# AN ANALYSIS OF DIGITAL WETLAND VEGETATION MAP COVERAGES

# PRODUCED BASED ON AERIAL PHOTOGRAPHY AND SATELLITE IMAGERY

# NETLEY-LIBAU MARSH, 2001

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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. Landsat imagery, though of a coarser spatial resolution, has the advantage of high temporal and spectral resolution. In this study, a classified digital vegetation map was created for Netley-Libau Marsh in 2001 using GIS software, Landsat 7 imagery, and a visual classification methodology, for the purposes of comparison with an existing digital vegetation map produced by Grosshans et al (2004) from aerial photography obtained during the same year.

Visual delineation and classification of Landsat multispectral imagery was a method suitable for producing wetland maps which distinguish vegetated from non-vegetated areas with a high degree of accuracy, as compared to the truthed Grosshans et al map. Whereas that photography-based mapping exercise distinguished 23 vegetation classes grouped under six marsh zones; this study was able to successfully distinguish five marsh zones – *water, not vegetated, emergent wetland vegetation, wet meadow,* and *upland.* Further distinction and categorization of three marsh zones into seven vegetation classes was also possible, but with a lower degree of accuracy.

This report describes the methods used to evaluate differences in surface area of equivalent classes between the two mapping exercises. It also provides recommendation for the future analysis of Landsat images to produce a time series of classified digital vegetation maps that may be used to explore relationships between lake and river hydrology and wetland plant cover. This knowledge will be fundamental to guide management and remediation efforts for the benefit of Netley-Libau Marsh and Lake Winnipeg.

# 2.0 TABLE OF CONTENTS

# 3.0 LIST OF FIGURES



# 4.0 LIST OF TABLES



# 5.0 LIST OF APPENDICES

# 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. 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. 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 attempt to map and classify vegetation within the marsh was undertaken by Verbiwski (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%.

Among other factors to which emergent vegetation loss in Netley-Libau has been attributed – including the introduction of the invasive common carp (*Cyprinus carpio*), the increased nutrient load of the Red River, and changing dredging practices in Netley's channels – Grosshans et al (2004) provides compelling circumstantial evidence that contributing causes may include changes to Lake Winnipeg water level regime, due to isostatic rebound and the regulation of the lake for hydroelectric power, and an increased frequency and severity of flooding on the Red River. Though Netley's vegetation cover has been observed to change following low and high water levels on Lake Winnipeg, (Grosshans et al 2004), it is difficult to infer a long term trend 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 (~1m at the scale of the 2001 photographs of Netley), 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. Landsat 8, launched in 2013, captures imagery with six discrete wavelength bands in the visible to near infrared range, and provides repeat coverage at a period of 16 days (NASA 2014). Earlier generation Landsat satellites, including Landsat 7 (launched 1999) and Landsat 5 (launched 1984), both still operational, acquired comparable imagery. However, the spatial resolution of imagery acquired by these three satellites is 30m.

This report examines whether the relatively coarse Landsat imagery can be used to produce a vegetation map of Netley-Libau Marsh in 2001, for which year a high-resolution, photography-based map has already been produced

(Grosshans et al 2004). If the accuracy and level of detail of such a map are satisfactory, the techniques described in this document may be used to map the state of vegetation in Netley-Libau for nearly every year since, and many years between, the 1979 and 2001 snapshots produced by Verbiwksi and Grosshans. The resultant vegetation maps will allow for an examination of the ecological response of Netley's vegetation community to hydrological trends on Lake Winnipeg and the Red River, which can be used to guide future remediation measures.

# 6.0 METHODOLOGY

## 6.1 IMAGE PROCESSING

Landsat imagery, obtained by Environment Canada geomatics specialist Guy Létourneau, was georeferenced to UTM Zone 14N / WGS 84, cropped to focus on Netley-Libau Marsh, and saved in PCI Geomatica format (.pix). Landsat imagery was viewed under several combinations of visible and near infrared wavelength bands (Table 6.1). An RGB display of bands 4,5,3 was used primarily because of its strengths in distinguishing between soil moisture levels and variations in chlorophyll between plant species (Geospatial Innovation Facility 2008), with other band composites providing supplementary information.

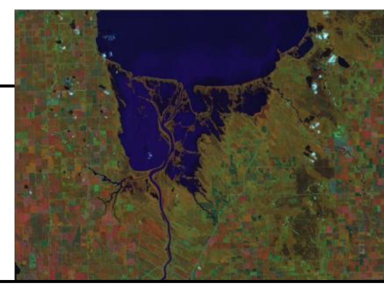
As several images from various generations of Landsat satellite were available for 2001, a Landsat 7 image captured August 2nd 2001 was ultimately chosen as the basis for this vegetation mapping exercise. The state of wetland plant development and the water levels on Lake Winnipeg (Water Survey of Canada) at the time of this image were deemed to be most comparable to the August 3rd 2001 photographs upon which the Grosshans map was based.

## 6.2 VEGETATION DELINEATION AND CLASSIFICATION

Creating vegetation feature maps from remotely sensed imagery can be accomplished manually on the basis of visual inspection, or through automated or semi-automated processes, including pixel-based or object-based segmentation. Pixel-based automated classification of Landsat imagery has proven less successful at incorporating contextual information that allows the generation of realistically non-patchy vegetation features (Flanders et al 2003), as well as less successful at capturing change in wetland cover over time (Dingle Robertson and King 2011). Object-based image analysis has shown some success at mapping wetland vegetation (Baschuk et al 2012), including from Landsat imagery (Ceccarelli et al 2013; Dingle Robertson and King 2011). However, an object-based image analysis would require specialist software suites, which were prohibitively expensive for the scope of this investigation; though it could be explored in future. Therefore, in keeping with the methodology of Grosshans et al (2004), and so that the vegetation coverage produced would be more directly comparable with the one produced by their study, the vegetation feature map was generated manually using Esri ArcGIS 9.2 software by delineating stands of vegetation in Netley-Libau Marsh that were visibly distinct on Landsat imagery.

Vegetation polygons were classified according to a scheme modified from Grosshans et al (2004). Where Landsat imagery did not provide sufficient spectral resolution to distinguish between vegetation classes, the scheme was

Table 6.1: Landsat 7 Enhanced Thematic Mapper (ETM) band combinations; the red-green-blue channels in which these band combinations were displayed; their properties which relate to the visualisation of wetland vegetation; and a view of the Netley-Libau area as a sample of each composite. † Geospatial Innovation Facility 2008.

| Name | Red | Green | Blue | Properties | Sample |
|---|---|---|---|---|---|
| True Colour | 3<br>red | 2<br>green to yellow | 1<br>blue to green | - best approximates realistic colours<br>- short wavelengths, prone to atmospheric scattering, produce a hazy image † |  |
| False Colour Infrared (FCIR) | 4<br>near IR | 3<br>red | 2<br>green to yellow | - comparable colour composite to FCIR aerial photography<br>- moderately affected by atmospheric scatter †<br>- land-water interface is well-defined<br>- good differentiation of vegetation species |  |
| Vegetation and Soil Moisture | 4<br>near IR | 5<br>short wave IR | 3<br>red | - long wavelengths produce very crisp images †<br>- land-water interface very clearly defined<br>- differences in soil moisture are visible<br>- good differentiation of vegetation species<br>- non-vegetated soils can be over-represented |  |
| Green Vegetation | 5<br>short wave IR | 4<br>near IR | 1<br>blue to green | - similar features as *vegetation & soil moisture*<br>- more realistic colour composite<br>- fairly crisp image<br>- non-vegetated soils slightly over-represented |  |

altered to combine the classes. This scheme of marsh zones and vegetation classes, and how it translates to the Grosshans classification system, is presented in Table 6.2. The digital map data provided with the Grosshans et al (2004) report was used to recalculate marsh zone and vegetation class tallies based on this new revised classification scheme.

To train the classification exercise, a subset of up to 30 polygons of each vegetation class was truthed to the Grosshans map (which in turn was ground-truthed based on field surveys conducted in 2001). Based on these truthed polygons, a vegetation key was created which captured examples of each vegetation class, displayed in all band combinations. This key (Tables 6.3a; 6.3b) was used as a reference for further classification. A high degree of colour perception was required by the analyst in order to distinguish between vegetation classes with similar spectral signatures.

Table 6.2: Key presenting equivalent marsh zones and vegetation classes used in this mapping exercise, and the equivalent vegetation types and marsh zones used by Grosshans et al (2004). Marsh zones are separated by solid lines, and vegetation classes are separated by a dotted line.

