REMOTE SENSING OF INVASIVE SPECIES, PHRAGMITES AUSTRALIS ON GEORGIAN BAY ISLANDS NATIONAL PARK SHORELINES

By

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DECLARATION

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ABSTRACT

Georgian Bay Islands National Park (GBINP) is located in the Canadian Province of Ontario. The study focused on Beausoleil Island, located in the Georgian Bay portion of Lake Huron. The goal was to use image processing techniques on remotely sensed imagery to determine areas of Phragmites australis invasion along the shoreline of the island, enabling the park to possibly take remedial action and engage in management planning. There is a native species of Phragmites that occurs naturally in North America, often referred to as the common species Phragmites. The invasive species Phragmites australis is native to Eurasia (herein referred to as Phragmites). It is a concern for the park, because it reduces wetland ecosystem biodiversity. Pansharpened Quickbird imagery from 2003 and orthophotos from 2009 were combined with additional information layers including Normalized Difference Vegetation Index (NDVI), texture measures (mean) and Digital Elevation Model (DEM) data to create a maximum likelihood supervised classification of Phragmites invasion. The best classification results were achieved using a combination of the Red, Green, Blue and Near Infra-Red image bands, plus NDVI, and mean texture measures with accuracies of 86% and 88% respectively. The results showed that an area of approximately 0.303 square kilometres (2.68% of Beausoleil Island) is covered with Phragmites. The image processing was conducted using PCI Geomatica and ESRI ArcGIS software.

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I dedicate this Major Research Paper to my aunt Nalini Mhatre, who unfortunately is not with us anymore. She always believed in my abilities and encouraged me when others did not. She taught me so many things, the most important being to live life with zest and never aim low but always for the best. I love you Auntie.

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DEM – Digital Elevation Model

ELC – Ecological Land Classification

ESRI – Environmental Systems Research Institute

GBINP – Georgian Bay Islands National Park

GIS – Geographic Information Systems

NDVI – Normalized Difference Vegetation Index

OGDE – Ontario Geospatial Data Exchange

CHAPTER 1: INTRODUCTION

Georgian Bay Islands National Park (GBINP) is located in the world's largest freshwater archipelago (Parks Canada, 2010) within the Canadian Province of Ontario. The invasive species, Phragmites australis is a concern for the park as this wetland grass reduces biodiversity (Liira et. al., 2010) in wetlands and has found its way into the GBINP. "It [Phragmites] is a Eurasian species which originally came here through the holds of ships and has been traced back several decades. It has slowly spread from east to west, found in pockets where it could take root, and is widespread along the 400 highway" (Weatherall, 2009). A native common species of Phragmites exists in North America. However, the invasive species is a problematic wetland grass in many respects. "In particular, invasive plant species have been found to alter wetland decomposition rate and nutrient cycling, lead to reduction in wetland plant diversity, threaten rare and endangered plant and animal species, reduce pollination and seed output of native plants, as well as reduce habitat suitability for several wetland bird species…." (Laba et al., 2008). GBINP is interested in maintaining ecological integrity, as the park is home to endangered and threatened species (Parks Canada, 2011).

1.1 OBJECTIVES

The goal of this project was to use image processing techniques on early fall 2009 orthophotos to determine areas of Phragmites invasion along the shoreline of GBINP. Quickbird imagery from October 10, 2003 was used to create a vegetation change detection analysis to examine growth over time. This was achieved by subtracting the two spectral signatures from the images and determining change over time. The two datasets are then compared to the level of growth or decline of Phragmites. The park will be able to take remedial action and engage in management planning with this new information.

1.2 STUDY AREA

The South-Eastern portion of Georgian Bay contains Georgian Bay Islands, where the bedrock changes from Great Lakes and St. Lawrence Lowlands limestone to Canadian Shield granite bedrock. The study area (Figure 1.1) is Georgian Bay Islands National Park, but more specifically the Beausoleil Island shoreline. GBINP has a variety of land cover, such as forested areas, boat docks, camp areas, and trails. In the summer months, many vacationers frequent the area for camping, hiking, boating and swimming, which brings an influx of people to the area. Beausoleil Island is home to many species of snakes, turtles, birds, fish and a plethora of wildlife (Parks Canada, 2010).

1.3 MAJOR RESEARCH PAPER (MRP) STRUCTURE

This Major Research Paper (MRP) is presented in manuscript format. Chapter 1 contains a brief introduction, objectives and study area of the project, followed by a literature review in Chapter 2. Chapter 3 has been formatted as a standalone manuscript to meet the specifications of the target journal, *Remote Sensing of the Environment*. The manuscript format is organized as introduction, data and methods, results, limitations, discussion and conclusions. Chapter 4 contains specific recommendations and conclusions for Georgian Bay Islands Park. References contain all of the literature cited throughout the MRP.

Figure 1.1: Study Area

CHAPTER 2: LITERATURE REVIEW

2.1 INVASIVE PHRAGMITES BACKGROUND

Phragmites is a fast growing species that reduces native species in wetlands. "[Phragmites] Spreads into new areas through seed dispersal and rhizomes especially in disturbed sites" (Gilbert and Letourneau, 2009). The plant produces 2000 seeds/head (Gilbert and Letourneau, 2009), but Phragmites have a low germination rate because bare moist soil is needed for germination to occur. This invasive species mainly spreads through rhizomes after it is established. "Phragmites grows on soils with a wide range of organic matter, nutrient concentrations and pH. Colonization is facilitated by high levels of nutrients especially nitrogen originating from urban areas and farmlands" (Hudon et al., 2005). Thus the fast growing nature of Phragmites is problematic because of the habitat reduction that it induces for native species.

> "Phragmites marshes offer poor-quality habitats for larval and juvenile fish whose mobility is reduced by the progressive clogging of shallow-water areas following litter and sediment accumulation. Dense colonies produce a large litter biomass that increases sediment accretion and bottom aggradation, leading to the progressive drying out of littoral zones. The proliferation of Phragmites reduces avian diversity by limiting available nesting and feeding habitat for waterfowl. In addition, to reducing potential avian shelter and the structural heterogeneity of riparian habitats, Phragmites also modifies faunal food quality and thus the structure of food webs that may be supported by wetlands. For ducks, geese, and muskrats, Phragmites has a lower nutritive value…" (Hudon et al., 2005).

As GBINP is home to many endangered and threaten species, it is important for the park to maintain ecological integrity for its native species. Boulton and Brooks (2010) determined the effect that Phragmites had on turtle habitat in Long Point, Ontario. They showed that Phragmites destroys turtle nest sites, by reducing sunlight and disturbing eggs, thus reducing the viability of turtle reproduction.

> "Data were collected on 38 spiny soft-shell nests. At the time of oviposition, all experienced constant sun exposure throughout the day. Nevertheless, within a few weeks, Phragmites grew up and almost entirely shaded 5 nests during most of the day…Additionally, the root systems of these plants grew through the 5 nests (in and around the egg mass). Three of the 5 nests were engulfed by advancing Phragmites failed to hatch any eggs." (Boulton and Brooks, 2010).

Therefore, the damaging effects of potential habitat loss for GBINP could also be significant, because of substantial turtle populations in the park and surrounding area.

Additionally, low water levels (Liira et al., 2010) have been cited as a possible reason for reed expansion. "Low water levels in the summer may provide suitable conditions for the down-slope germination and clonal expansion…" (Liira et al., 2010). "Between 1999 and 2008, water levels in Georgian Bay fluctuated at approximately 50 cm below the long-term average, and this has led to major shifts in the wetland plant community, from emergent and floating vegetation to increased meadow vegetation…" (Midwood and Chow-Fraser, 2010). Therefore, changing water levels may encourage Phragmites growth, with dire consequences for native species and biodiversity.

2.2 SATELLITE IMAGERY

International studies using image processing analysis of Phragmites have been conducted all over the world such as, Lake Võrtsjärv, in the Southern part of Estonia (Lirra et al., 2010), and Amudarya River delta, Uzbekistan (Sivanpillai and Latchininsky, 2008). Studies done in the United States include, the Hudson River National Estuarine Research Reserve in New York state (Laba et al., 2008 and 2010), Ragged Rock Creek

Marsh on the western bank of the Connecticut River (Gilmore et al., 2008), Lake Erie, North Maumee Bay, Michigan (Ghioca-Robrecht et al., 2008), and the mid-Atlantic region of Chesapeake and Delaware Bay (Nielsen et al., 2008). Canadian research has focused on the south shore of Montreal, Quebec (Maheu-Giroux and de Bois, 2005), and Walpole Island on the St. Clair River, Ontario (Arzandeh and Wang, 2003). Even though, Georgian Bay has not been analysed using image classification techniques, the techniques are transferable because of wetland similarities but more importantly Phragmites similarities. Not all of these studies were conducted using the same techniques and processes. However, the problems encountered, results, and solutions can be drawn upon to further the research on invasive species identification from images. The techniques and process were adjusted to fit the scope, scale and requirements of this study.

Previous studies were performed to determine areas of Phragmites growth using Landsat images by Sivanpillai and Latchinisky (2008), Nielsen et al. (2008) and Liira et al. (2010), whom determined that "…medium resolution satellite images can successfully be used for the retrospective monitoring of macrophyte vegetation in the littoral zone of large water bodies by applying very simple image classification methodology" (Liira et al., 2010). Other satellites, such as SPOT-5 (Davranche et al., 2010), IKONOS (Laba et al., 2010 and Midwood and Chow-Fraser, 2010) and Quickbird (Ghioca-Robrecht et al., 2008, and Laba et al., 2008), were used to determine locations of Phragmites. LiDAR (Gilmore et al., 2008) has also been used to isolate Phragmites. There is disagreement as to the best image data for this purpose, as Laba et al. (2010), argues that "…Landsat Thematic Mapper TM imagery is not sufficient to discern small areas of invasive species

… and does not enable the identification of an invasive impact until the undesirable species has reached dominance". Davranche et al. (2010) argue for the benefits of SPOT-5 imagery, whereas Ghioca-Robrecht et al. (2008) recognize the benefits of different satellite images.

> "Quickbird imagery has only four spectral bands. Unlike Landsat TM, ETM+ or SPOT imagery, Quickbird does not have a mid-IR band, but only NIR (760 to 900nm). The fact that mid-IR bands and hyperspectral imagery have been demonstrated to provide separablitity between wetland types…constitutes a disadvantage of using Quickbird for wetland mapping. However, QuickBird's fine spatial resolution offers advantages over course resolution hyperspectral satellite imagery, such as Hyperion, in instances where wetlands are configured in strips narrower than image pixel dimensions" (Ghioca-Robrecht et al. 2008).

While Quickbird imagery and air photos are used for the Major Research Paper (MRP), insights gained from other studies will be drawn upon for a better result.

There is agreement that the best time for Phragmites location is "…image of late summer from mid-July till early September" (Liira et al., 2010). Gilmore et al. (2008), "…determined that these species were best differentiated in late August," and that "…Phragmites is best distinguished by its high NIR response late in the growing season…" The Quickbird imagery used for the MRP is from October 10, 2003.

2.3 ORTHOPHOTO IMAGERY

Orthophotos from late August to early September 2009 were analyzed and compared to the Quickbird Imagery. "Aerial photographs are ideal for mapping small ecosystems and fine-scale landscapes features, such as riparian areas …, because they often possess a high level of spatial and radiometric (tonal) detail" (Morgan et al., 2010).

The orthophotos used have near infrared, red, green and blue bands, which is similar to the Quickbird imagery.

> "One important development associated with the recent emphasis on satellite imagery, however, has been the advent of a wide range of digital image analysis techniques. While many of these techniques were originally developed for satellite imagery, they have also expanded upon the range of analysis techniques now available for aerial photographs." (Morgan et al., 2010)

The similarity of the orthophoto and the satellite images enables a comparison between the two results. Orthophotos have also a been used as a source of ground truth in some studies. Maheu-Giroux and Blois (2005), used colour aerial photographs to determine distribution of Phragmites in linear wetland corridors. This study conducts analysis on the orthophotos using image processing techniques.

2.4 NORMALIZED DIFFERENCE VEGETATION INDEX

Many of the studies in the literature review used the Normalized Difference Vegetation Index (NDVI) to illustrate areas of vegetation. NDVI was used with Quickbird data by Ghioca-Robrecht (2008), and Gilmore et al. (2008). "In the Quickbird data, Phragmites uniquely displayed high NDVI and NIR/red values in the growing season…" (Gilmore et al., 2008).

2.5 SLOPE AND PHOSPHORUS

Li and Chen (2005) indicated that areas with less than 8% slope are potential wetlands and can therefore be included in the classification. Phosphorus levels have also been shown to be an indicator in Phragmites growth. "…[H]uman populations are the strongest independent predictor of total phosphorus levels, and significant factor affecting several other water quality variables" (DeCatanzaro et al., 2009). Holdredge et al. (2010) conducted experiments on native and invasive species of Phragmites and found that:

> "…nutrient enrichment in our natural field experiment provides convincing evidence that eutrophication is playing a central role in the aggressive expansion of invasive clonal plants…Consequently, we promote the protection of pristine, low nutrient wetlands that can harbour native biodiversity and aggressive reduction of anthropogenic nutrient sources to these ecosystems" (Holdredge et al., 2010).

Holdredge et al. (2010) also suggest that native species of Phragmites can flourish. "Our findings, however, suggest that native Phragmites can persist within pristine, nutrient-limited marshes even in the presence of invasive stands because it is a strong nutrient competitor" (Holdrege et al., 2010). The data available for Beausoleil Island have some phosphorus records (30 records for Beausoleil Island); however, they are limited in number of samples and coverage over the island. Thus the phosphorus information will be used post classification, as supplementary data in the specific recommendations and conclusion sections, for park management planning.

2.6 TEXTURE

"Texture is the frequency of tonal change on an image" (Lillesand and Kiefer, 2000). There are many texture measures that can be generated in PCI Geomatica, however, the commonly used ones according to the literature are mean, homogeneity, contrast, standard deviation (Arzandeh and Wang, 2003), and variance (Laba et al., 2010). "Comparison of spectral and spectral-textural classification accuracies indicated that the overall accuracy was slightly increased by using texture features" (Arzandeh and Wang, 2003).

2.7 MASK

The literature also indicates "An Area of Interest (AOI) mask was created to exclude non-wetland areas" (Ghioca-Robrecht et al., 2008), as this increases classification accuracy. "Non-marsh features such as houses, trees and lawns were eliminated from the input data" (Gilmore et al., 2008). A mask will be used to exclude forest in the Park, as other data are difficult to obtain for the exclusion of constructed objects.

2.8 SUPERVISED CLASSIFICATION

The literature indicates that the Maximum likelihood classifier is used frequently and successfully for supervised classification of Phragmites, by Laba et al. (2008), Laba et al. (2010), Knudby and Nordlund, (2011), and Dekker et al. (2005). "Several supervised classifications methods were trialled, and the Maximum Likelihood Classifier achieved the highest separation between classes" (Dekker et al. 2005). For supervised classification, the consensus indicates that Maximum likelihood classification will yield the best result, therefore it is used in this study.

CHAPTER 3: MANUSCRIPT

REMOTE SENSING OF INVASIVE SPECIES, PHRAGMITES AUSTRALIS ON GEORGIAN BAY ISLANDS NATIONAL PARK SHORELINES

3.1 ABSTRACT

Georgian Bay Islands National Park (GBINP) is located in the Canadian Province of Ontario. The study focused on Beausoleil Island, located in the Georgian Bay portion of Lake Huron. The goal was to use image processing techniques on remotely sensed imagery to determine areas of Phragmites australis invasion along the shoreline of the island, enabling the park to possibly take remedial action and engage in management planning. There is a native species of Phragmites that occurs naturally in North America, often referred to as the common species Phragmites. The invasive species Phragmites australis is native to Eurasia (herein referred to as Phragmites). It is a concern for the park, because it reduces wetland ecosystem biodiversity. Pansharpened Quickbird imagery from 2003 and orthophotos from 2009 were combined with additional information layers including Normalized Difference Vegetation Index (NDVI), texture measures (mean) and Digital Elevation Model (DEM) data to create a maximum likelihood supervised classification of Phragmites invasion. The best classification results were achieved using a combination of the Red, Green, Blue and Near Infra-Red image bands, plus NDVI, and mean texture measures with accuracies of 86% and 88% respectively. The results showed that an area of approximately 0.303 square kilometres (2.68% of Beausoleil Island) is covered with Phragmites. The image processing was conducted using PCI Geomatica and ESRI ArcGIS software.

Keywords: Phragmites australis, invasive species, Quickbird, Orthophoto, Supervised classification, NDVI, DEM.

3.2 INTRODUCTION

Georgian Bay Islands National Park (GBINP) is located on the South Eastern shores of Georgian Bay. The main island of GBINP, Beausoleil Island (Figure 3.1) shoreline is the area of interest for examining the invasive species Phragmites australis proliferation in wetlands.

