brandon University
1992 - 1995	**Adjunct Professor** Department of Botany, University of Manitoba
1989 - 1993	**Assistant Professor** Department of Botany, Brandon University
1986 - 1989	**Killam / NSERC Postdoctoral Fellow** Department of Botany, University of Alberta
1985	**Research Scientist** Water Quality Management Section, Manitoba Department of Environment

Education

1985	***Doctor of Philosophy (Department of Botany, University of Manitoba)*** Thesis: Effects of two triazine herbicides on the structure and metabolism of freshwater marsh periphyton. 288pp.
1981	***Bachelor of Science, Honours (Department of Botany, University of Manitoba)*** Thesis: The effect of phytoplankton dynamics in a eutrophic prairie reservoir and in a receiving stream. 128pp.

Research Interests

- ecology of algae and plants in freshwater lakes and wetlands
- lake and wetland water quality as affected by agricultural and forestry practises
- response of coastal wetlands to introduced exotic species, pollutants, and altered hydrology
- ecosystem structure and function in freshwater wetlands
- reconstruction of past environmental conditions via stratigraphic analysis of diatom microfossils and plant pigments in lake sediment cores
- environmental history of prairie Canada, focusing on impacts of aquatic dredging and channeling, land use and social changes

Research Skills

- use of spectrophotometric, chromatographic, gravimetric and other techniques for routine water chemistry
- light microscopic techniques for the taxonomic identification and enumeration of extant and fossil plant micromaterials, with particular emphasis on diatoms
- use of radioisotopes for the measurement of aquatic primary production
- environmental chemistry methods and application techniques in the use of chemical herbicides
- use and development of biological assays for pesticide toxicity based on inorganic carbon uptake, in vivo chlorophyll fluorescence, elemental analysis (C,N,P), quantitative pigment concentrations and light microscopy
- techniques for the isolation and cultivation of freshwater microalgae

Research Publications

1. Refereed Papers in print or in press

Gerard, G., D. Applin, E. Cloutis, J. Stromberg, R. Sharma, P. Mann, S. Grasby, R. Bezys, B. Horgan, K. Londry, M. Rice, B. Last, F. Last, P. Badiou, G. Goldsborough and J. Bell. 2013. A hypersaline spring analogue in Manitoba, Canada for potential ancient spring deposits on Mars. Icarus 224:399-412.

Baschuk, M. S., Ervin, M. D., Clark, W. R., Armstrong, L. M., Wrubleski, D. A. and Goldsborough, L. G. 2012. Using satellite imagery to assess macrophyte response to water-level manipulations in the Saskatchewan River Delta, Manitoba. Wetlands DOI 10.1007/s13157-012-0339-z.

Baschuk, M. S., Koper, N., Wrubleski, D. A., and Goldsborough, L. G. 2012. Effects of water depth, cover, and food resources on marsh birds and waterfowl in boreal wetlands of Manitoba, Canada. Waterbirds 35(1): 44-55.

Hobson, K. A., Norris, D. R., Goldsborough, G. and Sealy, S. G. 2012. Requiem for a field station: The loss of a Canadian ornithological treasure. Avian Conservation and Ecology 7(2):7.

Goldsborough, L. G. 2013. Book review: Bruce D. J. Batt: The Marsh Keepers Journey: The Story of Ducks Unlimited Canada. Wetlands DOI 10.1007/s13157-013-0427-8.

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Badiou, P. H. and Goldsborough, L. G. 2010. Ecological impacts of an exotic benthivorous fish, in large experimental wetlands, Delta Marsh, Canada. Wetlands 30(4):657-667.

Badiou, P. H. and Goldsborough, L. G. Ecological impacts of an exotic benthivorous fish, the Common Carp (Cyprinus carpio L.) and nutrient additions in small experimental mesocosms. II. Planktonic and benthic communities. In preparation.

Badiou, P. H., Goldsborough, L. G. and Malley, D. F. Quantitative and qualitative assessment of dissolved organic carbon (DOC) in wetlands of central North America using scanning UV spectroscopy and multivariate statistics. In preparation.

Badiou, P., L. G. Goldsborough and D. Wrubleski 2011. Impacts of the Common Carp (Cyprinus carpio) on freshwater ecosystems: A review. Chapter 4 in Carp: Habitat, Management and Diseases, J. D. Saunders and S. B. Peterson (editors), Nova Science Publishers.

