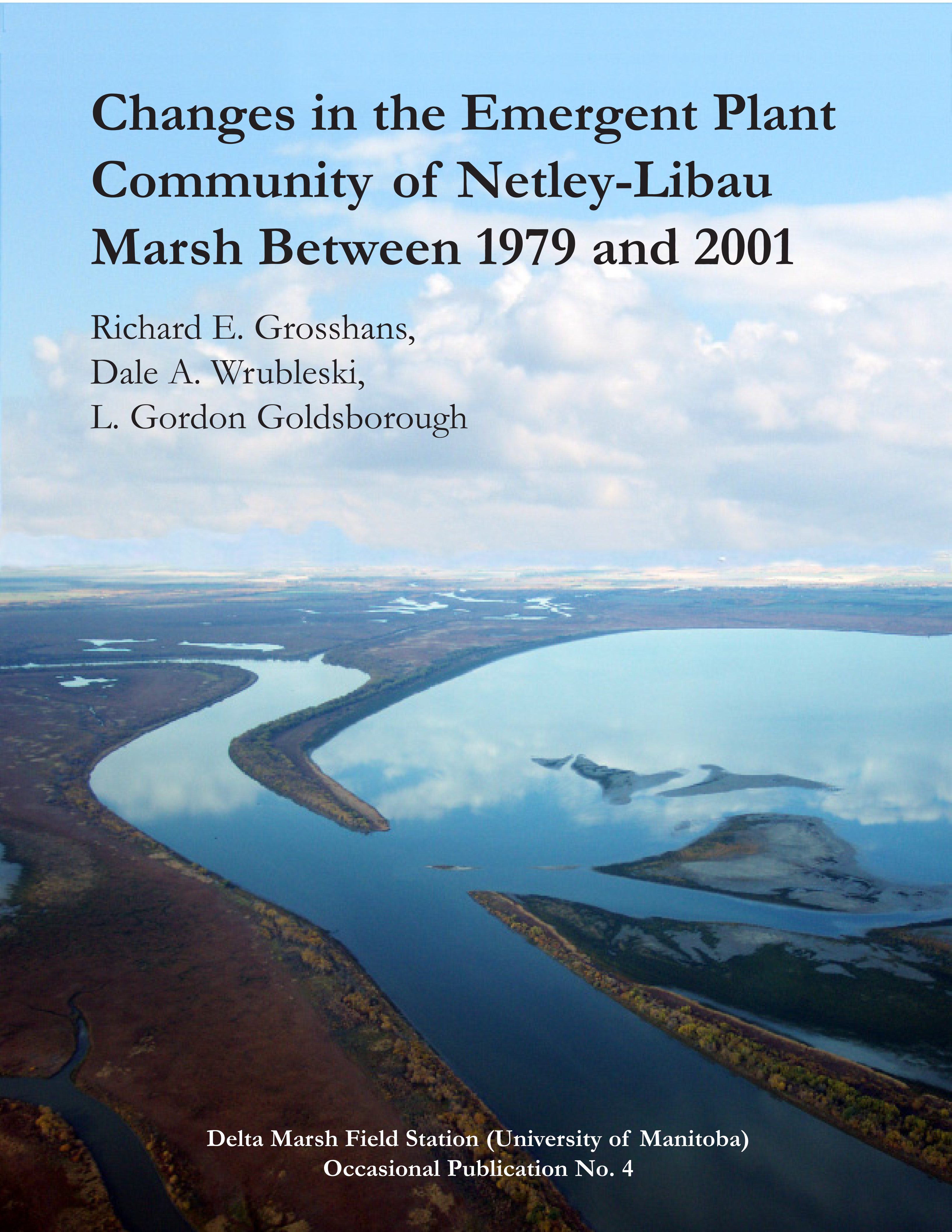

Changes in the Emergent Plant Community of Netley-Libau Marsh Between 1979 and 2001

Richard E. Grosshans,
Dale A. Wrubleski,
L. Gordon Goldsborough

Delta Marsh Field Station (University of Manitoba)
Occasional Publication No. 4

Delta Marsh Field Station (University of Manitoba)
Box 38, Rural Route 2
Portage la Prairie, MB, Canada R1N 3A2
Telephone: (204) 857-8637 Fax: (204) 857-4683
E-mail: delta_marsh@umanitoba.ca
Web: www.umanitoba.ca/delta_marsh

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The cover photo shows Netley Cut connecting the Red River and the southeast side of Netley Lake, 8 October 2003. Photo: Gordon Goldsborough.

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Changes in the Emergent Plant Community of Netley-Libau Marsh Between 1979 and 2001

by

Richard E. Grosshans
Institute for Wetland and Waterfowl Research,
Ducks Unlimited Canada, Stonewall, Manitoba, Canada

Dale A. Wrubleski
Institute for Wetland and Waterfowl Research,
Ducks Unlimited Canada, Stonewall, Manitoba, Canada

L. Gordon Goldsborough
Delta Marsh Field Station & Department of Botany,
University of Manitoba, Winnipeg, Manitoba, Canada

Delta Marsh Field Station (University of Manitoba)
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SUMMARY

We used aerial photography combined with field observations to develop a detailed aquatic vegetation map for Netley-Libau Marsh in south-central Manitoba. This report describes the creation of a new geographically accurate map (georeferenced for use in a Geographic Information System - GIS), based on aerial photos taken in 2001, and construction of a detailed vegetation map for evaluating the changing state of Netley-Libau Marsh. This provides a basis for comparison with a 1979 vegetation map enabling a quantitative assessment of changes in the marsh over a 22-year period.

Comparisons between 1979 and 2001 reveal several significant changes in Netley-Libau Marsh. Loss of emergent vegetation and the erosion of separating uplands between adjoining water bodies has been extensive, resulting in the amalgamation and expansion of many marsh bays and ponds. Currently, half of the entire marsh (13,125 ha, 51%) is open water, compared to 35% (8,884 ha) in 1979. Cattail (*Typha* spp.) continues to be the dominant emergent plant in the marsh, showing little change between surveys. However, hard- and soft-stem bulrush (*Schoenoplectus* spp.) have declined ten-fold in abundance, from 3,247 ha (13%) to 317 ha (1%). The mixed river bulrush and sedge community, along with the wet meadow communities, have also declined in abundance. Plant communities at drier sites, however, have remained relatively unchanged.

Reasons for the observed changes in the marsh are not well known or understood, but change is not a recent development. Maps of the marsh from the 1920s to the present show a pattern of increasing open water area and loss of upland and island habitats. These changes are likely related to a number of factors, but the influence of Lake Winnipeg and the Red River are likely the most important.

Lake Winnipeg dictates water levels within Netley-Libau Marsh. Since the droughts of the 1930s and 1940s, water levels on Lake Winnipeg and the marsh have included few intervening dry periods. Without extended dry periods, to periodically allow the germination of new emergent vegetation, there has been a slow but consistent loss of emergent vegetation in the marsh. As this vegetation is lost, the protection that it provides for the soft sediments that make up island and upland habitats is also lost, and these habitats are slowly being washed away. The current management of Lake Winnipeg for hydroelectric production works to prevent low water levels on the lake and the marsh.

The Red River passes through Netley-Libau Marsh and it has likely contributed to some of the observed changes. High flow events on the river result in the erosion and collapse of weak points in the levees that border the river and other channels. Netley Cut, which was originally dredged in 1913, has been gradually eroded to a point where it now carries a substantial portion of the Red River flow into Netley Lake. The end of dredging on the Red River in 1999 has also likely contributed to the alteration of Red River flows through the marsh. High nutrient loads in the Red River, along with the arrival of common carp, may be contributing to enhanced algal growth and loss of submersed vegetation within the marsh. Loss of submersed vegetation results in the destabilization of bottom sediments and increased wind-induced wave action, which further helps erode island and upland habitats.

Without an ability to manage marsh water levels independently of Lake Winnipeg, only a prolonged drought will help restore the emergent plant communities of Netley-Libau Marsh. Dry conditions experienced in 2003 helped re-establish some of the emergent plant communities of the marsh, but the recent return to wet conditions may make this reversal short-lived.

We conclude that Netley-Libau Marsh resembles a shallow turbid lake more than a healthy coastal wetland. Any benefits to Lake Winnipeg which the marsh could provide as wildlife and fisheries habitat, and in removing and storing nutrients that would otherwise enrich the lake, have probably been degraded or lost.

Keywords: Netley-Libau Marsh, Red River, Lake Winnipeg, coastal marsh, infrared aerial photography, vegetation mapping, emergent macrophytes, species composition, landscape change, Geographic Information System, wetland ecology, conceptual model.

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INTRODUCTION

Lakes Winnipeg, Manitoba, and Winnipegosis, often considered among the "Great Lakes" of North America, are important to the provincial economy of Manitoba in several respects. Collectively covering over 35,000 km^2 of the province, they provide habitat for valuable fish and wildlife populations, and areas for recreation and ecotourism. In addition, Lake Winnipeg is an important source of water for hydroelectric power generation.

Around the periphery of these lakes are extensive coastal wetlands, comprising some 1,710 km^2 (Mooney *et al.* 2003). These freshwater marshes are increasingly recognized as important for wildlife habitat, as well as for recreational activities, agriculture, local fisheries, flood protection, and in improving water quality through their natural filtering properties. Two of the largest marshes, Delta Marsh at the south end of Lake Manitoba, and Netley-Libau Marsh at the south end of Lake Winnipeg, are widely acknowledged as important wildlife and fisheries habitats (Janusz and O'Connor 1985, Wrubleski 1998, Batt 2000, Lindgren and The Netley Libau Marsh Foundation Inc. 2001), and have received provincial, national, and international recognition. However, these coastal wetlands are changing as a result of human impacts.

Whereas Delta Marsh has received attention recently (e.g., Shay *et al.* 1999; Goldsborough and Wrubleski 2001; Grosshans *et al.* 2005), the current condition of Netley-Libau Marsh is relatively unknown. Providing resources for early aboriginal people, and subsequently for European settlers, the Netley-Libau Marsh area developed into an important recreational and agricultural area during the 20th century. Present uses of the marsh include recreational activities such as hunting, fishing, boating, birdwatching, and ecotourism. The marsh is recognized internationally as a major habitat for nesting, staging, and molting waterfowl (Mowbray 1980), and was recently designated an Important Bird Area (IBA) by Bird Studies Canada and the Canadian Nature Federation through a program administered locally by the Manitoba Naturalists Society (Lindgren and The Netley Libau Marsh Foundation Inc. 2001). It is also a candidate for designation as a "Manitoba Heritage Marsh" by the provincial government.

Historically the bays and channels of the marsh were replete with aquatic plants providing habitat for fish, waterbirds, and mammals (Verbiwski 1986). However, amalgamation of water bodies, loss of aquatic plants and upland areas, and declining waterbird populations have been reported by local residents and other interested groups. As a first step towards determining the current condition of the marsh, a new emergent vegetation map was created in 2001 and compared with a similar map drawn in 1979 (Verbiwski 1980, 1986). The composition and distribution of emergent vegetation can be used to indicate wetland health. This report describes the current emergent vegetation community of Netley-Libau Marsh and provides a quantitative description of how the marsh has changed.

Netley-Libau Marsh

At approximately 26,000 ha, Netley-Libau Marsh is one of the largest freshwater coastal wetlands in Canada. It lies along the south shore of Lake Winnipeg (Figure 1) and is separated from the lake by a narrow sand ridge (also referred to as barrier islands by Nielsen and Conley 1994). The marsh consists of a complex of shallow lakes, lagoons, and channels through which the Red River flows on its way to the lake. Soils within flooded and waterlogged areas of the marsh are poorly drained organic muck overlying a high content of silt and clay ranging in texture from sandy loam to silty clay. These, in turn, overlay glacial deposits, as well as shale and limestone of Ordovician age (Moulding 1979). More detailed descriptions of the marsh can be found in Mowbray (1980) and Verbiwski (1986).

Marsh water levels are influenced locally by tributary flows and on a broader scale by water levels of Lake Winnipeg. Long-term water levels are the same on the lake and marsh, while short-term fluctuations due to wind set-up can be substantial (Einarsson and Lowe 1968, Moulding 1979). For example, water level increases due to wind set-up can exceed 1 m, but are on average less than 30 cm. Because Netley-Libau Marsh is fairly flat and shallow, large expanses of mudflats stretching for hundreds of metres are not an uncommon sight, occurring when strong south winds push lake and marsh water to the north.

Figure 1. Netley-Libau Marsh, Manitoba, at the southern extent of Lake Winnipeg, where the Red River empties into the lake.

Lake Winnipeg water levels fluctuate due to long-term water level changes, seasonally due to spring runoff and Manitoba Hydro's water requirements, and almost daily because of wind set-ups (Figure 2). Since 1975, water levels of Lake Winnipeg have been regulated for hydroelectric power generation, maintaining lake water levels between 711 ft (216.7 m) and 715 ft (217.9 m) above sea level, a narrower range (4 ft, 1.2m) than had occurred historically, which was 8.8 ft [2.7 m; recorded high of 718.2 ft (218.9 m) in July of 1974, and a recorded low of 709.4 ft (216.2 m) in December of 1940, see also Figure 2]. Because of its connection with the lake, water levels of Netley-Libau Marsh have been regulated as well.

Previous Vegetation Studies of Netley-Libau Marsh

Hinks (1936) provided the earliest known description of the vegetation of Netley-Libau Marsh during the drought of the 1930s. He found 30 emergent plant species, with dominant emergents being softstem bulrush, cattail, awned sedge, and giant reed grass (see Appendix 4 for a list of plant species names, scientific and common). In 1944, while investigating the impact of common carp on the marsh, McLeod and Moir (1944) reported that the dominant plant was giant reed grass, with some sparse and patchily distributed cattail present. Bulrush was also fairly abundant during this time.

In 1979, the Manitoba Department of Natural Resources began an intensive investigation of all aspects of Netley-Libau Marsh, preparing a comprehensive wetland development and management plan (Verbiwski 1986). As part of this study, the emergent plant community was photographed and mapped using aerial colour-infrared photography. Nine major plant communities were broadly defined and listed in order of decreasing relative abundance: cattail, bulrush, agriculture, sedge, river bulrush, giant reed grass, uplands, trees, and willows (Verbiwski 1986). At about the same time, Hathout and Simpson (1982) used the west side of Netley-Libau Marsh to compare the effectiveness of colour and infrared films for delineating emergent and submersed plant communities. More recently, Ruta *et al.* (1999) described the vegetation communities in the Libau PFRA community pasture. They found that wet meadow and low prairie areas were dominated by reed canary grass and awned sedge.

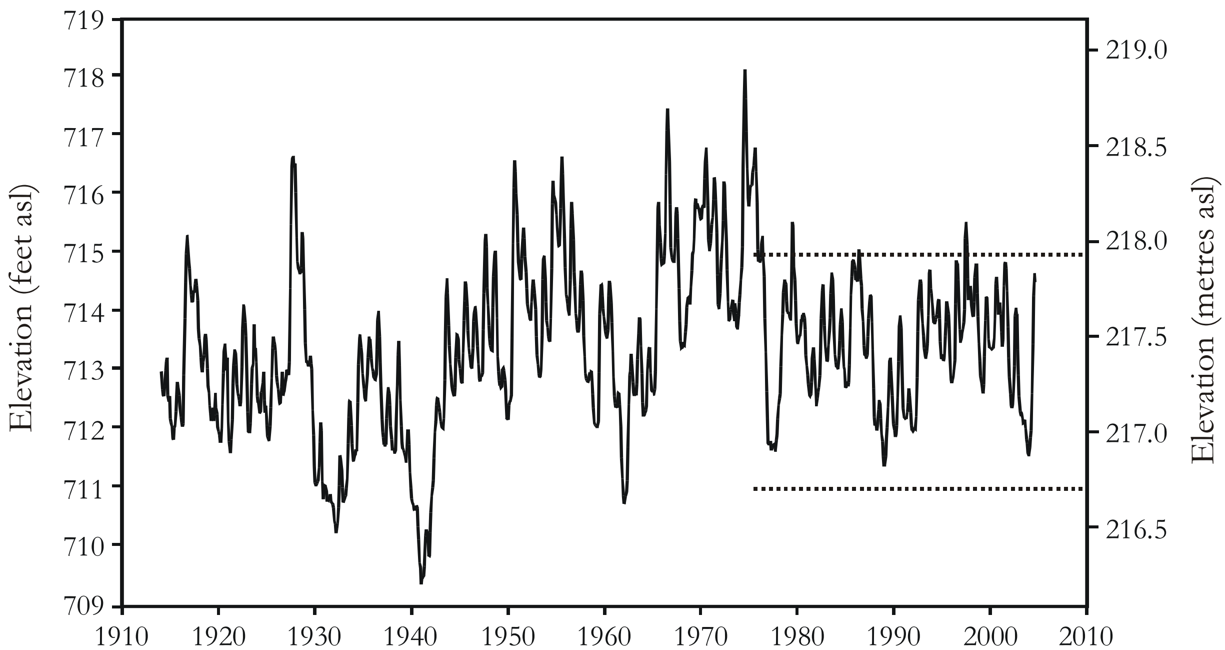

Figure 2. Monthly mean water levels for Lake Winnipeg, January 1914 to August 2004. Values are the mean of seven gauging stations around the lake, intended to eliminate the local effects of wind and therefore give a better estimate of overall lake level. Since 1975, water levels have been managed within the range of 711 ft (216.7 m) and 715 ft (217.9 m), as indicated by horizontal dashed lines. Data provided by Manitoba Hydro.

METHODS

Aerial Photography and Field Methods – 2001 Map

Netley-Libau Marsh was photographed as a mosaic of 106 colour infrared aerial photographs on 3 August 2001, when plant growth and biomass were near full development. Photographs were taken at an altitude of 1,920 m and produced at a scale of 1:10,000. All photography was done with a Wild RC-30 15/4 UAG-S large format camera. Film used was Kodak Aerochrome III IR film type 1443. Infrared film was used to map the distribution of individual emergent plant species or assemblages based on their differential reflection of infrared light, that appears in the final image as shades of red.

Colour photocopies were produced of all aerial photographs and placed in plastic sheet protectors for use in the field. Vegetation zones and boundaries were identified on aerial photographs by ground verification. Plant species composition, diversity and density, as well as neighbouring plant communities were all noted in the field to aid in vegetation zone classification. An interpretive key of vegetation infrared signatures for colour infrared aerial photographs was used from Grosshans (2002), determined primarily by colour, texture, shadow, and general appearance (Table 1). This key was used in conjunction with the aerial photos to identify vegetation boundaries, and create the digital vegetation cover map.

Digital Mapping – 2001 Map

All 2001 aerial photographs were scanned at 300 dpi using a Canon flatbed colour copier/scanner. A Trimble Pathfinder Basic Global Positioning System (GPS) receiver was used in the field to collect ground control points (Universal Transverse Mercator Zone 14, North American Datum 83) of visible landmarks on the aerial photographs to aid in georeferencing scanned images. Each image was georeferenced using a combination of the collected GPS data and existing GPS data from digital orthophotographs based on aerial photography acquired in August 1991 (Linnet Geomatics Inc. 2001). Images were geometrically corrected using ERDAS Imagine 8.5, and used in ESRI ArcView 3.2 GIS software with the "IMAGINE image support" extension. A final TIFF image of the photomosaic was created and seams between photographs were blended using Adobe Photoshop 5.5 to produce a large format seamless color photograph of the entire marsh (Figure 3).

