WATER AND VEGETATION COVER IN NETLEY-LIBAU MARSH 1990 – 2013

PHASE II REPORT: A TIME SERIES ANALYSIS BASED ON LANDSAT IMAGERY

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1.0 ABSTRACT

Netley-Libau Marsh, the largest coastal wetland adjoining Lake Winnipeg, has been mapped by aerial photography in the past (Grosshans et al 2004; Verbiwski 1986), indicating a trend of vegetation loss, but a lack of historic aerial photography has limited mapping efforts to sporadic intervals. Satellite imagery, though of a coarser spatial resolution, has the advantage of high temporal and spectral resolution. Using Landsat images and a methodology developed in an earlier phase of this study (Watchorn 2014), a time series of classified vegetation cover maps was produced for twelve years between 1990 and 2013. Water cover maps were produced for another eight years within this interval, resulting in a time series representing 20 years of this 23-year period. This time series allowed for an investigation into relationships between the extent and distribution of Netley's vegetation community to underlying hydrological factors on adjoining Lake Winnipeg and the Red River, which can be used to guide future marsh remediation measures.

The analysis of this time series indicates that the long-term trend of vegetation loss in Netley-Libau Marsh has not been steady, nor has it been unidirectional. Observed vegetation change – both loss and gain – was characterised by sudden dramatic changes disrupting periods of relative stasis. Lake Winnipeg water level was identified as the major factor responsible for shifting the balance between emergent wetland vegetation and open water. Periods of low water as short as one year had dramatic and persistent effects on emergent vegetation cover, particularly in smaller lakes. Regenerated emergent vegetation was less persistent in the large Netley Lake, suggesting that marsh bathymetry is dynamic. This study also identified that Lake Winnipeg water level and Red River flow are both contributing factors which influence the extent of wet meadows around Netley-Libau Marsh. Decreased river discharges and lake levels were correlated with increasing use of these regions as hayed or cultivated land. Finally, the interpretation of the cover map time series indicates the connectivity between the marsh lakes and Lake Winnipeg has varied and is presently increasing.

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6.0 INTRODUCTION

Lake Winnipeg is a large, shallow, hypereutrophic lake in Manitoba, Canada, which has experienced more frequent harmful algal blooms as nutrient loading has increased from its tributaries, particularly the Red River (Environment Canada and Manitoba Water Stewardship 2011). Netley-Libau Marsh, located adjacent to the Lake Winnipeg's south shore (50.3°N, 96.8°W), forms the delta of the Red River as it flows north into the lake (Figure 6.1). Hydrogeomorphically classified as a barred drowned river mouth (Watchorn et al 2012), Netley-Libau is a complex of over 20,000 ha of open bays, channels, and wetland vegetation, separated from Lake Winnipeg by an incomplete barrier beach ridge. Though historically the marsh abounded with emergent vegetation, which sequestered nutrients (Cicek et al 2006; Grosshans et al 2004) and provided fish and wildlife habitat, it has long been noted that the extent of open water bays has been increasing, while areas of emergent wetland vegetation have become reduced (Verbiwski 1986). This degradation is thought to have reduced the ability of the marsh to sequester nutrients transported to Lake Winnipeg by the Red River (Grosshans et al 2004).

Maps displaying vegetated and open water areas of Netley date back to 1922 (Public Works Canada 1922), but the first attempts to map and classify vegetation within the marsh were undertaken in the 1980s by Hathout and Simpson (1982) and Verbiwski (1980; 1986). Using colour infrared aerial photography shot in 1979, Verbiwski created a map delineating nine classes of vegetation within five marsh zones: *water, emergent, wet meadow, low prairie,* and *upland*. Comparable imagery was used by Grosshans (et al 2004) to create a map of Netley for the year 2001, using a comparable classification methodology which was able to resolve a further thirteen cover classes including a sixth marsh zone of *non-vegetated* areas. Between 1979 and 2001, the area of open water within Netley-Libau Marsh had increased by 48%, while the extent of emergent and wet meadow vegetation had declined by 41%.

Many factors have been implicated in the loss of emergent vegetation and other land in Netley-Libau Marsh. Grosshans et al (2004) proposed that the introduction of the invasive common carp (*Cyprinus carpio*) and the increased nutrient load of the Red River may have contributed to some deterioration of wetland vegetation. Nielson (1998) identified a centuries-long trend of southward transgression of the barrier beach ridge due to isostatic rebound following the last period of glaciation. Grosshans et al (2004) also provide compelling circumstantial evidence that contributing causes of Netley's vegetation degradation may include changes to the hydrological regime of Lake Winnipeg and the Red River. Flows on the Red River have been increasing since the 1990s (Lake Winnipeg Stewardship Board 2006; Lévesque and Page 2011) and the frequency of major floods has also increased over this period (Red River Basin Commission 2011). The cessation of dredging of the Red River at its mouth in 1999 (KGS Group 2002) has caused a backflood effect, causing greater volumes of water to enter Netley-Libau Marsh via channels through the riverbanks, before it can reach Lake Winnipeg (Manitoba Hydro 2014). One of these channels, The Cut, was excavated as a narrow channel to Netley Lake in 1913 (Goldsborough 2015) but is now wider than the river itself, and carries approximately one third of its flow into the wetland rather than along its traditional channel (Clark 2014). A long wet cycle across the Lake Winnipeg watershed has contributed to a higher water level regime in recent decades (McCullough 2015), while the regulation of Lake Winnipeg levels by Manitoba Hydro has dampened the potential for periodic lowest water levels (Hutchinson 2014). Though Netley's vegetation cover has been observed to change following low and high water flows to and levels on Lake Winnipeg (Grosshans et al 2004), it is difficult to infer a long term trend or underlying relationships between vegetation distribution and hydrology based on only the two snapshots in time provided by Verbiwski and Grosshans: impacts to the vegetation community of antecedent conditions in the short term – such as a period of low water facilitating recruitment of emergent vegetation from the seedbank – are unknown. A time series of vegetation maps, with sufficient temporal and comparable spatial resolution, would be necessary in order to explore trends in vegetation change and their relationship to hydrological alterations.

Although aerial photography has been the preferred imagery for wetland vegetation classification based on its spatial resolution, it is expensive to obtain, and only sporadic historic images exist. Satellite imagery, though often with lower spatial resolution, can provide increased temporal resolution, increased spectral resolution, and an easily-accessible archive of the complete historic record since the launch of the satellite in question. In a previous phase of this study, a visual delineation and classification methodology was developed to create a classified digital vegetation map of Netley-Libau Marsh in 2001 using GIS software and Landsat 7 imagery (Watchorn 2014). A comparative analysis of this map with that produced by Grosshans et al (2004) demonstrated that satellite imagery may be used to map wetland vegetation, accurately and in sufficient detail.

In this second phase, the techniques developed in that work were employed to produce a time series of vegetation maps for Netley-Libau Marsh from 1990 to 2013. This time series allowed for an investigation into relationships between the extent and distribution of Netley's vegetation community to underlying hydrological factors on adjoining Lake Winnipeg and the Red River, which can be used to guide future remediation measures.

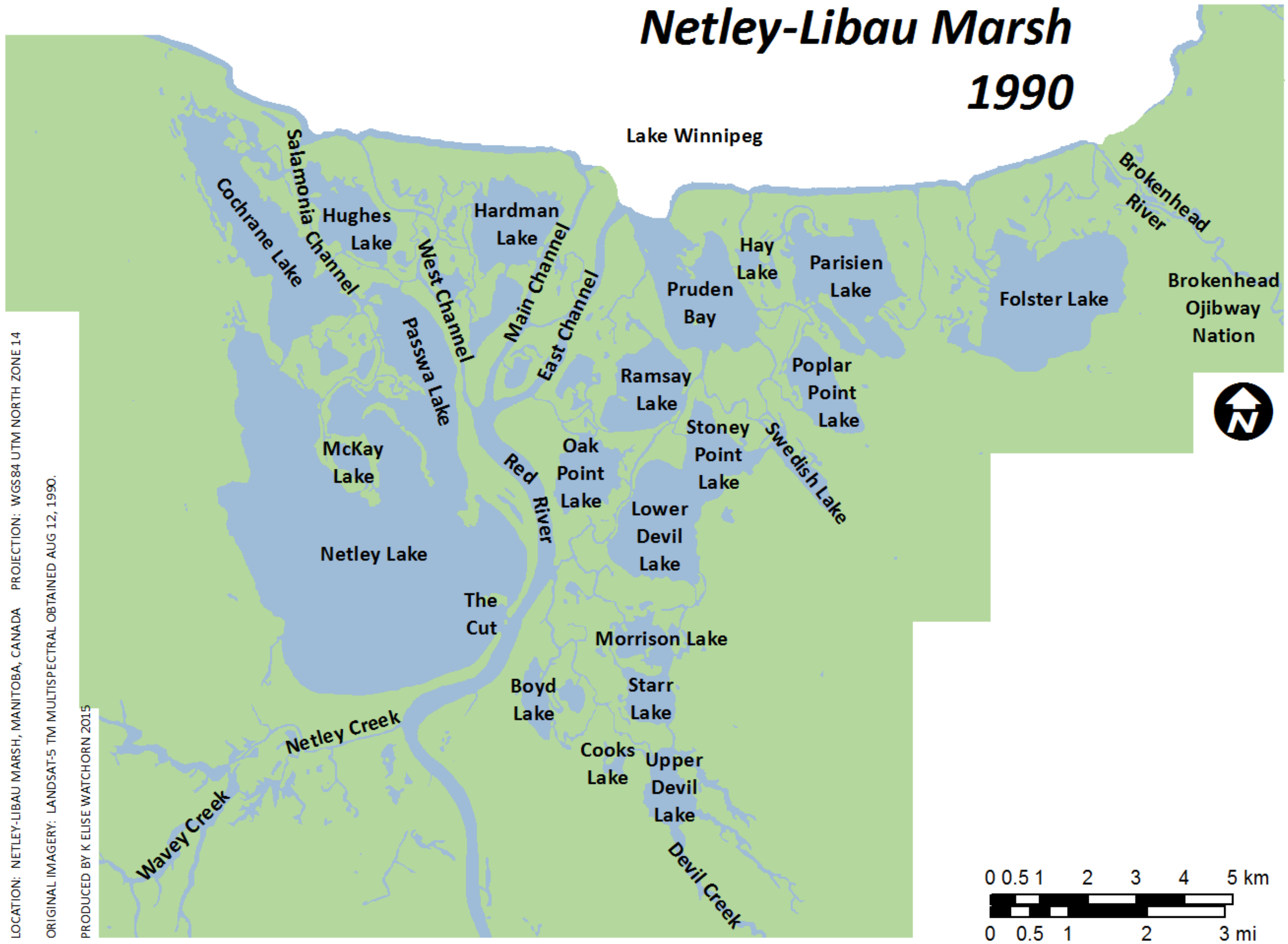


Figure 6.1: Waterbodies and landmarks on Netley-Libau Marsh, 1990.

7.0 METHODOLOGY

7.1 IMAGES SELECTION AND PROCESSING

Imagery from Landsat-5, Landsat-7 and Landsat-8 with 30m spatial resolution was provided by Environment Canada geomatics specialist Guy Létourneau, for as many years as possible between 1990 and 2013. In several years, only one suitable Landsat image was available. For years in which multiple Landsat images were available, a single image was selected for analysis, according the following hierarchy of rules. First, cloud-free images were chosen over images in which some portion of the area of interest was obscured by clouds. Secondly, images captured within the last week of July or first week of August were preferred to images captured earlier or later, so that plants were at approximately the same stage of development, and therefore appeared with similar spectral signatures as in the 2001 Landsat image which has been truthed to aerial photography (Watchorn 2014). Thirdly, images obtained via the same Landsat thematic mapper as the preceding and following years were chosen where possible, to minimize artefacts from minor differences in band spectra. Table 7.1 lists those images which were ultimately selected, and on which further mapping has been based.

All images were georeferenced to UTM Zone 14N / WGS 84, cropped to focus on Netley-Libau Marsh, and saved in PCI Geomatica format (.pix) by Guy Létourneau. Minor georeferencing issues with the 1997 image were rectified with a nearest neighbour / first order polynomial technique, through the addition of 8 road intersections as control points, based on the 1999 image. Comparable band combinations to those described in Watchorn (2014, Table 6.1) were used to display and visualise the images.

7.2 VEGETATION DELINEATION AND CLASSIFICATION

Esri ArcGIS 10.2 software was used for image analysis and cover mapping, following a methodology modified from Watchorn (2014). The 2001 polygon coverage produced by that work, comprising 34799 ha of the Netley-Libau area, was used as a template for the 2000 and 2002 maps. In each case, a copy of the 2001 polygon feature class was made, then modified according to differences in the distribution of water and vegetation. Similarly, polygons from 2000 were used as templates for 1999; 2002's polygons were used as templates for 2003; and so on. By these means, the introduction of classification artefacts was minimised.

Table 7.1: Landsat images selected for a time series analysis of cover types in Netley-Libau Marsh, 1990 - 2013. Digital water coverage maps were produced from all available images; vegetation coverages were produced from those images of appropriate quality and in which seasonal plant development was suitable for classification (see Section 7.2.1.)

Year	Image Type	Date	Water Coverage	Vegetation Coverage
1990	Landsat-5	12/08/1990	x	x
1992	Landsat-5	17/08/1992	x	x
1993	Landsat-5	20/08/1993	x	x
1994	Landsat-5	22/07/1994	x	x
1995	Landsat-5	26/08/1995	x	
1996	Landsat-5	12/08/1996	x	
1997	Landsat-5	30/07/1997	x	x
1999	Landsat-7	28/07/1999	x	x
2000	Landsat-7	30/07/2000	x	x
2001	Landsat-7	02/08/2001	x	x
2002	Landsat-7	05/08/2002	x	x
2003	Landsat-5	16/08/2003	x	
2005	Landsat-5	05/08/2005	x	x
2006	Landsat-5	25/09/2006	x	
2007	Landsat-5	11/08/2007	x	
2008	Landsat-5	29/08/2008	x	
2009	Landsat-5	01/09/2009	x	
2010	Landsat-5	03/08/2010	x	x
2011	Landsat-5	07/09/2011	x	
2013	Landsat-8	11/08/2013	x	x

Each polygon was inspected to determine whether the cover type still matched the class assigned for the previously mapped year, guided by the vegetation classification key (Watchorn 2014, Table 6.3). Where a stand completely changed from one cover type to another, the polygon's attributes were edited and reclassified. Images were then inspected at a 1:15000 resolution to determine where a cover type remained consistent through to the adjacent year, but with shifted stand boundaries. Existing polygons were edited, reshaped, merged, clipped, exploded, and/or split to appropriately represent changing stand shapes. The error inspector tool, referenced to a customised geodatabase topology, ensured that polygon coverages remained complete, without gaps, slivers, or overlaps.

7.2.1 Challenges

Clouds posed a small challenge to producing the time series of Netley-Libau Marsh cover maps. Though imagery with cloud cover was avoided to the extent possible, a limited selection meant it was inevitable but that some maps would need to be produced from images showing minimal clouds. Where clouds obscured a portion of the area of interest, as they did in the 1993, 2007, 2008, and 2013 images, cover class boundaries were assumed to be the same as the adjacent year that had already been mapped.

Some spectral challenges were anticipated because of the variation in Landsat sensors. The images used in this time series were captured by three different Landsat satellite thematic mappers: Landsat-5, Landsat-7, and Landsat-8. The main band combination for inspection were bands 4,5,3 on Landsat-5 and Landsat-7, and bands 5,6,3 on Landsat-8. (Other band combinations, as described in Watchorn 2014, contributed supplemental classification information.) These bands measure a comparable, but not precisely equivalent, range of spectra: each satellite has slight differences in the endpoints of wavelengths captured on each band, particularly Landsat-8. The challenge posed by switching back and forth between differently sensed imagery from year to year was mainly avoided by image selection rules which accounted for sensor consistency. Only one Landsat-8 image was the basis of a cover map (2013); it was of high quality, and its band information translated well between the Landsat-5 image from the adjacent year.

There were greater spectral challenges posed by the wide range in time of year when images were captured. The images selected for this time series mapping exercise ranged from July 22 to September 25. Images dated between late July and mid-August showed appropriate and distinct spectral signatures for the major vegetation types (comparable to Figure 6.3, Watchorn 2014), and were suitable for producing vegetation cover maps.

However, images dated from late August through September did not produce sufficiently distinct spectral signatures for distinguishing most vegetation subclasses. This lack of distinguishing information for classification can be attributed to a loss of chlorophyll and moisture as leaves cease growing and begin to senesce. The effect was particularly pronounced in the inner marsh amongst newer growth, presumably because there is less organic litter contributing to a background signal. (For example, new cattail growing near open water zones appears different from cattail growing deeper inland, partly because of the presence of litter. In midsummer, there is sufficient spectral information to differentiate litter-less cattail from the bulrush/sedge/phragmites complex. However, as the vegetation starts to senesce, where there is little to no litter, the two stand types appear less distinct.) Despite an investment of effort, it was not deemed feasible to produce vegetation coverages for several years in which the only available images were taken too late in the season. Those years for which vegetation coverages were produced are indicated in Table 7.1. Water coverages, however, were mapped for all years in which Landsat imagery was available.

A final challenge was presented where new growth of emergent vegetation appears: it can be very difficult or impossible to classify newly established emergent plants. In the case of small new stands there is so much edge noise from the surrounding water or vegetation that the spectral signal is diluted. In the case of large new stands, the lack of organic litter from previous seasons means that water or exposed mud between shoots can overwhelm the signal.

The effects of these multiple challenges to vegetation delineation and classification were cumulative, with the result that some new emergent stands could not be identified to vegetation class. It is unfortunate that the zone of most interest to this investigation should be so challenging to classify. The emergent stands which eluded classification were assigned a vegetation class of *unidentified emergent*.

7.3 Hydrological Relationships

Relationships between hydrology and vegetation extent were investigated by linear regression. The yearly total area of each vegetation class and marsh zone, as well as the change in area since the last mapped year in the areas of each vegetation class and marsh zone were treated as dependent variables.

Hydrometric parameters, including metrics of the level on Lake Winnipeg at Gimli and discharge on the Red River at Lockport (1990-2008) and Selkirk (2008-2013), were treated as independent variables. Selkirk river discharges were assumed to be equivalent to those at Lockport; given the short distance between the two (~12 km by river), that the slope of the river in this reach is almost flat (<0.00001m/m; Lindenschmidt 2012), and that Water Survey of Canada reports their drainage areas as equal.

Lake level parameters considered were mean daily lake level on the date of Landsat image capture, maximum daily lake level between April and July, minimum daily lake level between April and July, mean April to July lake level, mean June to July lake level, and mean June lake level. Red River discharge parameters investigated included daily discharge on the date of Landsat image capture, maximum daily charge between April and July, minimum daily discharge between April and July, mean April discharge, mean May discharge, mean June discharge, mean July discharge, mean April to July discharge, and mean June to July discharge. For one daily discharge value that was unavailable, it was linearly interpolated based on values the previous and next available reading. Where mean monthly discharges were not available, missing daily discharges were determined by linear interpolation, then the mean of daily discharges was calculated. Both actual hydrometric parameters, as well as the change in those hydrometric parameters since the previously mapped year, were considered.

Correlations where $p < 0.05$ have been reported as significant. Due to the very small sample sizes of the comparisons in question ($n = 11$ to 20), Type II errors are to be expected, and therefore any relationships where $p < 0.1$ have been reported as suggestive, and warranting further investigation.

7.4 Vegetation Cover Surrounding Reference Points

A list of eight fixed reference points was provided by Environment Canada (Table 7.2), for the assessment of 2011 and 2013 vegetation cover within 500m and 1000m of each. Of the eight points, only one (Site ID

I) was wholly within the mapped area of Netley-Libau Marsh (as defined by Grosshans et al 2004 and Watchorn 2014). Four were partially within the mapped area (Site IDs *C, F, K, L*); while three were completely outside (Site IDs *B, J, M*). Vegetation and water was delineated and classified in these additional zones for 2013, then clipped to a 500m and 1000m radius of each reference point using the buffer tool.

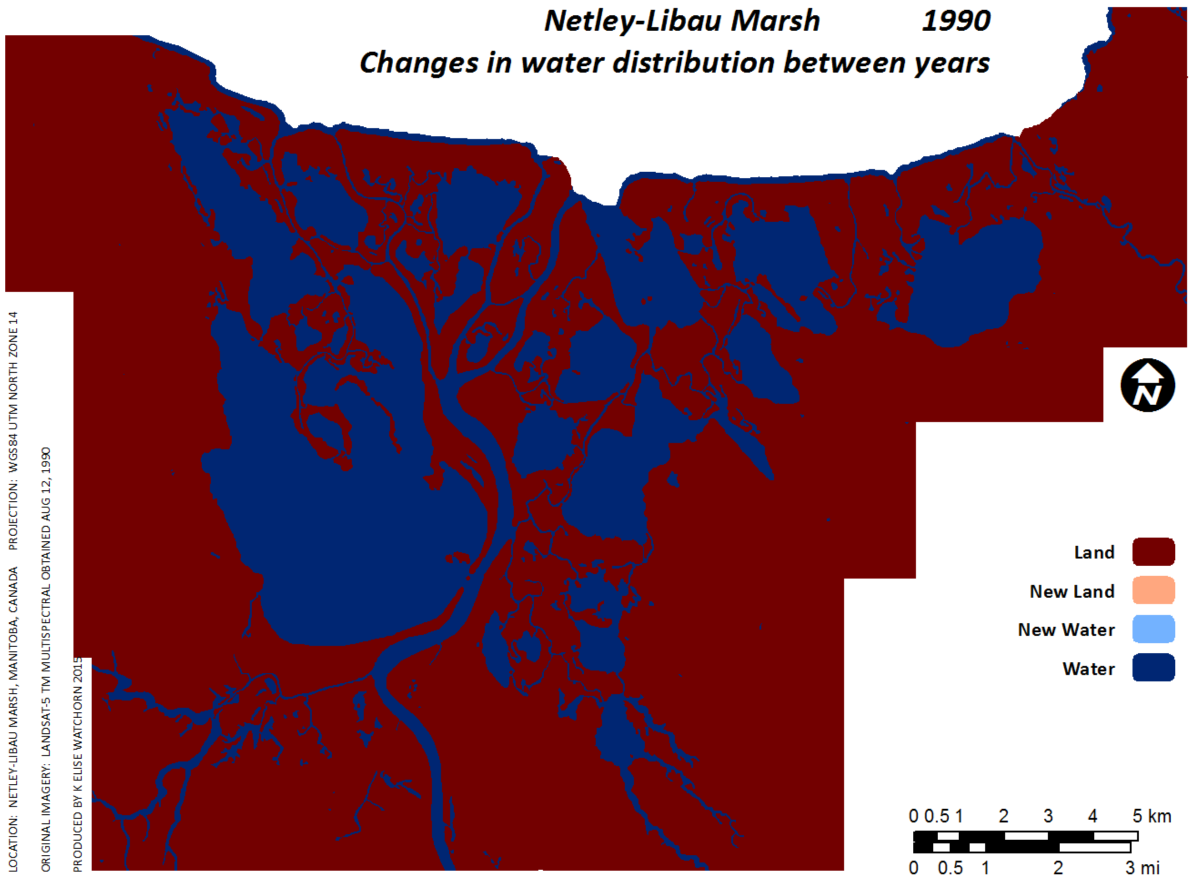
The Landsat image for 2011 was taken in September, which was deemed too late in the season to be reliably mapped for emergent vegetation (Table 7.1). However, because the majority of the reference points were located in upland areas, where late-season vegetation signatures were somewhat more distinct, an attempt was made to map 2011 vegetation only in their immediate vicinity. It should be noted that the classification of emergent vegetation and wet meadow may be less accurate in these 2011 maps than elsewhere. The 2013 coverage was used as a template, which was modified as appropriate for 2011.

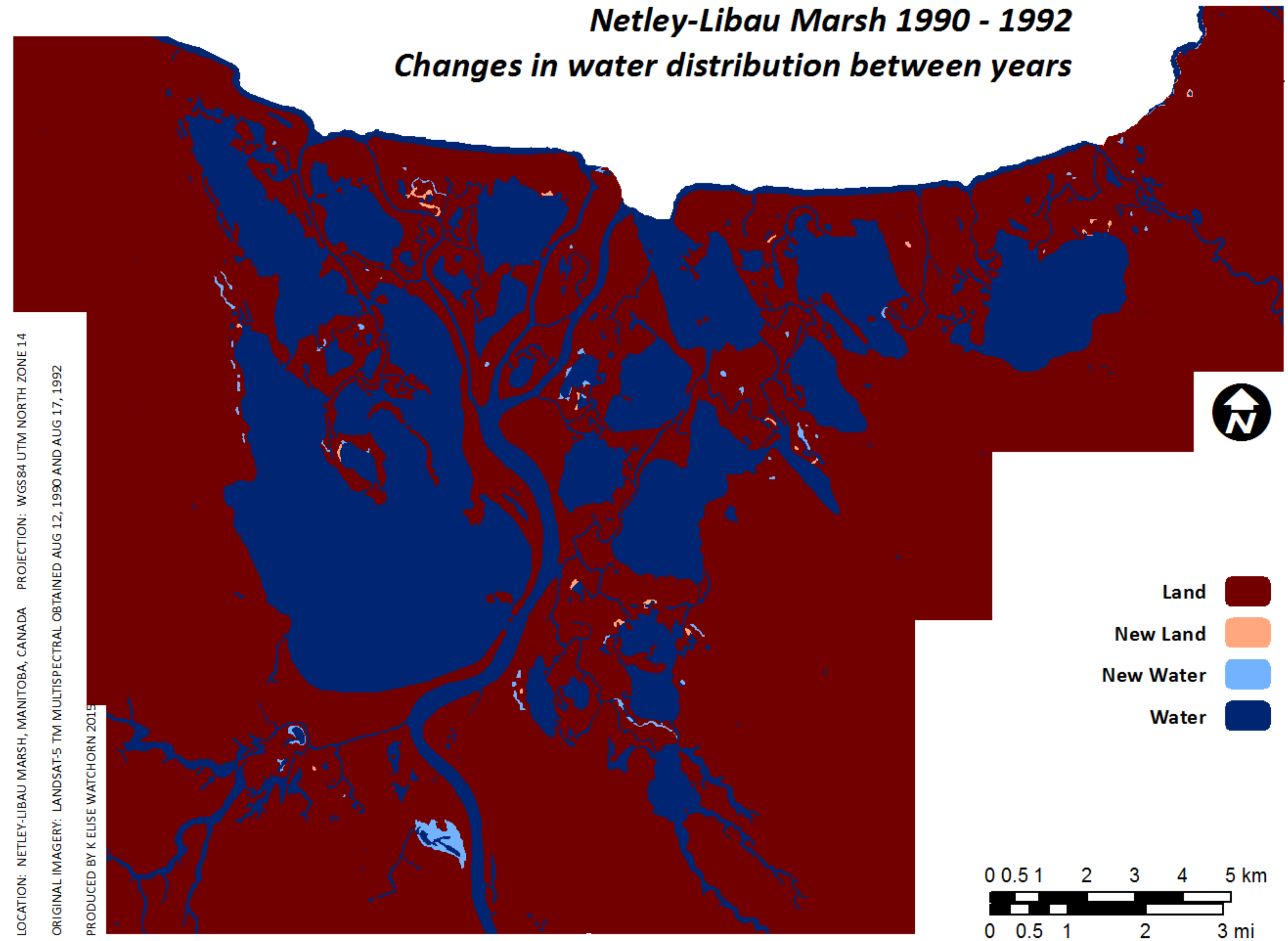
Table 7.2: Locations of reference points specified by Environment Canada around which surrounding vegetation was quantified.

Reference Point	Coordinates N	Coordinates W	Within Netley mapped extent?	Comments
B	50.243653	96.880225	no	
C	50.246439	96.844153	partial	cloudy in 2013
F	50.337914	96.697086	partial	
I	50.291889	96.917806	yes	cloudy in 2013
J	50.211536	96.839794	no	
K	50.359808	96.623475	partial	settled area of Brokenhead Ojibway Nation
L	50.424392	96.608219	partial	
M	50.240386	96.95375	no	somewhat cloudy in 2013

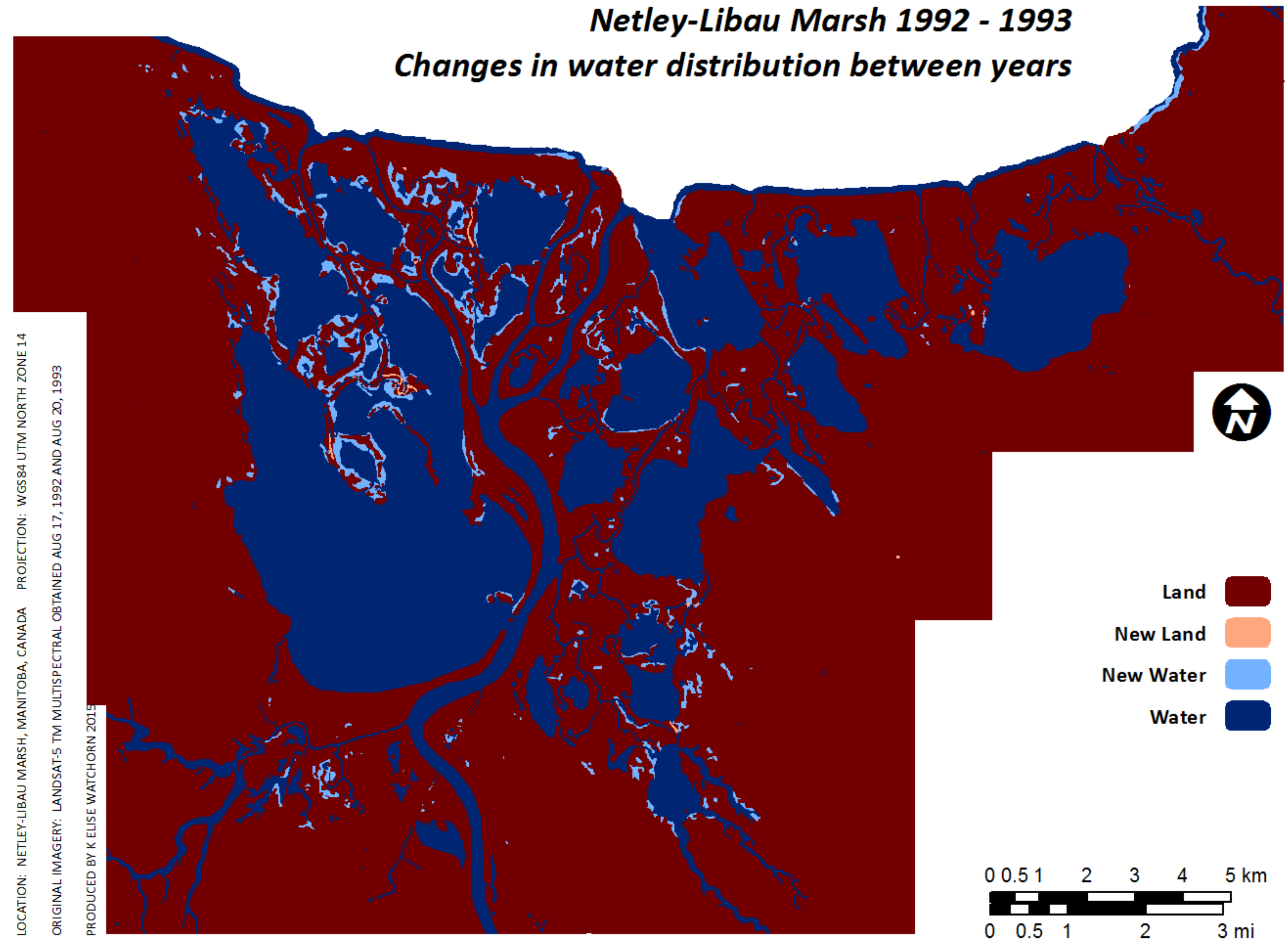
8.0 MAP SERIES

Map Series 8.1: Annual maps of Netley-Libau Marsh, 1990 – 1993, displaying areas which changed between water and other marsh zones from the previous mapped year.

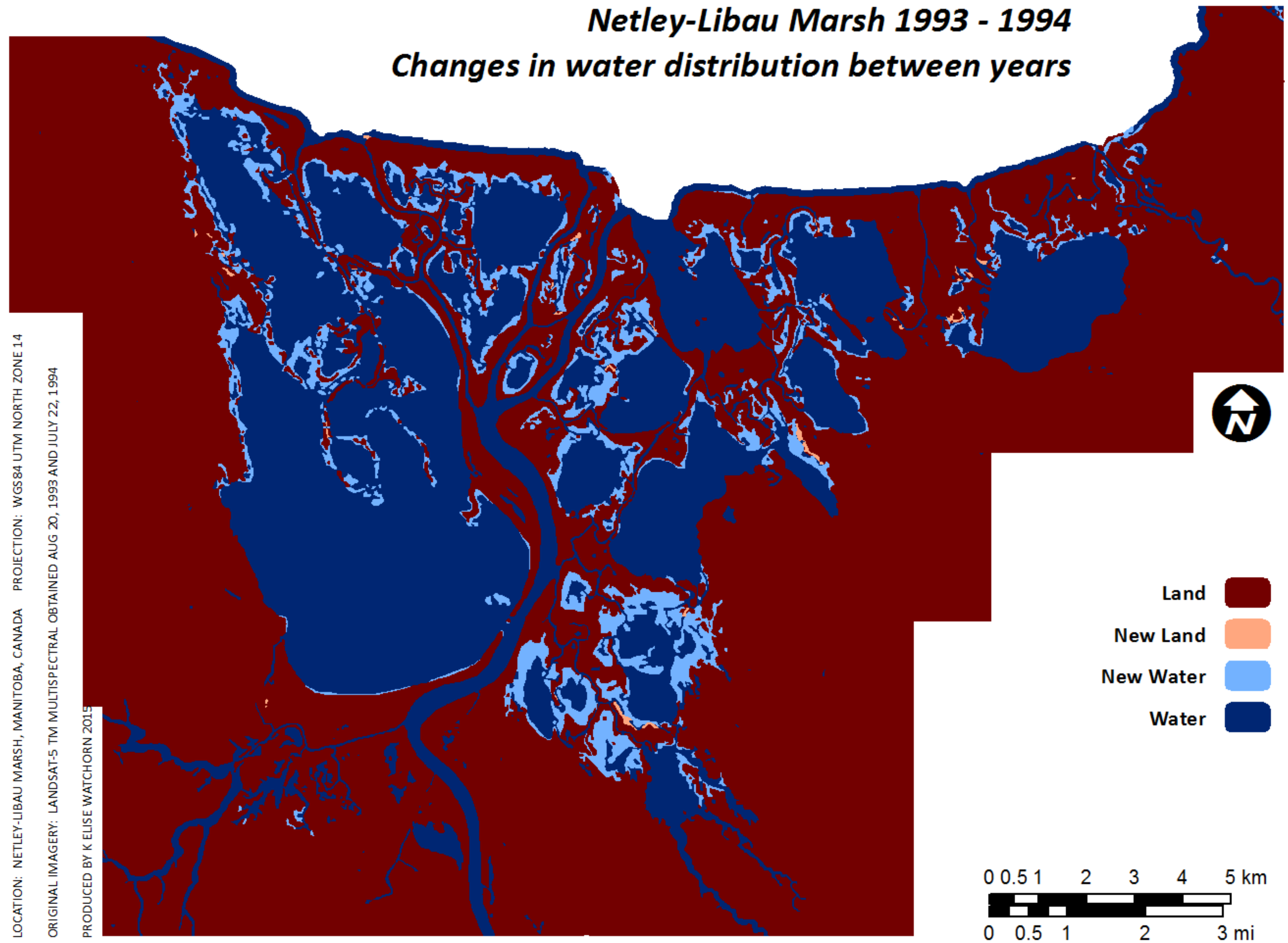




Netley-Libau Marsh 1990 - 1992
Changes in water distribution between years
Land
New Land
New Water
Water
N
0 0.5 1 2 3 4 5 km
0 0.5 1 2 3 mi
LOCATION: NETLEY-LIBAU MARSH, MANITOBA, CANADA PROJECTION: WGS84 UTM NORTH ZONE 14
ORIGINAL IMAGERY: LANDSAT-5 TM MULTISPECTRAL OBTAINED AUG 12, 1990 AND AUG 17, 1992
PRODUCED BY K ELISE WATCHORN 2015



Netley-Libau Marsh 1992 - 1993
Changes in water distribution between years
LOCATION: NETLEY-LIBAU MARSH, MANITOBA, CANADA PROJECTION: WGS84 UTM NORTH ZONE 14
ORIGINAL IMAGERY: LANDSAT-5 TM MULTISPECTRAL OBTAINED AUG 17, 1992 AND AUG 20, 1993
PRODUCED BY K ELISE WATCHORN 2015
N
Land
New Land
New Water
Water
0 0.5 1 2 3 4 5 km
0 0.5 1 2 3 mi


Netley-Libau Marsh 1993 - 1994
Changes in water distribution between years
Land
New Land
New Water
Water
0 0.5 1 2 3 4 5 km
0 0.5 1 2 3 mi
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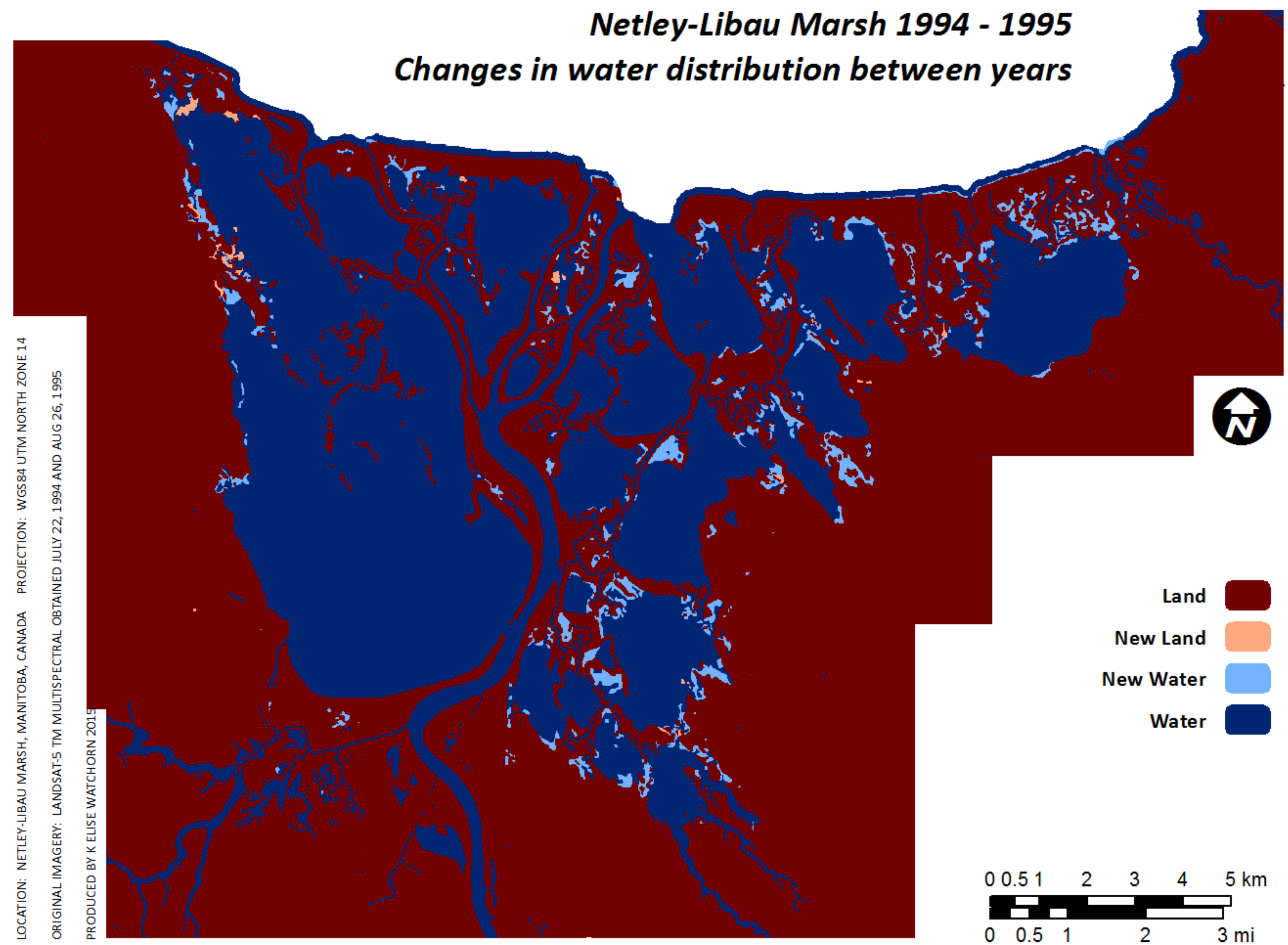
PRODUCED BY K ELISE WATCHORN 2015



Netley-Libau Marsh 1994 - 1995
Changes in water distribution between years
LOCATION: NETLEY-LIBAU MARSH, MANITOBA, CANADA   PROJECTION: WGS84 UTM NORTH ZONE 14
ORIGINAL IMAGERY: LANDSAT-5 TM MULTISPECTRAL OBTAINED JULY 22, 1994 AND AUG 26, 1995
PRODUCED BY K ELISE WATCHORN 2015
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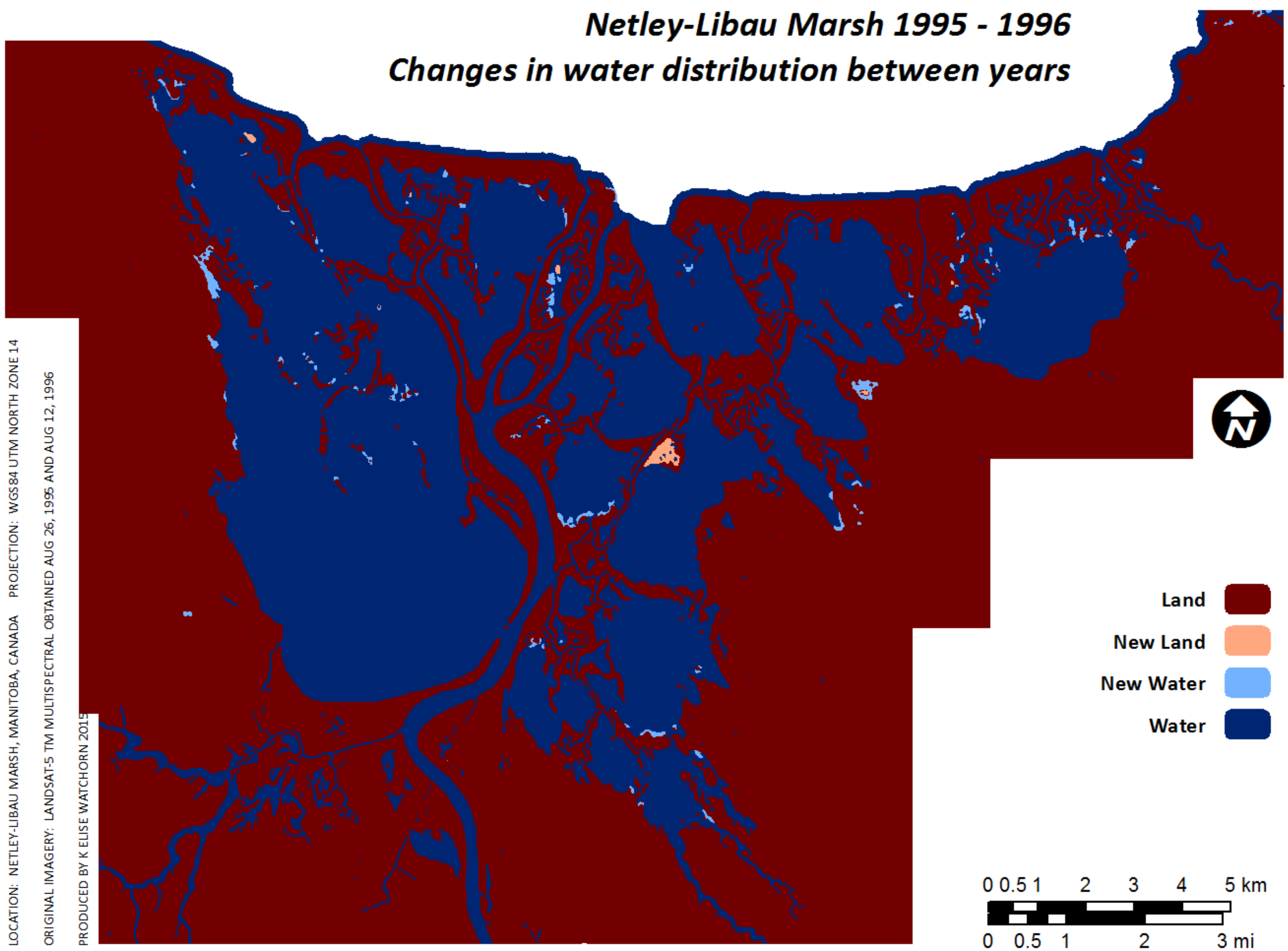
Land
New Land
New Water
Water
0 0.5 1 2 3 4 5 km
0 0.5 1 2 3 mi