Figure 3.1: Study Area Georgian Bay Island National Park, Canada

Two parks are located in this area, GBINP and Awenda Provincial Park. Urban centres such as Midland and Penetanguishene are relatively close and Barrie is an hour's drive south of the park. Beausoleil Island (Figure 3.2) is a destination for many park goers, with many activities. There is an influx of people in park area in the summer months, because many vacationers use the area for camping, hiking, boating, cottage retreats and touring.

The park is home to many species that are endangered or threatened. The Phragmites invasion is causing ecological issues in terms of biodiversity.

> "In particular, invasive plant species have been found to alter wetland decomposition rate and nutrient cycling, lead to reduction in wetland plant diversity, threaten rare and endangered plant and animal species, reduce pollination and seed output of native plants, as well as reduce habitat suitability for several wetland bird species including black terns, least bitterns, pied billed grebes, and marsh wrens…" (Laba et al., 2008).

Georgian Bay has many threatened and endangered amphibians and reptiles, such as snakes and turtles. Rare birds such as the black tem and the snowy owl are also visitors to the park (Parks Canada, 2011). However, there are many other creatures such as fish, and plant species that may be affected by the Phragmites growth. The "[e]xtreme expansion of tall macrophytes, however, causes biodiversity loss and the reduction of ecosystem services provided by coastal habitats, such as recreational areas used for swimming, boating and fishing, and therefore growth of macrophytes affects lakes' economic potential" (Lira et al., 2010).

The GBINP mandate is to maintain the ecological integrity of the Park, thus the park has embarked on attempting to manage the Phragmites invasion with studies, data collection and pilot trials of eliminating the invasive wetland grass. This study builds on the park's work by using image processing techniques on early fall 2009 orthophotos to determine areas of Phragmites invasion along the shoreline of GBINP. Quickbird imagery from October 10th, 2003 and the orthophotos were used to create a vegetation change detection analysis to examine growth over time.

Figure 3.2: Map of Beausoleil Island (Source: Parks Canada, 2011)

This analysis was completed using the image arithmetic function in PCI Geomatica, by subtracting the green bands from the images and determining change over time. The two datasets are then compared to the level of growth or decline of Phragmites.

3.3 DATA PREPARATION

3.3.1 DATA FILES

Data were obtained from GBINP consisting of access trails, buildings, docks, facilities, GBINP Ecological Land Classification (ELC), tents, trails 2010, washrooms, imagery, phragmites research, and phosphorous data. The water layer, and the Digital Elevation Model (DEM) files were obtained through Ontario Geospatial Data Exhange (OGDE), via Ryerson University. The satellite imagery was acquired on October 10, 2003 Quickbird Image (Figure 3.3), pansharpened to a resolution of 60 cm, and the orthophotos (Figure 3.4) were acquired in late August/early September of 2009, with a spatial resolution of 40 cm. Both images included a red, green, blue and Infrared band. The Quickbird imagery contains haze on the bottom portion of the island.

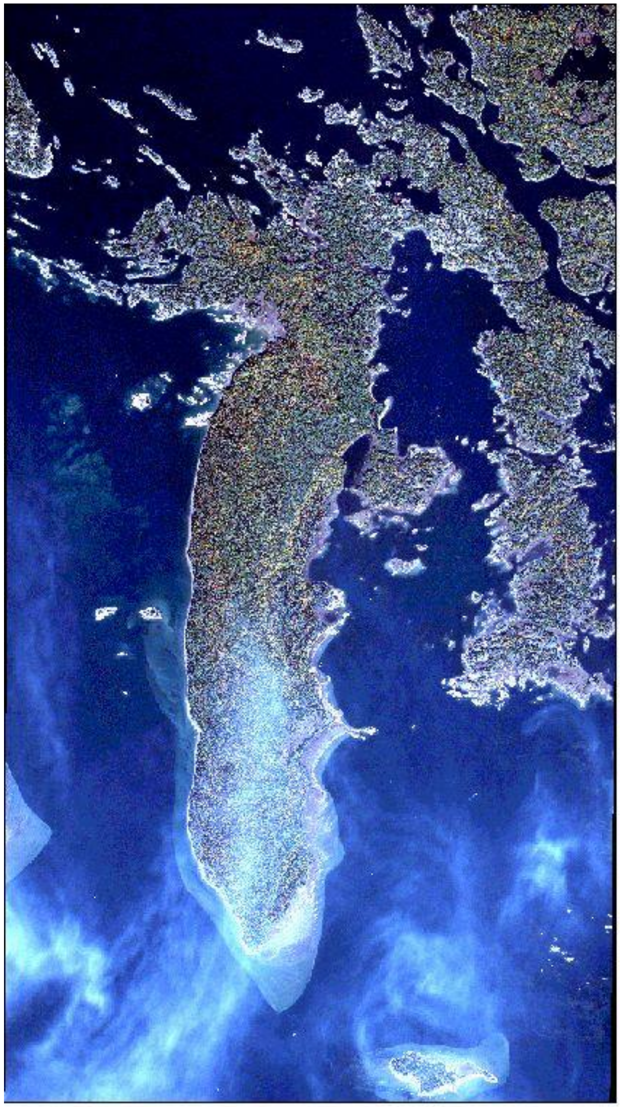

Figure 3.3: Quickbird Image 2003

Figure 3.4: Orthophoto Image 2009

3.3.2 MASK

Initially, a mask was going to be created of areas of non-concern with the shapefiles received from the park. The shapefiles, upon closer examination proved to not line up to the buildings and infrastructure such as washrooms, trails, docks, and kitchens in question according to the images. Therefore, it was determined that the time commitment was too great to clean up the data and create a mask of non-concern. However, a mask of forested area was created from the ELC file by exporting coniferous forest, deciduous forest, and mixed forest classes into a bitmap in PCI Geomatica (Figure 3.5). An known issue with the mask is that it contains homogenous forest, but not heterogenous treed area such as a treed bog or treed mixed swamps or bare rock and treed areas. As a result of not having a complete mask for forest cover or treed areas, a forest class was created as well.

3.3.3 NDVI

Several additional layers were generated to add to the images before classsification, which include a Normalized Difference Vegetation Index (NDVI), texture measure and DEM slope analysis. A NDVI layer was generated from both images (Figure 3.6 and 3.7) using the Infrared and Red bands, which were added to the Quickbird and orthophoto images respectively.

Figure 3.5: Forest Mask

Figure 3.6: Quickbird NDVI

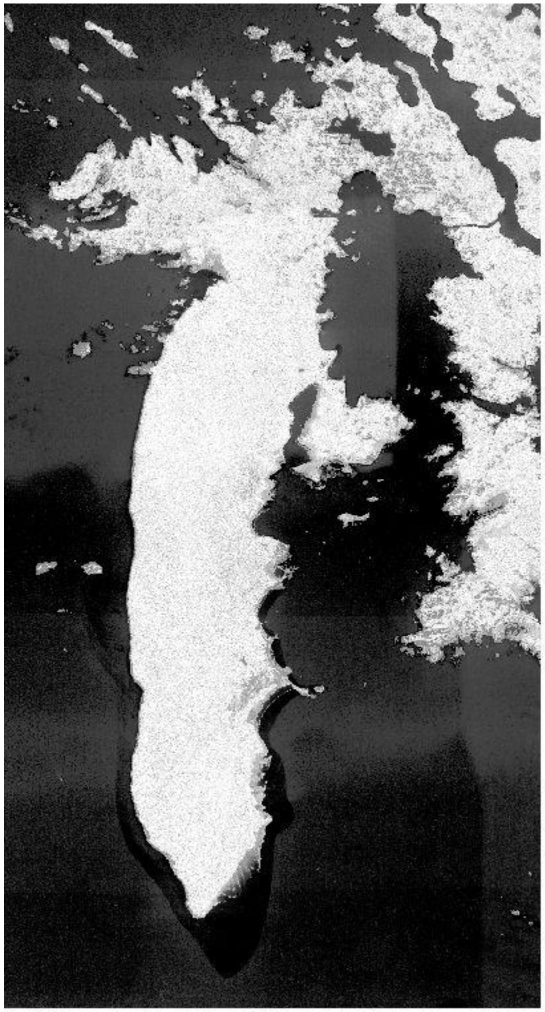

Figure 3.7: Orthophoto NDVI

3.3.4 TEXTURE

A texture analysis was performed on both images using, homogenity, contrast, disimilarity, mean, variance, entropy, angular second moment, correlation, and inverse difference. All of the texture analyses were performed with a 3x3 filter on all bands. Of all the texture measures attempted, the best resulting texture measure for phragmites in the 60 cm resoultion Quickbird image was the NIR (band 4) mean texture (Figure 3.8). For the 40cm resoultion orthophoto, there were three texture measures that were added to the image, the contrast green (band 3) (Figure 3.9), mean green (band3) (Figure 3.10), and mean infrared (band1) (Figure 3.11). These three texture measures were added, because it was not clear which of them was the most suitable for the final analysis for this image. After supervised classification was completed for the image, it was clear that the mean (green band) texture measure was the best, based on the post classification accuracy results.

3.3.5 DEM

A DEM (Figure 3.12) was used to create a slope analysis raster (Figure 3.13) of areas of less than 8% gradient. According to Li and Chen (2005), areas of less than 8% gradient are potential weltand locations. As wetland plants tend to grow in wet locations, greater than 8% gradient is an unlikely location for this type of vegetative growth, because it is too dry. A slope of less than 8% gradient remains moist enough for wetland plants to flourish. Thus, the DEM raster was included as an additional layer in the images to isolate the potential areas of Phragmites invasion.