<table>
<tr><th>Marsh Zone (this study)</th><th>Vegetation Class (this study)</th><th>Vegetation Type (Grosshans)</th><th>Marsh Zone (Grosshans)</th></tr>
<tr><td rowspan="3">Water</td><td>Open Water Marsh</td><td rowspan="3">Open Water</td><td rowspan="6">Non-vegetated</td></tr>
<tr><td>Lake Winnipeg</td></tr>
<tr><td>Red River</td></tr>
<tr><td rowspan="3">Not Vegetated</td><td>Disturbed</td><td>Disturbed</td></tr>
<tr><td rowspan="2">Beach</td><td>Sand</td></tr>
<tr><td>Mudflat</td></tr>
<tr><td rowspan="6">Emergent Wetland Vegetation</td><td>Bulrush</td><td>Bulrush</td><td rowspan="5">Emergent</td></tr>
<tr><td>Cattail</td><td>Cattail</td></tr>
<tr><td rowspan="4">Bulrush / Care, Prig</td><td>Bulrush / Carex</td></tr>
<tr><td>Acorus</td></tr>
<tr><td>Sonchus</td></tr>
<tr><td>Phrag</td><td rowspan="7">Wet Meadow</td></tr>
<tr><td rowspan="10">Wet Meadow</td><td rowspan="10">Wet Meadow</td><td>Carex</td></tr>
<tr><td>Whitetop</td></tr>
<tr><td>Phalaris</td></tr>
<tr><td>Phrag / Willow</td></tr>
<tr><td>Willow</td></tr>
<tr><td>Salt flats</td></tr>
<tr><td>Grass / Forb</td><td rowspan="3">Low Prairie</td></tr>
<tr><td>Grasses</td></tr>
<tr><td>Prairie</td></tr>
<tr><td>Pasture</td><td rowspan="5">Upland</td></tr>
<tr><td rowspan="4">Upland</td><td>Hayed</td><td>Hayed grass / forb</td></tr>
<tr><td>Cultivated</td><td>Cultivated</td></tr>
<tr><td rowspan="2">Trees</td><td>Scrub</td></tr>
<tr><td>Trees</td></tr>
</table>

Table 6.3a: Vegetation classification key used in this study, showing spectral signatures of each vegetation class under four band combinations. (Assessments of extent are based on qualitative observation to be more fully examined.)

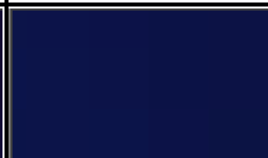
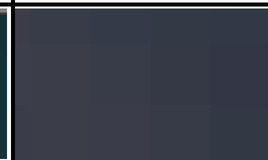
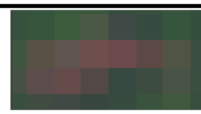
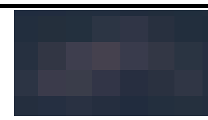
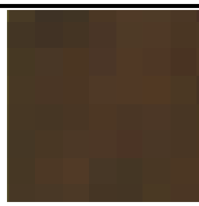
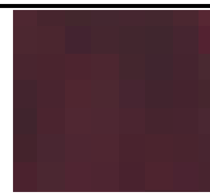
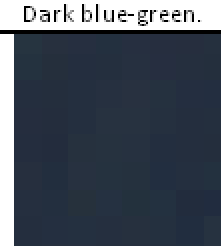
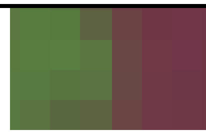
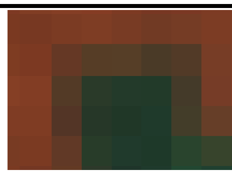
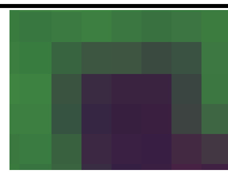
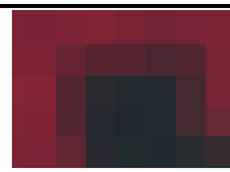
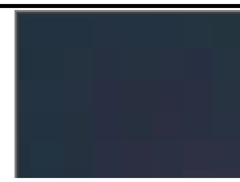
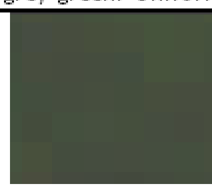
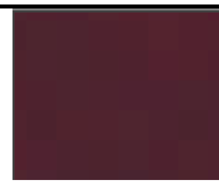
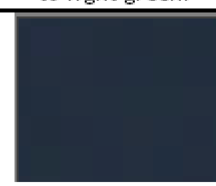
| Veg Type | Veg + Moisture | Green Veg | False Colour IR | True Colour |
|---|---|---|---|---|
| Water |  Dark blue (turbid water) to black. |  Royal (turbid water) to dark blue. |  Aqua. |  Mauve to light grey. |
| Not Vegetated |  Mint green. Extent is over-estimated. |  Light pink. Extent is slightly over-estimated. |  Pale grey-blue. |  Mauve. Slighly paler than water. |
| Bulrush |  Similar to water, but with a hint more orange / black. |  Similar to water, but with slightly warmer / green tones. |  Dark aqua. |  Dark blue-green. |
| Cattail |  Medium brown to grey-brown to red-brown. Warmer tones than trees. |  Medium green to purple-green. Colder tones than trees. |  Dark pink. |  Dark hazy green with some dark blue pixels. |
| Bulrush / Carex, Phrag |  Light yellow-green. |  Pale emerald green to pale pink-orange. |  Brighter pink. |  Dark green. |

Table 6.3b: Vegetation classification key used in this study, showing spectral signatures of each vegetation class under four band combinations. (Assessments of extent are based on qualitative observation to be more fully examined.)

| Veg Type | Veg + Moisture | Green Veg | False Colour IR | True Colour |
|---|---|---|---|---|
| Wet Meadow |  Pale yellow to pale orange, or emerald. Similar to BCP but warmer tones. |  Pale emerald green. |  Colder pink. |  Dark green. |
| Hayed |  Medium orange or emerald green. |  Emerald green or bright pink. |  Pink-red or grey-aqua. |  Dark green or light grey-purple. |
| Cultivated |  Bright orange or dark green or red. Uniform. |  Electric green or purple or grey-green. Uniform. |  Red or dark green or lilac. |  Dark green to dark purple to light purple to light green. |
| Trees |  Medium brown. Similar to cattail but more olive. |  Medium green. Similar to cattail but with warmer tones. |  Dark red. |  Dark green. |

## 6.3 Wetland Extent

The extent to which Netley-Libau was mapped was defined by the extent of the 2001 vegetation map (Grosshans et al 2004), with the exception that Lake Winnipeg was excluded. The remaining extent comprised a total of 34,797 ha, which included some 1-3km of the inland region surrounding the marsh proper.

Grosshans et al (2004) did not include Lake Winnipeg in their tally of the *open water* marsh zone. However, the digital map data accompanying the report did include Lake Winnipeg, with no obvious line indicating the boundary used to crop that water body from the Netley-Libau Marsh. Ideally, the delineation of coastal wetland should extend outward in the lake to include shallow water capable of supporting submersed aquatic vegetation (Ingram et al 2004). In Lake Winnipeg's south basin, shallow depths, easily resuspended bottom sediments, and a long fetch, contribute to a highly turbid environment (McCullough and Lévesque 2011), particularly near the mouth of the Red River, its most sediment-laden tributary (McCullough 2001; Brunskill 1980). The euphotic depth (the depth to which at least 1% of the photosynthetically-active radiation incident at the water's surface penetrates through the water column, Wetzel 2001), averaged across the south basin of Lake Winnipeg, has been reported to be around 0.8 m (McCullough and Lévesque 2011). The best available bathymetric model for Lake Winnipeg (Yarubandi 2014), based on a spatial grid of 650m and no points with depths below 2m, is not of sufficient resolution to delineate the euphotic zone where submersed aquatic vegetation could grow. In cases where bathymetric data are unavailable, Watchorn et al (2012) recommended setting the lakeward boundary of a coastal wetland at the shoreline visible on digital imagery. However, since Lake Winnipeg is affected by "wind setup" or seiche events which can influence water levels by up to 1.2m (Baird and Stantec 2000), the position of the shoreline visible on satellite imagery obtained on different dates may vary considerably. Thus, the maps produced for this report include a buffer extending into Lake Winnipeg enough to account for the effect of a seiche. The boundary of Netley-Libau marsh was set at 150m beyond the shoreline visible on the August 2, 2001 Landsat imagery, based on the approximate distance from the south shore to an average depth of 1.2m (Watchorn personal observations; Environment Canada unpublished data), allowing for one pixel (30m) of error on either side. To ensure both 2001 maps covered the same extent, the Grosshans map was also cropped to this 150m buffer, and the area of the open water marsh zone was recalculated. Therefore, the values reported as totals of the open water as mapped from aerial photography differ from those published in Appendix 3 of Grosshans et al (2004).

The inland boundary of Netley-Libau Marsh should ideally be defined through a combination of historic high water level data (as per the Water Survey of Canada) and digital topographic data, as recommended by Ingram et al (2004). Topographic data for the Netley-Libau region are available through two sources. LiDAR sensing conducted between 1999 and 2002 was used to create a digital elevation models for much of the Red River valley, with 15cm vertical accuracy on a 5m grid (Aeroscan International et al 2003). Bathymetry for Netley-Libau's open water bays was obtained in 2010 (Aquatics Environmental 2013), but does not extend inland into wet meadow zones. Neither source of topographic data covers the entire extent of the Netley-Libau region. Watchorn et al (2012) set the inland boundary of large freshwater coastal wetlands (which can extend far inland without obvious discontinuity) at a distance of 10km from the closest point of contact to open water, based on the estimated distance that water arising from seiche activity on Lake Manitoba travels inland within its large coastal marshes (Bortoluzzi 2007, personal communication). A 10km buffer would be advisable for maps generated to assess wetland vegetation change between years. However, for the purposes of this report, assessing difference between digital vegetation maps created based on different types of imagery, vegetation features were not cropped to a 10km buffer. Instead, the produced map coverage was clipped to the extent of the Grosshans et al (2004) map. In this way, no vegetation comparison information was discarded. This was especially crucial as it would have been impossible to train the classification of the few upland areas located well within Netley-Libau Marsh without data from the upland areas surrounding the periphery.