The 2001 digital vegetation map was based on this mosaic of georeferenced colour infrared photographs. All digital mapping was done in ArcView. Vegetation areas were created by on-screen digitizing in a polygon theme and colour coded with a unique value-legend type approach based on vegetation cover type. This approach was adopted due to sublety in the distinction of discrete plant assemblages (Table 1). The final vegetation polygon theme was checked for errors using the "CLU Quality Control" ArcView extension (Heald 1999). The map printouts were created in ArcView Layout.

Vegetation Classification – 2001 Map

The vegetation of Netley-Libau Marsh was categorized into five zones: non-vegetated, emergent vegetation (permanently-seasonally flooded), wet meadow (seasonally-temporarily flooded), low prairie (temporary-no flooding) and upland (no flooding), distinguished by water depth (surface water or depth to water-table) and plant community composition (Appendix 2). Emergent zones are permanently to seasonally flooded, generally having standing water throughout most, if not all, of the growing season. Plant species found in this zone are also found in waterlogged organic soils above the water table. Wet meadows are characterized by flooding for a few weeks in the spring, with 0 to 0.3 m of surface water persisting until mid-summer. Soil water usually remains within the rooting zone throughout the growing season. Low prairies experience temporary to no flooding, with standing water to saturated soil conditions in the early spring, with most of the standing water lost rapidly to seepage and evapotranspiration. Soil moisture within these areas varies throughout the growing season. Uplands generally experience little flooding. Surface water is present only during spring snowmelt and heavy rains, and is rapidly lost to seepage and evapotranspiration.

For the 2001 map, these five vegetation zones were further separated into vegetation classes represented by one or more dominant species or distinct species associations. Generally, vegetation

Figure 3. Netley-Libau Marsh 2001 colour infrared photomosaic, based on a compilation of 106 1:10,000 colour infrared aerial photos acquired on 3 August 2001.

classes are dominated by one species, although usually composed of several species. Descriptions of dominant and characteristic plant species found within each zone are found in Appendix 2.

1. Non-vegetated (little to no emergent macrophytes)
    - 1A. Open water
    - 1B. Sand (beaches, exposed sand)
    - 1C. Mudflat
2. Emergent Vegetation (permanently-seasonally flooded)
    - 2A. Bulrush (*Schoenoplectus* spp.)
    - 2B. Bulrush, Sedge, *Acorus*
    - 2C. Cattail (*Typha* spp.)
    - 2D. Giant reed grass (*Phragmites australis*)
    - 2E. Dead material
3. Wet meadow (seasonally-temporarily flooded)
    - 3A. Awned sedge (*Carex* spp.)
    - 3B. Sedges and rushes (*Carex, Beckmania, Eleocharis*)
    - 3C. Reed canary grass (*Phalaris arundinacea*)
    - 3D. Whitetop (*Scolochloa festucacea*)
    - 3E. Willow (*Salix* spp.)
    - 3F. Giant reed grass and Willow
    - 3G. Salt flats (*Hordeum, Puccinellia*)
4. Low prairie (temporary-no flooding)
    - 4A. Grasses (*Elymus, Bromus, Poa*) (>75% grass cover)
    - 4B. Grasses and forbs (<50% forb cover)
    - 4C. Prairie (>50% forb cover)
5. Upland (temporary-no flooding)
    - 5A. Hayed grasses and forbs
    - 5B. Grazed
    - 5C. Treed prairies
    - 5D. Trees (tree and shrub cover)
    - 5E. Cultivated

Digital Mapping – 1979 Paper Maps

Existing emergent vegetation maps created from aerial photographs of Netley-Libau Marsh in 1979 (Verbiwski 1980, 1986) were scanned on a large-format drum scanner at 300 dpi to create digital images. These images were geometrically corrected using ERDAS Imagine 8.5. Ground control points used to digitize these images were collected from quarter section grid locations identified on the digital images from provincial orthophotographs. The final georeferenced image of the 1979 vegetation map was imported to Arcview GIS 3.2, and a digital vegetation map was redrawn following the procedures used to create the 2001 map.

Map Comparisons – 1979 vs. 2001

Aerial photography and vegetation mapping in 2001 covered a larger area than that presented for 1979. The area covered in the 1979 map is bordered primarily by municipal roads, dikes, and the Brokenhead River to the northeast (approximately 25,773 ha). To properly report changes in the plant communities from 1979 to 2001, maps were simplified to a common vegetation classification, and clipped to an identical area of coverage based on that selected in 1979. Area estimates for the emergent plant communities for 1979 presented in this report are from the new digitized map, and are different from those reported in Verbiwski (1986: Table 2). These discrepancies probably result from procedural differences between this report and those used in the 1986 report. The complete 2001 vegetation map (approximately 34,480 ha) and vegetation area estimates are presented in Appendix 3.

Table 1. Interpretation key of vegetation signatures for colour infrared aerial photographs modified from Grosshans *et al.* (2005).

Vegetation Zone	Colour	Texture	Location/Comments
Open water	Blue/black White to green/white	Smooth, rippled in some areas from wave action	Very dark and distinct Shallow water or reflections off water will often appear white to green/white
Sand (beaches, exposed)	White, usually quite bright	Smooth, flat appearance	Mostly devoid of vegetation, so appears bright white
Mudflat	White to blue/white, to greeny black	Navy/greeny black and white patches	Found bordering water, disturbed areas
Bulrush *(Schoenoplectus)*	Dark deep red, brick red to dark navy, to browny red	Blurry appearance and patchy; open water patches due to sparseness	Found in water, along water's edge, or deeper water areas; sparse patches appear as shadowed areas on open water
Cattail *(Typha)*	Medium to deep red	Smooth to grainy; pock marked appearance from open water, and inter-mixed patches of deadfall	Found mainly bordering open water to low water-filled areas; also borders whitetop, giant reed grass as well as sedges/ rushes
Giant reed grass *(Phragmites)*	Pink to dark pink	Grainy to lumpy, shadows along edges gives depth to these patches appearing almost three-dimensional on photos, and much higher than surrounding areas with stereoscopes	Found bordering water, upland areas, cattail and whitetop; often a thin ring of cattail between giant reeds and water; also borders sedges and rushes, grasses, grasses with forbs.
Sedges and rushes *(Carex, Eleocharis, Juncus)*	Dark red to dark pink	Appears flatter on photos, does not have three-dimensional appearance as cattail does; with stereoscope appears flat	Usually occurs around/near whitetop areas, as well as cattail and fen grasses; also borders reed canary grass, grasses, and forbs; found in wet, waterlogged areas
Whitetop *(Scolochloa festucacea)*	White, to pale/light pink to green (shallow water)	Fine mottled appearance, white or green patches from open water areas	Often found bordering cattail, wet meadows, and giant reed patches; also borders fen grasses, sedges/rushes, and grasses

Table 1. Continued

Willows	Burgundy, maroon to dark red	Lumpy, gravelly, dotted patches	Uplands, dikes, along river channels; borders and surrounds sedge patches
Reed canary grass	Dark pink to browny red, a darker pink than Whitetop	Grainy lumpy appearance, to smooth	Usually occurs between whitetop and grasses/forb areas; also occurs next to cattail and giant reed; is a wet meadow grass, found where soils are moist to wet
Salt flat species *(Hordeum, Puccinellia)*	Cream, brown to browny red	Flat smooth texture, low flat appearance with use of stereoscopes	Occurs all over, but usually associated with mudflats, white-top, sedges/rushes and fen grasses; occurs in grass/forb areas as well
Grasses (> 75% cover)	Light pink, light brown, to cream	Flat smooth texture, often more light pink to cream and not as patchy as Grasses/forbs	Low prairie areas found bordering wet meadows of whitetop, reed canary grass and sedges/rushes; slightly moister areas than grass/forbs
Grasses and forbs (< 50% forb cover)	Pink, light brown, gray and cream	Flat smooth texture, often patchy and mixed light pink, brown, gray to cream	Low prairie areas near wet meadows of whitetop, fen grasses and sedges/rushes; transition to upland areas of prairie grasses; presence of forbs cause mixed patches of browns and grays
Prairie (> 50% forb cover)	Medium pink to dark pink	Smooth to grainy	Upland areas, borders grasses and forbs, woodlands, cultivated fields and hayfields
Hayed grasses and forbs	White light green, to light pink	Lined, pinstriped, and patchy; can see haybales as large dots if already cut; hayed, fallen dead grasses and forbs appear white to light green	Low prairie areas which are hayed; often intermixed with grasses/forbs, as well as prairie; borders wet meadows and low prairie areas alike; many sedge/rush meadows are hayed as well
Grazed (prairie and shrubs)	Dark pink, cream, brown and gray	Smooth texture, patchy mixed dark pink, cream, brown and gray	Occur near and intermixed with woodlands while bordering cultivated areas and hayfields; patchy cream colors and browns from grazing

Tabled 1. Continued

Cultivated	White, yellow, brown, gray, beige, yellow-green, red to pink; quite variable	Lined, pinstriped, patchy or smooth to grainy; can see rows of crops	Human disturbance is very distinct; found upland on higher ground
Trees (trees and shrubs)	Burgundy, maroon to dark red	Lumpy, patchy, gravelly with shadows; cauliflower appearance; tall, three-dimensional appearance with stereoscope	High upland areas, borders next to prairie, grass/forbs, and cultivated fields; willow bluffs appear as smaller, lumpy, dotted areas surrounding small cattail and fen grass marshes
Disturbed	Browny-gray, gray to white; light green	Smooth to grainy appearance; freshly disturbed bare soils and deadfall appear white to light green	Disturbed areas very distinct; usually found in grass/forb areas, or near trees

RESULTS

Emergent Vegetation Zones of Netley-Libau Marsh - 2001

Dense communities of giant reed grass, willows, and mixed trees (Appendix 2) dominated the higher riverbanks or levees bordering the Red River and its major creeks and channels (Figure 5). Along the south shore of Lake Winnipeg, a heavily wooded beach ridge bordered by willows and giant reed grass formed the northern boundary of Netley-Libau Marsh and separated the marsh from the lake. From these mixed reed grass and willow communities of the river levees and beach ridge, the vegetation community progressed through sedge meadows to dense communities of cattail and bulrush toward open water. In the areas away from the lake and river, the typical vegetation sequence within Netley-Libau Marsh followed a decreasing moisture gradient. Vegetation began its progression from open water (often too deep for emergents) with submersed aquatics (e.g., sago pondweed, *Stuckenia pectinatus*). Bordering these areas were the emergent macrophytes cattail, bulrush, and mixed patches of coarse emergents including hard- and soft-stem bulrush, the three-sided river bulrush, sweet flag, and awned sedge, as well as cattail in lower abundances. Wet meadows, dominated primarily by awned sedge, reed canary grass and willows, fringed the emergent zones at seasonally flooded elevations where soils remained waterlogged throughout the growing season. Low prairie grasses composed of mixed communities of low herbaceous grasses and forbs continued the transition from wet meadows to uplands, with increased proportions of upland forbs as moisture levels decreased up the elevation gradient. These meadows progressed from moist soil grasses and forb meadows (<50% forb cover), up to prairies (>50% forb cover), treed prairies and trees at the furthest edges of the marsh before reaching cultivated fields.

Community Composition and Abundance

In 2001, half of the entire Netley-Libau Marsh (13,125 ha, 51%) was open water (Table 2), consisting of interconnected shallow bays and channels. Intermixed throughout this open water was a mosaic of emergent plant communities. The dominant emergent species within Netley-Libau Marsh were cattail, giant reed grass, awned sedge, reed canary grass, willow, and bulrush, forming large continuous monodominant vegetation zones and mixed vegetation patches. Of the total 25,773 ha of the marsh, cattail was by far the most abundant plant species at 4,620 ha, or 18% of the marsh area (Table 2). The next most abundant was the wet meadow community of sedges, rushes, and reeds, covering 2,071 ha or 8% of the marsh. Next were the treed areas, which covered 1,791 ha or 7% of the marsh area. Agricultural areas were next, covering 1,630 ha or 6% of the marsh (Table 2).

1979 vs. 2001

When comparing the 2001 vegetation community (Figure 5) with that present in 1979 (Figure 4), it is apparent that a significant amount of emergent vegetation has been lost from Netley-Libau Marsh. The most noticeable physical change in the marsh has been the increase in open water, from 35% (8,884 ha) in 1979 to 51% (13,125 ha) of the marsh in 2001 (Table 2). Ponds and bays throughout the marsh have increased dramatically in size since 1979. Erosion of separating uplands and loss of emergent vegetation between adjoining water bodies since 1979 has been extensive, resulting in the amalgamation of many marsh bays. This has been particularly apparent in the Netley Lake area (Figures 4, 5).

Cattail accounted for almost 20% of the marsh area in 1979 (4,987 ha), and in 2001 continued to be the dominant plant species with over 18% of the marsh area (4,620 ha) (Table 2). The plant species impacted the most since 1979 have been hard- and soft-stem bulrush, decreasing ten-fold in abundance from 3,247 ha (13%) to 317 ha (1%). Other plant communities that have changed over time include mixed river bulrush and sedge, and mixed wet meadow communities, decreasing from 922 and 2,326 ha, to 166 and 2,071 ha, respectively. However, plant communities at drier sites, such as giant reed grass, low prairies, and uplands, have essentially remained unchanged (Table 2).

Table 2. Netley-Libau Marsh plant communities in 1979 and 2001.

		1979		2001	
Marsh Zone	Vegetation Class	Area (ha)	% Cover	Area (ha)	% Cover
Open water	open water	8,884	34.5	13,125	50.9
Emergent		9,807	38.0	5,835	22.6
	bulrush	3,247	12.6	317	1.2
	river bulrush, sedge, *Acorus*	922	3.6	166	0.6
	cattail	4,987	19.3	4,620	17.9
	giant reed grass	650	2.5	732	2.8
Wet meadow		2,682	10.4	2,482	9.6
	sedges, rushes, reed grasses	2,326	9.0	2,071	8.0
	willow	356	1.4	411	1.6
Low prairie	grasses, forbs	913	3.5	910	3.5
Upland		3,489	13.5	3,422	13.3
	trees	1,149	4.5	1,791	6.9
	agriculture	2,340	9.1	1,630	6.3
Totals		25,774	100.0	25,773	100.0

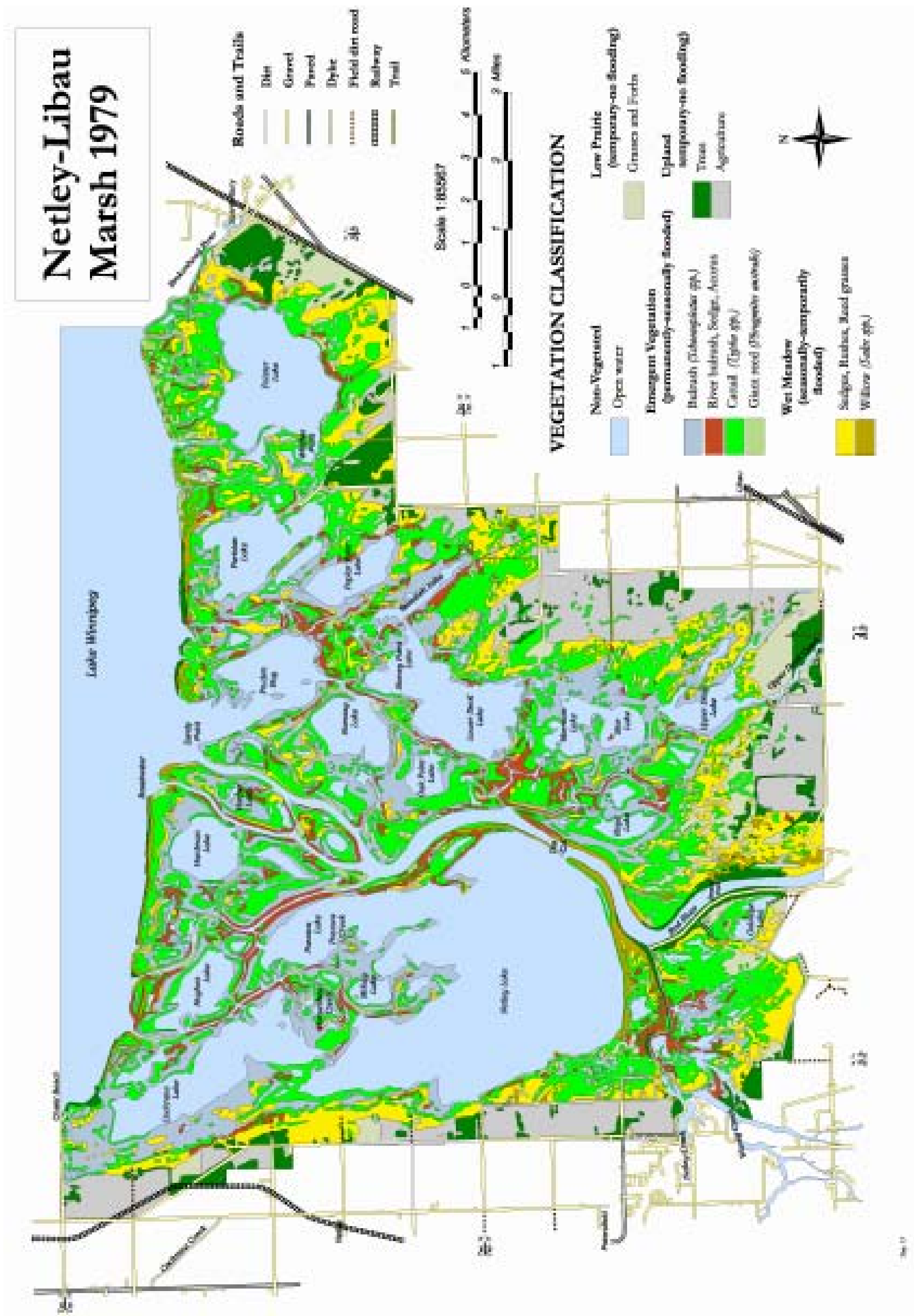

Figure 4. Netley-Libau Marsh, 1979. This vegetation map is based on a region selected in 1979 bordered primarily by municipal roads, dikes, and the Brokenhead River to the northeast (25,773 ha). The map was based on a previous black-and-white paper vegetation map created in 1979 from 1:10,000 color infrared aerial photographs and ground observations (Verbiwski 1986).