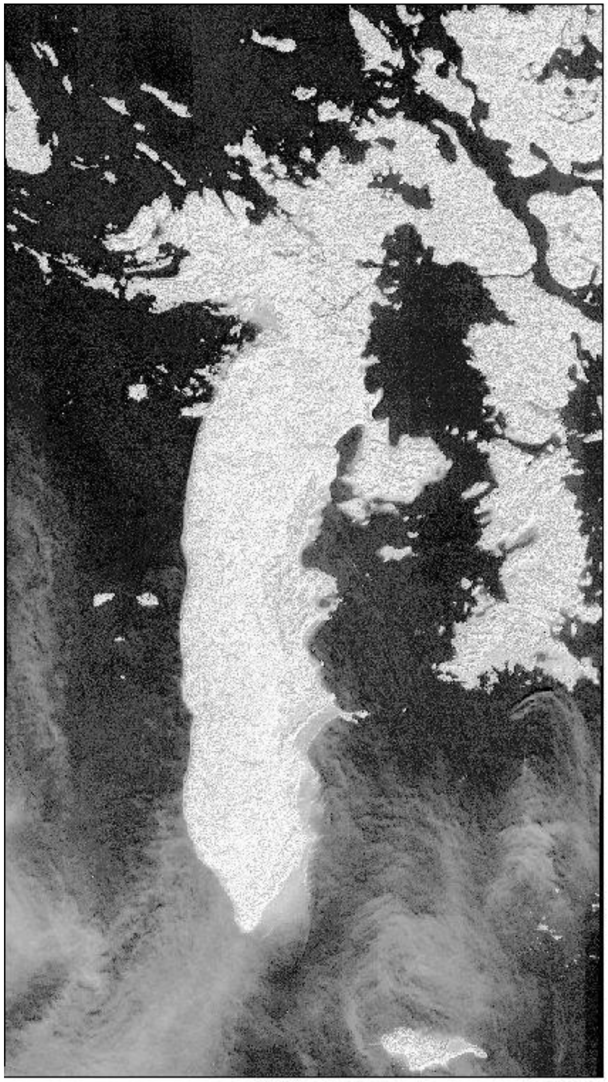

Figure 3.8: Quickbird NIR Band Mean

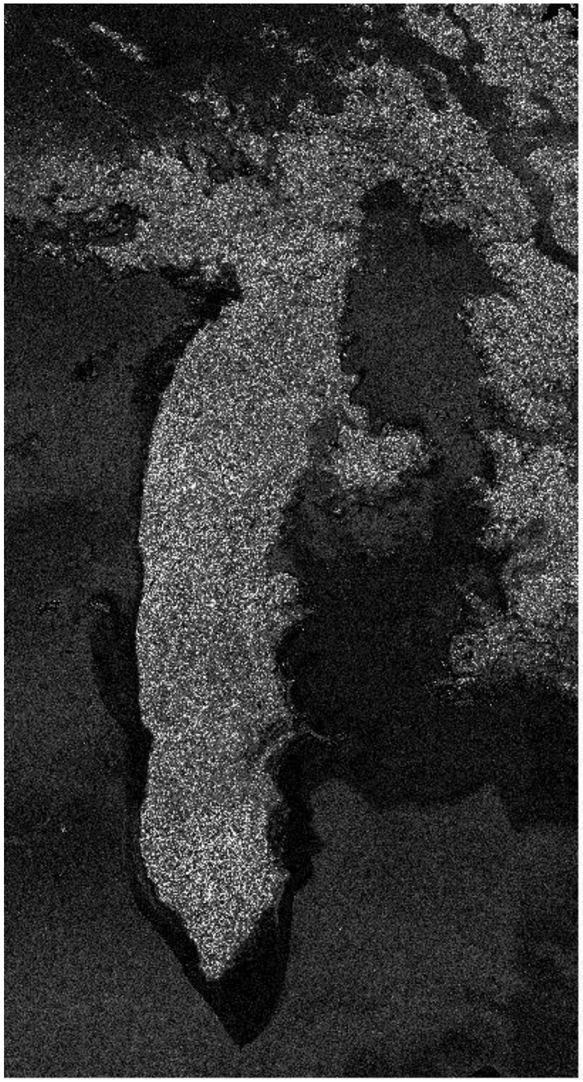

Figure 3.9: Orthophoto Contrast Green Band

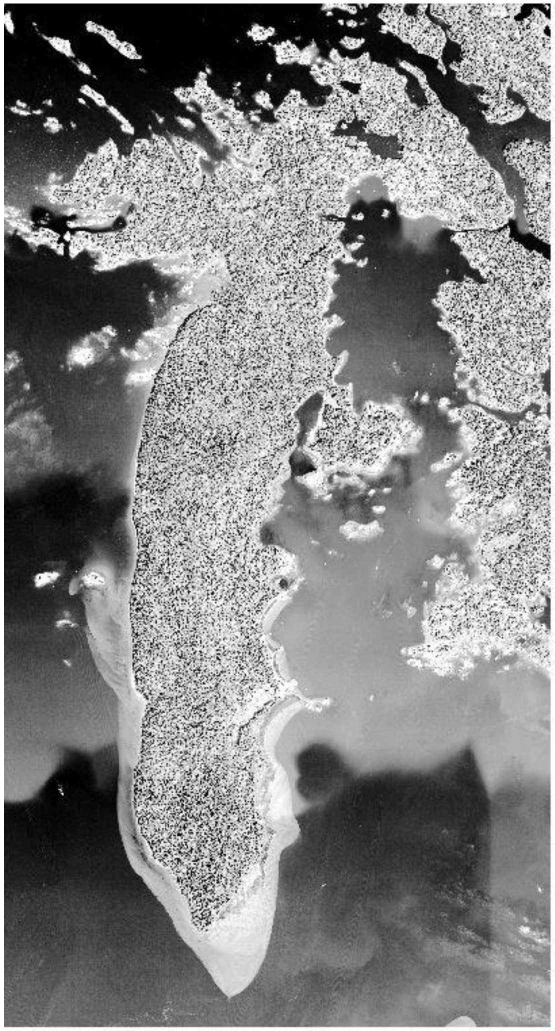

Figure 3.10: Orthophoto Mean Green Band

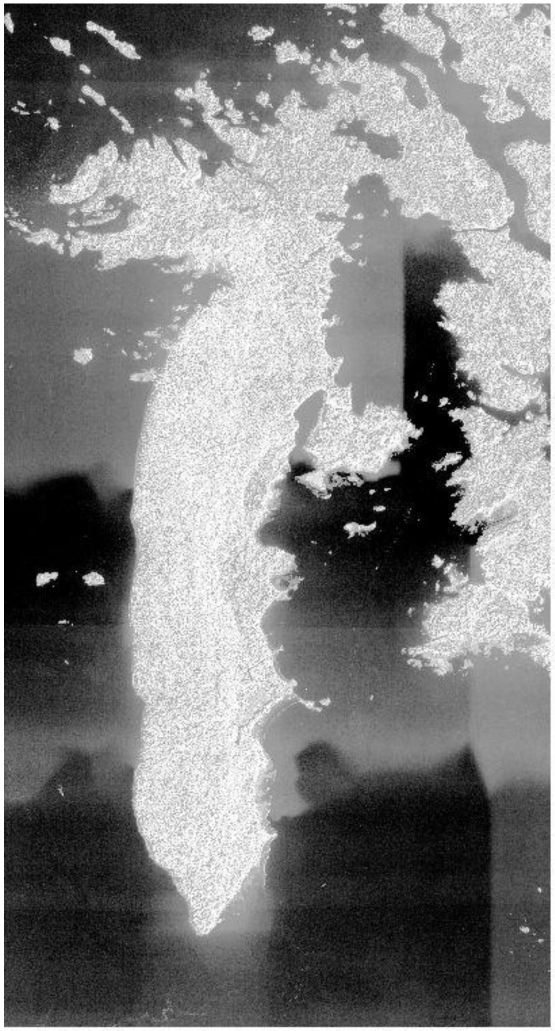

Figure 3.11: Orthophoto Mean Infrared Band

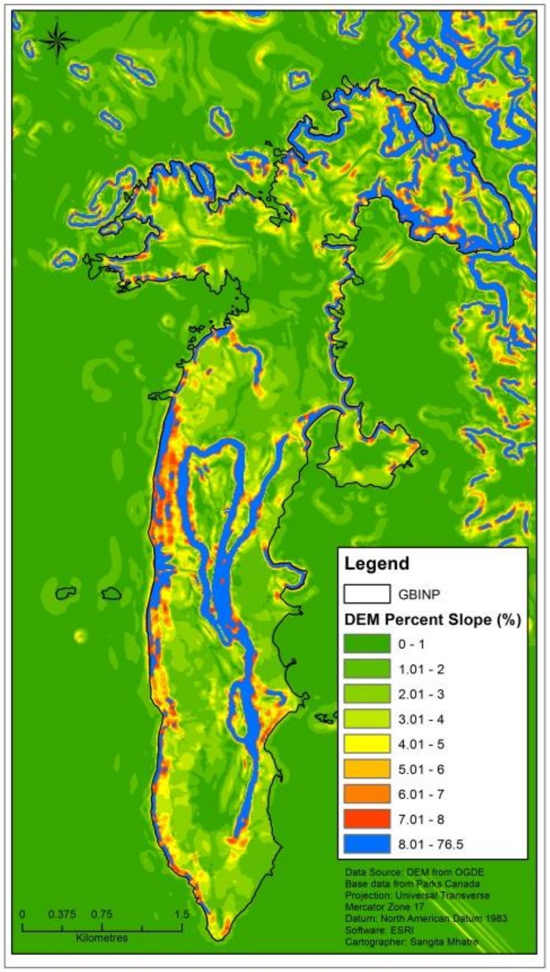

Figure 3.12: DEM

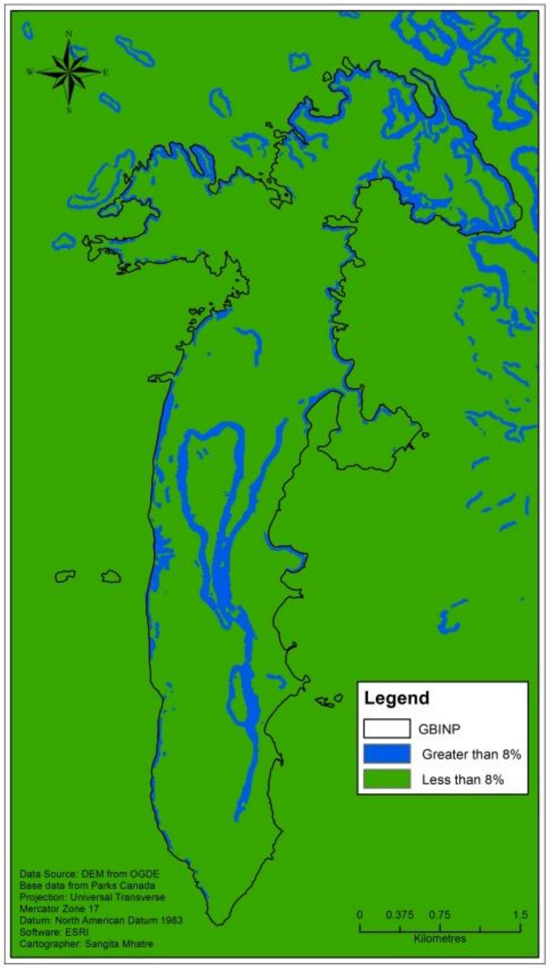

Figure 3.13: DEM Less than 8% Slope Reclass

3.4 CLASSIFICATION

Classifications were performed in PCI Geomatica using the Quickbird imagery and orthophotos. The orthophotos were exported from a file geodatabase mosaic dataset to an Erdas Imagine file in ArcGIS, then converted to a .pix file in PCI Geomatica, and clipped to the study area. Several attempts of unsupervised classifications were tried on both images, to get a sense of spectral seperablity and a different range of class numbers from 10 to 255. However, this was abandoned when the difficulty of extracting the phragmites from the rest of the image could not be done with confidence. The haze in the Quickbird and mosaic nature of the orthophoto created many problems.

Supervised classifications were intially performed without the mask, which resulted in the haze skewing the spectral signature between the specific class grouping on the Quickbird image. Also, for both images without the mask, the spectral signatures created a great amount of confusion between the forest and the phragmites. According to Ghioca-Robrecht et al. (2008) and Gilmore et al. (2008) a mask increases accuracy. Therefore, a mask was created for the forested areas that made the haze issue managable in the southern portion of the island. The haze issue was significantly reduced, since it was concentrated on the southern portion of the island, and the mask was complete in terms of forest coverage on that portion of the image. The mask reduced the spectral confusion for the forest class and phragmites class at the masked location. The field data from the park and the shapefile of known Phragmites GPS locations (Figure 3.14) were used as a source of ground truth.

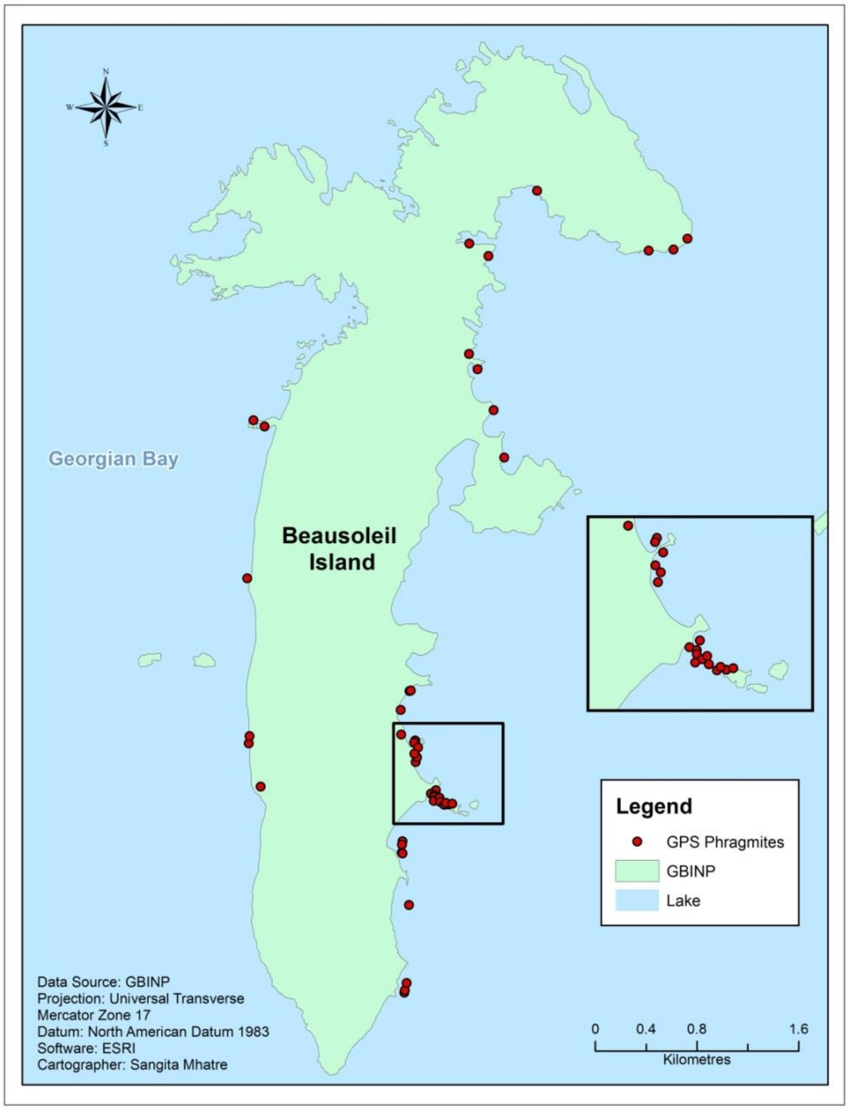

Figure 3.14: GPS Locations of Phragmites

The training classes were intially experimented with, in terms of the number of classes and type of classes. Some classes were taken out, such as docks and buildings, because of the low accuracy, while others such as shoreline and bare ground/ rock were added. The final classes that were used for the orthophoto were forest/vegetation, lake, shoreline, bare ground/rock, Phragmites, wetland, and polygon mask. The Quickbird image training classes were forest/vegetation, lake, shoreline, bare ground/rock, wetland and polygon mask. The Quickbird image was initally provided with a phragmites class.

However, if phragmites were present in the image, they covered only a very small area and the accuracy was poor. On further inspection of the NIR band, the phragmites were not visible on the image. Thus, a wetland class was only used in the Quickbird image. A supervised classification using Maximum-likelihood classification (Laba et al., 2008) was used for both images; and training classes were created seperately for both images. A similar method to Forsythe and Wheate (2003) was used for classification on the following layers:

With 1) Red, Green, Blue, NIR

Then 2) Red, Green, Blue, NIR, NDVI

Then 3) Red, Green, Blue, NIR, NDVI, Mean Texture (Green band)

Then 4) Red, Green, Blue, NIR, NDVI, Mean Texture (Green band), DEM

The three texture measures (contrast green band, mean green band, and mean NIR) were used in the orthophoto classification, however, after accuracy assessment the best results were produced with the mean green band. The best classification for the Quickbird image was the four bands, plus the NDVI and mean texture (NIR band) (Figure 3.15). The best classification for the orthophoto was the four bands, plus NDVI, and mean texture (green band) (Figure 3.16).

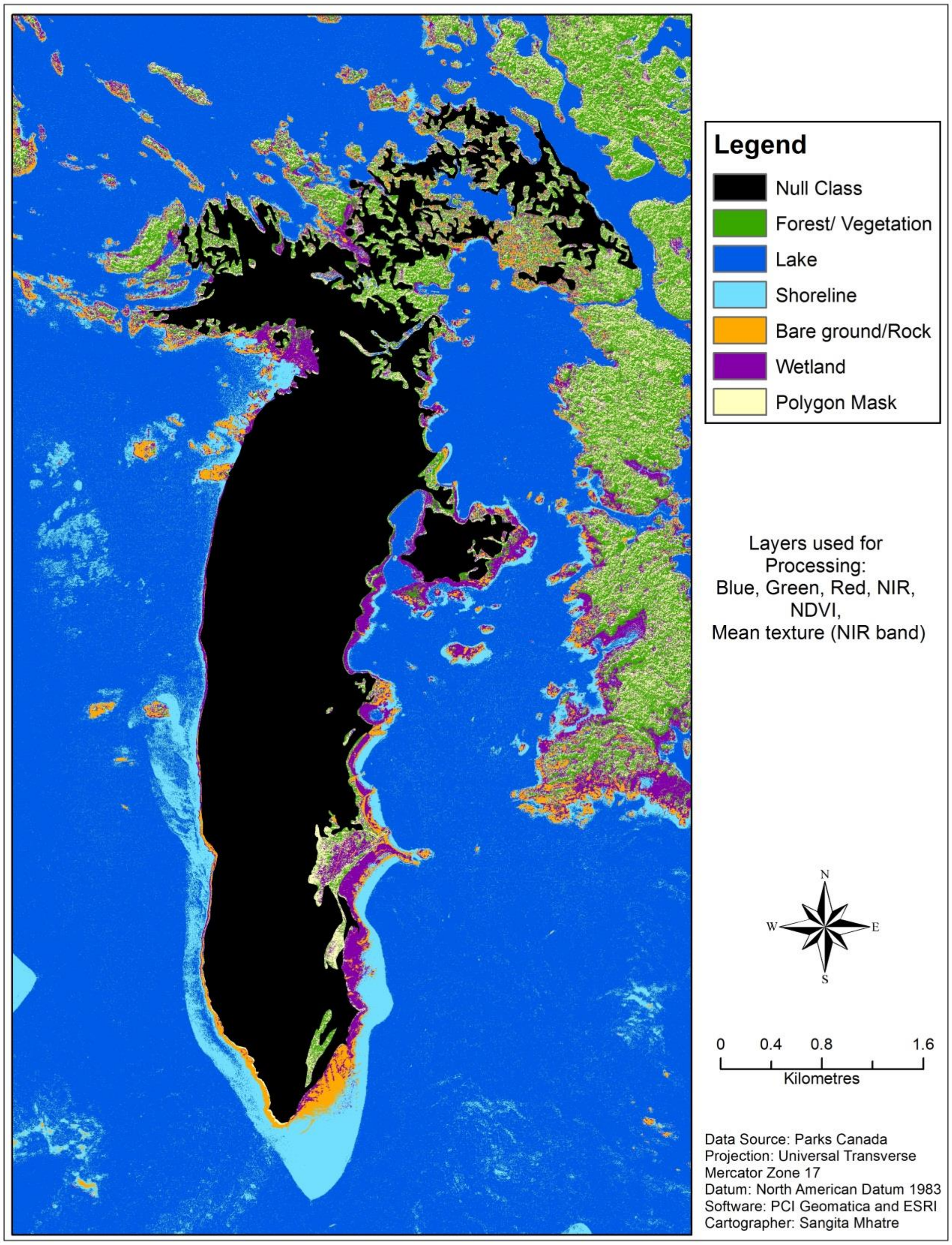

Figure 3.15: Best Supervised Classification of Quickbird Image

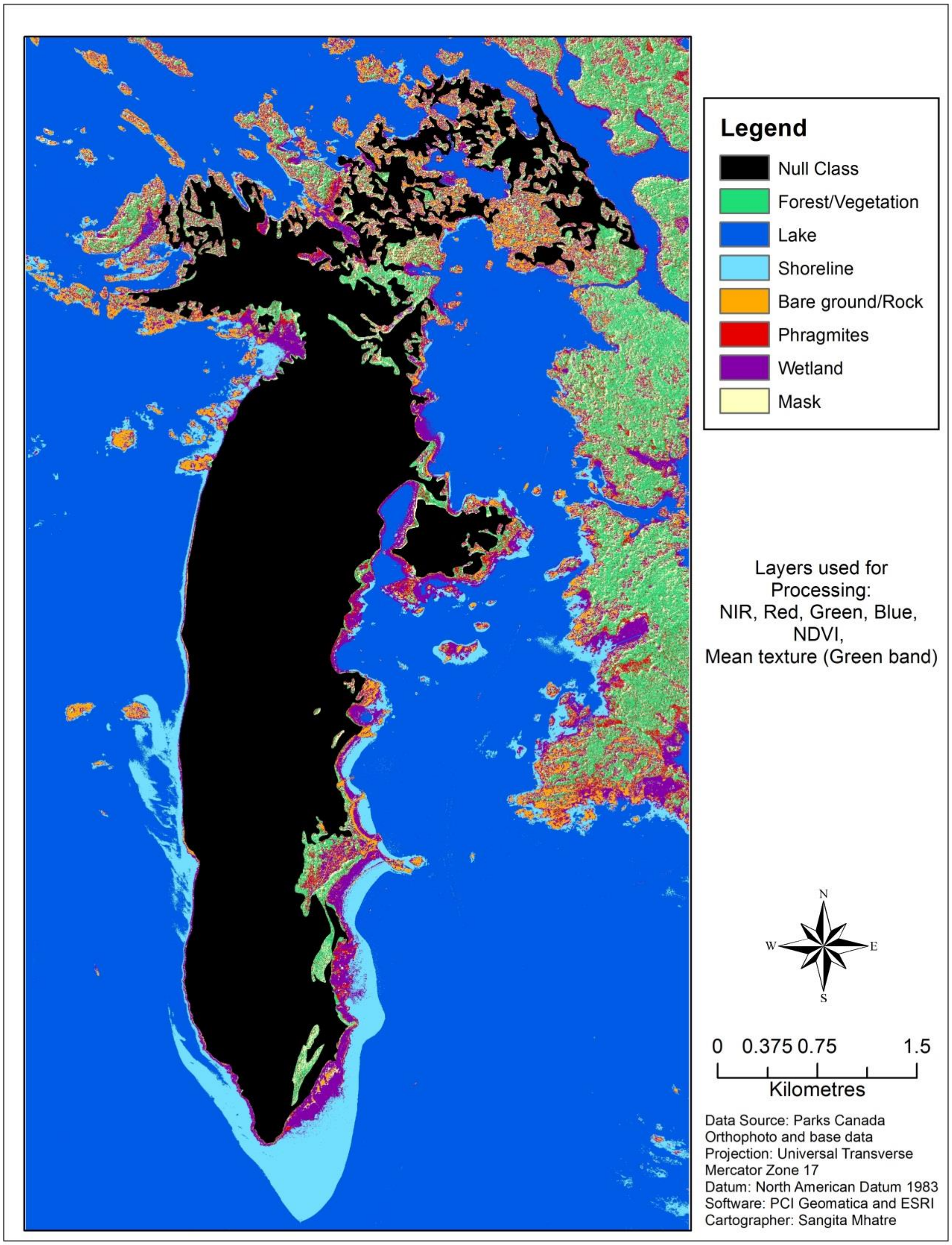

Figure 3.16: Best Supervised Classification of Orthophoto

According to the GBINP pilot study research, a south-eastern shoreline was determined to contain some of the largest patch sizes for Phragmites (Parks Canada, 2011). The supervised classification of the orthophoto does verify the large patch sizes, as the Phragmites cover a large area in the wetland (Figure 3.17). The Phragmites invasion areas are clearly visible on the orthophoto, as well as the supervised classification image.