### 6.4 Quality Assurance / Quality Control (QAQC)

The completed vegetation feature map was quality control checked for classification errors, gaps, slivers, overlaps and multipart features. The quality control extension used for QAQC of the Grosshans vegetation feature map (Heald 1999) was not scripted in a language facilitating forward compatibility to more recent ArcGIS software, so a similar quality assurance / quality control system was designed as follows.

Simple queries were used to determine that no polygons were left unclassified in the fields for marsh zone and vegetation class, and that no polygons were assigned mismatching zone–class pairings (for example, upland–cattail or water–trees). A subset of 2.5% of polygons was randomly selected for re-inspection to check against classification errors.

Gaps – small spaces between polygons sharing a boundary – were identified and eliminated by creating a duplicate layer of the vegetation coverage with all features merged into a single polygon. When this new layer was compared against the final vegetation feature map, each gap was viewed individually, and new features were created and classified to fill the voids. Slivers – very narrow polygons between two vegetation features, usually created as an artefact of trimming nearby features – were identified and eliminated by examining any polygon with an area below 0.1 ha or an area to perimeter ratio below 15. Each sliver polygon was merged with its appropriate neighbour.

Overlapping polygons – found where the same area of the map was covered by more than one polygon – were identified using the ArcGIS intersect tool to create a new layer consisting of only overlapping areas. Each polygon of overlap was viewed and the final vegetation feature map was clipped appropriately.

Multipart features – non-adjacent polygons of the same class which were considered as a single feature – were identified using the ArcGIS Count True Parts tool (Tchoukanski 2004). Multipart polygons were generally located near the periphery of the map – those polygons with multiple arms which crossed the boundary of the Grosshans map in more than one place became multipart polygons as an artefact of process of clipping the new vegetation feature layer to Grosshans's extent. These multipart features were separated into individual features using the ArcGIS Explode tool.

# 7.0 Results and Discussion

Vegetation maps produced using Landsat 7 imagery and the aforementioned methods, symbolised by marsh zone and by vegetation class, are presented in Figures 7.1 and 7.2. They are displayed for side-by-side comparison with the Grosshans photography-based maps, which have been resymbolised under the revised classification scheme.

Visual delineation and classification of Landsat-7 imagery was suitable for producing wetland maps which distinguish vegetated from non-vegetated areas with a high degree of accuracy. The Landsat-based map coverage of Netley-Libau Marsh in 2001 differed by only +2.1% of total vegetated area from the Grosshans photography-based map (Table x). This mapping method also produced highly comparable total areas for most marsh zones, including *emergent wetland vegetation* (+5.2%), *wet meadow* (-1.3%), and *upland* (1.4%).

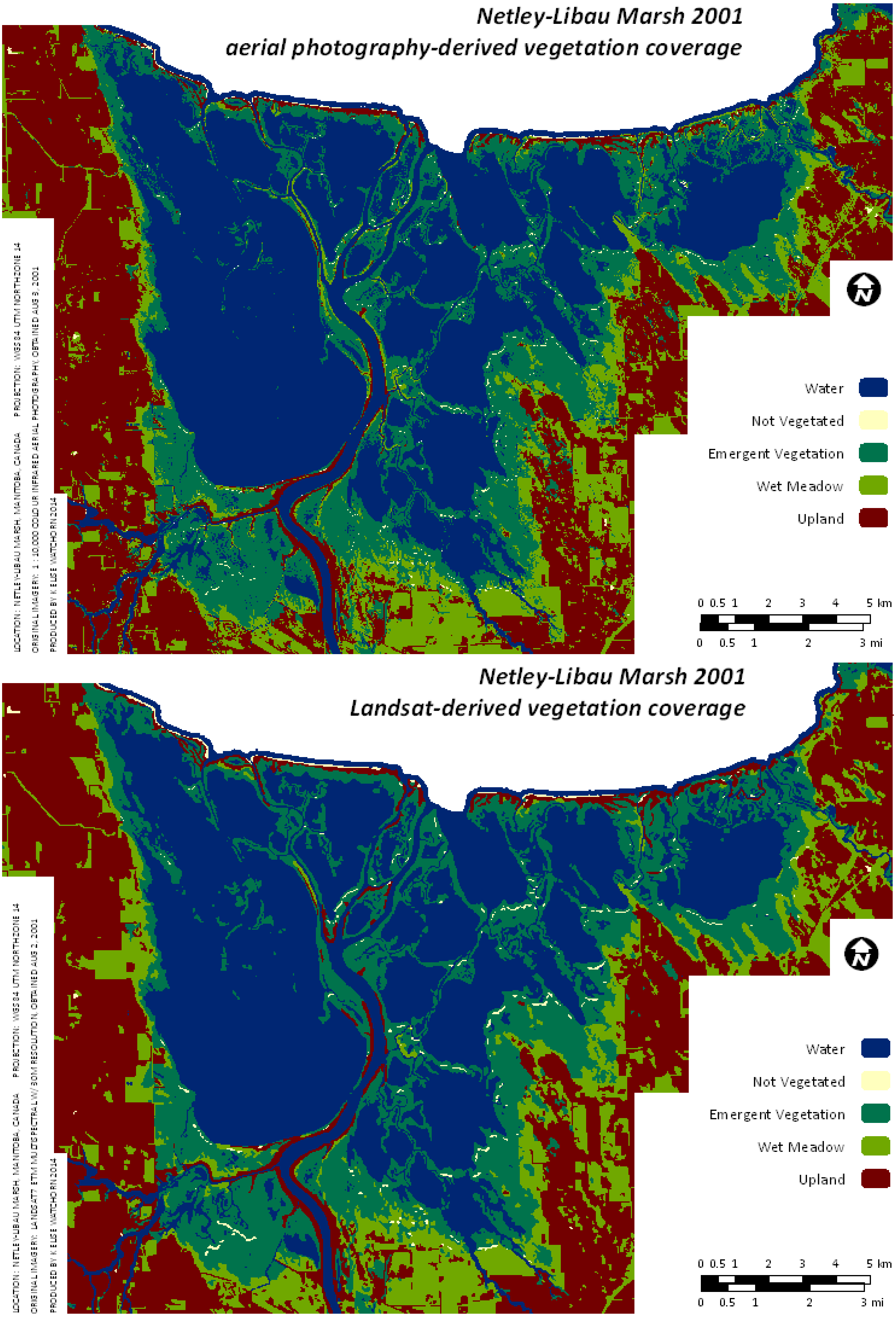



Figure 7.1: Comparative classified vegetation maps organised by marsh zone, created based on colour infrared aerial photographs at 1:10000 scale (above, modified from Grosshans *et al* 2004) and Landsat 7 imagery with a spatial resolution of 30m (below).

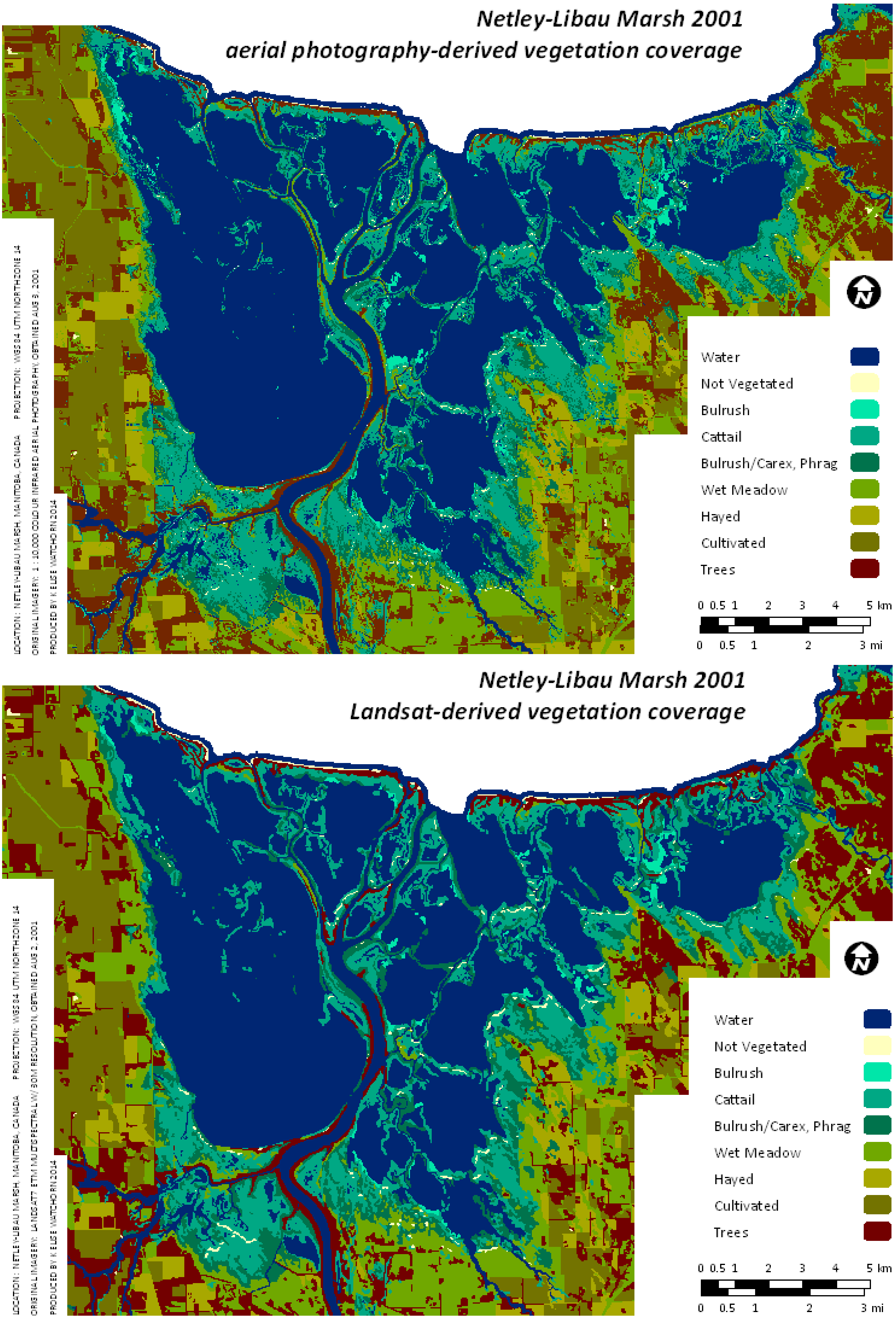



Figure 7.2: Comparative classified vegetation maps organised by vegetation class, created based on colour infrared aerial photographs at 1:10000 scale (above, modified from Grosshans *et al* 2004) and Landsat 7 imagery with a spatial resolution of 30m (below).