Netley-Libau Marsh 1995 - 1996
Changes in water distribution between years
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ORIGINAL IMAGERY: LANDSAT-5 TM MULTISPECTRAL OBTAINED AUG 26, 1995 AND AUG 12, 1996
PRODUCED BY K ELISE WATCHORN 2015
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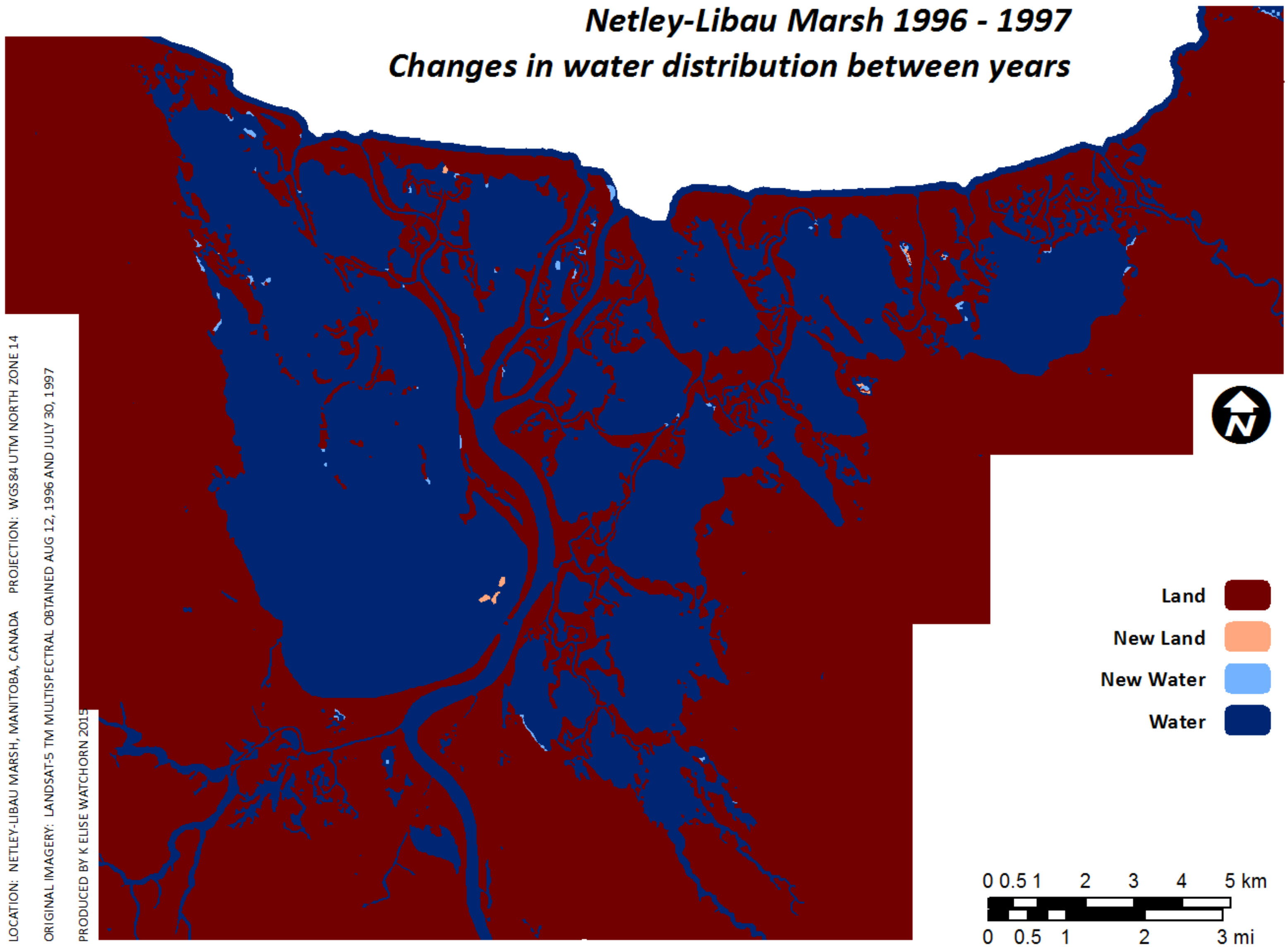
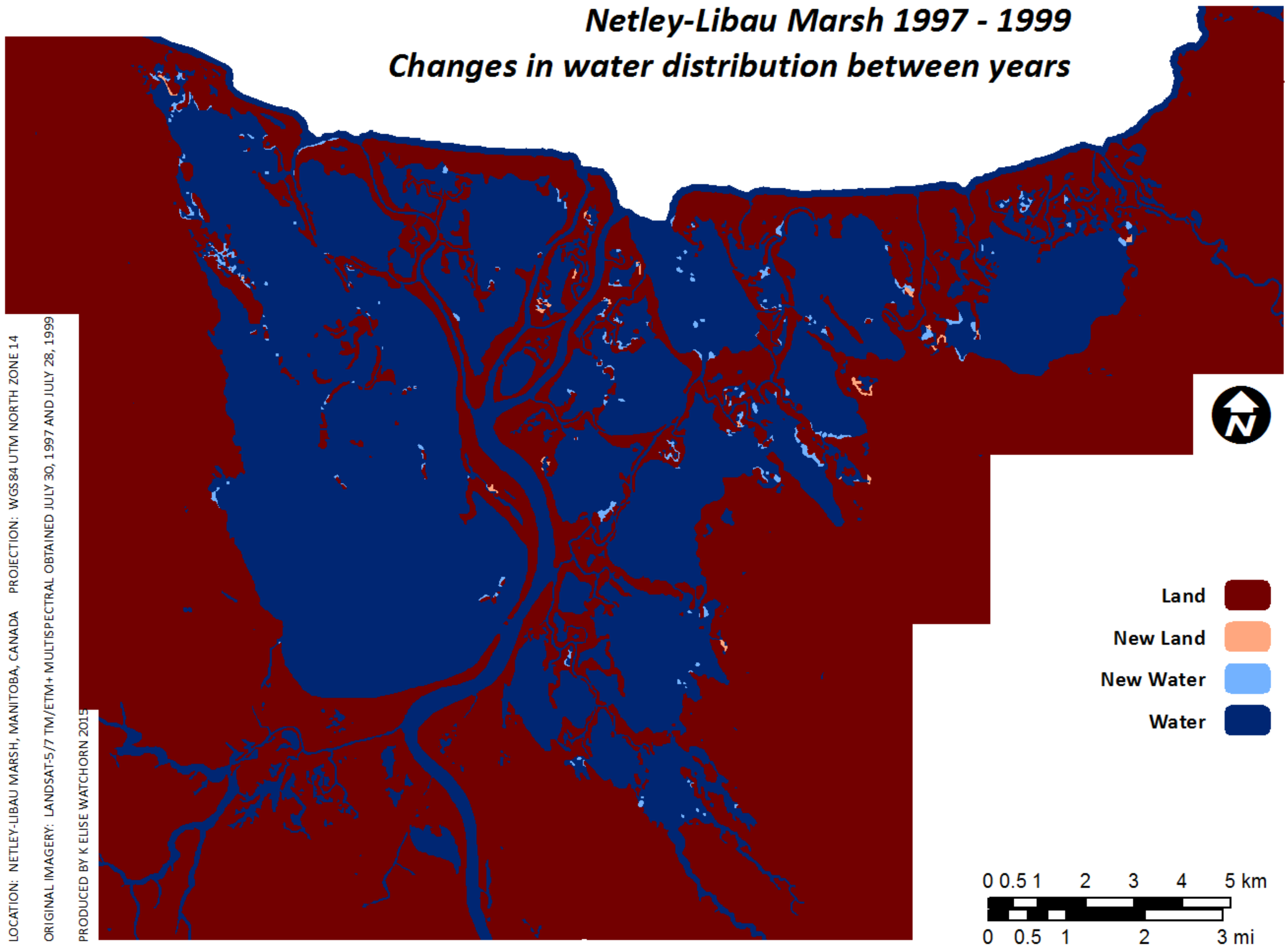
Land
New Land
New Water
Water
0 0.5 1 2 3 4 5 km
0 0.5 1 2 3 mi



Netley-Libau Marsh 1996 - 1997
Changes in water distribution between years
LOCATION: NETLEY-LIBAU MARSH, MANITOBA, CANADA PROJECTION: WGS84 UTM NORTH ZONE 14
ORIGINAL IMAGERY: LANDSAT-5 TM MULTISPECTRAL OBTAINED AUG 12, 1996 AND JULY 30, 1997
PRODUCED BY K ELISE WATCHORN 2015
N
Land
New Land
New Water
Water
0 0.5 1 2 3 4 5 km
0 0.5 1 2 3 mi


Netley-Libau Marsh 1997 - 1999
Changes in water distribution between years
LOCATION: NETLEY-LIBAU MARSH, MANITOBA, CANADA PROJECTION: WGS84 UTM NORTH ZONE 14
ORIGINAL IMAGERY: LANDSAT-5/7 TM/ETM+ MULTISPECTRAL OBTAINED JULY 30, 1997 AND JULY 28, 1999
PRODUCED BY K ELISE WATCHORN 2015
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Land
New Land
New Water
Water
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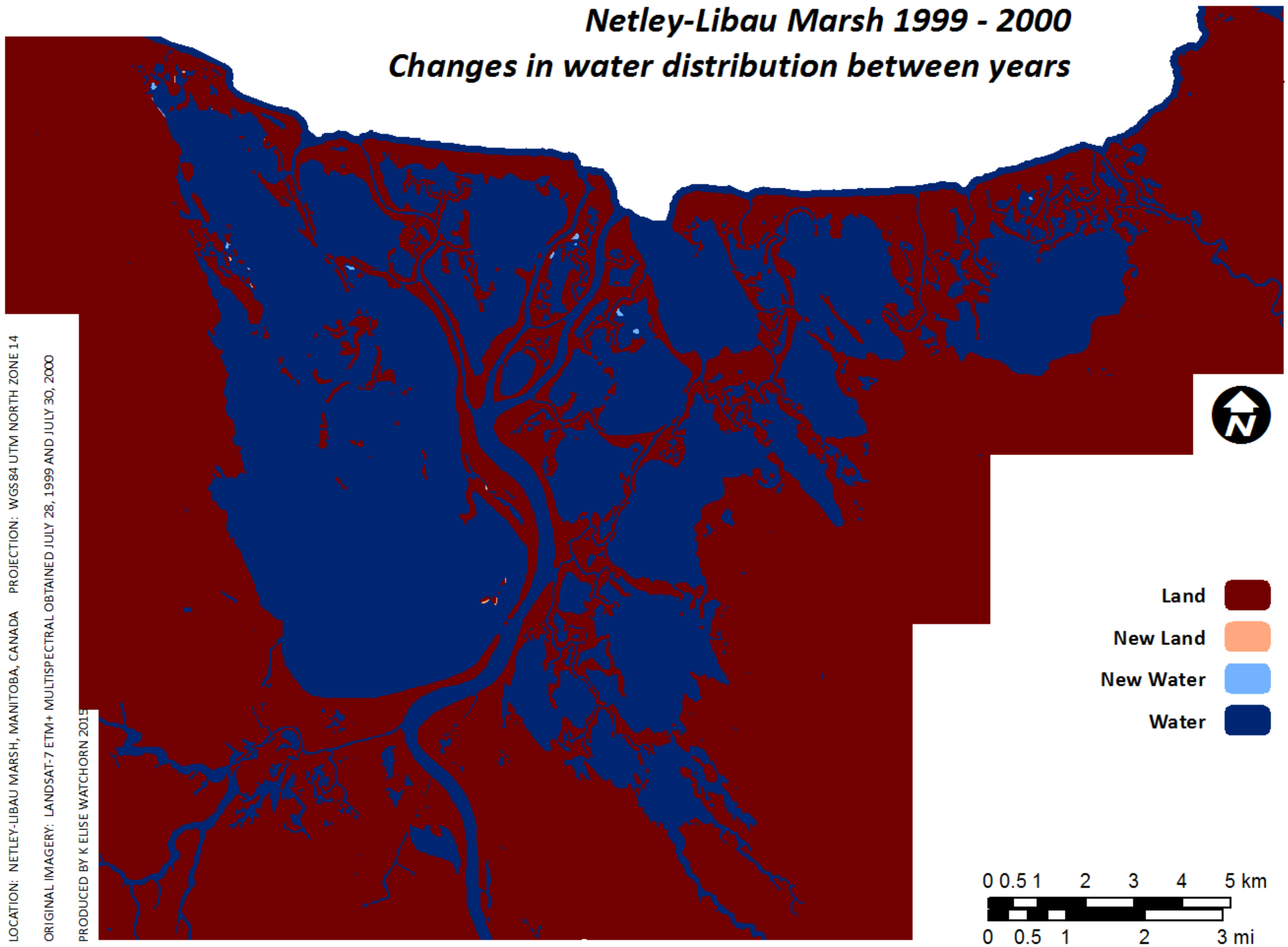
0 0.5 1 2 3 mi



Netley-Libau Marsh 1999 - 2000
Changes in water distribution between years
Land
New Land
New Water
Water
0 0.5 1 2 3 4 5 km
0 0.5 1 2 3 mi
LOCATION: NETLEY-LIBAU MARSH, MANITOBA, CANADA PROJECTION: WGS84 UTM NORTH ZONE 14
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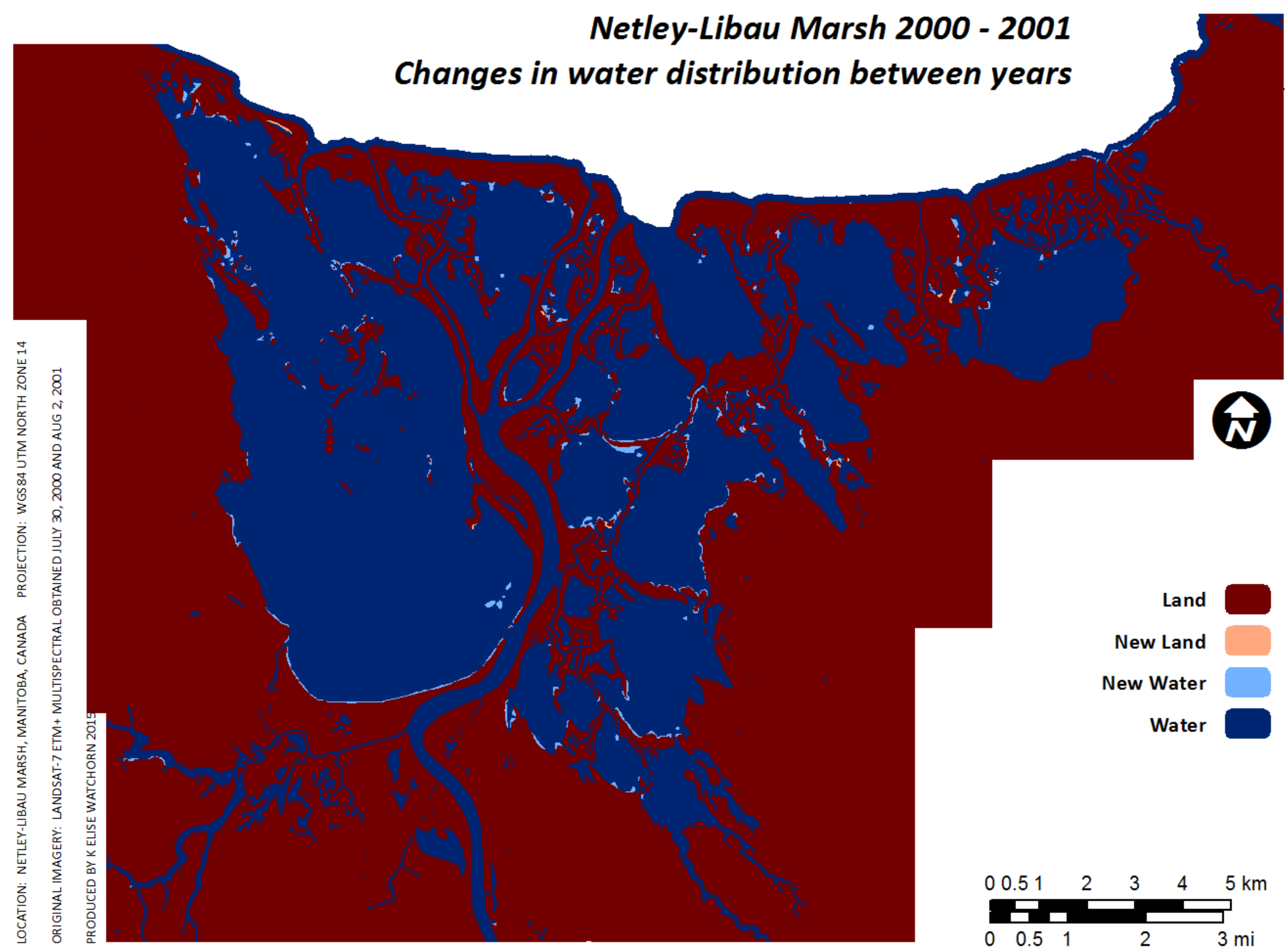
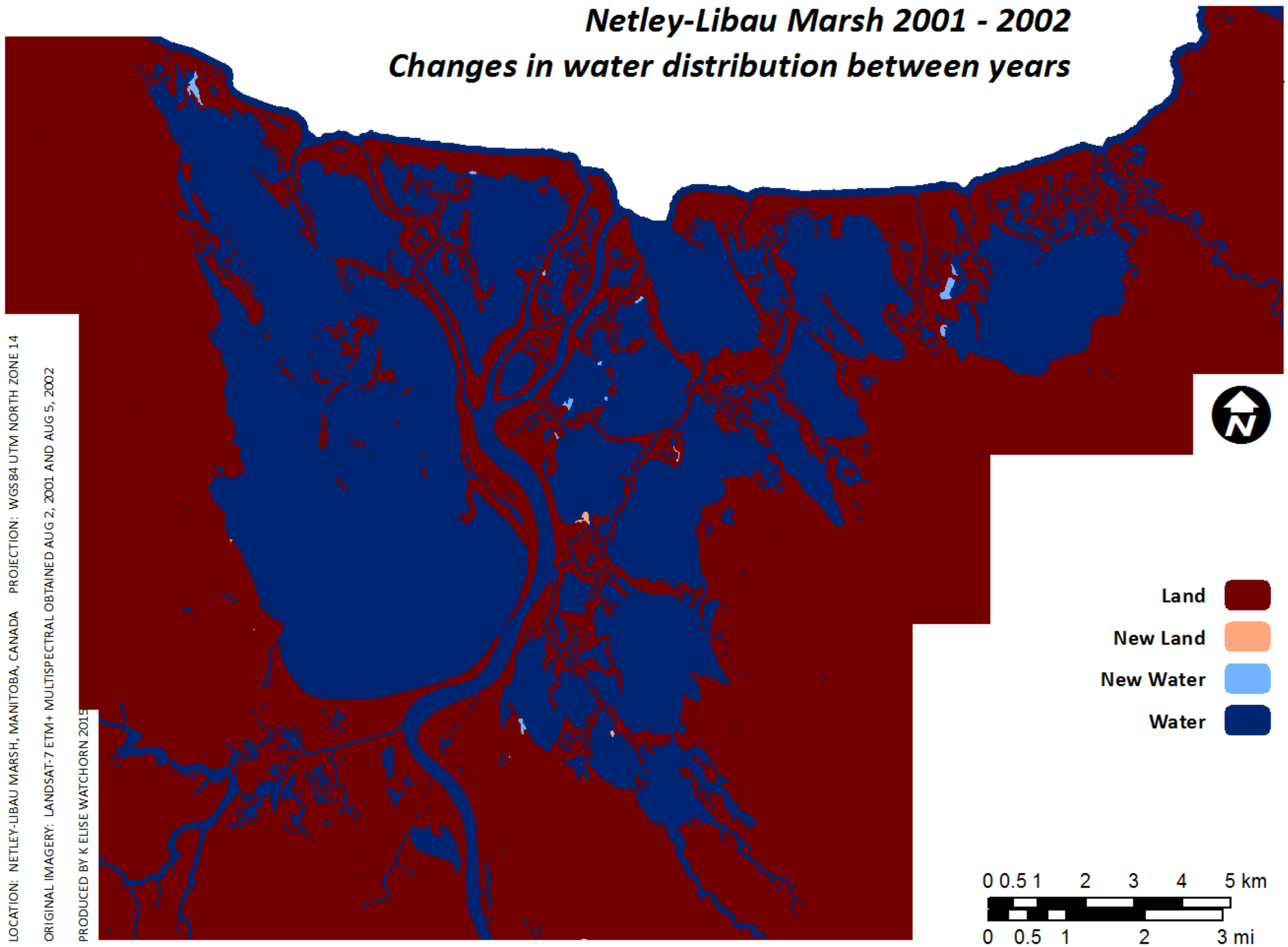
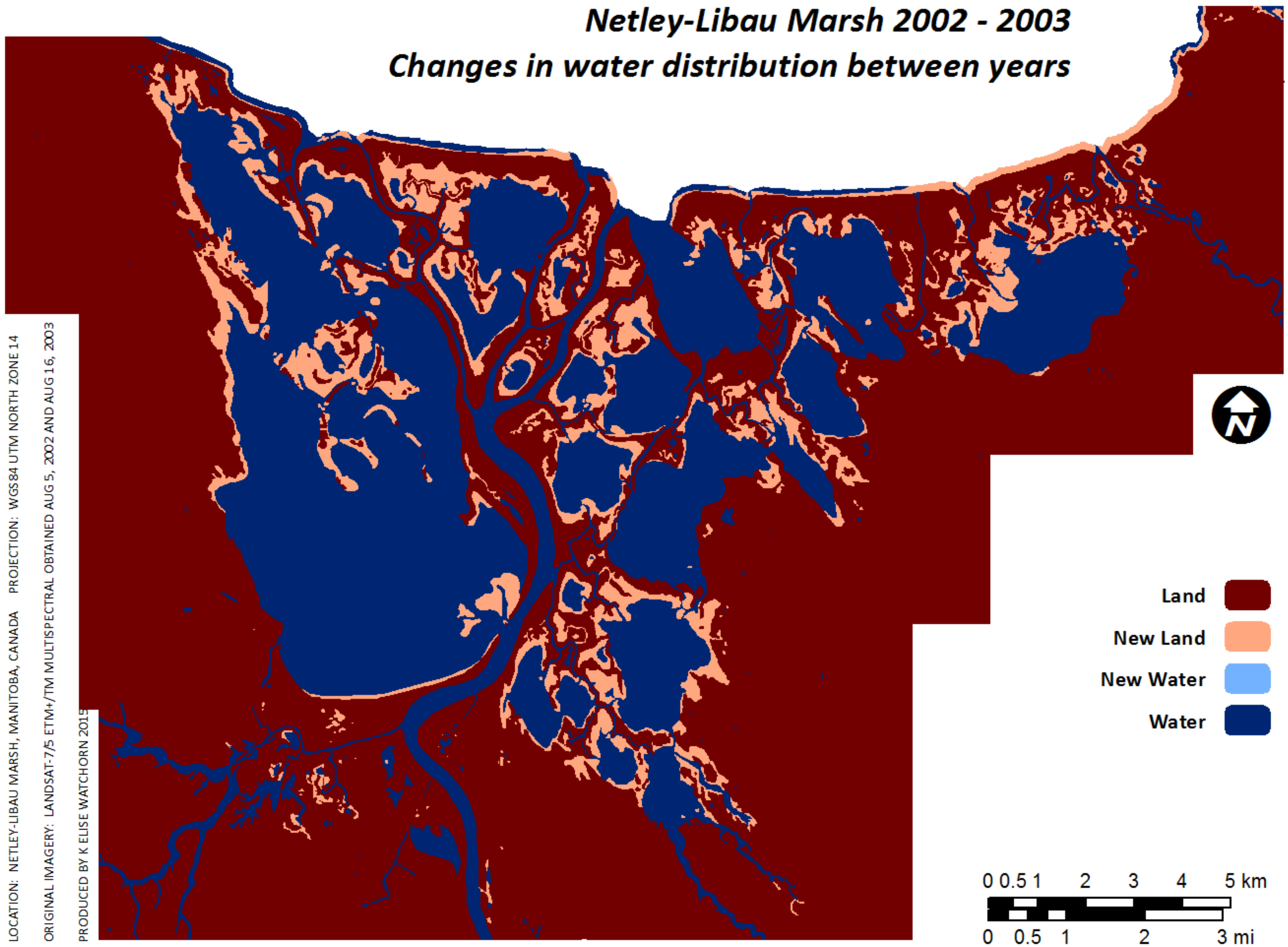
PRODUCED BY K ELISE WATCHORN 2015

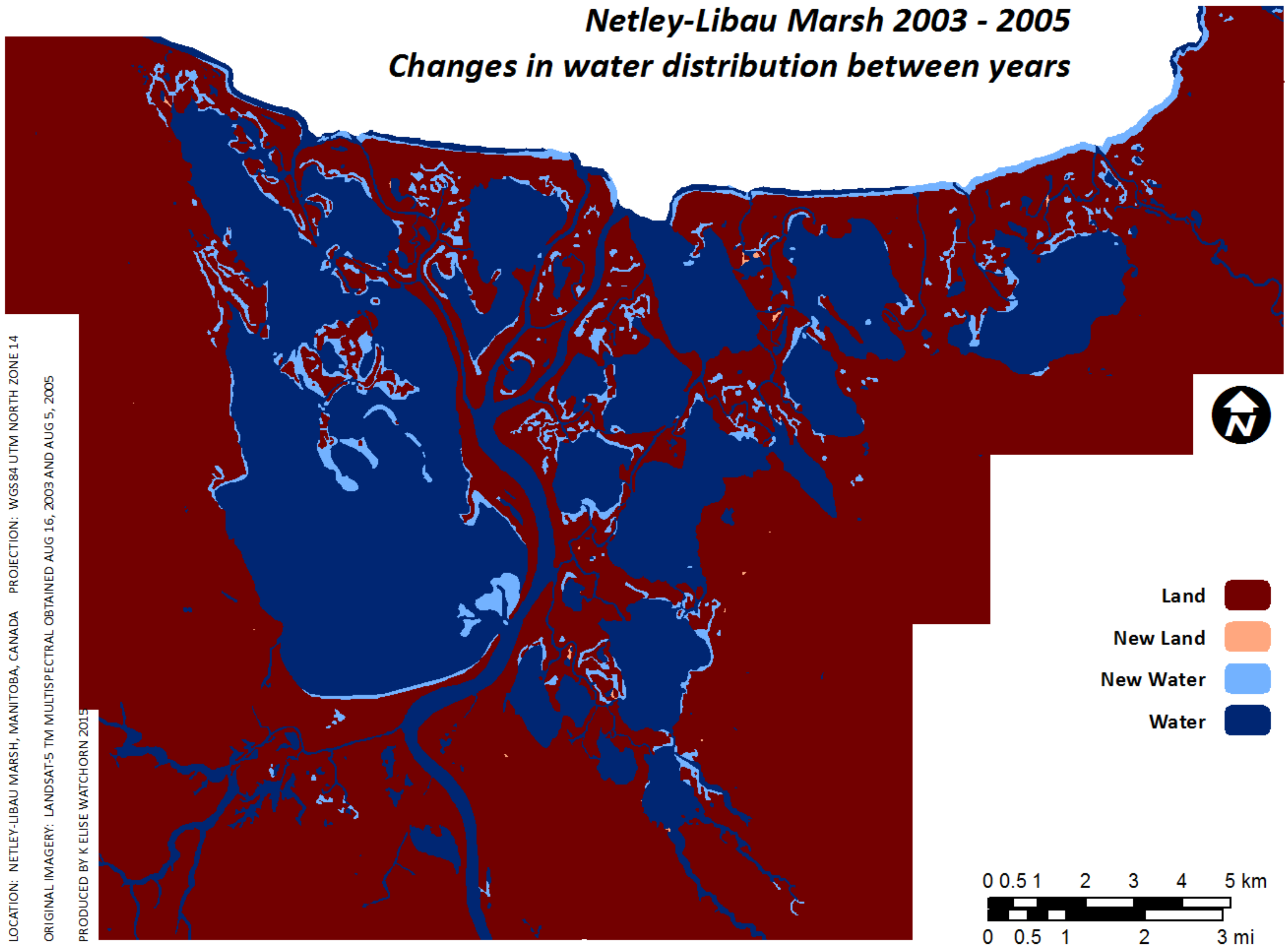


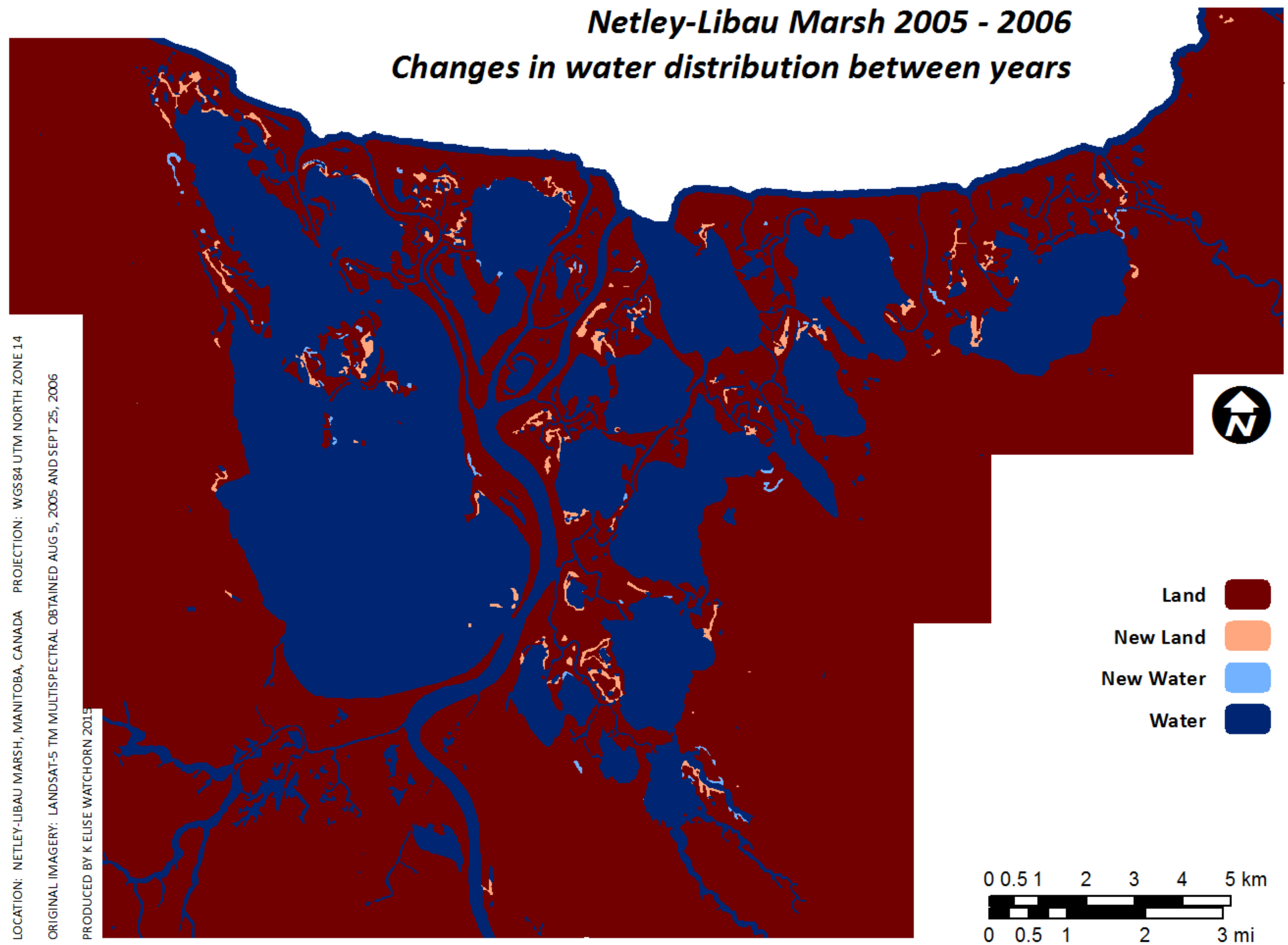
Netley-Libau Marsh 2000 - 2001
Changes in water distribution between years
Land
New Land
New Water
Water
N
0 0.5 1 2 3 4 5 km
0 0.5 1 2 3 mi
LOCATION: NETLEY-LIBAU MARSH, MANITOBA, CANADA PROJECTION: WGS84 UTM NORTH ZONE 14
ORIGINAL IMAGERY: LANDSAT-7 ETM+ MULTISPECTRAL OBTAINED JULY 30, 2000 AND AUG 2, 2001
PRODUCED BY K ELISE WATCHORN 2015

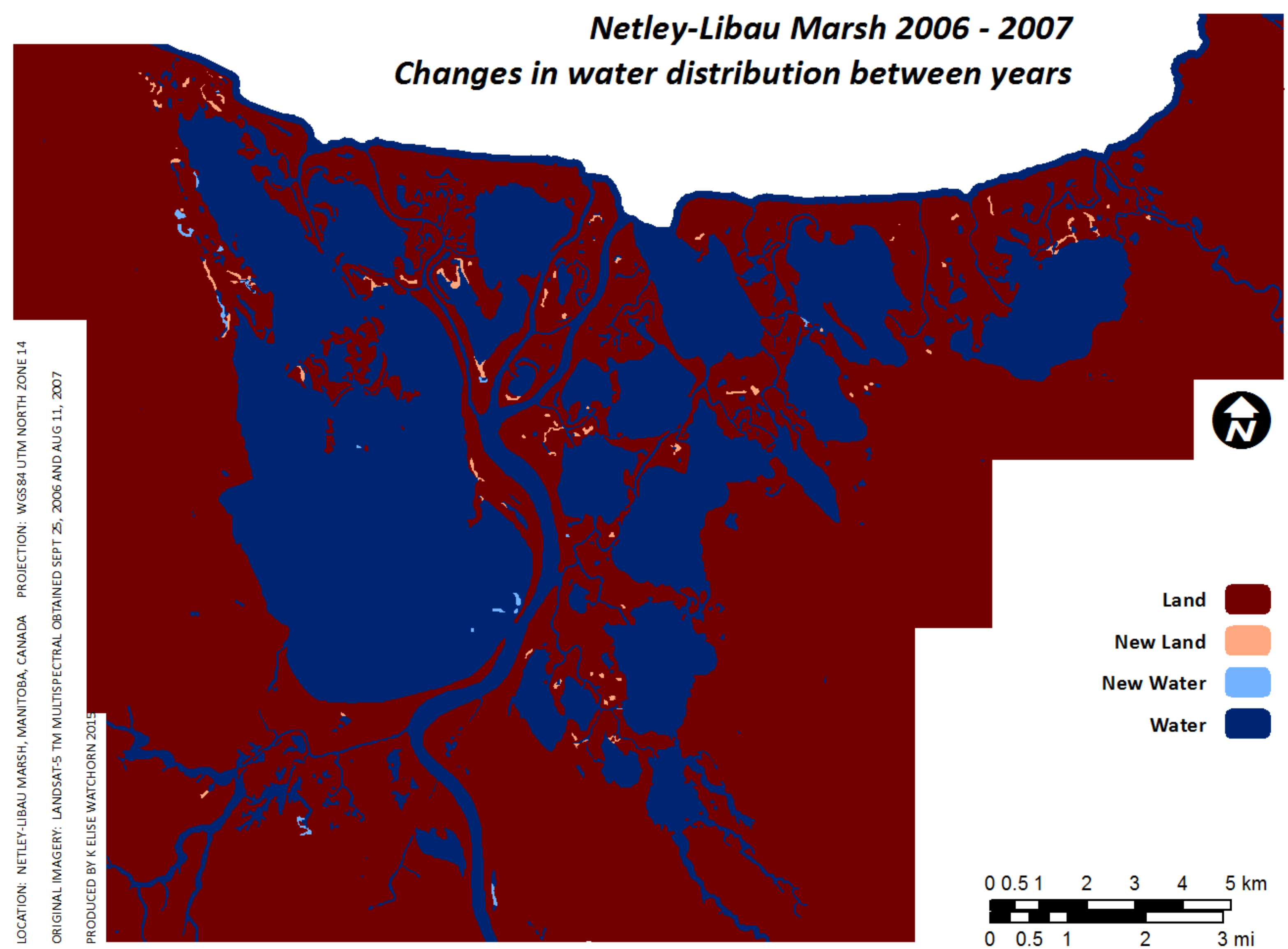


Netley-Libau Marsh 2001 - 2002
Changes in water distribution between years
LOCATION: NETLEY-LIBAU MARSH, MANITOBA, CANADA PROJECTION: WGS84 UTM NORTH ZONE 14
ORIGINAL IMAGERY: LANDSAT-7 ETM+ MULTISPECTRAL OBTAINED AUG 2, 2001 AND AUG 5, 2002
PRODUCED BY K ELISE WATCHORN 2015
N
Land
New Land
New Water
Water
0 0.5 1 2 3 4 5 km
0 0.5 1 2 3 mi

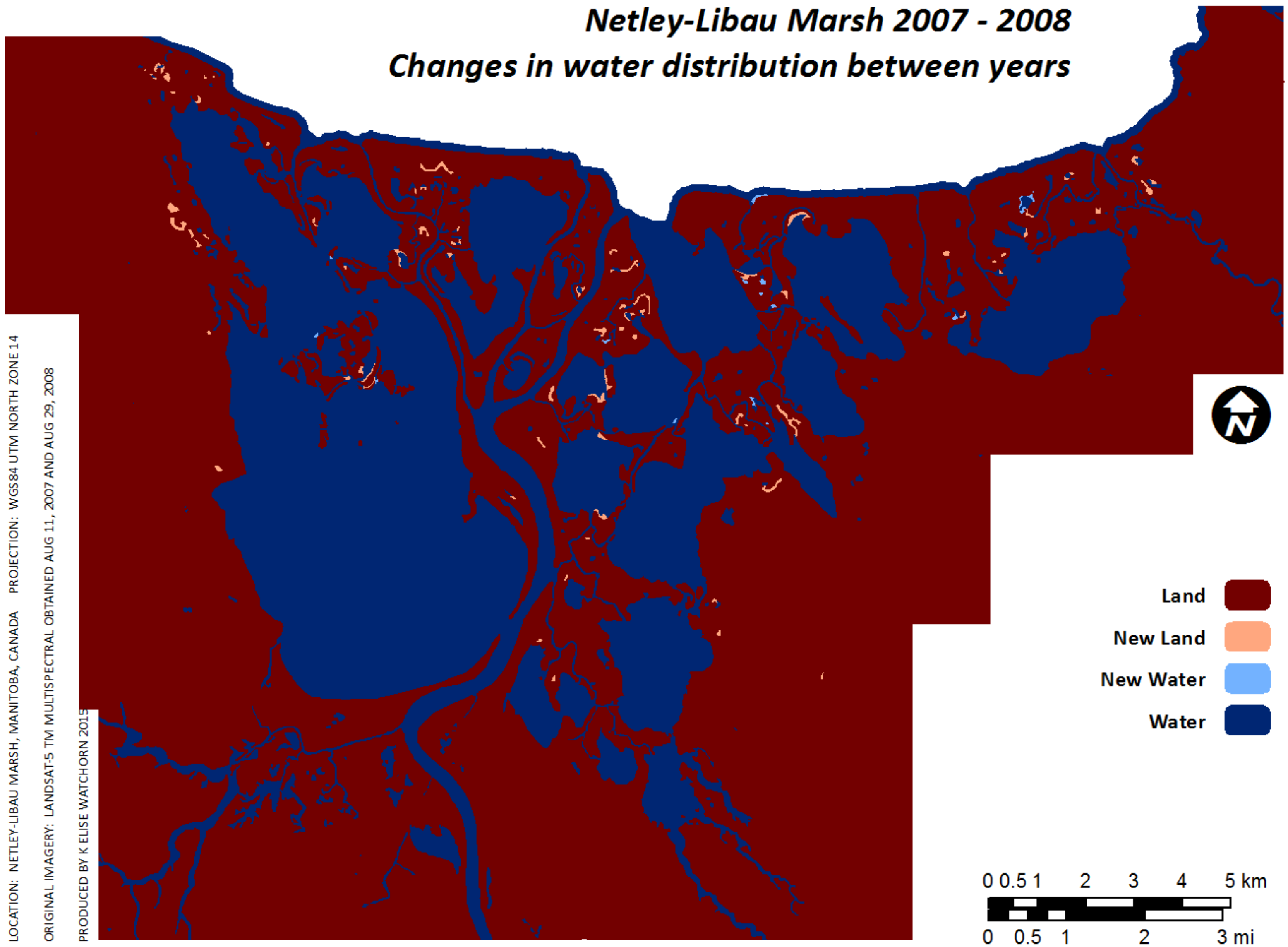

Netley-Libau Marsh 2002 - 2003
Changes in water distribution between years
LOCATION: NETLEY-LIBAU MARSH, MANITOBA, CANADA PROJECTION: WGS84 UTM NORTH ZONE 14
ORIGINAL IMAGERY: LANDSAT-7/5 ETM+/TM MULTISPECTRAL OBTAINED AUG 5, 2002 AND AUG 16, 2003
PRODUCED BY K ELISE WATCHORN 2015
N
Land
New Land
New Water
Water
0 0.5 1 2 3 4 5 km
0 0.5 1 2 3 mi

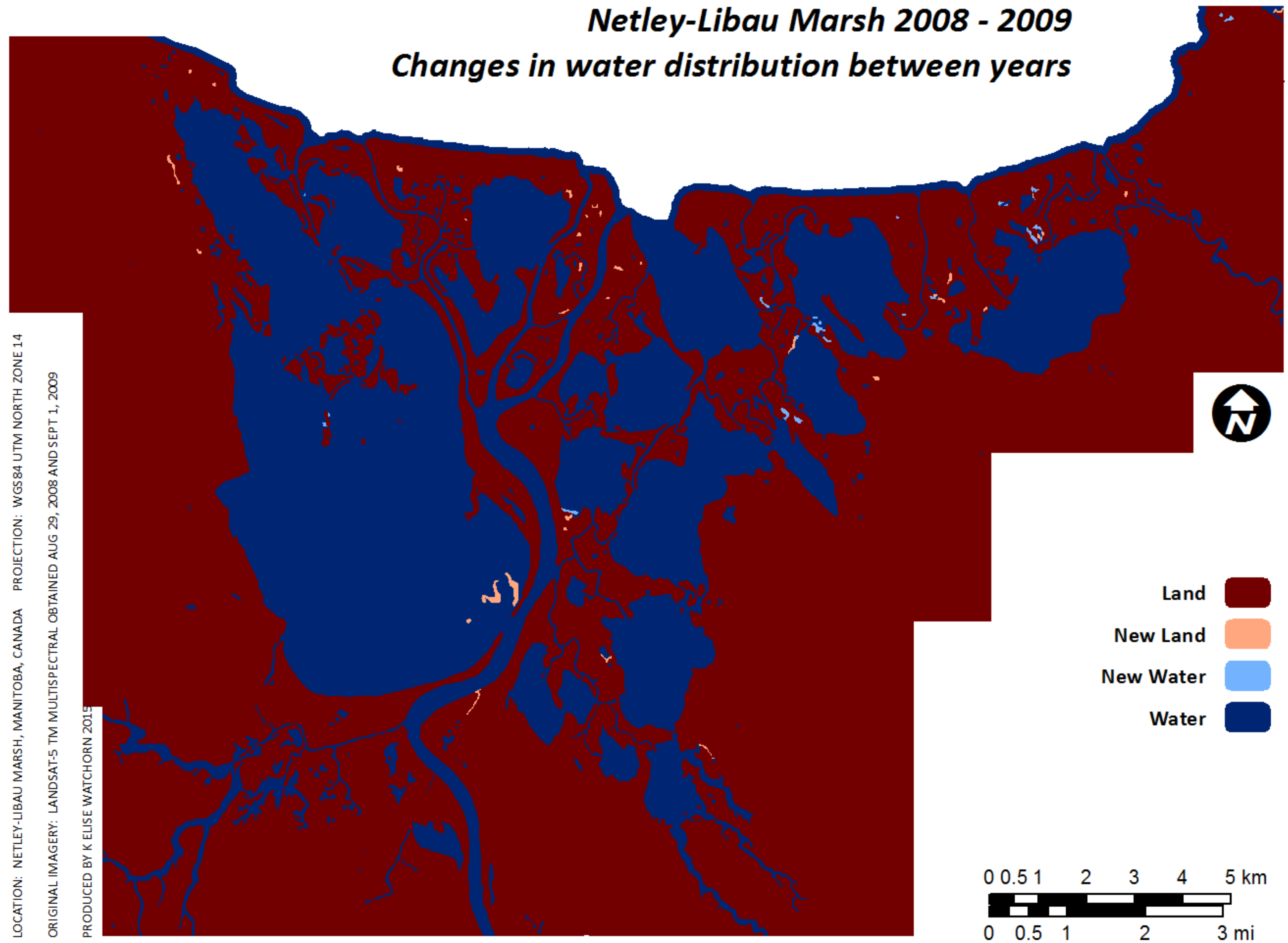

Netley-Libau Marsh 2003 - 2005
Changes in water distribution between years
LOCATION: NETLEY-LIBAU MARSH, MANITOBA, CANADA PROJECTION: WGS84 UTM NORTH ZONE 14
ORIGINAL IMAGERY: LANDSAT-5 TM MULTISPECTRAL OBTAINED AUG 16, 2003 AND AUG 5, 2005
PRODUCED BY K ELISE WATCHORN 2015
N
Land
New Land
New Water
Water
0 0.5 1 2 3 4 5 km
0 0.5 1 2 3 mi