Watchorn, E., L. G. Goldsborough, D. A. Wrubleski, and B. Mooney. 2012. An inventory of coastal wetlands of Lakes Winnipeg, Manitoba, and Winnipegosis: the “Manitoba Great Lakes”, *Journal of Great Lakes Research* 38:115-122.

Ross, L. C. M., D. A. Lobb, D. J. Pennock, L. G. Goldsborough and L. A. Armstrong. 2009. The vegetation of prairie wetlands in native and agricultural landscapes: implications for wetland health and restoration. *Biodiversity*: in press (July 2009).

Badiou, P. H. J. and L. G. Goldsborough. 2006. Northern range extension and invasion by the common carp (*Cyprinus carpio* L.) of the Churchill River system in Manitoba, Canada. *Canadian Field-Naturalist* 120(1):83-86.

Goldsborough, L. G., R. L. McDougal and A. K. North. 2005. Periphyton in freshwater lakes and wetlands, Chapter 5, pages 71 to 89 in *Periphyton: Ecology, Exploitation and Management*. Azim, M. E. *et al.* (editors), CABI Publishing, UK.

Weidman, P., M. A. Turner and L. G. Goldsborough. 2005. Limitations on the effects of ultraviolet radiation on benthic algae in a clear boreal forest lake. *Journal of the North American Benthological Society* 24:820-831.

Friesen-Pankratz, B., C. Doebel, A. Farenhorst and L. G. Goldsborough. 2003. Interactions between algae (*Selenastrum capricornutum*) and pesticides: Implications for managing constructed wetlands for pesticide removal. *Journal of Environmental Science and Health Part B. Pesticides, Food Contaminants, and Agricultural Wastes.* B38:147-155.

Zrum, L., B. J. Hann and L. G. Goldsborough. 2002. Invertebrates associated with submersed macrophytes in a prairie wetland: Effects of organophosphorus insecticide and inorganic nutrients. *Archiv für Hydrobiologie* 154:413-445.

Mundy, C. J., B. J. Hann and L. G. Goldsborough. 2001. Snail-periphyton interactions in a prairie lacustrine wetland. *Hydrobiologia* 457:167-175.

Goldsborough, L. G. 2001. Sampling algae in wetlands. pp. 263-295. Rader, R. B., D. P. Batzer and S. Wissinger (eds.) Biomonitoring and Management of North American Freshwater Wetlands. Academic Press.

Sandilands, K. A., B. J. Hann and L. G. Goldsborough. 2000. The impact of nutrients and submersed macrophytes on invertebrates in a prairie wetland, Delta Marsh, Manitoba. *Archiv für Hydrobiologie* 148:441-459.

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Robinson, G. G. C., S. E. Gurney and L. G. Goldsborough. 2000. Algae in prairie wetlands. pp. 163-199 H. Murkin, A. van der Valk, and W. R. Clark (eds.), Prairie Wetland Ecology: The Contribution of the Marsh Ecology Research Program. Ames: Iowa State University Press.

Murkin, H. R., A. G. van der Valk, W. R. Clark, D. A. Wrubleski and L. G. Goldsborough. 2000. Marsh Ecology Research Program: Management Implications for Prairie Wetlands. pp. 317-344. H. Murkin, A. van der Valk, and W. R. Clark (eds.) Prairie Wetland Ecology: The Contribution of the Marsh Ecology Research Program. Ames: Iowa State University Press.

Richmond, K-A. and L. G. Goldsborough. 1999. Late Holocene paleolimnology of Killarney Lake, Manitoba. In: D. S. Lemmen and R. E. Vance (eds), Holocene climate and environmental change in the Palliser Triangle: a geoscientific context for evaluating the impacts of climate change on the southern Canadian Prairies. Geological Survey of Canada Bulletin 534.

Goldsborough, L. G. and W. G. Crumpton. 1998. Distribution and environmental fate of pesticides in prairie wetlands. *Great Plains Research* 8:73-95.

Crumpton, W. G. and L. G. Goldsborough. 1998. Nitrogen transformation and fate in prairie wetlands. *Great Plains Research* 8:57-72.

Pettigrew, C. T., B. J. Hann and L. G. Goldsborough. 1997. Waterfowl feces as a source of nutrients to a prairie wetland: responses of microinvertebrates to experimental additions. *Hydrobiologia* 362:55-66.

Timoney, K., S. Zoltai and L. G. Goldsborough. 1997. Boreal diatom ponds: a rare wetland associated with nesting whooping cranes. *Wetlands* 17:539-551.

McDougal, R.L., L. G. Goldsborough and Hann, B. J. 1997. Responses of a prairie wetland to press and pulse additions of nitrogen and phosphorus: production by planktonic and benthic algae. *Archiv für Hydrobiologie* 140:145-167.