Table 7.1: Netley-Libau plant communities in 2001, as mapped based upon aerial photography (modified from Grosshans et al 2004 to fit a new classification scheme) and based upon Landsat 7. Total area (ha) and percent cover (as a percentage of the entire mapped area, and as a percentage of the vegetated area only) are presented for each marsh zone and vegetation class.

| Marsh Zone | Aerial Photography | | | Landsat 7 | | | % Change |
|---|---|---|---|---|---|---|---|
| Vegetation Class | Area (ha) | % Cover (entire marsh) | % Cover (vegetated area) | Area (ha) | % Cover (entire marsh) | % Cover (vegetated area) | |
| **Water** | 13587 | 39.0% | 64.5% | 13083 | 37.6% | 60.8% | ( 3.7% ) |
| Open Water | | | | | | | |
| Marsh | | | | 12073 | 34.7% | 56.1% | |
| Red River | | | | 609 | 1.7% | 2.8% | |
| Lake Winnipeg | | | | 401 | 1.2% | 1.9% | |
| **Not Vegetated** | 134 | 0.4% | 0.6% | 190 | 0.5% | 0.9% | 41.1% |
| Beach | 41 | 0.1% | 0.2% | 60 | 0.2% | 0.3% | 48.7% |
| Disturbed | 94 | 0.3% | 0.4% | 129 | 0.4% | 0.6% | 37.6% |
| **Emergent Wetland Veg** | 7343 | 21.1% | 34.8% | 7726 | 22.2% | 35.9% | 5.2% |
| Bulrush | 321 | 0.9% | 1.5% | 199 | 0.6% | 0.9% | ( 37.9% ) |
| Cattail | 4760 | 13.7% | 22.6% | 4912 | 14.1% | 22.8% | 3.2% |
| Bulrush/Carex, Phrag | 2262 | 6.5% | 10.7% | 2614 | 7.5% | 12.1% | 15.6% |
| **Wet Meadow** | 4442 | 12.8% | 21.1% | 4383 | 12.6% | 20.4% | ( 1.3% ) |
| **Upland** | 9290 | 26.7% | 44.1% | 9417 | 27.1% | 43.7% | 1.4% |
| Hayed | 1664 | 4.8% | 7.9% | 1530 | 4.4% | 7.1% | ( 8.0% ) |
| Cultivated | 3327 | 9.6% | 15.8% | 3361 | 9.7% | 15.6% | 1.0% |
| Trees | 4299 | 12.4% | 20.4% | 4525 | 13.0% | 21.0% | 5.3% |
| **Total Marsh Area** | 34797 | 100.0% | | 34797 | 100.0% | | |
| **Total Vegetated Area** | 21076 | | 100.0% | 21525 | | 100.0% | 2.1% |

There was wider error between the 2001 Netley-Libau maps for the marsh zone *not vegetated*, which the Landsat vegetation map over-estimated by 41.1%. Non-vegetated areas had a particularly distinctive spectral signature, which tended to bleed into neighbouring pixels when displayed under most band combinations (Table 6.3a). *Not vegetated* was over-estimated even though its tendency to appear larger had been taken into account during the classification training stage, and polygons had accordingly been delineated more narrowly. It should be noted that the *not vegetated* marsh zone was equivalent to less than 1% of the vegetated zones of Netley-Libau.

The two classes of the *not vegetated* marsh zone – *beach* and *disturbed* (mainly consisting of mudflats) – were each similarly over-estimated in the Landsat map (48.7% and 37.6% respectively). It is plausible that this phenomenon might be partially explained by a slight seiche event on Lake Winnipeg. Indeed, the extent of mapped *open water* decreased between the two dates by ~500 ha, while the *not vegetated* zone increased by ~65 ha. Mean daily water levels on Lake Winnipeg at Gimli (Water Survey of Canada 2014) between August 1$^{st}$ and 4$^{th}$ ranged only ~15cm, which argues against a wind setup having occurred. However, extreme seiches on the lake can be sudden and dissipate quickly (Einarsson and Lowe 1968), and therefore may not be captured by a mean daily value. Additionally, the Gimli hydrometric station is located 30 km to the north, midway up the west shore of Lake Winnipeg, where any seiche effect would be dampened as compared to the south shore, where Netley-Libau sits at the end of the lake's longest fetch.

It is also conceivable that differences in the extent of *not vegetated* zones could be explained by an underestimation of the true size of mudflats when mapping from aerial photography. The boundaries of recently exposed mudflats are not always distinct (Murkin and Caldwell 2000) but rather form a continuum from no shoots of emergent vegetation, through scattered shoots, to a shoot density with a percent cover that would be sufficient to mask the spectral signature of the mud by the Landsat sensors. Even on higher-resolution aerial photography, delineating the edge of a mudflat must inevitably be subjective; Grosshans et al (2004) may have included sparser shoots with *emergent vegetation* rather than with *not vegetated*.

The accuracy estimate for *wet meadow* (1% change in total area between maps) may be misleading because over 20% of this marsh zone was identified by Grosshans et al. (2004) as pasture. Whereas pastures were typically easily identifiable fields of large size (even exceeding 100 ha), the smaller, wetter, patchier areas of wet meadow interspersed throughout Netley-Libau were considerably more difficult to resolve from surrounding emergent vegetation, and especially from the *bulrush/Carex, Phragmites* (*BCP*) vegetation class. The accuracy of classifying *upland* areas would have been similarly over-estimated. Though including these *upland* and *wet meadow* pasture areas as a part of the mapping exercise was essential for training the classification, it is likely that they skewed upward the accuracy estimate. A more realistic expectation for an accuracy estimate of these two marsh zones would have been closer to that of *emergent vegetation*, or ~5%.

The classification accuracy of vegetation classes was highly variable. *Cultivated*, *cattail*, *trees*, and *hayed* vegetation classes were each reasonably accurate (1 – 8% difference; Table 7.1). *BCP* was moderately accurately classified (15.6% difference), being confused with *cattail* or *wet meadow*, whereas *bulrush* was highly inaccurate (37.9% difference). *Bulrush*, when visible on Landsat imagery, was reasonably distinctive from other classes of vegetation. However, it had a very similar spectral signature to (Tables 6.3a and 6.3b), and was frequently misclassified as *water*. Approximately 57% of vegetation that was classified as *bulrush* by Landsat was also classed as *bulrush* by aerial photography, but only ~35% of *bulrush* identified by photography was classified as *bulrush* by Landsat, in part