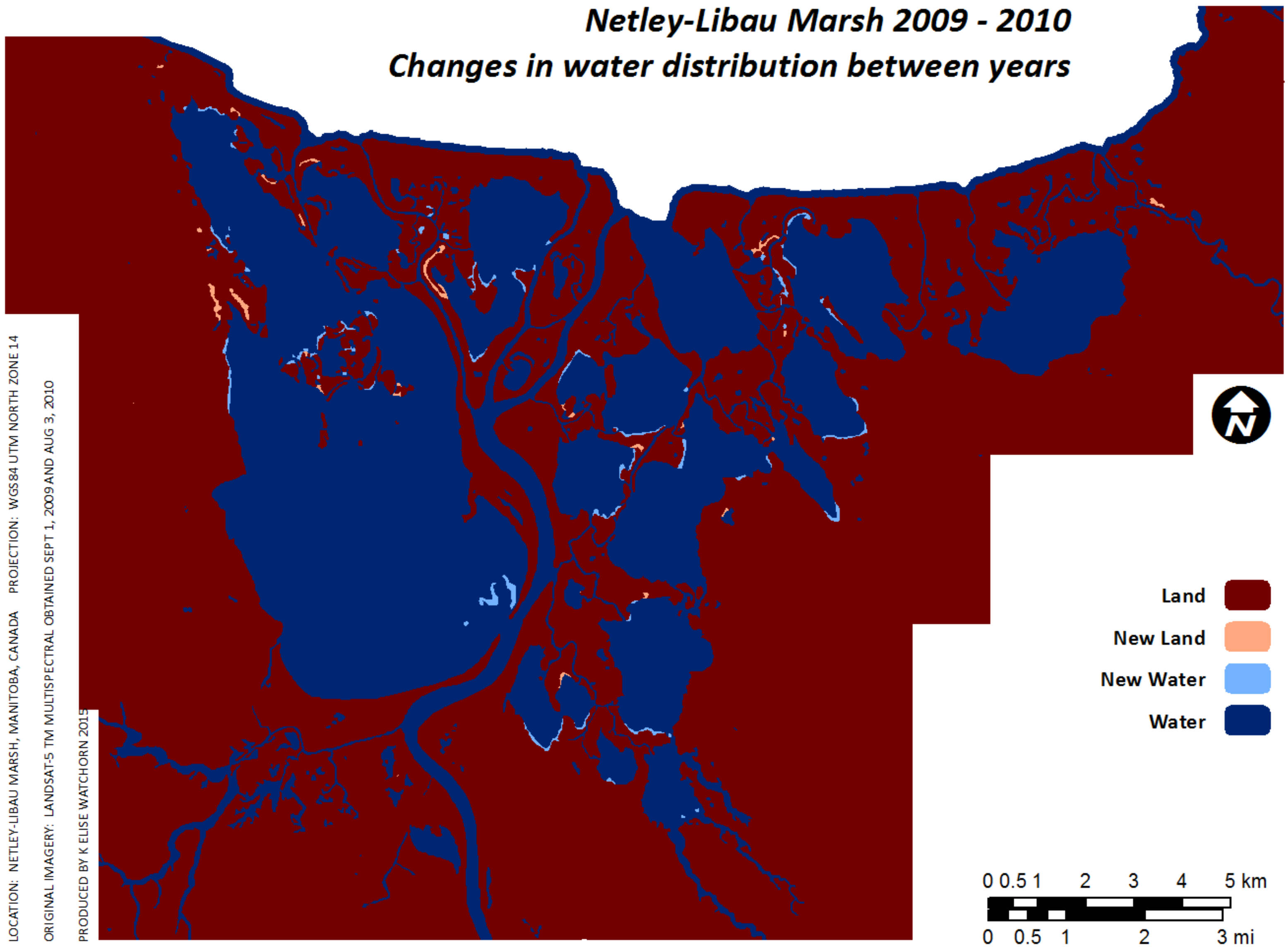

Netley-Libau Marsh 2005 - 2006
Changes in water distribution between years
LOCATION: NETLEY-LIBAU MARSH, MANITOBA, CANADA PROJECTION: WGS84 UTM NORTH ZONE 14
ORIGINAL IMAGERY: LANDSAT-5 TM MULTISPECTRAL OBTAINED AUG 5, 2005 AND SEPT 25, 2006
PRODUCED BY K ELISE WATCHORN 2015
N
Land
New Land
New Water
Water
0 0.5 1 2 3 4 5 km
0 0.5 1 2 3 mi



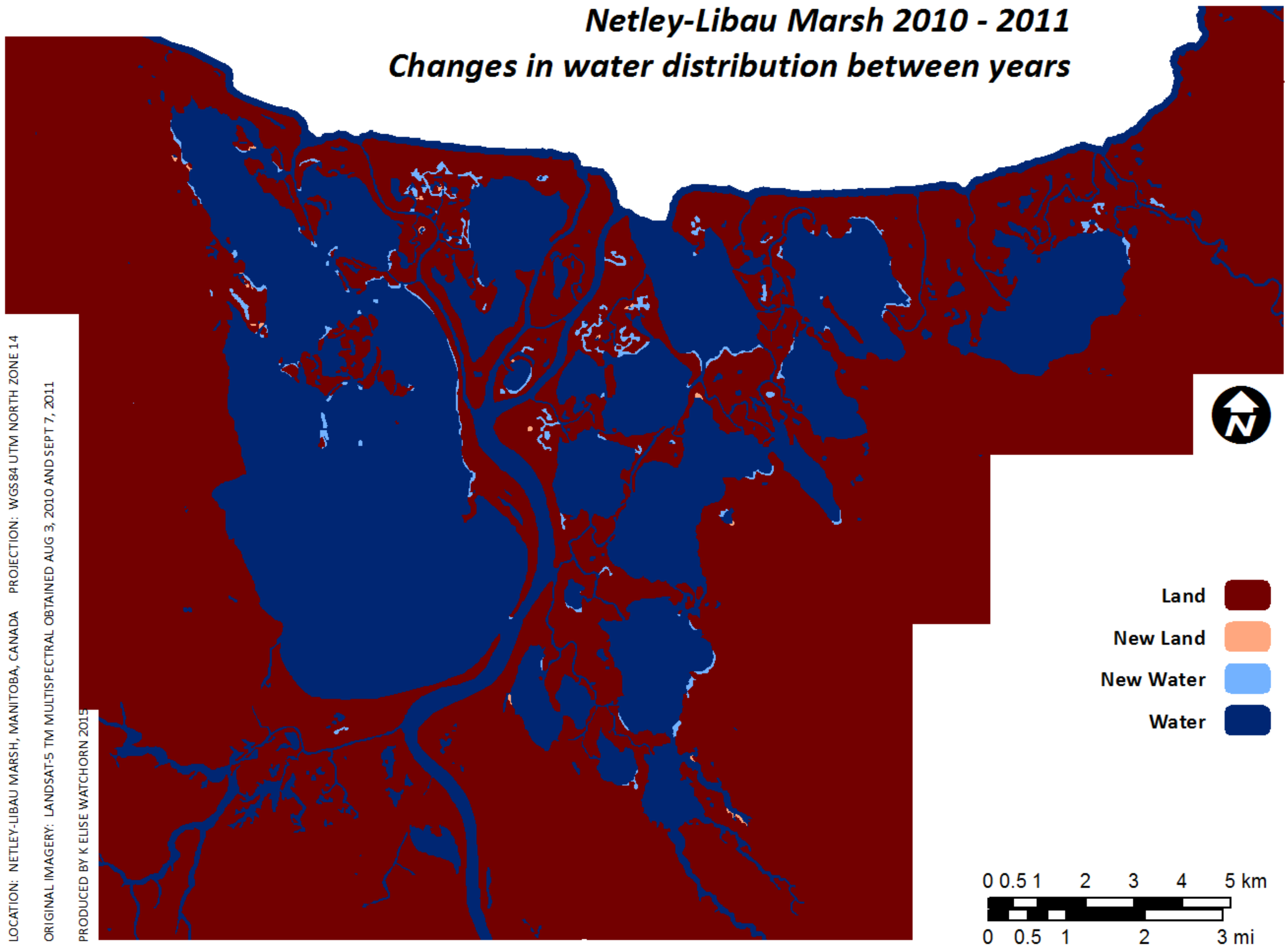
Netley-Libau Marsh 2006 - 2007
Changes in water distribution between years
LOCATION: NETLEY-LIBAU MARSH, MANITOBA, CANADA PROJECTION: WGS84 UTM NORTH ZONE 14
ORIGINAL IMAGERY: LANDSAT-5 TM MULTISPECTRAL OBTAINED SEPT 25, 2006 AND AUG 11, 2007
PRODUCED BY K ELISE WATCHORN 2015
N
Land
New Land
New Water
Water
0 0.5 1 2 3 4 5 km
0 0.5 1 2 3 mi

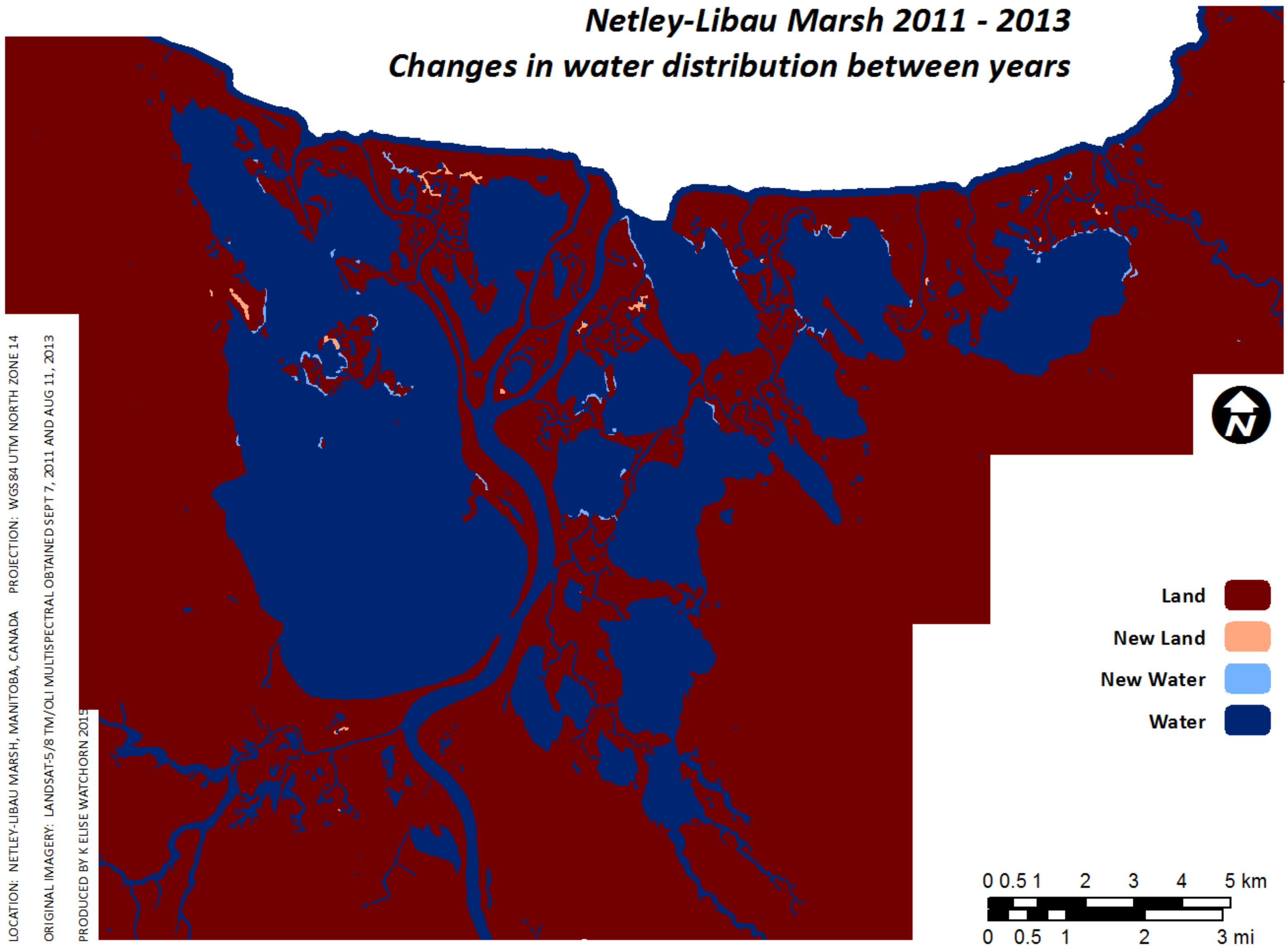

Netley-Libau Marsh 2007 - 2008
Changes in water distribution between years
LOCATION: NETLEY-LIBAU MARSH, MANITOBA, CANADA PROJECTION: WGS84 UTM NORTH ZONE 14
ORIGINAL IMAGERY: LANDSAT-5 TM MULTISPECTRAL OBTAINED AUG 11, 2007 AND AUG 29, 2008
PRODUCED BY K ELISE WATCHORN 2015
N
Land
New Land
New Water
Water
0 0.5 1 2 3 4 5 km
0 0.5 1 2 3 mi


Netley-Libau Marsh 2008 - 2009
Changes in water distribution between years
Land
New Land
New Water
Water
0 0.5 1 2 3 4 5 km
0 0.5 1 2 3 mi
LOCATION: NETLEY-LIBAU MARSH, MANITOBA, CANADA PROJECTION: WGS84 UTM NORTH ZONE 14
ORIGINAL IMAGERY: LANDSAT-5 TM MULTISPECTRAL OBTAINED AUG 29, 2008 AND SEPT 1, 2009
PRODUCED BY K ELISE WATCHORN 2015


Netley-Libau Marsh 2009 - 2010
Changes in water distribution between years
LOCATION: NETLEY-LIBAU MARSH, MANITOBA, CANADA PROJECTION: WGS84 UTM NORTH ZONE 14
ORIGINAL IMAGERY: LANDSAT-5 TM MULTISPECTRAL OBTAINED SEPT 1, 2009 AND AUG 3, 2010
PRODUCED BY K ELISE WATCHORN 201
N
Land
New Land
New Water
Water
0 0.5 1 2 3 4 5 km
0 0.5 1 2 3 mi

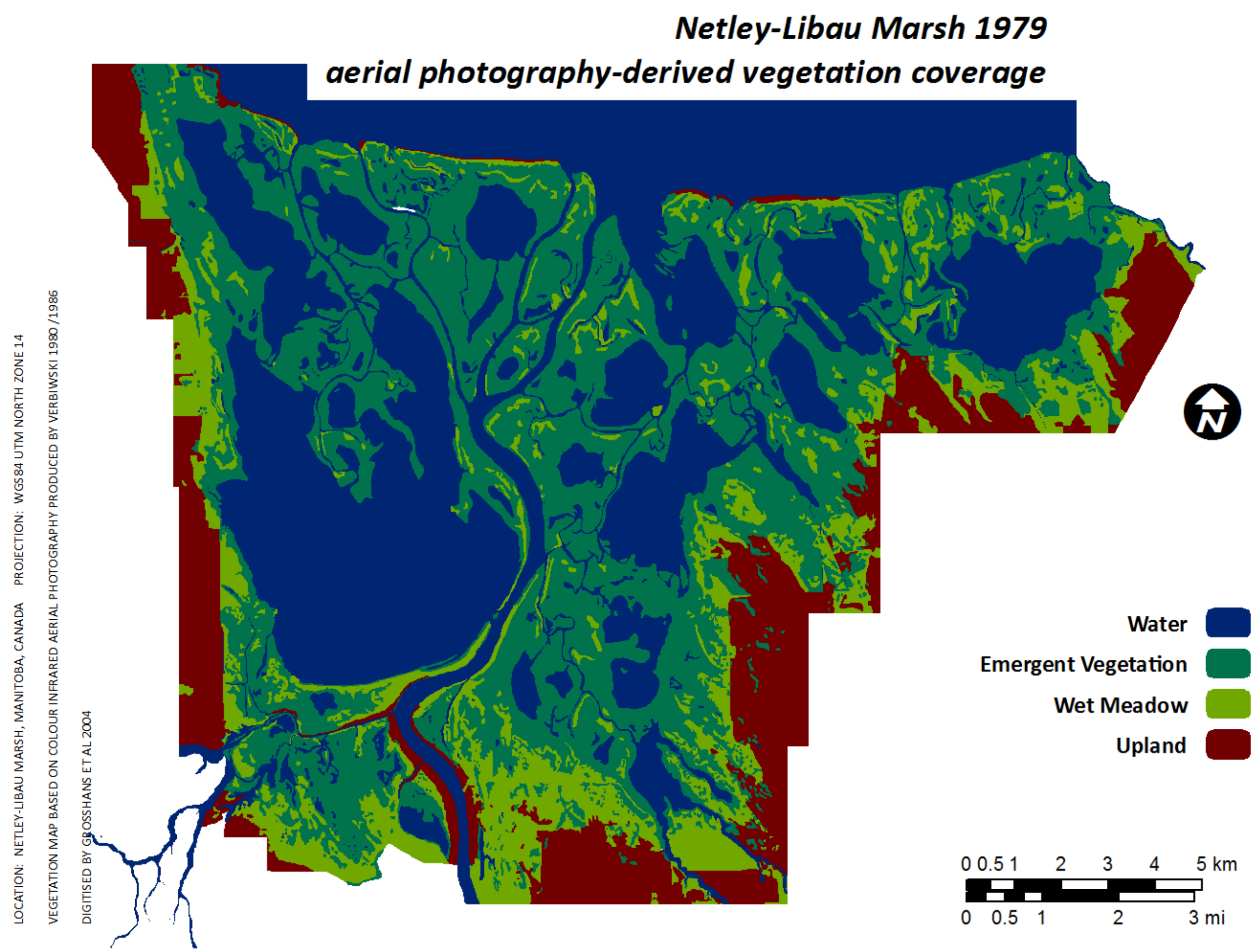
Netley-Libau Marsh 2010 - 2011
Changes in water distribution between years

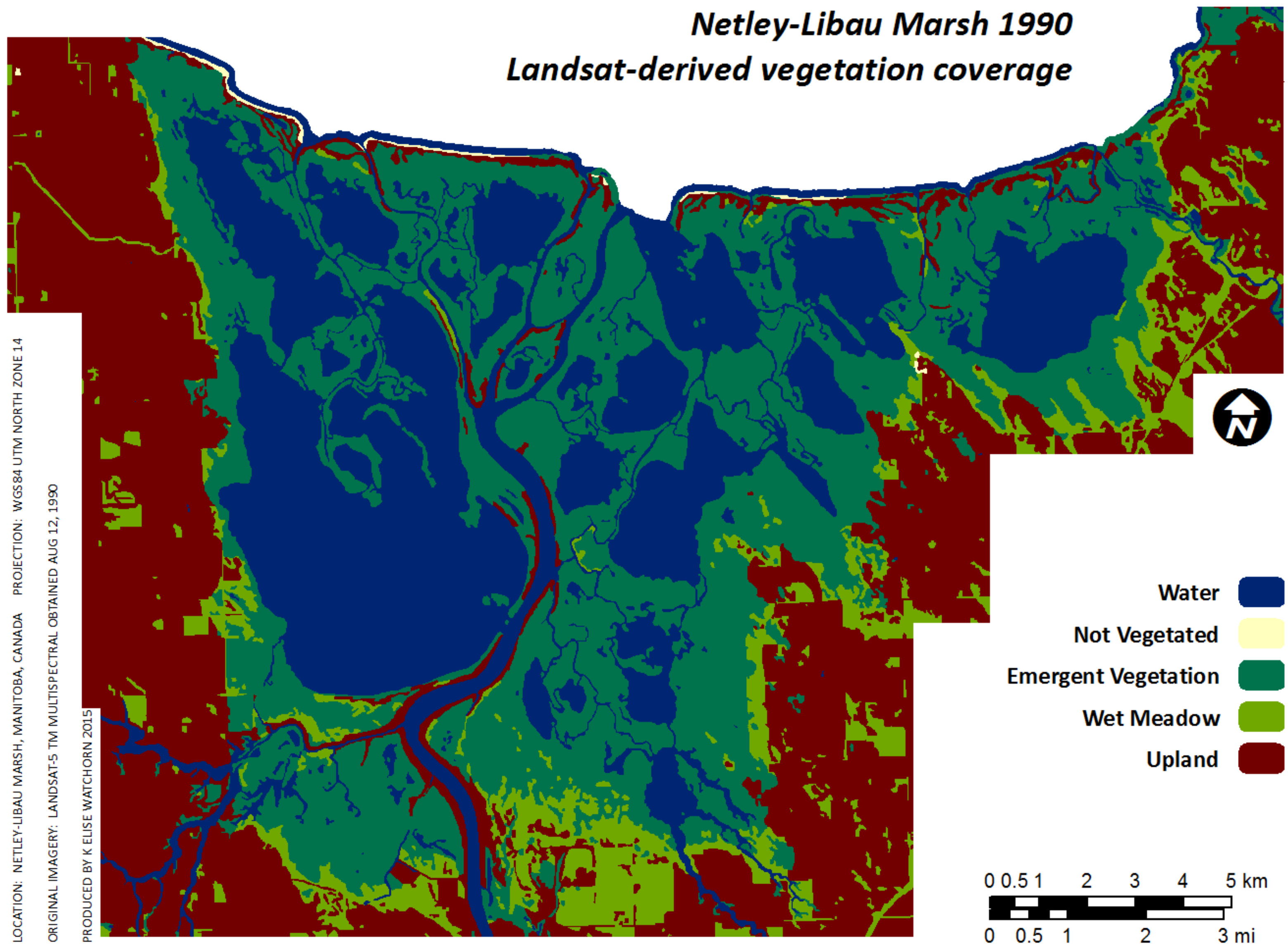




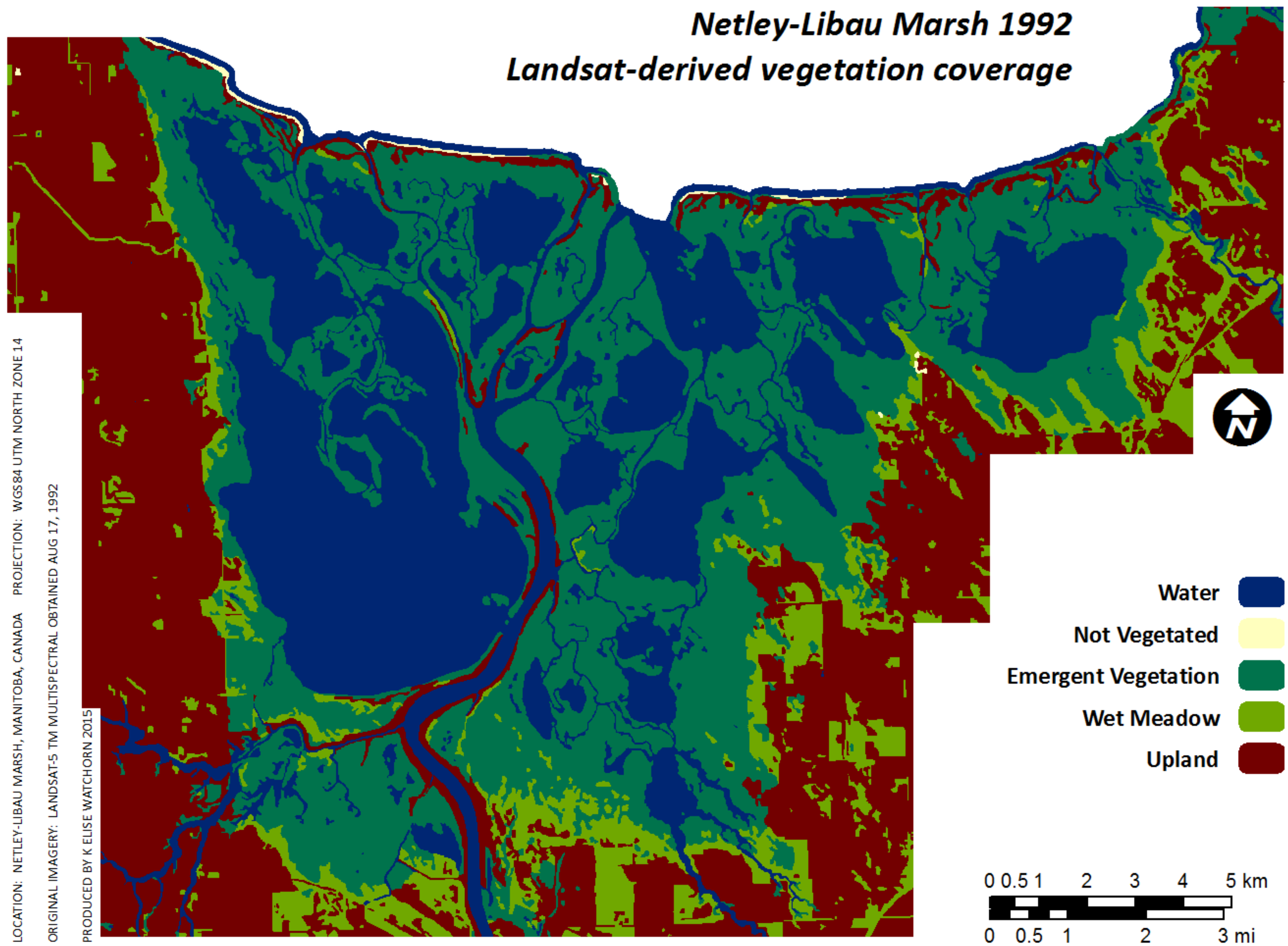
Netley-Libau Marsh 2011 - 2013
Changes in water distribution between years
LOCATION: NETLEY-LIBAU MARSH, MANITOBA, CANADA PROJECTION: WGS84 UTM NORTH ZONE 14
ORIGINAL IMAGERY: LANDSAT-5/8 TM/OLI MULTISPECTRAL OBTAINED SEPT 7, 2011 AND AUG 11, 2013
PRODUCED BY K ELISE WATCHORN 2015
N
Land
New Land
New Water
Water
0 0.5 1 2 3 4 5 km
0 0.5 1 2 3 mi

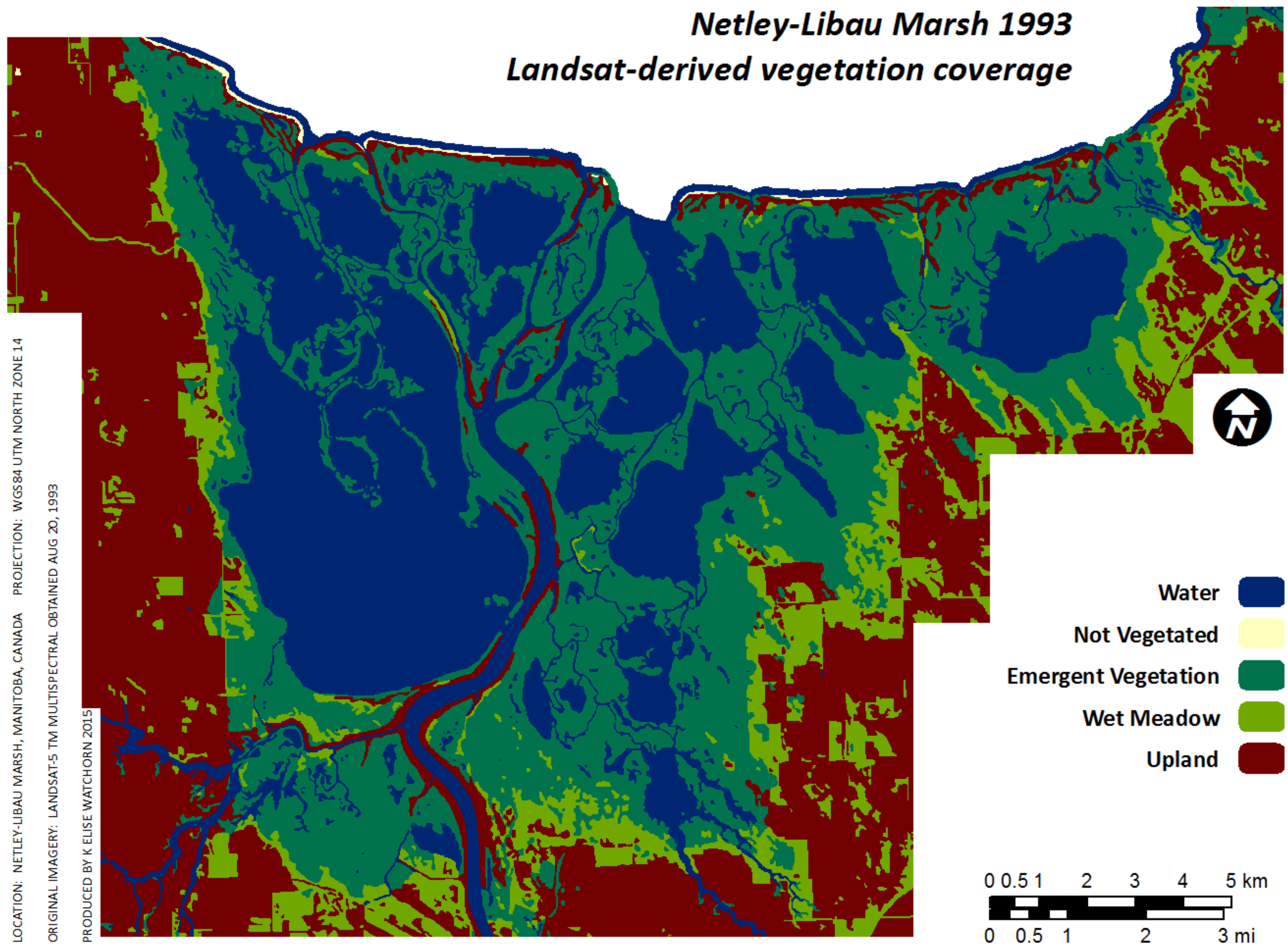
Map Series 8.2: Classified annual vegetation maps of Netley-Libau Marsh, 1990 – 2013, displayed by marsh zone, created based on Landsat-5, Landsat-7, and Landsat-8 multispectral imagery with a spatial resolution of 30m. A 1979 map based on aerial photography is shown for comparative purposes (Verbiski 1986; Grosshans et al 2004).



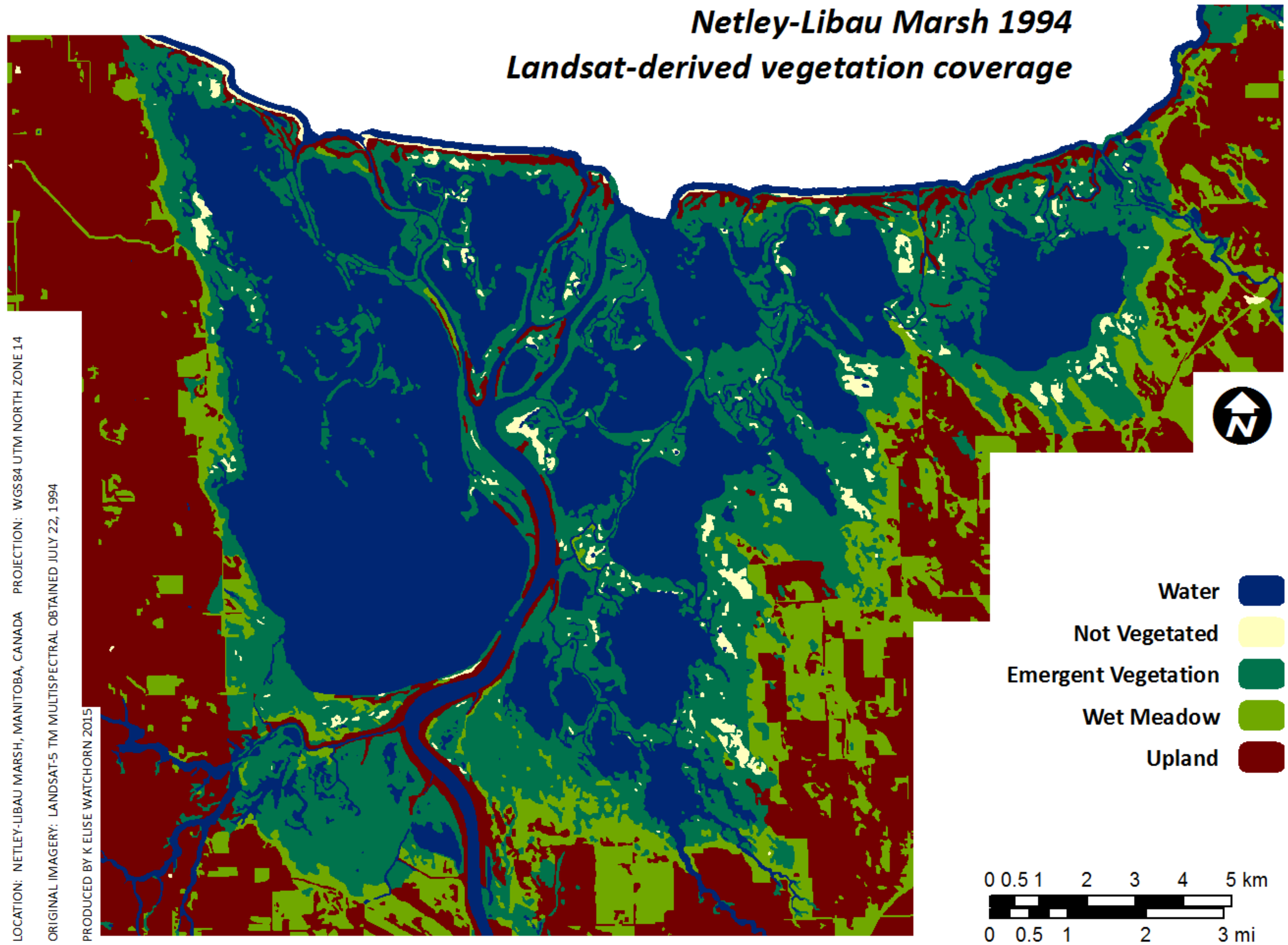


Netley-Libau Marsh 1990
Landsat-derived vegetation coverage
LOCATION: NETLEY-LIBAU MARSH, MANITOBA, CANADA PROJECTION: WGS84 UTM NORTH ZONE 14
ORIGINAL IMAGERY: LANDSAT-5 TM MULTISPECTRAL OBTAINED AUG 12, 1990
PRODUCED BY K ELISE WATCHORN 2015
N
Water
Not Vegetated
Emergent Vegetation
Wet Meadow
Upland
0 0.5 1 2 3 4 5 km
0 0.5 1 2 3 mi

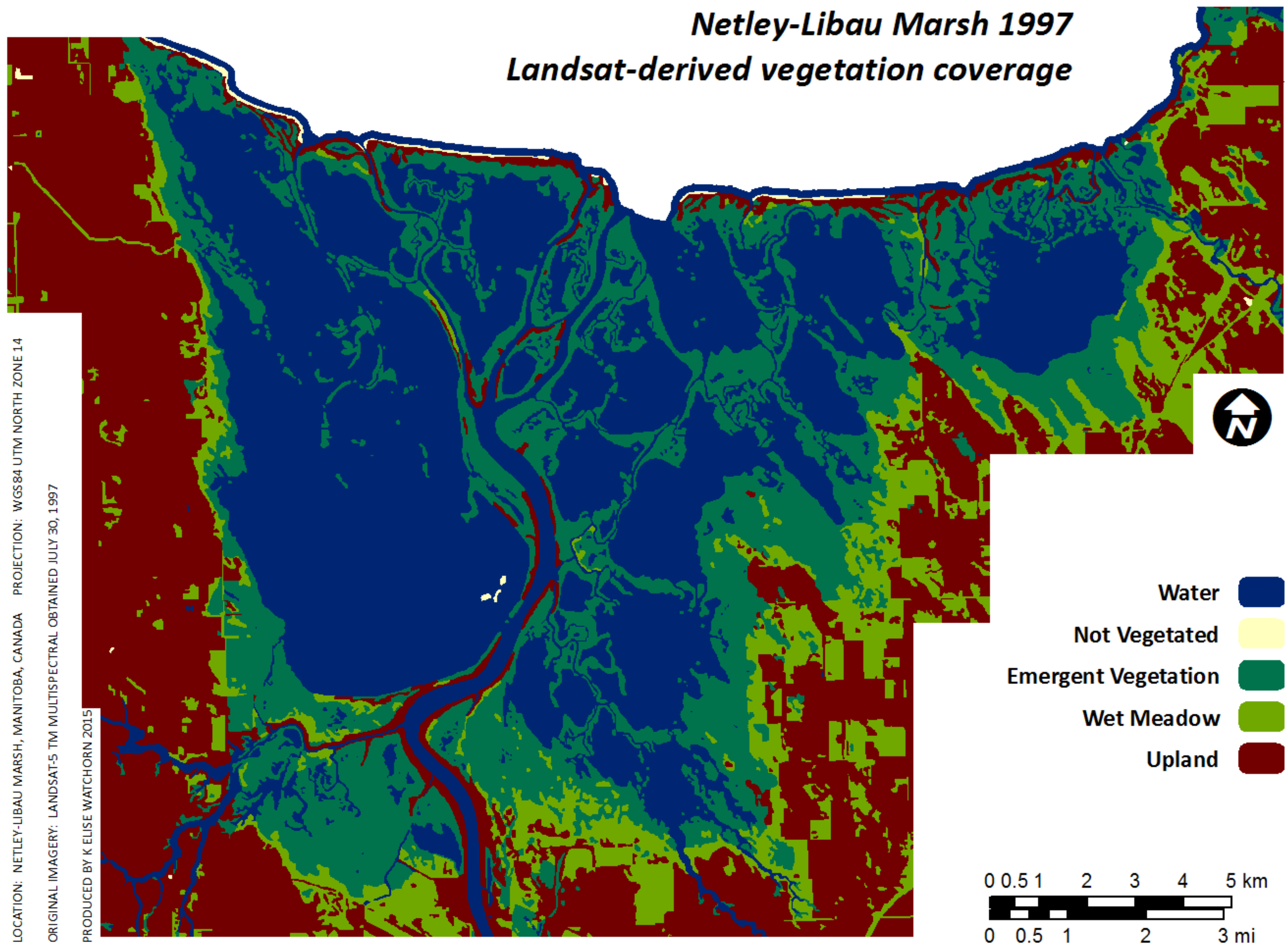

Netley-Libau Marsh 1992
Landsat-derived vegetation coverage
LOCATION: NETLEY-LIBAU MARSH, MANITOBA, CANADA PROJECTION: WGS84 UTM NORTH ZONE 14
ORIGINAL IMAGERY: LANDSAT-5 TM MULTISPECTRAL OBTAINED AUG 17, 1992
PRODUCED BY K ELISE WATCHORN 2015
N
Water
Not Vegetated
Emergent Vegetation
Wet Meadow
Upland
0 0.5 1 2 3 4 5 km
0 0.5 1 2 3 mi



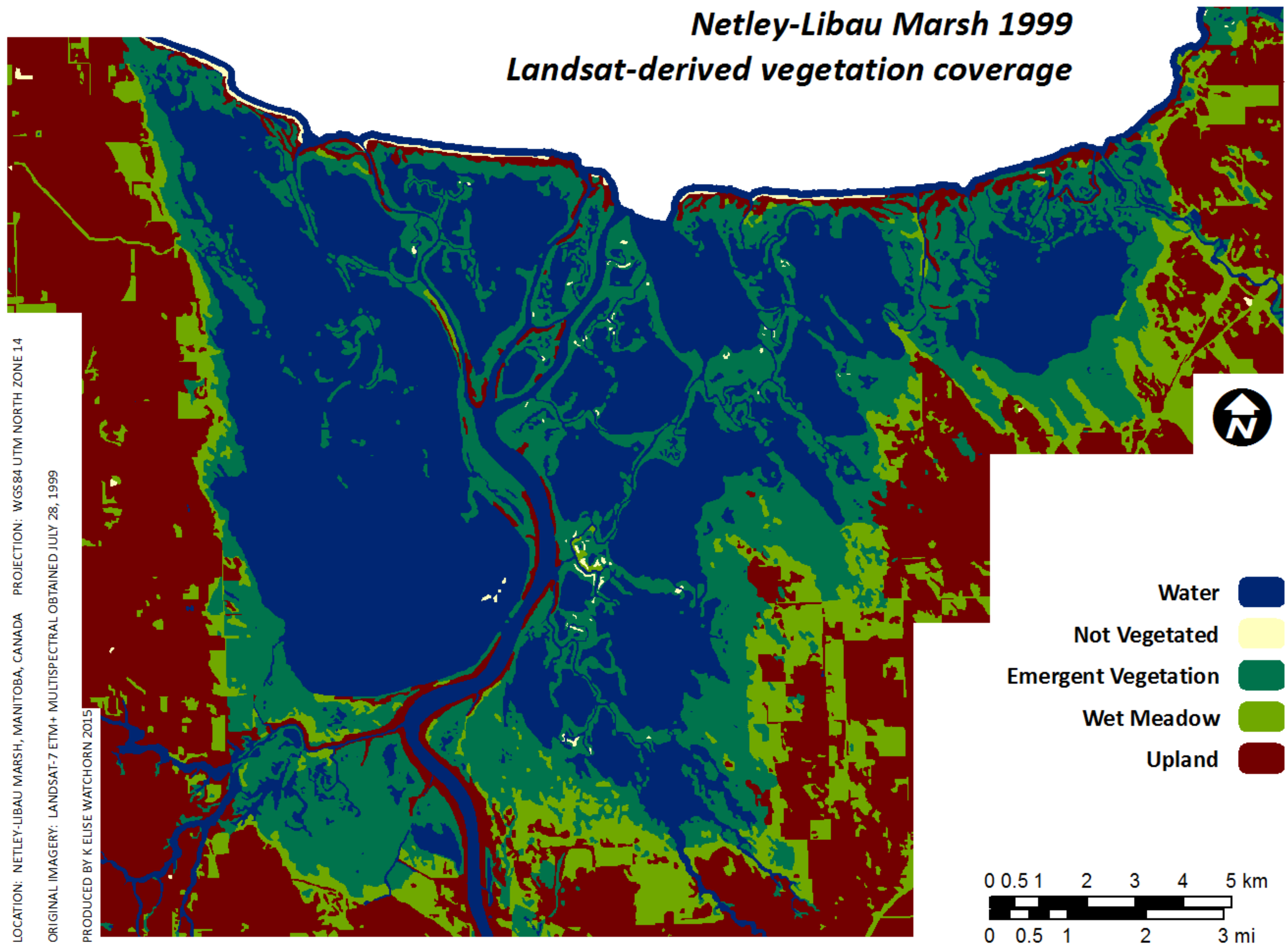
Netley-Libau Marsh 1993
Landsat-derived vegetation coverage
Water
Not Vegetated
Emergent Vegetation
Wet Meadow
Upland
0 0.5 1 2 3 4 5 km
0 0.5 1 2 3 mi
N
LOCATION: NETLEY-LIBAU MARSH, MANITOBA, CANADA PROJECTION: WGS84 UTM NORTH ZONE 14
ORIGINAL IMAGERY: LANDSAT-5 TM MULTISPECTRAL OBTAINED AUG 20, 1993
PRODUCED BY K ELISE WATCHORN 2015

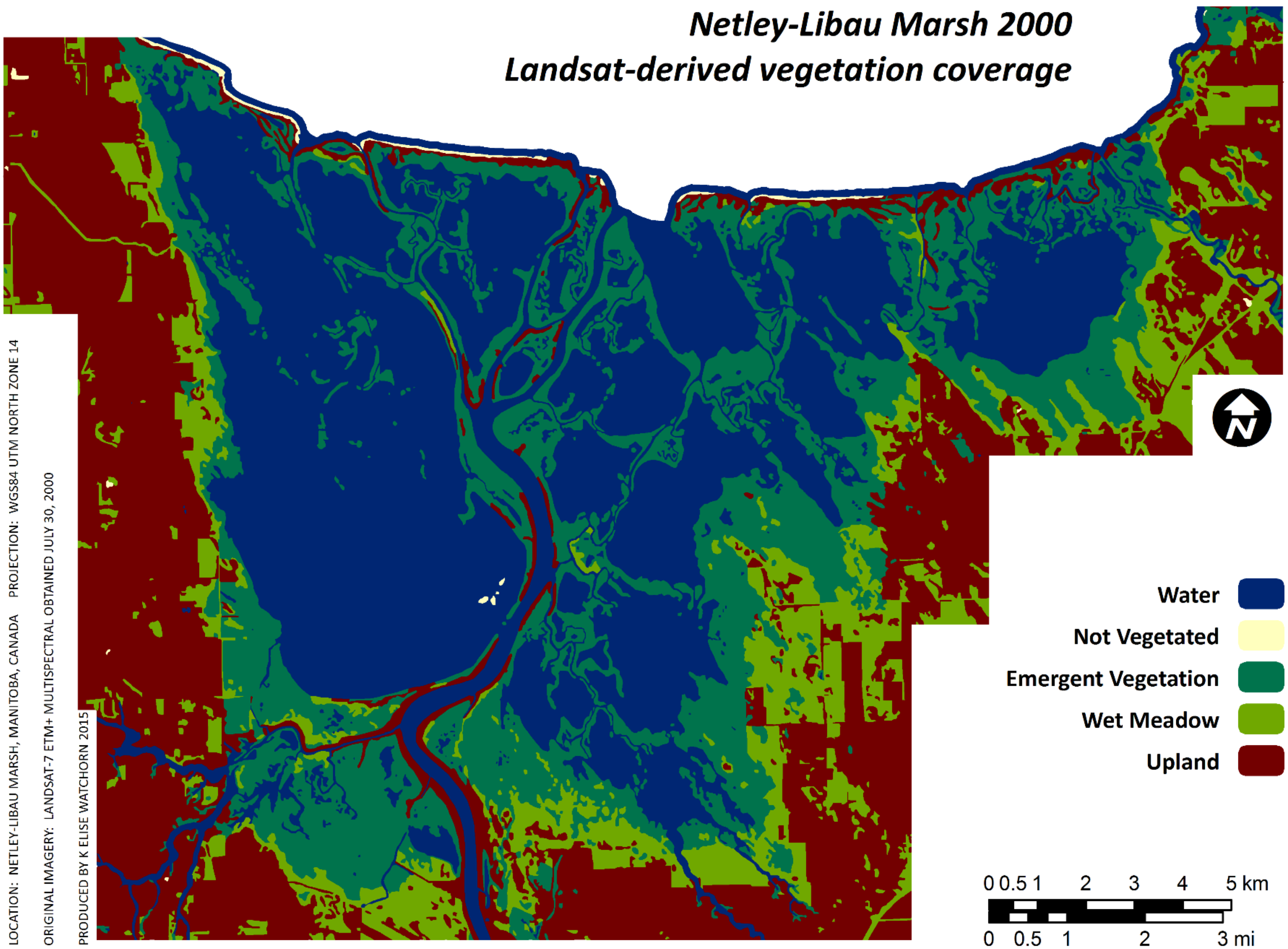


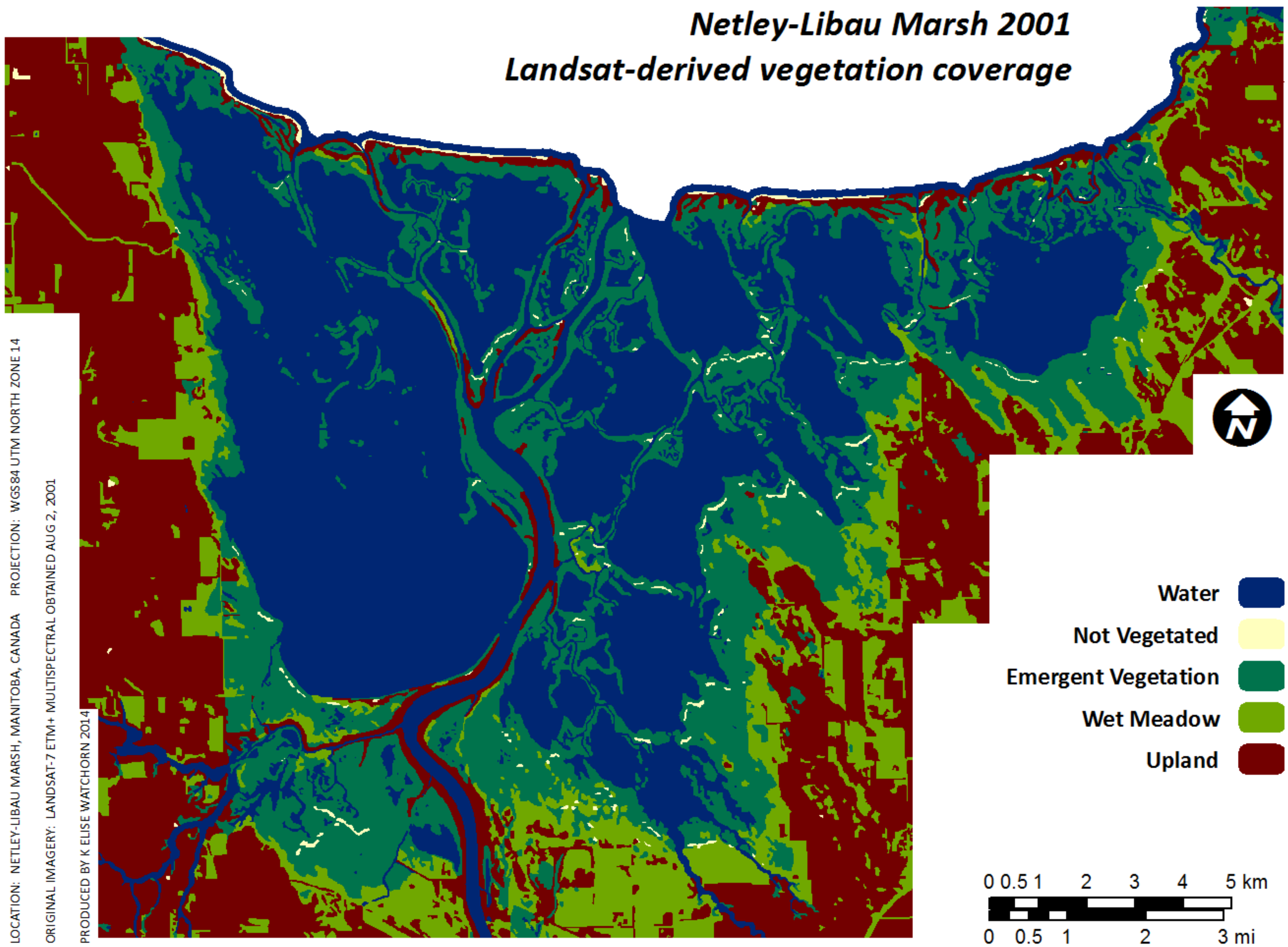
Netley-Libau Marsh 1994
Landsat-derived vegetation coverage
Water
Not Vegetated
Emergent Vegetation
Wet Meadow
Upland
N
0 0.5 1 2 3 4 5 km
0 0.5 1 2 3 mi
LOCATION: NETLEY-LIBAU MARSH, MANITOBA, CANADA PROJECTION: WGS84 UTM NORTH ZONE 14
ORIGINAL IMAGERY: LANDSAT-5 TM MULTISPECTRAL OBTAINED JULY 22, 1994
PRODUCED BY K ELISE WATCHORN 2015