The tallest Phragmites (Parks Canada, 2011) are found on the southern tip of Beausoleil Island (Figure 3.18). The Phragmites appear as small patch areas on the map, but the respective heights of the patch areas are not evident on the orthophoto or in the classification. The Phragmites patches located along the edge of the shoreline are quite tall (Figure 3.19). The trees located at a distance in the background of the photo provide a visual perspective for the relative size of the Phragmites.

Phragmites patches are present in areas of high visitor traffic (Figure 3.20), including trails, campgrounds, docks, showers, and picnic spots. The Phragmites are dispersed in small patches along this south-eastern part of the shoreline. According to the park there is often mixed vegetation where Phragmites growth is occurring (Parks Canada, 2011). The area represented by Figure 3.20 indicates that one large homogeneous patch of Phragmites growth is occurring along the northern shoreline of Papoose Bay. The Phragmites are evident in the orthophoto but in some areas look very similar to the native vegetation. Thus, the classified image illustrates some of that area as wetland.

The north-eastern shore of Beausoleil (Figure 3.21) near camp Wana Keta and a docking area contains native vegetation, mixed with Phragmites growth. From the orthophoto, the Phragmites are visible, as is other wetland vegetation. The other vegetation is classed within the wetland class. Also, within the bare ground/rock class docks and boats appear to be included in this class when comparing the orthophoto to the classified image.

Docks, campsites, and trails are located around Ojibway Bay (Figure 3.22) and Treasure Bay (Figure 3.23). These areas have Phragmites growth that is clearly visible on the maps. The Phragmites class is isolated from the other classes to highlight the problem areas. Ojibway Bay and Treasure Bay are two areas that have been highlighted by the park for phosphorus pollution (Parks Canada, 2011), as eutrophication will lead to the extensive growth of Phragmites. “The primary assumption about causes of reed expansion according to literature could be related to water eutrophication…” (Liira et al., 2010) From the maps in the two bays, there is clear indication of extensive Phragmites growth.

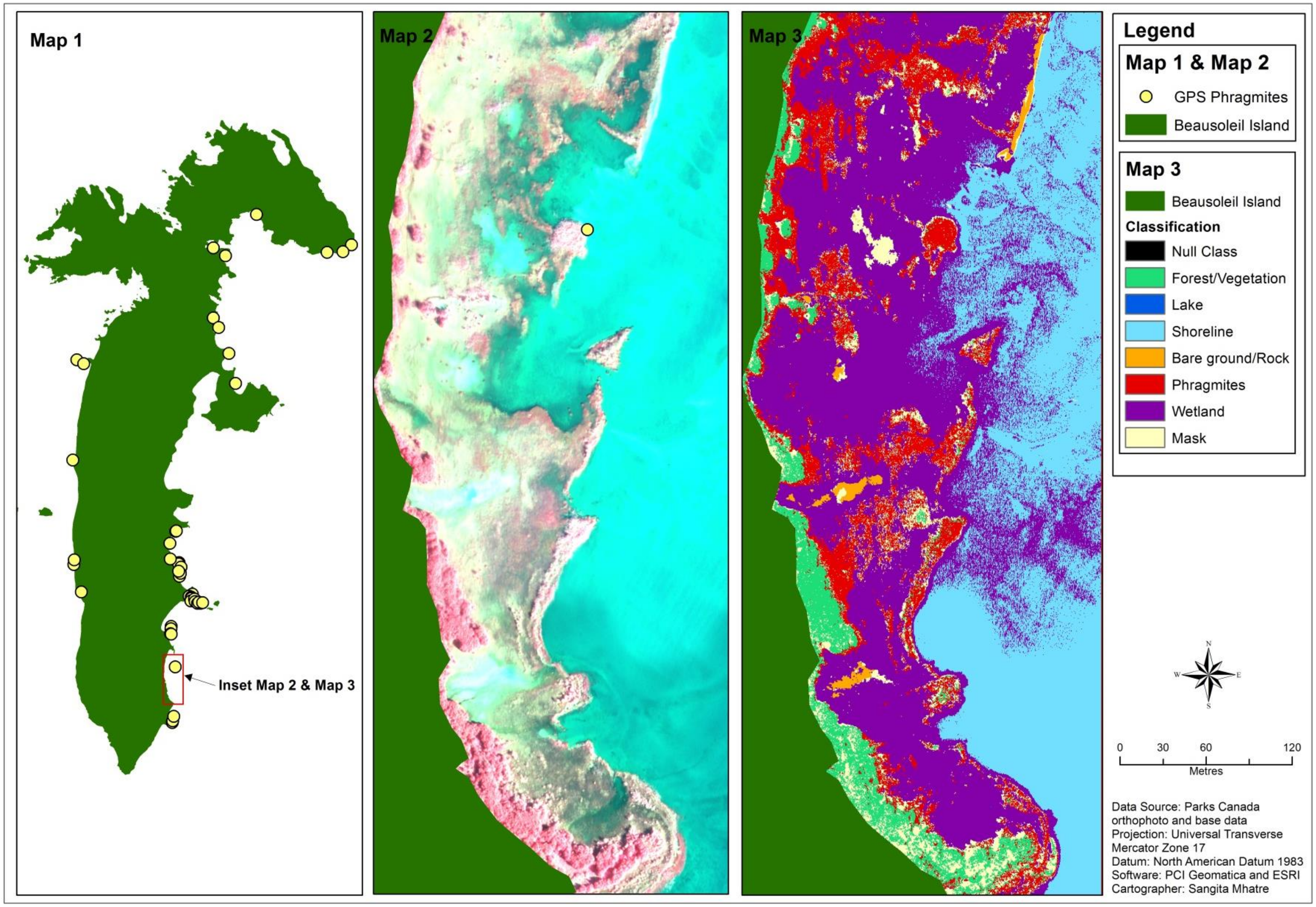

Figure 3.17: Large Phragmites Patch Size

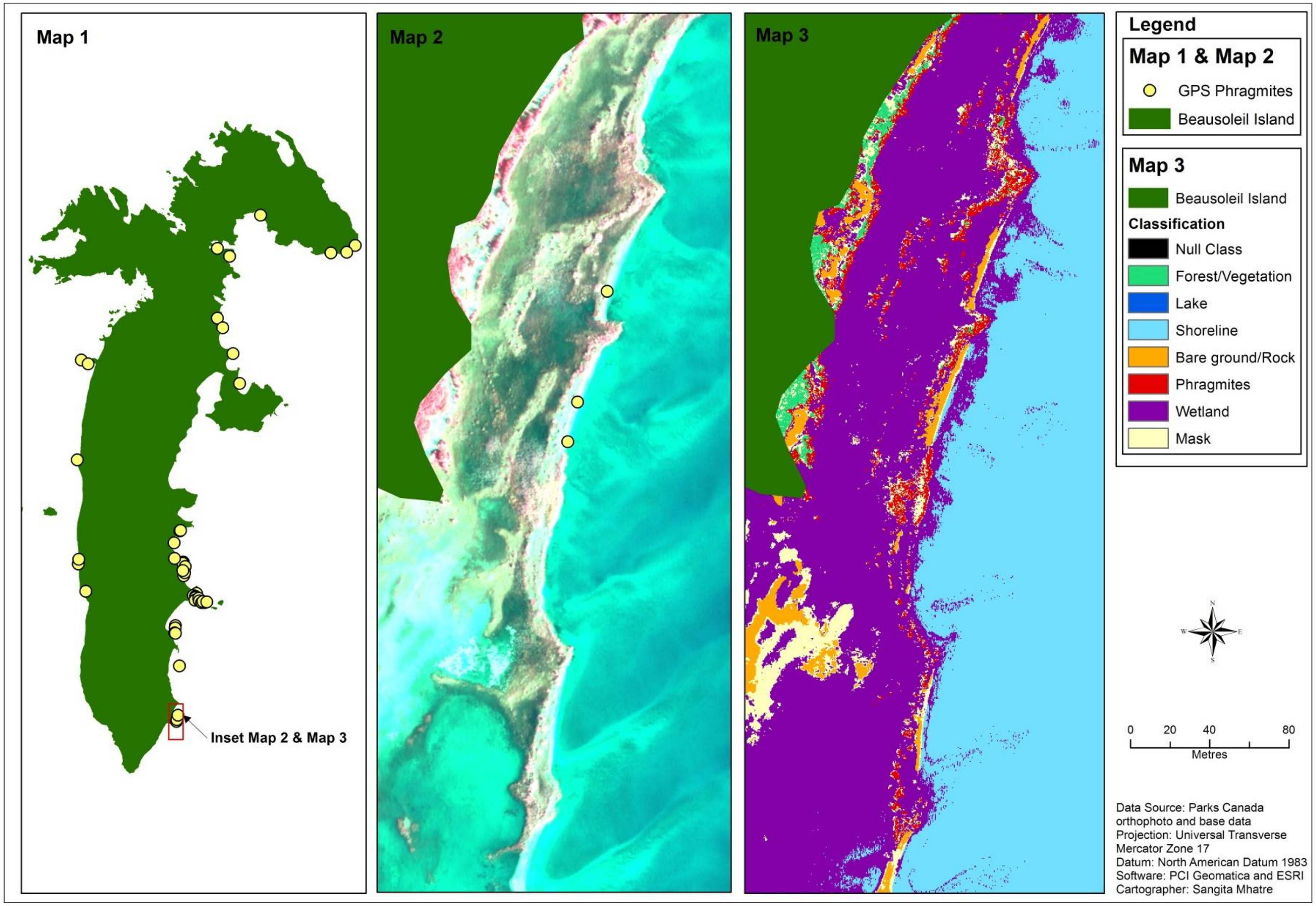

Figure 3.18: Tall Phragmites Location

Figure 3.19: Photo of Tall Phragmites (Photo from Parks Canada, 2011)

