Dana Powell
REU August 17, 2007
Melanie Gunn, Ted Anderson,
Cindy Mom, Heather Siersma

# Distribution and Success of Native and Invasive *Phragmites australis* in Northern Michigan

## Abstract

*Phragmites australis*, or common reed, is represented by several subspecies (haplotypes) in North America. The native haplotypes are important components of wetland ecosystems, while a non-native haplotype introduced in the nineteenth century has become an aggressive invader. The goals of this study were to characterize the native and invasive haplotype distribution of Phragmites in northern Michigan, to determine which environmental characteristic are correlated with native, invasive, and overall Phragmites success, and to analyze the trends so that local potential predictors of Phragmites variable distribution and success might be identified. Fourteen wetlands were surveyed for native and invasive Phragmites stands. Ten native and four invasive stands were sampled. Environmental variables (including temperature, pH, proximity to human development, surface moisture, water conductivity and DO) and variables related to Phragmites success (stand area and density, height and diameter of the tallest stem, and leaf litter depth) were measured. In addition, each Phragmites site was paired to a similar site with no Phragmites. The data was compared for native, invasive, and control sites using paired T-tests and regressions. Temperature, human development, and, to some extent, water pH were found to be significantly linked to Phragmites haplotype variable distribution and success. Despite the limitation of small sample size, these early trends could be of particular relevance for land managers working to protect wetlands and slow invasive success. Among the environmental characteristic variables, temperature measurements resulted in the most comparisons with significance. Increased temperature seems to be linked to increased invasive success and decreased native success, with potential implications regarding the affects of climate change on wetlands in northern Michigan.

## Introduction

*Phragmites australis* (common reed, hereafter referred to as Phragmites) is a tall perennial grass found worldwide. Native varieties are an important component of mixed wetland communities (DEQ 2007). At least eleven native haplotypes (genetic strains) of Phragmites are known in the United States (Saltonstall 2002). Together, these related haplotypes form the subspecies *P. australis* subsp. *americanus* (Lambert and Casagrande 2006). In the late nineteenth century, a Eurasian strain (haplotype M, *P. australis* subsp. *australis*) was introduced to the eastern U.S., probably in ship ballast (Meadows and Saltonstall 2007). Throughout the past century this aggressive invader has spread across the contiguous United States and southern Canada, forming especially dense monocultures along the east coast (Saltonstall 2002). Once established, *P. australis* subsp. *australis* spreads quickly, replacing *P. australis* subsp. *americanus* and other native plants and diminishing habitat quality and overall biodiversity (Saltonstall and Stevenson 2007).

Attempts to protect important and already threatened wetlands from this invader have prompted management actions, including burning, flooding, and herbicide treatments (DEQ 2007). However, the morphological distinctions between invasive and native Phragmites are only beginning to be understood and are not widely known. There is concern that efforts to eradicate invasive Phragmites fail to protect native strains (Lambert and Casagrande 2006). Recognizing the differences in morphological characters could help wetlands managers make informed decisions about invasive Phragmites control. Such morphological distinctions are becoming better known, with guidelines established by Bernd Blossey at Cornell University and others (Blossey 2003). However, limited time and resources often prevent thorough surveys of regions with Phragmites growth of unknown origin. It would be useful to develop reliable predictors of invasive versus native success, especially at a local to regional scale. These predictors could be derived from correlations between habitat characteristics and Phragmites success. Invasive monitoring could then be effectively prioritized for these regions of potential susceptibility, while areas important for native Phragmites success could be protected.

Northern Michigan may be at a critical time regarding non-native Phragmites invasion. While the non-native was introduced to the region relatively recently, Phragmites can spread at alarming rates (Wilcox et al. 2003). Taking management action soon may be necessary to prevent the growth of harmful invasive monocultures. The invasive haplotype was first established on the lower Great Lakes by the 1960's (Wilcox et al. 2003). Recently, a study on Lake Erie Phragmites in southwest Ontario found 90% of local stands (28/30 stands) to be the M haplotype (Wilcox et al. 2003). Preliminary observations revealed both native and invasive Phragmites stands in northern Michigan, though very large monocultures (greater than 1 ha) were not observed. Land managers have noticed a substantial Phragmites increase in recent years, though it is generally unknown which stands are native and which are invasive (Mom and Gunn, pers comm). The westward spread of invasive Phragmites, confirmed and dramatic invasions to the south, and preliminary observations suggest that this could be a critical time for monitoring and potentially managing invading Phragmites in northern Michigan.

Though generally considered a wetland species, Phragmites grows successfully in marshes, along streams and riverbanks, on brackish and freshwater shorelines, in roadside ditches, submerged more than 2m underwater (Herrick and Wolf 2005), and in dry upland areas. It reproduces from both seeds and vegetative growth. The rhizomes can spread up to 10 meters a season to form new shoots and roots. The seeds are shed from November through January, establishing in new, exposed sites earlier than most propagules (Wilcox et al. 2003).

Non-native Phragmites stands are denser (more culms per meter) than native stands, have greater biomass, and disperse more rapidly (Meadows and Saltonstall 2007). The closely packed stems and deep leaf litter inhibit growth of other species, leading to the formation of large monocultures. Extensive Phragmites growth may build up sediments, alter water flow, and reduce existing habitat heterogeneity (Wang et al., 2006). Stands can also inhibit growth of other species, slow organic decomposition and alter nutrient cycling, and change the environment in other ways (Wilcox et al. 2003).

Recent Phragmites literature hypothesizes several environmental factors that may be correlated with native and especially invasive success. It is possible that one of these factors is the primary driver behind native and/or invasive Phragmites success. Most likely, there are combinations of habitat conditions that, if well understood, could potentially predict native Phragmites success or susceptibility of an area to non-native Phragmites invasion. This study aimed to measure native and invasive Phragmites success in a variety of habitats in northern Michigan. It compared environmental factors (including salinity, disturbance, nutrients, pH, and others) at each site to Phragmites success to determine if any correlations are apparent. Any observed trends could then help identify potential Phragmites success predictors that can be used to direct monitoring and management activities. It is hoped that this will assist in protecting susceptible habitats in the region from invasive Phragmites.