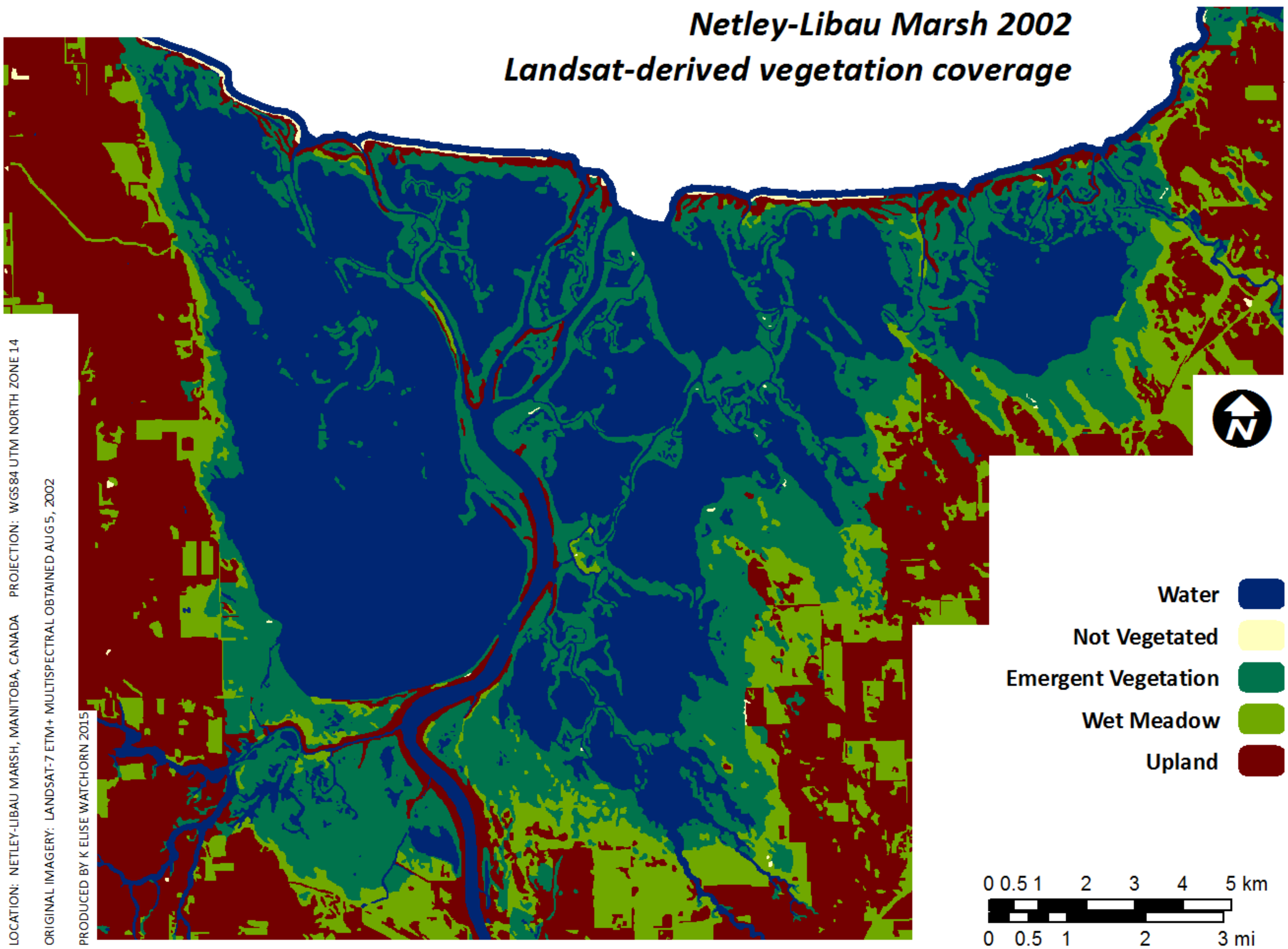


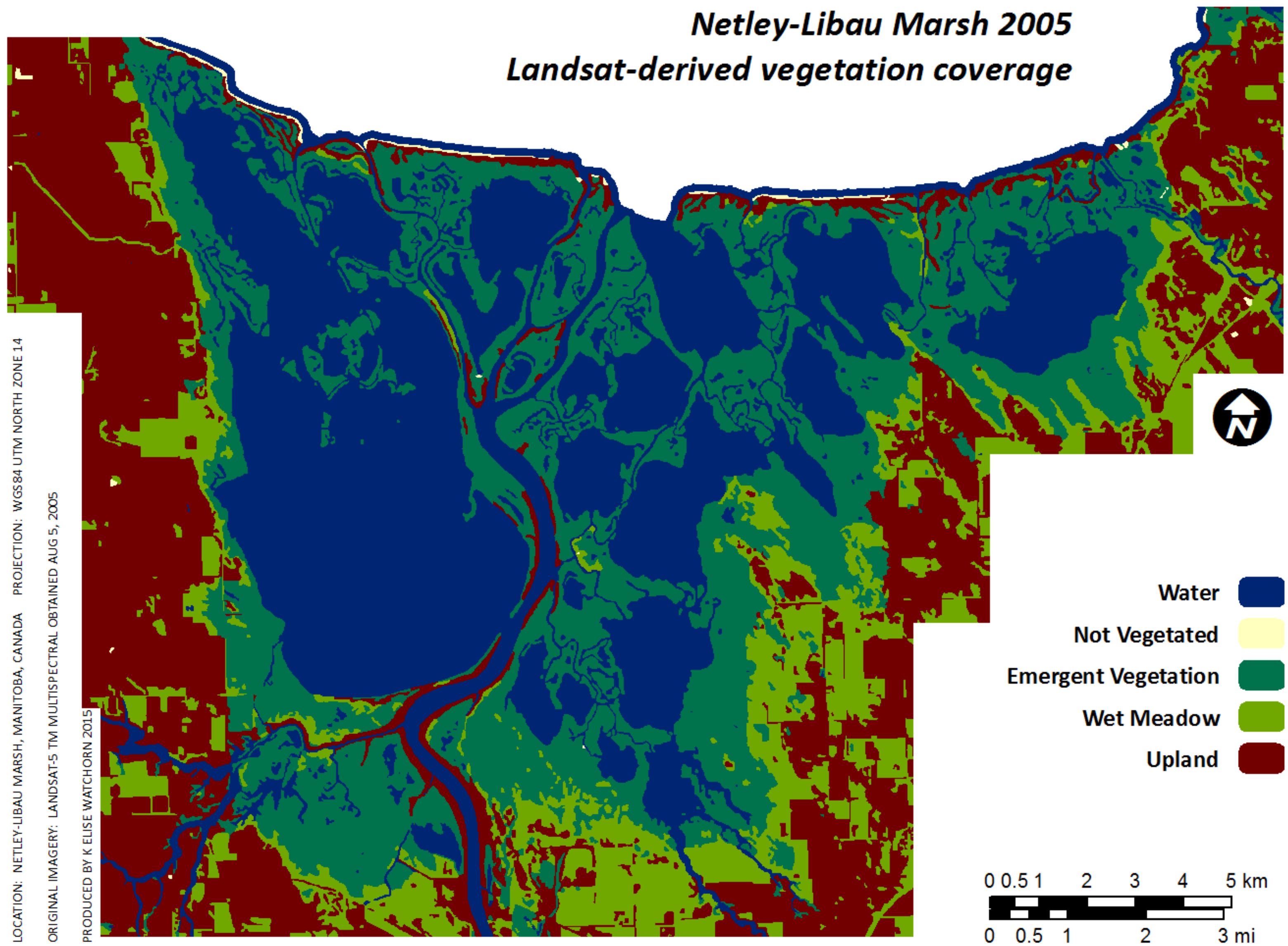
Netley-Libau Marsh 1997
Landsat-derived vegetation coverage
Water
Not Vegetated
Emergent Vegetation
Wet Meadow
Upland
N
0 0.5 1 2 3 4 5 km
0 0.5 1 2 3 mi
LOCATION: NETLEY-LIBAU MARSH, MANITOBA, CANADA PROJECTION: WGS84 UTM NORTH ZONE 14
ORIGINAL IMAGERY: LANDSAT-5 TM MULTISPECTRAL OBTAINED JULY 30, 1997
PRODUCED BY K ELISE WATCHORN 2015

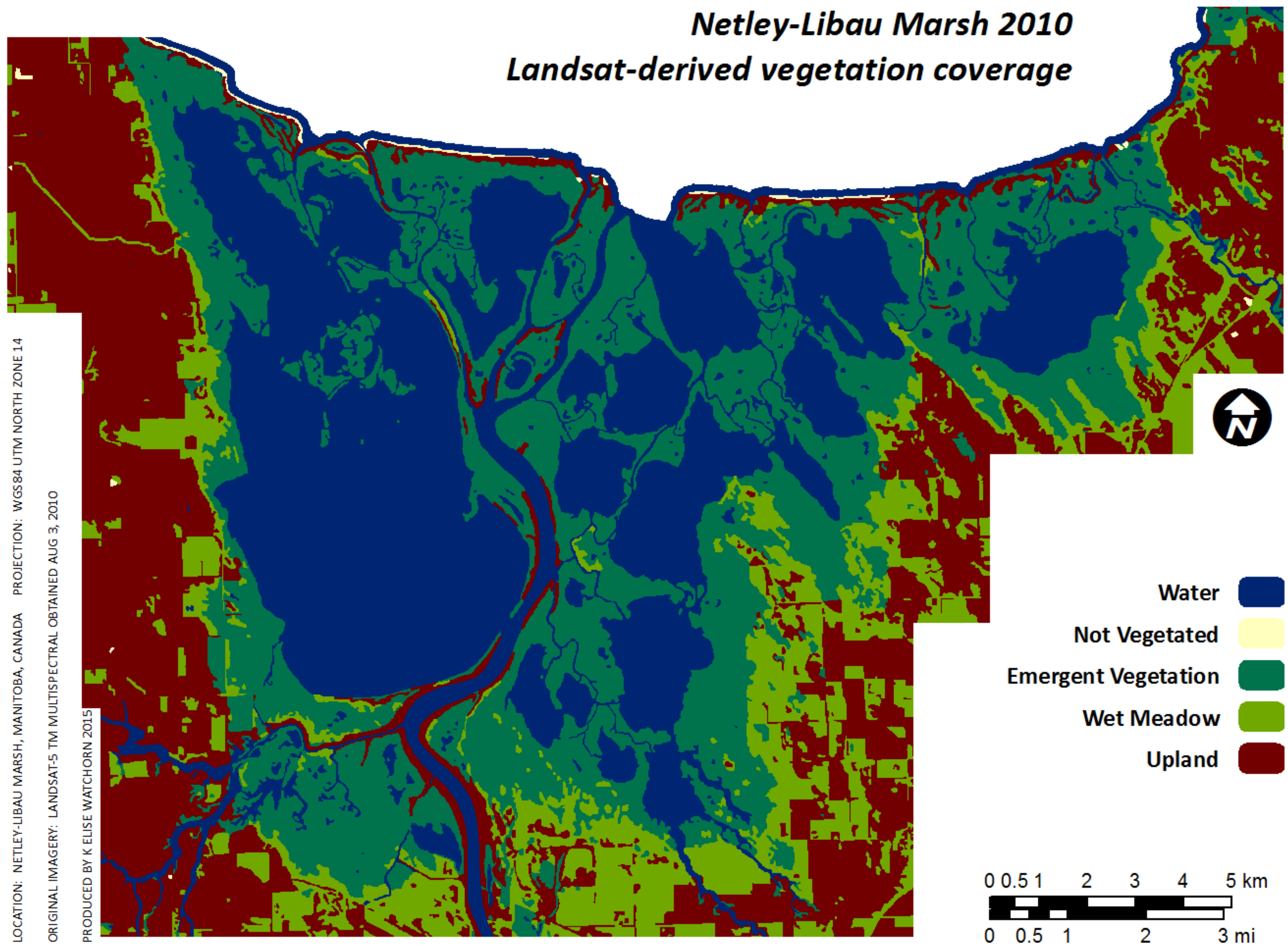

Netley-Libau Marsh 1999
Landsat-derived vegetation coverage
Water
Not Vegetated
Emergent Vegetation
Wet Meadow
Upland
0 0.5 1 2 3 4 5 km
0 0.5 1 2 3 mi
N
LOCATION: NETLEY-LIBAU MARSH, MANITOBA, CANADA PROJECTION: WGS84 UTM NORTH ZONE 14
ORIGINAL IMAGERY: LANDSAT-7 ETM+ MULTISPECTRAL OBTAINED JULY 28, 1999
PRODUCED BY K ELISE WATCHORN 2015


Netley-Libau Marsh 2000
Landsat-derived vegetation coverage
Water
Not Vegetated
Emergent Vegetation
Wet Meadow
Upland
N
0 0.5 1 2 3 4 5 km
0 0.5 1 2 3 mi
LOCATION: NETLEY-LIBAU MARSH, MANITOBA, CANADA PROJECTION: WGS84 UTM NORTH ZONE 14
ORIGINAL IMAGERY: LANDSAT-7 ETM+ MULTISPECTRAL OBTAINED JULY 30, 2000
PRODUCED BY K ELISE WATCHORN 2015

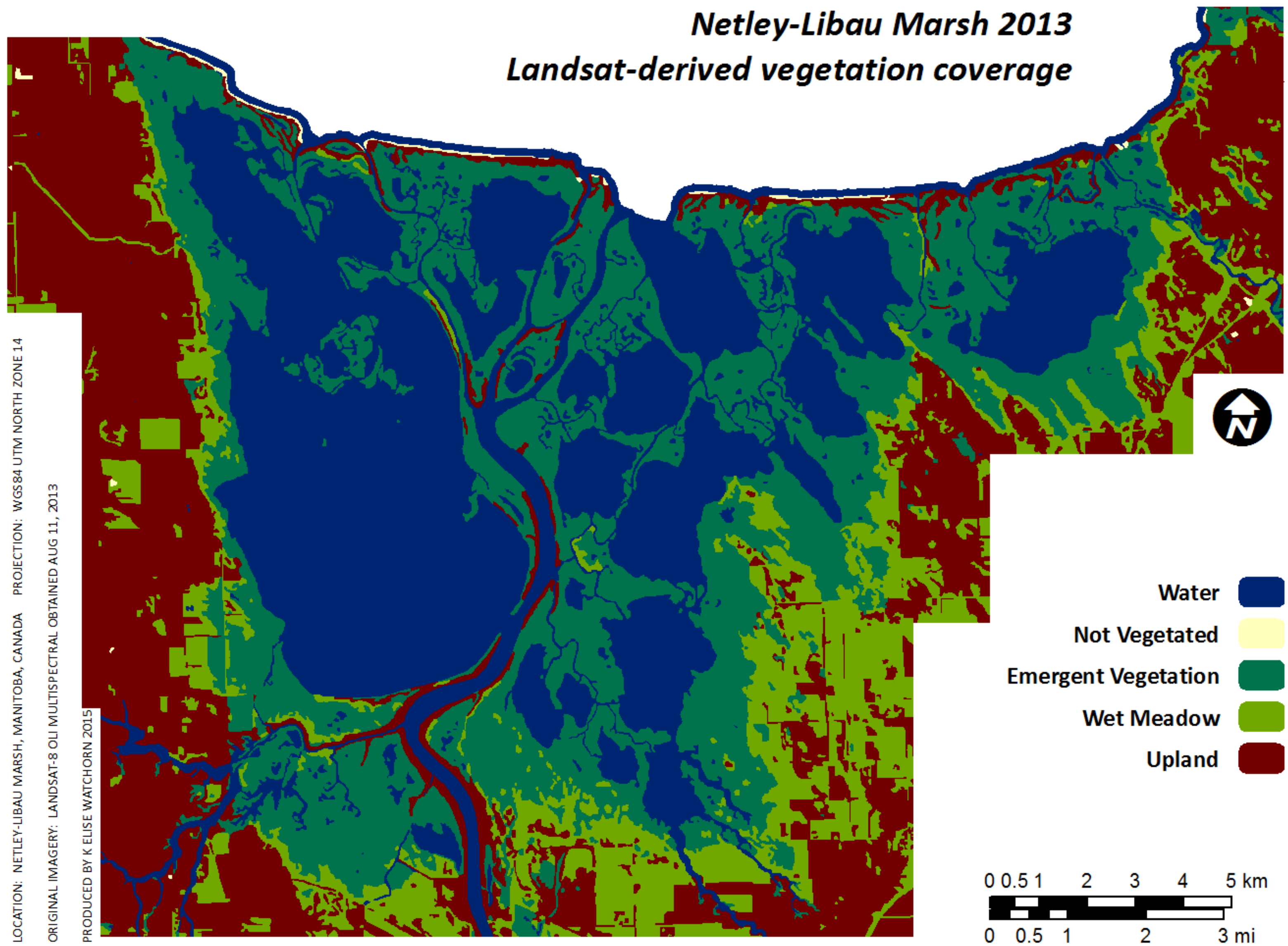

Netley-Libau Marsh 2001
Landsat-derived vegetation coverage
Water
Not Vegetated
Emergent Vegetation
Wet Meadow
Upland
0 0.5 1 2 3 4 5 km
0 0.5 1 2 3 mi
LOCATION: NETLEY-LIBAU MARSH, MANITOBA, CANADA PROJECTION: WGS84 UTM NORTH ZONE 14
ORIGINAL IMAGERY: LANDSAT-7 ETM+ MULTISPECTRAL OBTAINED AUG 2, 2001
PRODUCED BY K ELISE WATCHORN 2014


Netley-Libau Marsh 2002
Landsat-derived vegetation coverage
LOCATION: NETLEY-LIBAU MARSH, MANITOBA, CANADA PROJECTION: WGS84 UTM NORTH ZONE 14
ORIGINAL IMAGERY: LANDSAT-7 ETM+ MULTISPECTRAL OBTAINED AUG 5, 2002
PRODUCED BY K ELISE WATCHORN 2015
Water
Not Vegetated
Emergent Vegetation
Wet Meadow
Upland
0 0.5 1 2 3 4 5 km
0 0.5 1 2 3 mi

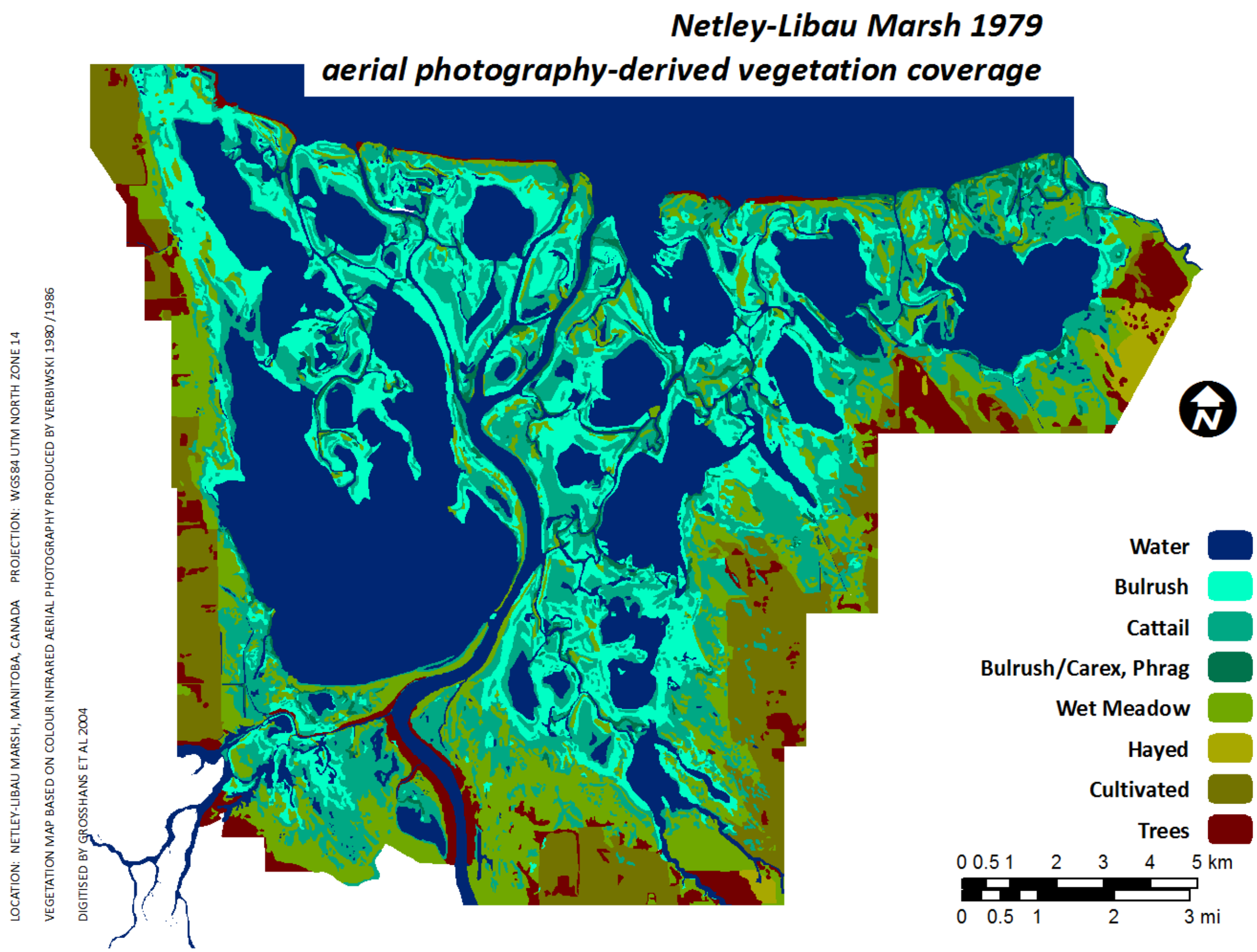

Netley-Libau Marsh 2005
Landsat-derived vegetation coverage
Water
Not Vegetated
Emergent Vegetation
Wet Meadow
Upland
0 0.5 1 2 3 4 5 km
0 0.5 1 2 3 mi
N
LOCATION: NETLEY-LIBAU MARSH, MANITOBA, CANADA PROJECTION: WGS84 UTM NORTH ZONE 14
ORIGINAL IMAGERY: LANDSAT-5 TM MULTISPECTRAL OBTAINED AUG 5, 2005
PRODUCED BY K ELISE WATCHORN 2015

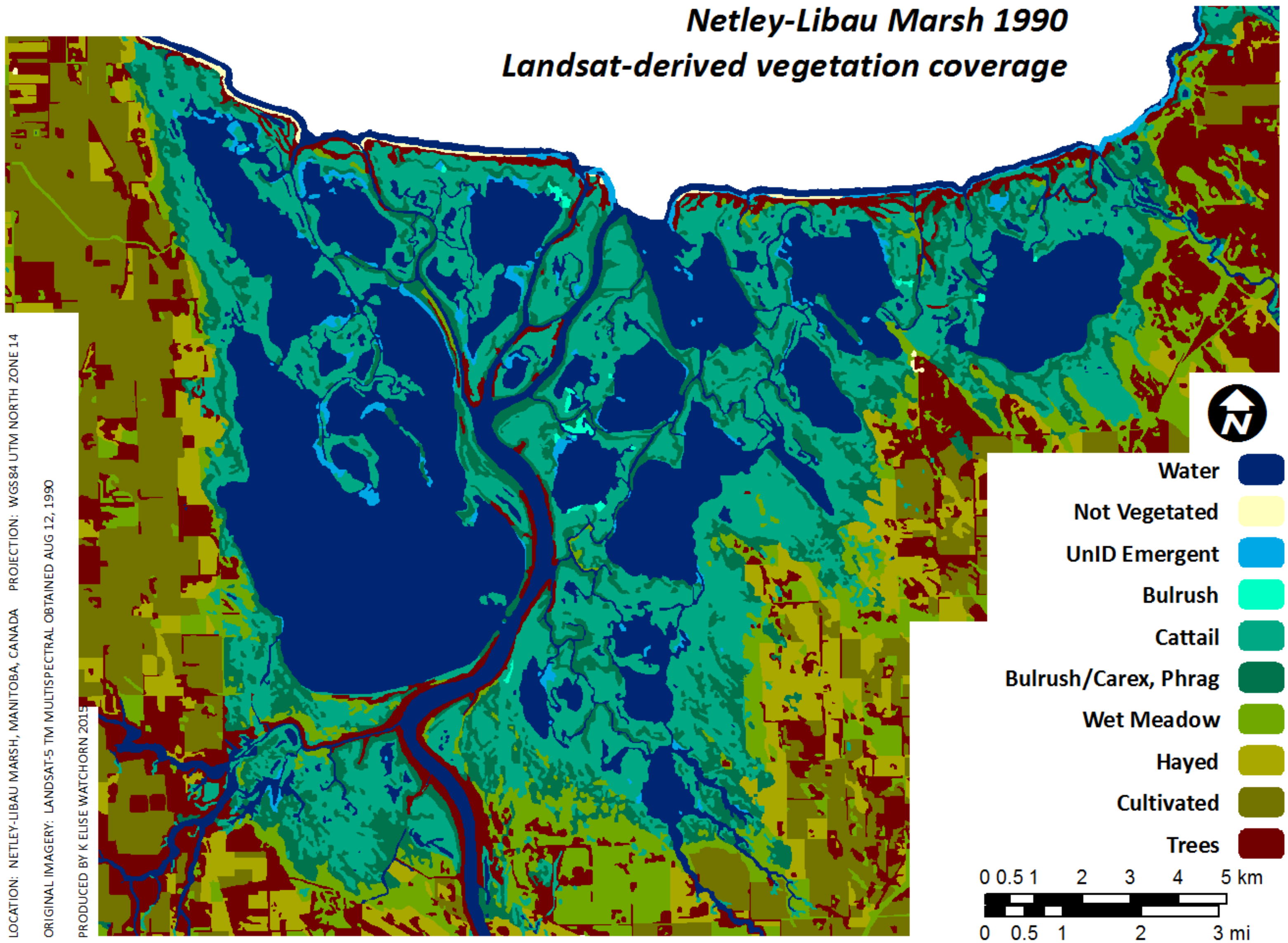


Netley-Libau Marsh 2010
Landsat-derived vegetation coverage
Water
Not Vegetated
Emergent Vegetation
Wet Meadow
Upland
0 0.5 1 2 3 4 5 km
0 0.5 1 2 3 mi
N
LOCATION: NETLEY-LIBAU MARSH, MANITOBA, CANADA PROJECTION: WGS84 UTM NORTH ZONE 14
ORIGINAL IMAGERY: LANDSAT-5 TM MULTISPECTRAL OBTAINED AUG 3, 2010
PRODUCED BY K ELISE WATCHORN 2015

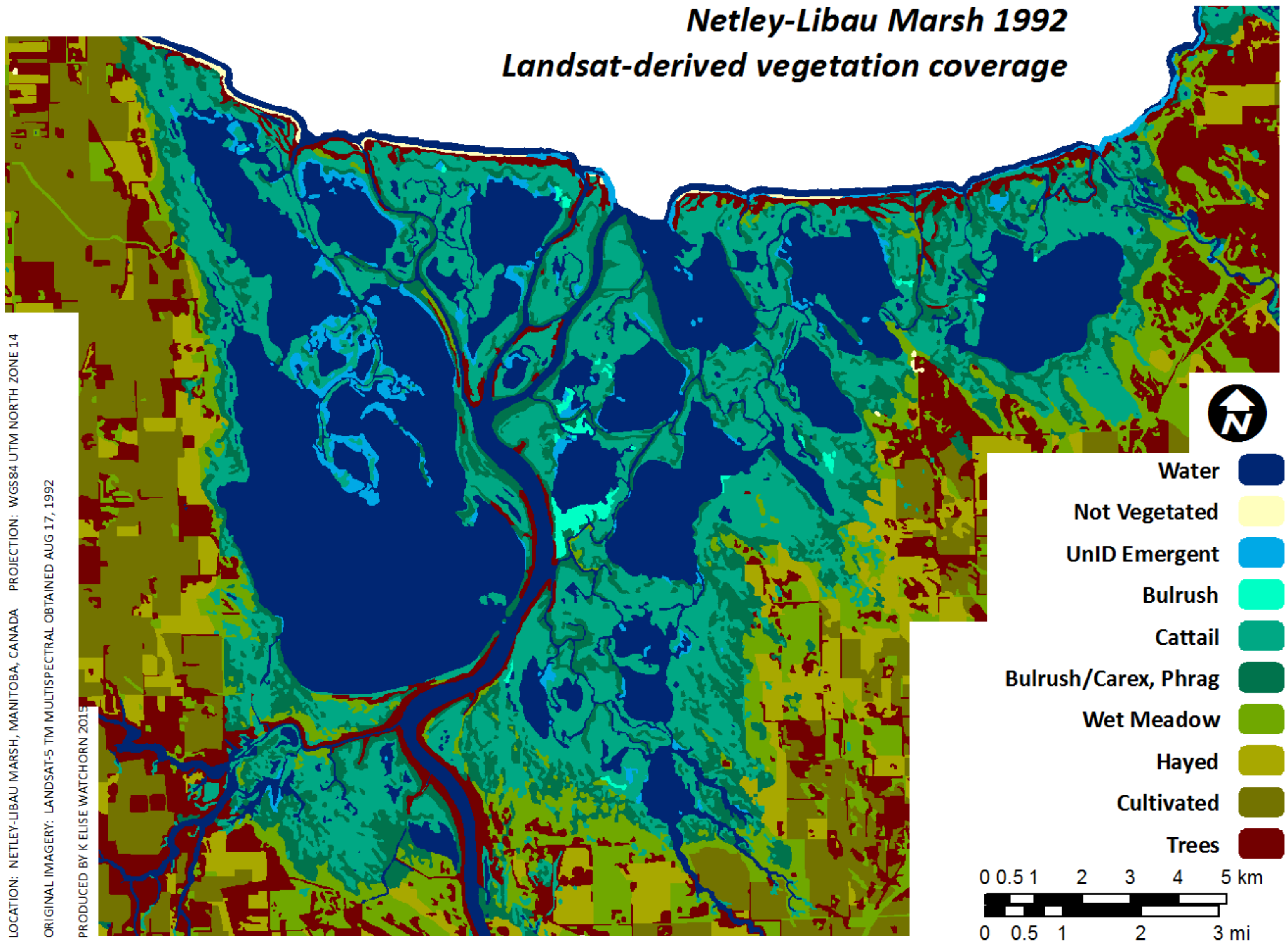

Netley-Libau Marsh 2013
Landsat-derived vegetation coverage
Water
Not Vegetated
Emergent Vegetation
Wet Meadow
Upland
0 0.5 1 2 3 4 5 km
0 0.5 1 2 3 mi
LOCATION: NETLEY-LIBAU MARSH, MANITOBA, CANADA PROJECTION: WGS84 UTM NORTH ZONE 14
ORIGINAL IMAGERY: LANDSAT-8 OLI MULTISPECTRAL OBTAINED AUG 11, 2013
PRODUCED BY K ELISE WATCHORN 2015

Map Series 8.3: Classified vegetation maps of Netley-Libau Marsh, 1990 – 2013, displayed by vegetation class. Created based on Landsat-5, Landsat-7, and Landsat-8 multispectral imagery with a spatial resolution of 30m. A 1979 map based on aerial photography is shown for comparative purposes (Verbiwski 1986; Grosshans et al 2004).

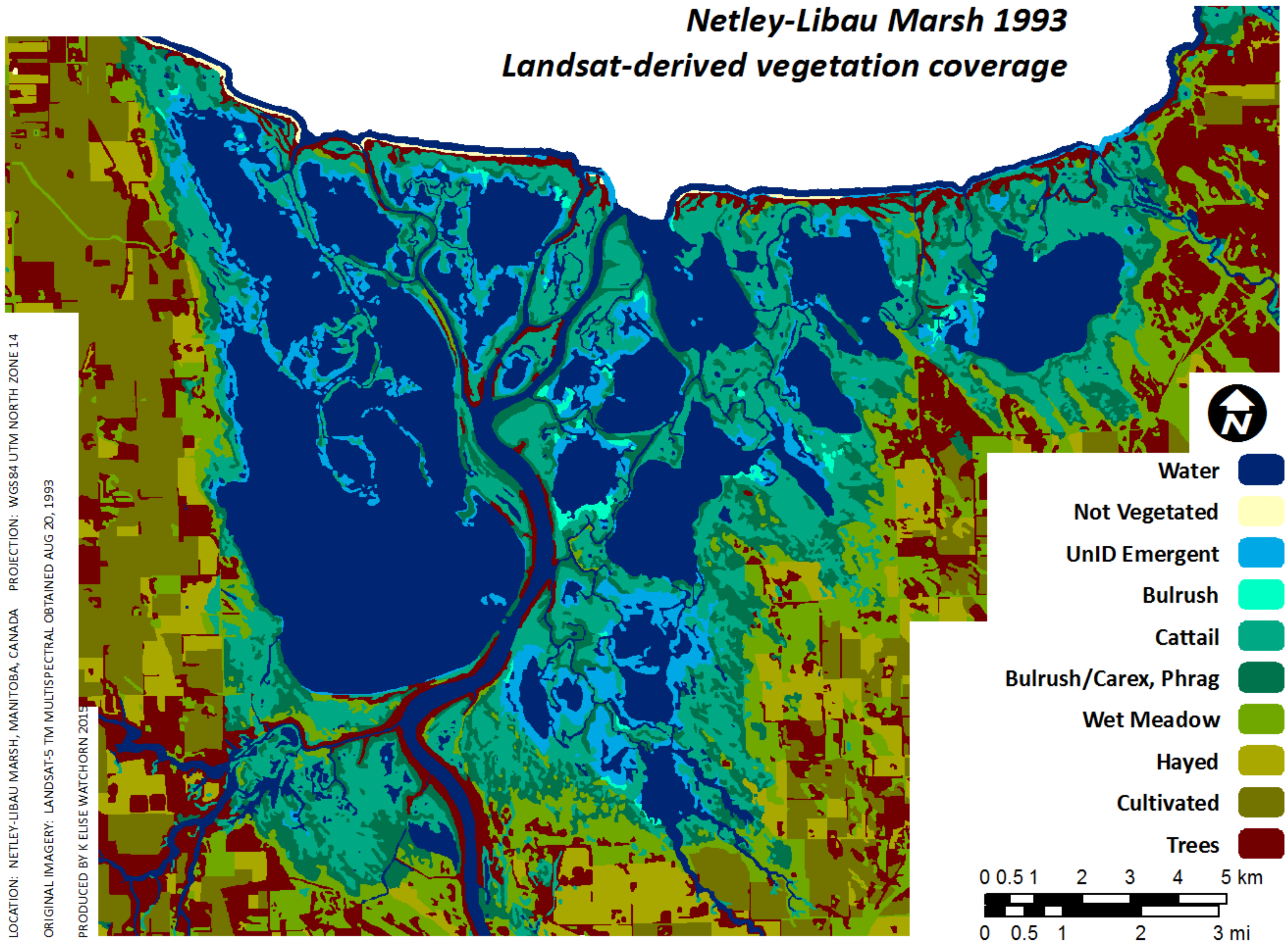


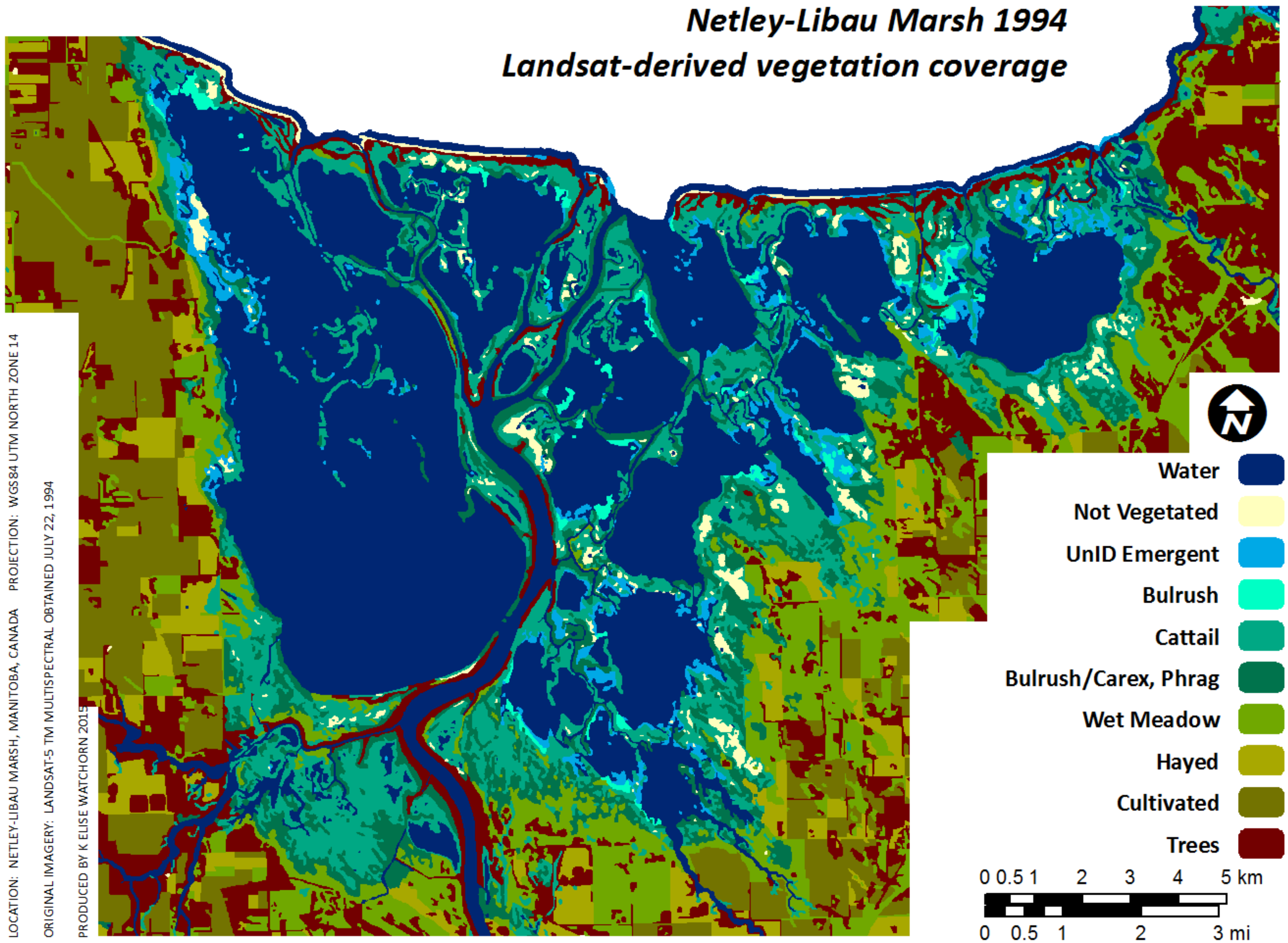


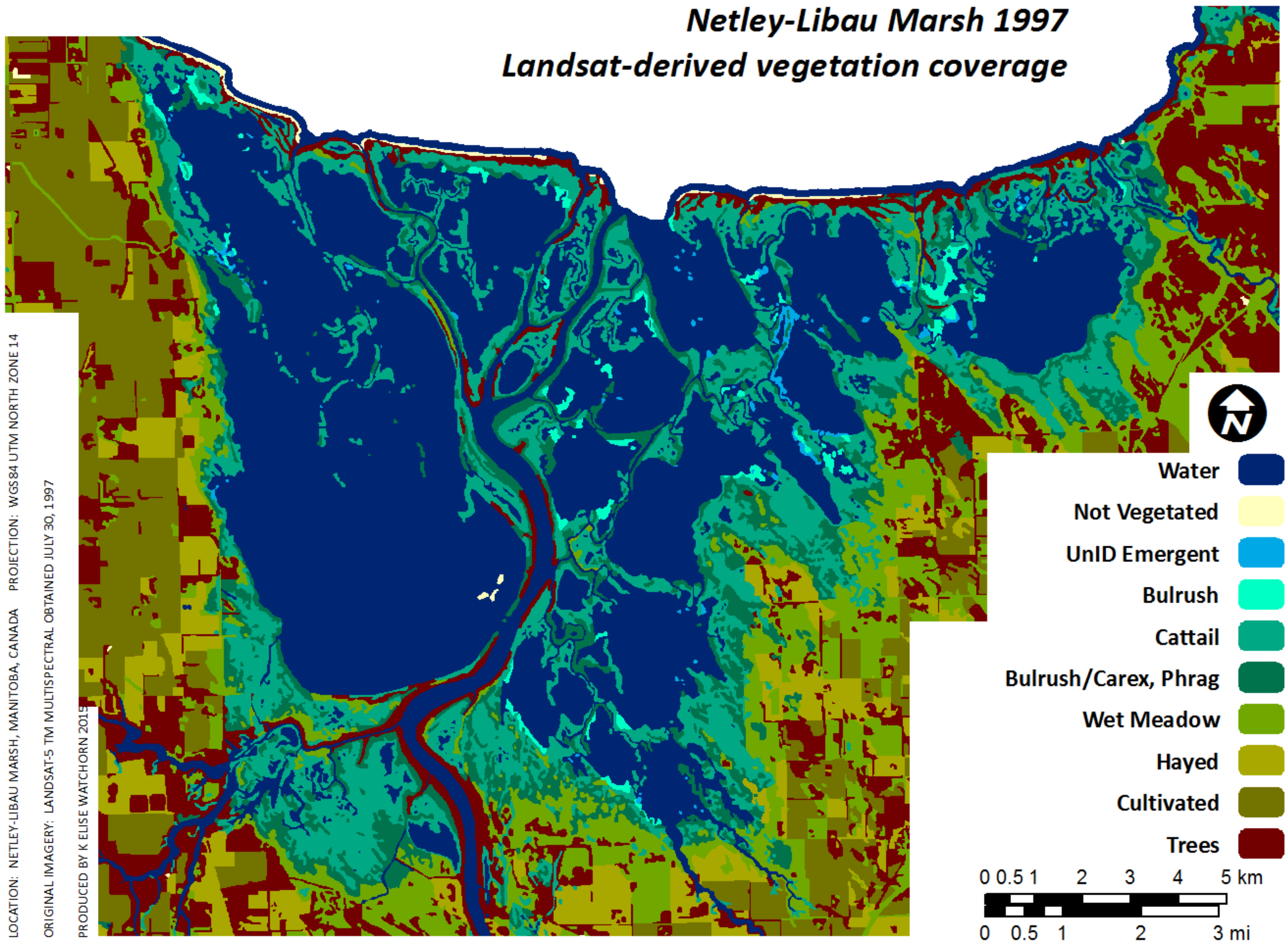
Netley-Libau Marsh 1990
Landsat-derived vegetation coverage
Water
Not Vegetated
UnID Emergent
Bulrush
Cattail
Bulrush/Carex, Phrag
Wet Meadow
Hayed
Cultivated
Trees
0 0.5 1 2 3 4 5 km
0 0.5 1 2 3 mi
LOCATION: NETLEY-LIBAU MARSH, MANITOBA, CANADA PROJECTION: WGS84 UTM NORTH ZONE 14
ORIGINAL IMAGERY: LANDSAT-5 TM MULTISPECTRAL OBTAINED AUG 12, 1990
PRODUCED BY K ELISE WATCHORN 2015