Hann, B. J. and L. G. Goldsborough. 1997. Responses of a prairie wetland to press and pulse additions of nitrogen and phosphorus: invertebrate community structure and interactions. *Archiv für Hydrobiologie* 140:169-194.

Robinson, G. G. C., S. E. Gurney and L. G. Goldsborough 1997. Response of benthic and planktonic algal biomass to water level manipulation in a prairie wetland. *Wetlands* 17:167-181.

Robinson, G. G. C., S. E. Gurney and L. G. Goldsborough 1997. The primary productivity of benthic and planktonic algae in a prairie wetland under controlled water-level regimes. *Wetlands* 17:182-194.

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Goldsborough, L. G., G. G. C. Robinson and S. E. Gurney 1986. An enclosure/substratum system for in situ ecological studies of periphyton. *Archiv für Hydrobiologie* 106:373-393.

Goldsborough, L. G. and G. G. C. Robinson 1985. Seasonal succession of diatom epiphyton on dense mats of *Lemna minor* L. *Canadian Journal of Botany* 63:2332-2339.

Goldsborough, L. G. and G. G. C. Robinson 1985. Effect of an aquatic herbicide on sediment nutrient flux in a freshwater marsh. *Hydrobiologia* 122:121-128.

Shamess, J. J., G. G. C. Robinson and L. G. Goldsborough 1985. The structure and comparison of periphytic and planktonic algal communities in two eutrophic prairie lakes. *Archiv für Hydrobiologie* 103:99-116.

Goldsborough, L. G. and G. G. C. Robinson 1984. A simple bioassay for photosystem II inhibitors in water using in vivo chlorophyll fluorescence. *Weed Research* 24:351-358.

Goldsborough, L. G. and G. G. C. Robinson 1983. The effect of two triazine herbicides on the productivity of freshwater marsh periphyton. *Aquatic Toxicology* 4:95-112.

2. Refereed Papers in review

Parks, C. R., D. A. Wrubleski, and L. G. Goldsborough. Pond connectivity affects the small fish community of a large coastal wetland in south-central Manitoba, Canada. *Journal of Great Lakes Research* (submitted November 2014).

Badiou, P. H. and L. G. Goldsborough. Ecological impacts of an exotic benthivorous fish, the Common Carp (*Cyprinus carpio* L.), on water quality, sedimentation rates and submerged macrophyte biomass in small wetland mesocosms. *Hydrobiologia* (submitted August 2014).

3. Papers in preparation

Lindeman, D. H. and L. G. Goldsborough. Winter is critical: seasonal changes in water chemistry, algae and invertebrates in prairie pothole wetlands of central Saskatchewan.

Badiou, P. H., L. G. Goldsborough, B. Friesen-Pankratz, S. Hnatiuk, T. L. Bortoluzzi, and D. F. Malley. Quantitative and qualitative assessment of dissolved organic carbon (DOC) in wetlands of central North America using scanning ultraviolet spectrophotometry and multivariate statistics.

Bortoluzzi, T. L., R. L. McDougal and L. G. Goldsborough. Inorganic nitrogen supply limits periphytic algal growth in three large prairie wetlands in south-central Canada.

Goldsborough, L. G., D. A. Wrubleski, and R. E. Grosshans. Long term changes in the emergent vegetation communities of two freshwater coastal marshes, Delta and Netley-Libau, Manitoba, Canada.

McDougal, R. L. and L. G. Goldsborough. Macrophyte exclusion and inorganic nutrient loading affects planktonic and benthic algal production in a lacustrine prairie wetland.

Friesen-Pankratz, B., L. G. Goldsborough and A. Farenhorst. Influence of water column and sediment organic matter on the persistence of atrazine in wetland microcosms.

Friesen-Pankratz, B., L. Smith, A. Farenhorst and L. G. Goldsborough. The influence of suspended solids, light, and nitrate on the persistence of pesticides in prairie wetlands.

Goldsborough, L. G. and G. G. C. Robinson. Wetland algal production in response to spiked additions of inorganic nitrogen and phosphorus.

Goldsborough, L. G. Effects of a herbicidal stressor on the biomass and productivity of periphyton communities in wetland enclosures.

Hawryliuk, Y., L. G. Goldsborough and S. E. Gurney. Water quality along four small creeks in the City of Winnipeg.

Goldsborough, L. G. and M. J. Forster. Do pre-exposure duration and architectural development affect the toxicity of a herbicide to a periphyton community?