Disturbance, either due to anthropogenic or natural stresses, may make wetlands more susceptible to Phragmites invasive expansion (Lambert and Casagrande 2006). Lambert and Casagrande's study in Rhode Island found native Phragmites in an area that was only recently developed, while elsewhere older coastal development had enriched salt marsh nitrogen and led to the subsequent growth of invasive Phragmites (2006). In addition, the invasive was found in increasing abundance in areas that were more disturbed. It has also been suggested that environmental stresses may alter competitive relationships between native and invasive species such that a habitat could become more invasable (Alpert et al. 2000). Eutrophic conditions may facilitate Phragmites establishment (Meadows and Saltonstall 2007). In the mid-Atlantic U.S., present and historic census data for human population density has been correlated to differential invasive Phragmites success in different regions. Geographical isolation seems to be negatively correlated with non-native establishment and vigor. For example, the most southern part of the Delmarva Peninsula (surrounded on three sides by the Atlantic Ocean and Chesapeake Bay), has the fewest invasive and most native Phragmites in the region (Meadows and Saltonstall 2007).

It has been suggested that Phragmites invasion in the Great Lakes region is facilitated in part by declines in water levels and an increase in ambient air temperature. Higher average daily temperature has been linked to increases in Phragmites shoot elongation during the main growth phase (Wilcox et al. 2003). Temperature has already been seen to increase in the region due to global climate change, and both temperature and water level are predicted to change further with future climate projections (Wilcox et al. 2003). This raises another potential benefit of understanding Phragmites' invasion drivers: we will be more capable of predicting how climate change may exacerbate invasive success.

Salinity may play a role in Phragmites success, either by providing favorable conditions for optimal growth, or less directly by affecting competitive success. Native Phragmites stands have been known to grow with water salinity up to 27% (Lambert and Casagrande 2006). However, it is thought that native Phragmites prefers lower salinity, and lab experiments confirm that invasive strains are more successful than native strains in higher salinity (Meadows and Saltonstall 2007). It has been suggested that Phragmites spread could be linked to increased salinity in wetlands due to de-icing road salts (Wilcox et al. 2003).

There are other factors that may be influencing differential Phragmites success. These could include nutrient levels (Saltonstall and Stevenson 2007) and pH. Because wetlands are complicated systems with interacting components, it is important to test as many plausible contributors to Phragmites success as possible. This study is limited by time and resources, and is able to address only some of the many potential contributors. However, any environmental factor that can be strongly correlated with Phragmites success may prove useful in determining the true drivers. This is true whether the factor is acting as a direct or indirect driver, or if the environmental variable co-varies with a true driver. Any correlation could potentially help in directing conservation efforts towards areas with greater invasion susceptibility.

## Study Questions

The goals of this study were three-fold: to characterize the native and invasive haplotype distribution of Phragmites in Northern Michigan, to determine which environmental characteristic are correlated with native, invasive, and overall Phragmites success, and to analyze the trends so that local potential predictors of Phragmites variable distribution and success might be identified. These study questions can be broken down into four specific stages:

Stage 1: Large scale distribution

1a. What is the distribution of invasive Phragmites in northern Michigan?

1b. What is the distribution of native Phragmites in northern Michigan?

Stage 2: Local success

2a. Within areas that have invasive Phragmites, where is it most successful?

2b. Within areas that have native Phragmites, where is it most successful?

Stage 3: Potential drivers of local success (using paired presence vs. absence samples to measure variables)

3a. Within areas that have invasive Phragmites, what determines its success?

3b. Within areas that have native Phragmites, what determines its success?

Stage 4: Relative success

4a. Within areas that have both native and invasive Phragmites, what determines relative success?

## Methods

Sampling took place between 4 July and 8 August, 2007. Areas with Phragmites were located in a variety of regions, including wetlands, shorelines, and roadsides in Northern Michigan' Cheboygan, Emmett, and Mackinac counties. Locations were selected where Phragmites had been seen or was suspected based on habitat (i.e. areas that meet known requirement for Phragmites growth in early stages of invasion[1]). Most sites in this study were suggested by other researchers at University of Michigan Biological Station and by Little Traverse Conservancy staff and volunteers[2]. At each area proximity of the nearest road, public beach, boat traffic,

[1] Area must be somewhat inundated with water at any time of year (Gunn, pers comm 2007).

[2] We are not concerned that this creates biased site selection because morphological distinctions between native and invasive are not common knowledge; no site suggestions included even attempted identification of haplotype.

impermeable surface, and other signs of human development was noted. For site descriptions, see Appendix A. For GPS projections of sample site locations, see Appendix B.

Starting at the point of first access to the area, the entire area was surveyed along the lake shore, road, etc., walking more north than south and more east than west to eliminate bias. Each stand[3] was identified as native or invasive. The number of native and/or invasive stands was recorded. This basic data regarding presence and absence of Phragmites is included in Appendix A. Phragmites stands ("P+ Sites") to sample within the area were then located: the first stand of invasive ("P+I"), and the first stand of native ("P+N") encountered in the survey were sampled. A control site with no Phragmites ("P- site") was then chosen for the area. This site was located approximately 100 meters from the first P+ site sampled with neither invasive nor native Phragmites (further than 20 meters from any stand). Furthermore, the P- Site was chosen to have at least three abundant non-Phragmites plant species that match those of the first P+ site, and, if applicable, with at least three abundant non-Phragmites species that match those of the second P+ site.

Each site was described as "more developed" or "less developed" based on the rough estimate of human activity nearby. If a site was on a highway or within five kilometers of a city it was considered more developed. If it was not, it was considered less developed. This rough estimation allowed for a larger sample size for each category and gave more power to the statistical analysis.

Because Phragmites (especially invasive stands) could be altering the habitats in which it is found (Wang et al., 2006 and Wilcox et al. 2003), it was important to distinguish between pre-existing characteristics of an area (such as sediment type) and characteristics of an area with Phragmites present when looking for potential Phragmites drivers. Samples had to be taken far enough from a stand to reduce the chance that Phragmites affected the variables, but near enough to be useful in describing the conditions as they were likely to have been when Phragmites became established at that site. P+ sites were sampled with this in mind, using the following protocol:

1. At each stand, measure/record:
    a. GPS location.
    b. Dimensions (max. width by max. length). Calculate area assuming stand is ellipse shape.