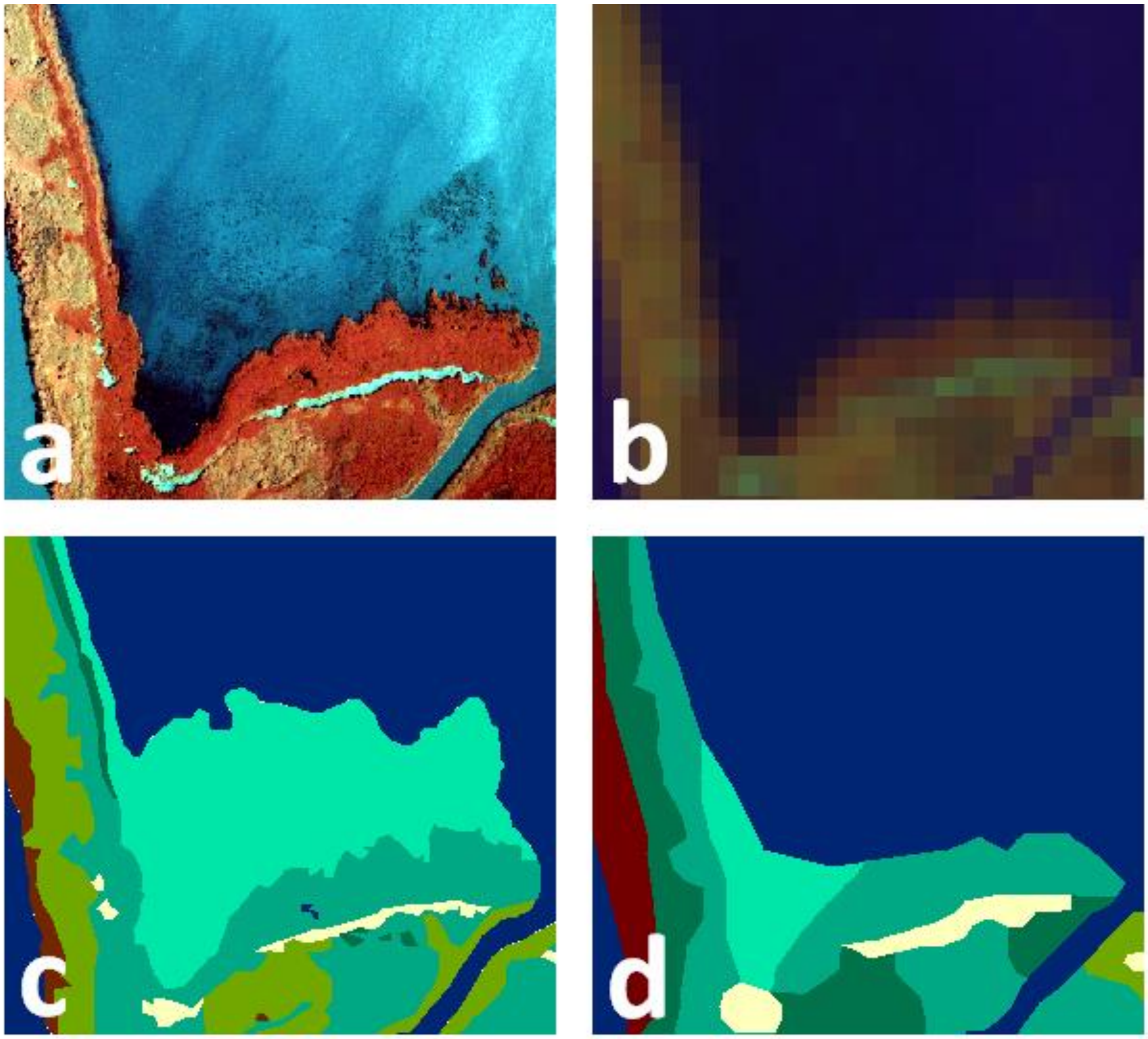




Figure 7.3: A bulrush stand in Netley-Libau Marsh at 1:11100 scale, displayed as a) FCIR aerial photography, 1m resolution, obtained Aug 3, 2001; b) Landsat 7 ETM imagery, 30m resolution, obtained Aug 2, 2001, with RGB band configuration of 4,5,3; c) digital vegetation coverage produced by Grosshans based on aerial photography; d) digital vegetation coverage produced by this study based on Landsat imagery.

because some bulrush stands were very sparse, with water making up the majority percent cover of the stand (Figure 7.3). Complete matrices summarising the area of features in every possible permutation of mismatched marsh zones or vegetation classes are presented in Appendices 1 through 3.

The spatial error between the Landsat and photography based maps was reasonably low, with 13.3% of the total mapped extent assigned different marsh zones. This spatial error can be visualised in Figure 7.4, which contrasts areas where the marsh zones assigned by each analyst match (green), against those areas where the assigned marsh zones mismatch (orange). Smaller orange areas may be accounted for by slight differences where each analyst drew the boundary between neighbouring zones. Some large orange areas warrant further discussion.

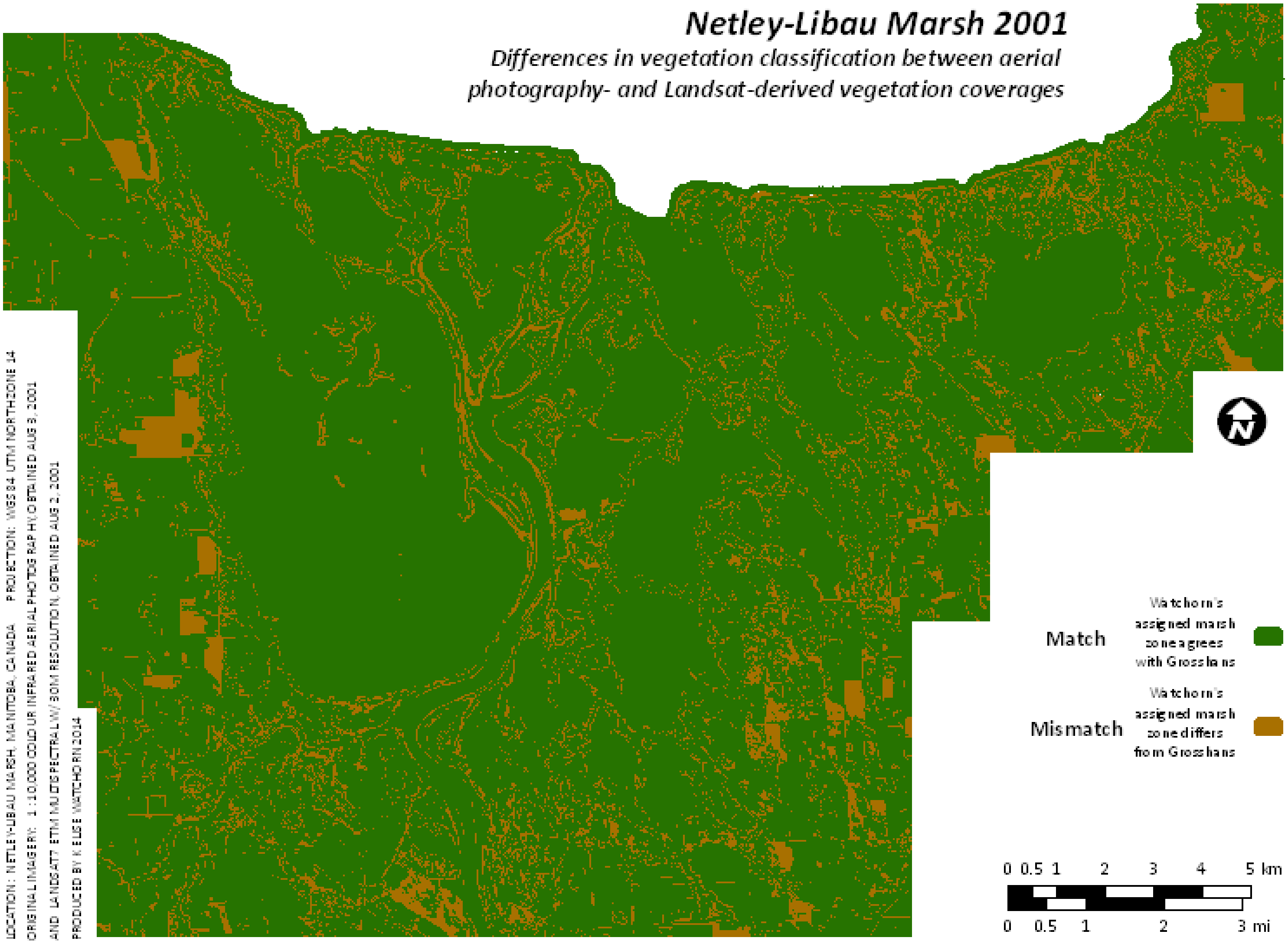



Figure 7.4: An error map displaying areas of Netley-Libau Marsh which were classified differently between a vegetation map created based on 1:10000 colour infrared aerial photography (Grosshans *et al* 2004) and a vegetation map created based on Landsat 7 imagery with a spatial resolution of 30m.

Large rectangular zones of mismatch towards the edge of the map represent mismatch between *upland* and *wet meadow*, specifically mismatch between *hayed* and pasture lands. Though the two classes were usually quite distinct, wetter and/or longer *hayed* land could be confused with drier and/or shorter *wet meadow* pasture. Along the northern periphery of Netley-Libau, the similar spectral signatures of *cattail* and the barrier beach ridge *trees* were confused with each other. Lining the channels at the fork of the three main channels of the Red River, several stands of willow (*wet meadow)* were mistaken for *trees*.

Because of the nearly ninety-fold loss of spatial resolution between the two sources of remotely sensed imagery under review, it was inevitable that the Landsat-based vegetation map would be considerably coarser than the photography-based map. Though differences in the mean area of individual features within a vegetation class were