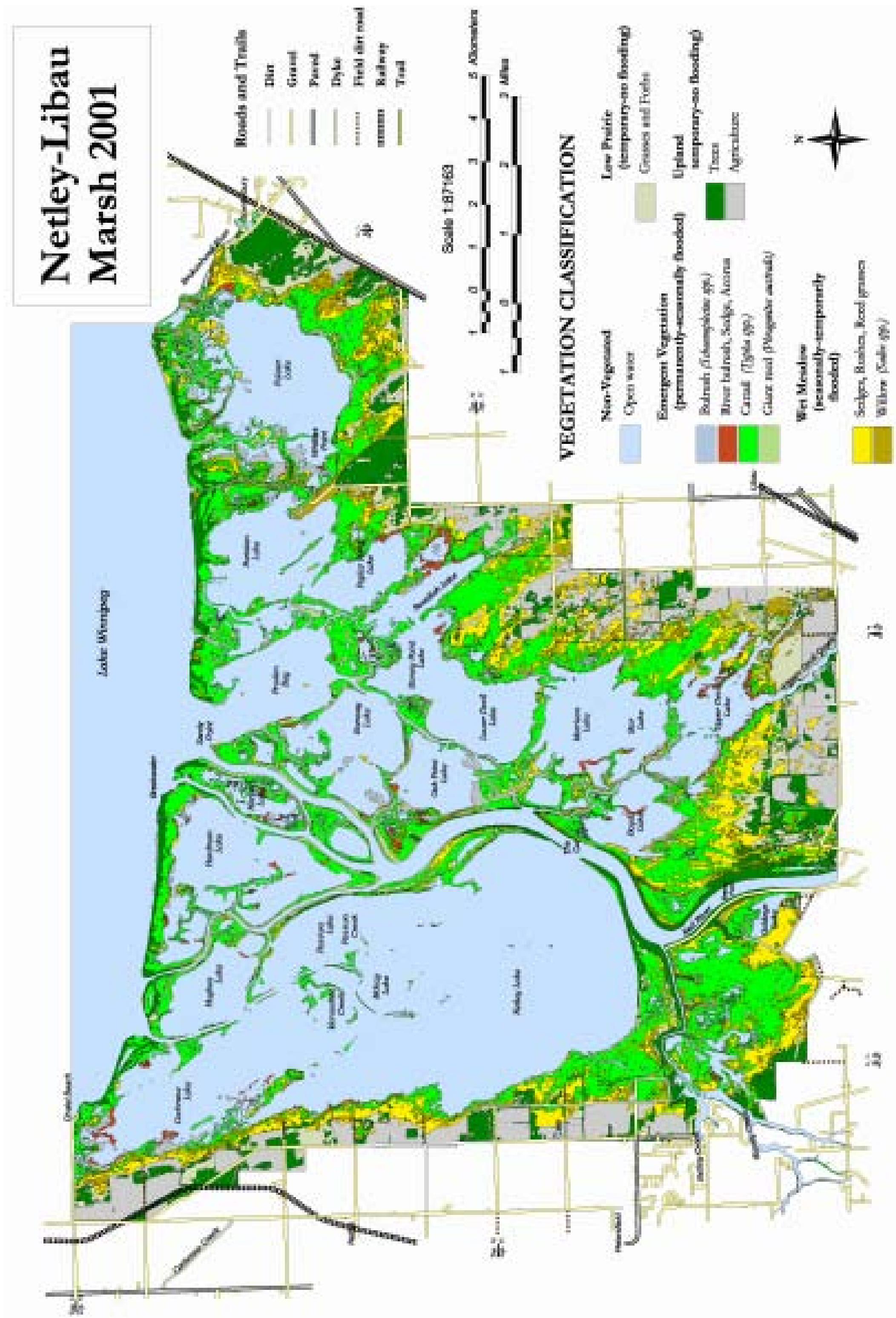

Figure 5. Netley-Libau Marsh, 2001. For the purposes of comparison this 2001 vegetation map is simplified to a common legend with the 1979 vegetation map (Figure 4). Both maps are based on a region selected in 1979 bordered primarily by municipal roads, dikes and the Brokenhead River to the northeast (25,773 ha). The map was based on 1:10,000 color infrared aerial photographs (photography on 3 August 2001) and ground observations. See Appendix 3 for the complete area mapped in 2001 (34,480 ha) with area estimates.

DISCUSSION

Current Vegetation Community

At present, cattail, giant reed grass, awned sedge, reed canary grass, willow and bulrush are the dominant emergent species within Netley-Libau Marsh. These six dominant species and their associated understory flora form distinct zonation patterns following a water depth gradient. These zones are often dense monodominant stands with thick accumulations of fallen and standing litter. The predominant vegetation throughout the marsh is cattail, a well-known competitive invasive plant across its North American range, often dominating wherever standing water persists (Stewart and Kantrud 1971, Beule 1979, Ball 1990, Sojda and Solberg 1993, Solberg and Higgins 1993). Nevertheless, areas of high plant species diversity remain in Netley-Libau Marsh. Mixed communities of bulrush, river bulrush, awned sedge, and sweet flag can be found at the northern end of Netley, Oak Point, Ramsay, and Boyd Lakes, as well as within Folster Lake to the east (Figure 5). Folster Lake, on the east side of the marsh, is by far the most floristically diverse area of the marsh. Its partial isolation from influence by the Red River and Lake Winnipeg may be permitting a more diverse vegetation community to survive. Dominant plants included bulrushes, river bulrush, awned sedge, sweet flag, and cattail.

1979 vs. 2001

In general, the plant communities were similar between the two surveys, although some dominant communities in 1979 were no longer present in 2001. River bulrush was once a dominant species in 1979 forming large monodominant patches throughout the marsh (Verbiwski 1986). In 2001, it was no longer as monodominant patches but rather present in mixed communities with soft- and hard-stem bulrush, awned sedge, and sweet flag. However, the abundance of river bulrush appears to fluctuate often in Netley-Libau Marsh. Verbiwski (1986) noted that in only one year, pure stands of river bulrush in 1979 had been replaced by a sedge-upland community by 1980. Low water levels in 1980 were implicated for the change. McLeod (1976) reported that river bulrush was one of the most dominant emergents in the marsh between 1944 and 1952, whereas Hinks (1936) did not mention its presence in the marsh during the 1930s.

Other plant communities that were not present in 1979 formed dominant communities in 2001. Reed canary grass, an introduced species which was not considered a problem in 1979, now occurs as dense monodominant stands throughout the marsh. A recent vegetation study conducted in the Libau PFRA Community Pasture (Ruta *et al.* 1999) also indicated reed canary grass to be a major dominant of wet meadow habitats, forming large homogenous stands and creating its own dominant zone. Other dominants were awned sedge, blue grass and alsike clover. Ruta *et al.* (1999) also indicated purple loosestrife was prevalent, as did Verbiwski (1986) in 1979. In 2001, it was prevalent in wet meadow and low prairie habitats throughout Netley-Libau Marsh, although it could not be distinguished from other grass and forb communities on the colour infrared photographs. Hinks (1936) reported no purple loosestrife in Netley-Libau Marsh in the 1930s. Lindgren and The Netley Libau Marsh Foundation Inc. (2001) indicated that purple loosestrife likely entered the marsh in the late 1940s to early 1950s. Beetle releases for biocontrol during the last five years have proven reasonably effective at controlling the spread of purple loosestrife (Lindgren 2000).

Since the marsh was mapped in 1979, several significant changes have occurred. The most apparent has been a loss of uplands and islands, resulting in an increase in open water area. For example, in the center of Netley Lake, there were several named ponds and channels existing in 1979 (Figure 4). In 2001, the open water proportion of this area increased drastically with only a few scattered island remnants remaining (Figure 5). The Salamonia Channel, once a prominent local landmark, has been breached in numerous places and is mostly gone. McKay and Passwa Lakes have merged into Netley Lake, along with Hughes and Cochrane Lakes at the north end. East of the Red River, Boyd and Swedish Lakes have expanded since 1979. Morrison and Star Lakes have expanded to become one large open-water body (Figures 4, 5).

Table 3. Changes in shoreline length and area within Netley-Libau Marsh, determined by analysis of aerial photographs from three different years (Unies Ltd. 1972).

		Year of Photography		
		1946	1963	1970
Shoreline length (km)	marsh	512	456	418
	channel	164	185	158
Marsh area (ha)	beach ridge	485	463	268
	natural levee	621	486	403
	marsh	9,070	9,514	5,592
	lagoon	10,030	9,191	13,540
	cultural	14,129	14,505	13,295

The differences in the marsh between 1979 and 2001 appear to reflect long-term trends rather than short-term annual variation. It could be argued that observed differences result from a high-water year in which uplands are submersed compared to a low-water year when they are exposed. However, the difference in mean lake level during the eight months preceding August of 1979 and 2001 was small (714.55 and 714.20 feet, respectively), as was the three-year cumulative mean level preceding each mapping year (713.12 and 713.75 feet, respectively). Therefore, we see no evidence that the inundation history immediately prior to the two study years could be a basis for observed differences.

Reasons for Change in Netley-Libau Marsh

Coastal wetlands are dynamic habitats, constantly changing and responding to a wide range of environmental and anthropogenic influences. Netley-Libau Marsh is no different and has seen significant change over the past 22 years. Of concern, however, is the underlying cause of this change. Loss of emergent vegetation, along with uplands and islands, reduces the habitat value of Netley-Libau Marsh for fish and wildlife, and in turn, its economic importance. If the underlying causes can be determined, then actions can be taken to help reverse them.

Although Netley-Libau Marsh has seen significant change in the past 22 years, this is not a recent development. A series of maps from 1922 to the present (Figures 6 to 10) reveal a loss of island and upland habitats over the past 80 years, a trend that is supported by two earlier studies. Mowbray (1980) noted that, prior to 1960, approximately 50 individual water bodies collectively represented Netley-Libau Marsh. These bays and ponds were mostly closed; that is, they were not influenced directly by Lake Winnipeg water levels. By 1980, the number of distinct water bodies had decreased to 17. Upland areas and levees had been eroded allowing greater wind set-up and water movement within the marsh, contributing to increased turbidity and erosion of peripheral shorelines. A report by Unies Ltd. (1972) used aerial photography from 1946, 1963, and 1970 to document a significant loss of upland area and shoreline length during intervening years (Table 3).

Ultimately, the loss of upland, island and levee habitats within Netley-Libau Marsh can be linked to changes in the marsh plant community. The sediments that make up islands and levees are fine grained, offering little resistance to wind and wave action (Unies Ltd. 1972). Persistence of these habitats is dependent on shoreline stability which, in turn, is dependent upon protection by aquatic vegetation and their roots. Factors that inhibit or destroy healthy shoreline plant growth ultimately contribute to shoreline erosion and the subsequent reduction in area of island and upland habitats and concurrent increase in open water area (Unies Ltd. 1972). There are potentially many natural and anthropogenic factors that, individually or in combination, may be responsible for the loss of emergent vegetation (Figure 11).

This study was intended to map the changes in marsh vegetation occurring in Netley-Libau Marsh but not to critically evaluate the factors contributing

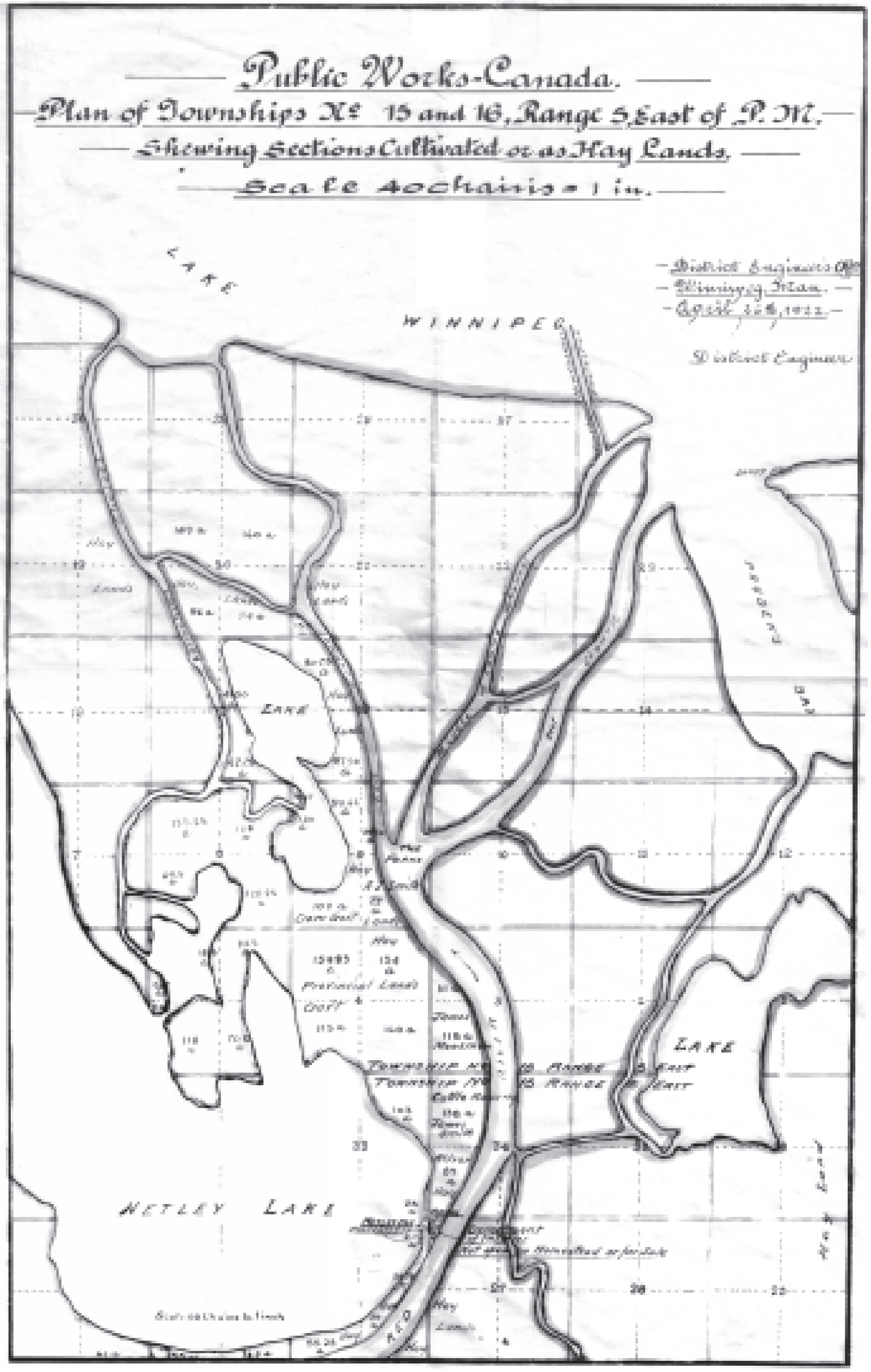

Figure 6. Netley-Libau Marsh, 1922, showing Netley Cut at the southeastern shore of Netley Lake, and the extensive area of hayland north of it. The dredged cut near "34", to the creek leading to Devil's Lake (labeled "Lake" in the lower right side of this map) is also visible. Source: Library and Archives Canada (Winnipeg), Accession W84-85/493 Box 26 Netley.

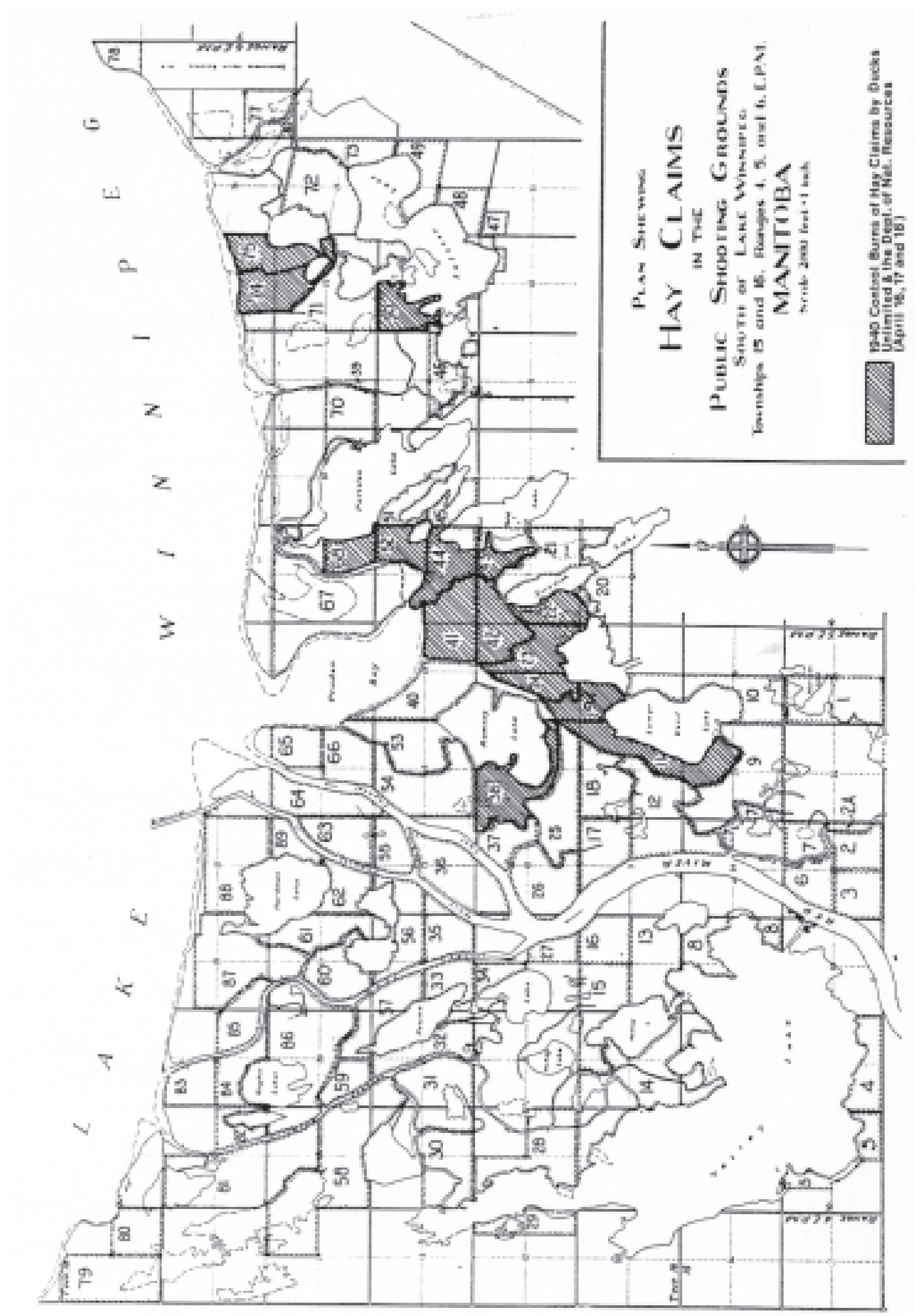

Figure 7. Netley-Libau Marsh, 1936 showing controlled burns of hay claims in the public shooting grounds south of Lake Winnipeg. Source: Verbiwski 1986, Figure 7.