Badiou, P. H., L. G. Goldsborough. Combined impacts of an exotic benthivorous fish, the common carp (Cyprinus carpio) and nutrient additions in small experimental mesocosms. II. Effects on algal, invertebrate, and fish communities.

Purcell, S. L., and L. G. Goldsborough. Waterfowl feces additions do not stimulate algal production in a large prairie marsh.

Goldsborough, L. G. and D. A. Wrubleski. A 50-year photographic record of morphometric change in Delta Marsh, Canada.

North, A. D. K. and L. G. Goldsborough. Effects of simultaneous insecticide and nutrient additions on algal production in a prairie coastal wetland.

Bourne, A. L. E. and L. G. Goldsborough. Biomass determination of sediment-associated algae at three sites in a shallow prairie marsh.

4. Presented Papers (- invited)*

Peterson, H. M. and L. G. Goldsborough, 2014. Typha x glauca growth and nutrient uptake as a function of water depth in Oak Hammock Marsh, Canada. Society of Wetland Scientists, 2014 Annual Meeting, Portland, Oregon.

Wasko, J., T. McGonigle, and L. G. Goldsboough 2014. Typha species and hybid distribution and generalized linear model of T x glauca and environment in Canada's prairie pothole region. Society of Wetland Scientists, 2014 Annual Meeting, Portland, Oregon.

Goldsborough, L. G. 2010. A history of wetland science in prairie Canada. Society of Wetland Scientists, 2010 Annual Meeting, Salt Lake City, Utah. (*)

Grosshans, R. E., L. G. Goldsborough, N. Cicek, D. A. Wrubleski, and H. D. Venema 2010. The efficient cattail: harvesting the egs benefits of cattail for nutrient abatement in the watershed. Society of Wetland Scientists, 2010 Annual Meeting, Salt Lake City, Utah.

Geard, N., L. G. Goldsborough, D. A. Wrubleski, G. Ball and J. Wasko 2010. Evaluation of methods for invasive cattail management in Delta Marsh, Manitoba, Canada. Society of Wetland Scientists, 2010 Annual Meeting, Salt Lake City, Utah.

Watchorn, E., L. G. Goldsborough, and D. A. Wrubleski 2010. Effects of water level management on water chemistry and primary production in boreal marshes of northern Manitoba, Canada. Society of Wetland Scientists, 2010 Annual Meeting, Salt Lake City, Utah.

Goldsborough, L. G. 2010. Legacy of the Stinking River: Wetland loss and restoration on Manitoba's southern prairies. Prairie Conservation and Endangered Species Workshop, Winnipeg, Manitoba, 2010.

Goldsborough, L. G. 2007. A review of the limnology of Lake Manitoba: a large, shallow lake in south-central Canada. North American Lake Management Society, 27th Annual Meeting, Orlando, FL.

Ackerman, J., N. Cicek, R. Grosshans, M. Paetkau, L. G. Goldsborough and M. Tenuta. 2007. Phosphorus removal potential from surface water through yearly harvesting of cattails in a delta marsh. Water Environment Federation Annual Exhibition and Conference, 13-17 October, San Diego, USA.

Bortoluzzi, T. L. and L. G. Goldsborough. 2007. The influence of Lake Manitoba on the hydrology, water chemistry, and algal nutrient status of a coastal freshwater marsh, Delta Marsh, located in south-central Canada. XXX SIL Congress, Montreal.

Goldsborough, L. G. 2007. A review of the limnology of Lake Manitoba: a large, shallow lake in south-central Canada. XXX SIL Congress, Montreal.

Dyszy, K. A., D. A. Wrubleski, J. R. Spence and L. G. Goldsborough. 2006. Effects of pond connectedness on three anuran life stages at Delta Marsh, Manitoba, Canada. Society of Wetland Scientists, 27th Annual Meeting, Cairns, Australia.

Goldsborough, L. G. and B. Kotak. 2006. Wide-spread occurrence of total microcystins in lakes throughout Manitoba, Canada. North American Lake Management Society, 26th Annual Meeting, Indianapolis, IN.

Goldsborough, L. G., R. E. Grosshans and D. A. Wrubleski. 2006. Long term changes in the emergent vegetation of two freshwater coastal marshes in Manitoba, Canada. Society of Wetland Scientists, 27th Annual Meeting, Cairns, Australia.

Goldsborough, L. G. and M. W. Zbigniewicz. 2006. Tree composition in a pristine riverbank forest of south-central Manitoba. Ecological Monitoring and Assessment Network of Environment Canada, National Science Meeting, Winnipeg.