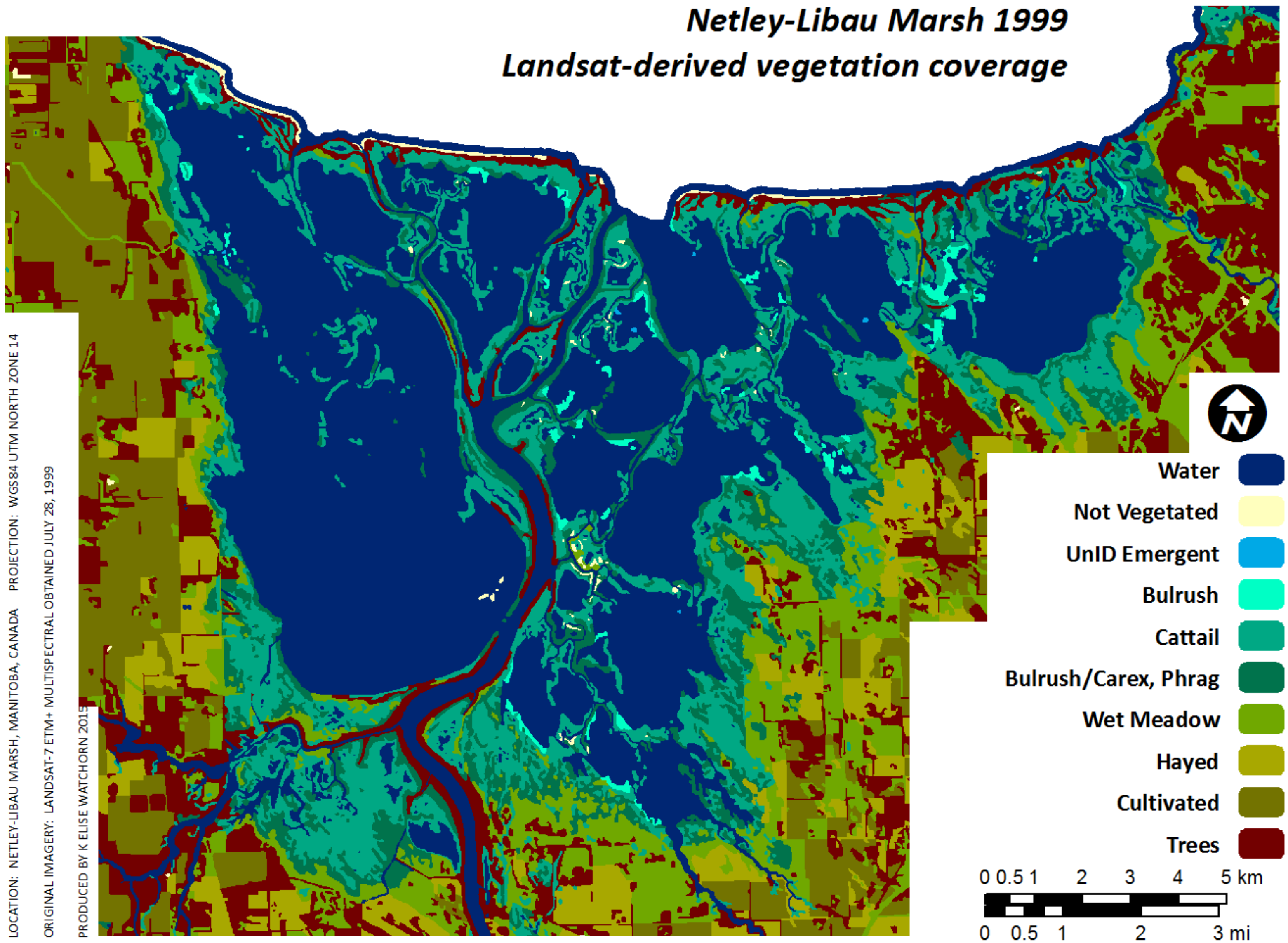


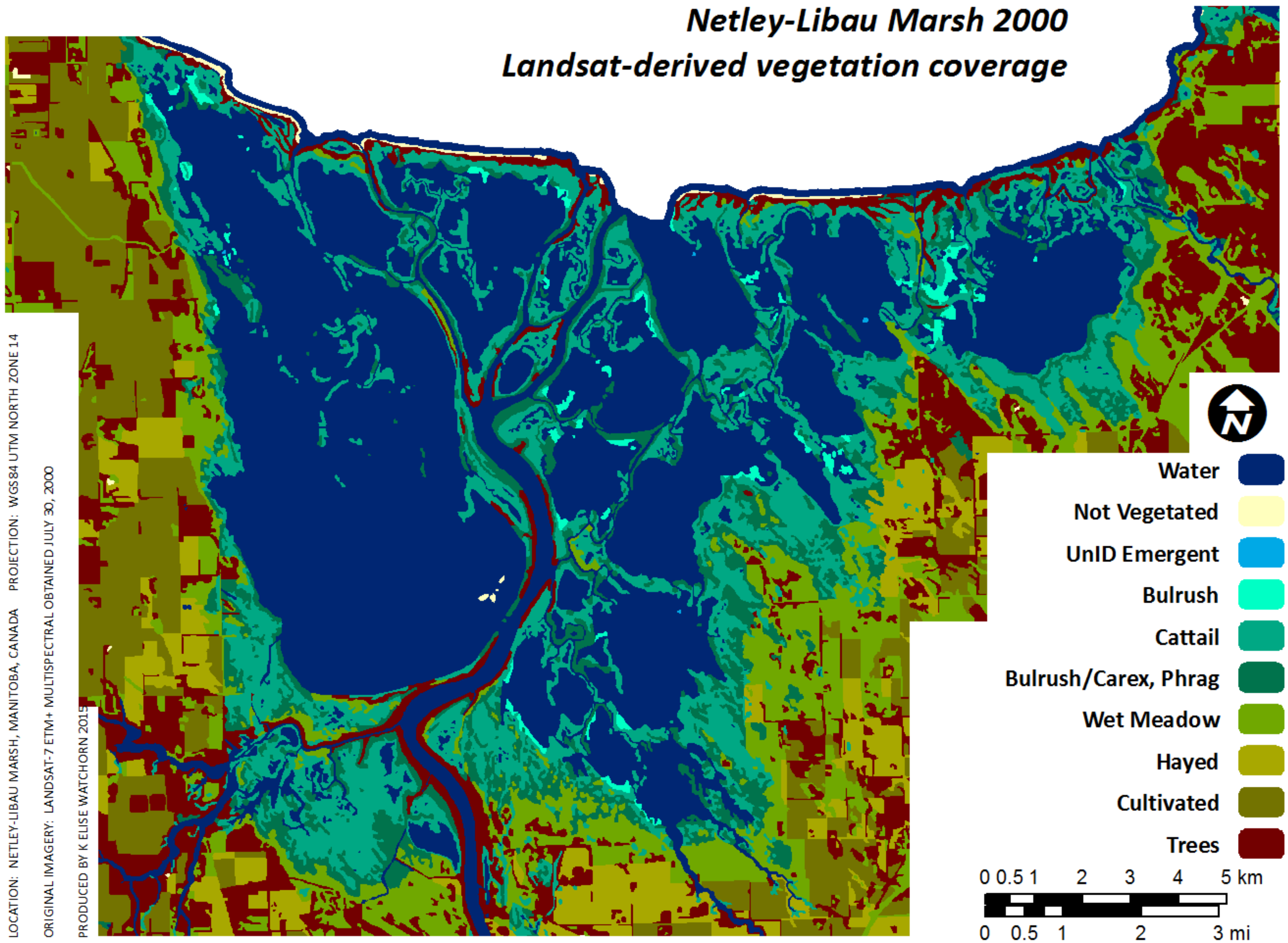
Netley-Libau Marsh 1992
Landsat-derived vegetation coverage
Water
Not Vegetated
UnID Emergent
Bulrush
Cattail
Bulrush/Carex, Phrag
Wet Meadow
Hayed
Cultivated
Trees
0 0.5 1 2 3 4 5 km
0 0.5 1 2 3 mi
LOCATION: NETLEY-LIBAU MARSH, MANITOBA, CANADA PROJECTION: WGS84 UTM NORTH ZONE 14
ORIGINAL IMAGERY: LANDSAT-5 TM MULTISPECTRAL OBTAINED AUG 17, 1992
PRODUCED BY K ELISE WATCHORN 2015

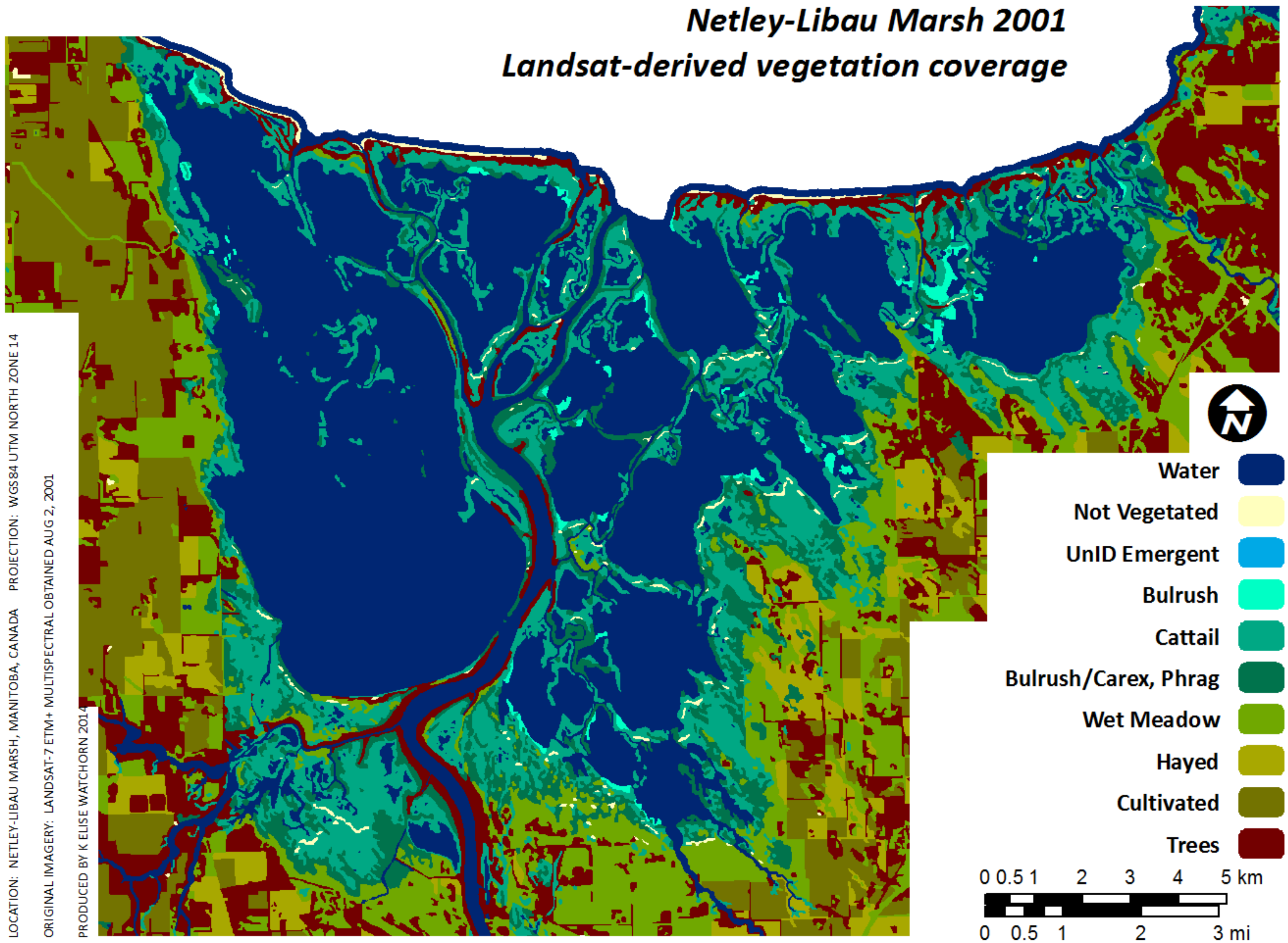

Netley-Libau Marsh 1993
Landsat-derived vegetation coverage
Water
Not Vegetated
UnID Emergent
Bulrush
Cattail
Bulrush/Carex, Phrag
Wet Meadow
Hayed
Cultivated
Trees
0 0.5 1 2 3 4 5 km
0 0.5 1 2 3 mi
LOCATION: NETLEY-LIBAU MARSH, MANITOBA, CANADA PROJECTION: WGS84 UTM NORTH ZONE 14
ORIGINAL IMAGERY: LANDSAT-5 TM MULTISPECTRAL OBTAINED AUG 20, 1993
PRODUCED BY K ELISE WATCHORN 2015

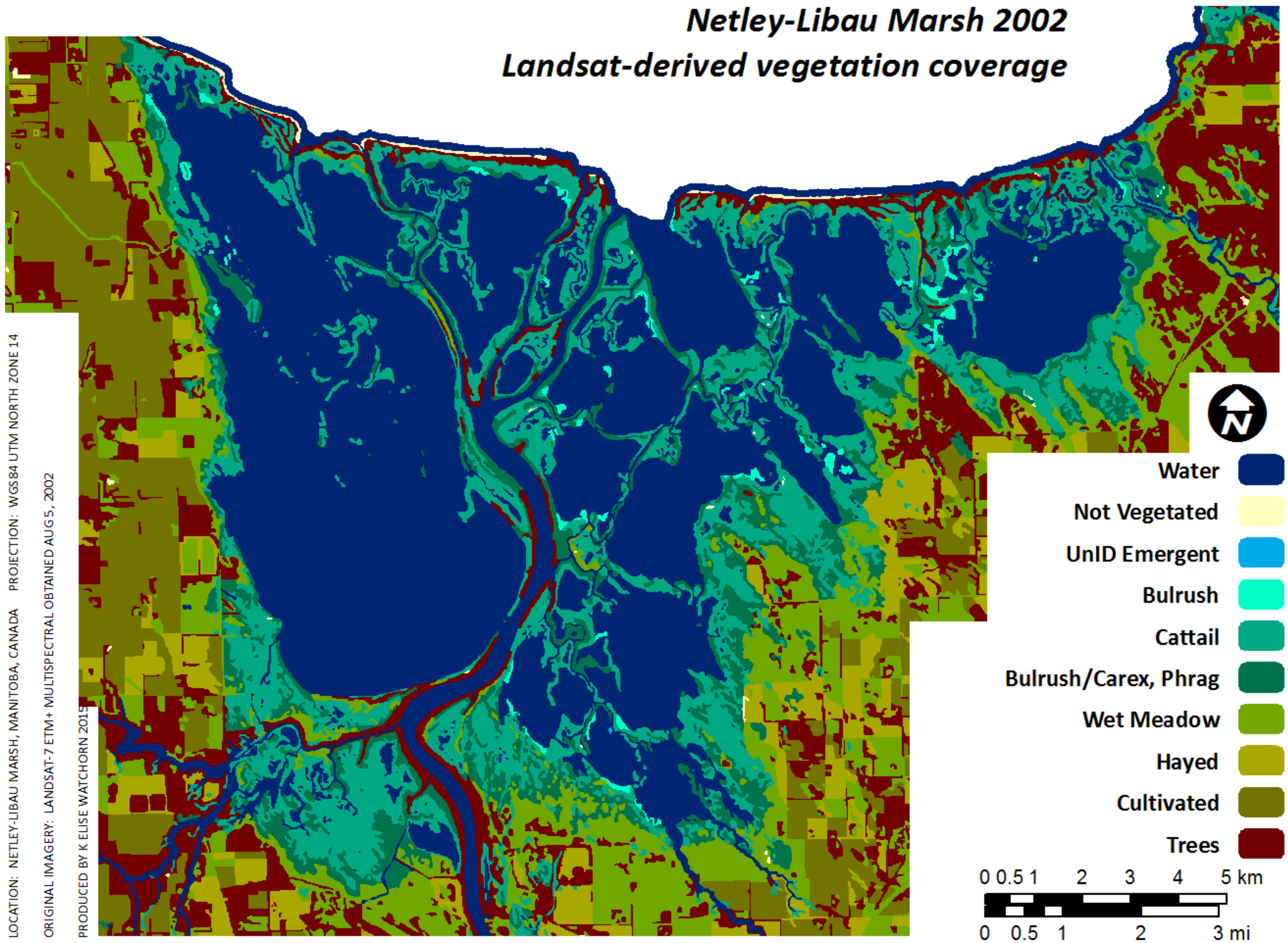

Netley-Libau Marsh 1994
Landsat-derived vegetation coverage
Water
Not Vegetated
UnID Emergent
Bulrush
Cattail
Bulrush/Carex, Phrag
Wet Meadow
Hayed
Cultivated
Trees
0 0.5 1 2 3 4 5 km
0 0.5 1 2 3 mi
N
LOCATION: NETLEY-LIBAU MARSH, MANITOBA, CANADA PROJECTION: WGS84 UTM NORTH ZONE 14
ORIGINAL IMAGERY: LANDSAT-5 TM MULTISPECTRAL OBTAINED JULY 22, 1994
PRODUCED BY K ELISE WATCHORN 2015

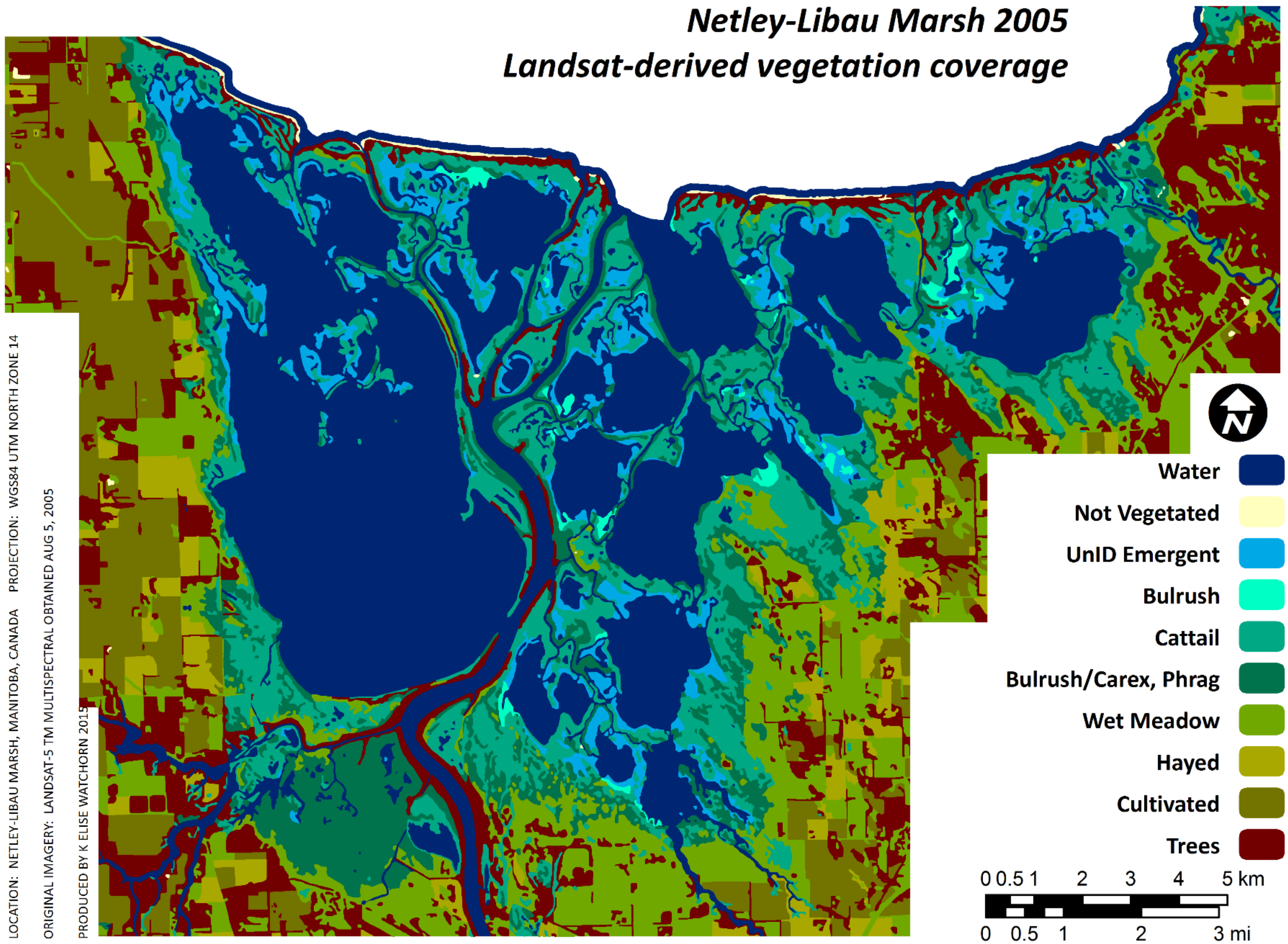

Netley-Libau Marsh 1997
Landsat-derived vegetation coverage
Water
Not Vegetated
UnID Emergent
Bulrush
Cattail
Bulrush/Carex, Phrag
Wet Meadow
Hayed
Cultivated
Trees
0 0.5 1 2 3 4 5 km
0 0.5 1 2 3 mi
LOCATION: NETLEY-LIBAU MARSH, MANITOBA, CANADA PROJECTION: WGS84 UTM NORTH ZONE 14
ORIGINAL IMAGERY: LANDSAT-5 TM MULTISPECTRAL OBTAINED JULY 30, 1997
PRODUCED BY K ELISE WATCHORN 2015

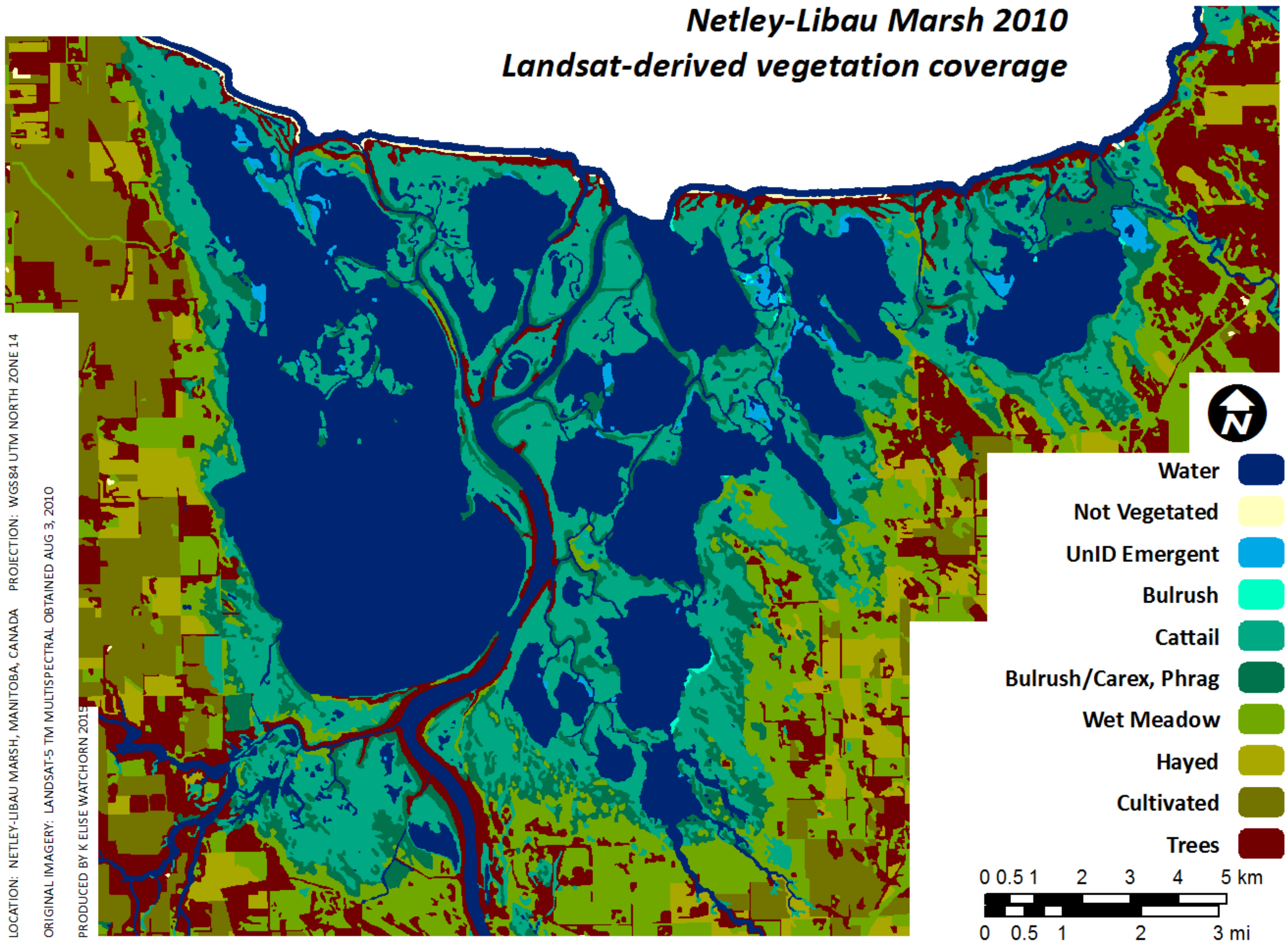

Netley-Libau Marsh 1999
Landsat-derived vegetation coverage
LOCATION: NETLEY-LIBAU MARSH, MANITOBA, CANADA PROJECTION: WGS84 UTM NORTH ZONE 14
ORIGINAL IMAGERY: LANDSAT-7 ETM+ MULTISPECTRAL OBTAINED JULY 28, 1999
PRODUCED BY K ELISE WATCHORN 2015
N
Water
Not Vegetated
UnID Emergent
Bulrush
Cattail
Bulrush/Carex, Phrag
Wet Meadow
Hayed
Cultivated
Trees
0 0.5 1 2 3 4 5 km
0 0.5 1 2 3 mi

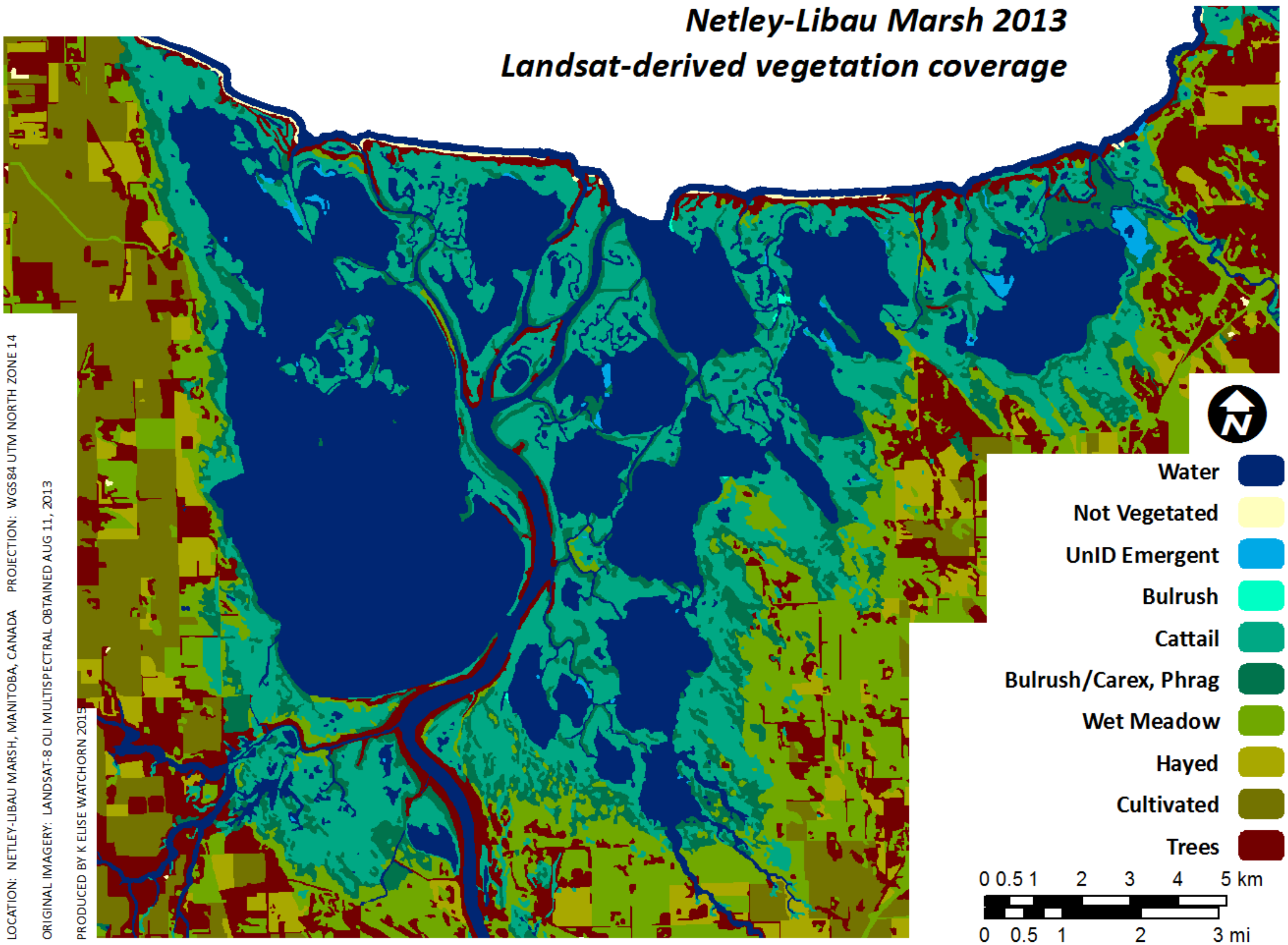

Netley-Libau Marsh 2000
Landsat-derived vegetation coverage
Water
Not Vegetated
UnID Emergent
Bulrush
Cattail
Bulrush/Carex, Phrag
Wet Meadow
Hayed
Cultivated
Trees
0 0.5 1 2 3 4 5 km
0 0.5 1 2 3 mi
N
LOCATION: NETLEY-LIBAU MARSH, MANITOBA, CANADA PROJECTION: WGS84 UTM NORTH ZONE 14
ORIGINAL IMAGERY: LANDSAT-7 ETM+ MULTISPECTRAL OBTAINED JULY 30, 2000
PRODUCED BY K ELISE WATCHORN 2015


Netley-Libau Marsh 2001
Landsat-derived vegetation coverage
Water
Not Vegetated
UnID Emergent
Bulrush
Cattail
Bulrush/Carex, Phrag
Wet Meadow
Hayed
Cultivated
Trees
0 0.5 1 2 3 4 5 km
0 0.5 1 2 3 mi
LOCATION: NETLEY-LIBAU MARSH, MANITOBA, CANADA PROJECTION: WGS84 UTM NORTH ZONE 14
ORIGINAL IMAGERY: LANDSAT-7 ETM+ MULTISPECTRAL OBTAINED AUG 2, 2001
PRODUCED BY K ELISE WATCHORN 2014

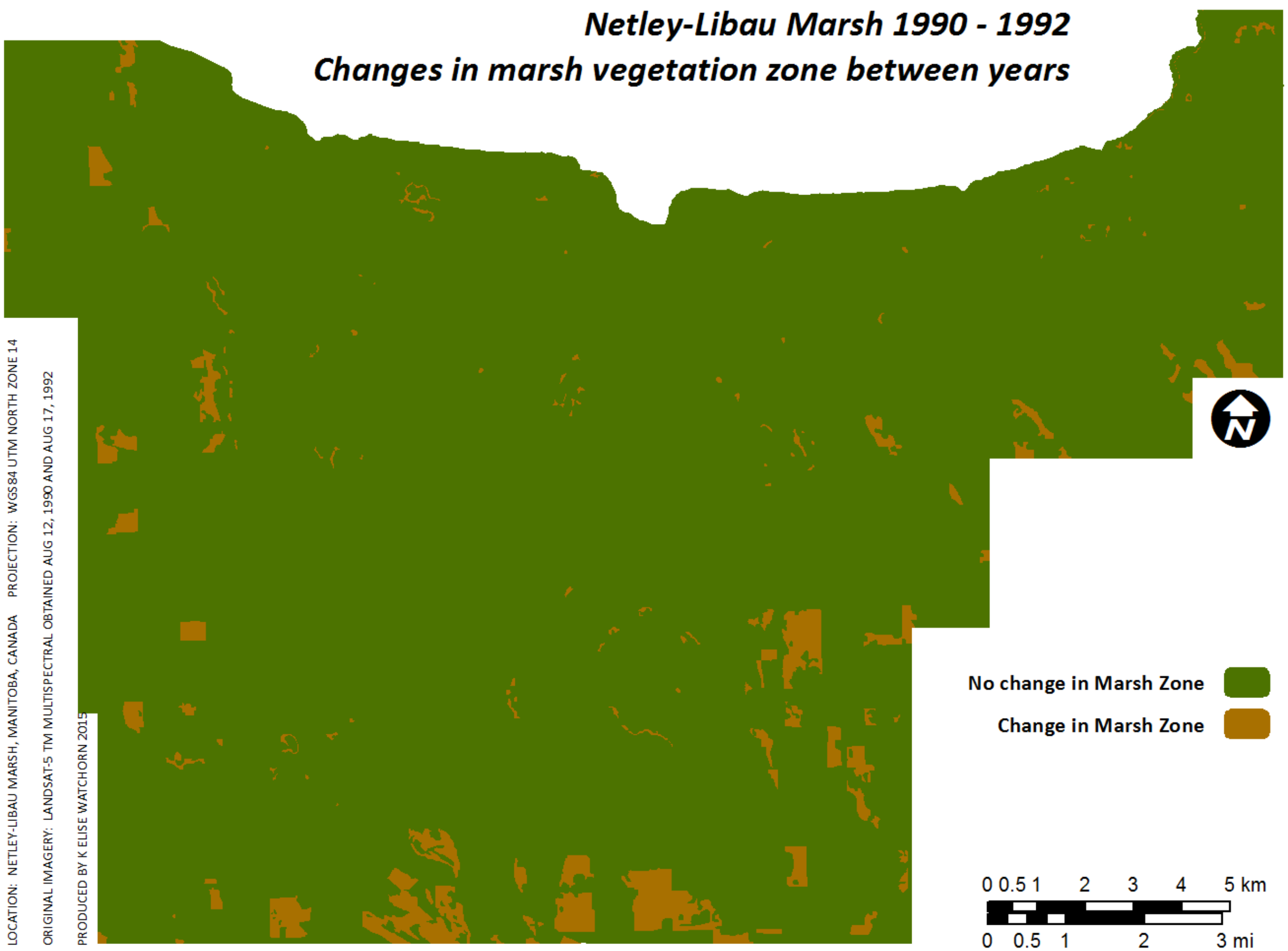

Netley-Libau Marsh 2002
Landsat-derived vegetation coverage
Water
Not Vegetated
UnID Emergent
Bulrush
Cattail
Bulrush/Carex, Phrag
Wet Meadow
Hayed
Cultivated
Trees
0 0.5 1 2 3 4 5 km
0 0.5 1 2 3 mi
LOCATION: NETLEY-LIBAU MARSH, MANITOBA, CANADA PROJECTION: WGS84 UTM NORTH ZONE 14
ORIGINAL IMAGERY: LANDSAT-7 ETM+ MULTISPECTRAL OBTAINED AUG 5, 2002
PRODUCED BY K ELISE WATCHORN 2015

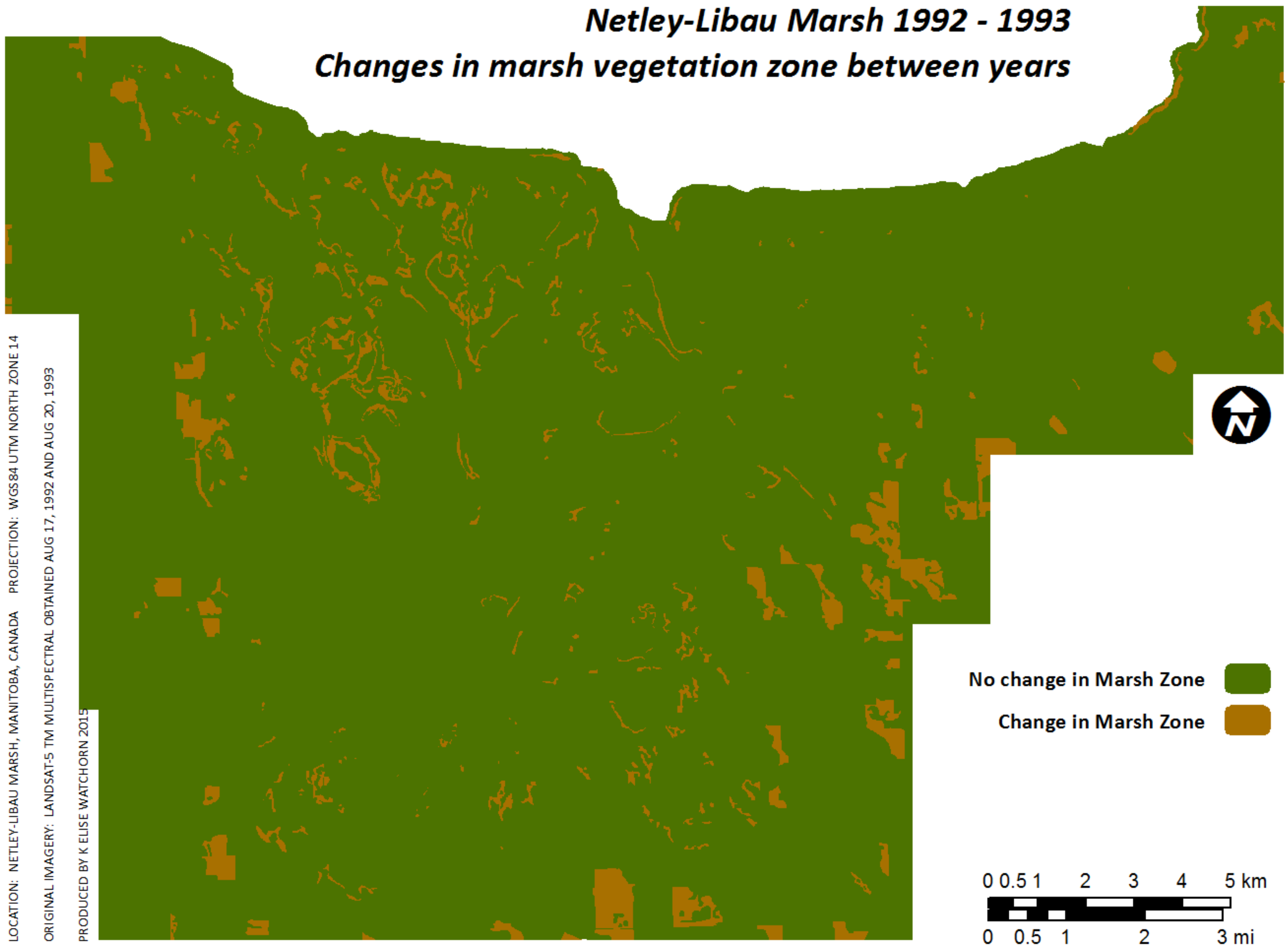

Netley-Libau Marsh 2005
Landsat-derived vegetation coverage
LOCATION: NETLEY-LIBAU MARSH, MANITOBA, CANADA PROJECTION: WGS84 UTM NORTH ZONE 14
ORIGINAL IMAGERY: LANDSAT-5 TM MULTISPECTRAL OBTAINED AUG 5, 2005
PRODUCED BY K ELISE WATCHORN 2015
N
Water
Not Vegetated
UnID Emergent
Bulrush
Cattail
Bulrush/Carex, Phrag
Wet Meadow
Hayed
Cultivated
Trees
0 0.5 1 2 3 4 5 km
0 0.5 1 2 3 mi

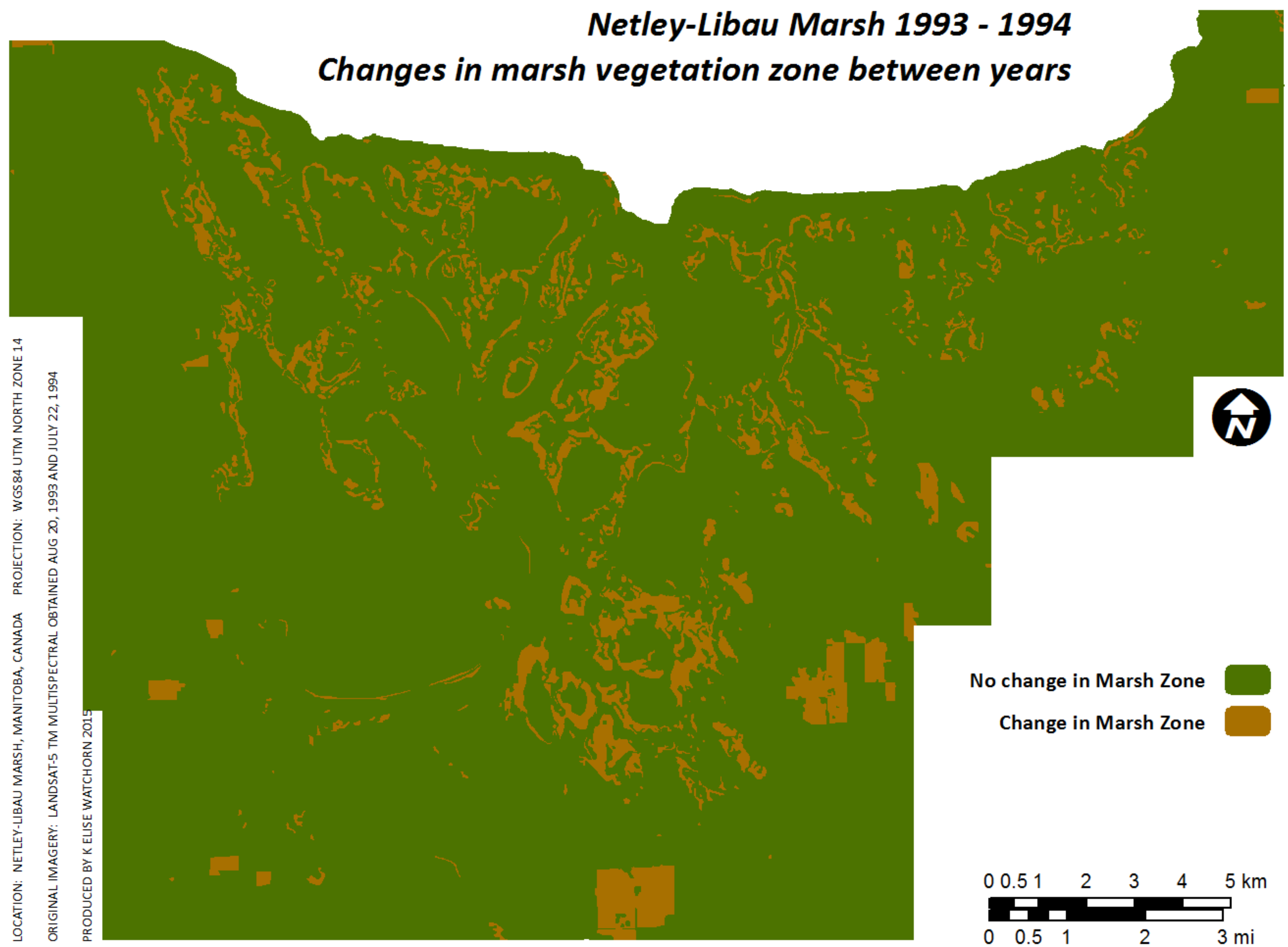

Netley-Libau Marsh 2010
Landsat-derived vegetation coverage
LOCATION: NETLEY-LIBAU MARSH, MANITOBA, CANADA PROJECTION: WGS84 UTM NORTH ZONE 14
ORIGINAL IMAGERY: LANDSAT-5 TM MULTISPECTRAL OBTAINED AUG 3, 2010
PRODUCED BY K ELISE WATCHORN 2015
N
Water
Not Vegetated
UnID Emergent
Bulrush
Cattail
Bulrush/Carex, Phrag
Wet Meadow
Hayed
Cultivated
Trees
0 0.5 1 2 3 4 5 km
0 0.5 1 2 3 mi