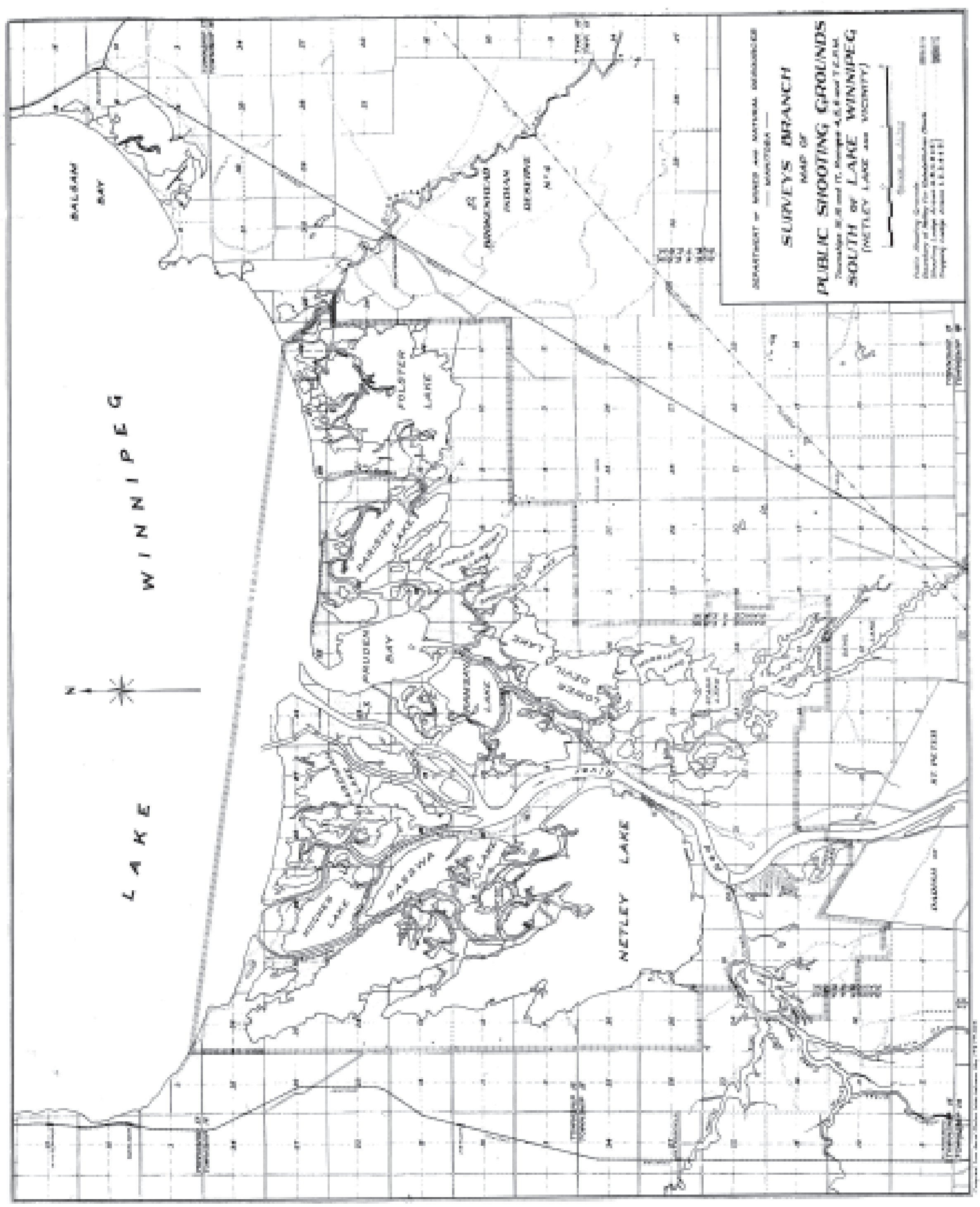

Figure 8. Netley-Libau Marsh, 1946 showing the public shooting grounds south of Lake Winnipeg. Source: Unpublished map of the Manitoba Department of Mines and Natural Resources, March 1951.

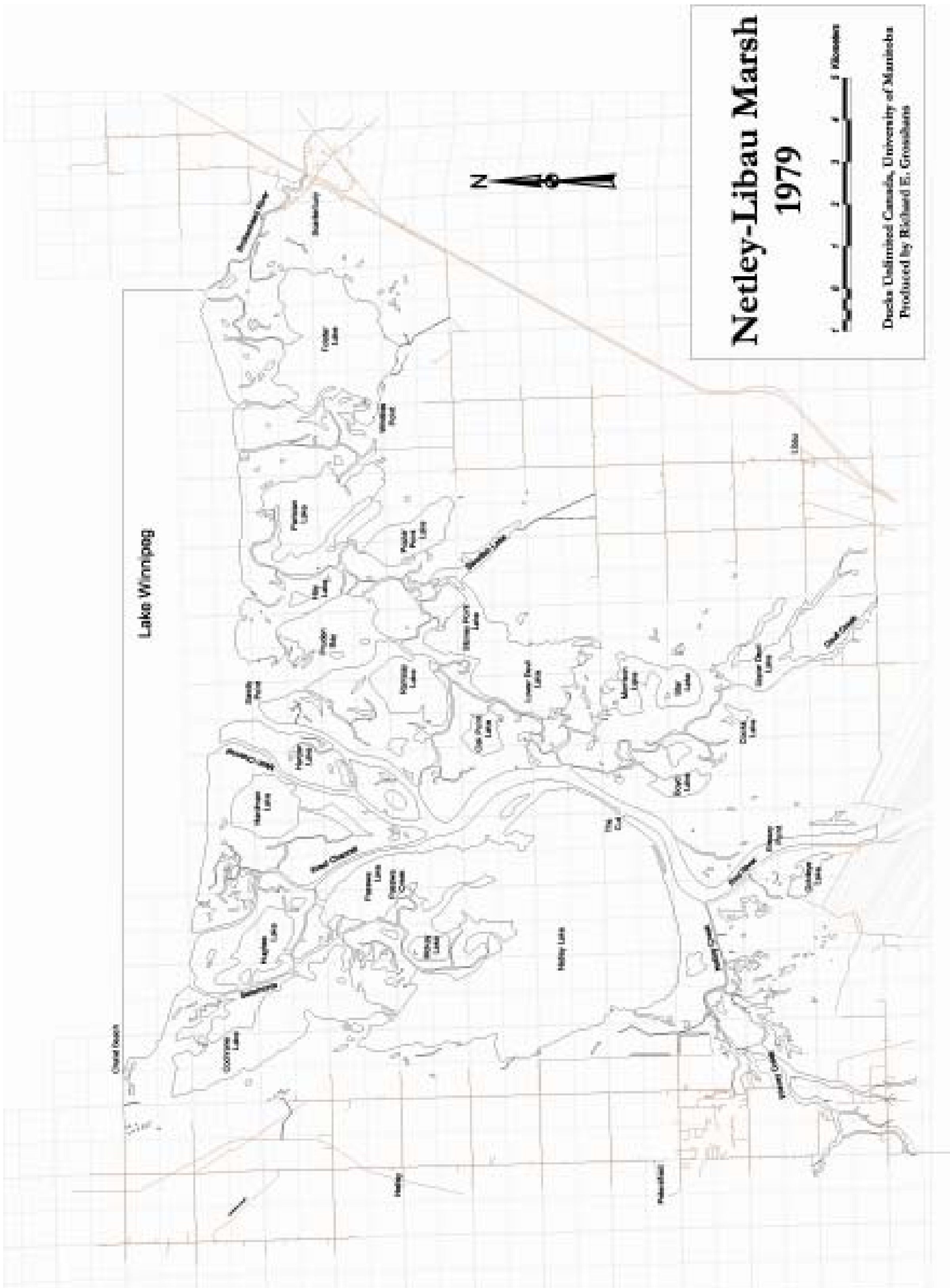

Figure 9. Outline map of Netley-Libau Marsh, 1979 based on vegetation maps (Figure 4) from Verbiwski (1986).

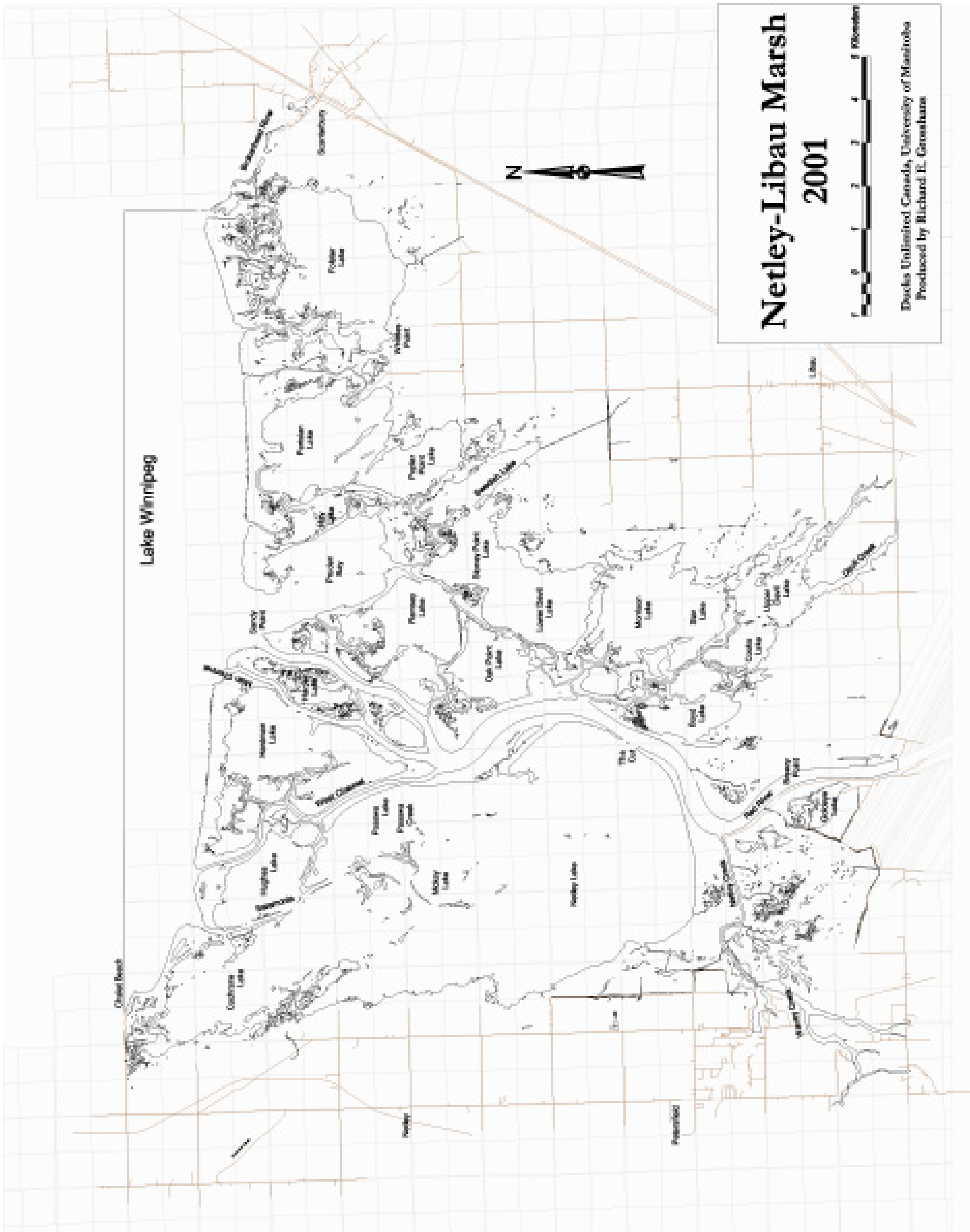

Figure 10. Outline map of Netley-Libau Marsh, 2001 produced in the present study.

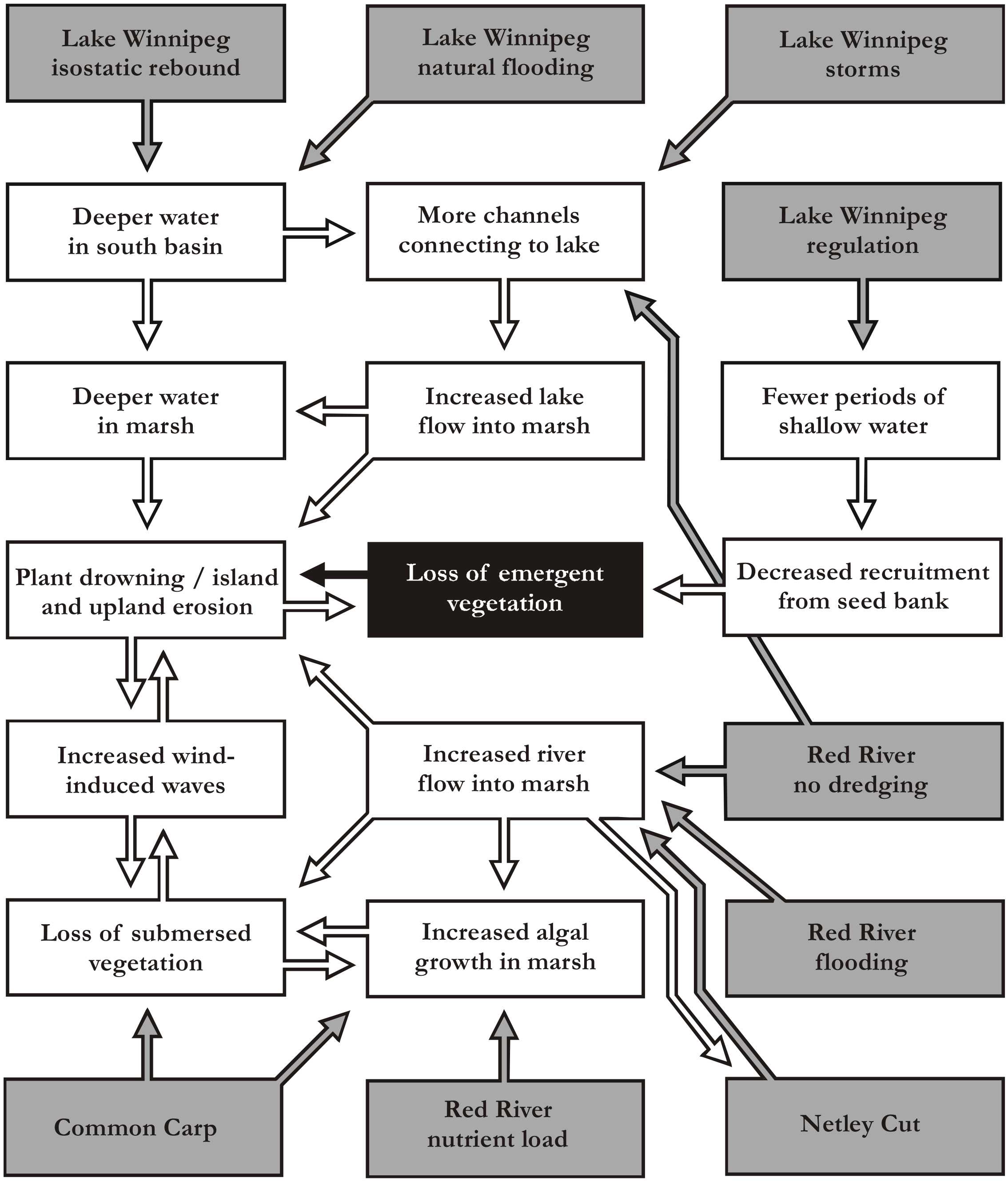

Figure 11. Conceptual diagram of some factors thought to be contributing to the decline of emergent vegetation in Netley-Libau Marsh. Shaded boxes are identified as potential primary causes of vegetation loss (see text).

to them. However, such an evaluation is a necessary precursor to any attempt at marsh restoration and to focus further research activities. We have grouped these factors into the two most important influences: Lake Winnipeg and the Red River.

Lake Winnipeg

Coastal marshes are susceptible to dramatic water level changes due to their connection with adjoining lakes (Warner and Rubec 1997). As water levels fluctuate over the long term, vegetation community composition and physical structure changes (Burton 1985, Chow-Fraser 1998, Chow-Fraser *et al.* 1998, Keough *et al.* 1999). Alternating high and low water periods cause changes in plant composition, where marsh and wet meadow vegetation undergo natural cycles of succession (Weller and Spatcher 1965, van der Valk and Davis 1978). High water levels kill off marsh emergents due to their intolerance to prolonged flooding, causing extensive vegetation diebacks (Figure 11). Conversely, low water periods expose mudflats allowing plants to recolonize areas from the rhizome/seedbank. It is clearly recognized that these periodic disturbance events are essential to maintaining habitat diversity and productivity within these marshes (Harris and Marshall 1963, Walker 1965, Weller and Spatcher 1965, van der Valk and Davis 1978, van der Valk 1981, Pederson and van der Valk 1984, Kenkel 1992, Bornette and Amoros 1996, van der Valk 2000, Grosshans 2001).

Lake Winnipeg dictates water levels within Netley-Libau Marsh and, as a consequence, has a significant impact on the structure of the marsh and its aquatic vegetation. How the marsh responds to Lake Winnipeg water level fluctuations can be determined to some extent from maps of the marsh from 1922 to 2001 (Figures 6 to 10). The accuracy of the early maps may not be up to modern standards, but we believe that the entire sequence provides a reasonable indication of how the marsh has changed over the past 80 years. The first map from 1922 shows extensive areas of uplands on the north and east sides of Netley Lake. These areas are labeled as hay land and the names of farmers with leases on the area are shown (Figure 6). The second map from 1936 also indicates extensive haylands within the marsh (Figure 7). Between 1922 and 1936, there was a brief period of high water levels in 1927 (716.7 ft, 218.4 m in September), but the early 1930s was a period of very low water levels on Lake Winnipeg [monthly mean of 711.7 ft (216.8 m) between 1930 and 1935; Figure 2]. The 1936 map of the marsh is much more detailed than the 1922 map, and shows the marsh as a complex system of channels, small ponds and bays that formed a mosaic of habitat. Extensive upland areas probably consisted of seasonally flooded grass and sedge meadows bordered by emergent macrophytes. The low water period in the early 1930s would have exposed the marsh bottom and permitted germination and expansion of the emergent plant communities. Many of the smaller ponds at this time were isolated systems and not significantly influenced by Lake Winnipeg.

Vegetation change in Netley-Libau Marsh does not always seem to occur synchronously with Lake Winnipeg water levels. The degree of change probably reflected the nature of the plant community at a given time and its sensitivity to inundation. By 1946 (Figure 8), many of the bays and ponds within the marsh had increased in size, even though water levels on the adjoining Lake Winnipeg had remained relatively low [monthly mean of 712.2 ft (217.1 m) between 1936 and 1946; Figure 2]. The lowest recorded water level to occur on the lake (709.4 ft, 216.2 m) was observed in December 1940. Average monthly water levels increased from the mid-1940s to 1960 [monthly mean of 714.0 ft (217.6 m) between 1945 and 1960; Figure 2], but marsh area did not change significantly (Table 3). However, from the mid-1960s to mid-1970s, Lake Winnipeg, and consequently Netley-Libau Marsh, underwent a prolonged period of higher water levels [monthly mean of 715.2 ft (218.0 m) between 1965 and 1975; Figure 2]. During this period, area of emergent marsh habitat declined 41% or almost 4000 ha, with an associated increase in open water area (Table 3). Our results indicate that since 1979 there has been a further loss of almost 4000 ha of upland and emergent marsh habitat (Table 2, Figure 9, 10), even though there have been no major fluctuations in water levels in the intervening period.

There is, however, some evidence that shifts in the area of open water and upland habitat in Netley-Libau Marsh do reflect changes in Lake Winnipeg water levels. The extended dry periods during the 1930s and 1940s resulted in the development of extensive emergent vegetation within the marsh, shown in the maps from 1936 and 1946. During this period, extensive mudflats within the marsh would have provided ideal conditions for the germination and expansion of emergent vegetation. Since that period, other intervals of low water have been relatively short (Figure 2). There were low water periods in the early 1960s, late 1970s, and the late 1980s and early 1990s, but these dry periods were not of the magnitude or duration of the low water period of the 1930s and 1940s (Figure 2). Since 1945, there have been no extended dry periods equivalent to those in the 1930s and 1940s, which would permit reestablishment of emergent vegetation throughout the marsh. Without this revegetation and the stabilizing effects of plant roots, shorelines and levees were increasingly susceptible to erosion (Figure 11).