Grosshans, R. E., L. G. Goldsborough, N. Cicek, D. A. Wrubleski, H. D. Venema and E. Bibeau. 2006. Potential water quality improvement in Lake Winnipeg, Canada, through Netley-Libau Marsh. Society of Wetland Scientists, 27th Annual Meeting, Cairns, Australia.

Jacobs, K. and L. G. Goldsborough. 2006. Landscape level influences on water quality in the boreal region of Manitoba: a lakes survey. Canadian Society of Limnologists, Calgary, 5-7 January.

Kolochuk, J. S., L. G. Goldsborough and D. Flaten. 2006. Effects of agricultural land use on water quality in farm ponds of south-central Manitoba, Canada. North American Lake Management Society, 26th Annual Meeting, Indianapolis, IN.

Shipley, E. and L. G. Goldsborough. 2006. Spatial and temporal variation in water quality in Lake Manitoba. North American Lake Management Society, 26th Annual Meeting, Indianapolis, IN.

Shipley, E. and L. G. Goldsborough. 2006. Spatial and temporal variation in water quality in a large shallow lake of central Canada (Lake Manitoba, Canada). 5th International Conference on Reservoir Limnology and Water Quality, Brno, Czech Republic.

Bortoluzzi, T. L. and L. G. Goldsborough. 2005. Spatial variability in the water chemistry, nutrient status and hydrology of a coastal freshwater water marsh in south-central canada, as influenced by its adjoining large lake. Society of Wetland Scientists, 26th Annual Meeting, Charleston, SC.

Dyszy, K. A., D. A. Wrubleski, J. R. Spence, J. R. and L. G. Goldsborough. 2005. Who's calling where: anuran breeding site selection at Delta Marsh, Manitoba. Society of Wetland Scientists, 26th Annual Meeting, Charleston, SC.

Goldsborough, L. G., D. A. Wrubleski, R. E. Grosshans, R. Hempel, T. L. Bortoluzzi, and C. R. Parks. 2005. Studies on the dynamics of Lake Winnipeg coastal marshes. Society of Wetland Scientists, 26th Annual Meeting, Charleston, SC.

Grosshans, R. E., L. G. Goldsborough, D. A. Wrubleski, N. Cicek and H. D. Venema. 2005. Using a natural wetland for nutrient removal and biopower/carbon emission credits: improving water quality in Lake Winnipeg through Netley-Libau Marsh in Manitoba, Canada. Society of Wetland Scientists, 26th Annual Meeting, Charleston, SC.

Kolochuk, J. S. and L. G. Goldsborough. 2005. Effects of agricultural land use on water quality in farm ponds of south-central Manitoba, Canada. North American Lake Management Society, 25th Annual Meeting, Madison, WI.

Shipley, E., L. G. Goldsborough and P. Sellers. 2005. Spatial and temporal variation in water quality in Lake Manitoba, one of the “Manitoba Great Lakes” of central Canada. North American Lake Management Society, 25th Annual Meeting, Madison, WI.

Bortoluzzi, T. L. and L. G. Goldsborough. 2004. Spatial patterns in the water chemistry and nutrient status of a coastal freshwater marsh in south-central Canada, as influenced by its adjoining lake. Society of Wetland Scientists, 25th Annual Meeting, Seattle, WA.

Dyszy, K. A., D. A. Wrubleski, J. Spence and L. G. Goldsborough. 2004. Impacts of introduced benthivorous common carp (*Cyprinus carpio*) on amphibian life stages at Delta Marsh, Manitoba. Society of Wetland Scientists, 25th Annual Meeting, Seattle, WA.

Goldsborough, L. G. and D. A. Wrubleski. 2004. Effects of stabilized water levels in Lake Manitoba on the natural history of Delta Marsh in south-central Manitoba, Canada. American Fisheries Society, 134th Annual Meeting, Madison, WI. (*)

Goldsborough, L. G. and D. A. Wrubleski. 2004. Effects of stabilized water levels in Lake Manitoba on the natural history of Delta Marsh in south-central Manitoba, Canada. Society of Wetland Scientists, 25th Annual Meeting, Seattle, WA.

Hempel, R., L. G. Goldsborough and D. A. Wrubleski. 2004. The use of GIS in understanding changes in wetland complexes in the south basin of Lake Winnipeg, Canada. Society of Wetland Scientists, 25th Annual Meeting, Seattle, WA.