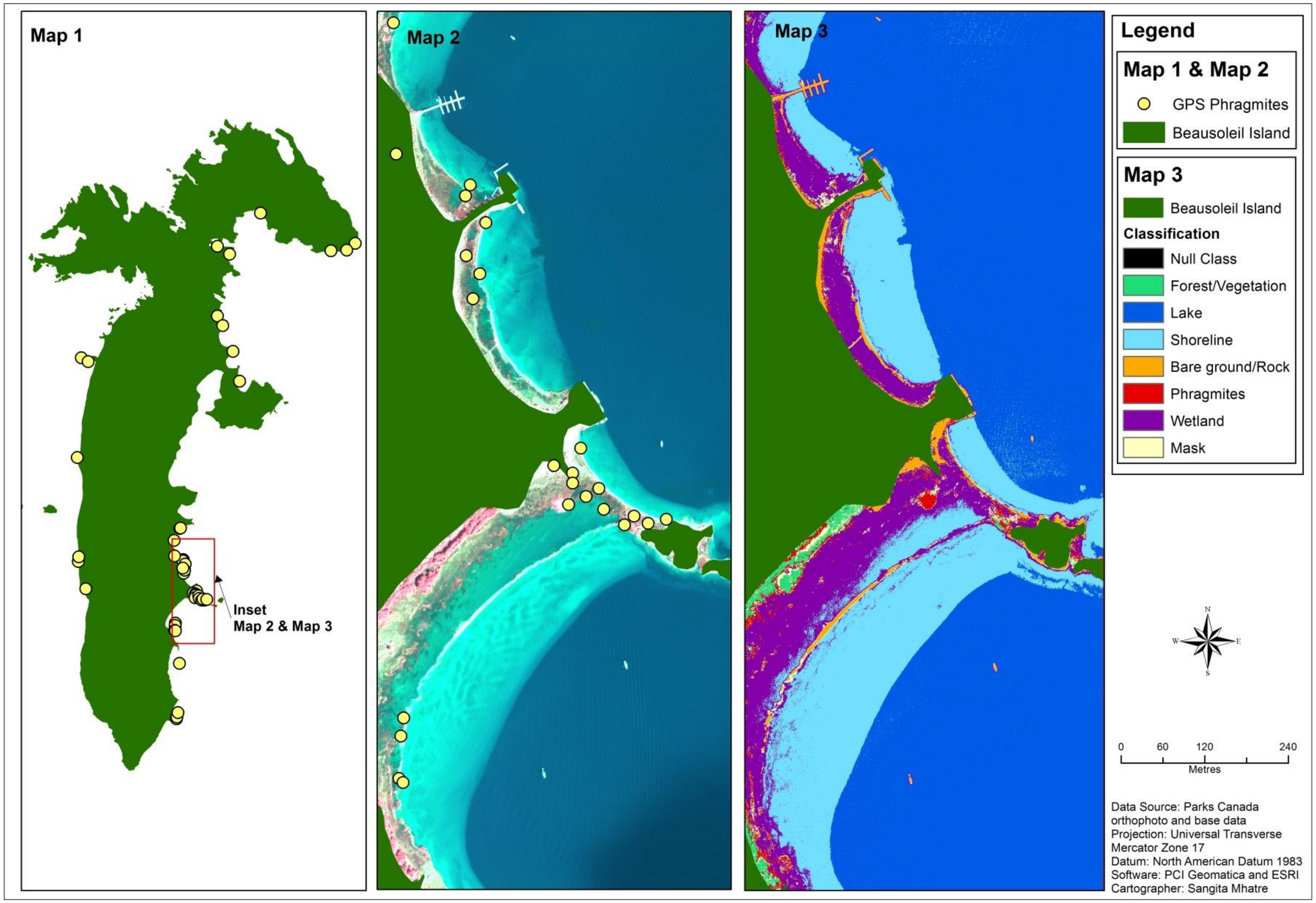

Figure 3.20: High Visitor Traffic Area

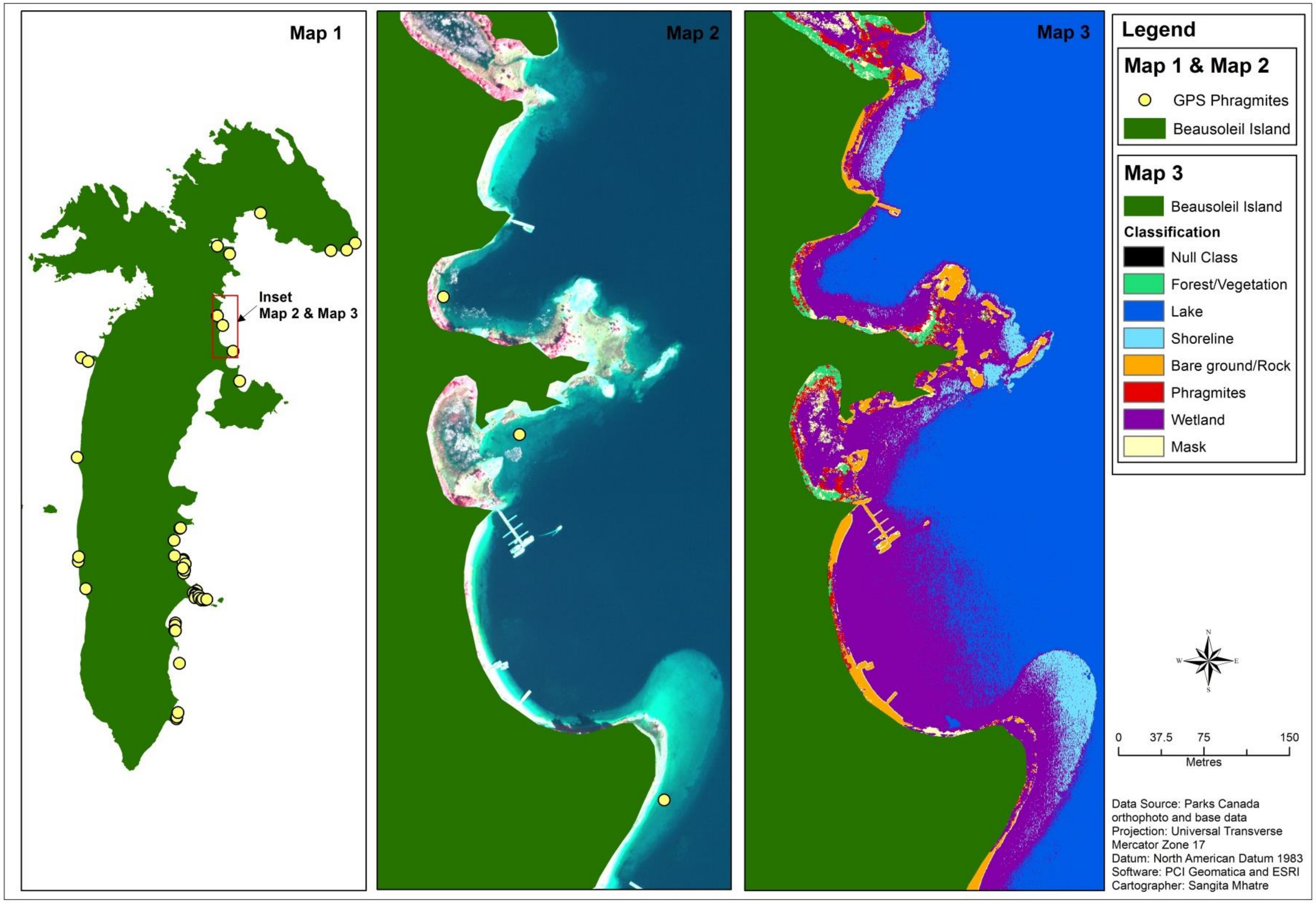

Figure 3.21: Camp Wana Keta and Docking Areas

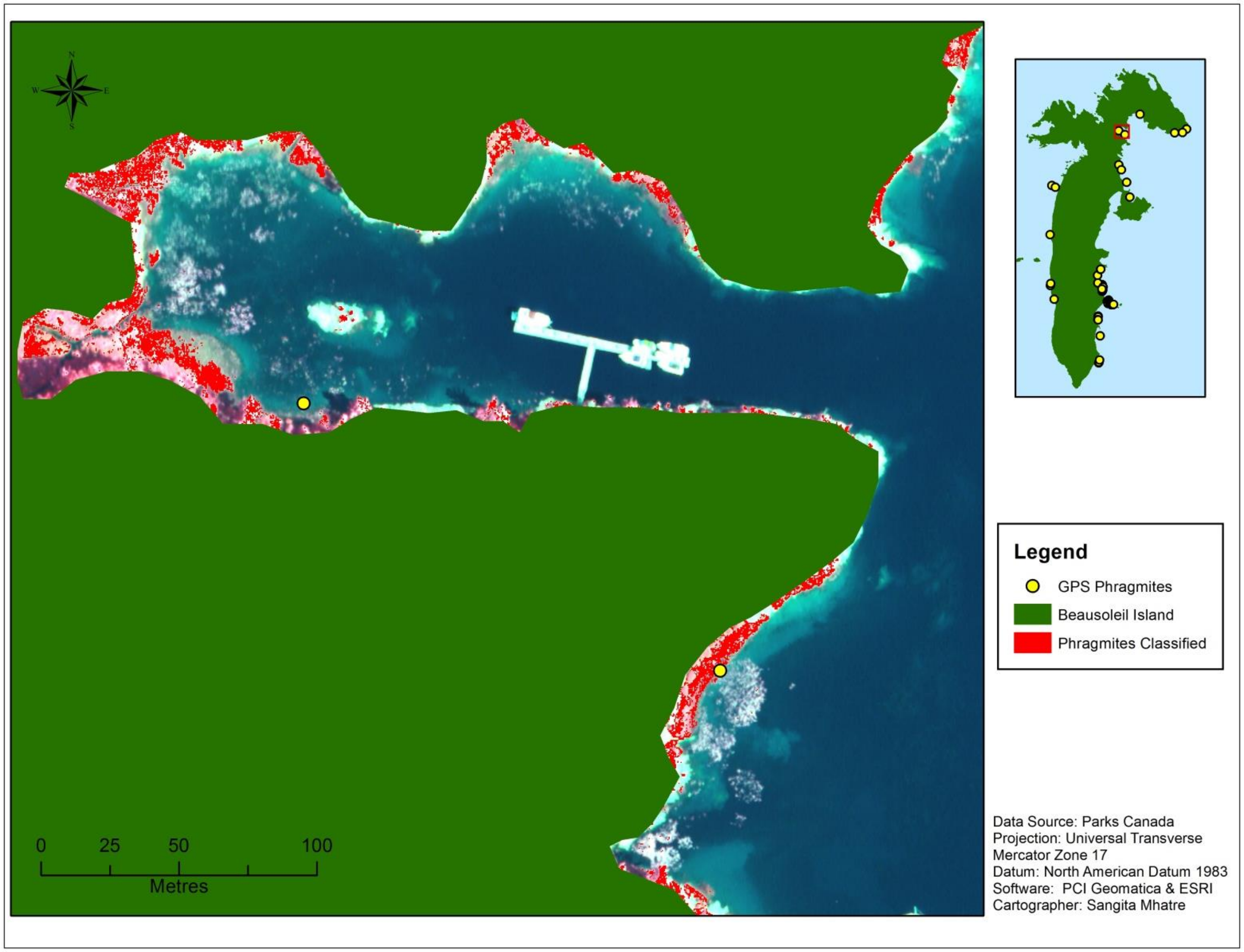

Figure 3.22: Ojibway Bay Phragmites (classification imposed on orthophoto)

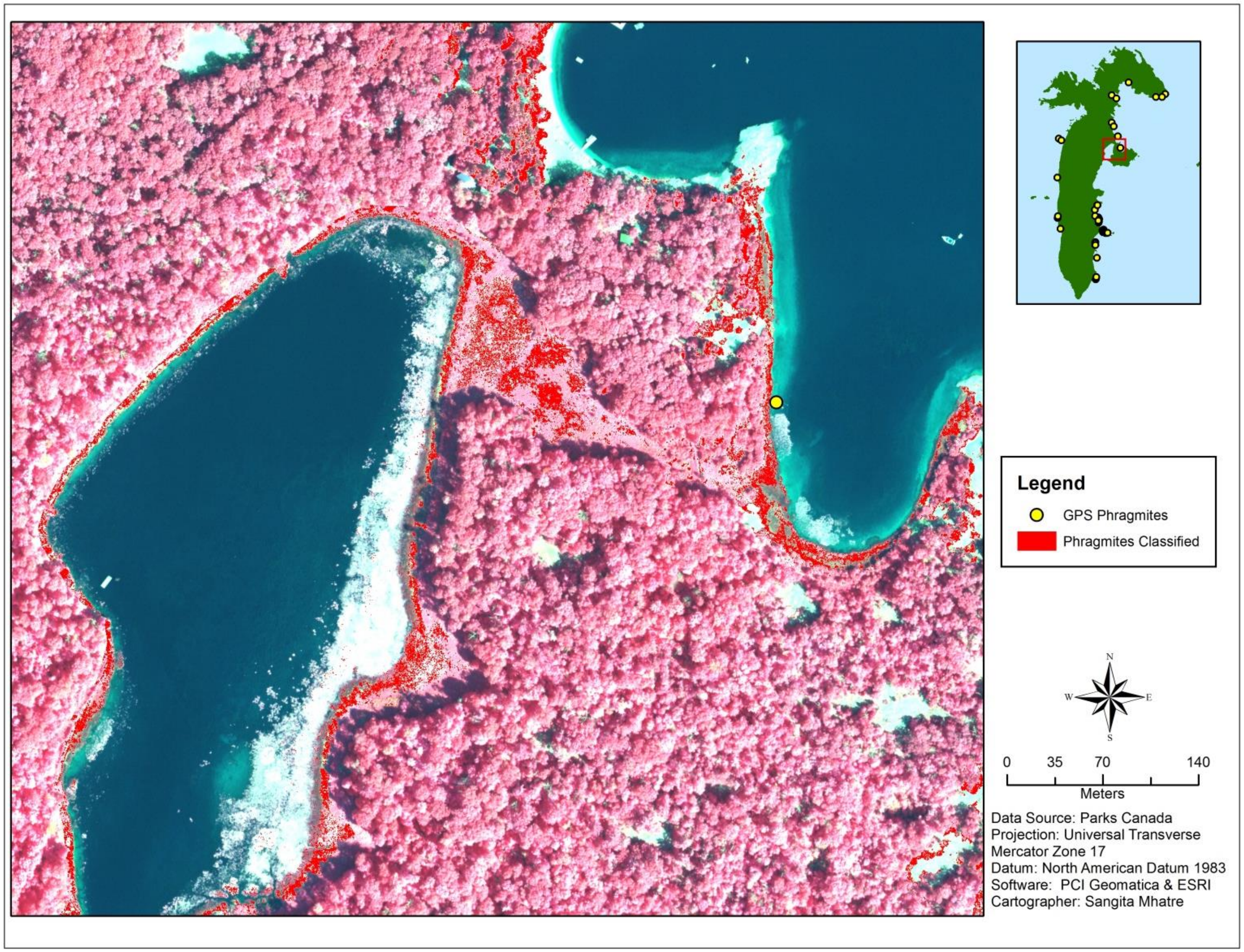

Figure 3.23: Treasure Bay/Camp Kitchikewana Phragmites (classification imposed on orthophoto)

3.4 CHANGE DETECTION

For a change detection analysis, an arithmetic calculation was done on the orthophoto, subtracting the Quickbird image (newer image subtract older image) in PCI Geomatica. Two subtractions, the NIR band (Figure 3.24) and the green band (Figure 3.25), were calculated and then exported out into Arc GIS.

Ranges of pixel values were determined for the black and white areas for high and low values. The rasters were then reclassified as white and black areas denoting change and the grey values denoting no change. The green band difference resulted in the best illustration of phragmites change, which was reclassified (Figure 3.26).

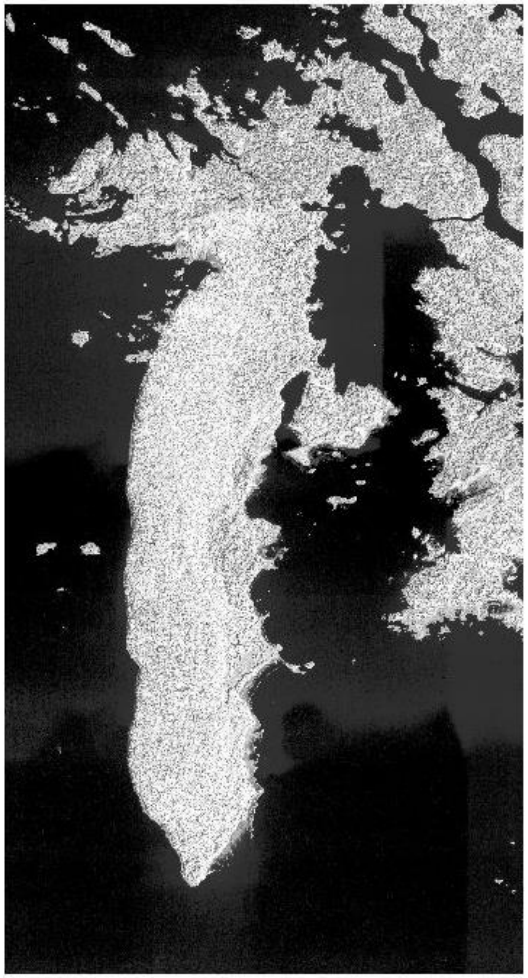

Figure 3.24: NIR Band Difference

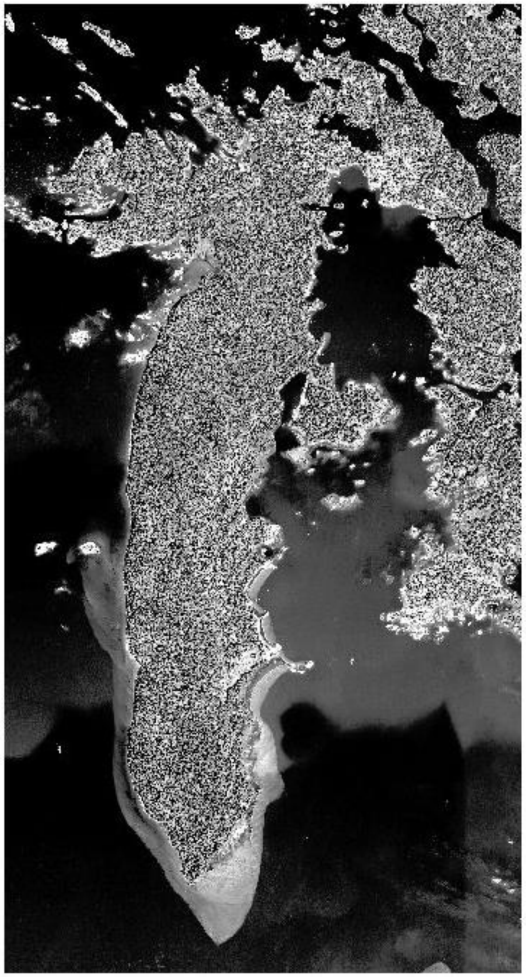

Figure 3.25: Green Band Difference

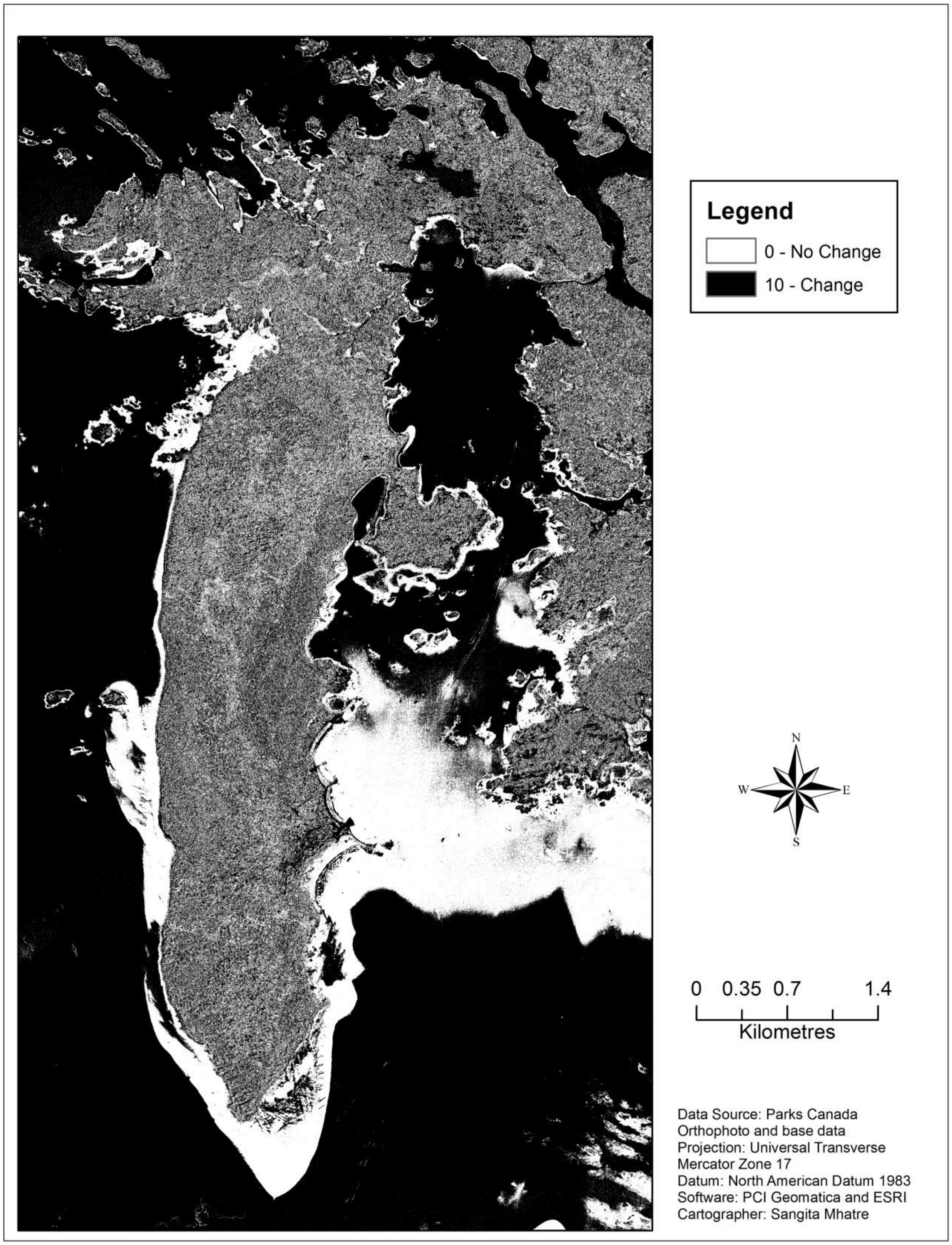

Figure 3.26: Change Image Reclass of Difference Green Band

Then the green band difference was combined in a raster calculator against the best newer classified image, to show change in phragmites image (Figure 3.27). The white areas are no-change and the coloured areas are changes in each class. The lake was considered as change according to the difference image, because of the varying spectral signatures of life within the water. Additionally, the mosaicked orthophoto resulted in changes across the water.

A zoomed in map of change/ no-change (Figure 3.28) on the south-eastern shoreline of Beausoleil Island illustrates the wetlands and the phragmites. According to this area of the change/no-change map, there is less phragmites growth when compared to the classification of the orthophoto of Figure 3.17. The difference in resolutions between the two images may have caused issues in detecting change.