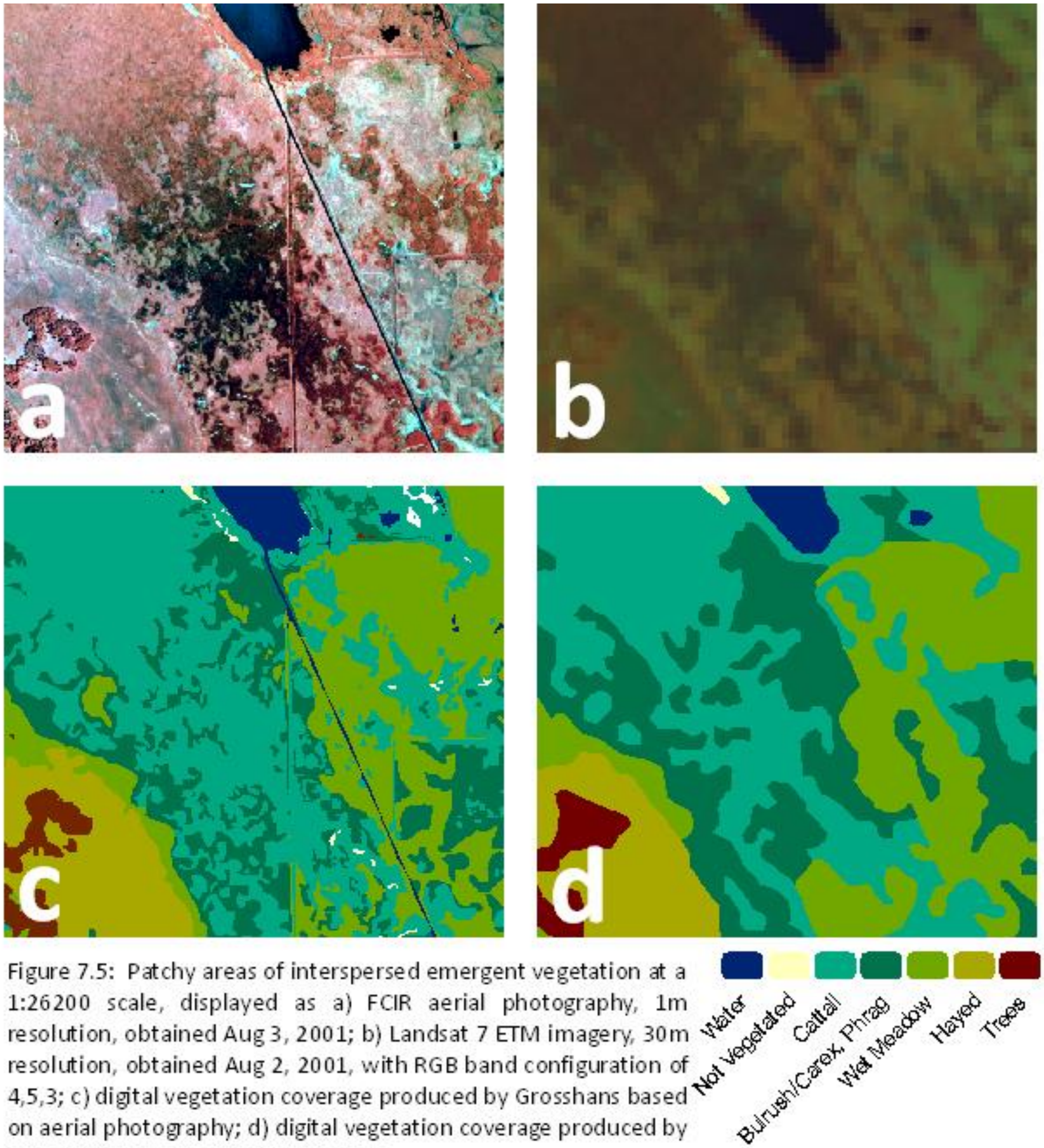



Figure 7.5: Patchy areas of interspersed emergent vegetation at a 1:26200 scale, displayed as a) FCIR aerial photography, 1m resolution, obtained Aug 3, 2001; b) Landsat 7 ETM imagery, 30m resolution, obtained Aug 2, 2001, with RGB band configuration of 4,5,3; c) digital vegetation coverage produced by Grosshans based on aerial photography; d) digital vegetation coverage produced by this study based on Landsat imagery.

not statistically significant due to the large variance (<1 – >5000 ha), it's notable that ~2000 distinct features were identified from Landsat vegetation map, whereas ~13000 could be distinguished from aerial photography. Thus much of the patchiness of highly interspersed vegetation stands in the map created by Grosshans et al (2004) has been lost in the map produced by this study's methods. It was extremely difficult to map well-interspersed vegetation features from Landsat imagery, where edge effects from each stand boundary muddled the spectral signature of neighbouring pixels. However, as Figure 7.5 demonstrates, although considerable detail has been lost, the overall character of the wetland landscape has been captured, and the approximate extent of vegetation classes was reasonably consistent between maps.

Edge effects seen in well interspersed areas also explain the marsh zone mismatch and possible over-estimation of small islands of emergent vegetation (particularly in Netley-Lake west of the Red River, Figure 7.6). It may be possible to determine, based on pixel colours that are intermediate between the spectral signatures of two classes (in this case, *emergent* and *cattail)* that the two were interspersed, but the resolution of the Landsat imagery is not sufficiently fine to determine precisely where their boundaries lie. As a result, the extents of such small islands were over-estimated, and finer details, such as small channels of water, were lost. Other locations which suffered from the loss of spatial resolution were some of the narrow banks lining Netley-Libau Marsh's many channels (Figure 7.7), where aerial photography allowed more thin bands of vegetation to be distinguished than there were visible pixels on the Landsat imagery.

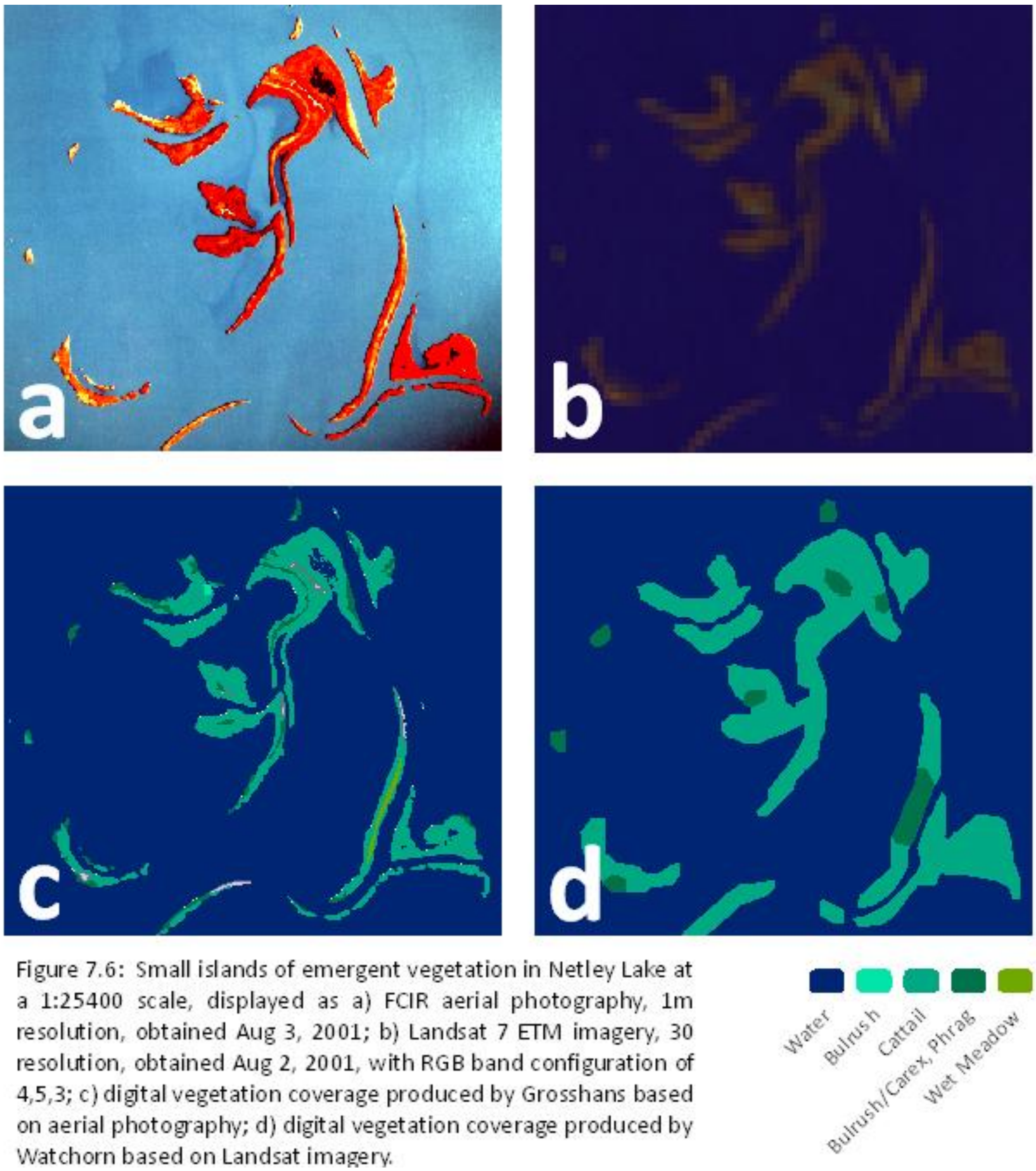



Figure 7.6: Small islands of emergent vegetation in Netley Lake at a 1:25400 scale, displayed as a) FCIR aerial photography, 1m resolution, obtained Aug 3, 2001; b) Landsat 7 ETM imagery, 30 resolution, obtained Aug 2, 2001, with RGB band configuration of 4,5,3; c) digital vegetation coverage produced by Grosshans based on aerial photography; d) digital vegetation coverage produced by Watchorn based on Landsat imagery.