Hertam, S., L. G. Goldsborough and D. A. Wrubleski. 2004. The effects of large benthivorous fish activity on nutrient dynamics in a natural marsh ecosystem. Society of Wetland Scientists, 25th Annual Meeting, Seattle, WA.

Jacobs, K., L. G. Goldsborough and B. Kotak. 2004. Landscape influences on water quality in boreal region of Manitoba: a lakes survey. North American Lake Management Society, 24th Annual Meeting, Victoria, BC.

Badiou, P. and L. G. Goldsborough. 2003. The impacts of the common carp (*Cyprinus carpio*) in large experimental wetlands and small enclosures. Society of Wetland Scientists, 24th Annual Meeting, New Orleans, LA.

Bortoluzzi, T. L. and L. G. Goldsborough. 2003. The hydrological influence of a large lake on the nutrient dynamics of an adjoining coastal wetland in south-central Manitoba. Society of Wetland Scientists, 24th Annual Meeting, New Orleans, LA.

Friesen-Pankratz, B. and L. G. Goldsborough. 2003. Landscape-level variability of wetlands in the prairie pothole region of North America. Society of Wetland Scientists, 24th Annual Meeting, New Orleans, LA.

Hnatiuk, S., L. G. Goldsborough and D. A. Wrubleski. 2003. Effects of common carp on water quality and primary producers in Delta Marsh, a coastal wetland in south central Canada. Society of Wetland Scientists, 24th Annual Meeting, New Orleans, LA.

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7. Newspaper Articles

“Netley-Libau loses ecological luster.” *Interlake Spectator*, 14 January 2005.

“Netley Marsh loses ability to filter pollutants.” *Winnipeg Free Press*, 6 January 2005, page B8.

“‘Black algae’ infest Manitoba lakes.” *Winnipeg Free Press*, 7 September 2004, page A3.

“Dugout water worse than realized, survey reveals” *The Manitoba Co-operator*, 12 February 2004, page 3.

“Water level a source of conflict” *Winnipeg Free Press*, 10 February 2004, page B12.

“U of M botanist calls for improved stewardship” *Winnipeg Free Press*, 10 February 2004, page B12.

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“Black plague at lakes” *Winnipeg Free Press*, 27 July 2003, page A1.

“Lake Manitoba needs help too: prof; U of M scientist warns of neglect based on politics” *Winnipeg Free Press*, 18 March 2003.

“Delta Marsh near death: Traditional plant, animal species in dramatic decline” *Winnipeg Free Press*, 4 March 2001, page A1.

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8. Student theses

Bortoluzzi, T. 2013. Spatial and temporal patterns in the hydrology, water chemistry and algal nutrient status of a coastal freshwater marsh, Delta Marsh, as influenced by the hydrology of adjoining Lake Manitoba, located in south-central Manitoba, Canada. PhD thesis, University of Manitoba, 409 pp.

Fred, D. 2013. Internal nutrient loading of the Lake Manitoba south basin. MSc thesis, University of Manitoba, 147 pp.

Grosshans, R. E. 2013. Cattail (*Typha* spp.) biomass harvesting for nutrient capture and sustainable bioenergy for integrated watershed management. PhD thesis, University of Manitoba, 274 pp.

Wasko, J. 2013. Distribution and environmental associations throughout southwestern Manitoba and southeastern Saskatchewan for the cattail species *Typha latifolia*, and *T. angustifolia*, and for the hybrid, *T. x glauca*. MSc thesis, University of Manitoba, 286 pp.

Berke, K. 2012. Water quality in Lake Manitoba during the flood of 2011. BSc thesis, University of Manitoba, 67 pp.

Bjornson, F. 2012, Delta Marsh and the effects of a one-in-four-hundred year flood on the fish community, BSc thesis, University of Manitoba, 81 pp.

Ewacha, M. 2012. Bioassay of glyphosate toxicity tested on taxonomic algae with cell density and chlorophyll-a as endpoints. BSc thesis, University of Manitoba, 60 pp.

Nicholson, M. 2012. Phosphorus loading and sequestration in Lake Manitoba from 2009 to 2011. BSc thesis, University of Manitoba, 44 pp.

Tarleton, P. 2012. Algal blooms in Moon Lake, past and present. BSc thesis, University of Manitoba, 47 pp.

Page, E. C. M. 2011. A water quality assessment of Lake Manitoba, a large shallow lake in central Canada. MSc thesis, University of Manitoba, 177 pp.

Watchorn, K. E. 2011. Effects of water level management on water chemistry and primary Production of boreal marshes in northern Manitoba, Canada. MSc thesis, University of Manitoba, 187 pp.