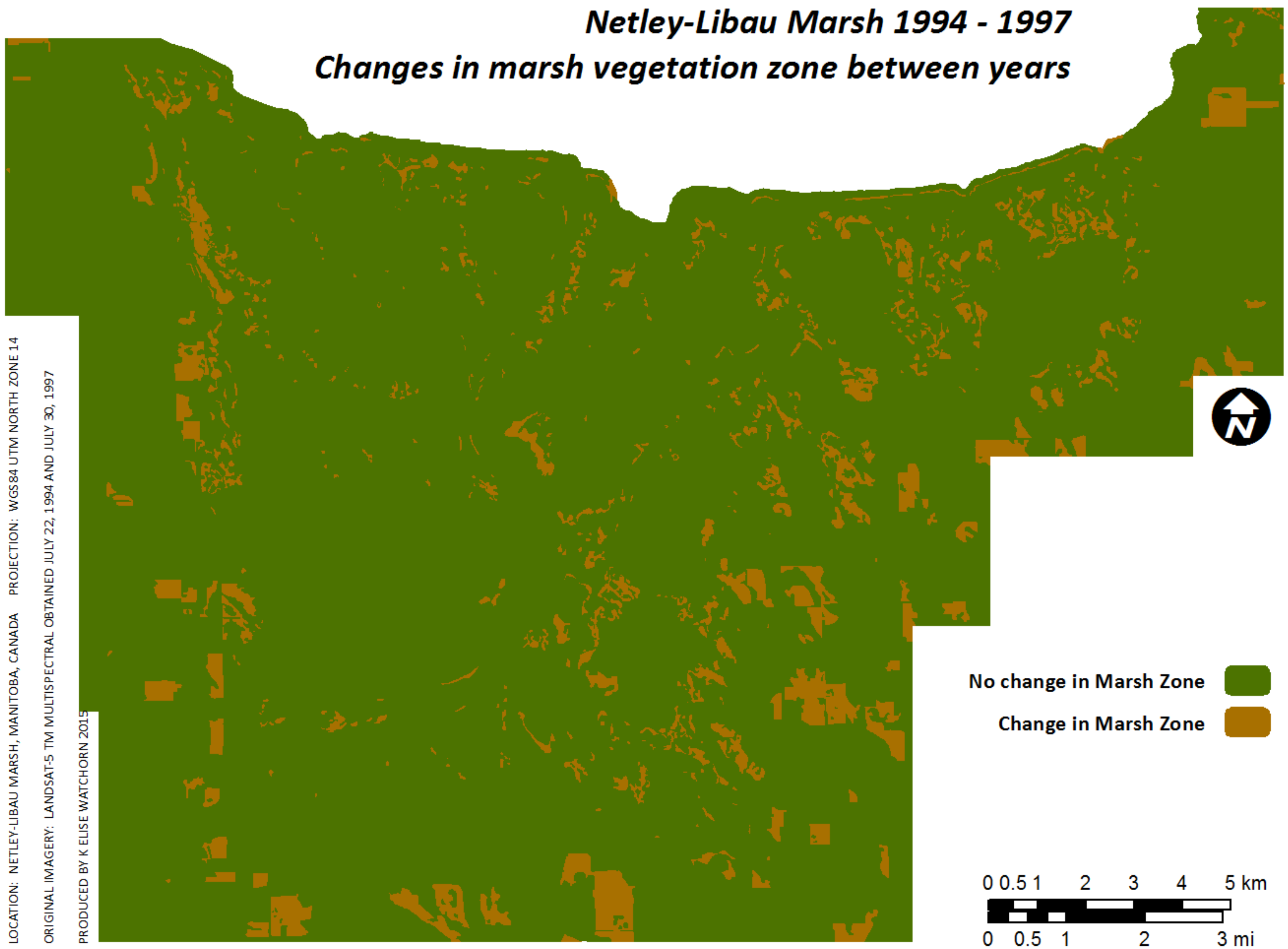

Netley-Libau Marsh 2013
Landsat-derived vegetation coverage
Water
Not Vegetated
UnID Emergent
Bulrush
Cattail
Bulrush/Carex, Phrag
Wet Meadow
Hayed
Cultivated
Trees
0 0.5 1 2 3 4 5 km
0 0.5 1 2 3 mi
LOCATION: NETLEY-LIBAU MARSH, MANITOBA, CANADA PROJECTION: WGS84 UTM NORTH ZONE 14
ORIGINAL IMAGERY: LANDSAT-8 OLI MULTISPECTRAL OBTAINED AUG 11, 2013
PRODUCED BY K ELISE WATCHORN 2015

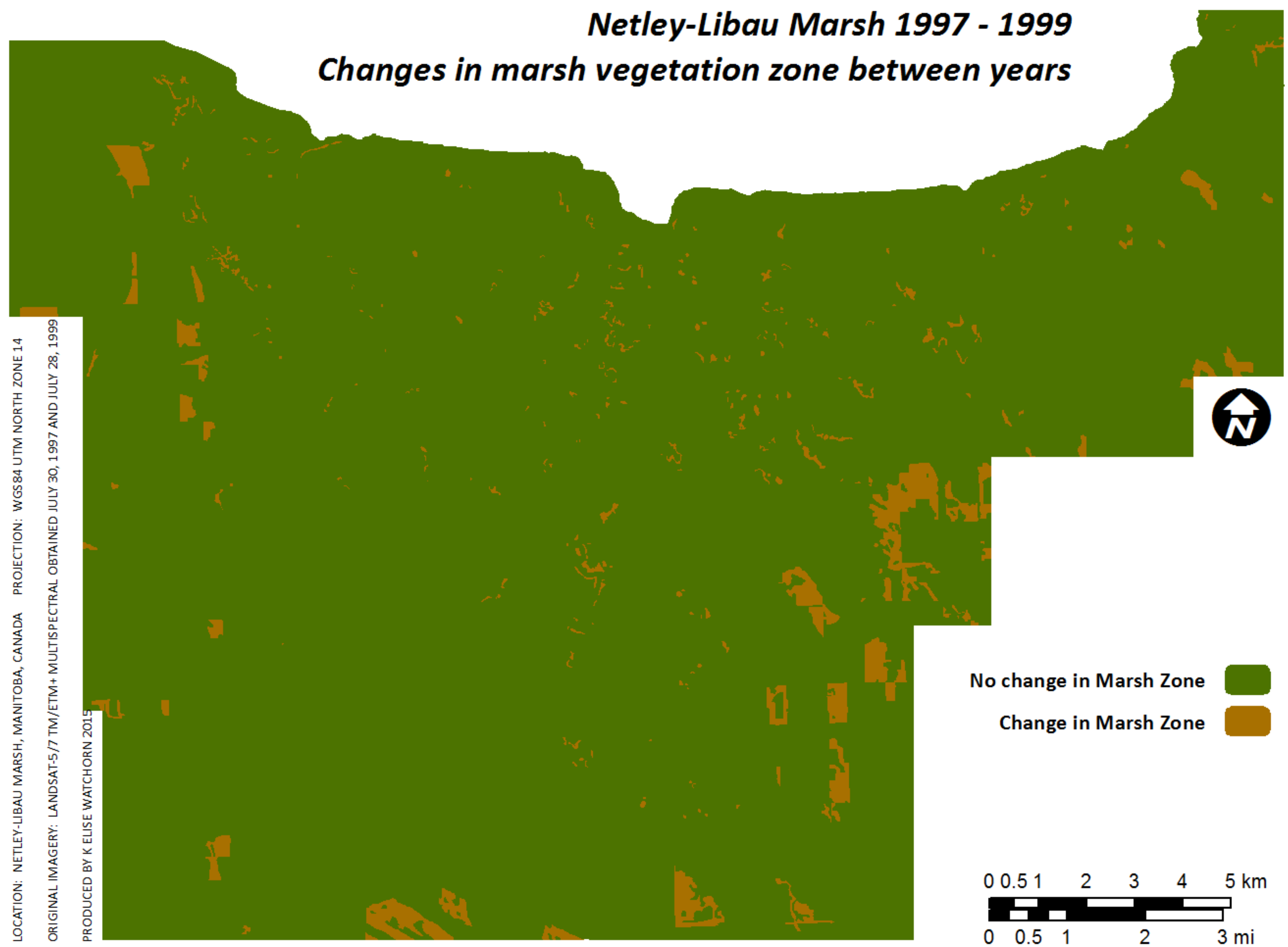
Map Series 8.4: Maps of Netley-Libau Marsh, 1990 – 2013, displaying areas in which the classified marsh zone changed from the previous mapped year.

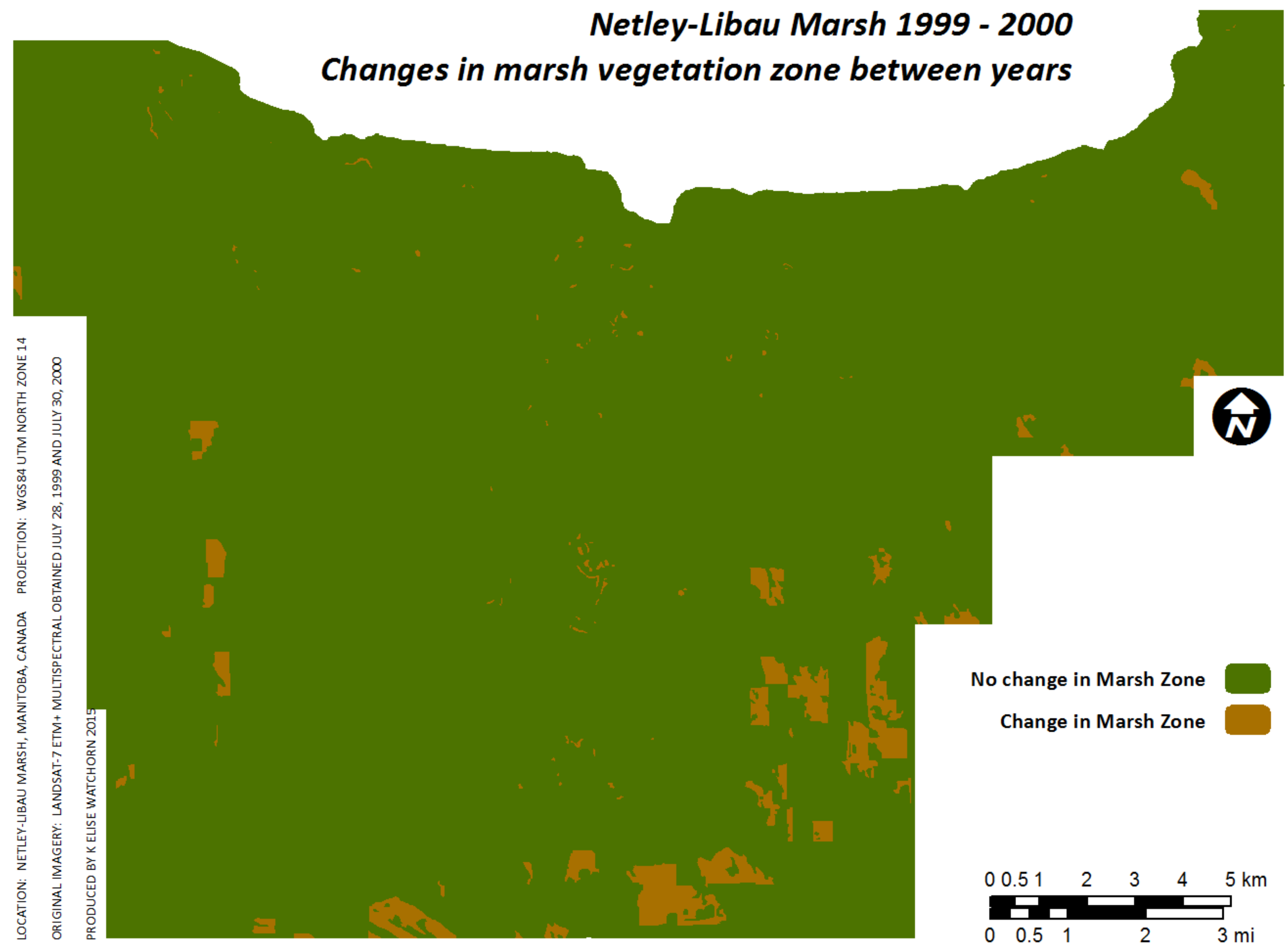



Netley-Libau Marsh 1992 - 1993
Changes in marsh vegetation zone between years
LOCATION: NETLEY-LIBAU MARSH, MANITOBA, CANADA PROJECTION: WGS84 UTM NORTH ZONE 14
ORIGINAL IMAGERY: LANDSAT-5 TM MULTISPECTRAL OBTAINED AUG 17, 1992 AND AUG 20, 1993
PRODUCED BY K ELISE WATCHORN 2015
N
No change in Marsh Zone
Change in Marsh Zone
0 0.5 1 2 3 4 5 km
0 0.5 1 2 3 mi

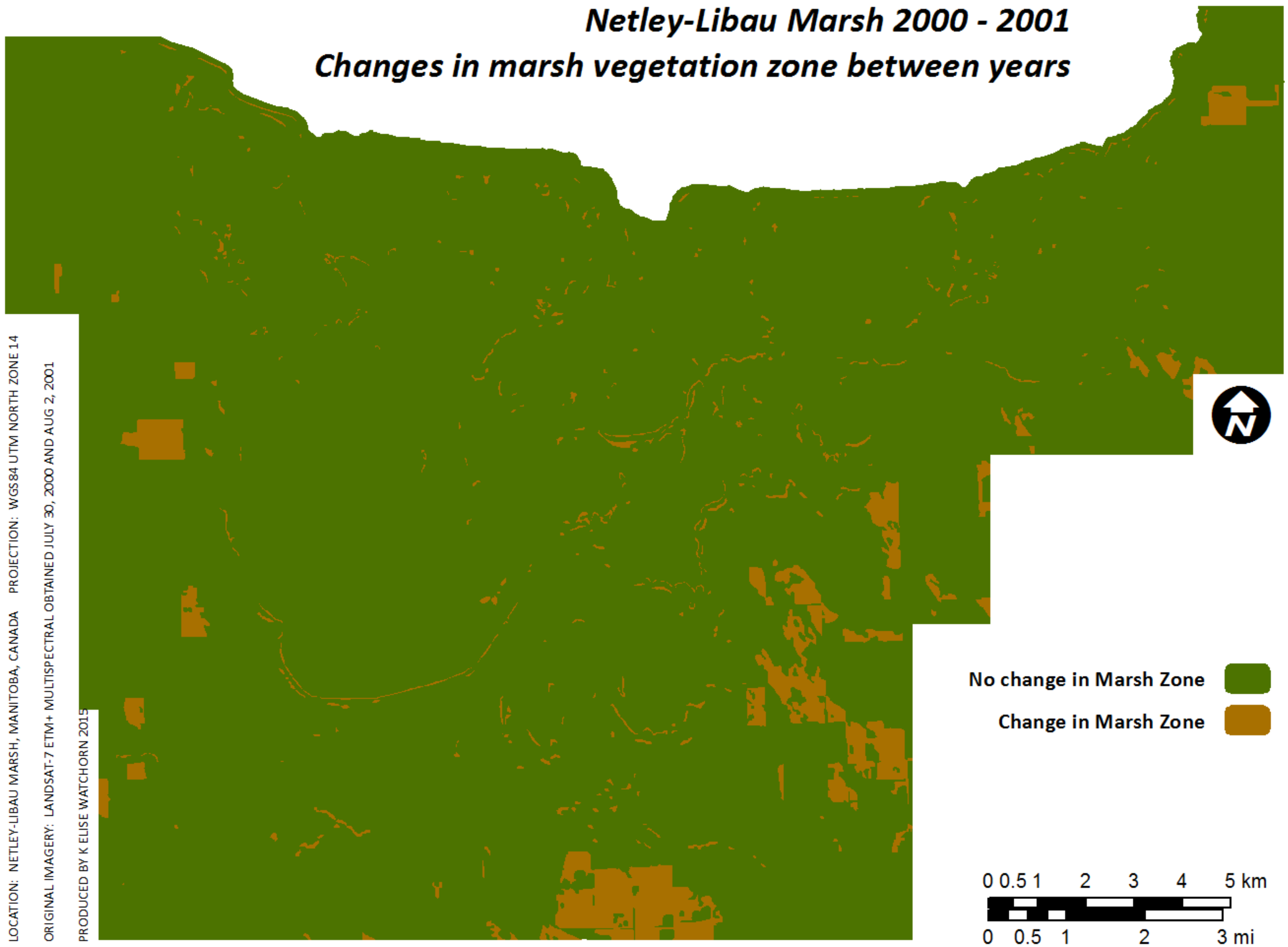

Netley-Libau Marsh 1993 - 1994
Changes in marsh vegetation zone between years
No change in Marsh Zone
Change in Marsh Zone
0 0.5 1 2 3 4 5 km
0 0.5 1 2 3 mi
LOCATION: NETLEY-LIBAU MARSH, MANITOBA, CANADA PROJECTION: WGS84 UTM NORTH ZONE 14
ORIGINAL IMAGERY: LANDSAT-5 TM MULTISPECTRAL OBTAINED AUG 20, 1993 AND JULY 22, 1994
PRODUCED BY K ELISE WATCHORN 2015

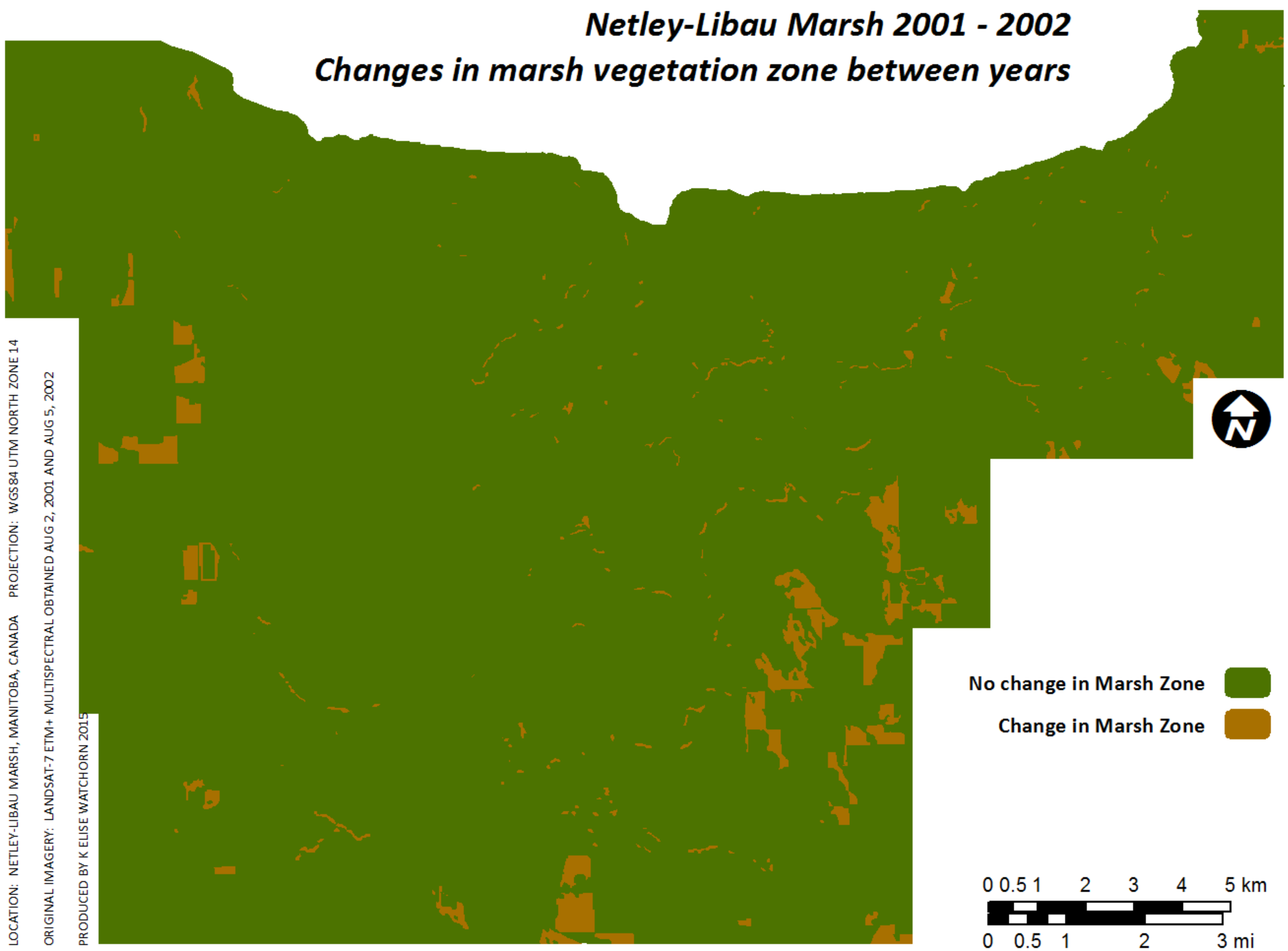

Netley-Libau Marsh 1994 - 1997
Changes in marsh vegetation zone between years
No change in Marsh Zone
Change in Marsh Zone
0 0.5 1 2 3 4 5 km
0 0.5 1 2 3 mi
LOCATION: NETLEY-LIBAU MARSH, MANITOBA, CANADA PROJECTION: WGS84 UTM NORTH ZONE 14
ORIGINAL IMAGERY: LANDSAT-5 TM MULTISPECTRAL OBTAINED JULY 22, 1994 AND JULY 30, 1997
PRODUCED BY K ELISE WATCHORN 2015

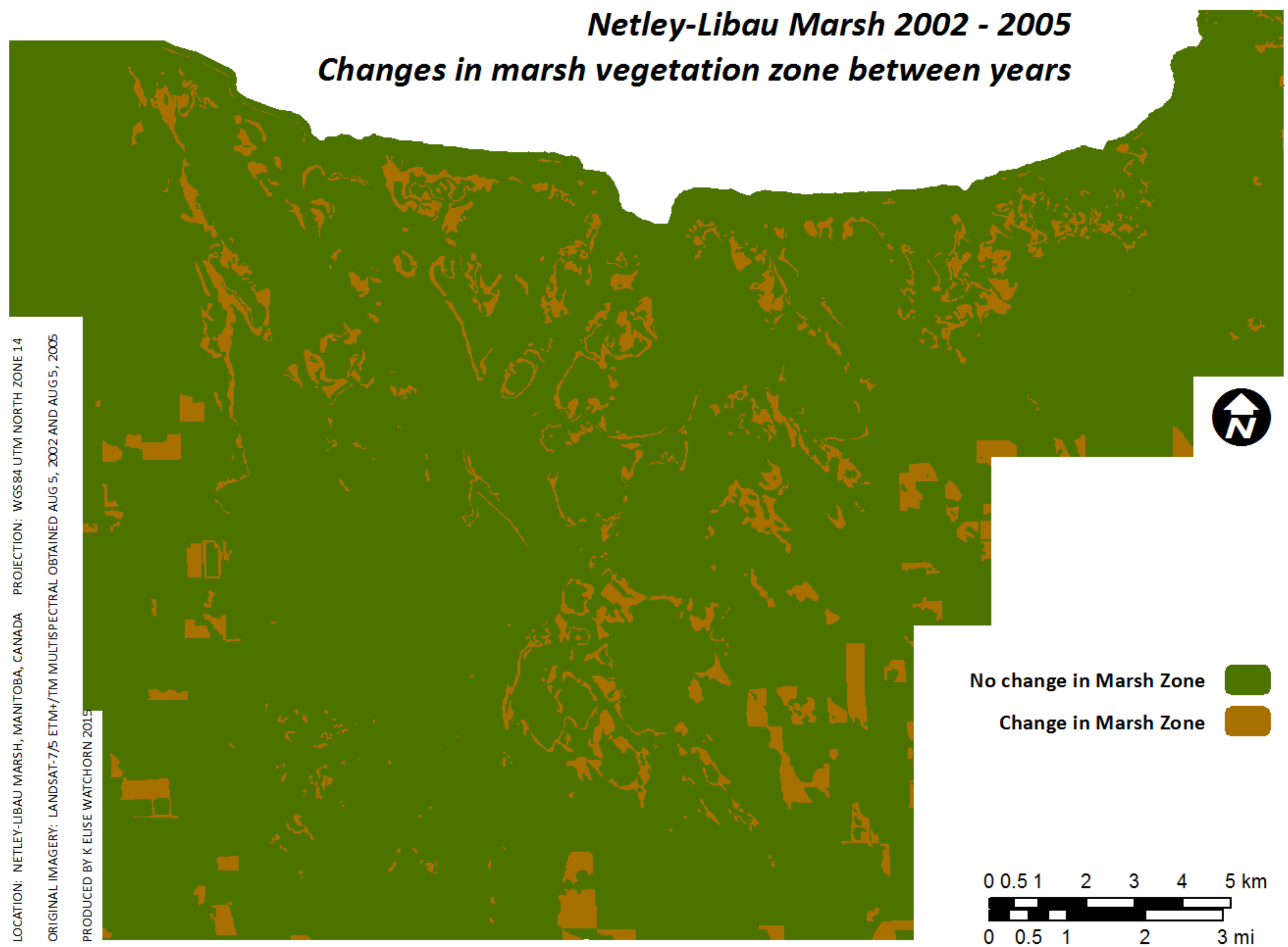

Netley-Libau Marsh 1997 - 1999
Changes in marsh vegetation zone between years
LOCATION: NETLEY-LIBAU MARSH, MANITOBA, CANADA PROJECTION: WGS84 UTM NORTH ZONE 14
ORIGINAL IMAGERY: LANDSAT-5/7 TM/ETM+ MULTISPECTRAL OBTAINED JULY 30, 1997 AND JULY 28, 1999
PRODUCED BY K ELISE WATCHORN 2015
N
No change in Marsh Zone
Change in Marsh Zone
0 0.5 1 2 3 4 5 km
0 0.5 1 2 3 mi

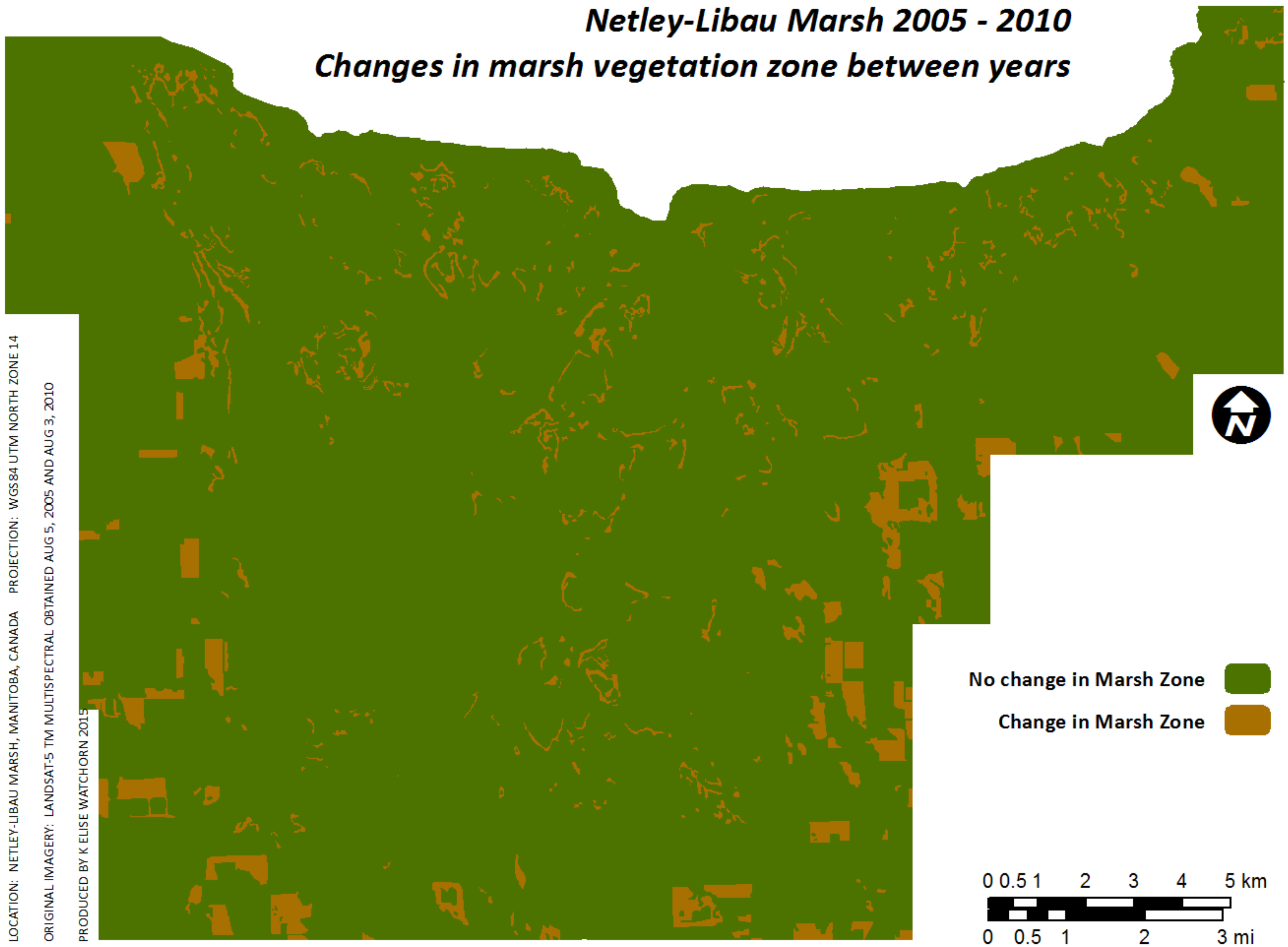

Netley-Libau Marsh 1999 - 2000
Changes in marsh vegetation zone between years
LOCATION: NETLEY-LIBAU MARSH, MANITOBA, CANADA PROJECTION: WGS84 UTM NORTH ZONE 14
ORIGINAL IMAGERY: LANDSAT-7 ETM+ MULTISPECTRAL OBTAINED JULY 28, 1999 AND JULY 30, 2000
PRODUCED BY K ELISE WATCHORN 2015
N
No change in Marsh Zone
Change in Marsh Zone
0 0.5 1 2 3 4 5 km
0 0.5 1 2 3 mi

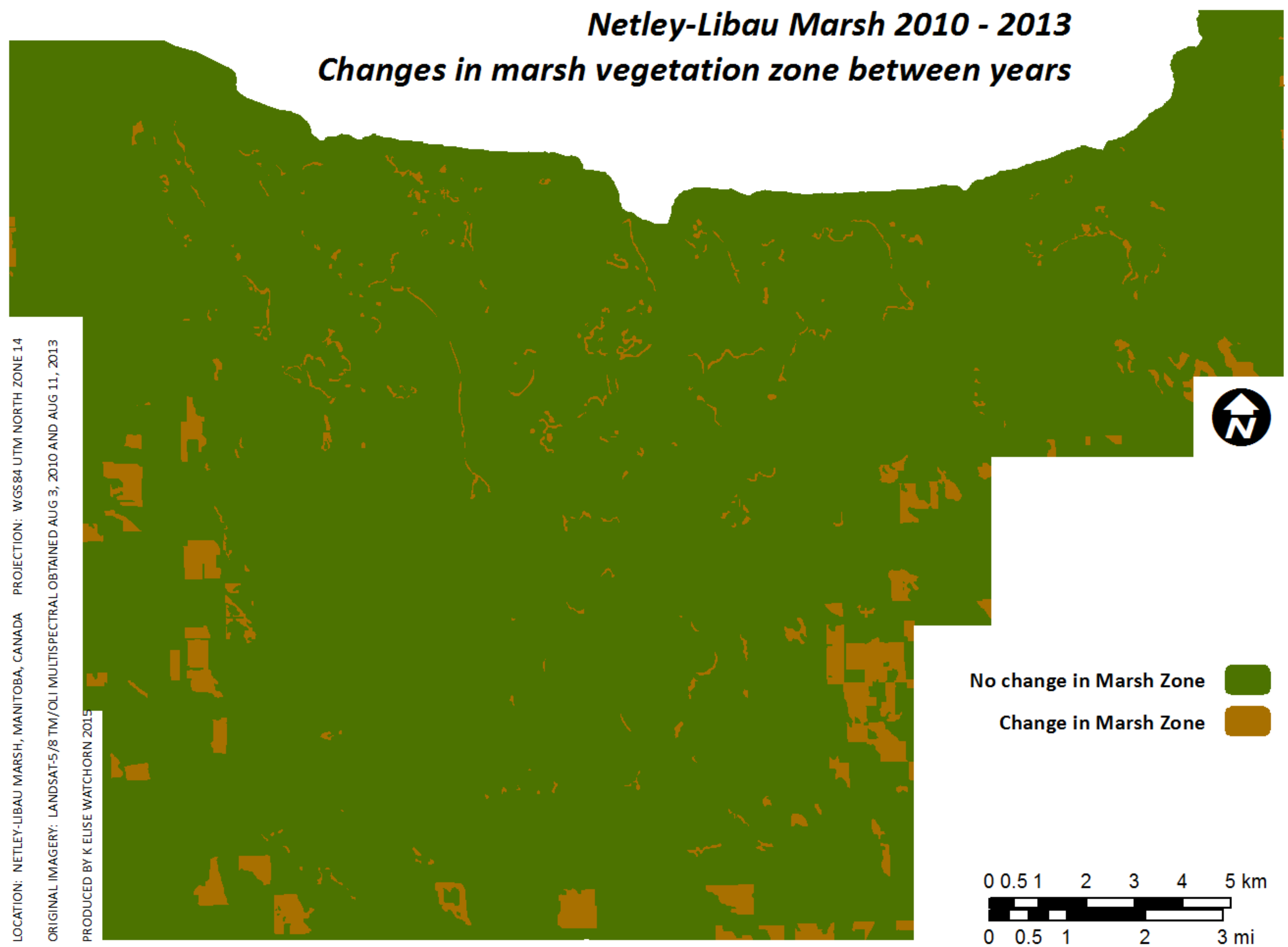
Netley-Libau Marsh 2000 - 2001
Changes in marsh vegetation zone between years




Netley-Libau Marsh 2001 - 2002
Changes in marsh vegetation zone between years
LOCATION: NETLEY-LIBAU MARSH, MANITOBA, CANADA PROJECTION: WGS84 UTM NORTH ZONE 14
ORIGINAL IMAGERY: LANDSAT-7 ETM+ MULTISPECTRAL OBTAINED AUG 2, 2001 AND AUG 5, 2002
PRODUCED BY K ELISE WATCHORN 2015
N
No change in Marsh Zone
Change in Marsh Zone
0 0.5 1 2 3 4 5 km
0 0.5 1 2 3 mi


Netley-Libau Marsh 2002 - 2005
Changes in marsh vegetation zone between years
LOCATION: NETLEY-LIBAU MARSH, MANITOBA, CANADA PROJECTION: WGS84 UTM NORTH ZONE 14
ORIGINAL IMAGERY: LANDSAT-7/5 ETM+/TM MULTISPECTRAL OBTAINED AUG 5, 2002 AND AUG 5, 2005
PRODUCED BY K ELISE WATCHORN 2015
N
No change in Marsh Zone
Change in Marsh Zone
0 0.5 1 2 3 4 5 km
0 0.5 1 2 3 mi


Netley-Libau Marsh 2005 - 2010
Changes in marsh vegetation zone between years
LOCATION: NETLEY-LIBAU MARSH, MANITOBA, CANADA   PROJECTION: WGS84 UTM NORTH ZONE 14
ORIGINAL IMAGERY: LANDSAT-5 TM MULTISPECTRAL OBTAINED AUG 5, 2005 AND AUG 3, 2010
PRODUCED BY K ELISE WATCHORN 2015
N
No change in Marsh Zone
Change in Marsh Zone
0 0.5 1 2 3 4 5 km
0 0.5 1 2 3 mi


Netley-Libau Marsh 2010 - 2013
Changes in marsh vegetation zone between years
LOCATION: NETLEY-LIBAU MARSH, MANITOBA, CANADA PROJECTION: WGS84 UTM NORTH ZONE 14
ORIGINAL IMAGERY: LANDSAT-5/8 TM/OLI MULTISPECTRAL OBTAINED AUG 3, 2010 AND AUG 11, 2013
PRODUCED BY K ELISE WATCHORN 2015
N
No change in Marsh Zone
Change in Marsh Zone
0 0.5 1 2 3 4 5 km
0 0.5 1 2 3 mi

9.0 Results and Discussion

9.1 Water

The areal extents of *open water marsh* in each year, compared with that of the remaining cover classes, are presented in Table 9.1. The proportion of the entire mapped area comprised by *open water marsh* in each year is also displayed in Figure 9.1, which better emphasizes changes through time. The distribution of *water* is displayed in Map Series 8.1.

Table 9.1: Surface areas, percent cover, and percent change from the previous year of open water marsh and other cover classes, from 1990 – 2013. Parentheses represent negative values.

Year	Open Water Marsh			Remaining Cover Classes	
	Area (ha)	% Cover	% Change	Area (ha)	% Cover
1990	8796	25.3%		26003	74.7%
1992	8867	25.5%	0.8%	25932	74.5%
1993	9463	27.2%	6.7%	25336	72.8%
1994	11118	31.9%	17.5%	23681	68.1%
1995	11662	33.5%	4.9%	23103	66.4%
1996	11766	33.8%	0.9%	22999	66.2%
1997	11796	33.9%	0.3%	23003	66.1%
1999	11920	34.3%	1.1%	22878	65.7%
2000	11926	34.3%	0.0%	22873	65.7%
2001	12071	34.7%	1.2%	22728	65.3%
2002	12093	34.7%	0.2%	22706	65.3%
2003	9594	27.6%	(20.7%)	25205	72.4%
2005	10566	30.4%	10.1%	24232	69.6%
2006	10351	29.7%	(2.0%)	24448	70.3%
2007	10282	29.5%	(0.7%)	24517	70.5%
2008	10202	29.3%	(0.8%)	24597	70.7%
2009	10181	29.3%	(0.2%)	24618	70.7%
2010	10248	29.5%	0.7%	24550	70.5%
2011	10447	30.0%	1.9%	24352	70.0%
2013	10486	30.1%	0.4%	24313	69.9%

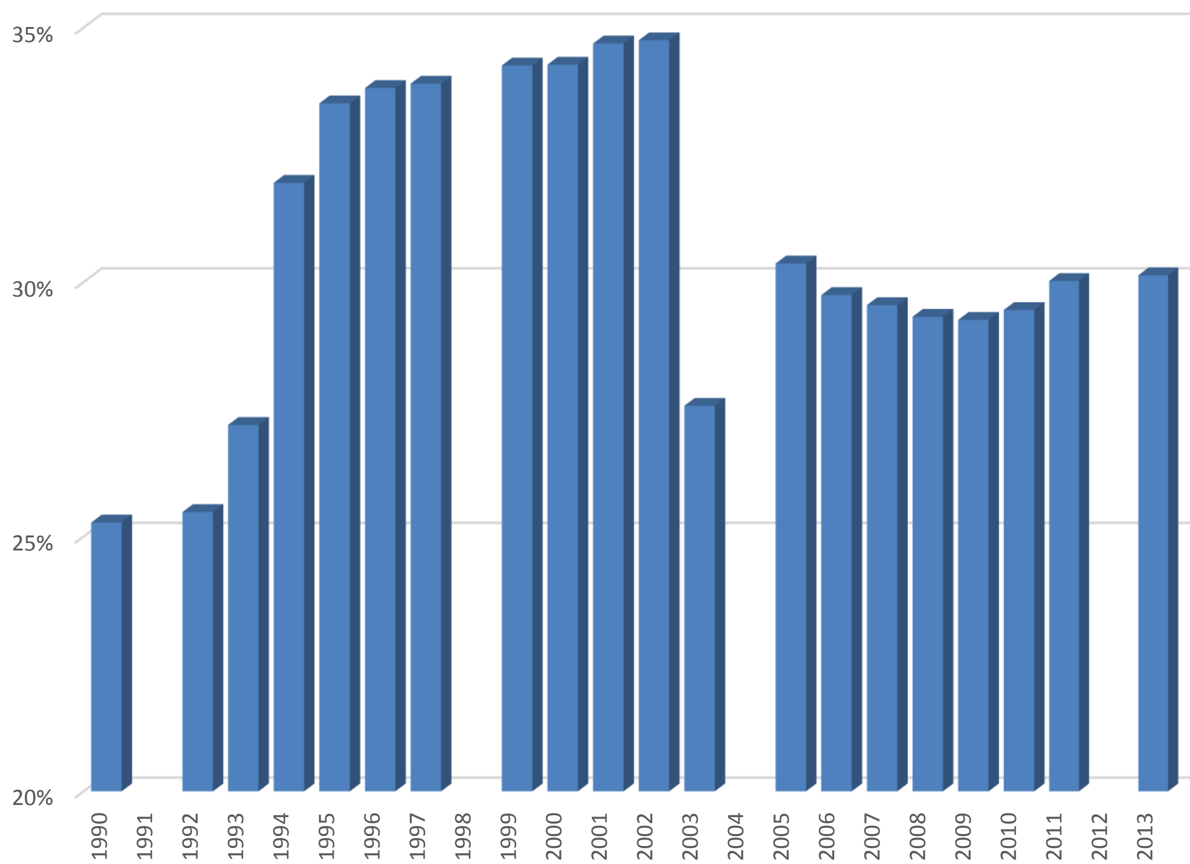


Figure 9.1: Percent of the mapped extent of Netley-Libau Marsh which the open water marsh subclass covers in each of the years for which maps have been produced. (Note that the vertical axis has been scaled to better highlight yearly changes.)

Changes in the spatial extent of water seem to be defined by fits and starts, wherein a period of stasis or gradual change is disrupted by a major event. *Open water* was at its lowest extent in 1990, when it covered only one quarter of Netley-Libau Marsh. The proportion of open water to vegetated area remained constant through 1992, then increased gradually in 1993 and more sharply in 1994. From 1995 to 2002, the surface area of open water changed relatively little, reaching a maximum of nearly 35% in 2002. A marked regeneration of emergent wetland vegetation in 2003 led to an abrupt decline of open water area. By 2005, much of the vegetated area had given way to open water again. Since that year there have been no major fluctuations in the areal extent of open water marsh, which has settled around 30% coverage.

The spatial distribution of water, relative to other marsh zones and vegetation classes in Netley-Libau Marsh, is displayed in Map Series 8.2 and 8.3. The change between water and other marsh zones can best be visualised in the change maps presented in Map Series 8.1. Between 1990 and 1992, there was very little change in water distribution. The increase in open water in 1993 was due to reduction and loss of islands in Netley Lake, as well as the expansion of Hardman Lake. (See Figure 6.1 for landmark and lake names.) 1994 saw a major increase in open water throughout the marsh, but most dramatically in several southeastern lakes, particularly Morrison, Starr, Boyd and Cooks Lake. Further contraction of islands in the west marsh led to the near total assimilation of Cochrane, Passwa, and McKay Lakes into Netley Lake. A further, though smaller, increase in open water in 1995 was most marked in the eastern extremities of the marsh, especially in Folster, Starr and Morrison Lakes, and east of Swedish Lake. Between 1995 and 2002, there were only minor and gradual increases to the extent of open water, with no clear distribution pattern.

In 2003, a massive regeneration of emergent vegetation returned the west marsh islands nearly their 1990 size, re-establishing partitions between Netley Lake and other west marsh bays. Mudflats in the area of The Cut were also much expanded in 2003. In the east marsh, this 2003 renewal of emergent vegetation reduced northern lakes, including Hardman, Parisien, Poplar Point and Folster Lakes, to roughly their 1990 proportions. However, the expansion was less pronounced in the south, where Boyd, Morrison and Starr Lakes only slightly reduced in size and connectivity.

By 2005, much of the new vegetation had again been replaced by water, but with a different distribution than had been seen before 2003. A proliferation of small ponds and small interconnected channels developed in recently revegetated areas, producing hemi-marsh environments in many places in the east marsh and below the northern beach ridge. However, the loss of islands in Netley Lake was substantial.

From 2006 to 2013, the extent of open water varied only slightly; first waning, then waxing. Many, but not all, of the small ponds and hemi-marsh areas that appeared in 2005 gradually disappeared. Midsized and large lakes and bays did not greatly increase in size over this interval. However, by 2013, the west marsh islands had become reduced to nearly the minimum extent they had reached in 2002, though with fewer and larger islands than were seen in that year.

9.2 Vegetation Changes

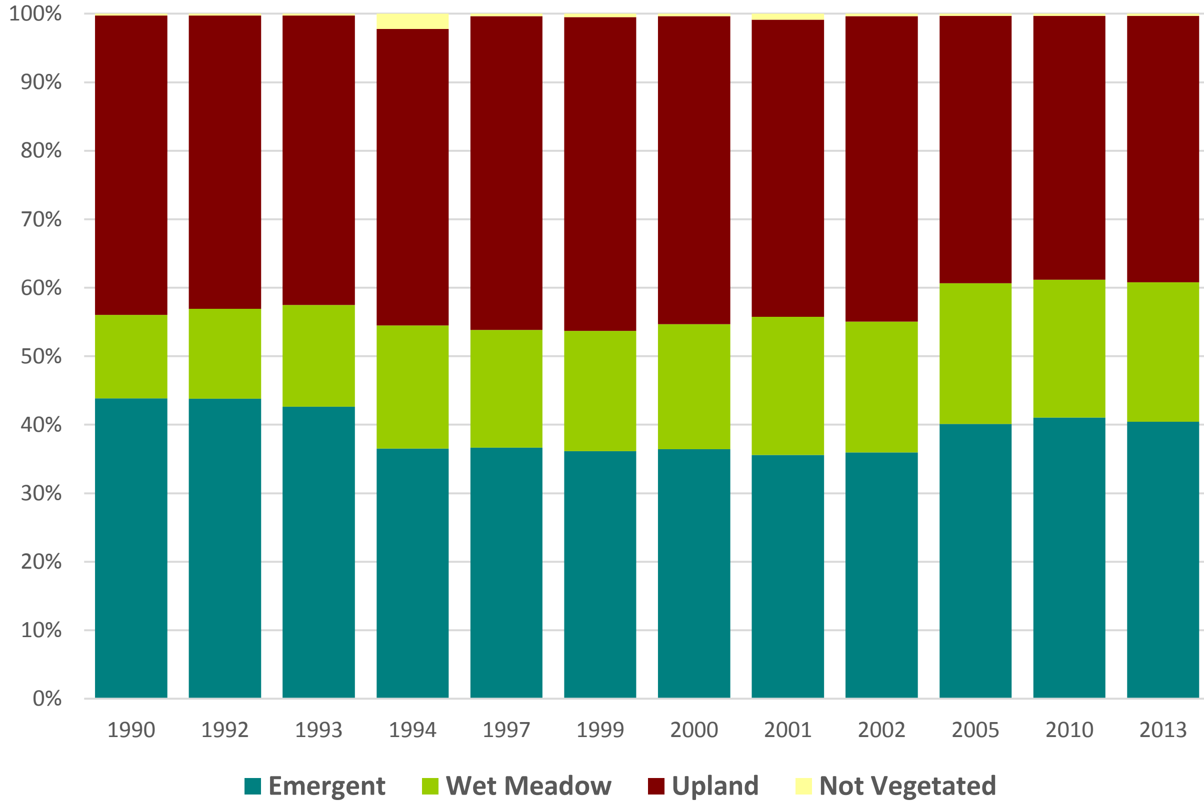


Figure 9.2: The changing proportions of four marsh zones in each year. Water has been omitted.