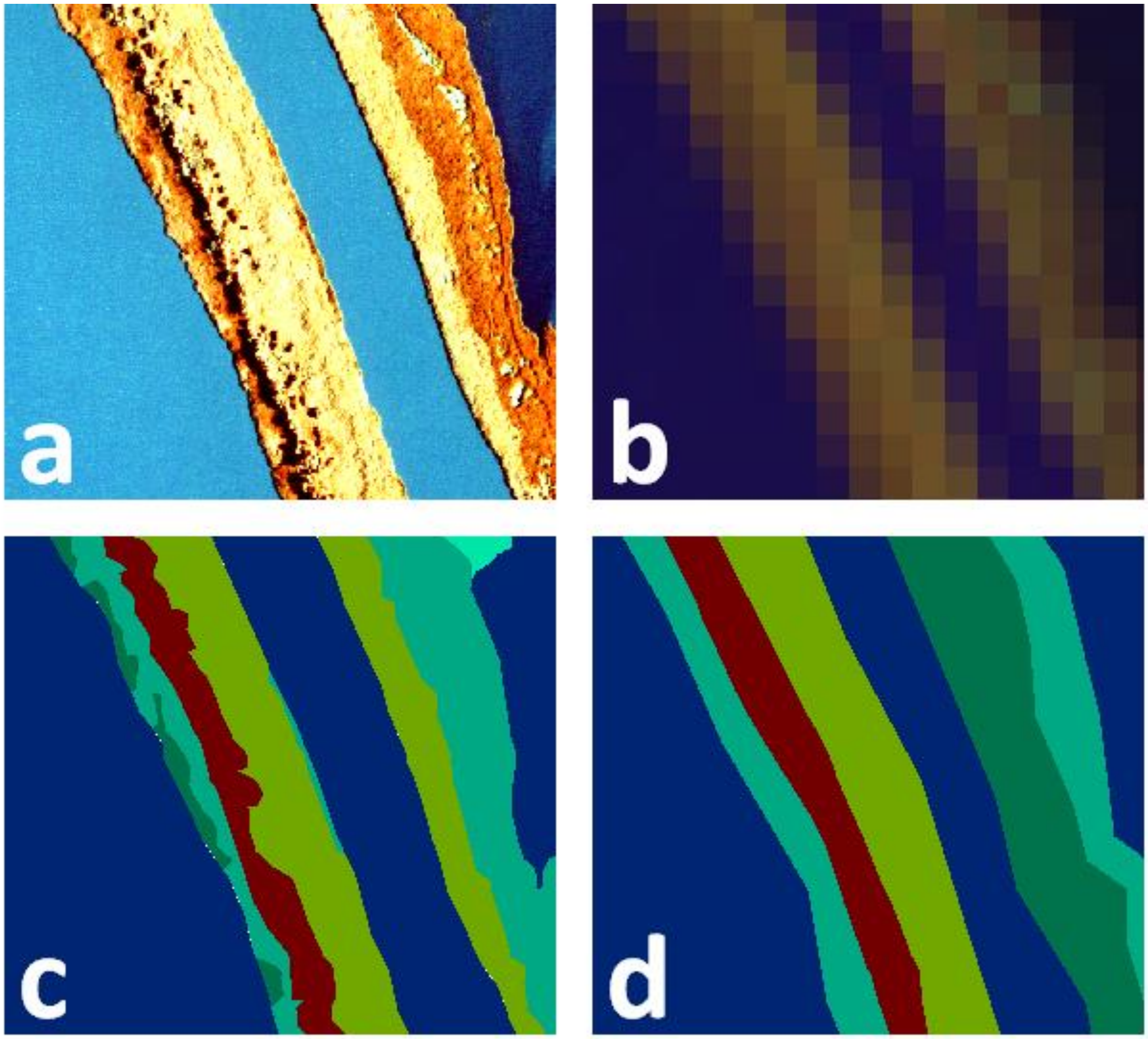



Figure 7.7: Narrow bands of vegetation lining the channels of Netley-Libau Marsh at a 1:6800 scale, displayed as a) FCIR aerial photography, 1m resolution, obtained Aug 3, 2001; b) Landsat 7 ETM imagery, 30 resolution, obtained Aug 2, 2001, with RGB band configuration of 4,5,3; c) digital vegetation coverage produced by Grosshans based on aerial photography; d) digital vegetation coverage produced by Watchorn based on Landsat imagery.

# 8.0 RECOMMENDATIONS FOR FUTURE WORK

## 8.1 LANDSAT FOR BROAD-SCALE VEGETATION MAPPING

Visual delineation and classification of Landsat imagery is a suitable method for large-scale wetland vegetation mapping. A time series of annual vegetation cover maps derived from Landsat images captured though the period 1990 – 2013 would be a valuable tool for an investigation into the response of wetland plants to hydrological conditions on the lake when combined with archived hydrometric data. Landsat-based maps give good agreement with those produced from higher resolution imagery, both in the areal extents of marsh zones and in their spatial distribution. However, the degree of confidence in the accuracy of such maps is lower at a finer level of classification: while marsh zones can be confidently described, parameters relating to vegetation classes should be reported more cautiously.

## 8.2 UNDERSTANDING THE LIMITATIONS AND STRENGTHS OF LANDSAT-BASED MAPPING

The decision regarding further use of Landsat imagery to track wetland vegetation change through time must be made after careful consideration of its limitations. Landsat's lower resolution results in a poor ability to portray the patchy or finely banded nature of some of Netley-Libau's emergent vegetation stands. Small islands and channels, where vegetation cover changes in response to hydrological variable may be most pronounced, can cause delineation challenges. Highly interspersed vegetation can confuse the spectral signatures of vegetation classes, potentially leading to misclassification between *wet meadow* and mixed bulrush/*Carex, Phragmites* stands.

The inability to tease out all emergent vegetation species from the larger vegetation classes which were achieved by this study will limit the availability of future work to examine species differences in recruitment or nutrient uptake under different hydrological conditions. The inconsistency with which bulrush could be identified is especially relevant, given that bulrush can be a major species to recruit to mudflats during low water periods in Manitoba wetlands (Goldsborough 2003, personal communication; van der Valk 2000).

Another drawback to Landsat based maps is the inability to distinguish the phragmites species guild from mixed stands of bulrush and sedges. The ability to track changes in phragmites cover would be particularly valuable in light of the impending threat posed the invasive subspecies *Phragmites australis australis.* The plant's first Manitoba sighting was in 2010 (Invasive Species Council of Manitoba 2014), and though it has not yet been reported in Netley-Libau Marsh, it would be interesting to know the distribution of phragmites before and after potential colonisation.

Despite these limitations, there is still beneficial information to be gained though Landsat vegetation mapping. Indeed, Landsat maps classified only to marsh zone would provide more information than the older black-and-white aerial photography with which they might be compared. Using these historic photographs, it may only be possible to distinguish open water from emergent vegetation – a distinction which is a major strength of Landsat-derived maps.

## 8.3 RECOMMENDATIONS FOR FUTURE METHOD DEVELOPMENT

If visual delineation and classification of Landsat imagery is to be used to create a vegetation map time series, it is strongly recommended that all mapping be completed by the same analyst. Slight differences in the interpretation of pixel hue can result in marsh zone classification differences as drastic as *emergent* to *upland.* While the production of this study's map included a truthing step, maps for other years will not have this advantage. Therefore it will be important that artefacts are not incorporated into subsequent maps through introducing new sets of eyes with varying abilities to perceive subtle colour differences.

Maps for other years should be created using the existing 2001 geodatabase as a template, and modifying shared boundaries between polygons as appropriate. Not only will modifying the existing coverage be less time-consuming that mapping from scratch, but this method reduces the possibility of introducing misclassification artefacts between years. Similarly, it is recommended that imagery for all years since 2001 be mapped in chronological order, and all years before 2001 be mapped in reverse chronological order, to prevent misdelineation artefacts. To this end, the complete subset of years of interest should be defined before mapping continues.

Cloud-free Landsat imagery that coincides with the period of peak wetland plant development (August to early September) for the years 1990 – 2013 includes images captured by Landsat 5, Landsat 7, and Landsat 8. Although the bands of most value for wetland plant mapping are measured by sensors on all three satellites, there is slight variation in the precise wavelength range in each band between the satellites' sensors' generations. A modified vegetation key or similar classification training methodology must necessarily be developed to translate between the sensors of the three Landsats. It is convenient that the first vegetation map produced used Landsat 7, whose sensor's wavelength ranges were intermediate those aboard the older and newer platforms.

Finally, it may still be worth investigating further into development of an automated or semi-automated classification method through an object-based image analysis. The larger monetary investment for software such as Definiens eCognition or Overwater Feature Analyst could return a lower required investment of time to produce a modified vegetation map for every year of interest. Additionally, a strictly defined object-based process would increase the reproducibility of classified vegetation maps. Wetland classification using either of these software suites with Landsat imagery is an emerging field, as Landsat object based image analysis has mainly been used at broader scales.

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# *APPENDICES*

## APPENDIX I

Table A-I: Matrix presenting mismatched assigned marsh zones between the Landsat-based vegetation map of Netley-Libau Marsh, 2001, created as part of this study, and the photography-based vegetation map by Grosshans et al (2004). Values represent total area of each marsh zone permutation in hectares. Matching marsh zones have been highlighted in green. *Accuracy A* refers to the percent of the mapped area in which a marsh zone identified by Grosshans et al was assigned the matching marsh zone by this study. The most common mismatching zone (or zones) which contributed to reduce *Accuracy A* is listed as *Mismatch A*, with *% Mismatch A* describing the frequency of that most common mismatch. *Accuracy B* refers to the percent of the mapped area in which a marsh zone identified by this study was assigned the matching marsh zone by Grosshans et al. The most common mismatching zone which contributed to reduce *Accuracy B* is listed as *Mismatch B*, with *% Mismatch B* describing the frequency of that most common mismatch.

| | | Marsh Zone (assigned by Grosshans) | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | **Not Vegetated** | **Water** | **Emergent** | **Wet Meadow** | **Upland** | **Accuracy B** | **Mismatch B** | **% Mismatch B** |
| **Marsh Zone (assigned by this study)** | **Not Vegetated** | 83 | 20 | 66 | 9 | 13 | 43.6% | Emergent | 34.6% |
| | **Water** | 3 | 12714 | 324 | 26 | 15 | 97.2% | Emergent | 2.5% |
| | **Emergent** | 33 | 747 | 6424 | 420 | 100 | 83.2% | Water | 9.7% |
| | **Wet Meadow** | 5 | 27 | 355 | 3164 | 832 | 72.2% | Upland | 19.0% |
| | **Upland** | 11 | 79 | 174 | 822 | 8330 | 88.5% | Wet Meadow | 8.7% |
| | **Accuracy A** | 61.5% | 93.6% | 87.5% | 71.2% | 89.7% | | | |
| | **Mismatch A** | Emergent | Emergent | Wet Meadow, Water | Emergent | Wet Meadow | | | |
| | **% Mismatch A** | 24.8% | 5.5% | 4.8%<br>4.4% | 9.5% | 9.0% | | | |