Hertam, S. C. 2010. The effects of common carp (*Cyprinus carpio* L.) water quality, algae and submersed vegetation in Delta Marsh, Manitoba. MSc thesis, University of Manitoba, 186 pp.

Zanzerl, H. 2010. A decade of change: Studies on the Common Carp (*Cyprinus carpio*) population in Delta Marsh, Manitoba. BSc thesis, University of Manitoba, 49 pp.

Pernerowski, R. 2010. The Portage Diversion and its impact on Lake Manitoba's water quality. Bsc thesis, University of Manitoba, 44 pp.

Baschuk, M. S. 2010. Effects of water-level management on the abundance and habitat use of waterfowl and marsh birds in the Saskatchewan River Delta, Manitoba, Canada. MSc thesis, University of Manitoba, 241 pp.

Hille, K. A. 2008. Does aquaculture impact benthic algal ecology? A study on the effects of an experimental cage aquaculture operation on epilithic biofilms. MSc thesis, University of Manitoba, 338 pp.

Kolochuk, J. S. 2008. Landscape and land use impacts on farm pond water quality in the Portage Plains of south-central Manitoba. MSc thesis, University of Manitoba, 246 pp.

Atchison, S. 2008. Water quality on the Saskatchewan River, The Pas region, Manitoba: Potential influences on water quality from the Carrot River, Pasquia River, and outflow from the Tolko kraft paper mill. BSc thesis, University of Winnipeg, 34 pp.

Hnatiuk, S. D. 2006. Experimental manipulation of ponds to determine the impact of common carp (*Cyprinus carpio* L.) in Delta Marsh, Manitoba: effects on water quality, algae, and submersed vegetation. MSc thesis, University of Manitoba, 174 pp.

Jacobs, K. 2006. The effects of watershed characteristics and disturbance history on lake water quality of the boreal region of south eastern Manitoba. MSc thesis, University of Manitoba, 266 pp.

Parks, C. R. 2006. Experimental manipulation of connectivity and common carp: The effects of native fish, water-column invertebrates, and amphibians in Delta Marsh, Manitoba. MSc thesis, University of Manitoba, 184 pp.

Badiou, P. H. 2005. Ecological impacts of an exotic benthivorous fish in wetlands: A comparison between common carp (*Cyprinus carpio* L.) additions in large experimental wetlands and small mesocosms in Delta Marsh, Manitoba. PhD dissertation, University of Manitoba, 251 pp.

Friesen-Pankratz, B. 2004. Descriptive and experimental studies on the biotic and abiotic determinants of selected pesticide concentrations in prairie wetland water columns. PhD dissertation, University of Manitoba, 327 pp.

Leclair, C. 2004. The effects of varying densities of cattle on water quality of farm ponds on the Portage Plains. BSc thesis, University of Manitoba, 79 pp.

Macbeth, A. 2004. Investigation of an introduced subtropical alga (*Lyngbya wollei*) in Whiteshell Provincial Park, Manitoba. MSc thesis, University of Manitoba, 185 pp.

Brown, S. 2003. Land use practices in the vicinity of Delta Marsh as they may be affecting water quality. Master of Environmental Design (Environmental Science), University of Calgary, 248 pp.

Owens, C. 2003. Impact of land use practices on the water quality of southern Lake Manitoba and Delta Marsh. BSc thesis, Acadia University.

Kuharski, S. 2002. Potential effects of livestock on wetland water quality. BSc (Agric) thesis, University of Manitoba, 45 pp.

Macbeth, A. 2002. Paleolimnology of five lakes in Whiteshell Provincial Park. BSc thesis, University of Manitoba, 72 pp.

McDougal, R. L. 2001. Algal primary production in prairie wetlands: The effects of nutrients, irradiance, temperature and aquatic macrophytes. PhD dissertation, University of Manitoba, 285 pp.

Bourne, A. L. E. 2000. Factors influencing the abundance of sediment-associated algae in two isolated ponds and a turbid channel of Delta Marsh. MSc thesis, University of Manitoba, 152 pp.

North, A. D. K. 2000. Impacts of nutrients and insecticide on algal production in a prairie wetland. MSc thesis, University of Manitoba, 117 pp.

Weidman, P. 2000. Distribution of ultraviolet light effects on periphyton in the littoral zone of an oligotrophic boreal forest lake. BSc thesis, University of Manitoba, 54 pp.

Purcell, S. L. 1999. The significance of waterfowl feces as a source of nutrients to algae in a prairie wetland. MSc thesis, University of Manitoba, 118 pp.