Map Series 8.2 and 8.3 display the distribution of marsh zones and vegetation classes in Netley-Libau Marsh for each year. Figures 9.2 and 9.3 indicate a pattern in the changing proportions of the non-water marsh zones, corresponding to three periods. The period from 1990 to 1992 was defined by approximately equal ratios of *emergent vegetation* and *uplands*, which a smaller proportion of wet *meadow*. These proportions began to shift in favour of *wet meadow* in the transitional year of 1993, while the period from 1994 to 2002 was relatively consistent in having less *emergent vegetation*, more *wet meadow*, and a slightly more *uplands*. A third period, from 2005 to 2013, was characterised by higher proportions of *emergent vegetation* and *wet meadow*, with a reduced *upland* fraction.

The most common emergent vegetation was *cattail*, followed by mixed bulrush, *Carex* and *Phragmites (BCP).* Stands were assigned to *unidentified emergent* most frequently in 1993 and 2005, indicating that it was those years of greatest change in which classifying emergent vegetation proved most challenging. Observed *bulrush* had nearly completely disappeared by 2013, though this trend should be interpreted cautiously, as this vegetation class had shown the lowest rate of classification accuracy by this Landsat mapping technique (Watchorn 2014) and some bulrush may have been included with *unidentified* emergent, or misclassified as water.

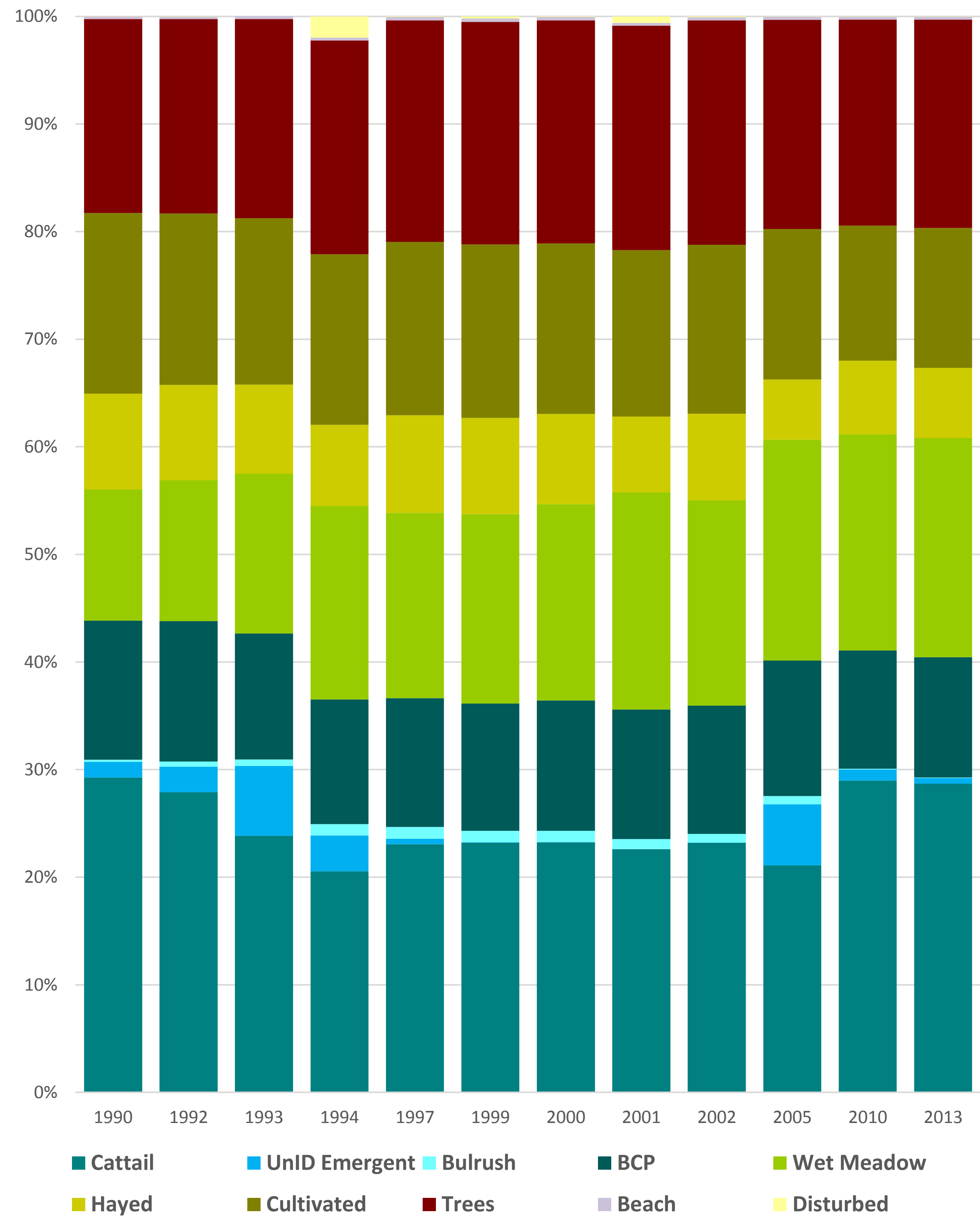


Figure 9.3: The changing proportions of vegetation classes in each year. Water cover classes have been omitted.

In the *uplands*, *trees* generally comprised the dominant vegetation class, followed by *cultivated*, then *hayed* areas. The *not vegetated* marsh zone did not make up an appreciable proportion of Netley-Libau Marsh in most years, though *disturbed* areas were notable in 2001 and especially 1994.

A more detailed impression of year-by-year changes in vegetation cover in Netley-Libau Marsh may be gleaned by an interpretation of the transition matrices presented in Appendices II and III, and by visualising those areas in which the assigned marsh zone changed from one year to the next (Map Series 8.4).

Between 1990 and 1992, most marsh zone change was seen in Netley's peripheral regions, where some *wet meadows* became *upland* (mainly *hayed*), and vice versa. In 1993, the shift from *wet meadow* to *hayed* and *cultivated* was again seen more than the reverse. In the central marsh, most marsh zone changes were due to the replacement of *open water* with *emergent vegetation*, particularly *cattail* but also some *unidentified emergent*. In 1994, changes in marsh zone were most apparent in the central marsh, where *open water* replaced *emergent vegetation* (dominantly *unidentified emergent* and *cattail*) and where large *disturbed* areas replaced *cattail* stands. *Hayed* lands also reverted back to *wet meadow*.

The transition from 1994 to 1997 was marked by changes marsh-wide. Previously *disturbed* areas were replaced by *emergent vegetation*, particularly *cattail*, but *emergent vegetation* (*unidentified* and *cattail*) was also lost to *open water*. Many stands of remaining *unidentified emergent* vegetation became identifiable as, and/or replaced by, mainly *cattail*. There was also considerable fluctuation between w*et meadow* and *hayed*/*cultivated* land, with the balance in favour of the latter.

Between 1997 and 1999, most change was between *wet meadows* and *hayed*/*cultivated* fields, with no net gain or loss. In 2000 and 2001, these regions shifted in favour of *hayed* and *cultivated* lands, and shifted back towards *wet meadow* in 2002. *Emergent vegetation* of all classes was reduced slightly each year between 1997 and 2002.

The 2002 to 2005 interval showed the most dramatic change in marsh zone distribution. Much *open water* transitioned to *emergent vegetation* (much of which was *unidentified*, but also ample *cattail*). There was some trade-off between *emergent vegetation* (especially *BCP*) and *wet meadow*. *Hayed* land became *wet meadow*, and some *treed* areas were lost to *cultivated* fields.

From 2005 to 2010, some *open water* grew in with *emergent* macrophytes (mainly *unidentified* stands and *cattail*); however, by 2013, much of this net growth of *emergent* vegetation had given way to *open water* again. Between 2005 and 2013, approximately equal areas of *emergent vegetation* (especially *BCP*) became *wet meadow* as *wet meadow* became primarily *BCP emergent* each year. Likewise, roughly equivalent extents of *wet meadow* and *hayed*/*cultivated* land fluctuated each year.

9.2.1 The barrier beach ridge and connectivity to Lake Winnipeg

The barrier beach ridge which divides Netley-Libau Marsh from the adjoining Lake Winnipeg consists of sand beach, wetland vegetation, and treed land, and is crossed by several connecting channels. The integrity of this barrier beach, and therefore, the degree of connectivity between lake and marsh, varied throughout the period of study (Map Series 8.1). Though the 30m spatial resolution of Landsat images may not allow for the detection of very small channels, the primary band combination used (4,5,3 with Landsat-5 and -7) shows very clear definition at the land-water interface, and is highly sensitive to soil moisture (Geospatial Innovation Facility 2008). The number of connecting channels passing completely through the beach ridge could therefore be counted in each year of the time series, and is displayed in Figure 9.4. It should be noted that each image represents only a snapshot in time; the lack of detectable water along a continuous channel from marsh to lake in a given image does not indicate that there was no exchange of water along that channel at any point in that year. The channel counts from maps produced before 1990 have also been presented, though it is important to recognise that the spatial resolution of the photographs on which these maps were based was varied. Lake-marsh connectivity is also related to the width and depth of connecting channels, but this could not be distinguished with the imagery available.

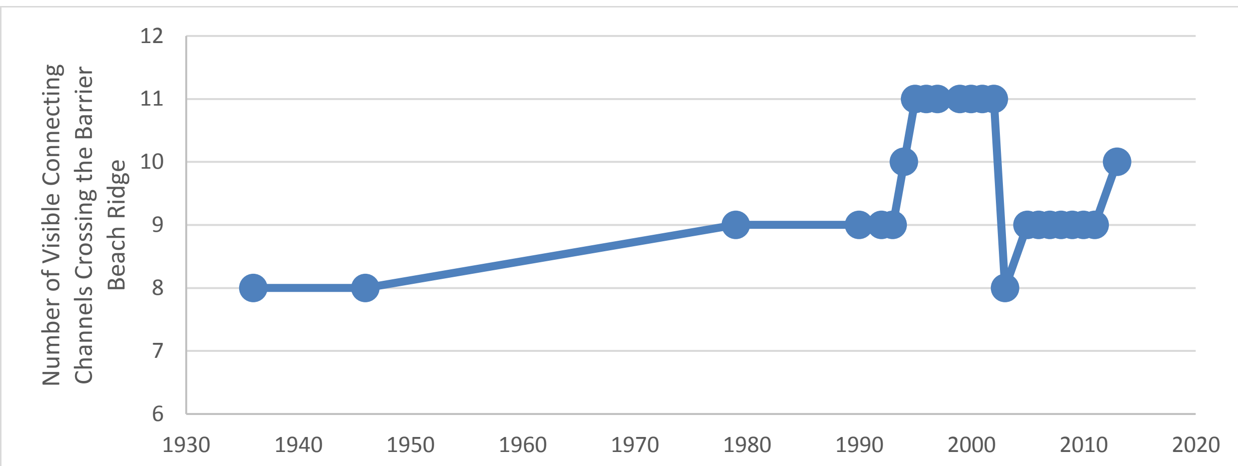


Figure 9.4: Number of connecting channels crossing the barrier beach ridge that comprises the northward boundary of Netley-Libau Marsh, separating it from Lake Winnipeg. (Maps produced before 1990 were of varied resolution – some finer and some coarser than the time series produced by this study – and therefore may not be directly comparable.)

From 1990 to 1992, the extent of the barrier beach remained consistent, but from 1993 to 1994, some erosion of lakeshore and rivermouth bank was observed along the lakeshore between the main and east Red River channels; on either side of the mouth of the Hay Lake connecting channel; and around the mouth of the Brokenhead River. The land lost was mainly *emergent* vegetation, through *treed* land was also lost near the far eastern portion of the Netley-Libau beach ridge. An additional connecting channel breached the beach ridge in 1994.

Substantial pieces of shoreline were lost in 1995. In this year, the loss of barrier beach took place in the east, and again between the main and east Red River mouths: a trend that continued at a slower rate over the next two years.

In 1999, widening of the Salamonia channel was observed due to loss of treed land. The mouth of Pruden Bay was also widened, as emergent vegetation in this region was reduced. From 2000 to 2002, very little change was noted, other than some minor loss of land near the mouth of the Brokenhead River and its neighbouring channels.

The year of most dramatic change was 2003. Vast expanses of new shoreline were exposed across the entire width of Netley-Libau Marsh. In many places, this new land extended out farther out into Lake Winnipeg than the 150m buffer zone which had originally been established as the lakeward boundary of the mapped extent of Netley-Libau Marsh. A full vegetation map could not be produced for this year, but cursory inspection of the satellite image suggests that east of the Brokenhead River, where the newly exposed land extended particularly far lakeward, the predominant new cover was emergent vegetation. However, along most of the lakeshore, the newly exposed land was sand beach. A huge peninsula of sand extended approximately two kilometres out into the lake just west of the eastern mouth of the Red River, and all three mouths of the Red were partially obstructed by sand bar islands (Figure 9.x). Sand also completely blocked the mouth of at least two connecting channel: one from Parisien Bay, and another east of the Brokenhead River. The Brokenhead and the eastern creek from Folster Bay, which had previously been two separate paths to Lake Winnipeg, fused again into just a single connection because the land-lake boundary was farther north.

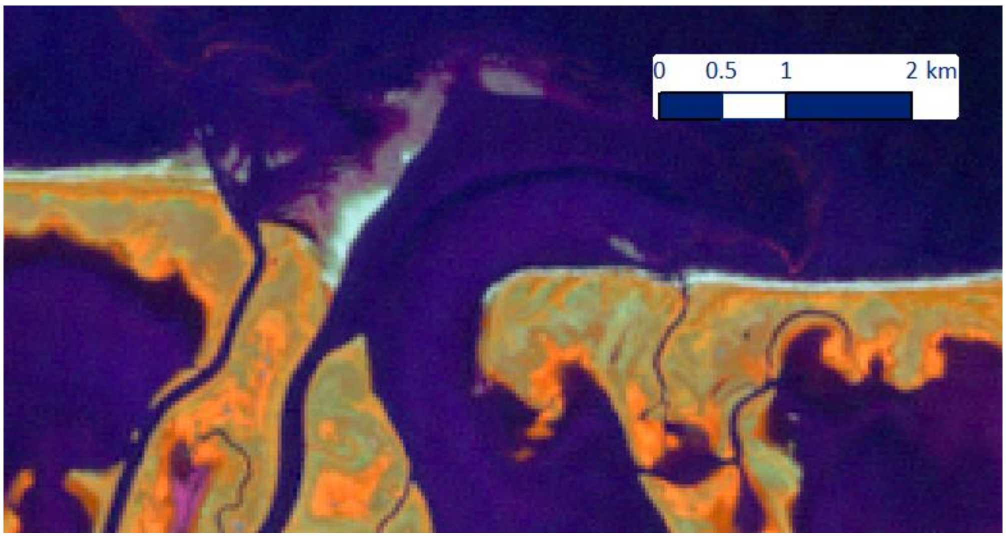


Figure 9.5: Landsat-5 image taken 7 Aug 2003, showing large areas of exposed beach between the main and eastern mouths of the Red River.

By 2005, all the gains of new land had disappeared, and much of the lake-marsh connectivity was restored. The easternmost connecting channels, however, did not immediately redevelop. There was no notable change from 2006 to 2011, except a slight widening of the mouth of the creek from Hay Lake in 2008. In 2013, the mouth of Pruden Bay also widened. Additionally, a short inlet had formed through the beach east of the Brokenhead River, possibly draining some of the small ponds in that area; this inlet may foreshadow the development a new connecting channel.

9.2.2 Bathymetry and regrowth of emergent vegetation

In 2010, the hydrographic consulting firm Aquatics Environmental Services surveyed the bathymetry of many of the large lakes and bays of Netley-LIbau Marsh, by single beam sonar (Aquatics Environmental 2013). The resulting contour maps are presented in Figure 9.6, together with the 2003 (or minimum) extent of open water. The lake level (both on the date of image capture, and the April-July mean) fell in the range of 217.10 - 217.19 masl, corresponding to the yellow-green contour.

Across most of the marsh, the 2010 bathymetric contours match the interface between open water and wetland vegetation / unvegetated areas. However, it is notable that certain areas which had been vegetated or exposed in 2003 were surveyed in 2010 to be as much as 0.8m below 2003 water levels. In particular, the bathymetry near the Netley Lake islands, and the mudflats adjacent to The Cut, appears to have been altered between 2003 and 2010. The Netley Lake islands became much reduced both above and below the water by 2010: they became surrounded by deeper water, which may reduce the ability emergent vegetation to expand outward during the next low-water period. Meanwhile, the pattern of channels through sedimented material deposited by the Red River has shifted between 2003 and 2010: The Cut seems to be behaving as a dynamic miniature delta.

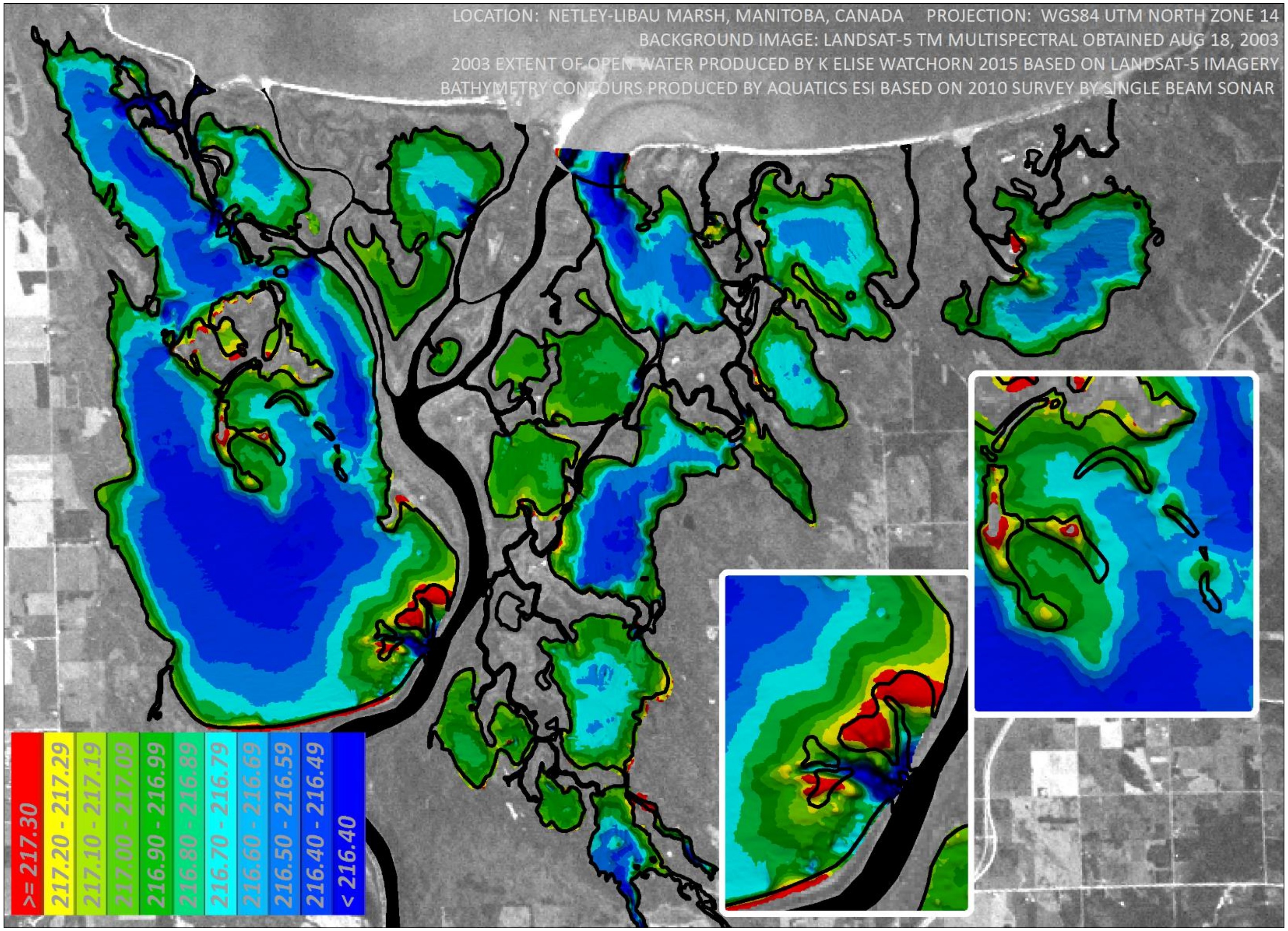
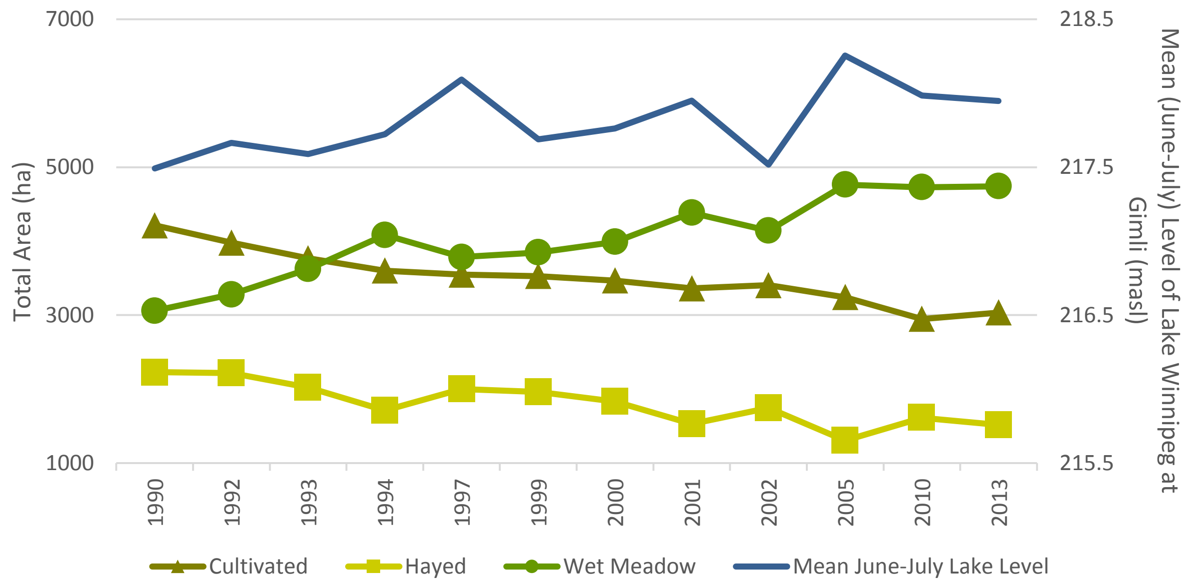


Figure 9.6: Map comparing the 2003 extent of open water of several of the large lakes in Netley-Libau with bathymetry captured in 2010 by Aquatics ESI. Insets show The Cut (left) and islands in Netley Lake (right).

9.3 Hydrological Relationships

Most Lake Winnipeg level and Red River discharge metrics were correlated with larger extents of *wet meadow* and smaller extents of *hayed* and *cultivated* land in Netley-Libau Marsh. Figures 9.7 and 9.8 present the relationship between these three vegetation classes and a single metric each for level and discharge. (All patterns of correlation between hydrometric variables and the total area, as well as the change in area, of marsh zones and vegetation cover classes are fully explored in Appendix IV.)



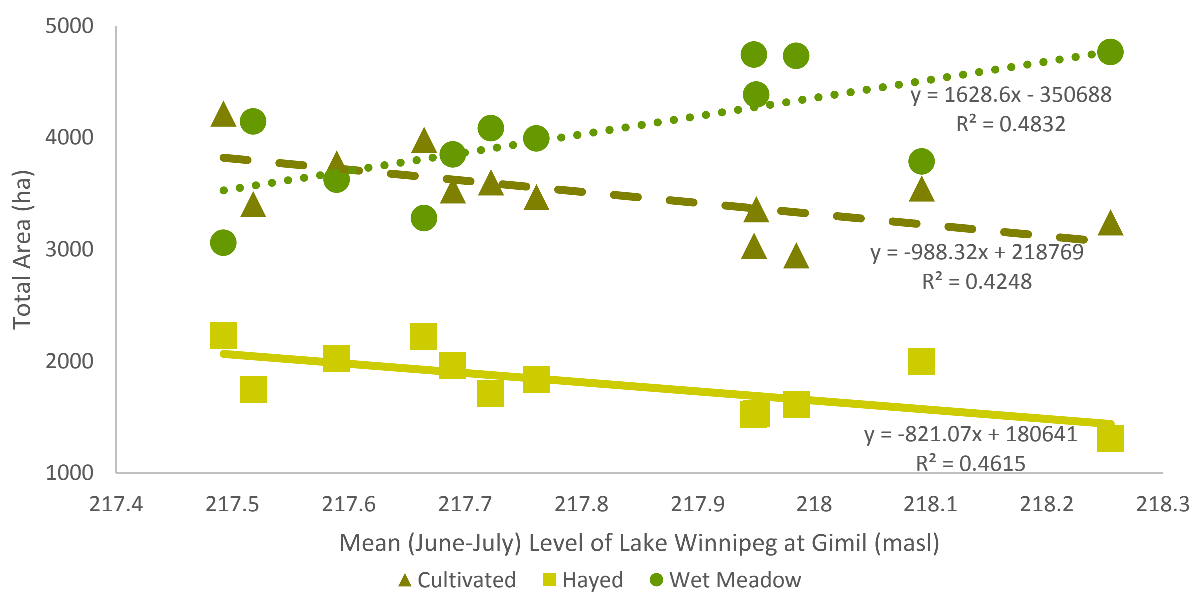


Figure 9.7: The relationship between total areas of the wet meadow, hayed, and cultivated vegetation cover classes in Netley-Libau Marsh, and mean June-July lake levels on Lake Winnipeg.

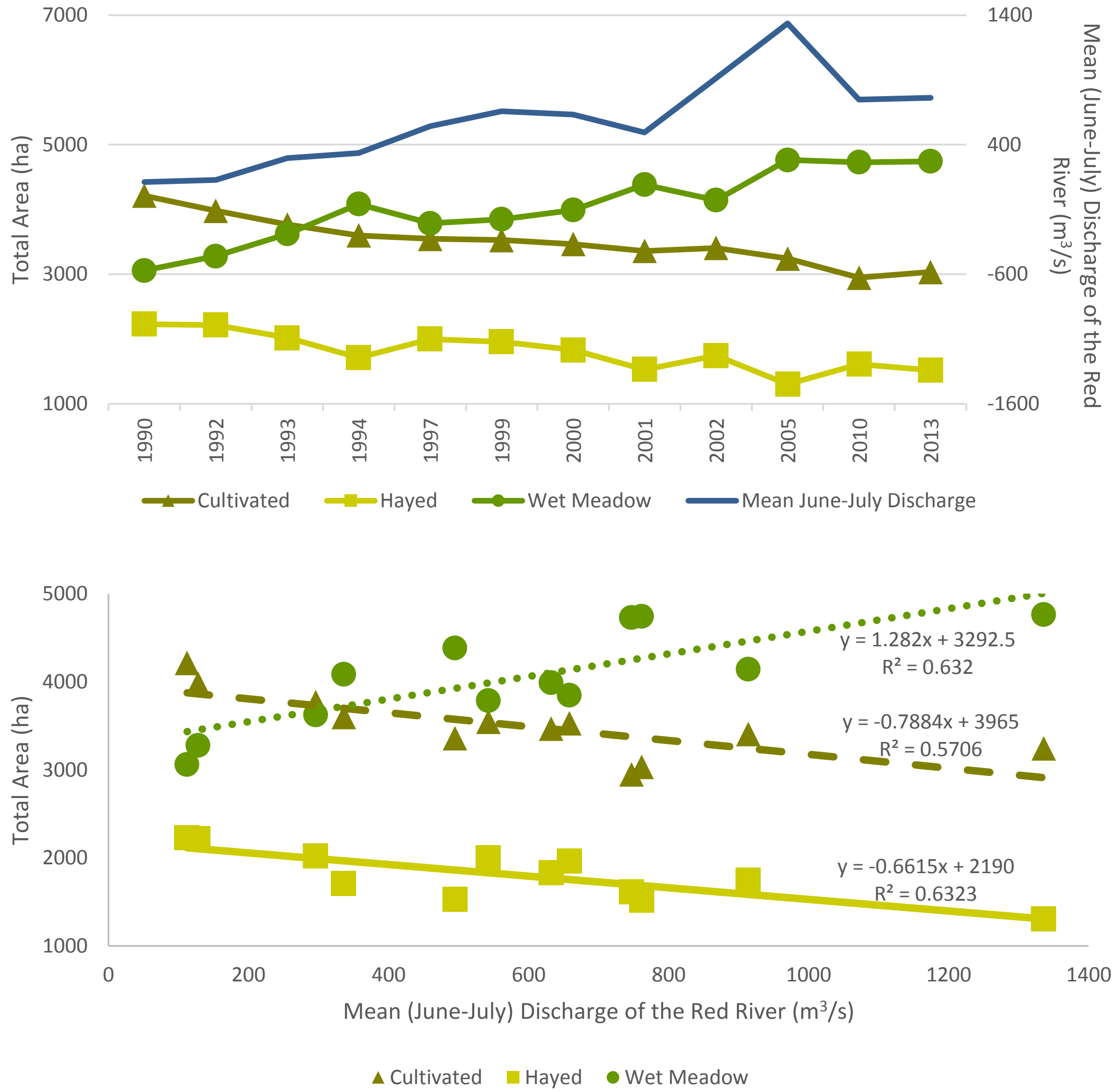


Figure 9.8: The relationship between total areas of the wet meadow, hayed, and cultivated vegetation cover classes in Netley-Libau Marsh, and mean June-July discharge on the Red River.

It was not always possible to tease out the influence of Lake Winnipeg levels versus discharges from the Red River. The water residence time in Lake Winnipeg is variable due to regulation by Manitoba Hydro, though short compared to other large lakes (~3.5 years; Lévesque 2011), but mean summer lake level was highly correlated with mean summer river discharge over the period of this study (R^2 = 0.66). Because wet years had both high levels and high discharges, while dry years had neither, it was difficult to determine which was the major factor in vegetation class extent and distribution.

The total extent of *water* in Netley was not correlated with lake levels or river discharges. However, there was a significant relationship between the change in the total area of *open water marsh* and most lake level metrics. (One such relationship is presented in Figure 9.9.) As lake level increased, there was a greater increase in the extent of *open water*, compared with the previously mapped year. However, though a linear correlation was significant, the relationship seems to be heavily influenced by the years of highest and lowest water: suggesting that Netley-Libau Marsh can undergo sudden changes in extreme years.

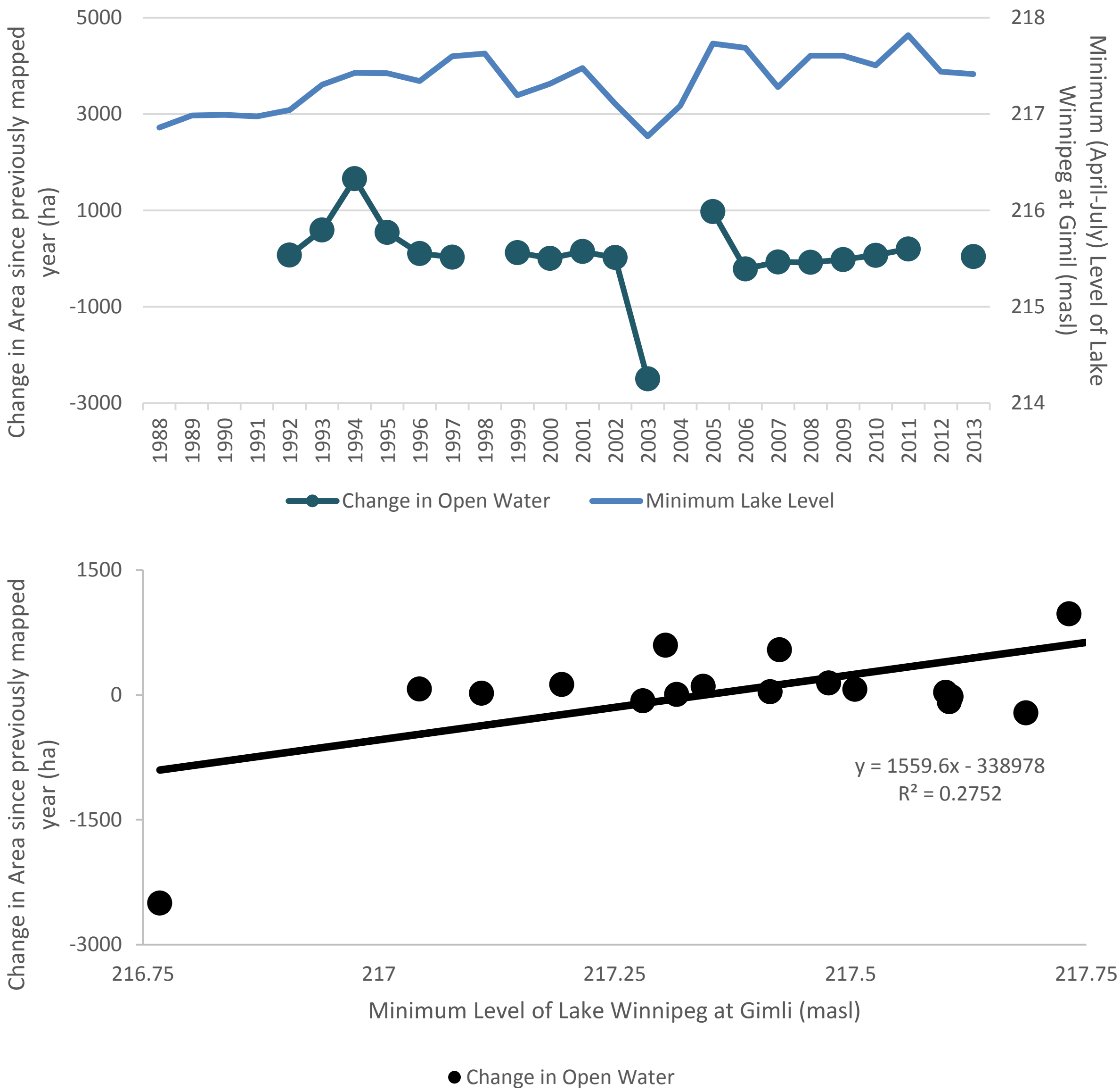


Figure 9.9: The relationship between the yearly change in total areas of the open water marsh cover class in Netley-Libau Marsh, and the minimum April-July level on Lake Winnipeg.

Emergent vegetation was most significantly correlated to open water marsh: as the total extent of open water marsh increased, so the total extent of emergent vegetation decreased (Figure 9.10). The only outlier in this tight relationship was 1994, where large mudflats were observed amongst the emergent vegetation. The total area of emergent vegetation was not related to any hydrometric variables. However, there were weak relationships between decreasing change in emergent vegetation extent and increasing June lake level, and increasing June-July river discharge. Inundation during this portion of the growing season may be key in determining whether the emergent vegetation species established in an area in previous years is able to persist.

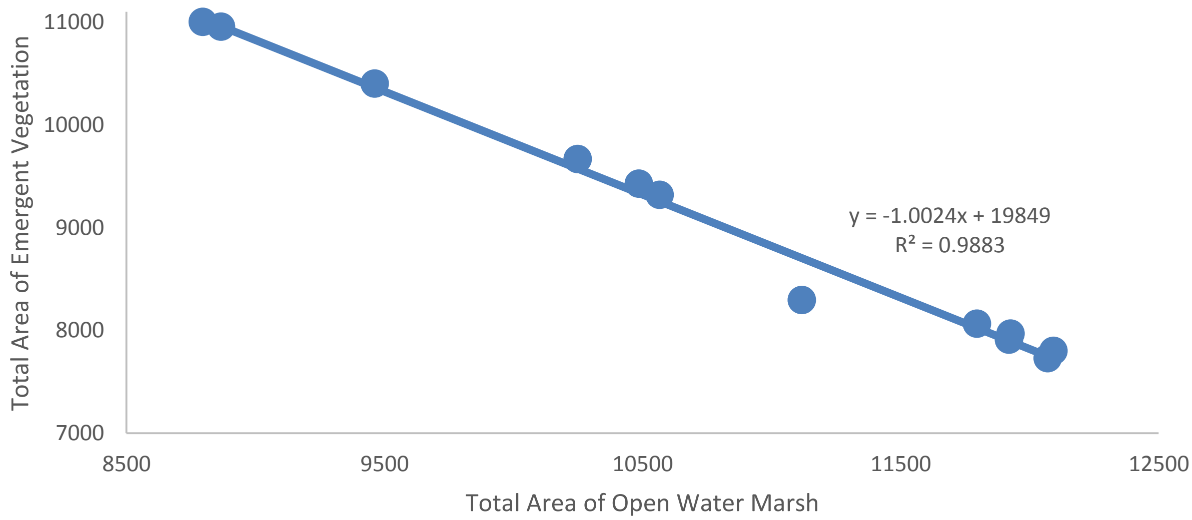


Figure 9.10: The relationship between the extent of emergent vegetation and the extent of open water marsh in Netley-Libau Marsh.

There were very few correlations between April or May discharge or maximum discharge and the extent, or change in extent, of wetland vegetation classes. This suggests that the spring freshet and spring flooding is not a major driver of vegetation change in Netley-Libau Marsh. The one exception to this pattern was seen in the relationship between maximum Red River discharge and the change in area of the not vegetated marsh zone, and specifically the disturbed cover class (Figure 9.11). When all years were included, there was a strong trend of net loss of disturbed area. However, this correlation was heavily influenced by two extreme years – 1997, the largest flood year, and 1994, the year with the smallest freshet. When these two extreme years were omitted, a weak trend of increasing disturbed areas with increasing maximum discharge was observed. This apparent contradiction can be explained by considering the multiple ways in which disturbed areas might form. In extreme flood years, any potential mud flats are likely to be under water later in the summer. In moderate flood years, prolonged inundation may kill emergent vegetation, leading to the formation of mudflats when the water recede. In the very driest years, any newly exposed mudflats may grow in with emergent vegetation by July/August; but in moderately dry years, new areas of mudflat may be exposed too late in the season to allow for this new growth.

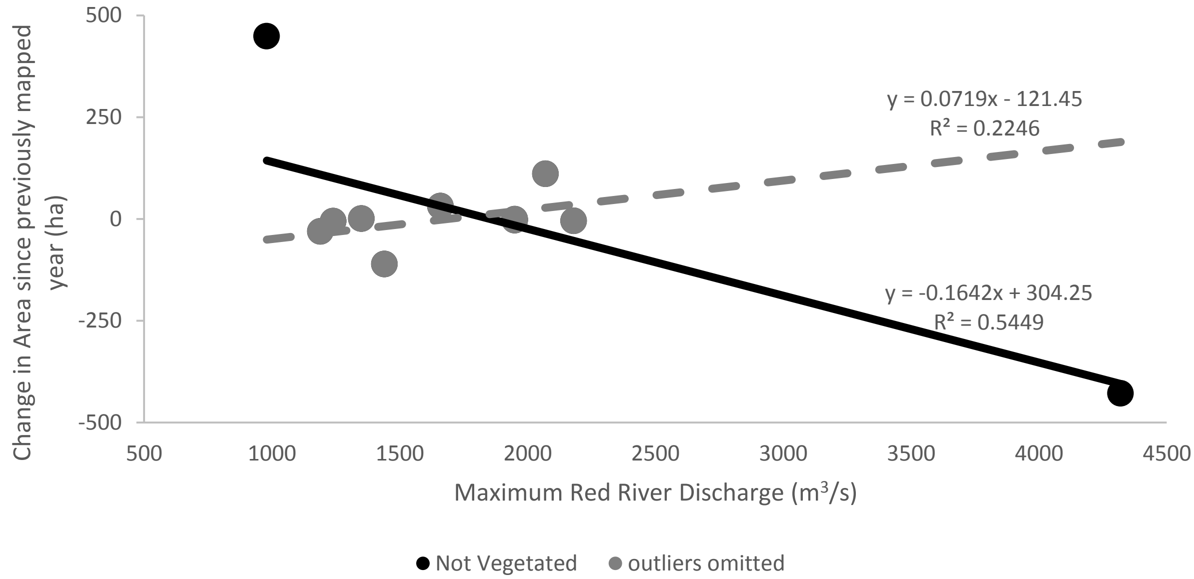


Figure 9.11: The relationship between the change in the area of the not vegetated cover class in Netley-Libau Marsh, and the maximum April-July discharge on the Red River.

There were no relationships between the change in hydrometric variables between years and the area, or change in area, of any marsh zone or vegetation class, with one exception: less emergent vegetation was classified as *unidentified* in years that were drier than the preceding year. This trend was an artefact related to the classification limitations described in Section 7.2.1. New emergent vegetation was difficult to identify when conditions were wet. When a drier year followed, it became possible to classify those stands which had not been assigned a value previously. Whether the actual vegetation cover also changed over the interval could not be determined.

The major hydrological drivers of vegetation change proposed by this analysis are summarised in Table 9.2. There are other hydrological factors, outside the scope of this study, which may contribute to the extent and distribution of vegetation within Netley-Libau Marsh. Lake Winnipeg undergoes large seiche or wind setup events, which can influence lake levels by up to 1.2m in a matter of hours (Baird and Stantec 2000; Einarsson and Lowe 1968). Investigation of any relationship between vegetation cover and seiche state or frequency was not possible, because water level data were not available at a finer temporal resolution than daily, nor were these data available from a gauging station on the south shore of the lake (where fetch, and seiche effect, would be maximised). However, there is some indication the findings of this study were not skewed by seiche effects: while there was a significant correlation between the change in open water extent and the daily lake level on the date of Landsat image capture, this relationship was less significant than the relationship between the change in open water and seasonal measures of water level. This suggests that the vegetation maps produced would not have been especially different had they been produced based on imagery captured on another day with different seiche conditions.

Ice might be another contributing factor to emergent vegetation loss, particularly in the west marsh. Since 2006, the province of Manitoba has annually conducted artificial ice cutting and breaking between Selkirk and The Cut (Manitoba Hydro 2014). This enables river ice to take the path of least resistance, through The Cut into Netley Lake (Lindenschmidt et al 2012), as the shallow marsh melts earlier than Lake Winnipeg. Besides the diversion of additional river water, the flowing chunks of ice could potentially scour out the shore vegetation and islands of Netley Lake.

Table 9.2: Proposed hydrological drivers of vegetation change in Netley-Libau Marsh.

Marsh Zone	Responding Variable		Influenced By	Key Timeframe
Not Vegetated	Change in Area	increases with	Maximum Discharge	most years
		decreases with	Maximum Discharge	extreme years
Water	Change in Area	increases with	Lake Level	
Emergent	Total Area	decreases with	Total Area of Open Water	extreme years
	Change in Area	decrease with	Lake Level	June
		decrease with	River Discharge	June and July
Wet Meadow	Total Area	decreases with	Lake Level and River Discharge	
Hayed; Cultivated	Total Area	increases with	Lake Level and River Discharge	

9.4 Vegetation Cover Surrounding Reference Points

The distribution of vegetation in 2011 and 2013 surrounding a series of eight fixed reference points is displayed in Figure 9.12. The proportion of each 500m and 1000m buffer zone comprised of each vegetation class has been quantified in Appendix V, and the percent change between years described.

There was little change in the total area or distribution of any vegetation classes within these zones. Most differences were related to shifts amongst wet meadow, hayed, and cultivated lands. Only points B, I, and J had any appreciable change in open water or emergent vegetation. Almost no change was observed in the vegetation surrounding reference points C and L.

There were some limitations to applying the vegetation classification techniques developed for Netley-Libau Marsh to these outlying peripheral areas. First, the cover classification scheme was developed for water, wetlands, and surrounding vegetation types; not for commercial and residential areas. Some misclassification is therefore to be expected around reference point K, which falls within the townsite of

Brokenhead Ojibway Nation. Mowed lawn may appear to be hayed, but large buildings and parking lots may have confused classification. As well, the Landsat images available for both years were problematic: the 2011 image was obtained so late in the year that several cover classes, particularly within the emergent vegetation and wet meadow marsh zones, were difficult to distinguish. The 2013 image was marred by popcorn clouds in the uplands regions, which obscured the land surface around points C, I, and K. Finally, because most the surface area analysed in this section was outside the defined extent of Netley-Libau Marsh, supporting information regarding cover in previous and subsequent years was unavailable. The cumulative effect of these challenges is that the classification of vegetation surrounding the reference points is likely to be less accurate than within Netley-Libau Marsh proper.