## Appendix II

Table A-II: Matrix presenting mismatched assigned vegetation classes between the Landsat-based vegetation map of Netley-Libau Marsh, 2001, created as part of this study, and the photography-based vegetation map by Grosshans et al (2004). Values represent total area of each vegetation class permutation in hectares. A dash indicates the mismatch pairing was never observed, whereas a zero indicates the rounding of totals below 0.5 ha. Matching vegetation classes have been highlighted in green. *Accuracy A* refers to the percent of the mapped area in which a vegetation class identified by Grosshans et al was assigned the matching vegetation class by this study. The most common mismatching class (or classes) which contributed to reduce *Accuracy A* is listed as *Mismatch A*, with *% Mismatch A* describing the frequency of that most common mismatch. *Accuracy B* refers to the percent of the mapped area in which a vegetation class identified by this study was assigned the matching vegetation by Grosshans et al. The most common mismatching class (or classes) which contributed to reduce *Accuracy B* is listed as *Mismatch B*, with *% Mismatch B* describing the frequency of that most common mismatch.

| Vegetation Class (assigned by this study) \ Vegetation Class (assigned by Grosshans) | Beach | Disturbed | Water | Bulrush | Cattail | BCP | Wet Meadow | Hayed | Cultivated | Trees | Accuracy B | Mismatch B | % Mismatch B | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Beach** | 27 | 1 | 18 | - | 1 | 1 | 1 | - | 1 | 10 | 45.2% | Water | 30.3% | |
| **Disturbed** | - | 54 | 1 | 0 | 55 | 9 | 8 | 0 | 0 | 2 | 42.0% | Cattail | 42.7% | |
| **Water** | 2 | 1 | 12714 | 116 | 153 | 56 | 26 | 1 | 0 | 14 | 97.2% | Cattail, Bulrush | 1.2% | 0.9% |
| **Bulrush** | - | 0 | 45 | 113 | 12 | 29 | 0 | - | - | - | 56.5% | Water | 22.5% | |
| **Cattail** | 4 | 17 | 546 | 71 | 3652 | 441 | 128 | 2 | 1 | 50 | 74.4% | Water, BCP | 11.1% | 9.0% |
| **BCP** | 0 | 12 | 156 | 20 | 614 | 1472 | 292 | 7 | 2 | 39 | 56.3% | Cattail | 23.5% | |
| **Wet Meadow** | 1 | 3 | 27 | 0 | 140 | 215 | 3164 | 455 | 35 | 342 | 72.2% | Hayed, Treed | 10.4% | 7.8% |
| **Hayed** | - | 2 | 2 | - | 9 | 9 | 312 | 1036 | 110 | 51 | 67.7% | Wet Meadow | 20.4% | |
| **Cultivated** | 0 | 0 | 1 | - | 8 | 1 | 122 | 93 | 3092 | 43 | 92.0% | Wet Meadow | 3.6% | |
| **Trees** | 5 | 3 | 77 | 2 | 115 | 30 | 389 | 70 | 87 | 3748 | 82.8% | Wet Meadow | 8.6% | |
| **Accuracy A** | 67.2% | 57.8% | 93.6% | 35.1% | 76.7% | 65.1% | 71.2% | 62.3% | 92.9% | 87.2% | | | | |
| **Mismatch A** | Trees, Cattail | Cattail, BCP | Cattail | Water | BCP | Cattail, Wet Meadow | Trees, Hayed, BCP | Wet Meadow | Hayed, Trees | Wet Meadow | | | | |
| **% Mismatch A** | 12.9%<br>10.1% | 17.9%<br>13.0% | 4.0% | 36.0% | 12.9% | 19.5%<br>9.5% | 8.7%<br>7.0%<br>6.6% | 27.4% | 3.3%<br>2.6% | 8.0% | | | | |

Table A-III: Matrix presenting mismatched between the vegetation classes assigned by the Landsat-based vegetation map of Netley-Libau Marsh, 2001, of this study, and the original vegetation type assigned by the photography-based vegetation map of Grosshans et al (2004). Values represent total area of each vegetation permutation in hectares. A dash indicates the mismatch pairing was never observed, whereas a zero indicates the rounding of totals below 0.5 ha. Matching vegetation types have been highlighted in green. *Accuracy A* refers to the percent of the mapped area in which a vegetation type identified by Grosshans et al was assigned the matching vegetation class by this study. The most common mismatching class (or classes) which contributed to reduce *Accuracy A* is listed as *Mismatch A*, with *% Mismatch A* describing the frequency of that most common mismatch. *Accuracy B*, the percent of the mapped area in which a vegetation class identified by this study was assigned a matching vegetation type by Grosshans et al, has been reported in Table A-II. The most common mismatching vegetation type (or types) which contributed to reduce *Accuracy B* is listed as *Mismatch B*, with *% Mismatch B* describing the frequency of that most common mismatch.

**Vegetation Type (as originally assigned by Grosshans)**

| Vegetation Class (assigned by this study) | Sand | Mudflat | Disturbed | Water | Bulrush | Cattail | Bul / Carex | Phrag | Acorus | Sonchus | Carex | Unknown | Salt Flats | Whitetop | Willow | Phrag / Willow | Phalaris | Grass / Forb | Grasses | Prairie | Pasture | Hayed | Cultivated | Trees | Scrub | Mismatch B | % Mismatch B | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Beach** | 27 | - | 1 | 18 | - | 1 | - | 1 | - | - | - | - | - | - | 0 | - | - | 1 | - | - | - | - | 1 | 10 | - | Water, Trees | 151% | 86% |
| **Disturbed** | - | - | 54 | 1 | 0 | 55 | 3 | 6 | - | 0 | 0 | - | - | - | 2 | 2 | 1 | 3 | - | 0 | 0 | 0 | 0 | 1 | 0 | Cat | 564% | |
| **Water** | 1 | 1 | 1 | 12714 | 116 | 153 | 18 | 23 | - | 15 | 1 | - | - | 0 | 8 | 13 | 0 | 5 | 0 | 0 | 0 | 1 | 0 | 14 | - | Cat, Bul | 272% | 119% |
| **Bulrush** | - | - | 0 | 45 | 113 | 12 | 8 | 1 | - | 20 | - | - | - | - | - | 0 | - | - | - | - | - | - | - | - | - | Water | 221% | |
| **Cattail** | 0 | 4 | 17 | 546 | 71 | 3652 | 233 | 129 | 0 | 78 | 6 | - | - | 1 | 48 | 35 | 12 | 17 | 0 | 0 | 8 | 2 | 1 | 49 | 0 | Water, BCP | 210% | 90% |
| **BCP** | 0 | 0 | 12 | 156 | 20 | 614 | 1066 | 341 | 1 | 65 | 7 | - | - | 3 | 105 | 78 | 47 | 46 | - | 0 | 6 | 7 | 2 | 39 | - | Cat | 152% | |
| **Wet Meadow** | 1 | - | 3 | 27 | 0 | 140 | 193 | 21 | - | 1 | 163 | 0 | - | 17 | 353 | 29 | 486 | 1160 | 45 | 164 | 747 | 455 | 35 | 319 | 23 | Hayed | 11% | |
| **Hayed** | - | - | 2 | 2 | - | 9 | 9 | - | - | - | 21 | - | 1 | 0 | 14 | - | 13 | 137 | 4 | 9 | 114 | 1036 | 110 | 50 | 1 | Past, Cult | 8% | 7% |
| **Cultivated** | 0 | - | 0 | 1 | - | 8 | 1 | - | - | - | 12 | - | 1 | - | 2 | 0 | 6 | 59 | 2 | 4 | 37 | 93 | 3092 | 42 | 1 | Hayed | 3% | |
| **Trees** | 5 | 0 | 3 | 77 | 2 | 115 | 16 | 14 | - | - | 14 | - | - | 0 | 45 | 59 | 18 | 166 | 6 | 43 | 37 | 70 | 87 | 3740 | 8 | G/F, Cat | 4% | 3% |
| **Accuracy A** | 78% | 0% | 58% | 94% | 35% | 77% | 69% | 64% | 58% | 36% | 73% | 100% | 0% | 81% | 61% | 13% | 83% | 73% | 78% | 74% | 79% | 6% | 3% | 88% | 23% | | | |
| **Mismatch A** | Trees | Cat | Cat, BCP | Cat | Water, Cat | BCP | Cat, Wet Mdw | Cat | Cat | BCP | Hayed | | Hayed, Cult | BCP | BCP | Cat, Wet Mdw | BCP | Trees, Hayed | Trees | Trees | Wet Mdw | Wet Mdw | Hayed | Wet Mdw | Wet Mdw | | | |
| **% Mismatch A** | 15% | 74% | 18%<br>13% | 4% | 36%<br>22% | 13% | 15%<br>12% | 24% | 42% | 36% | 9% | | 65%<br>35% | 13% | 18% | 16%<br>13% | 8% | 10%<br>9% | 11% | 26% | 79% | 27% | 3% | 7% | 71% | | | |