Richmond, K.-A. 1997. The paleolimnology of Killarney Lake, Manitoba. MSc thesis, University of Manitoba.

McDougal, R. L. 1995. An analysis of historical trends of primary production in Crawford Lake, Manitoba using an intact sediment core. BSc undergraduate research project, Brandon University, 58 pp.

Henderson, T. A. 1995. A paleolimnological analysis of Max Lake, Manitoba. BSc thesis, Brandon University, 54 pp.

McDougal, R. L. 1995. Responses of a wetland ecosystem to “press” and “pulse” additions of nitrogen and phosphorus. BSc thesis, Brandon University.

Forster, M. J. 1993. Manipulation of invertebrate community size-structure and responses of periphyton biomass. BSc thesis, Brandon University, 65 pp.

Forster, M. J. 1991. Effect of periphyton architectural development on short-term hexazinone toxicity to freshwater periphyton. BSc undergraduate research project, Brandon University, 41 pp.

Referee

- Analytical: Standard Methods for the Examination of Water and Wastewater (18th edition onwards): Joint Task Group on Periphyton, Joint Task Group on Aquatic Rooted Plants
- Book: *Algal Ecology in Freshwater Benthic Ecosystems,* R. J. Stevenson, M. L. Bothwell and R. L. Lowe, eds., Academic Press
- Grants: Delta Waterfowl Foundation, Michigan Sea Grant College Program, Ontario Innovation Trust, Natural Sciences and Engineering Research Council of Canada (Research Grant Competition), United States National Science Foundation (Research Grant Competition), United States Geological Survey (North Central Region), South Florida Water Management District
- Journals: *Aquaculture, Aquatic Sciences, Archiv für Hydrobiologie, Archives of Environmental Contamination and Toxicology, Canadian Journal of Botany, Canadian Journal of Fisheries and Aquatic Sciences, Canadian Water Resources Journal, Diatom Research*, *Ecology, Écoscience*, *Environmental Pollution, International Review of Hydrobiology, Journal of Paleolimnology, Journal of Phycology, Journal of the American Water Resources Association, Vegetation Science, Wetlands*

- Personnel: United States Environmental Protection Agency (Staff Review Committee, 2000), Faculty of Graduate Studies (University of Regina)
- Regulatory: Canadian Water Quality Guidelines: Glyphosate, Simazine (Environment Canada)

Professional Affiliations

- International Society of Limnology
- Society of Wetland Scientists

Other Activities

- Chair, Manitoba Water Council (2014 - present)
- Chair of Canadian Chapter, Society of Wetland Scientists (2002 - 2005, 2014 - present)
- Member, International Red River Board (2003 - present)
- Member, Lake Manitoba Lake St. Martin Regulation Review Advisory Committee (2011 - 2013)
- Chair, Lake Manitoba Stewardship Board (2007 - 2012)
- Technical Advisor and Committee Member, Lake Manitoba Regulation Review Advisory Committee, Province of Manitoba (2001 - 2004)
- Member of Editorial Board, *Environmental Pollution*, Elsevier Publishing (1999 - 2001)
- Co-editor (with R. G.Wetzel), *SIL Periphyton Methods Manual* (1996 - 2004)
- Consultant, Manitoba Department of Environment (Water Quality Management) (1986 - 2001)
- Organizer, 12th North American Diatom Symposium, University Field Station (Delta Marsh), 23-25 September 1993
- Editor, Delta Marsh Field Station (University of Manitoba) Annual Reports (1989 - 1998)
- Member of the Board of Directors, Manitoba Model Forest Inc. (1994 - 1995, 1997 - 2002)
- Webmaster, International Association of Applied and Theoretical Limnology (www.limnology.org)
- Webmaster, Manitoba Historical Society (www.mhs.mb.ca)
- Member of the Board of Directors, Canadian Water Resources Association, Manitoba Chapter (1998 - 2001)
- Member, Lake Winnipeg Research Consortium Inc. (2001 - present)
- Member, Editorial Board of “Freshwater Systems” (2000 - 2003)
- Co-organizer, “Ecology of wetlands and shallow lakes: alternative stable states, anthropogenic influences, and management options” (Delta Marsh, 15-19 August 2001)
- President, Manitoba Historical Society (2004 - 2006)
- Selection Committee for the Lieutenant-Governor of Manitoba’s Greenwing Conservation Award (2005 - present)
- Program Committee, Canadian Heritage Rivers Conference, Winnipeg (2006)