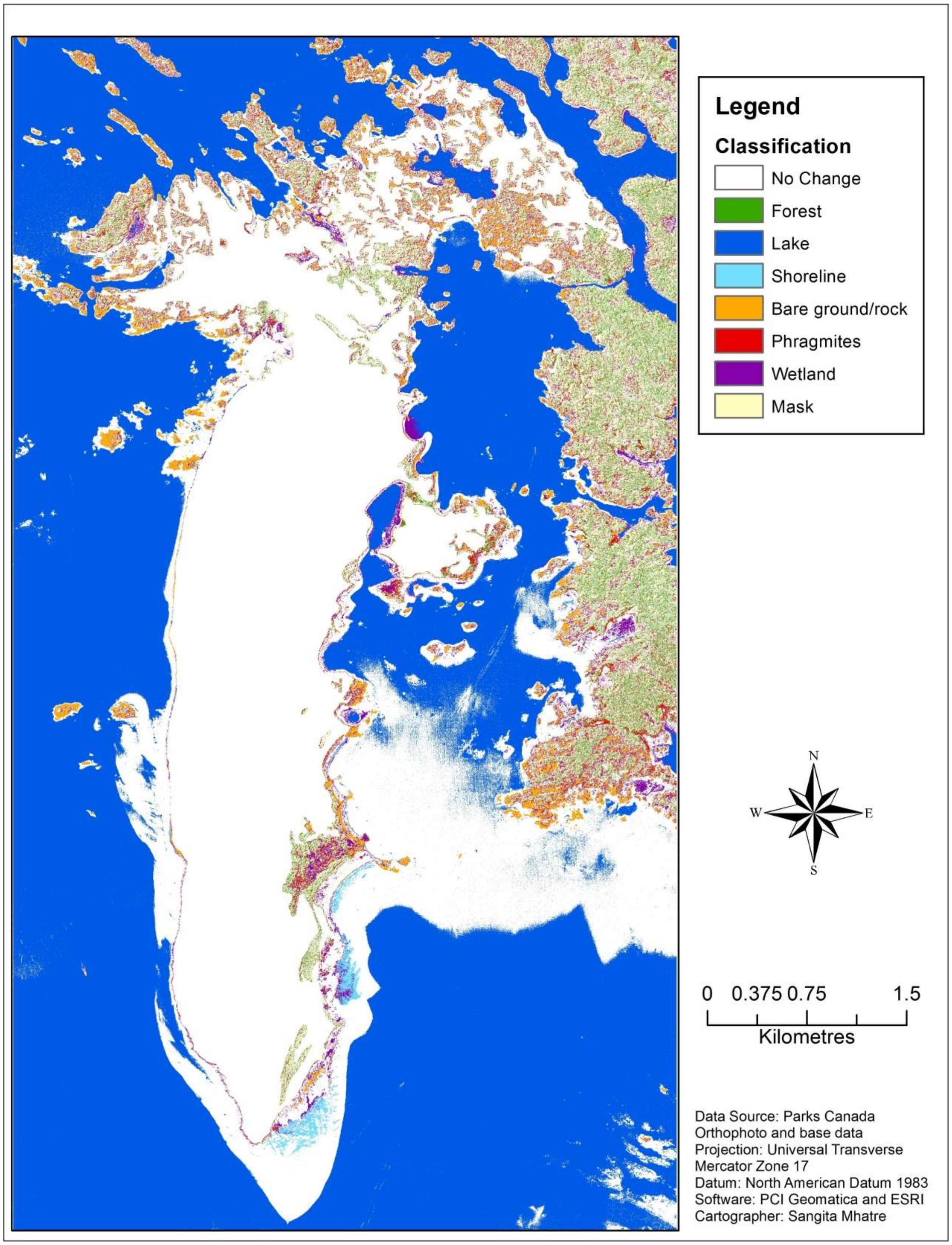

Figure 3.27: Change Image multiplied to Classified Image

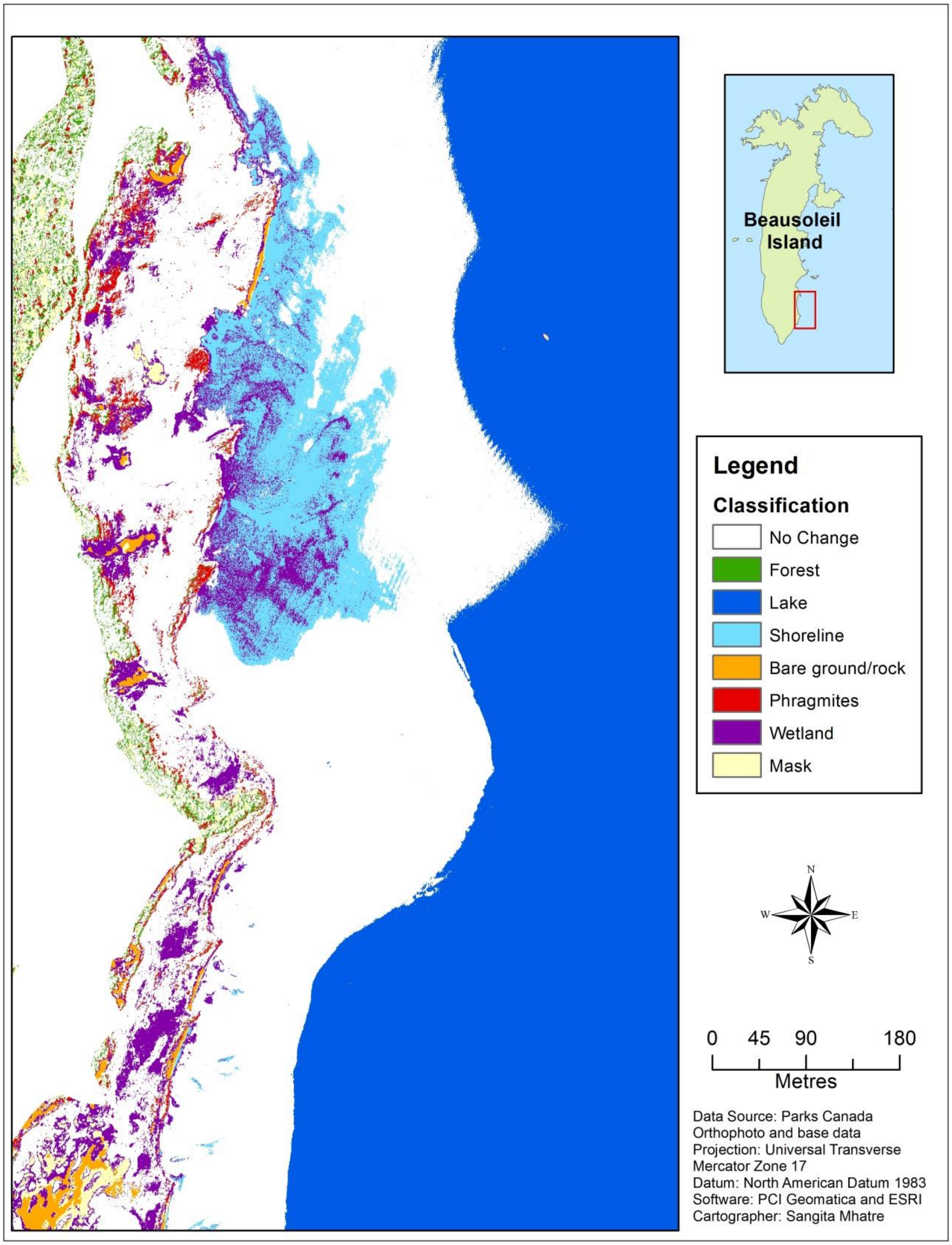

Figure 3.28: Phragmites and Wetland Change

3.5 ACCURACY ASSESSMENT

An accuracy assessment was performed on all the maximum likelihood classified images with 300 random samples sites chosen by PCI Geomatica. The Phragmites could not be detected at the 60cm resoultion in the Quickbird image, because the pixel size may have been too large for small patches or individual plants to be picked up at that resoultion. Phragmites may have been present at the park at the time in very small quantites, however, they were not detectable in the Quickbird image. Therefore, the wetland class is examined in the Quickbird image.

Four classification variations were performed on the Quickbird image (Table 3.1). The best of the classification for the wetland class is the four image bands plus the NDVI, and mean texture (NIR band). The best classification has an overall accuracy of 86.00%, and reflects the total number of correct classified pixels over the total number of referenced pixels (Lillesand and Kiefer, 2000). The mean texture classification has the best overall accuracy compared to the others, when taken into account with the producer's and user's accuracy. The producer's accuracy of 88.89%, indicates "…how well training set pixels of the given cover type are classified" (Lillesand and Kiefer, 2000). Therefore, the wetland training class was classified effectively. The user's accuracy is the probablity that a pixel classification is the same on the ground, which in this case is 88.89%, and again which is effectively classified. Even though the bands, plus the NDVI classification have a higher producer's accuracy and overall accuracy, the user's accuracy is low indicating that the pixels have a higher probability of being wrong on the ground. The worst classification of the Quickbird image were the four bands, indicating only that the NDVI and mean texture increased the accuracy.

Table 3.1: Quickbird Image (Wetland Class)

Bands	Overall Accuracy (%)	Producer's Accuracy (%)	User's Accuracy (%)
Blue, Green, Red, NIR	77.00	70.00	77.78
Blue, Green, Red, NIR, NDVI	87.33	100.00	76.47
Blue, Green, Red, NIR, NDVI, B4 (NIR) Mean Texture	86.00	88.89	88.89
Blue, Green, Red, NIR, NDVI, B4 (NIR) Mean Texture, DEM	84.33	60.00	85.71

The error confusion maxtrix of the bands, plus NDVI and NIR mean texture (Table 3.2) classification, illustrates the missclassified classes and the diagonal down represents the correctly classified. Therefore, the wetland class is well classified, but there is some confusion with the polygon mask class. The forest class also indicates low accuracy, because of confusion with the polygon mask class. The polygon class that the error confusion matrix refers to is the classification of spectral signatures under the mask, and determines the same signatures outside the mask. The lake is the best classified, because it has the most area on the image and has the most training sites.

Table 3.2: Error Confusion Matrix Quickbird Image

Referenced Data

Classified Data

	Null Class	Forest/ vegetation	Lake	Shoreline	Bare ground/ rock	Wetland	POLYGON	Totals
Null Class	0	0	0	0	0	0	0	0
Forest/vegetation	0	22	0	0	0	0	0	22
Lake	0	0	195	4	0	0	0	199
Shoreline	0	0	8	25	1	0	0	34
Bare ground/rock	0	0	0	0	8	0	0	8
Wetland	0	1	0	0	0	8	0	9
POLYGON	4	23	0	0	0	1	0	28
Unknown	0	0	0	0	0	0	0	0
Totals	4	46	203	29	9	9	0	300

For a closer look at the accuracy statistics of the best classification of bands plus NDVI and mean texture (Table 3.3), the overall kappa statistic is 73.4%, which is lower than the overall accuracy more so than usual. However, in the wetland class the kappa statistic is still in very good agreement at 0.886. According to the producer's accuracy the lake, bare ground/ rock, and wetland classes have the highest accuracy, indicating that the training pixels for these classes are the most accurate. The user's accuracy has the highest percentages in the forest/ vegetation, bare ground/ rock and lake classes, and the wetland class has a lower accuracy. This can be explained by the difficulty of determining training classes for the wetland, which were dependent on visual inspection of the image and only training areas of known wetlands.

Table 3.3: Accuracy Statistics of Bands + NDVI + Mean (NIR band)

Overall Accuracy: 86% Overall Kappa Statistic: 0.734%

Class Name	Producer's Accuracy	95% Confidence Interval	User's Accuracy	95% Confidence Interval	Kappa Statistic
Null Class	0.000%	(0.000% 0.000%)	0.000%	(0.000% 0.000%)	0.000
Forest/ Vegetation	47.826%	(32.303% 63.349%	100.000%	(97.727% 102.273%)	1.000
Lake	96.059%	(93.136% 98.982%)	97.990%	(95.789% 100.191%)	0.938
Shoreline	86.207%	(71.932% 100.481%)	73.529%	(57.229% 89.830%)	0.707
Bare ground/ Rock	88.889%	(62.801% 114.977%)	100.000%	(93.75% 106.250%)	1.000
Wetland	88.889%	(62.801% 114.977%)	88.889%	(62.801% 114.977%)	0.886
POLYGON	0.000%	(0.000% 0.000%)	0.000%	(0.000% 0.000%)	0.000

As mentioned before, the green band mean texture worked the best in terms of texture analysis for the Orthophoto. Several classifications were completed (Table 3.4) with different layers on the orthophoto. The best classification was the four bands plus NDVI and the B3(green) mean texture. This classification had an overall accuracy of 88%. There was not a great difference between the overall accuracy of all four classifications for the orthophoto. However, the combination of producer's accuracy and user's accuracy resulted in the best Phragmites classification. The producer's accuracy of 71.43%, illustrates training pixels accuracy and the user's accuracy of 83.33% illustrates that the probablity of pixel on the ground is better.

Table 3.4: Orthophoto (Phragmites Class)

Bands	Overall Accuracy (%)	Producers Accuracy (%)	User's Accuracy (%)
NIR, Red, Green, Blue	87.00	75.00	50.00
NIR, Red, Green, Blue, NDVI	88.33	57.14	33.33
NIR, Red, Green, Blue, NDVI, B3 (green) Mean Texture	88.00%	71.43	83.33
NIR, Red, Green, Blue, NDVI, B3 (green) mean Texture, DEM	87.67	100.00	57.14

The error confusion matrix (Table 3.5) for the orthophoto best classification of four bands plus NDVI and (green band) mean texture illustrates that the lake, bare ground/rock and wetland classes are well classified. The phragmites are comparitively, less well classified. However, the invasive species only takes up a small portion of the image, resulting in less pixels being trained as Phragmites. Also, training was only done for phragmites where known Phragmites were located, to ensure correct classification of the invasive species. From the error confusion matrix, it is clear that there was some confusion of the Phragmites class with the wetland and polygon mask class. Since Phragmites are a wetland species that confusion is expected. Also, the polygon mask class is basically the forest class, which has some spectral similarity with the Phragmites.

Table 3.5: Error Confusion Matrix Orthophoto

Referenced Data

Classified Data

	Null Class	Forest/ Vegetation	Lake	Shoreline	Bare ground/ rock	Phragmites	Wetland	POLYGON	Totals
Null Class	0	0	0	0	0	0	0	0	0
Forest/vegetation	0	22	0	0	0	0	0	0	22
Lake	0	0	202	6	0	0	0	0	208
Shoreline	0	0	4	23	0	0	0	0	27
Bare ground/rock	0	0	0	0	4	0	0	0	4
Phragmite	0	1	0	0	0	5	0	0	6
Wetland	0	2	0	0	0	1	8	0	11
POLYGON	0	19	0	0	0	1	2	0	22
Unknown	0	0	0	0	0	0	0	0	0
Totals	0	44	206	29	4	7	10	0	300

For an in-depth look at the four bands plus NDVI, and (green band) mean texture, the accuracy statistic table (Table 3.6) illustrates the overall kappa statistic of 76.1% is much lower than the overall accuracy of 88%. The Phragmites kappa statistic is 0.829, which is in very good agreement. This study is mostly interested in the phragmites and is not as concerned with the other classes and their accuracy. The wetland class is in good agreement. The best producer's and user's accuracies are the bare ground/ rock class, but the Phragmites class is well in acceptable means as is the wetland class. The number of training classes and the percentage of image that the classes represent may affect the accuracies of the classification.

Table 3.6: Accuracy Statistics of Bands + NDVI + Mean (Green band)
Overall Accuracy: 88% Overall Kappa Statistic: 0.761%

Class Name	Producer's Accuracy	95% Confidence Interval	User's Accuracy	95% Confidence Interval	Kappa Statistic
Null Class	0.000%	(0.000% 0.000%)	0.000%	(0.000% 0.000%)	0.0000
Forest/ Vegetation	50.000%	(34.090% 65.910%)	100.000%	(97.727% 102.273%)	1.0000
Lake	98.058%	(95.931% 100.185%)	97.115%	(94.600% 99.630%)	0.9079
Shoreline	79.310%	(62.843% 95.778%)	85.185%	(69.933% 100.437%)	0.8360
Bare ground/ Rock	100.000%	(87.500% 112.500%)	100.000%	(87.500% 112.500%)	1.0000
Phragmite	71.429%	(30.819% 112.038%)	83.333%	(45.180% 121.487%)	0.8294
Wetland	80.000%	(50.208% 109.792%)	72.727%	(41.863% 103.592%)	0.7179
POLYGON	0.000%	(0.000% 0.000%)	0.000%	(0.000% 0.000%)	0.0000

3.6 RESULTS

The best classifications occurred with the four image bands, plus NDVI and mean texture. The best texture measure in the Quickbird case utilized the NIR band and for the orthophoto it was the green band. However, in all classifications there was confusion between the Phragmites spectral class and the forest/vegetation class. "The spectral signatures of emergent aquatic vegetation largely overlap with the signatures of terrestrial vegetation" (Liira et al., 2010). Even with the mask, this problem persisted, partly because it was not a full coverage mask. The polygon mask class recognized spectral signatures under the mask and created a class for the same signature outside the mask. Although this problem persisted, the shoreline of Beausoleil Island has been classified suitably in the forest/ vegetation classification. The Phragmites classification visually appears correct when examining the classification on the orthophoto (Figure 3.29).