   In a 1 meter quadrant, placed at the densest part of the stand, measure/record dependent variables:
    c. Culm density (new year's growth). Also, collect 6 culms for reference/ID confirmation.
    d. Height of tallest culm.
    e. Diameter at base of tallest culm.
    f. Leaf litter depth.
    g. Distance to nearest standing water.

   At the driest point/shallowest water nearest the meter quadrant (but no less than 1.5 meters from any culm or Phragmites leaf litter), measure/record independent variables:
    h. Surface moisture on scale from 1 (moisture undetectable to touch) to 5 (standing water). If 5, record depth.
    i. Surface substrate type (especially: sandy or not sandy).
    j. Take soil core for future reference, using 25cm corer with diameter approx. 2cm.
    k. If no standing water available, take soil sample near soil core for pH. This is a composite sample of three soil cores taken 30cm apart.
    l. Ground temperature (while shading thermometer).
    m. Ambient temperature (about 1.3m height, while shading thermometer).
    n. Core temperature (depth about 15 cm, in hole left from soil core).

   At the wettest point/deepest water nearest the meter quadrant (but no less than 2 meters from any culm or Phragmites leaf litter), measure/record at about 10cm depth independent variables:
    o. DO and temperature (with DO meter).
    p. Conductivity and temperature (with conductivity meter).

[3] One stand is defined as a continuous clump of culms with no obvious physical connection to adjacent clumps, after Meadows and Saltonstall (2007). A mixed stand of invasive and native culms will be counted as one stand of each, but this is rarely seen in the region now.

q. pH (with pH meter).
r. Take water sample for future reference.

2. Sample P- sites: after locating control site, measure/record independent variables
3. Measuring pH from soil samples in the lab (protocol from Mike Grant, resident chemist at University of Michigan Biological Station):
    a. For each sample, homogenize soil in blender.
    b. Measure 10g (accurate within 0.1g) of soil into cup.
    c. Add 50mL deI. water, stir.
    d. Let sit undisturbed for 40min.[4]
    e. Measure pH with meter.

## Paired T-Tests

Several types of comparisons were analyzed to address the broad scope of the study questions. Each of each of the independent variables (environmental characteristics) was compared with paired T-tests for 1) native versus control sites, 2) invasive versus control sites, and 3) native versus control sites. The variables analyzed were water pH, soil pH, water temperature (from meters), ambient, ground and core temperature (from thermometer), the difference between ambient and ground temperature, the difference between ambient and core temperature, surface moisture, conductivity, and dissolved Oxygen. Also, if a paired T tests showed that there was no significant difference between native and invasive sites for a particular variable, the native and invasive values were averaged and compared in another paired T test to the control sites. This was to address the question of whether the variable influences the presence of Phragmites in general.

## Regressions

Linear regressions were run to compare each independent variable (environmental characteristic) to each dependent variable (measure of Phragmites success) for native and invasive stands. For regressions, independent variables were water pH, water temperature, ambient, core, and ground temperature, surface moisture, conductivity, and dissolved Oxygen. Dependent variables were area of the stand, height of the tallest culm, diameter at base of the tallest culm, culm density, and leaf litter. Scatterplots were created for selected regressions for assistance with locating outliers and recognizing trends.

## Sturgeon Bay Inorganic Nitrogen Comparison

To determine if nutrients could be influencing native and/or invasive Phragmites success, an inorganic Nitrogen comparison was performed at the Sturgeon Bay site. The protocol used was based on Freyman and Jankowski's unpublished protocol from 2005.

Composite soil samples (each sample is three cores taken 30cm apart) were collected at Sturgeon Bay. 15 samples total were collected from the native (6 samples), invasive (5), and control (4) site. The P+ samples were taken in a ring around the stand between 1 and 2 meters from all culms and leaf litter, except one sample in each (later excluded) from the stand center. The protocol for analysis is included as Appendix C.

## Flowering Times

At each stand, the presence or absence of inflorescences (at any stage of visible development) was noted. A stand was described as "flowering" if it had any inflorescences when observed on a date between Jul. 18 and Aug. 6, 2007 (the date of first observed inflorescence and last date on which both native and invasive were observed, respectively). If it was observed between these days and did not have any inflorescences, it was described as "not flowering". Berndt Blossey suggests flowering time may be an indicator of native or invasive status (Blossey 2003). To confirm this, both a Chi Square analysis with the Yates correction and a Fisher's Exact Test were used to compare invasive and native flowering.

---

[4] Samples from Cheboygan Marsh and Cheboygan State Park were measured at 40 min. and allowed to sit for an additional 40 min. to settle more completely; the pH values analyzed were from the 80 min. readings because multiple readings of each sample at this point were more accurate than multiple readings at the 40 min. mark. However, it is possible that more soil dissolved during the extra settling time, making these values less comparable to the samples from other sites read at 40 min.

## Results

Of 14 wetlands sampled, ten had native stands (Douglas Lake Maple Bay, Cecil Bay Road, Crooked Lake N, Crooked Lake S, Duck Bay, Douglas Lake North Fishtail Bay, Sturgeon Bay, Cheboygan Marsh, Cheboygan State Park, and Lark's Lake) and four had invasive stands (Cheboygan Marsh, Cheboygan State Park, Sturgeon Bay, and Rt. 31). Cheboygan Marsh's sampling site was a mixed stand, with one distinctly native half and one distinctly invasive half as well as some overlap. This mixed stand was considered as two stands: one invasive and one native stand. The only invasive stand at Cheboygan State Park completely surrounded a very small (area approx. $1m^2$) native stand; because the entire perimeter of the stand and the vast majority of the interior was invasive, this stand was used for the Cheboygan State Park invasive study site. It is not expected that the native culms in this stand would affect the variables measured in this study.

Our ability to correctly distinguish between native and invasive haplotypes using morphological features was confirmed by Dr. Bernd Blossey of Cornell University's invasive plants department. He pointed out the pronounced redness of the region's native Phragmites' culms, suggesting that our use of this characteristic as one of the primary identifiers was valid.