Since 1975, development of the Nelson River for hydroelectric power generation has resulted in the use of Lake Winnipeg as a water storage reservoir (Lake Winnipeg, Churchill and Nelson Rivers Study Board 1975). Water levels on the lake have been regulated between 711 ft (216.7 m) and 715 ft (217.9 m) above sea level, a narrower range (4 ft, 1.2 m) than had occurred historically (8.8 ft, 2.7 m, see also Figure 2). A similar situation has been in place on nearby Lake Manitoba. There, water levels have been regulated since 1961 to avoid extreme high and low levels for the benefit of local land owners but not, as it is widely perceived, for power production. Delta Marsh, a large coastal wetland at the south end of Lake Manitoba, has also had its water levels regulated because of its connection to Lake Manitoba. At Delta, shallow bays and ponds around the main marsh have seen an expansion of emergent vegetation and loss of open water habitat since lake regulation (Grosshans *et al.* in preparation). However, in the larger bays of the marsh, islands and shoreline emergent vegetation have been disappearing at the same time. Although we have seen no evidence of expansion of emergent vegetation in the shallow areas of Netley-Libau Marsh, the loss of island and upland habitats within the marsh is similar to what we have documented in the larger bays of Delta Marsh. We believe that regulation of lake water levels to prevent extreme low water levels has had deleterious effects on both coastal marshes (Figure 11). Without extended periods of low water levels to permit re-establishment of emergent vegetation, long-term inundation with high wind and wave action, eventually results in the loss of island and upland habitats due to erosion. It is unlikely that the emergent vegetation in larger bays within these marshes will return without an extended period of drawdown.

Regulation of Lake Winnipeg water levels has reduced the long-term amplitude of water level changes in Netley-Libau Marsh, but has not eliminated fluctuations completely. Occasional flood-drawdown conditions still occur throughout the marsh due to wind set-ups and the relatively shallow conditions of the marsh, exposing areas of mudflats when strong southerly winds force water out of the marsh. Unfortunately, these drawdown events are erratic and only last, at most, a few days. This is insufficient to allow major vegetation communities to become re-established from the seedbank (van der Valk and Davis 1976, Murkin *et al.* 2000).

Verbiwski (1986) reported that the seasonal trend in water levels on Lake Winnipeg was modified by lake regulation. He claimed that lake levels were increased by one foot (0.3 m) in September of each year, and then subsequently drawn down by two feet (0.6 m) in winter. This modified seasonal progression of water levels could potentially impact emergent vegetation by altering overwintering conditions. To determine the extent of seasonal changes in water levels brought about by lake regulation, we calculated mean water levels for each month for a 25-year period prior to (1950 to 1974) and following (1975 to 1999) lake regulation. Our analysis shows that, in the 25-year period since lake regulation began, monthly values are generally lower by an average 0.7 ft (0.2 m) compared to the 25 years prior to regulation (Figure 12) and that seasonal trends do not differ between pre- and post-regulation. We did, however, find that the range in water levels for each month was reduced following regulation, particularly during the winter (Figure 12).

Beyond the direct impact of water levels within Lake Winnipeg and Netley-Libau Marsh, changing water levels also alter the flow regimes between these two habitats. Periods of higher lake levels contribute to increased flow through marsh channels and further increase the opportunity for erosion of levees and upland habitats (Figure 11). Autumn storms in 1961 and 1962 are thought to be responsible for severe erosion of the barrier beach and the creation of new channels between the marsh and Lake Winnipeg (Unies Ltd. 1972). As a result, the bays

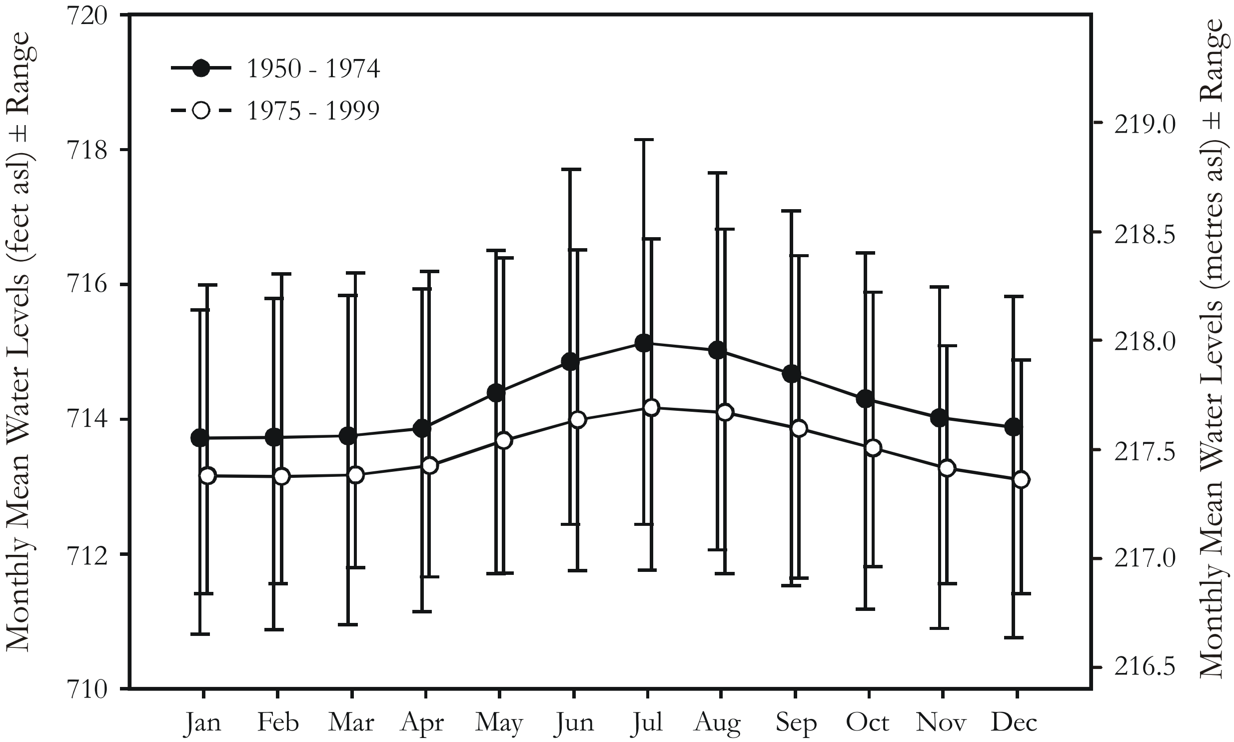

Figure 12. Monthly mean water level and range in Lake Winnipeg for the 25-year period preceding the 1975 start of lake level regulation, and the 25-year period following regulation. Data were calculated using mean monthly values at seven gauging stations, as in Figure 2.

immediately behind the ridge have experienced greater short-term water level fluctuations from wind set-up and set-down. The range of water level fluctuations within the marsh has increased. The 1946 aerial photographs show that there were seven openings in the barrier beach (Unies Ltd. 1972). There are eleven openings visible in our 2001 photographs.

Not only are water levels on Lake Winnipeg influenced by climatic conditions, they are also changing due to the glacial history of the region. Combining geological data and radiocarbon dates, Nielsen (1996) suggested that water levels at the south end of Lake Winnipeg are rising at a rate of about 15 to 20 cm per century due to isostatic uplift of the outlet at the north end of the lake. As a result, the barrier islands that make up the north shore of Netley-Libau Marsh have moved southward (Nielsen and Conley 1994, Nielsen 1996). What impact this slow increase in water levels has had on the emergent vegetation of the marsh is not known. Increasing water levels within coastal marshes will drown emergent vegetation and contribute to the loss of shoreline vegetation (Burton 1985). However, the loss of emergent vegetation within Netley-Libau Marsh has been extensive, and unlikely due solely to the small increase in water levels that has taken place in the last 80 years. We cannot discount the possibility of a threshold vegetation response to water deepening caused by isostatic rebound and a cumulative interaction with other factors (Figure 11).

Red River

The Red River passes through the middle of Netley-Libau Marsh, and flows differ greatly from year to year. Several severe floods have occurred in the past 50 years, with major floods in 1950, 1979 and 1997. In addition, between 1948 and 1999, there has been a greater incidence of extreme Red River flows than in the same time period prior to 1948 (Natural Resources Canada 2003). During major flood events, large parts of the Netley-Libau Marsh are inundated for extended periods of time. In addition to high water levels, floods also contribute to high rates of flow through the marsh (Figure 11). During these high flow events, weak points in the natural levees that border the river and other channels

Figure 13. This oblique, aerial view (looking southwest) of the Red River, Netley Cut, and Netley Lake was taken on 8 October 2003. The mouth of Netley Creek at the Red River is visible in the background. Low water levels in Netley-Libau Marsh and Lake Winnipeg in 2003 revealed sedimentary deposits northwest of Netley Cut that were presumably deposited by the Red River flowing into the marsh. Vegetation colonization of these newly exposed areas was rapid but the plants were inundated again in 2004 (Appendix 5).

are eroded or collapse. These extreme flow events on the Red River are likely to have had an impact on the levees and uplands of Netley-Libau Marsh.

The nature of river flow through Netley-Libau Marsh has been modified by humans for at least a century. For example, water flows from the Red River into the southeastern corner of Netley Lake through a breach in a narrow strip of upland between them (Figure 13). The so-called Netley Cut was excavated by the federal government in October 1913 (Library and Archives Canada, Winnipeg, Accession W84-85/493 Box 26 Netley). The excavation was justified as providing a means for water entering Netley Lake during wind set-up on Lake Winnipeg to exit more quickly and drain valuable hayfields. At that time, it apparently did not do so under normal conditions. It would also enable boat access by local residents wanting to collect cordwood and hay on the shores of Netley Lake. (The cut through the east bank of the Red River to the Devil's Lake portion of Netley-Libau Marsh – Figure 6 – had apparently been dredged prior to 1907.) Erosion of the Cut began almost immediately and became a recurring problem for government engineers. A small bridge, constructed to enable farmers to reach an estimated 445 hectares of hay land north of the channel, washed away in 1916. A sheet pile dam was built across the Cut during the winter of 1919-20 but it (and an associated bridge) was damaged by the summer of 1920. By 1924, the channel was over 24 m wide and averaged about 5 m deep. During replacement of the dam that year, the hull of a former river dredge that had been moored lengthwise across the channel to support a pile driver, sank and was abandoned, ostensibly to form part of the dam and a makeshift bridge. The

Figure 14. Landsat-7 satellite image of Netley-Libau Marsh, 28 July 1999. The selected band (6H, 60 m ground resolution) shows differences in surface temperature. A light gray, warm-water plume extending through Netley Cut into the darker gray, cooler water of Netley Lake is clearly visible, as is water flowing into Lake Winnipeg from the Red River's main and east channels. Source: Manitoba Lands Inventory (mli.gov.mb.ca), 2004.

channel was breached during the Red River flood of 1950 but was closed again by 1963 (Unies Ltd. 1972). By 1970, the breach was again open and it remains so today (Figure 13). Presently, the Cut is about 400 m wide, being broader than the Red River at that point.

A satellite image of southern Netley Lake shows prominent thermal plumes extending far into the lake as a result of intrusion by warm river water (Figure 14). The gradual widening of the Cut over time, and the conspicuous sediment deposits in Netley Lake at the mouth of the Cut (Figure 13) support a conclusion that Netley Cut has altered the flow pattern of the Red River (Figure 11). Some proportion of the Red River flow is now routed routinely through Netley Lake, rather than following its traditional main channel through the center of the marsh complex to discharge into Lake Winnipeg east of Hardman Lake (Figure 3).

As a meandering prairie river, the Red River has never been well suited to navigation by large boats. Efforts at improving its channel by dredging the bottom, especially at the mouth into Lake Winnipeg, began in early 1884 with the construction of a tugboat and dredging scow (*Winnipeg Daily Times*, 6 June 1884). River dredging generally occurred annually from 1960 to 1998 when the extent of work was reduced then eliminated entirely in 1999 (KGS Group 2002). No dredging has occurred since 1999. Overall, changes since 1998 in the bottom profile at dredging locations have been on the order of a few cm but up to 1 m in some locations (KGS 2002). It is claimed that, without dredging, the mouth of the Red River is becoming alarmingly shallow, being 2 m in 2002 compared to 6 m in 1982 (International Coalition 2002). Studies of the potential impacts of no dredging have considered loss of navigation to recreational, cargo, and fishing vessels; and local flooding due to ice jams in a shallower river channel. They have not considered the potential ecological effects on Netley-Libau Marsh. Specifically, lack of dredging at the mouth of the Red River – which represented over 75% of the total dredging prior to 1999 (KGS 2002) – will cause the water to take alternate routes to Lake Winnipeg, including ones through the marsh via the Netley Cut. A larger volume of water passing through the Cut will deliver larger quantities of river-borne silt, debris, nutrients, and pollutants to the marsh. In other words, the lack of Red River dredging probably exacerbates the impacts of the Cut on Netley Lake. The river may also erode new channels to Lake Winnipeg, with the result that a larger number of connections between Netley-Libau Marsh and the lake will allow greater water movement between them, especially during storms (Figure 11).

The increases in water velocity, water flow volume, and nutrient loading from the Red River and Lake Winnipeg are likely contributing factors to the decline in submersed and emergent macrophytes, erosion of smaller channels, uplands, and emergent islands, and increases in water column turbidity and algal blooms in Netley Lake (Figure 11). The movement of river water preferentially through the western unit of Netley-Libau Marsh, via Netley Cut, could explain why the magnitude of changes is more dramatic than in the easternmost unit of the marsh (Folster Lake), which has no connections with the Red River (Figure 3).

The Red River watershed covers an area of about 127,000 km^2, one of the largest in North America. Several urban and industrial centers, vast areas of chemical-intensive cereal agriculture, and numerous point and nonpoint sources of animal manure occur throughout the watershed, so it is perhaps not surprising that the river's water quality is threatened. Analyses of water samples collected from the river near Selkirk, between 1978 and 1999, reveal increases of 29% and 58% for total nitrogen and total phosphorus, respectively (Jones and Armstrong 2001). Both are essential nutrients which can stimulate algal growth in receiving waters. The high nutrient load of the Red River, routed into Netley-Libau Marsh to a greater extent than in the past, as a result of the Netley Cut and lack of dredging at the mouth of the river, could be a factor contributing to algal growth in Netley-Libau Marsh (Figure 11).

Excessive algal growth due to nutrient enrichment can lead directly to the loss of aquatic plants in at least two ways. First, epiphytic algae becomes more abundant, forming thick coatings which shade the host plants and compete with them for water column nutrients (Phillips *et al.* 1978). Phytoplankton blooms further decrease subsurface light below the point of photosynthetic compensation so submersed plants eventually die out. The gradual loss of submersed vegetation, whose roots help to stabilize sediments and reduce wind-initiated wave action (Carper and Bachmann 1984), initiates a feedback mechanism causing release of nutrients from disturbed sediments that further stimulates phytoplankton growth. There have been numerous studies on the occurrence and regulation of alternative states in shallow lakes and wetlands – characterized either by clear water and abundant submersed plants or turbid water filled with phytoplankton (Scheffer 1998) – to suggest that macrophyte decline occurs at a critical threshold of nutrient loading and, once achieved, is difficult to reverse merely through nutrient reduction. There are, to our knowledge, limited historical data on algal and submersed macrophyte biomass in Netley-Libau Marsh that would enable a comparison with present levels although early marsh surveys typically refer to clear water in which submersed plants were abundant (e.g., McLeod and Moir 1944). The marsh was still in a relatively "clear state" in the early 1980s (Baldwin, personal communication), when submersed plants remained sufficiently numerous that their distribution could be mapped (Hathout and Simpson 1982). Since then, it appears the marsh has, for the most part, shifted to the "turbid state" although sparse patches of submersed macrophytes remain today in isolated locations (Grosshans, personal observations). Phytoplankton biomass (12 to 124 µg/L total chlorophyll – mean 46 µg/L – in water samples collected in late June through August 2004; Goldsborough, unpublished data) is similar to that of eutrophic lakes (Wetzel 2001).

The contributions of common carp (*Cyprinus carpio*) to the decline of submersed and emergent macrophytes in Netley-Libau Marsh are unknown. The first confirmed catches of this introduced Eurasian fish species in Manitoba occurred in the Red River system at Lockport in 1938 (Hinks 1943) and, by 1944, the fish were "fairly abundant and widely distributed in the waters of the Netley area" (McLeod and Moir 1944). Carp are known to uproot submersed vegetation while spawning and feeding (Robel 1961, King and Hunt 1967, Crivelli 1983). They also increase turbidity by stirring up bottom sediments (Robel 1961, Lougheed *et al.* 1998), thereby contributing to low light conditions for submersed plants (Figure 11). Carp also release nutrients into the water column through disturbance of bottom sediments and excretion (Lamarra 1975, King *et al.* 1997, Lougheed *et al.* 1998), and these added nutrients may stimulate the growth of algae. High abundance of zooplanktivorous fish in Netley-Libau Marsh (Janusz and O'Connor 1985), along with a reduced amount of protective habitat for zooplankton, may contribute to low numbers of zooplankton. Low grazing pressure from zooplankton permits planktonic algae to flourish, further contributing to low light penetration into the water column (Bronmark and Weisner 1992). Through these direct and indirect effects, we believe that carp have contributed to the loss of submersed macrophytes from areas of the marsh to which they have access (Figure 11).

The loss of submersed macrophytes from the open-water areas of marsh bays could, in turn, lead to conditions promoting the loss of emergent macrophytes around the periphery. As noted earlier, submersed macrophytes typically help to stabilize the water column against wind-induced mixing so, in their absence, greater water movement and wave action against macrophytes in shallow water would erode the bases of plant stands, leading to their eventual destabilization and loss.

Netley-Libau Marsh in 2003

A prolonged period of low water in Lake Winnipeg, at least one year and probably much longer, would be required to restore the emergent vegetation in Netley-Libau Marsh naturally, by exposing mudflats from which seeds would germinate. Such periods have occurred with irregular frequency in the past, during the early 1930s, early 1940s, and early 1960s (Figure 2), but they are unlikely to occur now because the lake is managed to avoid low (and high) levels. Water levels in the marsh cannot be managed independently of Lake Winnipeg without constructing an extensive and costly network of dikes and pumps such as described by Verbiwski (1986). Therefore, natural revegetation can occur only when a severe drought lowers Lake Winnipeg below what would be maintained through management. In 2003, dry conditions prevailed across much of the prairies and Lake Winnipeg had its lowest water levels (711.7 ft in October) since 1988 (Figure 2). This afforded an opportunity to see whether marsh vegetation would become reestablished.