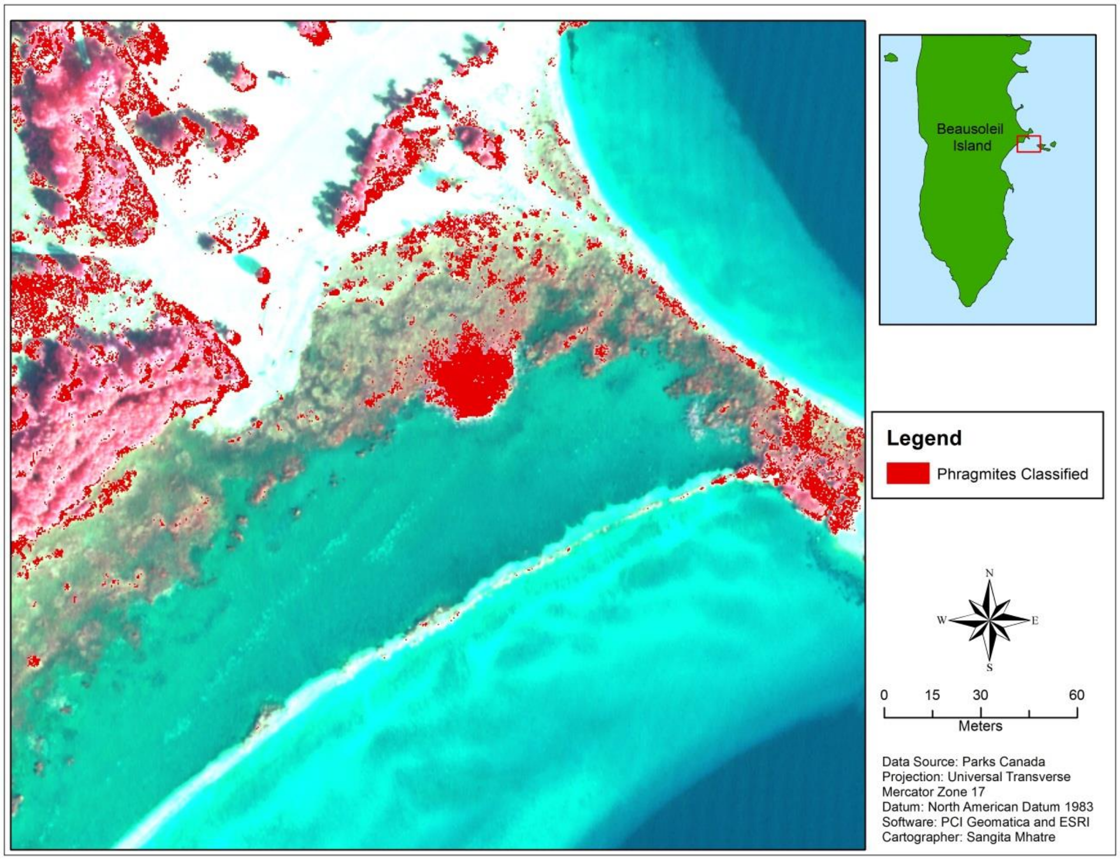

Figure 3.29: Phragmites Classification (classification imposed on orthophoto)

For the Quickbird image, the supervised classified areas were isolated for the wetland class. For the orthophoto, the supervised classified areas were isolated for wetland, Phragmites, and the combined wetland and Phragmites classes. Results from both images are shown below in Table 3.7. Wetland and Phragmites classes were also isolated from the change/no-change image to extract the area of change (Table 3.8).

Table 3.7: Raw Classification Areas for Images (km^2)

	Wetland classified	Phragmites Classified	Wetland & Phragmites Classified
Quickbird	2.12	N/A	N/A
Orthophoto	2.13	1.25	3.38

N/A – Not Applicable

Table 3.8: Change Image Areas (km2)

	Wetland Change	Phragmites Change	Total Wetland & Phragmites Change
Change Image	0.796	0.806	1.602

The Quickbird image supervised classification of the wetland (Figure 3.30) is accurate in terms of the location of wetlands. The wetland class within the Quickbird image has an area of 2.12 square kilometres. The wetland class within the orthophoto has an area of 2.13 square kilometres therefore, there is a negligible difference in area of wetland between the two images.

The orthophoto area of classified wetland was smaller at 2.13 square kilometres, and the Phragmites area (Figure 3.31) was calculated at 1.25 square kilometres. Therefore, the combined area of wetland, Phragmites (Figure 3.32) in the orthophoto is 3.38 square kilometres.

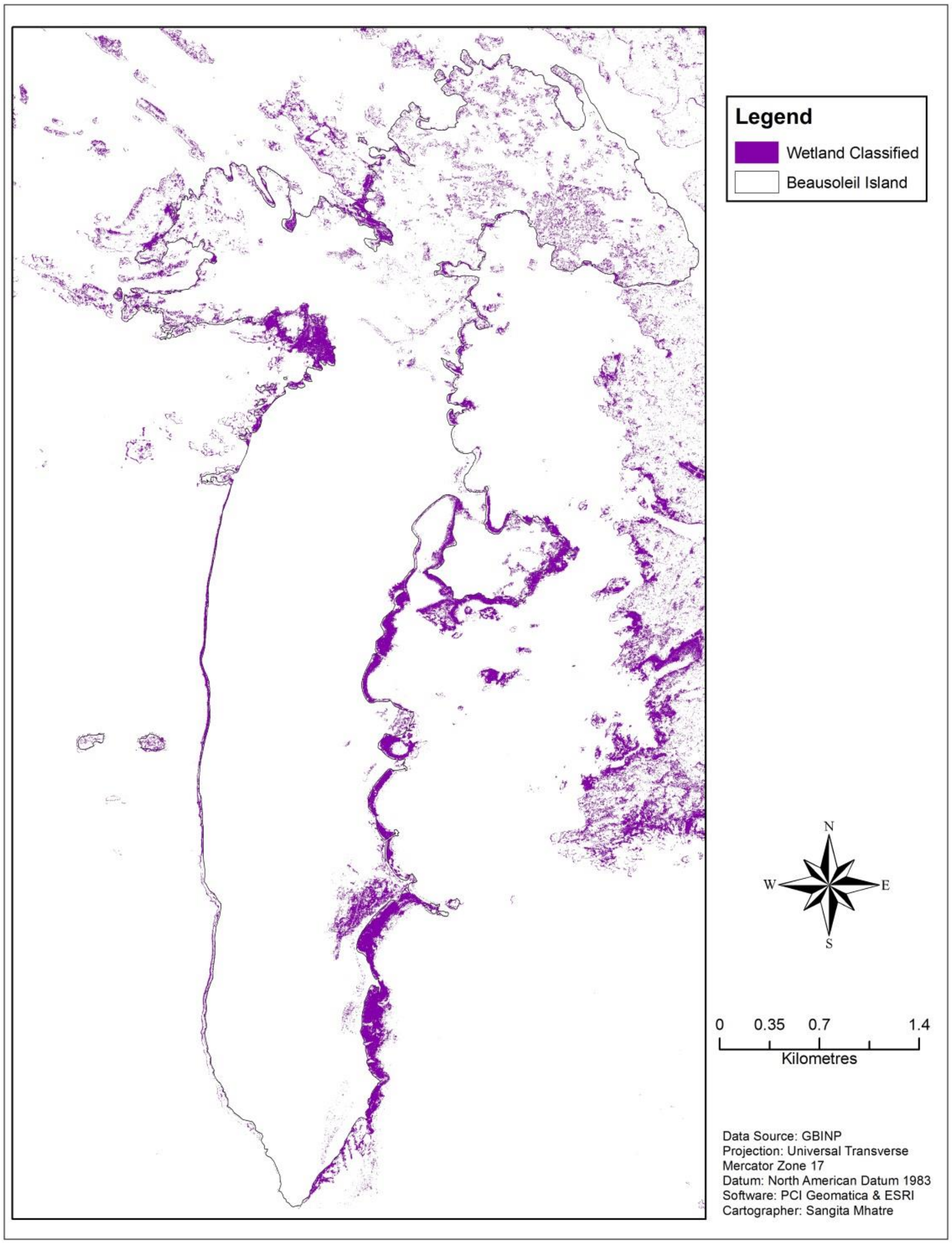

Figure 3.30: Quickbird Wetland Classification

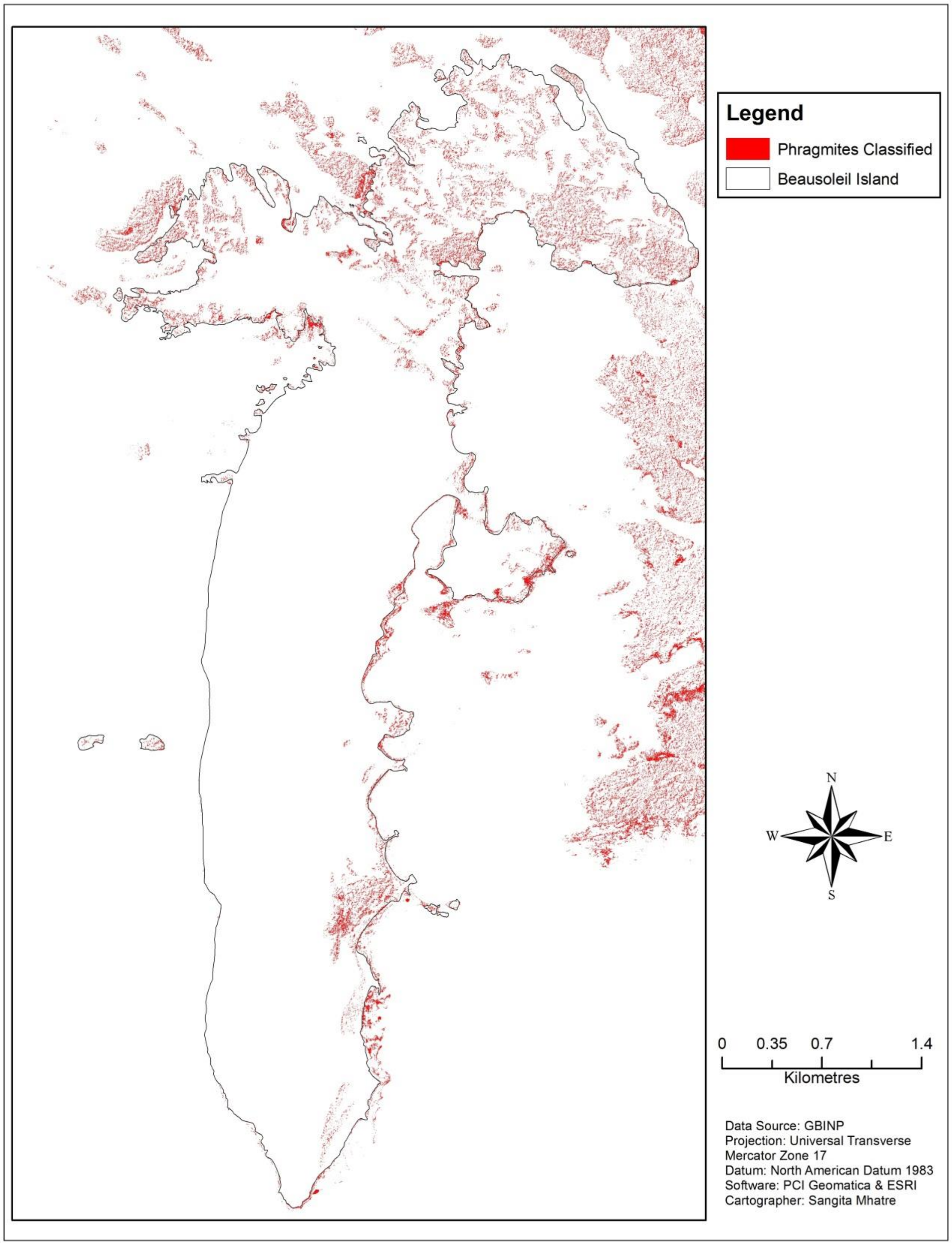

Figure 3.31: Phragmites Classification

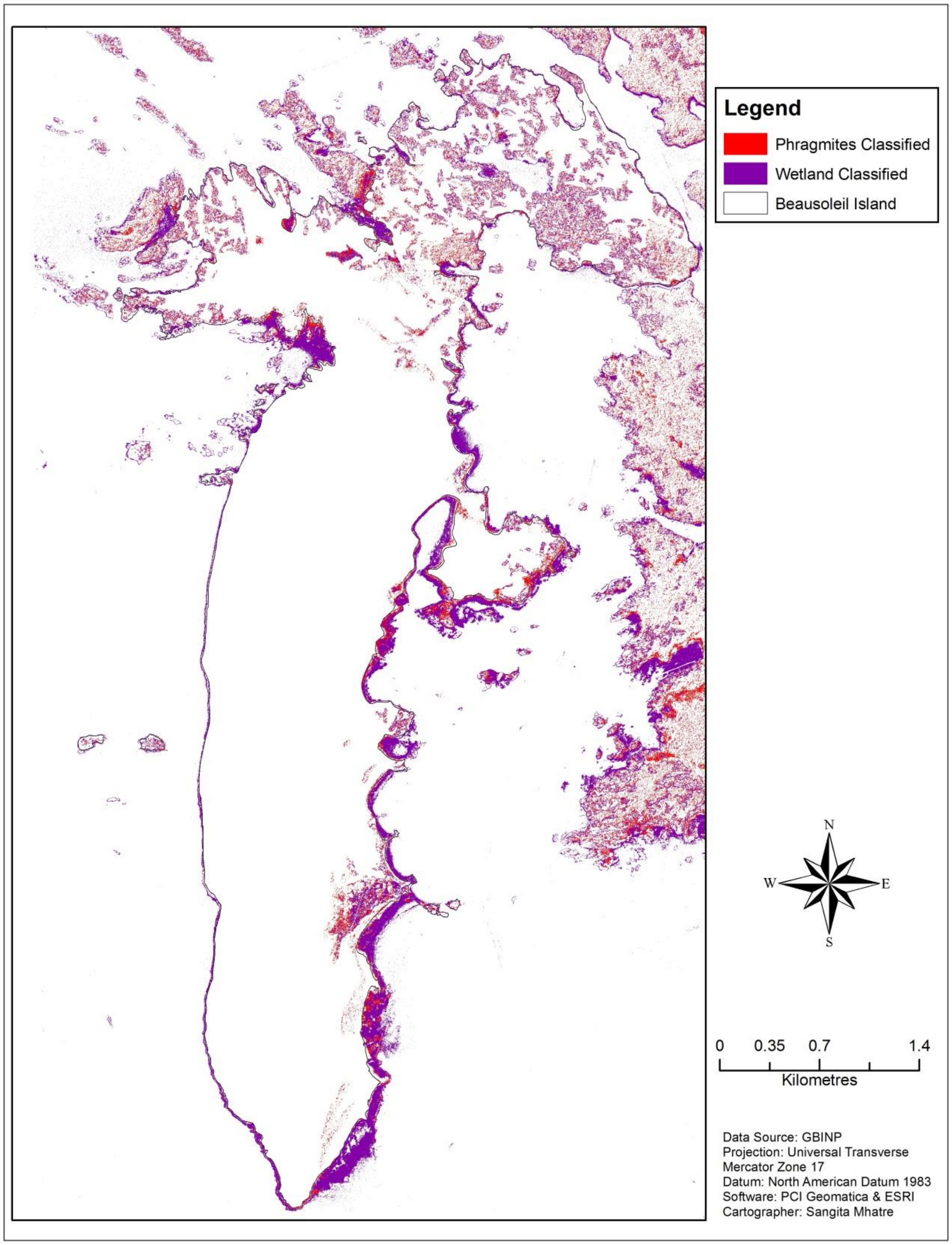

Figure 3.32: Phragmites and Wetland Classification

The isolated Phragmites class (Figure 3.33) from the change image, indicates less Phragmites than the raw classified image. The Phragmites class for the classified orthophoto has an area of 1.25 square kilometres, whereas the change image has an area of 0.806 square kilometres. The Quickbird image does not have a Phragmites class, so there should be no change in Phragmites area. However, this can be explained by the Phragmites taking over wetland area, thus change has occurred between wetland and Phragmites classes. The change image Phragmites has a smaller area than the raw classified, because the spectral similarity between classes would have been eliminated through the process of mathematical exclusion in creating the change image. Nevertheless, the change image Phragmites class still does have some spectral overlap seen in Figure 3.33, although not as extensive as the raw classified image.

The wetland class change image (Figure 3.34) highlights that there is less wetland than the raw classified image. The wetland change image has an area of 0.796 square kilometres, which is less than both classified images. Again, the smaller wetland class area can be attributed to elimination of errors through the subtraction process to create the change image and reduce spectral overlap.