### Paired T-Tests

Paired T-tests were used to compare native and invasive environmental variables. Because of the small sample size, it was impossible to make some of the comparisons for some of the variables. However, 36 paired T tests were run. Of these, two were significant.

The paired T-test used to compare surface moisture (on scale from 1: moisture undetectable to the touch, to 5: in standing water) for P- Control Sites and P+ Sites (P+ is the average of the P+N Sites and the P+I Sites) showed a significant relationship. Surface moisture was greater at sites with Phragmites (P+ Avg.) than at sites without (P-) P=0.028, df=8, n=9.

Results of the paired T-test for Ambient temperature (ºC), measured with a thermometer at 1.3m, for native stands (P+N) and control sites (P-) suggests that ambient temperature is significantly lower at the native sites (P=0.037, df=7, n=8).

### Regressions

40 regressions were run with data from native stands, and 20 regressions were run for invasive stands. (The smaller invasive sampling size resulted in insufficient data to run some of the regressions for some of the variables.) Of these, four regressions were significant ($p<0.05$), one was nearly significant ($p<0.1$), and the rest were non-significant. The significant and nearly significant results will be discussed here.

Water temperature and stand area are significantly negatively correlated (p=0.034) at native stands, with an R sq. linear value of 0.555 (Figure 1). Core temperature and stand area are significantly negatively correlated (p=0.018) at native stands, with an R sq. linear value of 0.706. (Figure 2).

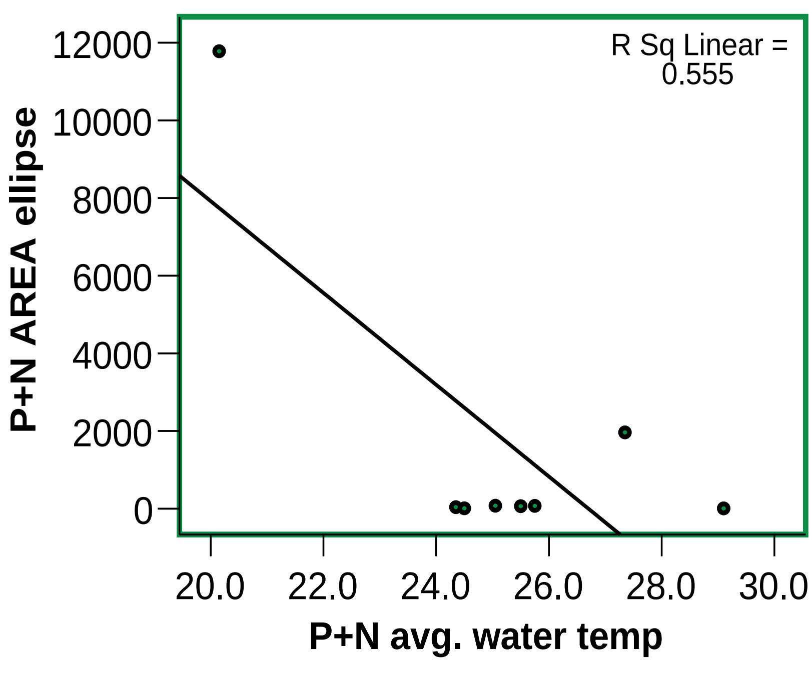
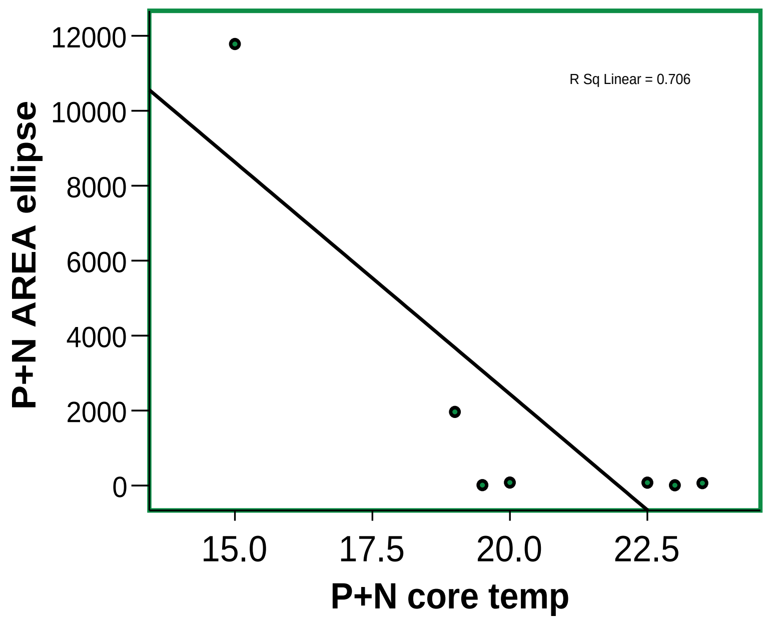



**Figure 1: Stand area ($m^2$) assuming ellipse-shaped stands is shown as compared with water temperature (average of water temperature (ºC) from conductivity and DO meters) for the sites with native Phragmites. The regression is shown with best-fit line. P=0.034, R Sq Linear=0.555.**

**Figure 2: Stand area ($m^2$) assuming ellipse-shaped stands is shown as compared with core temperature (measured with thermometer at depth 15cm) for the sites with native Phragmites. The regression is shown with best-fit line. P=0.018, R Sq Linear=0.706.**




When analyzed with the Duck Bay site outlier (area =11,781 $m^2$) removed, ambient temperature and stand area are positively correlated (p=0.013), with an R sq. linear value of 0.606. (Figure 3) The regression for ambient temperature and native stand area is not significant when the outlier is included (p=0.126). With the outlier removed, the regression for core area and native stand area is not significant (p=0.254). Also, with the outlier removed, native stand area and ground temperature are nearly significantly positively correlated (p=0.054), with an R sq value of 0.606.