Although marsh water levels were generally less than 0.5 m (1.5 foot) lower than average, expanses of mudflats were revealed in many parts of Netley-

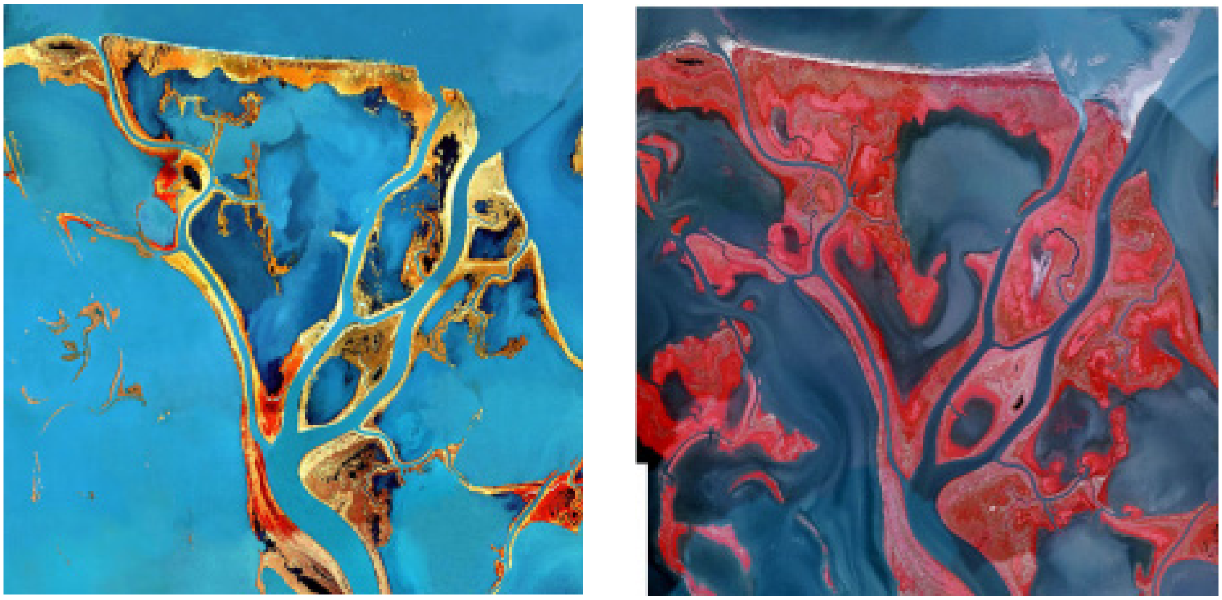

Figure 15. These colour infrared aerial photographs of Hardman Lake, Netley-Libau Marsh, taken in August of 2001 (left) and 2003 (right), illustrate the rapid expansion by marsh vegetation that occurred during the low water period of 2003.

Libau Marsh (personal observations). Prominent mudflats occurred on the northwest side of Netley Cut (Figure 13), presumably as a result of sediment deposition from the Red River over a period of years. Mudflats throughout the marsh became colonized extensively by cattails, bulrushes, and sedges (Grosshans, personal observations). Although we have no marsh-wide data on vegetation responses to low water, we were able to acquire color infrared aerial photography for subset areas of the marsh in August 2003 as part of a project on other coastal marshes in the south basin of Lake Winnipeg. These photographs demonstrate the dramatic plant growth that occurred, for example, in Hardman Lake, west of the Red River main channel, relative to 2001 (Figure 15). The open water area of Hardman Lake occupied about 470 hectares in 2003, compared to 755 hectares in 2001, due to extensive recruitment of emergent plant seedlings. Most of these plants persisted in 2004, even though water on Lake Winnipeg rose to more normal levels. It will remain to be seen, however, whether macrophytes will continue to thrive in deeper water.

Conclusion

Netley-Libau Marsh is not, in our view, functioning as a healthy coastal wetland. Instead, it resembles more closely a shallow turbid lake. In 1979, the marsh was a highly structured complex of channels, bays, island, and uplands. By 2001, amalgamation of small water bodies into large open expanses with few islands had resulted in simplification of the physical structure. Any benefits to Lake Winnipeg which the marsh could provide as wildlife and fisheries habitat, and in removing and storing nutrients that would otherwise enrich the lake, have probably been degraded or lost.

This marsh used to be a significant resource in southern Manitoba. Evidence provided here shows that it has undergone deterioration which has largely escaped scientific and public scrutiny. Serious consideration of its present state and future restoration is warranted.

RECOMMENDATIONS FOR FUTURE WORK

1. *Mapping* - We cannot assess whether vegetation changes in Netley-Libau Marsh are proceeding more rapidly than in the past because we had a single year, 1979, against which to compare our 2001 map. It would be useful to map emergent and submersed vegetation in other years from such archival sources as black-and-white aerial photographs available starting in the 1940s. A set of high-resolution, true color images from 1979 would enable the quantitative mapping of submersed macrophytes, which anecdotal observations suggest are far less abundant than in the past. Analyses of archival photographs would also enable the width of Netley Cut to be measured over time, to determine if the rate at which it is eroding is increasing. We believe it would be particularly useful to evaluate quantitatively, using all available imagery and maps, the degree to which vegetation changes have occurred in the western unit of the marsh (that is, west of the Red River main channel) relative to those in the eastern unit.
2. *Research on causal factors* - We speculated on factors which may be contributing to the deterioration of Netley-Libau Marsh in order to identify information needed for a critical evaluation. Such an evaluation is a necessary precursor to any attempt at marsh restoration. Factors that may be contributing to vegetation decline, alone or in combination, include Lake Winnipeg isostatic rebound, Lake Winnipeg natural flooding, Lake Winnipeg storms, Lake Winnipeg regulation, lack of Red River dredging, Red River flooding, Netley Cut, Red River nutrient load, and the proliferation of common carp.
3. *Water quality* - There are, to our knowledge, limited historical data on water quality in Netley-Libau Marsh so it is not possible to assess to what extent it has changed. It may be possible to use paleolimnological methods to infer past trends in water quality. A thorough investigation of water quality in various areas of Netley-Libau Marsh would be a useful foundation for future studies, and would provide a basis for evaluating the degree to which Red River water and its constituents are contributing to marsh degradation. Other fundamental studies could include an evaluation of marsh hydrology, specifically considering the flow of water through Netley Cut, and an assessment of the engineering feasibility and ecological impact of closing Netley Cut.
4. *Archival research* - Our ability to understand the historical context of changes in marsh vegetation was constrained, to some extent, by the absence of a thorough bibliography of existing data and reports on Netley-Libau Marsh. We suspect that substantial useful information exists in a variety of private and public sources. It would be helpful to carry out, as a basis for future research, a thorough search for existing publications, imagery, and data in all sources, including the provincial and federal archives, and in government and university files.
5. *Future monitoring* - We were able to obtain only limited data on vegetation regrowth during the the low water period of 2003. It would be desirable for marsh mapping to be done again in a few years, combined with on-the-ground study of vegetation in areas such as Hardman Lake which experienced considerable regrowth in 2003, following resumption of more usual water levels on the lake and marsh.
6. *Restoration* - When greater awareness of the factors contributing to marsh degradation has been obtained, we believe that the feasibility and benefits of marsh restoration should be evaluated. The potential for vegetation restoration by means other than natural water level drawdown must be assessed, because it is unlikely that water level reduction of sufficient magnitude to benefit the marsh could occur given the present and future demands for water in the Lake Winnipeg basin.

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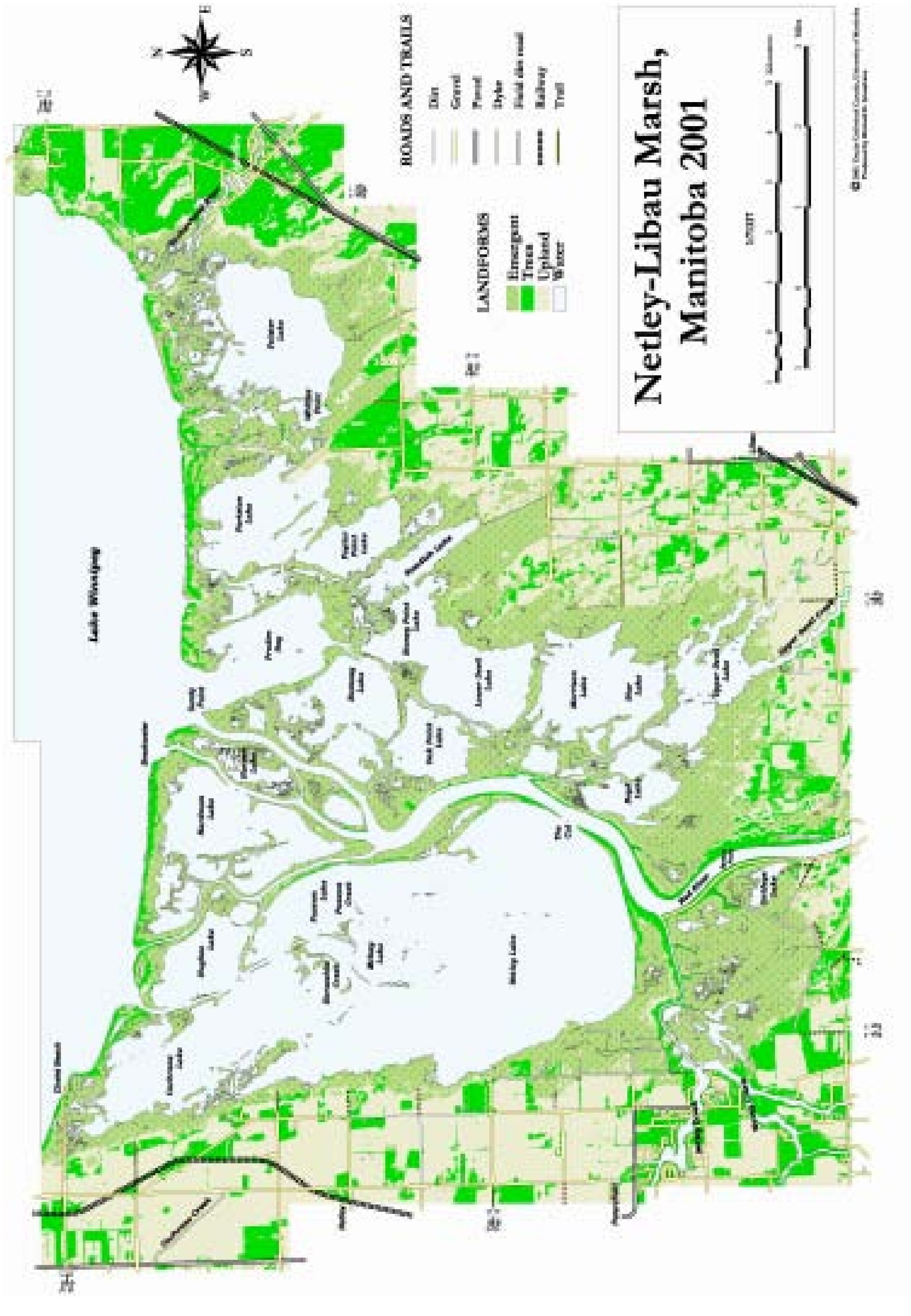
APPENDIX 1

Netley-Libau Marsh navigation map (2001). Vegetation mapping based on 1:10,000 color infrared aerial photographs (taken 3 August 2001) and ground observations.



APPENDIX 2
Vegetation zones of Netley-Libau Marsh (2001)

The following descriptions address the dominant and characteristic plant species found within each vegetation zone of Netley-Libau Marsh. A full species list is in Appendix 4. Plant scientific names follow the Integrated Taxonomic Information System online database, www.itis.usda.gov (ITIS 2004). Common names are from ITIS (2004), Looman and Best (1979) and Johnson *et al.* (1995). Vegetation zone descriptions follow Grosshans *et al.* (2005).

1. Non-vegetated

1A. Open water

These are permanent open water areas devoid of emergent vegetation. Water depth averages < 1 m but can reach a maximum depth of up to 3 m. Deepest areas typically have no vegetation whereas shallower areas support beds of submersed plants. Dominant submersed species include pondweed (*Stuckenia* spp.), coontail (*Ceratophyllum demersum*), water milfoil (*Myriophyllum sibiricum*), and bladderwort (*Utricularia macrorhiza*). Dense mats of duckweed (*Lemna minor, L. trisulca*) may be found in smaller sheltered bays.

1B. Sand (beaches, exposed sand areas)

These are areas of exposed sand with no to little vegetation growth, primarily the beaches and wind swept sand dunes along the lakeshore. Sparse vegetation found in these areas includes giant reed grass (*Phragmites australis*), shrub communities of willow (*Salix* spp.), wild rose (*Rosa* spp.), and chokecherry (*Prunus virginiana*), and grasses and herbs such as Canada wild rye (*Elymus canadensis*), couch grass (*E. repens*), and Canada thistle (*Cirsium arvense*).

1C. Mudflat

Patches of organic marsh sediment temporarily exposed by low water levels. Typically they support little to no vegetation growth. Newly exposed mudflats of Netley-Libau Marsh that remain exposed for an extended period of time are often revegetated with pioneer species such as goosefoot (*Chenopodium rubrum*), cattail (*Typha* spp.), bulrush (*Schoenoplectus* spp.), and sedges (*Carex* spp.).

2. Emergent Vegetation (permanently-seasonally flooded)

2A. Bulrush (*Schoenoplectus*)

Monodominant stands of bulrush (*Schoenoplectus* spp.) are primarily the taller round stemmed hard- and soft-stem bulrush (*S. acutus* and *S. tabernaemontani*) but also include the coarser three-sided river bulrush (*S. fluviatilis*). Standing water in these areas persists throughout the growing season. Hard- and soft-stem bulrushes grow mainly along open water borders, and can tolerate deeper water habitats by forming small islands. Typical associated species are sweet flag (*Acorus calamus*), awned sedge (*Carex atherodes*), and cattail (*Typha* spp.). Submersed species are often present, including bladderwort (*Utricularia macrorhiza*), pondweed (*Stuckenia* spp.), and water milfoil (*Myriophyllum sibiricum*) as well as the free-floating duckweeds (*Lemna minor, L. trisulca*). River bulrush inhabits flooded to waterlogged areas and is often associated with sweet flag, awned sedge, and bulrush. Many bulrush stands inhabit the east side of Netley-Libau Marsh and the northern corner of Netley Lake where gradually sloping shorelines allow for regular changes in water level.

2B. Bulrush, Sedge, Acorus

Mixed communities of coarse marsh emergents are dominated by stands of bulrush [including the taller round stemmed hard- and soft-stem bulrush (*Schoenoplectus acutus* and *S. tabernaemontani*)], sweet flag (*Acorus calamus*), awned sedge (*Carex atherodes*) as well as cattail (*Typha* spp.) and the coarser three-sided river bulrush (*S. fluviatilis*) in lower abundances. Standing water in these areas persists throughout the growing season. These mixed communities occur mainly along open water borders, and can tolerate deeper water habitats by forming small islands. Typical associated species are giant reed grass (*Phragmites australis*), water smart weed (*Polygonum amphibium*), arrowhead (*Sagittaria cuneata*), water hemlock (*Cicuta maculata*), and willows (*Salix* spp.). Submersed species are often present, including bladderwort (*Utricularia macrorhiza*), pondweed (*Stuckenia* spp.), and water milfoil (*Myriophyllum sibiricum*) as well as the free-floating duckweeds (*Lemna minor, L. trisulca*).

Many of these mixed communities occur on the east side of Netley-Libau Marsh.

2C. Cattail (*Typha*)

These monodominant stands of cattail (*Typha* spp.) are believed to be composed largely of common cattail (*T. latifolia*) and narrow-leaved (*T. angustifolia*), however a hybrid between these two species (*T.* X *glauca*) may also dominate the marsh. Stands are typically dense with a thick understory of fallen and standing deadfall. Cattail can grow up to 2 m in height and can survive in a range of water depths from 0 to 2 m. It is extremely widespread along shorelines, in ditches, and throughout shallow water areas, and forms dense floating mats or islands in deeper water. Cattail often borders open water and forms transition areas with *Phragmites*, bulrush (*Schoenoplectus* spp.) and wet meadows of awned sedge (*Carex atherodes*). Understory species include awned sedge, cursed crowfoot (*Ranunculus sceleratus*), and water smartweed (*Polygonum amphibium*). Submersed vegetation is often present when there is standing water, primarily bladderwort (*Utricularia macrorhiza*) and free floating duckweeds (*Lemna minor*, *L. trisulca*). It is also not uncommon to find dead trees and debris throughout these cattail stands deposited during river flooding.

2D. Giant reed grass (*Phragmites australis*)

These areas are dense mondominant stands of giant reed grass (*Phragmites australis*), characteristically with dense accumulations of fallen and standing deadfall. *Phragmites* can be found in water depths up to 0.6 m but normally grows in water-logged organic soils above the water table. Average height is 2 m but it can reach heights up to 3 m. Reeds can border open water but typically form transition areas with cattail (*Typha* spp.), willows (*Salix* spp.) or awned sedge (*Carex atherodes*). *Phragmites* are also a dominant species of the river levees and beach ridge, associated with willows and trees. Understory dominants of *Phragmites* include Canada thistle (*Cirsium arvense*), sow thistle (*Sonchus arvensis*), water hemlock (*Cicuta maculata*), stinging nettle (*Urtica dioca*), willows (*Salix* spp.), hedge bindweed (*Calystegia sepium*), wild cucumber (*Echinocystis lobata*), black bindweed (*Polygonum convolvulus*), western water horehound (*Lycopus asper*), and a variety of mints (*Scutellaria galericulata*, *Mentha canadensis, Stachys palustris*) depending on soil moisture. Other representative species found in lower abundance are spotted touch-me-not (*Impatiens capensis*) and western jewel weed (*I. noli-tangere*).

2E. Dead Material

Throughout the marsh are dense patches of fallen and accumulated dead material, which makes it difficult for new growth to establish. These patches are primarily within Cattail and *Phragmites* patches. Many of these patches occur near the southern shores where deadfall accumulates along these wave swept shorelines.

3. Wet meadow (seasonally-temporarily flooded)

3A. Awned sedge (*Carex atherodes*)

Awned sedge (*Carex atherodes*) forms dense monodominant meadows characterized by flooding for a few weeks in the spring, typically with 0 to 0.3 m of surface water persisting throughout the growing season. Awned sedge can also inhabit water levels up to 0.6 m, and dominate areas near the soil-water transition where the rooting zone remains saturated throughout the growing season. This coarse marsh emergent typically grows in dense stands on the margins of cattail and bulrush (classes 2B and 2C), as well as bordering reed canary grass (*Phalaris arundinacea*) (3C), willows (3E), and low prairie meadows. Awned sedge is the typical wet meadow transition between marsh emergents and low prairie vegetation within Netley-Libau Marsh, reaching heights of 0.5 to 1.4 m. Understory species include reed canary grass, sow thistle (*Sonchus arvensis*), Canada thistle (*Cirsium arvense*), water hemlock (*Cicuta maculata*), smartweed (*Polygonum* spp.), whitetop (*Scolochloa festucacea*), silverweed (*Argentina anserine*), purple loosestrife (*Lythrum salicaria*), mint (*Mentha canadensis)*, western water horehound (*Lycopus asper*), and white asters (*Symphyotrichum* spp.) all dependent on standing water or soil moisture.