Phragmites increased between 2003 and 2009 over the entire image area by approximately 0.806 square kilometres. The raw classified image indicated that an area of 0.496 square kilometres covered Beausoleil Island (Table 3.9). The results of the change image showed that an area of approximately 0.303 square kilometres (2.68% of Beausoleil Island) is covered with Phragmites.

Table 3.9: Beausoleil Island Phragmites Area

	Area (km^2)
Phragmites Classified	0.496
Phragmites Change	0.303

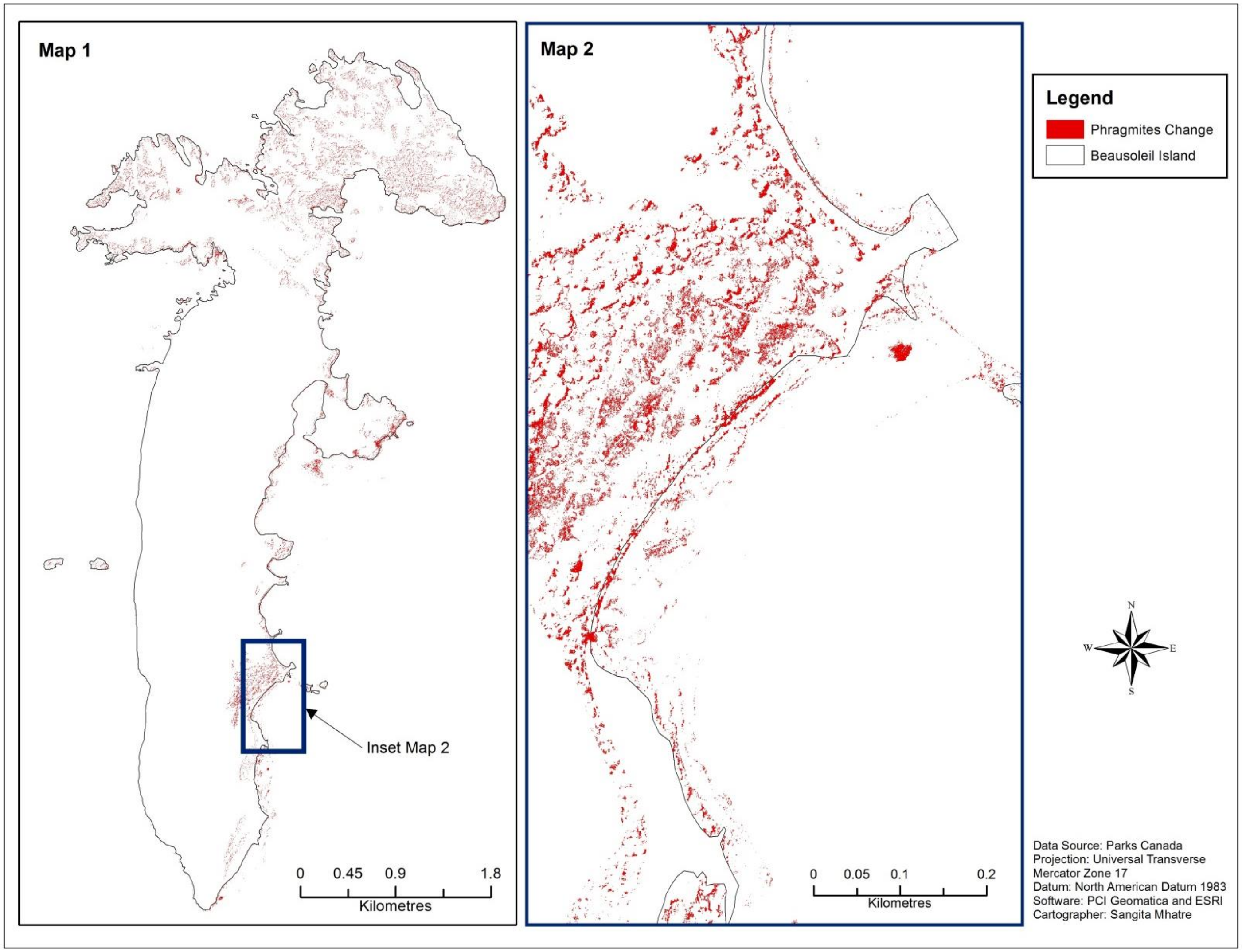

Figure 3.33: Change in Phragmites

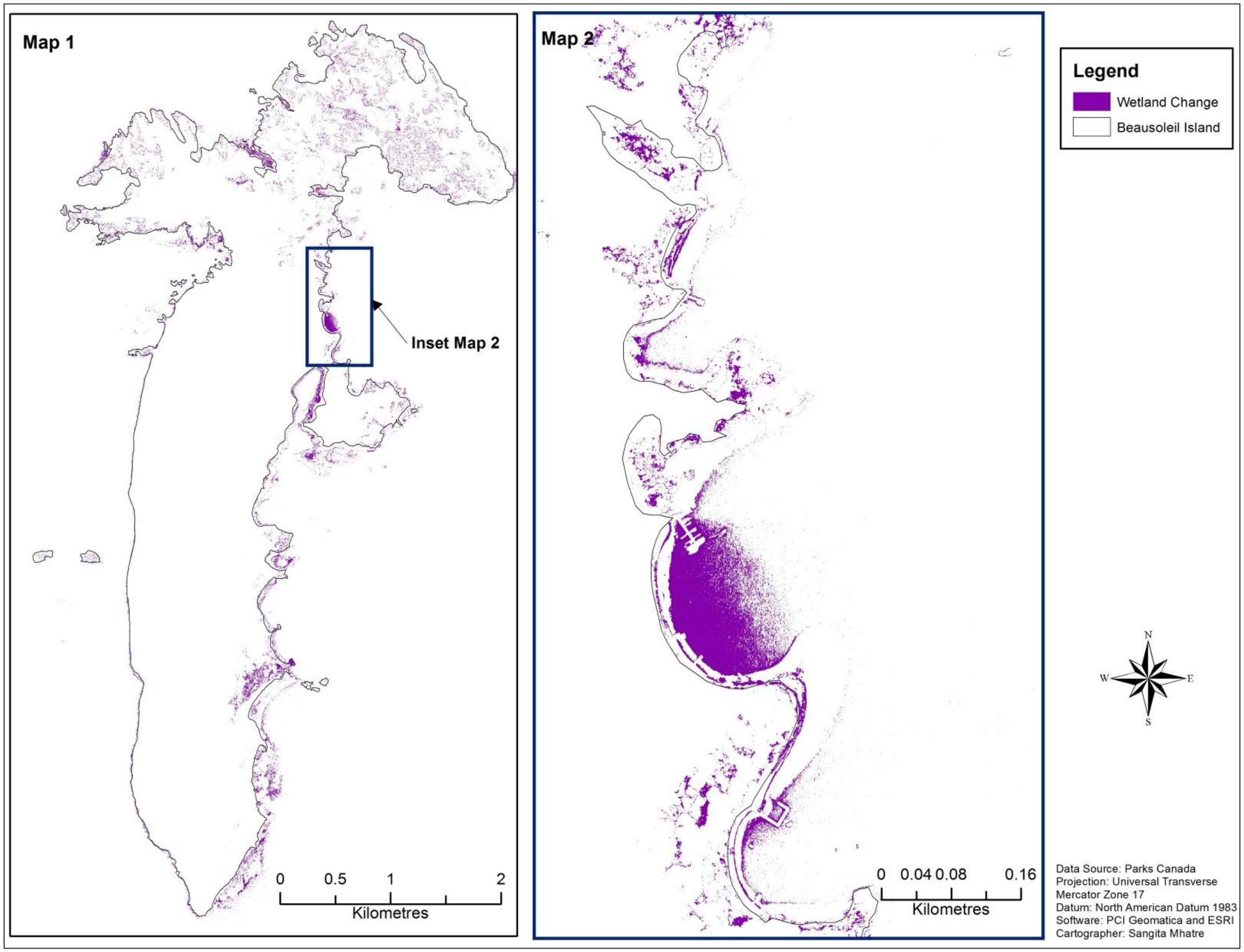

Figure 3.34: Change in Wetland

3.7 LIMITATIONS

The limitations of the study are the GPS Phragmites data accuracy of about 20 metres. A better accuracy could have been achieved by a differential GPS, which would have reduced the error and increased the accuracy to a few metres. Additionally, a high accuracy differential GPS would prove to be more effective than a handheld GPS. This would have made creating the training sites much more efficient and effective. However, the GBINP does not have access to this type of equipment.

The spatial resolution of the Quickbird image (60cm) was not as high as the orthophoto (40 cm), therefore, it was difficult to delineate training classes as there is a 20cm difference in pixel resolution. The difference in pixel resolution results in different spectral signatures, because pixels are merged together in the Quickbird image that would have ordinarily have been separated in the higher resolution image. The Phragmites training classes could not be determined from the Quickbird image, also the resolution made it difficult to determine refined wetland areas. A higher resolution image or one that was only a few years older than the orthophoto would have been beneficial. The other difficulty was the lack of visible Phragmites on the Quickbird image. It is not known if there were Phragmites in the park in 2003, and it was hard to determine if there were indeed any at the 60cm resolution.

The mask of the forested areas were extracted from the ELC data, extracted forest were included but not mixed with other types, such as treed bog or treed mixed swamps. This limited the analysis to shoreline wetlands and Phragmites invasion, because it excluded wetlands or water areas inside the island. Therefore, internal wetlands are excluded from the analysis. The incomplete nature of the mask for the forested areas created problems with the similar spectral signatures between the forest and the Phragmites, resulting in forest/ vegetation, Phragmites and mask polygon classes' confusion. Although, the change image removed some of the spectral overlap issues it did not solve all the overlap issues, especially where the mask did not cover forested areas as there was still confusion between the forest and Phragmites classes.

3.8 DISCUSSION

The mean classifications for both images performed the best, with high overall accuracies, for the Quickbird image 86%, and 88% for the orthophoto. The user's and producer's accuracies were acceptable. The kappa statistic for the Phragmites in the orthophoto was in good agreement. Confidence in the Phragmites classification is high. The accuracy results and the visual inspection of the classified Phragmites overlaid upon the orthophoto indicate correct classification along the shoreline. The classified Phragmites locations would correspond well with the reality on the ground based on the above examination even though there was some error incurred from the GPS Phragmites locations. The resulting error from the GPS locations proved to be minimal.

Despite the literature research of slope gradients, the DEM did not provide a significant increase in accuracies across the board. Beausoleil is a relatively flat area with little slope gradient, which may explain the lack of accuracy increase. However, the NDVI and texture measure of mean increased the accuracy of the classification.

Illustrated in the subset image, the Phragmites class has increased in area by approximately 0.806 square kilometres between 2003 and 2009. The area of Phragmites on only Beausoleil Island (excluding neighbouring islands) is 0.303 square kilometres, which is 2.68% of the Island. Phragmites do not appear to have been present in 2003, thus the invasion took place afterwards. The Eastern shoreline of Beausoleil Island appears to have the most Phragmites, this may be due to boat traffic and human activities prevalent along this shoreline. As well, the sheltered nature of the eastern shoreline may increase the Phragmites growth. Also, Phragmites seems to be prolific along private islands close to the eastern shore of Beausoleil.

3.9 CONCLUSION

The Quickbird image and orthophoto analysis provided a remotely sensed picture of Phragmites invasion along the shoreline of Beausoleil Island. From the images, there is a visible increase in Phragmites on Beausoleil Island, from 2003 to 2009. The classifications are improved by the inclusion of NDVI and mean texture measures. The DEM slope gradient proved less effective in increasing accuracy. The areas of Phragmites have been delineated according to classification. The green band difference change image combined with the classification illustrates the Phragmites growth.

This study was limited by the low accuracy of the Phragmites GPS points, incomplete forest mask, the exclusion of interior wetlands, the differences in image resolution and anniversary dates, and the lack of sufficient phosphorus data.

GBINP can use the classification information to go to the Phragmites locations on the ground and deal with the problem. The park can continue with management planning for Phragmites eradication, as they have already started a pilot project of cutting seed heads before they flower to reduce reproduction of the invasive species. The classification may also help the park compare data on patch sizes and areas of large invasion now that they have an overview of the area. The results confirmed their initial assessment of problem areas along the East shoreline of the Island. It also indicates that neighbouring islands may be contributing to the problem and if the park wants to eradicate the invasive species, they will have to work with its private neighbours. The park may be able to take remedial action and engage in management planning with this new information.

CHAPTER 4: SPECIFIC RECOMMENDATIONS AND CONCLUSIONS

Phragmites occur all along the shoreline of Georgian Bay as the supervised classification has verified. The plant species occurs in varying sizes, heights, patch densities, and may be mixed with other vegetation, or be contained in monotype stands. The reduction of biodiversity as Phragmites invades wetlands is well documented. Therefore, GBINP's interest in maintaining ecological integrity by developing a management plan for Phragmites is of great importance.

4.1 FURTHER REMOTE SENSING / GIS STUDY

Several remote sensing applications and GIS analyses may aid in providing a better picture of the problem by conducting a phosphorus study and/or embarking on a classification on the entire Georgian Bay area. Creating a statistically significant sample program for high traffic areas to determine phosphorous levels, which then can be analyzed in a Geographic Information System (GIS) would provide a better understanding of the interactions between human activities, water flow and plant growth. Further study of the entire Georgian Bay area, by performing another supervised classification on the whole area for Phragmites would enable the park and its neighbours to understand the larger macrosystem. This would enable the park to to gain a better perspective of this issue, in terms of how major or minor the invasion is for wetlands in the entire Georgian Bay area. A regional comparison can be used to determine how extensive the Phragmites invasion is in the park. Also, this may shed some light in what direction the Phragmites are spreading.

4.2 OPTIONS FOR REMOVAL OF PHRAGMITES

In terms of the physical elimination of Phragmites from the shoreline of GBINP, there are several options, including cutting, burning, weeding, smothering, compression, and herbicide (Gilbert and Letourneau, 2009). Cutting is the removal of seed heads before they burst into seed, which may be difficult in areas of submerged plants that are difficult to get to. Burning requires permission of government departments. However, the dangers of burning in an ecologically protected area may not make this a practical remedy considering the dangers to wildlife. The weeding option of hand pulling the Phragmites may be very labour intensive and time consuming considering the size and area that the plants cover. Smothering the plant in monotype stands by covering the area in a tarp cover for several years may be especially difficult in high traffic areas. Compression is the rolling heavy equipment on a dead stand once dry and brittle, often done in the winter months. The movement of heavy equipment into high water level areas would present many logistical challenges. The spread of herbicides requires permission from government departments. Herbicides are problematic, as they threaten endangered species and bio-accumulate in the wetland habitat. Children swimming and playing in the campground areas that are adjacent to the wetlands may be at health risk if spraying is conducted. Out of all the options, the cutting option is one that the park has attempted in a pilot project with some success (Parks Canada, 2011).

4.3 REQUIREMENTS FOR SUCCESSFUL REMOVAL OF PHRAGMITES

Considering the extensive nature of the Phragmites in the area, any plan will need to be attempted in conjunction with the park's private neighbours. Public education on Phragmites is necessary to generate public interest and awareness of the importance of the issue. As public interest regarding this issue increases, potentially more capital could be earmarked for GBINP to carry out a successful management plan for Phragmites removal. GBINP will need to work with federal departments and agencies as well as in partnerships with provincial and lower levels of government to ensure all parties act towards elimination of invasive Phragmites from Canadian wetlands. The Ontario Ministry of Natural Resources is involved with the provincial parks management of the Phragmites. The provincial parks may have advice on the most effective method of Phragmites removal in the Georgian Bay region. The Ministry of Transportation must be involved in ensuring policies and regulation to prevent the spread of Phragmites through the bilges of boats, as well as through transportation corridors. With an inter/intra governmental approach, the invasive Phragmites can be dealt with, thereby preventing the continued spread of this species throughout the region and Canada.

GBINP can use the results and maps presented in this study to illustrate where Phragmites are located on Beausoleil Island and on some neighbouring islands. By engaging in discussion with the parks neighbours, the maps provide visual evidence to educate their neighbours about the importance of eradication of Phragmites. The Park can also use this study as an independent unbiased resource for illustrating to the chain of command in the Parks Canada system, the importance of Phragmites removal. GBINP can also use the classified Phragmites locations as a map of where they need to focus Phragmites removal and prioritize areas to be dealt with first in the management planning for the Park. The results of this study also give an idea of the extent of the Phragmites problem on the shoreline of Beausoleil Island, and the Park may want to extend further study to the other Islands within the park in the future.

4.4 URGENCY OF THE PROBLEM

More research is needed but if that is the only focus it may just delay the management of the Phragmites, enabling the plant to have a stronger hold on the wetlands. Considering the biodiversity and sensitivity of the threatened and endangered species involved, action needs to occur as quickly as possible. Should no actions be taken in the immediate future in eliminating invasive Phragmites, many native species will lose habitat, forever altering the Georgian Bay ecosystem.

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