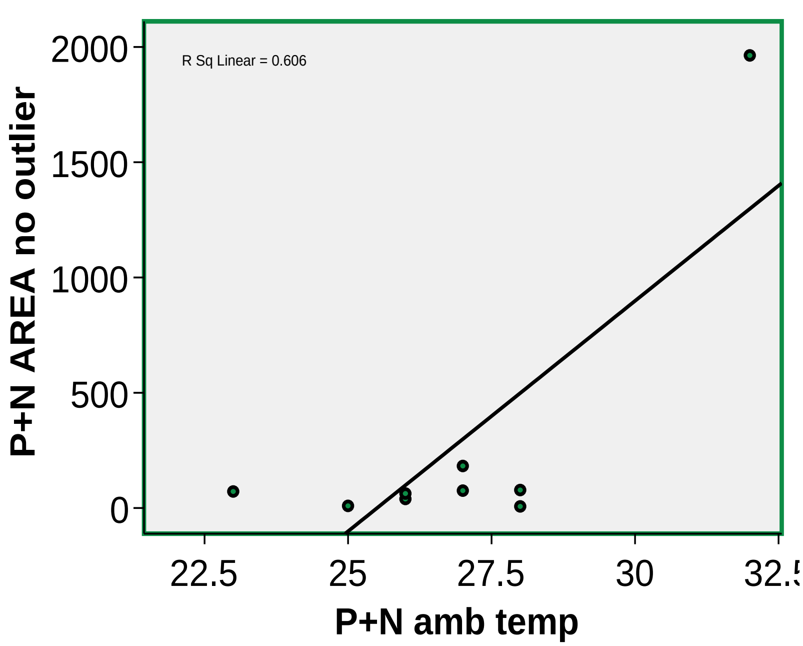



**Figure 3: Stand area ($m^2$) assuming ellipse-shaped stands is shown as compared with ambient temperature (°C), measured with thermometer at 1.3m, for sites with native Phragmites when the Duck Bay outlier is removed. The regression is shown with best-fit line. P=0.013, R Sq Linear=0.606.**

The regression for ambient temperature and average maximum height at invasive stands suggests a strongly significant positive correlation (p=0.001), with an R sq. linear value of 0.998 (Figure 4).

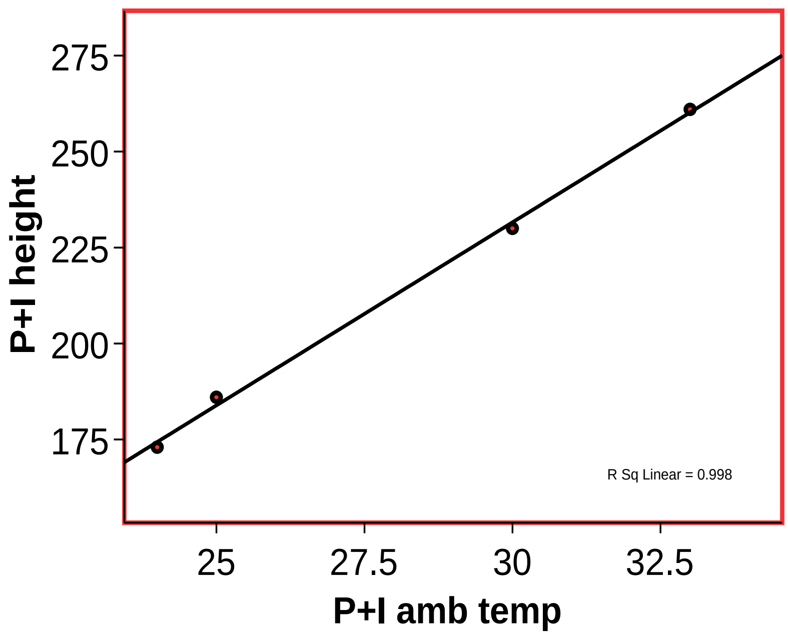



**Figure 4: Height of tallest culm (m) is shown as compared with ambient temperature (measured with thermometer at 1.3m) for the sites with invasive Phragmites. The regression is shown with best-fit line. P=0.001, R Sq Linear=0.998.**

The regression for water pH and density (culms/m) of native stands shows a significant positive correlation (p=0.030), with an R sq. linear value of 0.572, (Figure 5). However, the regression for water pH and native stand area is a nearly significant (p=0.053) negative correlation, with R sq. value of 0.491.

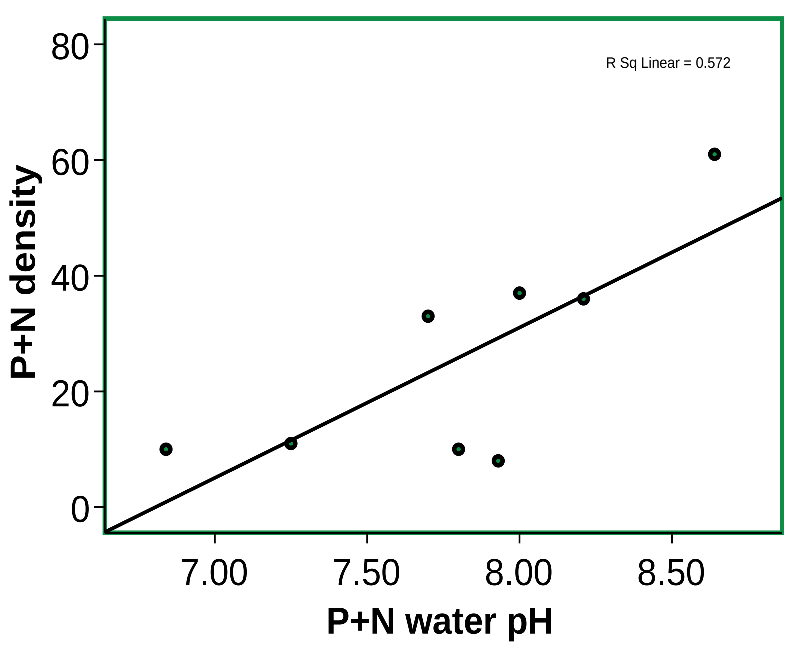



**Figure 5: Density (culms/m) is shown as compared with water pH (measured with meter at 10cm depth) for sites with native Phragmites. The regression is shown with best-fit line. P=0.001, R Sq Linear=0.998.**

### Sturgeon Bay Soil Nutrient Analysis

The Sturgeon Bay soil nutrient $NH_4$ and $NO_3$ comparisons between native, invasive, and control sites were analyzed with ANOVA. Results were non-significant for both nitrate (p=0.124) and ammonium (p=0.199), suggesting inorganic nitrogen does not differ significantly between the sites.