3B. Sedges and rushes (*Carex, Beckmania, Eleocharis*)

These areas are often inundated for a few weeks in the spring, and although standing water can persist until mid-summer it is usually lost to seepage and evapotranspiration. Soil water remains within the rooting zone throughout the growing season. Patches of sedges and rushes occur wherever soil water accumulates and persists, typically within low prairies and cultivated fields (5C). They also occur bordering or within wet meadows of awned sedge (*Carex atherodes)* and reed canary grass (*Phalaris arundinacea*) (classes 3A and 3C). Dominant species of sedge-rush patches include fine textured sedges (*Carex* spp.), spike rushes (*Eleocharis* spp.), slough grass (*Beckmannia syzigachne*), baltic rush (*Juncus balticus*), couch grass (*Elymus repens*), smartweed (*Polygonum* spp.), willows (*Salix* spp.), sow thistle (*Sonchus arvensis*), Canada thistle (*Cirsium arvense*), and dock (*Rumex* spp.) in varying proportions of percent cover. Species in lower abundances include foxtail (*Hordeum jubatum*), mint (*Mentha canadensis)*, western water horehound (*Lycopus asper*), white asters (*Symphyotrichum* spp.) marsh reed grass (*Calamagrostis* spp.) and silverweed (*Argentina anserina*), all dependent on soil moisture conditions.

3C. Reed canary grass (*Phalaris arundinacea*)

Reed canary grass (*Phalaris arundinacea*), an introduced exotic to Netley-Libau Marsh, forms dense monodominant meadows in areas that may experience brief flooding to saturated soil conditions in the early spring. Standing water is rapidly lost to seepage and evapotranspiration, while soils remain wet to moist throughout most of the growing season. Reed canary grass is widespread throughout Netley-Libau Marsh, occupying a moist soil zone between meadows of awned sedge (*Carex atherodes*) (3A) and low prairies. Patches of sedges and rushes (3B) as well as willows (*Salix* spp.) (3E) typically occur near reed canary grass. Understory species include awned sedge (*Carex atherodes*), water hemlock (*Cicuta maculata*), smartweed (*Polygonum* spp.), Canada thistle (*Cirsium arvense*), sow thistle (*Sonchus arvensis*), spike rushes (*Eleocharis* spp.), marsh reed grass (*Calamagrostis* spp.), and willow. Species in lower abundances include dock (*Rumex* spp.), western water horehound (*Lycopus asper*), white asters (*Symphyotrichum* spp.), and Canada Anemone (*Anemone canadensis*).

3D. Whitetop (*Scolochloa festucacea*)

Dense monodominant meadows of whitetop (*Scolochloa festucacea*) are usually inundated for a few weeks in the spring, with 0 to 0.3 m of surface water persisting until mid-summer. Soil in the rooting zone remains saturated throughout the growing season. Whitetop grows in dense stands bordering patches of awned sedge, cattail, and willows (classes 3A, 2C, and 3E). This marsh grass, which typically inhabits areas of higher soil salinity, reaches heights from 1 to 1.4 m. Understory species include awned sedge (*Carex atherodes*), reed canary grass (*Phalaris arundinacea*), mints (*Mentha canadensis, Stachys palustris*), western water horehound (*Lycopus asper*), white asters (*Symphyotrichum* spp.), marsh reed grass (*Calamagrostis* spp.), sow thistle (*Sonchus arvensis*), Canada thistle (*Cirsium arvense*), water hemlock (*Cicuta maculata*), smartweed (*Polygonum* spp.), and purple loosestrife (*Lythrum salicaria*). The few whitetop patches within Netley-Libau Marsh occur farther northeast.

3E. Willow (*Salix*)

Willow patches occur throughout Netley-Libau Marsh wherever low-lying areas receive occasional flooding, as well as along the river levees and channels. Willow bluffs are typically mixed with *Phragmites* and awned sedge (*Carex atherodes*). These areas are characterized by flooding for a few weeks in the spring, typically with 0 to 0.3 m of surface water persisting throughout the growing season. Willows typically grow in dense bluffs bordering or within meadows of awned sedge (*Carex atherodes*) (3A), reed canary grass (*Phalaris arundinacea*) (3C), and low prairies, as well as on the margins of cattail and *Phragmites* (classes 2B and 2D). Understory species include awned sedge, *Phragmites*, reed canary grass, sow thistle (*Sonchus arvensis*), Canada thistle (*Cirsium arvense*), whitetop (*Scolochloa festucacea*), purple loosestrife (*Lythrum salicaria*), mint (*Mentha canadensis)*, western water horehound (*Lycopus asper*), white asters (*Symphyotrichum* spp.), and stinging nettle (*Urtica dioica*).

3F. Giant reed (*Phragmites*) and Willow (*Salix*)

Mixed communities of *Phragmites* and willows occur along the natural levees and channels of the Red River, as well as bordering treed areas (5B) of the beach ridge. These dense stands typically have mixed patches of wet and low prairie species throughout. Understory dominants of *Phragmites* and willow include awned sedge (*Carex atherodes*), reed canary grass (*Phalaris arundinacea*), Canada thistle (*Cirsium arvense*), sow thistle (*Sonchus arvensis*), water hemlock (*Cicuta maculata*), stinging nettle (*Urtica dioca*), hedge bindweed (*Calystegia sepium*), wild cucumber (*Echinocystis lobata*), black bindweed (*Polygonum convolvulus*), western water horehound (*Lycopus asper*), mints (*Mentha canadensis, Stachys palustris*), purple loosestrife (*Lythrum salicaria*), and white asters (*Symphyotrichum* spp.). Other representative species found in lower abundance are spotted touch-me-not *(Impatiens capensis*) and western jewel weed (*I. noli-tangere*).

3G. Salt flats (*Hordeum, Puccinellia*)

These are poorly drained areas where soils are more saline, found where the water table is at or near the soil surface. These patches are often waterlogged in the early spring or have temporary standing water. Characteristic dominant species are foxtail (*Hordeum jubatum*), salt meadow grass (*Puccinellia nuttalliana*), slough grass (*Beckmannia syzigachne*), lamb's quarters (*Chenopodium album*), sow thistle (*Sonchus arvensis*), and dock (*Rumex* spp.), with lower abundances of couch grass (*Elymus repens*), Canada thistle (*Cirsium arvense*) and whitetop (*Scolochloa festucacea*). Few salt flats areas occur within Netley-Libau Marsh.

4. Low prairie (temporary to no flooding)

4A. Grasses (*Elymus, Bromus, Poa*) (>75% grass cover)

These are typical grassy lawns and meadows characterized by > 75% grass cover and < 25% forb cover. Soil moisture varies throughout the growing season. Mowing or haying has impacted most grassed areas. They are typically dominated by low to intermediate grasses and forbs, including couch grass (*Elymus repens*), blue grass (*Poa* spp.), awnless brome (*Bromus inermis*), sow thistle (*Sonchus arvensis*), Canada thistle (*Cirsium arvense*), and plantain (*Plantago major*). Species in lower abundances include salt meadow grass (*Puccinellia nuttalliana*), foxtail (*Hordeum jubatum*), sedges (*Carex* spp.), spike rushes (*Eleocharis* spp.), and silverweed (*Argentina anserina*).

4B. Grasses and forbs (<50% forb cover)

These areas are typical meadows and hayfields, characterized by > 50% grass and < 50% forb cover. They may experience brief flooding to saturated soil conditions in the early spring, which is rapidly lost to seepage and evapotranspiration. Various areas have been impacted by cattle grazing and haying at some time. Mixed grasses and forbs dominate these meadows in varying proportions of dominance, typically blue grass (*Poa* spp.), awnless brome (*Bromus inermis*), sow thistle (*Sonchus arvensis*), Canada thistle (*Cirsium arvense*), white asters (*Symphyotrichum* spp.), clover (*Trifolium* spp.), alfalfa (*Medicago sativa*), vetch (*Vicia americana*), marsh reed grass (*Calamagrostis* spp.), and sweet clover (*Melilotus* spp.). Less abundant species include reed canary grass *(Phalaris arundinacea*), couch grass (*Elymus repens*), timothy (*Phleum pratense*), salt meadow grass (*Puccinellia nuttalliana*), sedges (*Carex* spp.), western water horehound (*Lycopus asper*), and common mint (*Mentha canadensis*). Other species of low abundance are goldenrod (*Solidago* spp.), sunflower (*Helianthus* spp.), silverweed (*Argentina anserina*), Canada Anemone (*Anemone canadensis*), alkali cordgrass (*Spartina pectinata*), spike rushes (*Eleocharis* spp.), purple loosestrife (*Lythrum salicaria*), and sweet grass (*Hierochloe odorata*).

4C. Prairie (>50% forb cover)

These meadows are typical prairie fields dominated by upland grasses, herbs and shrubs, characterized by > 50% forb and < 50% grass cover. Flooding in these areas occurs only during spring snow melt and heavy rains. Water is rapidly lost by seepage and evapotranspiration. A few areas have been impacted by cattle grazing and haying. Mixed grasses and forbs dominate these meadows in varying proportions of dominance, which characteristically include awnless brome (*Bromus inermis*), blue grass (*Poa* spp.), Canada thistle (*Cirsium arvense*), sow thistle (*Sonchus arvensis*), white asters (*Symphyotrichum* spp.), goldenrod (*Solidago* spp.), big bluestem (*Andropogon gerardii*), sunflower (*Helianthus* spp.), clover (*Trifolium* spp.), alfalfa (*Medicago sativa*), vetch (*Vicia Americana*), sweet clover (*Melilotus* spp.), marsh reed grass (*Calamagrostis* spp.), low prairie rose (*Rosa acicularis*), and plantain (*Plantago major*). Species of lower abundances are couch grass (*Elymus repens*), Canada wild rye (*Elymus canadensis*), timothy (*Phleum pratense*), Canada Anemone (*Anemone canadensis*), western water horehound (*Lycopus asper*), common mint (*Mentha canadensis*), silverweed (*Argentina anserina*), purple loosestrife (*Lythrum salicaria*), beggarticks (*Bidens* spp.), and common yarrow (*Achillea millefolium*).

5. Upland (temporary to no flooding)

5A. Hayed grasses and forbs

These are grass and forb meadows of class 4A, 4B, and 4C that have been hayed. Mixed grasses and forbs found in the above classes characterize these areas. Wet meadows of classes 3A, 3B, and 3C are often hayed as well.

5B. Grazed

These are grass and forb meadows of class 4A, 4B, and 4C that have been used for cattle grazing. The extent of flooding in these areas varies dependent on the vegetation class. They may experience brief flooding to saturated soil conditions in the early spring, or only during heavy rains, which is rapidly lost to seepage and evapotranspiration. Cattle grazing has heavily impacted this land, with the vegetation typically cropped at low to medium height. Mixed grasses and forbs found in the above classes characterize these areas. Grazed areas can also include wet meadows and sedge meadows (Section 3).

5C. Treed prairie (mixed prairie, shrubs and trees)

These areas are typical of the landscape found within the prairie parkland region; characterized by patches of prairie dominated by upland grasses, herbs and shrubs, interspersed with willows and trees. Flooding in these areas would only occur during spring snowmelt and heavy rains. Water is lost rapidly to seepage and evapotranspiration. Prairie grasses and forbs include awnless brome (*Bromus inermis*), blue grass (*Poa* spp.), Canada thistle (*Cirsium arvense*), sow thistle (*Sonchus arvensis*), asters (*Symphyotrichum* spp.), clover (*Trifolium* spp.), goldenrod (*Solidago* spp.), big bluestem (*Andropogon gerardii*), sunflower (*Helianthus spp.*), alfalfa (*Medicago sativa*), low prairie rose (*Rosa acicularis*), couch grass (*Elymus repens*), clover (*Trifolium* spp.), alfalfa (*Medicago sativa*), vetch (*Vicia americana*), beggarticks (*Bidens* spp.), common yarrow (*Achillea millefolium*) and sweet clover (*Melilotus* spp.). Low shrubs such as wild rose (*Rosa* spp.), willows (*Salix* spp.), dogwood (*Cornus sericea*), low shrubs such as wolf-willow (*Elaeagnus commutata*), and chokecherry (*Prunus virginiana*), as well as various tree species are mixed throughout these areas.

5D. Trees (tree and shrub cover)

Treed areas include forests, willow bluffs, river levees and tall shrub cover where slightly higher elevation than the surrounding marsh enables tree species to grow. Trees are primarily deciduous with spruces or pines found well away from the marsh. Dense tree and shrub cover characterizes the forested beach ridge and river levees separating the marsh from Lake Winnipeg and the Red River. Representative trees include Manitoba maple, or boxelder (*Acer negundo*), green ash (*Fraxinus pennsylvanica*), plains cottonwood (*Populus deltoides*), willows (*Salix* spp.), chokecherry (*Prunus virginiana*) and American elm (*Ulmus americana*). Understory species include dogwood (*Cornus sericea*), stinging nettle (*Urtica dioica*), spreading dogbane (*Apocynum androsaemifolium*), wild sarsaparilla (*Aralia nudicaulis*), Canada thistle (*Cirsium arvense*), willows (*Salix* spp.), and poison ivy (*Toxicodendron radicans*). Willow thickets mixed with trees and shrubs occur in low prairie areas throughout the marsh, where wooded bluffs interspersed with meadows and pasture are also found. Treed areas dominate beyond the north-east portion of the marsh.

5E. Cultivated

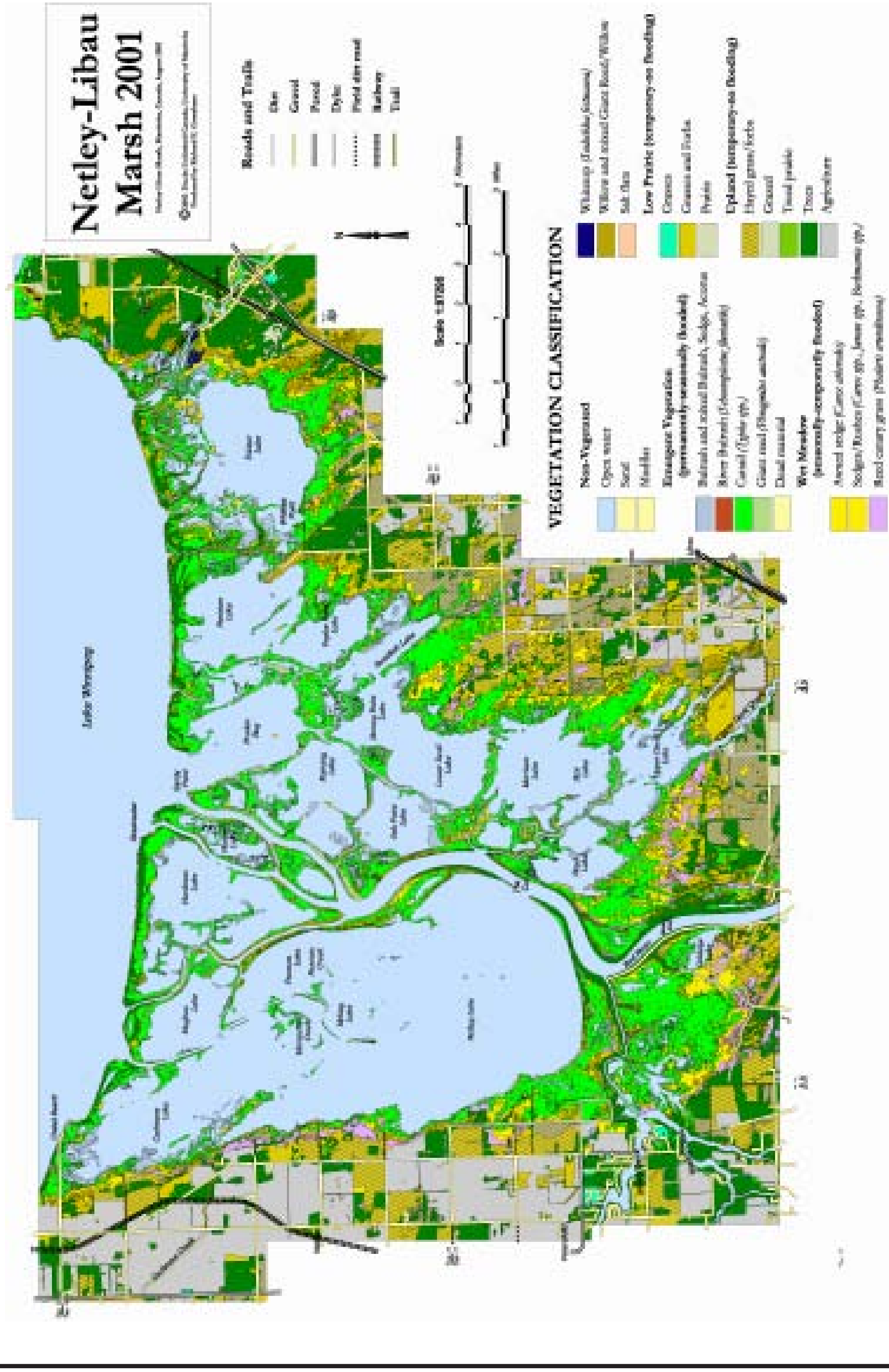
This class comprises any land that is plowed for crops such as canola, wheat, barley, flax, and others. Farming practices have heavily impacted the landscape west and south of the marsh, which is now predominantly farmland interspersed with forested bluffs, small marshes and remnant patches of prairie grasses.

APPENDIX 3
Netley-Libau plant communities and area estimates (2001)

Table A3. Netley-Libau plant communities in 2001 survey. Total area (ha) and percent cover (% of total marsh area, and % of vegetated area) by marsh zone and vegetation class.

Marsh Zone	Vegetation Class	Area (ha)	% Cover (entire marsh)	% Cover (vegetated area)
Non-vegetated		13,299	38.6	62.7
	Open water	13,258	38.5	62.5
	Sand	35	0.1	0.2
	Mudflat	6	0.0	0.0
Emergent		5,889	17.1	27.8
	Bulrush	322	0.9	1.5
	Bulrush, Sedge, Acorus	180	0.5	0.8
	Cattail	4,756	13.8	22.4
	Giant reed grass	536	1.6	2.5
	Dead material	96	0.3	0.4
Wet meadow		3,177	9.2	15.0
	Awned Sedge	1,549	4.5	7.3
	Sedges and rushes	225	0.7	1.1
	Reed canary grass	587	1.7	2.8
	Whitetop	22	0.1	0.1
	Willow	578	1.7	2.7
	Giant reed and Willow	215	0.6	1.0
	Salt flats	2	0.0	0.0
Low prairie		1,872	5.4	8.8
	Grasses	57	0.2	0.3
	Grasses and forbs	1593	4.6	7.5
	Prairie	222	0.6	1.0
Upland		10,241	29.7	48.3
	Hayed grass & forbs	1,666	4.8	7.8
	Grazed	950	2.8	4.5
	Treed Prairie	33	0.1	0.2
	Trees	4,266	12.4	20.1
	Agriculture	3,327	9.6	15.7
Total marsh area		34,479	100.0	
Total vegetated area		21,221		100.0

Figure A3. Netley-Libau Marsh, 2001. Complete vegetation mapping based on 1:10,000 infrared color aerial photography (taken 3 August 2001) and ground observations.