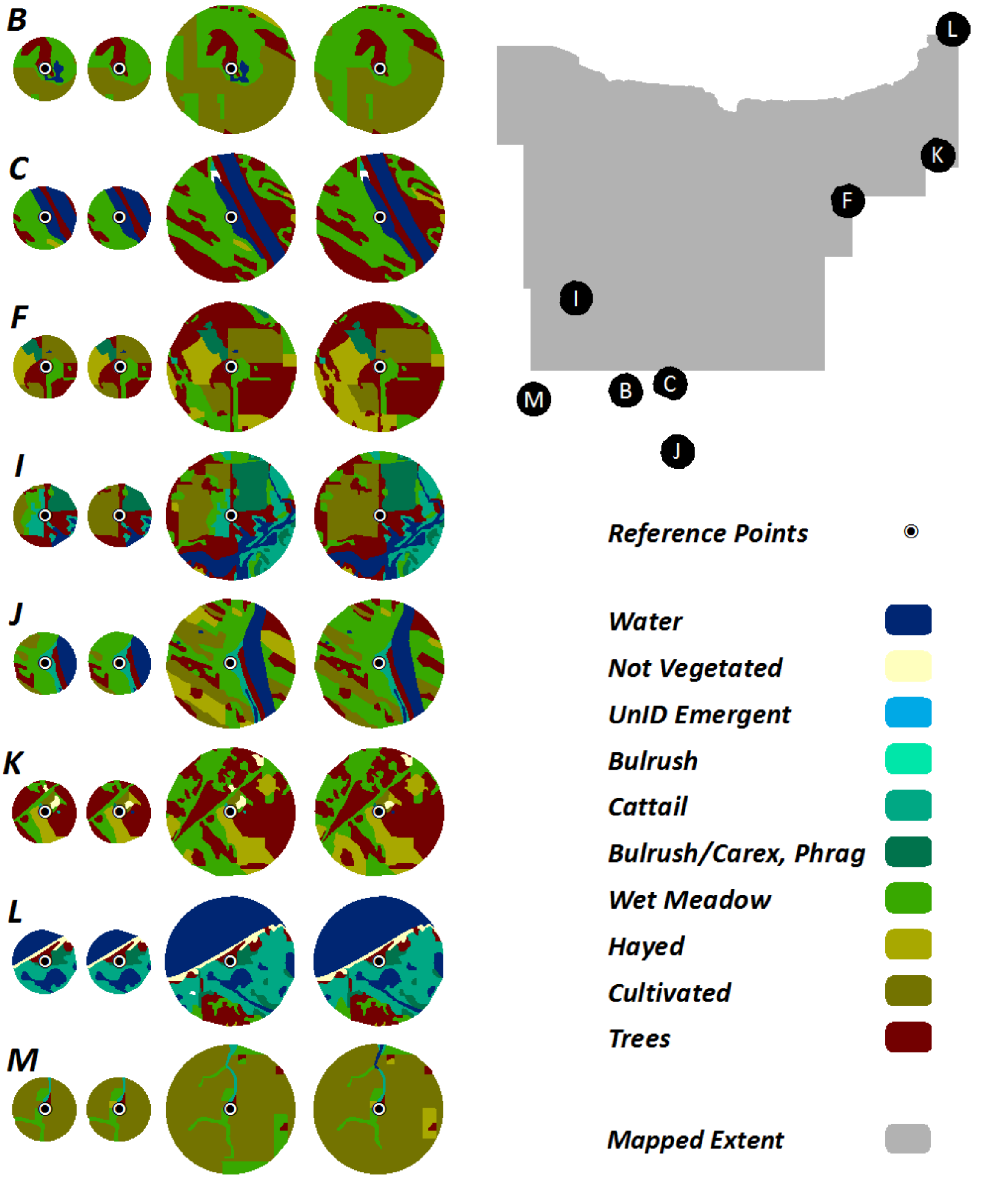


Figure 9.12: Distribution of vegetation cover classes in 2011 and 2013 within 500m and 1000m radii of fixed reference points specified by Environment Canada, and the location of those reference points in relation to the mapped extent of Netley-Libau Marsh. From left to right, each column of circular maps represents the 2011 vegetation within the 500m buffer zone; 2013 vegetation within the 500m buffer zone; 2011 vegetation within the 1000m buffer zone; and 2013 vegetation within the 1000m buffer zone of the corresponding reference point.

10.0 CONCLUSIONS

The long-term trend of vegetation loss in Netley-Libau Marsh is neither unidirectional nor linear.

A trend of vegetation loss over nearly the last century has been noted by other researchers, but the pattern of this change has not been understood. The very few cover maps that were available from that that period imply a steady and perhaps gradual downward trend in wetland plant extent. This study demonstrates that vegetation change in Netley-Libau Marsh has been neither steady nor one-directional. The most recent map of Netley, prior to those produced for this report, was produced based on 2001 imagery; it is now apparent that 2001 was essentially the low point of vegetation extent. In 2013, there was less open water area than was observed in 2001 (though more open water than in historic maps dating from 1922 to 1979).

Wetland vegetation changes in fits and starts.

Periods of stasis, interspersed with years of sudden change, define the pattern of vegetation change in Netley-Libau Marsh. Increases in emergent vegetation may be especially sudden: in a single year, from 2002 to 2003, the marsh was transformed from a maximum extent of most open water to its most vegetated state.

Lake Winnipeg water level is the driving factor controlling the balance between emergent vegetation and open water.

The level of Lake Winnipeg is positively correlated with the annual change in the total area of open water marsh. As the extent of open water marsh increases, emergent wetland decreases at a one-to-one rate.

Periods of low water as short as one year have dramatic and persistent effects on emergent vegetation.

The low water levels of 2003 led to extensive regeneration of emergent vegetation across the marsh. The time series shows that a marked amount of that regrowth has persisted 10 years, particularly in the smaller, more sheltered bays and lakes. In the first few years after re-inundation, some of these newly revegetated areas took the form of hemi-marsh, a patchy distribution of emergent vegetation, which is the preferred habitat of waterfowl and other wetland fauna.

Regenerated emergent vegetation is less persistent in Netley Lake than elsewhere in the marsh.

Mudflats were exposed and emergent vegetation sprang up in Netley Lake in 2003, as it did throughout the marsh. However, revegetated areas in and around Netley Lake did not persist as they did elsewhere. Contributing factors to the accelerated attrition may include the greater wave action across the comparatively large fetch of this bay, the rerouting of the majority of the Red River's flow through The Cut, or the effects of river ice being diverted into Netley Lake.

Netley Lake bathymetry is dynamic.

The bathymetric dataset obtained in 2010 does not represent the depths suggested by the patterns of vegetation and unvegetated areas observed in 2003, in the regions of The Cut and the islands within Netley Lake. Netley Lake's bathymetry appears to be changing, possibly through some combination of higher water levels, wave action, increasing Red River volumes, lack of dredging at the mouth of the Red, bank erosion around The Cut, delta formation, and/or ice scour. Predicting the areas in which emergent vegetation will be able to regenerate may prove challenging if patterns of water depth in Netley Lake vary from year to year.

Lake Winnipeg water levels and Red River flows are both factors controlling the extent of wet meadows.

Both lake levels and river flows were correlated positively with wet meadow and negatively with hayed and cultivated land – this study was unable to isolate which variable, if either, exerts the greatest influence on the shifting balance between wet meadows and uplands. In wet years, it appears that wet meadows are left under natural cover, while in drier years, some areas of wet meadow are treated as upland and hayed, or even cropped, by local producers.

Connectivity between Netley-Libau Marsh and Lake Winnipeg is variable and increasing.

When taken in conjunction with historic maps, the result of this investigation highlight a long-term trend of increasing connectivity between Lake Winnipeg and Netley-Libau Marsh. The number of channels linking lake to marsh was reduced during a dry year, but that reduction in connectivity has not entirely persisted. There may be implications for further degradation of emergent vegetation if the marsh becomes even more subject to lake level change and seiche effects.

Without rehabilitation, further degradation of Netley-Libau Marsh may be anticipated.

If climate trends continue, resulting in frequent floods and high Lake Winnipeg levels, further loss of emergent vegetation and amalgamation of open water areas of Netley-Libau Marsh can be expected, along with a further degradation of wetland function such as nutrient sequestration and wildlife habitat. Concurrently, wet meadow regions may be expanded outward toward the marsh's upland periphery. However, occasional intervals of lower lake level may slow or counteract the long-term trend of vegetation loss in Netley-Libau marsh. Reducing, whether spatially or temporally, the degree of connectivity between the marsh and the Red River, and the marsh and Lake Winnipeg, may also be of use in restoring this important coastal wetland.

11.0 ACKNOWLEDGEMENTS

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APPENDICES

APPENDIX I

The cover composition of Netley-Libau Marsh, in each year for which vegetation maps were produced. The total area, in hectares, and the percent cover of each marsh zone and vegetation class is shown.

Marsh Zone	1990		1992		1993		1994		1997		1999	
Vegetation Class	Area (ha)	% cover	Area (ha)	% cover	Area (ha)	% cover	Area (ha)	% cover	Area (ha)	% cover	Area (ha)	% cover
Not Vegetated	63	0.2%	64	0.2%	59	0.2%	507	1.5%	79	0.2%	111	0.3%
Beach	59	0.2%	59	0.2%	59	0.2%	60	0.2%	70	0.2%	70	0.2%
Disturbed	4	0.0%	5	0.0%	0	0.0%	447	1.3%	10	0.0%	41	0.1%
Water	9712	27.9%	9785	28.1%	10413	29.9%	12086	34.7%	12791	36.8%	12917	37.1%
Open Water	8796	25.3%	8867	25.5%	9462	27.2%	11118	31.9%	11796	33.9%	11920	34.3%
Lake Wpg	309	0.9%	311	0.9%	343	1.0%	359	1.0%	386	1.1%	389	1.1%
Red River	607	1.7%	607	1.7%	608	1.7%	608	1.7%	608	1.7%	608	1.7%
Emergent Vegetation	11001	31.6%	10955	31.5%	10401	29.9%	8296	23.8%	8065	23.2%	7907	22.7%
UnID Emergent	369	1.1%	590	1.7%	1587	4.6%	757	2.2%	112	0.3%	6	0.0%
Bulrush	47	0.1%	121	0.3%	145	0.4%	236	0.7%	244	0.7%	232	0.7%
Cattail	7342	21.1%	6980	20.1%	5815	16.7%	4668	13.4%	5075	14.6%	5081	14.6%
BCP	3243	9.3%	3264	9.4%	2855	8.2%	2635	7.6%	2634	7.6%	2588	7.4%
Wet Meadow	3059	8.8%	3278	9.4%	3622	10.4%	4084	11.7%	3785	10.9%	3849	11.1%
Upland	10964	31.5%	10717	30.8%	10304	29.6%	9826	28.2%	10078	29.0%	10015	28.8%
Hayed	2230	6.4%	2216	6.4%	2020	5.8%	1711	4.9%	2000	5.7%	1959	5.6%
Cultivated	4214	12.1%	3981	11.4%	3769	10.8%	3601	10.3%	3546	10.2%	3527	10.1%
Trees	4520	13.0%	4520	13.0%	4515	13.0%	4515	13.0%	4531	13.0%	4528	13.0%

Marsh Zone	2000		2001		2002		2005		2010		2013	
Vegetation Class	Area (ha)	% cover	Area (ha)	% cover	Area (ha)	% cover	Area (ha)	% cover	Area (ha)	% cover	Area (ha)	% cover
Not Vegetated	80	0.2%	191	0.5%	80	0.2%	75	0.2%	72	0.2%	72	0.2%
Beach	69	0.2%	61	0.2%	62	0.2%	66	0.2%	64	0.2%	64	0.2%
Disturbed	11	0.0%	129	0.4%	18	0.1%	10	0.0%	8	0.0%	7	0.0%
Water	12923	37.1%	13080	37.6%	13102	37.7%	11579	33.3%	11263	32.4%	11501	33.0%
Open Water	11926	34.3%	12071	34.7%	12093	34.7%	10566	30.4%	10248	29.5%	10486	30.1%
Lake Wpg	389	1.1%	401	1.2%	401	1.2%	405	1.2%	407	1.2%	407	1.2%
Red River	608	1.7%	608	1.7%	608	1.7%	608	1.7%	608	1.7%	609	1.7%
Emergent Vegetation	7969	22.9%	7727	22.2%	7799	22.4%	9319	26.8%	9666	27.8%	9426	27.1%
UnID Emergent	2	0.0%	0	0.0%	1	0.0%	1320	3.8%	240	0.7%	122	0.4%
Bulrush	231	0.7%	199	0.6%	175	0.5%	175	0.5%	20	0.1%	9	0.0%
Cattail	5085	14.6%	4912	14.1%	5038	14.5%	4900	14.1%	6821	19.6%	6686	19.2%
BCP	2650	7.6%	2616	7.5%	2585	7.4%	2924	8.4%	2585	7.4%	2608	7.5%
Wet Meadow	3991	11.5%	4383	12.6%	4143	11.9%	4764	13.7%	4730	13.6%	4742	13.6%
Upland	9835	28.3%	9417	27.1%	9676	27.8%	9062	26.0%	9068	26.1%	9058	26.0%
Hayed	1832	5.3%	1530	4.4%	1744	5.0%	1305	3.7%	1613	4.6%	1517	4.4%
Cultivated	3467	10.0%	3360	9.7%	3405	9.8%	3243	9.3%	2948	8.5%	3034	8.7%
Trees	4536	13.0%	4527	13.0%	4527	13.0%	4514	13.0%	4508	13.0%	4508	13.0%

Appendix II

Transition matrix, presenting the change in areal extent of marsh zones between years. Old year marsh zones are listed on the left; new year marsh zones are listed along the top. Values represent the total area of each marsh zone permutation, rounded to the nearest hectare. Matching marsh zones have been highlighted in green. Change A refers to the percent cover of a particular marsh zone which was classified differently in the previous year; the most commonly lost marsh zone is listed. Change B refers to the percent cover of a particular marsh zone which became classified differently in the later year; the most commonly gained marsh zone is listed.

1990-1992	Not Vegetated	Water	Emergent	Wet Meadow	Upland	Change B	Zone Gained
Not Vegetated	63					0.0%	
Water		9683	28			0.3%	
Emergent		102	10859	25	3	1.2%	Water
Wet Meadow			14	2621	423	14.3%	Upland
Upland	1		40	632	10290	6.1%	Wet Meadow
Change A	1.4%	1.0%	0.8%	20.0%	4.0%		
Zone Lost	Upland	Emergent		Upland	Wet Meadow		

1992-1993	Not Vegetated	Water	Emergent	Wet Meadow	Upland	Change B	Zone Gained
Not Vegetated	59			5		8.1%	Wet Meadow
Water		9771	14	0		0.1%	
Emergent		643	10293	9	10	6.0%	Water
Wet Meadow		0	69	2938	271	10.4%	Upland
Upland		0	24	670	10022	6.5%	Wet Meadow
Change A	0.0%	6.2%	1.0%	18.9%	2.7%		
Zone Lost		Emergent	Wet Meadow	Upland	Wet Meadow		

1993-1994	Not Vegetated	Water	Emergent	Wet Meadow	Upland	Change B	Zone Gained
Not Vegetated	59					0.0%	
Water	3	10378	33			0.3%	
Emergent	438	1708	8237	13	4	20.8%	Water
Wet Meadow	6		25	3554	37	1.9%	Upland
Upland	1	0		517	9785	5.0%	Wet Meadow
Change A	88.4%	14.1%	0.7%	13.0%	0.4%		
Zone Lost	Emergent	Emergent		Upland	Wet Meadow		

1994-1997	Not Vegetated	Water	Emergent	Wet Meadow	Upland	Change B	Zone Gained
Not Vegetated	62	50	391	3		87.7%	Emergent
Water	6	12047	33			0.3%	
Emergent	8	692	7553	17	25	8.9%	Water
Wet Meadow			67	3327	690	18.5%	Upland
Upland	3	1	21	438	9363	4.7%	Wet Meadow
Change A	21.3%	5.8%	6.3%	12.1%	7.1%		
Zone Lost	Emergent	Emergent	Not Vegetated	Upland	Wet Meadow		

1997-1999	Not Vegetated	Water	Emergent	Wet Meadow	Upland	Change B	Zone Gained
Not Vegetated	76	2	0			3.6%	Water
Water		12766	25			0.2%	
Emergent	32	146	7881	6		2.3%	Water
Wet Meadow	1		1	3373	410	10.9%	Upland
Upland	2	3		469	9604	4.7%	Wet Meadow
Change A	30.9%	1.2%	0.3%	12.4%	4.1%		
Zone Lost	Emergent	Emergent		Upland	Wet Meadow		

1999-2000	Not Vegetated	Water	Emergent	Wet Meadow	Upland	Change B	Zone Gained
Not Vegetated	79		28	4		28.6%	Emergent
Water	1	12915	1			0.0%	
Emergent		8	7894	5		0.2%	
Wet Meadow			22	3473	354	9.8%	Upland
Upland			25	509	9481	5.3%	Wet Meadow
Change A	1.4%	0.1%	0.9%	13.0%	3.6%		
Zone Lost	Water			Upland	Wet Meadow		

2000-2001	Not Vegetated	Water	Emergent	Wet Meadow	Upland	Change B	Zone Gained
Not Vegetated	66	12		1	1	17.3%	Water
Water	0	12915	8			0.1%	
Emergent	115	144	7699	12	0	3.4%	Water
Wet Meadow	9	1	18	3544	419	11.2%	Upland
Upland	1	9	2	827	8996	8.5%	Wet Meadow
Change A	65.2%	1.3%	0.4%	19.2%	4.5%		
Zone Lost	Emergent	Emergent		Upland	Wet Meadow		

2001-2002	Not Vegetated	Water	Emergent	Wet Meadow	Upland	Change B	Zone Gained
Not Vegetated	70		112	8	1	63.1%	Emergent
Water		13075	5			0.0%	
Emergent	9	26	7677	8	6	0.6%	
Wet Meadow			4	3808	571	13.1%	Upland
Upland		1		318	9099	3.4%	Wet Meadow
Change A	11.8%	0.2%	1.6%	8.1%	6.0%		
Zone Lost	Emergent		Not Vegetated	Upland	Wet Meadow		

2002-2005	**Not Vegetated**	**Water**	**Emergent**	**Wet Meadow**	**Upland**	**Change B**	**Zone Gained**
Not Vegetated	66	3	11			17.3%	Emergent
Water	3	11505	1595		0	12.2%	Emergent
Emergent	5	68	7655	70		1.8%	Wet Meadow
Wet Meadow	1		58	3930	153	5.1%	Upland
Upland		3		764	8909	7.9%	Wet Meadow
Change A	12.4%	0.6%	17.9%	17.5%	1.7%		
Zone Lost	Emergent		Water	Upland	Wet Meadow		

2005-2010	**Not Vegetated**	**Water**	**Emergent**	**Wet Meadow**	**Upland**	**Change B**	**Zone Gained**
Not Vegetated	72	2	1	0		4.6%	Water
Water	0	11109	469	1		4.1%	Emergent
Emergent		152	9115	52		2.2%	Water
Wet Meadow			45	4108	610	13.8%	Upland
Upland			35	569	8458	6.7%	Wet Meadow
Change A	0.3%	1.4%	5.7%	13.1%	6.7%		
Zone Lost		Emergent	Water	Upland	Wet Meadow		

2010-2013	Not Vegetated	Water	Emergent	Wet Meadow	Upland	Change B	Zone Gained
Not Vegetated	71				1	0.8%	
Water		11242	21			0.2%	
Emergent		258	9354	53		3.2%	Water
Wet Meadow			49	4122	558	12.9%	Upland
Upland		0	2	567	8499	6.3%	Wet Meadow
Change A	0.0%	2.2%	0.8%	13.1%	6.2%		
Zone Lost		Emergent		Upland	Wet Meadow		

Appendix III

Transition matrix, presenting the change in areal extent of vegetation classes between years. Old year vegetation classes are listed on the left; new year vegetation classes are listed along the top. Values represent the total area of each vegetation class permutation rounded to the nearest hectare. Matching vegetation classes have been highlighted in green. Change A refers to the percent cover of a particular vegetation class which was classified differently in the previous year; the most commonly lost vegetation class is listed. Change B refers to the percent cover of a particular vegetation class which became classified differently in the later year; the most commonly gained marsh zone is listed.

1990-1992	**Beach**	**Disturbed**	**Open Water**	**Lake Winnipeg**	**Red River**	**UnID Emergent**	**Bulrush**	**Cattail**	**BCP**	**Wet Meadow**	**Hayed**	**Cultivated**	**Trees**	**Change B**	**Class Gained**
Beach	59													0.0%	
Disturbed		4												0.0%	
Open Water			8768			4	1	24						0.3%	Cattail
Lake Winnipeg				308										0.0%	
Red River					607									0.0%	
UnID Emergent			3	3		364								1.5%	Lake Winnipeg
Bulrush						3	43	0						8.0%	UnID
Cattail			92			207	73	6814	130	25			1	7.2%	BCP
BCP			4				4	134	3087	1	2			4.5%	Cattail
Wet Meadow								6	8	2621	393	30	0	14.3%	Hayed
Hayed		1						0	39	563	1592	35		28.6%	Wet Meadow
Cultivated										68	229	3916		7.1%	Hayed
Trees								1					4519	0.0%	
Change A	0.0%	18.0%	1.1%	0.9%	0.0%	37.1%	64.3%	2.4%	5.4%	20.0%	28.2%	1.6%	0.0%		
Class Lost		Hayed	Cattail	UnID		Cattail	Cattail	BCP	Cattail	Hayed	Wet Meadow	Hayed			

1992-1993	Beach	Disturbed	Open Water	Lake Winnipeg	Red River	UnID Emergent	Bulrush	Cattail	BCP	Wet Meadow	Hayed	Cultivated	Trees	Change B	Class Gained
Beach	59													0.0%	
Disturbed										5				100.0%	Wet Meadow
Open Water			8853			6		8	0	0				0.2%	
Lake Winnipeg				311										0.0%	
Red River					607									0.0%	
UnID Emergent			216	32	1	334	2	4						43.4%	Open Water
Bulrush			3			10	76	32						36.9%	Cattail
Cattail			363			1218	53	5177	157	2	10		1	25.8%	UnID
BCP			27			18	13	557	2642	7				19.1%	Cattail
Wet Meadow			0					27	42	2938	271			10.4%	Hayed
Hayed			0					3	15	614	1438	145		35.1%	Wet Meadow
Cultivated										56	301	3624		9.0%	Hayed
Trees								6					4514	0.1%	
Change A	0.0%	0.0%	6.4%	9.4%	0.2%	79.0%	47.4%	11.0%	7.5%	18.9%	28.8%	3.8%	0.0%		
Class Lost			Cattail	UnID		Cattail	Cattail	BCP	Cattail	Hayed	Cultivated	Hayed			

1993-1994	Beach	Disturbed	Open Water	Lake Winnipeg	Red River	UnID Emergent	Bulrush	Cattail	BCP	Wet Meadow	Hayed	Cultivated	Trees	Change B	Class Gained
Beach	59													0.0%	
Disturbed														0.0%	
Open Water		2	9428			15	8	10	0					0.4%	UnID
Lake Winnipeg	1			342										0.3%	
Red River					608									0.0%	
UnID Emergent		6	1261	17	0	285	12	5						82.0%	Open Water
Bulrush			4			9	130	2						10.0%	UnID
Cattail	0	420	419			438	81	4379	71	2	4			24.7%	UnID
BCP		12	7			9	5	269	2543	11				10.9%	Cattail
Wet Meadow		6				1		3	21	3554	37			1.9%	BCP
Hayed		1								463	1532	25		24.2%	Wet Meadow
Cultivated		1								54	138	3576		5.1%	Hayed
Trees			0										4515	0.0%	
Change A	2.4%	100.0%	15.2%	4.8%	0.0%	62.3%	44.9%	6.2%	3.5%	13.0%	10.5%	0.7%	0.0%		
Class Lost	Lake Winnipeg	Cattail	UnID	UnID		Cattail	Cattail	BCP	Cattail	Hayed	Cultivated	Hayed			

1994-1997	Beach	Disturbed	Open Water	Lake Winnipeg	Red River	UnID Emergent	Bulrush	Cattail	BCP	Wet Meadow	Hayed	Cultivated	Trees	Change B	Class Gained
Beach	59		0	1										2.6%	Lake Winnipeg
Disturbed		4	49				1	374	17	3				99.2%	Cattail
Open Water		6	11080			9	4	10	9					0.3%	
Lake Winnipeg				359										0.0%	
Red River					608									0.0%	
UnID Emergent	8		554	26	0	74	11	63	21					90.2%	Open Water
Bulrush			5				221		10					6.5%	BCP
Cattail			100			27	5	4488	45	1			1	3.9%	Open Water
BCP			7			1	2	127	2458	16			24	6.7%	Cattail
Wet Meadow								10	58	3327	570	120	0	18.5%	Hayed
Hayed	3		1					2	16	359	1218	113		28.8%	Wet Meadow
Cultivated										74	213	3314		8.0%	Hayed
Trees								3	1	5			4506	0.2%	
Change A	15.5%	63.3%	6.1%	7.0%	0.0%	33.6%	9.5%	11.6%	6.7%	12.1%	39.1%	6.5%	0.6%		
Class Lost	UnID	Open Water Marsh	UnID	UnID		Cattail	UnID	Disturbed	Wet Meadow	Hayed	Wet Meadow	Wet Meadow			

1997-1999	Beach	Disturbed	Open Water	Lake Winnipeg	Red River	UnID Emergent	Bulrush	Cattail	BCP	Wet Meadow	Hayed	Cultivated	Trees	Change B	Class Gained
Beach	69							0						0.7%	
Disturbed		7	2											24.2%	Open Water
Open Water			11772				3	21	1					0.2%	
Lake Winnipeg				386										0.0%	
Red River					608									0.0%	
UnID Emergent			79			6	1	27						94.5%	Cattail
Bulrush			14	1			229							6.2%	Open Water
Cattail	0	12	43					5011	3	5				1.3%	Open Water
BCP		20	9					20	2584	1				1.9%	Open Water
Wet Meadow		1						1		3373	394	16		10.9%	Hayed
Hayed										426	1470	105		26.5%	Wet Meadow
Cultivated		2								43	95	3406		4.0%	Hayed
Trees			1	1						0			4528	0.1%	
Change A	0.6%	82.1%	1.2%	0.6%	0.0%	0.0%	1.4%	1.4%	0.1%	12.4%	25.0%	3.4%	0.0%		
Class Lost		BCP	UnID				Open Water Marsh	UnID		Hayed	Wet Meadow	Hayed			

1999-2000	Beach	Disturbed	Open Water	Lake Winnipeg	Red River	UnID Emergent	Bulrush	Cattail	BCP	Wet Meadow	Hayed	Cultivated	Trees	Change B	Class Gained
Beach	70													0.0%	
Disturbed		9						11	17	4				77.0%	BCP
Open Water		1	11918				0	1	0					0.0%	
Lake Winnipeg				389										0.0%	
Red River					608									0.0%	
UnID Emergent			4			2								60.3%	Open Water
Bulrush			1				230	0						0.7%	
Cattail			3				1	5062	11	3				0.4%	
BCP			0					6	2580	2				0.3%	
Wet Meadow								2	19	3473	328	26		9.8%	Hayed
Hayed								2	21	499	1378	57	3	29.7%	Wet Meadow
Cultivated								1		10	126	3384	6	4.1%	Hayed
Trees									1				4528	0.0%	
Change A	0.0%	10.9%	0.1%	0.0%	0.0%	0.0%	0.4%	0.4%	2.6%	13.0%	24.8%	2.4%	0.2%		
Class Lost		Open Water							Hayed	Hayed	Wet Meadow	Hayed			

2000-2001	Beach	Disturbed	Open Water	Lake Winnipeg	Red River	UnID Emergent	Bulrush	Cattail	BCP	Wet Meadow	Hayed	Cultivated	Trees	Change B	Class Gained
Beach	61	0		7									1	12.5%	Lake Winnipeg
Disturbed		5	5							1				52.0%	Open Water
Open Water	0		11917	0			4	4	0					0.1%	
Lake Winnipeg	0			389										0.0%	
Red River					608									0.0%	
UnID Emergent			2											100.0%	Open Water
Bulrush			35				195	1	0					15.7%	Open Water
Cattail		100	72	1			0	4882	25	5				4.0%	Disturbed
BCP		15	33					20	2576	6		0		2.8%	Open Water
Wet Meadow		9	1	0				4	14	3544	419		1	11.2%	Hayed
Hayed			0							780	1001	50	0	45.3%	Wet Meadow
Cultivated										47	110	3310		4.5%	Hayed
Trees		1	5	4				2					4525	0.3%	
Change A	0.5%	96.1%	1.3%	3.1%	0.0%	0.0%	2.1%	0.6%	1.5%	19.2%	34.5%	1.5%	0.0%		
Class Lost		Cattail	Cattail	Beach			Open Water	BCP	Cattail	Hayed	Wet Meadow	Hayed			

2001-2002	Beach	Disturbed	Open Water	Lake Winnipeg	Red River	UnID Emergent	Bulrush	Cattail	BCP	Wet Meadow	Hayed	Cultivated	Trees	Change B	Class Gained
Beach	61													0.0%	
Disturbed	1	8						97	15	8			1	93.5%	Cattail
Open Water			12066			1	3	1						0.0%	
Lake Winnipeg				401										0.0%	
Red River					608									0.0%	
UnID Emergent														0.0%	
Bulrush			25				172	2						13.5%	Open Water
Cattail	0	9						4839	59	2	3			1.5%	BCP
BCP			1					94	2510	6	3			4.0%	Cattail
Wet Meadow								4	0	3808	564	7		13.1%	Hayed
Hayed										311	1134	85		25.9%	Wet Meadow
Cultivated										7	40	3313		1.4%	Hayed
Trees			1										4526	0.0%	
Change A	1.8%	51.9%	0.2%	0.0%	0.0%	100.0%	1.8%	3.9%	2.9%	8.1%	35.0%	2.7%	0.0%		
Class Lost	Disturbed	Cattail				Open Water Marsh	Open Water	Disturbed	Cattail	Hayed	Wet Meadow	Hayed			

2002-2005	Beach	Disturbed	Open Water	Lake Winnipeg	Red River	UnID Emergent	Bulrush	Cattail	BCP	Wet Meadow	Hayed	Cultivated	Trees	Change B	Class Gained
Beach	59		0	3				0						5.2%	Lake Winnipeg
Disturbed		7						7	4					60.2%	Cattail
Open Water			10498	0		1223	77	274	19			0		13.2%	UnID
Lake Winnipeg	3			398										0.6%	
Red River					608	1								0.1%	
UnID Emergent						1								0.0%	
Bulrush			24			40	96	16						45.4%	UnID
Cattail	3	2	28	2		43	1	4514	442	4				10.4%	BCP
BCP	1		14			13	1	85	2405	66				7.0%	Cattail
Wet Meadow		1						5	54	3930	147	6		5.1%	Hayed
Hayed										671	961	111		44.9%	Wet Meadow
Cultivated										90	196	3119		8.4%	Hayed
Trees			3	1						2		7	4514	0.3%	
Change A	9.9%	28.6%	0.7%	1.6%	0.0%	99.9%	45.2%	7.9%	17.7%	17.5%	26.3%	3.8%	0.0%		
Class Lost	Cattail	Cattail		Beach		Open Water Marsh	Open Water Marsh	Open Water Marsh	Cattail	Hayed	Cultivated	Hayed			

2005-2010	Beach	Disturbed	Open Water	Lake Winnipeg	Red River	UnID Emergent	Bulrush	Cattail	BCP	Wet Meadow	Hayed	Cultivated	Trees	Change B	Class Gained
Beach	64			2										2.3%	Lake Winnipeg
Disturbed		8	0					1	1	0				19.8%	BCP
Open Water		0	10096			28		415	27	1				4.5%	Cattail
Lake Winnipeg				405										0.0%	
Red River					608									0.0%	
UnID Emergent			107			173	10	989	41					86.9%	Cattail
Bulrush			8				9	156	3					95.0%	Cattail
Cattail			32	0		36	0	4538	286	8				7.4%	BCP
BCP			5			3	1	670	2200	44				24.7%	Cattail
Wet Meadow								17	27	4108	477	134		13.8%	Hayed
Hayed								9		410	772	113		40.8%	Wet Meadow
Cultivated								27		158	363	2695		16.9%	Hayed
Trees											0	6	4508	0.1%	
Change A	0.0%	2.6%	1.5%	0.4%	0.0%	27.8%	55.8%	33.5%	14.9%	13.1%	52.1%	8.6%	0.0%		
Class Lost		Open Water Marsh	UnID			Cattail	UnID	UnID	Cattail	Hayed	Wet Meadow	Wet Meadow			

2010-2013	Beach	Disturbed	Open Water	Lake Winnipeg	Red River	UnID Emergent	Bulrush	Cattail	BCP	Wet Meadow	Hayed	Cultivated	Trees	Change B	Class Gained
Beach	64													0.0%	
Disturbed		7									1			7.4%	Hayed
Open Water			10228				1	17	2					0.2%	
Lake Winnipeg				407										0.0%	
Red River					608									0.0%	
UnID Emergent			32			118	1	87	2					51.0%	Cattail
Bulrush			11				6	2	1					70.4%	Open Water
Cattail			181				1	6531	107	0				4.2%	Open Water
BCP			33		1	5		42	2451	53				5.2%	Wet Meadow
Wet Meadow								6	43	4122	487	72		12.9%	Hayed
Hayed										425	972	216		39.7%	Wet Meadow
Cultivated			0						2	142	57	2747		6.8%	Wet Meadow
Trees			0										4508	0.0%	
Change A	0.0%	0.0%	2.5%	0.0%	0.1%	3.9%	35.2%	2.3%	6.0%	13.1%	35.9%	9.5%	0.0%		
Class Lost			Cattail			BCP	UnID	UnID	Cattail	Hayed	Wet Meadow	Hayed			

APPENDIX IV

Statistical coefficients describing relationships between hydrometric parameters and vegetation class / marsh zone areal extents / annual change. For each relationship, four statistics are reported: + or – to indicate the direction of the correlation (top left), slope (top right), p-value (bottom left), and correlation coefficient r^2 (bottom right). Relationships where $p < 0.05$ have been reported as significant and are highlighted in green; those where $p < 0.1$ have been reported as suggestive, warranting further investigation, and are highlighted in yellow.

Marsh Zone Total Area

		Not Vegetated		Water		Emergent		Wet Meadow		Upland	
Lake Winnipeg Level	Daily Lake Level							+	1664	-	1800
								0.0215	43%	0.0228	39%
	Max Lake Level							+	1285.8	-	1450
								0.0153	46%	0.0148	46%
	Min Lake Level							+	1804	-	2017
								0.0068	54%	0.0072	53%
	April-July Lake Level							+	1536	-	1718
								0.0149	46%	0.0155	46%
	June-July Lake Level							+	1628.6	-	1816
								0.0121	48%	0.013	48%
Red River Discharge	Daily Discharge										
	Max Discharge			+	0.4453						
				0.0925	15%						
	Min Discharge							+	2.3591	-	2.6216
								0.0393	36%	0.0422	35%
	April Discharge										
	May Discharge										
	June Discharge			+	1.2244			+	1.343	-	1.5277
				0.0955	15%			0.0007	70%	0.0005	71%
	July Discharge							+	0.881	-	0.9989
								0.0278	40%	0.0261	41%
	April-July Discharge			+	1.0143	-	1.5103	+	0.867	-	1.0029
				0.0898	15%	0.0907	18%	0.0487	34%	0.041	36%
	June-July Discharge			+	1.1936			+	1.2541	-	1.4246
				0.1075	14%			0.0028	61%	0.0024	62%

Marsh Zone Change in Area

		Not Vegetated	Water	Emergent	Wet Meadow	Upland
Lake Winnipeg Level	Daily Lake Level		+ 1940 0.0039 40%			
	Max Lake Level		+ 1074 0.0412 22%			
	Min Lake Level		+ 1718 0.0172 29%			
	June Lake Level	- 244.5 0.0978 9%	+ 1113 0.0691 18%		- 105 0.0228 1%	+ 111 0.0174 1%
	April-July Lake Level		+ 1372 0.0453 22%			
	June-July Lake Level		+ 1296 0.0392 23%			
Red River Discharge	Daily Discharge		+ 1.4305 0.0367 23%			
	Max Discharge	- 0.0244 0.0095 3%				
	Min Discharge					
	April Discharge					
	May Discharge	- 0.0138 0.0654 1%				
	June Discharge			- 1.5103 0.0328 18%		
	July Discharge			- 1.2759 0.032 17%		
	April-July Discharge	- 0.0463 0.0967 2%				
	June-July Discharge			- 1.6064 0.0157 20%		

Vegetation Class Total Area

		Beach	Disturbed	Open Water Marsh	Lake Winnipeg	Red River	UnID Emergent	Bulrush	Cattail	BCP	Wet Meadow	Hayed	Cultivated	Trees
Lake Winnipeg Level	Daily Lake Level										+ 1664 0.0215 43%	- 870 0.0192 44%	- 908 0.064 30%	- -22 0.0726 28%
	Max Lake Level				+ 79 0.024 42%						+ 1286 0.0153 46%	- 714 0.0069 53%	- 736 0.0389 36%	
	Min Lake Level				+ 104 0.0215 43%						+ 1804 0.0068 54%	- 936 0.0062 54%	- 1072 0.0166 45%	
	April-July Lake Level				+ 90.7 0.0316 39%						+ **1536** 0.0149 46%	- 788 0.0156 46%	- 925 0.0271 40%	
	June-July Lake Level				+ 93.6 0.0326 38%						+ 1629 0.0121 48%	- 821 0.0151 46%	- 988 0.0216 42%	
Red River Discharge	Daily Discharge						+ 1.0972 0.0541 35%		- 1.7906 0.0676 30%					
	Max Discharge	+ 0.0025 0.0432 32%		+ 0.417 0.0945 14%										
	Min Discharge										+ 2.3591 0.0393 36%	- 1.1849 0.0462 34%	- 1.4222 0.0591 31%	
	April Discharge													
	May Discharge	+ 0.0025 0.088 24%												
	June Discharge	+ 0.0063 0.0763 27%			+ 0.092 0.0001 79%	+ 0.0009 0.0329 29%				- 0.4098 0.0559 32%	+ 1.343 0.0007 70%	- 0.6295 0.0043 58%	- 0.8939 0.0004 74%	
	July Discharge	+ 0.0055 0.0753 28%			+ 0.0612 0.0157 46%				- 1.3677 0.0577 31%		+ 0.881 0.0278 40%	- 0.4925 0.0143 47%	- 0.5074 0.0575 32%	
	April-July Discharge	+ 0.0071 0.0193 40%		+ 0.9464 0.1061 14%	+ 0.0707 0.0073 53%					- 0.3576 0.0771 28%	+ 0.867 0.0487 34%	- 0.3947 0.0895 26%	- 0.6106 0.0281 40%	
	June-July Discharge	+ 0.0068 0.0521 32%			+ 0.0867 0.0008 69%	+ 0.0008 0.056 28%					+ 1.2541 0.0028 61%	- 0.6411 0.0033 60%	- 0.782 0.0049 56%	

		Vegetation Class Change in Area										
		Beach	Disturbed	Open Water Marsh	UnID Emergent	Bulrush	Cattail	BCP	Wet Meadow	Hayed	Cultivated	Trees
Lake Winnipeg Level	Daily Lake Level			+ 1745 0.0059 37%								
	Max Lake Level			+ 958.7 0.0522 20%				+ 389 0.0757 31%				
	Min Lake Level			+ 1560 0.0211 28%								
	June Lake Level		- 248.1 0.0953 9%	+ 1003 0.0803 17%		- 75 0.0463 9%	+ 1284 0.0052 16%		+ 59 0.0134 0%	- 105 0.0228 1%		
	April-July Lake Level			+ 1236 0.0546 20%								
	June-July Lake Level			+ 1165 0.048 21%								
Red River Discharge	Daily Discharge			+ 1.3366 0.0365 23%								
	Max Discharge	+ 0.0025 0.0789 32%	- 0.0306 0.0091 5%									
	Min Discharge					- 0.04 0.0716 0%						- 0.0144 0.0339 5%
	April Discharge											
	May Discharge		- 0.0224 0.0645 2%									
	June Discharge					- 0.0296 0.0189 1%	- 0.6572 0.0359 5%					
	July Discharge							- 0.2134 0.0341 11%				
	April-July Discharge		- 0.0748 0.0962 4%									
	June-July Discharge							- 0.346 0.0604 23%				

		Marsh Zone Total Area					Vegetation Class Total Area										
		Beach	Disturbed	Open Water Marsh	Lake Winnipeg	Red River	Beach	Disturbed	Open Water Marsh	UnID Emergent	Bulrush	Cattail	BCP	Wet Meadow	Hayed	Cultivated	Trees
Change in Lake Winnipeg Level	Daily Lake Level																
	Max Lake Level																
	Min Lake Level									+ 0.0164 1359.8 53%							
	June Lake Level																
	April-July Lake Level									+ 0.0723 929 35%							
	June-July Lake Level																
Change in Red River Discharge	Daily Discharge																
	Max Discharge																
	Min Discharge																
	June Discharge																
	July Discharge																
	April-July Discharge																
	June-July Discharge																

Appendix V

Cover classes within a 500m and 1000m radius of reference points in the vicinity of Netley-Libau Marsh. Percent cover of each vegetation class in 2011 and 2013 is listed, as well as the percent change between the two years.

B	500m Buffer			1000m Buffer		
	2011	2013	% Change	2011	2013	% Change
Open Water Marsh	5.7%	0.0%	-5.7%	1.4%	0.0%	-1.4%
Wet Meadow	40.4%	46.1%	5.7%	35.9%	46.4%	10.5%
Hayed	0.0%	0.0%	0.0%	1.4%	0.0%	-1.4%
Cultivated	35.3%	35.3%	0.0%	51.0%	43.3%	-7.7%
Trees	18.7%	18.7%	0.0%	10.3%	10.3%	0.0%

F	500m Buffer			1000m Buffer		
	2011	2013	% Change	2011	2013	% Change
Open Water Marsh	0.4%	0.4%	0.0%	0.1%	0.1%	0.0%
Cattail	1.7%	0.0%	-1.7%	0.7%	0.3%	-0.4%
BCP	8.5%	8.5%	0.0%	4.6%	4.6%	0.0%
Wet Meadow	13.2%	14.8%	1.7%	17.3%	10.4%	-6.9%
Hayed	14.5%	14.5%	0.0%	14.3%	21.6%	7.4%
Cultivated	29.7%	29.7%	0.0%	18.4%	18.4%	0.0%
Trees	32.1%	32.1%	0.0%	44.6%	44.6%	0.0%

C	500m Buffer			1000m Buffer		
	2011	2013	% Change	2011	2013	% Change
Open Water Marsh	18.4%	18.4%	0.0%	5.7%	5.7%	0.0%
Red River	19.9%	20.0%	0.0%	13.1%	13.1%	0.0%
Cattail			0.0%	0.7%	0.7%	0.0%
BCP	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Wet Meadow	41.7%	43.7%	2.0%	41.0%	40.5%	-0.5%
Hayed	2.0%	0.0%	-2.0%	1.3%	1.8%	0.5%
Trees	17.9%	17.9%	0.0%	38.2%	38.2%	0.0%

I	500m Buffer			1000m Buffer		
	2011	2013	% Change	2011	2013	% Change
Open Water Marsh	6.1%	9.4%	3.3%	14.3%	14.3%	0.0%
Cattail	20.3%	7.5%	-12.8%	18.0%	14.2%	-3.8%
BCP	15.9%	24.5%	8.6%	14.5%	14.5%	0.0%
Wet Meadow	14.1%	2.2%	-11.9%	12.7%	9.9%	-2.8%
Hayed	0.0%	0.0%	0.0%	0.7%	0.3%	-0.4%
Cultivated	12.0%	7.5%	-4.5%	16.3%	23.3%	7.0%
Trees	31.6%	48.8%	17.2%	23.5%	23.5%	0.0%

J	500m Buffer			1000m Buffer		
	2011	2013	% Change	2011	2013	% Change
Open Water Marsh	2.1%	2.1%	0.0%	1.3%	1.3%	0.0%
Red River	19.9%	19.9%	0.0%	12.5%	12.5%	0.0%
Cattail	11.3%	11.3%	0.0%	3.8%	3.8%	0.0%
Wet Meadow	39.6%	45.9%	6.2%	28.8%	46.6%	17.8%
Hayed	0.0%	0.0%	0.0%	15.3%	1.0%	-14.3%
Cultivated	12.4%	6.2%	-6.2%	20.4%	16.9%	-3.6%
Trees	14.6%	14.6%	0.0%	17.8%	17.8%	0.0%

L	500m Buffer			1000m Buffer		
	2011	2013	% Change	2011	2013	% Change
Open Water Marsh	16.8%	16.8%	0.0%	7.6%	7.4%	-0.2%
Lake Winnipeg	27.2%	27.2%	0.0%	39.0%	39.0%	0.0%
Beach	7.8%	7.8%	0.0%	4.3%	4.3%	0.0%
Cattail	35.0%	35.0%	0.0%	32.2%	31.7%	-0.5%
BCP	11.4%	11.4%	0.0%	6.3%	6.3%	0.0%
Wet Meadow			0.0%	3.2%	3.9%	0.7%
Hayed	0.0%	0.0%	0.0%	0.2%	0.2%	0.0%
Trees	9.6%	9.6%	0.0%	11.6%	11.6%	0.0%

K	500m Buffer			1000m Buffer		
	2011	2013	% Change	2011	2013	% Change
Open Water Marsh	0%	0%	0%	0%	0%	0%
Disturbed	3%	2%	-2%	1%	1%	0%
Cattail	2%	0%	-2%	1%	0%	-1%
BCP	0%	2%	2%	0%	1%	1%
Wet Meadow	22%	21%	-1%	34%	29%	-4%
Hayed	15%	18%	2%	15%	19%	5%
Cultivated	5%	6%	1%	1%	1%	0%
Trees	52%	52%	0%	48%	48%	0%

M	500m Buffer			1000m Buffer		
	2011	2013	% Change	2011	2013	% Change
Open Water Marsh	0.0%	0.0%	0.0%	0.0%	0.6%	0.6%
Cattail	1.9%	1.9%	0.0%	1.5%	0.9%	-0.6%
BCP	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Wet Meadow	12.6%	12.6%	0.0%	13.3%	5.9%	-7.4%
Hayed	0.0%	1.7%	1.7%	0.0%	3.5%	3.5%
Cultivated	83.4%	81.7%	-1.7%	83.8%	87.7%	3.9%
Trees	2.1%	2.1%	0.0%	1.5%	1.5%	0.0%