### Flowering Times

During the defined flowering observation period, five native stands were seen flowering and no native stands were observed without inflorescences. Two invasive stands were seen with inflorescences and two were seen without. The Yates Chi Square analysis of native versus invasive flowering resulted in $X^2 = 0.972$, less than the critical value of 3.84. This result is non-significant. Confirming non-significance was the Fisher's Exact Test for flowering, which resulted in p=0.166.

### Development

In this study, three out of four invasive sites sampled were considered more developed and one was considered less developed. One native site was more developed and nine were less developed. The Yates Chi Square analysis of native versus invasive development level had a $X^2 = 3.159$, or nearly significant (p =0.076) result that invasive occurs with more development more than native. The Fisher's Exact Test result was significant (p=0.041).

## Discussion

### Temperature

This study suggests that temperature may be one of the most important environmental factors contributing to variation in distribution and success of native and invasive Phragmites. This trend was seen in paired T tests and in regression analyses with significant and nearly significant data. Higher temperature is correlated with invasive success, specifically as measured in height, confirming the findings of Wilcox et al. (2003). Increased temperature is also associated with reduced native success (particularly with area measurements). Furthermore, the trend of higher temperature correlated with variable native and invasive success is suggested from several different kinds of temperature readings (water, soil, and ambient temperature).

Reasons why increased temperature might be more detrimental for native while favoring invasive Phragmites need to be elucidated with further research. It may be that higher temperature benefits both haplotypes. Invasive Phragmites may be more able to take advantage of this change, perhaps enabling the invasive haplotype to compete better with the native. It would also be interesting to study whether temperature affects invasive and/or native initial establishment as compared to their clonal spread.

If temperature is favoring invasive Phragmites growth, there could be several implications for land managers and policy makers. It is important to study whether other invasive plants may be benefiting in similar ways. The possibility of increased temperature favoring invasive *Phragmites* and other invasive success is an alarming example of the complex implications of climate change. With temperatures already rising in the Great Lakes region and predictions for much higher temperatures in the future, now is the time for control and mitigation (Wilcox et al. 2003). The more we understand about specific alterations climate change is imposing on local ecosystems, the more apparent it is that this global issue needs to be addressed.

### pH

One regression analysis—the comparison of pH with stand density—suggests that native stands may do better in more basic environments. However, the data remains somewhat ambiguous, with the pH and native stand area regression showing a nearly significant negative correlation. pH may be a secondary variable, reflecting an indirect affect of another variable that could be more directly related to Phragmites success. If pH is related to a limiting resource for native Phragmites, it would benefit land managers to develop a better understanding of these processes and their potential implications for successfully managing Phragmites. For instance, monitoring efforts could look to more basic environments if the pH trend of this study is confirmed to locate and protect the most successful native Phragmites stands as the region becomes more threatened by the invading non-native haplotype.

### Sturgeon Bay Soil Nutrient Analysis

The particularly small sample size in this component of the study (only one stand of invasive, and native, along with a control sites) makes it difficult to elicit broad conclusions from the nutrient data. However, if additional samples revealed similar results at Sturgeon Bay and other sites to those collected, it would seem that inorganic Nitrogen has a small role if any in Phragmites distribution and success. More in-depth studies should be pursued to better understand the influences of nutrient levels, but at this time there seems to be little predictive value in inorganic Nitrogen as it relates to native or invasive Phragmites.

### Flowering

No significant trend was seen in flowering time variation between the two haplotypes. However, sampling limitations again may have resulted in less powerful statistical analyses. The trend of native stands tending to flower earlier than invasive stands has been described broadly, but use of this characteristic for northern Michigan haplotypes remains ambiguous (Blossey 2003). If additional data collected for this variable were to confirm earlier flowering times of native versus invasive stands, flowering time may prove to be a useful tool in the local field identification of haplotypes.

### Development

The variable of human development was perhaps most difficult to define given the relatively small scope of this study. All sites were described in overly simplistic categories of more developed or less developed to enhance the power of statistical analyses with the small sample size. However, a significant trend emerged within this framework such that invasive Phragmites stands tended to be observed in areas of more development while native stands seemed to be in less developed areas.

That development may be favoring invasive Phragmites has large implications for local land managers, land owners, and policy makers. Limited wetland conservation resources can be directed to give monitoring priority to developed and developing areas. In this case, roadside monitoring and early invasive mitigation may be a relatively easy way for local governments to prevent widespread non-native Phragmites invasion. Roads inherently enable access to what seem to be susceptible areas. On that note, however, the specific factors contributing to variable Phragmites success in more developed regions need to be further elucidated. Studies have suggested that roadside salting may be increasing Phragmites spread (Wilcox et al. 2003), and that increased salinity may favor the invasive (Meadows and Saltonstall 2007). Along with the early trend seen here for development and invasive success, a simple study could investigate the role of salinity may have as a more direct distribution and success driver. The lack of standing water at several sites in this study prevented conductivity measurements. Perhaps a comparison of soil salinity at Phragmites stands throughout the region could provide more insight into the relationship between salinity, and Phragmites success and distribution, and potentially human development.

## Conclusions and Future Directions

By far, the strongest trend of this study is the tendency for increased temperatures to predict decreased native Phragmites success and increased invasive success. Significant results followed this trend for a variety of temperature measurements (ambient, soil, and water readings), and for different success variables (particularly with stand area and height). While it is important to engage in further research that could help sort out these variables, there is certainly a strong call to action with this preliminary data.