APPENDIX 4
Netley-Libau Marsh plant species list (2001)

Scientific Name (ITIS 2004)	Scientific Name (Scoggans 1979)	Common Name	Family
Acer negundo	*Acer negundo*	Manitoba maple, boxelder	Aceraeae
Achillea millefolium	*Achillea millefolium*	common yarrow	Asteracea
Acorus americanus	*Acorus americanus*	sweet flag	Acoraceae
Agrostis stolonifera	*Agrostis stolonifera*	redtop	Poaceae (Graminae)
Alisma triviale	*Alisma triviale*	common water plantain	Alismataceae
Ambrosia coronopifolia	*Ambrosia psilostachya*	perennial ragweed	Asteracea
Andropogon gerardii	*Andropogon gerardii*	big bluestem	Poaceae (Graminae)
Anemone canadensis	*Anemone canadensis*	Canada anemone	Ranunculaceae
Apocynum androsaemifolium	*Apocynum androsaemifolium*	spreading dogbane	
Aralia nudicaulis	*Aralia nudicaulis*	wild sarsaparilla	Araliaceae
Argentina anserina	*Potentilla anserina*	silverweed	Rosaceae
Artemesia absinthium	*Artemesia absinthium*	absinthe	Asteraceae
Artemesia biennis	*Artemesia biennis*	biennial wormwood	Asteraceae
Artemesia dracunculus	*Artemesia dracunculus*	tarragon	Asteraceae
Artemesia frigida	*Artemesia frigida*	praire sagewort	Asteraceae
Artemesia ludoviciana	*Artemesia ludoviciana*	white sage	Asteraceae
Astragalus bisulcatus	*Astragalus bisulcatus*	two grooved milk-vetch	Fabaceae (Leguminosae)
Astragalus canadensis	*Astragalus canadensis*	Canada milk-vetch	Fabaceae (Leguminosae)
Atriplex patula	*Atriplex patula*	orache, spearscale	Chenopodiaceae
Beckmannia syzigachne	*Beckmannia syzigachne*	slough grass	Poaceae
Bidens cernua	*Bidens cernua*	nodding beggarticks	Asteraceae
Bidens frondosa	*Bidens frondosa*	devil's beggarticks	Asteraceae
Bromus inermis	*Bromus inermis*	awnless brome	Poaceae (Graminae)
Butomus umbellatus	*Butomus umbellatus*	Flowering rush	Butomaceae
Calamagrostis canadensis	*Calamagrostis canadensis*	marsh reed grass	Poaceae (Graminae)
Calamagrostis stricta ssp. *inexpansa*	*Calamagrostis inexpansa*	northern reed grass, reed bent-grass	Poaceae (Graminae)
Calystegia sepium	*Convolvulus sepium*	morning glory, hedge bindweed	Convolvulaceae
Campanula rotundifolia	*Campanula rotundifolia*	harebell, bluebell	Campanulaceae
Carex assiniboinensis	*Carex assiniboinensis*	sedge	Cyperaceae
Carex atherodes	*Carex atherodes*	awned sedge	Cyperaceae
Carex lanuginosa	*Carex lanuginosa*	sedge	Cyperaceae
Carex retrorsa	*Carex retrorsa*	sedge	Cyperaceae
Celtis occidentalis	*Celtis occidentalis*	hackberry	Ulmaceae

Ceratophyllum demersum	*Ceratophyllum demersum*	coontail	Ceratophyllaceae
Chenopodium album	*Chenopodium album*	lamb's quarters	Chenopodiaceae
Chenopodium rubrum	*Chenopodium rubrum*	red goosefoot, coast-blite	Chenopodiaceae
Cicuta maculata	*Cicuta maculata*	water hemlock, spotted cowbane	Umbelliferae
Cirsium arvense	*Cirsium arvense*	Canada thistle	Asteraceae
Corispermum orientale	*Corispermum hyssopifolium*	bugseed	Chenopodiaceae
Cornus sericea	*Cornus stolonifera*	dogwood, red osier	Cornaceae
Cuscuta gronovii	*Cuscuta gronovii*	viney berry, dodder	Convolvulaceae
Echinocystis lobata	*Echinocystis lobata*	wild cucumber	Cucurbitaceae
Elaeagnus commutata	*Elaeagnus commutata*	wolf-willow, silverberry	Eleagnaceae
Eleocharis acicularis	*Eleocharis acicularis*	spike rush	Cyperaceae
Eleocharis palustris	*Eleocharis palustris*	creeping spike rush	Cyperaceae
Elymus canadensis	*Elymus canadensis*	Canada wild rye	Poaceae (Graminae)
Elymus trachycaulus ssp. *subsecundus*	*Agropyron trachycaulum*	slender wheatgrass, couch-grass	Poaceae (Graminae)
Elymus repens	*Agropyron repens*	quackgrass, couch-grass	Poaceae (Graminae)
Equisetum arvense	*Equisetum arvense*	common horsetail	Equisetaceae
Eupatorium maculatum	*Eupatorium maculatum*	joe-pye-weed	Asteraceae
Fraxinus pennsylvanica	*Fraxinus pennsylvanica*	green ash, red ash	Oleaceae
Galium boreale	*Galium boreale*	northern bedstraw	Rubiaceae
Galium trifidum	*Galium trifidum*	small bedstraw	Rubiaceae
Glaux maritima	*Glaux maritima*	sea milkwort	Primulaceae
Glyceria grandis	*Glyceria grandis*	tall manna grass, reed-meadow grass	Poaceae (Graminae)
Glycyrrhiza lepidota	*Glycyrrhiza lepidota*	wild licorice	Fabaceae (Leguminosae)
Grindelia squarrosa	*Grindelia squarrosa*	gumweed	Asteraceae
Helianthus maximiliani	*Helianthus maximiliani*	narrow-leaved sunflower	Asteraceae
Helianthus pauciflorus ssp. *subrhomboides*	*Helianthus laetiflorus*	rhombic-leaved sunflower	Asteraceae
Heracleum maximum	*Heracleum lanatum*	cow parsnip	Apiaceae
Hierochloe odorata	*Hierochloe odorata*	common sweet grass	Poaceae (Graminae)
Hippuris vulgaris	*Hippuris vulgaris*	mare's tail	Hippurridaceae
Hordeum jubatum	*Hordeum jubatum*	foxtail, wild barley, squirrel-tail grass	Poaceae (Graminae)
Impatiens capensis	*Impatiens capensis*	spotted touch-me-not	Balsaminaceae
Impatiens noli-tangere	*Impatiens noli-tangere*	western jewel weed	Balsaminaceae
Juncus balticus var. *littoralis*	*Juncus balticus*	baltic rush	Juncaceae
Koeleria macrantha	*Koeleria cristata*	june grass	Poaceae (Graminae)
Lactuca tatarica	*Lactuca pulchella*	blue lettuce	Asteraceae

Lathyrus palustris	*Lathyrus palustris*	vetchling	Fabaceae (Leguminosae)
Lemna minor	*Lemna minor*	lesser duckweed	Lemnaceae
Lemna trisulca	*Lemna trisulca*	star duckweed	Lemnaceae
Leucanthemum vulgare	*Chrysanthemum leucanthemum*	Ox-eye daisy	Asteraceae
Leymus innovatus	*Elymus innovatus*	hairy wild rye, wild rye	Poaceae (Graminae)
Liatris ligulistylis	*Liatris ligulistylis*	meadow blazing star	Asteraceae
Lycopus asper	*Lycopus asper*	western water horehound	Labiatae
Lythrum salicaria	*Lythrum salicaria*	purple loosestrife	Lythraceae
Matricaria discoidea	*Matricaria matricaroides*	pineapple weed	Asteraceae
Medicago sativa	*Medicago sativa*	alfalfa	Fabaceae (Leguminosae)
Melilotus alba	*Melilotus alba*	white sweet clover	Fabaceae (Leguminosae)
Melilotus officinalis	*Melilotus officinalis*	yellow sweet clover	Fabaceae (Leguminosae)
Mentha canadensis	*Mentha arvensis*	common mint	Labiatae
Mirabilis hirsuta	*Mirabilis hirsuta*	four-o-clock flower	Nyctaginaceae
Monarda fistulosa	*Monarda fistulosa*	wild bergamot	Labiatae
Myriophyllum sibiricum	*M. spicatum* var. *exalbescens*	water milfoil	Haloragaceae
Parthenocissus quinquefolia	*Parthenocissus quinquefolia*	virgina creeper	Vitaceae
Phalaris arundinacea	*Phalaris arundinacea*	reed canary grass	Poaceae (Graminae)
Phleum pratense	*Phleum pratense*	common timothy	Poaceae (Graminae)
Phragmites australis	*Phragmites australis*	giant reed grass, cane reed	Poaceae (Graminae)
Plantago major	*Plantago major*	common plantain	Plantaginaceae
Poa palustris	*Poa palustris*	fowl blue grass, fowl meadow-grass	Poaceae (Graminae)
Poa pratensis	*Poa pratensis*	Kentucky blue-grass	Poaceae (Graminae)
Polygonum amphibium	*Polygonum amphibium*	water smartweed	Polygonaceae
Polygonum amphibium var. *emersum*	*Polygonum coccineum*	smartweed, swamp persicaria	Polygonaceae
Polygonum convolvulus	*Polygonum convolvulus*	black bindweed, wild buckwheat	Polygonaceae
Populus deltoides	*Populus deltoides*	plains cottonwood	Salicaceae
Populus tremuloides	*Populus tremuloides*	trembling aspen	Salicaceae
Potamogeton richardsonii	*Potamogeton richardsonii*	Richardson's pondweed	Zosteraceae
Prenanthes recemosa ssp. *multiflora*	*Prenanthes recemosa*	rattlesnake root	Asteraceae
Prunus virginiana	*Prunus virginiana*	chokecherry	Rosaceae
Puccinellia nuttalliana	*Puccinellia nuttalliana*	salt meadow grass, alkali-grass	Poaceae (Graminae)
Quercus macrocarpa	*Quercus macrocarpa*	bur oak	Fagaceae
Ranunculus cymbalaria	*Ranunculus cymbalaria*	seaside crowfoot	Ranunculaceae

Ranunculus sceleratus	*Ranunculus sceleratus*	cursed crowfoot, celery leaved buttercup	Ranunculaceae
Ribes americanum	*Ribes americanum*	wild black current	Saxifragaceae
Rosa acicularis	*Rosa acicularis*	prickly rose	Rosaceae
Rosa arkansana	*Rosa arkansana*	low prairie rose	Rosaceae
Rosa woodsii	*Rosa woodsii*	wood's rose	Rosaceae
Rubus idaeus	*Rubus idaeus*	raspberry	Rosaceae
Rudbeckia hirta	*Rudbeckia serotina*	black-eyed susan	Asteracea
Rumex aquaticus var. *fenestratus*	*Rumex occidentalis*	western dock	Polygonaceae
Rumex maritimus	*Rumex maritimus*	golden dock	Polygonaceae
Ruppia occidentalis	*Ruppia cirrhosa*	wigeon grass	Ruppiceae
Sagittaria cuneata	*Sagittaria cuneata*	arrowhead	Alismataceae
Sagittaria latifolia	*Sagittaria latifolia*	arrowhead	Alismataceae
Salicornia rubra	*Salicornia rubra*	red samphire	Chenopodiaceae
Salix amygdaloides	*Salix amygdaloides*	peachleaf willow	Salicaceae
Salix bebbiana	*Salix bebbiana*	beaked willow	Salicaceae
Salix exigua	*Salix interior*	sandbar willow	Salicaceae
Sambucus pubens	*Sambucus racemosa* ssp. *pubens*	elderberry, red-berried elder	Caprifoliaceae
Schoenoplectus acutus	*Scirpus acutus*	hardstem bulrush	Cyperacea
Schoenoplectus fluviatilis	*Scirpus fluviatilis*	river bulrush	Cyperaceae
Schoenoplectus maritimus	*Scirpus maritimus*	alkali bulrush	Cyperacea
Schoenoplectus maritimus var. *paludosus*	*Scirpus paludosus*	alkali bulrush	Cyperacea
Schoenoplectus pungens	*Scirpus americanus*	three square bulrush	Cyperacea
Schoenoplectus tabernaemontani	*Scirpus validus*	softstem, great bulrush	Cyperacea
Scolochloa festucacea	*Scolochloa festucacea*	whitetop, spangle-top	Poaceae (Graminae)
Scutellaria galericulata	*Scutellaria galericulata*	marsh skullcap, common skullcap	Labiatae
Senecio congestus	*Senecio congestus*	marsh ragwort, marsh-fleabane	Asteraceae
Sium suave	*Sium suave*	water-parsnip	Apiaceae
Solidago canadensis var. *gilvocanescens*	*Solidago canadensis*	Canada goldenrod	Asteraceae
Solidago rigida	*Solidago rigida*	stiff goldenrod	Asteraceae
Sonchus arvensis ssp. *uliginosus*	*Sonchus arvensis*	sowthistle, field-sowthistle	Asteraceae
Sparganium eurycarpum	*Sparganium eurycarpum*	bur-reed	Sparganiaceae

Spartina pectinata	*Spartina pectinata*	alkali cord grass, fresh-water cord-grass	Poaceae (Graminae)
Stachys palustris ssp. *pilosa*	*Stachys palustris*	marsh hedge-nettle, woundwort	Labiatae
Stellaria longifolia	*Stellaria longifolia*	long-leaved chickweed	Caryophyllaceae
Stuckenia pectinatus	*Potamogeton pectinatus*	sago pondweed	Zosteraceae
Stuckenia vaginatus	*Potamogeton vaginatus*	sheathed pondweed	Zosteraceae
Suaeda calceoliformis	*Suaeda depressa*	sea-blite	Chenopodiaceae
Symphoricarpus albus	*Symphoricarpus albus*	thin-leaved snowberry	Caprifoliaceae
Symphoricarpus occidentalis	*Symphoricarpus occidentalis*	snowberry	Caprifoliaceae
Symphyotrichum borealis	*Aster borealis*	northern aster	Asteraceae
Symphyotrichum ciliatum	*Aster brachyactis*	rayless aster	Asteraceae
Symphyotrichum ericoides var. *pansus*	*Aster ericoides*	heath aster	Asteraceae
Symphyotrichum laeve var. *laeve*	*Aster laevis*	smooth aster	Asteraceae
Symphyotrichum lanceolatum var. *hesperium*	*Aster hesperius*	western willow aster	Asteraceae
Symphyotrichum lanceolatum var. *lanceolatum*	*Aster simplex*	aster	Asteraceae
Taraxacum officinale	*Taraxacum officinale*	common dandelion	Asteraceae
Teucrium canadense var. *occidentale*	*Teucrium occidentalis*	mint, germander	Labiatae
Toxicodendron radicans	*Rhus radicans*	poison ivy	Anacardiaceae
Trifolium pratense	*Trifolium pratense*	red clover	Fabaceae
Trifolium repens	*Trifolium repens*	white clover	Fabaceae
Trifolium hybridum	*Trifolium hybridum*	alsike clover	Fabaceae
Triglochin maritima	*Triglochin maritima*	arrow-grass	Juncaginaceae
Typha angustifolia	*Typha angustifolia*	narrow leaved cattail	Typhaceae
Typha latifolia	*Typha latifolia*	common cattail	Typhaceae
Typha X *glauca*	*Typha* X *glauca*	hybrid cattail	Typhaceae
Ulmus americana	*Ulmus americana*	American elm	Ulmaceae
Urtica dioica ssp. *gracilis*	*Urtica dioica*	stinging nettle	Urticaceae
Utricularia macrorhiza	*Utricularia vulgaris*	common bladderwort	Lentibulariaceae
Viburnum edule	*Viburnum edule*	lowbush cranberry, mooseberry	Caprifoliaceae
Viburnum trilobum	*Viburnum trilobum*	highbush cranberry	Caprifoliaceae
Vicia americana	*Vicia americana*	American vetch, vetch	Fabaceae (Leguminosae)

APPENDIX 5
Netley-Libau Marsh project files

The two DVDs included with this report contain all files associated with the study. The files include:

1. Infrared aerial photographs in JPEG format; 106 images in total, each scanned from the original contact prints at 300 dpi, saved initially in TIFF format then converted to JPEG after georectification was complete (see below). Files were numbered sequentially (netley001.jpg to netley106.jpg) and Figure A5 is an index to their locations.
2. Georectified, uncropped infrared aerial photographs based on the scanned TIFF images. These images were georectified using ERDAS Imagine 8.5 and saved originally in proprietary IMG format then converted to GeoTIFF (netley001.tif to netley106.tif) which preserves georeferencing data within the file. The coordinate system used in all files was UTM Zone 14, NAD 83. These files can be viewed by most image viewers, and will display in correct geographic coordinates in a GIS.
3. Georectified, cropped infrared aerial photographs in IMG format (netley001.img to netley106.img), each with a corresponding data file (netley001.rrd to netley106.rrd). These images were cropped to eliminate the photo boundaries for mosaicing the images together. The RRD files created by Imagine 8.5 contain the geographic data, without which the files will not be displayed in the correct geographic coordinates. The extension "IMAGINE image support" must be loaded to view these images using ArcView 3.2.
4. Georeferenced vegetation maps of Netley-Libau Marsh from the 2001 study, as well as from 1979 and other associated GIS layers such as roadways and labels. All digital vegetation map files and printable map products were created in ArcView 3.2. The latter can be printed from the included ArcView 3.2 project files (e.g., 2001 final netley-libau veg maps.apr). Because of the way that ArcView organizes its files, the program will ask for the location of all layer files or Themes (such as vegetation, road, and name layers) when the project is opened initially. Follow the prompts and locate all files that are requested from the Netley Marsh Study folder. Once the project is resaved, this step will not be needed when the project is reopened. Each vegetation map or ArcView Theme has three to five associated files that are all needed to use them in Arcview 3.2. The primary Shapefile (.shp), the database table (.dbf), and three other related files (e.g., 1979 netley veg complete.shp, 1979 netley veg complete.dbf, 1979 netley veg complete.shx, 1979 netley veg complete.sbn, and 1979 netley veg complete.sbx). Some only consist of the SHP, DBF, and SHX files. All required legends (AVL files) for the vegetation classification are supplied for use in ArcView 3.2. Logos from the partners involved in this study (used by the project files for the large printable map products) are included.
5. A final uncompressed TIFF image ("Netley-Libau Marsh mosaic 2001.tif") of the photomosaic was created and seams between tiles were blended using Adobe Photoshop 5.5 to produce a large format seamless color photograph of the entire marsh. The file can be viewed in most image viewers. Accuracy of the associated world file (TFW) is minimal and is only meant to be used for navigation purposes. The 2001 vegetation map was based on this photomosaic.
6. The original scanned copies of the 1979 paper maps, which are all georectified for use in a GIS (e.g., goldeye1979.aux, goldeye1979.rrd, and goldeye 1979.tif). The TIFF images can be viewed alone but the RRD file is needed for them to be viewed with correct geographic coordinates in a GIS. The AUX file is an Imagine 8.5 data file.
7. Scanned copies of historical paper maps from various years. These are all provided in TIFF format, which can be viewed in most image viewers.

Also contained on the DVDs are the digital files for this report in Adobe Acrobat 6 (PDF) and Adobe Pagemaker 7 (PMD) formats, and aerial photographs taken over Netley-Libau Marsh in October 2003 and November 2004 (JPEG format).

Figure A5. Index map to the numbered IMG files contained on the accompanying DVDs.