Affects of rising temperatures are of great concern in northern Michigan, where climate change has been linked to already rising temperatures and warmer conditions are predicted for the future (Wilcox et al. 2003). That non-native Phragmites growth (and potentially other invasives) may be favored by such an altered environment adds to the complexity of the issue. While researchers work to better understand the nature of this relationship, controlling the underlying drivers for climate change should be of utmost priority. The accumulating evidence that global climate change is leading to varied, complex, and predominantly detrimental effects for ecosystems emphasize the need for a greater understanding of local temperature changes (IPCC 2007).

Altered hydraulic regimes due to climate change and other factors may be particularly relevant to variable Phragmites success in northern Michigan, which has many types of wetlands. *Phragmites*, unlike other prominent invasives, has been found to be more common in undiked (as opposed to diked) wetlands in the Great Lakes region. Diked wetlands are typically shallower, but have more intense waves and thus sandier soil (Herrick and Wolf 2005); these factors could be linked to *Phragmites* success. However, *Phragmites* is considered by some to have low tolerance for wave and current action, which can break culms and interfere with rhizome bud formation (Wilcox et al. 2003). Also, wide-ranging water level fluctuations have been shown to favor *Phragmites* (Herrick and Wolf 2005). Less flooding during growth stages is generally conducive to *Phragmites* success, but it may be that the invasive is more flood and wave tolerant than the native. One morphological distinction used by Berndt Blossey is sturdiness of stems: the invasive tends to have more upright stems in a strong wind than the native (Blossey 2003). Native and invasive *Phragmites* success should be compared in areas with various hydraulic regimes. It is possible that stand location (say, a stand nearer water) within a given area could also be correlated with relative flood tolerance and success. It is thought that the Great Lakes water levels will decline with rising global temperature (Wilcox et al. 2003). This makes it imperative to study the variable distribution and success of Phragmites haplotypes as they relate to both temperature and hydraulic regime. More data could help elucidate the specific implications of climate change for the role of invasives in future wetlands vegetative community composition.

As drivers for non-native Phragmites and other invasives success become clearer, land managers, policy makers, and conservationists will become more enabled to control and mitigate non-native invasions. Herbivory may be a major source for variations in invasive success (Alpert et al. 2000); researching local Phragmites variability may be the next step in northern Michigan. In this study it was casually observed that herbivores (especially aphids) were often seen on native Phragmites, but not on invasive Phragmites. This was especially notable in mixed stands. The predominantly invasive stand sampled at Cheboygan State Park surrounded a small stand of a few native culms, all of which were covered in aphids. However, none of the invasive culms at this site seemed to have aphids. This pattern was also casually observed at other sites. It would be useful to study variations in herbivory on the different haplotypes—work that has been started for various species with invasive and native taxa (see, for example Alpert et al. 2000). If herbivory is burdening native stands to a greater degree, this data could provide more insight into the drivers for invasive success in the non-native haplotype.

The purpose of this study was to examine a wide range of variables to determine any suggestions of environmental predictors of invasive and native Phragmites distribution and success. Because the study was limited by time, the sample size was small, reducing the power of some statistical tests and making it difficult to interpret the data conclusively. That several trends were observed despite the study's limitations emphasizes the need for continued investigations into local drivers for variable Phragmites haplotype distribution and success. Meanwhile, timing is critical regarding non-native Phragmites invasion. The preliminary work done in this study can be used by land managers to more efficiently monitor for invasive Phragmites, and to more effectively prevent large-scale invasion, while protecting native Phragmites.

## Acknowledgements

Heather Siersma, Melanie Gunn, Ted Anderson, Cindy Mom, Dave Karowe, Mary Anne Carroll, Lane Barham, Dan Larkin, and the Team *Typha* lab, Mike Grant and Johnna, and Bob Vande Kopple, the National Science Foundation, and the staff and volunteers of the Little Traverse Conservancy were all vital to the completion of this project. I thank them for all their generous assistance, and my fellow R.E.U. interns for their insights and support.

## Literature Cited


Alpert, Peter, Elizabeth Bone and Claus Holzapfel. 2000. Invasiveness, invasibility and the role of environmental stress in the spread on non-native plants. Perspective in Plant Ecology, Evolution and Systematics 3(1):52-66.

Blossey, Bernd, Cornell University. 2003. Phragmites: Common reed. Retrieved July 2007. <http://www.invasiveplants.net/phragmites>

DEQ (Michigan Department of Environmental Quality) Office of the Great Lakes. 2007. A Landowner's Guide to Phragmites Control. Lansing, MI.

Freyman, Monika and KJ Jankowski. Unpublished protocol: Soil/sediment Ammonia and Nitrate Method Used Summer 2005 [sic]. University of Michigan Biological Station. Pellston, MI.

Gunn, Melanie E, M.S., Lecturer, School of Natural Resources & Environment, University of Michigan. University of Michigan Biological Station. Pellston, MI. Jul. 2007.

Herrick, B.M. and A.T. Wolf. 2005. Invasive plant species in diked vs. undiked Great Lakes wetlands. J. Great Lakes Res., Internat. Assoc. Great Lakes Res. 31(3): 277-287.

IPCC: Intergovernmental Panel on Climate Change. Climate Change 2007: Impacts, Adaptation and Vulnerability, Working Group II Contribution to the Intergovernmental Panel on Climate Change Fourth Assessment Report, Summary for Policymakers. Brussels, Apr. 2007.

Lambert, Adam M. and Richard A. Casagrande. 2006. Distribution of Native and Exotic *Phragmites australis* in Rhode Island. Northeastern Naturalist 13(4):551-560.

Meadows, Robert E. and Kristin Saltonstall. 2007. Distribution of native and introduced *Phragmites australis* in freshwater and oligohaline tidal marshes of the Delmarva Peninsula and southern New Jersey. Journal of the Torrey Botanical Society 134(1): 99-107.

Mom, Cindy. Stewardship Specialist, Little Traverse Conservancy. Petoskey, MI. Jul. 2007.

Saltonstall, Kristin. 2002. Cryptic invasion by a non-native genotype of the common reed, *Phragmites australis*, into North America. PNAS 99(4): 2445-2449.

Saltonstall, Kristin and J. Court Stevenson. May 2007. The effect of nutrients on seedling growth of native and introduced *Phragmites australis*. Aquatic Botany 86(4):331-336.

Wang, Q., C.H. Wang, B. Zhao, Z.J. Ma, Y.Q. Luo, J.K. Chen, and B. Li. 2006. Effects of growing conditions on the growth of and interactions between salt marsh plants: implications for invasability of habitats. Biological Invasions 8:1547-1560.

Wilcox, Kerrie L., Scott A. Petrie, Laurie A. Maynard, and Shawn W. Meyer. 2003. Historical Distribution and Abundance of *Phragmites australis* at Long Point, Lake Erie, Ontario. J. Great Lakes Res., Internat. Assoc. Great Lakes Res. 29(4):664-680.

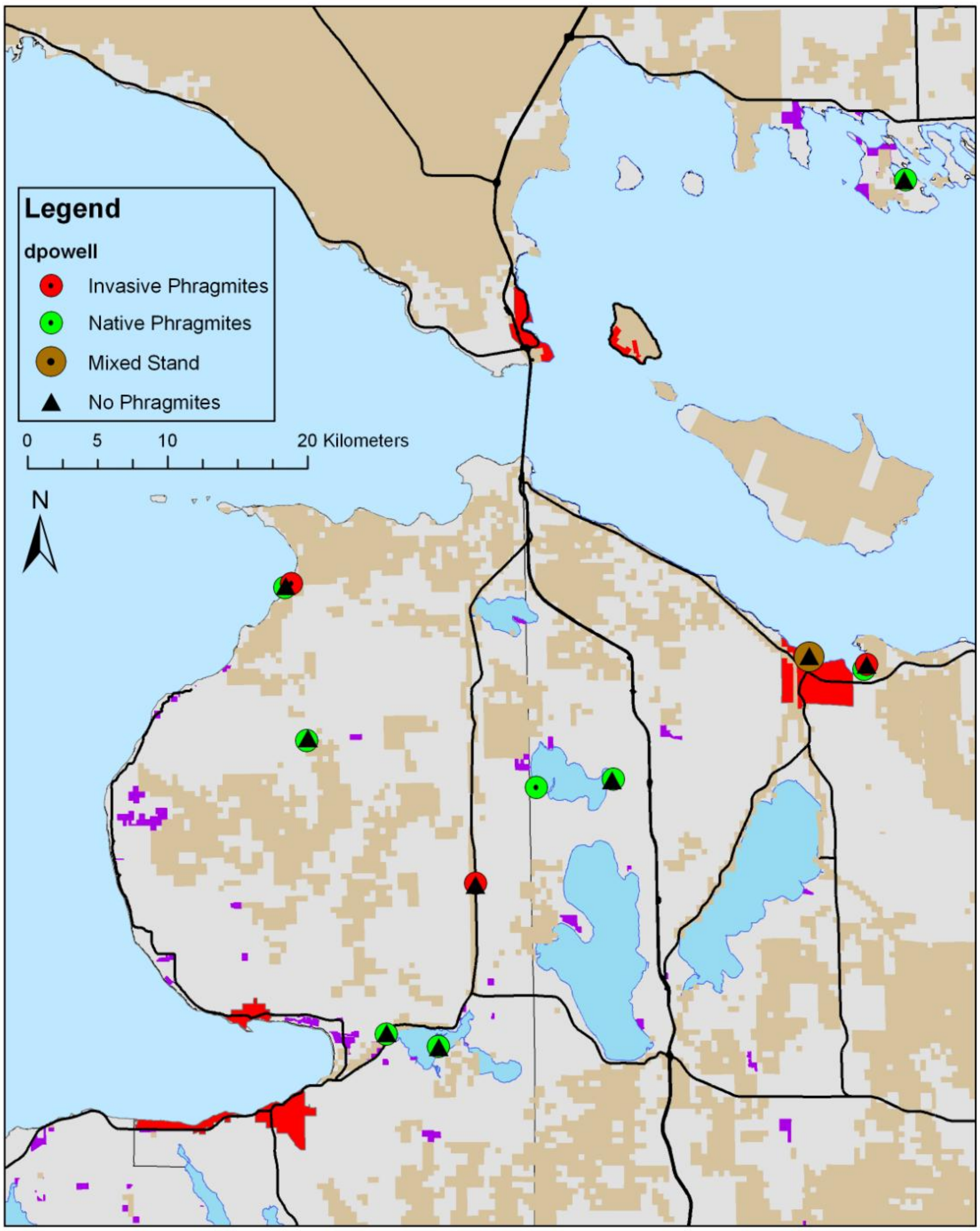
Appendix A: Description of Phragmites sampling sites in northern Michigan.

| **Phragmites Site Descriptions** | | | | | |
|---|---|---|---|---|---|
| **Stand/s Sampled, (Other stands seen in area)** | **County** | **Region Name** | **Region Description** | **Area Name** | **Area Description** |
| Native (Only on shore, Emergent Native stand seen in Lake on Phragmites Flat) | Cheboygan | Douglas Lake (Maple Bay) | Inland freshwater lake w/ boat traffic | Maple Bay | Maple Point. SW part of lake, accessed by Silver Strand Rd. |
| Native (Possibly more Native stands on roadside to the N) | Emmett | Cecil Bay Road | 2 lane back road | Cecil Bay Rd. roadside | On vegetated roadside ditch, ending at forest |
| Native (Only stand seen) | Emmett | Crooked Lake (N) | Inland freshwater lake w/ boat traffic | Along US Rt. 31, just NE of Little Traverse Township Park | On vegetated roadside slope, which ends at sandy lake edge |
| Native (Several Native stands seen) | Emmett | Crooked Lake (S) | Inland freshwater lake w/ boat traffic | Along Oden Island Rd. (SW side), accessed by Channel Rd. | On vegetated roadside slope, which ends at cobbled lake edge |
| Native (Other stands seen in Duck Bay, haplotype unknown) | Mackinac | Duck Bay on Marquette Is., in Les Cheneaux Islands | Freshwater bay w/ boat traffic, off of Straits of Mackinac | N side of bay, in state-owned land | Extensive marsh, with conifers to N and W bordering wide grass-dominated area in which stand was found, with *Schoenoplectus sp.* (?) and then *Typha sp.* stands towards water |

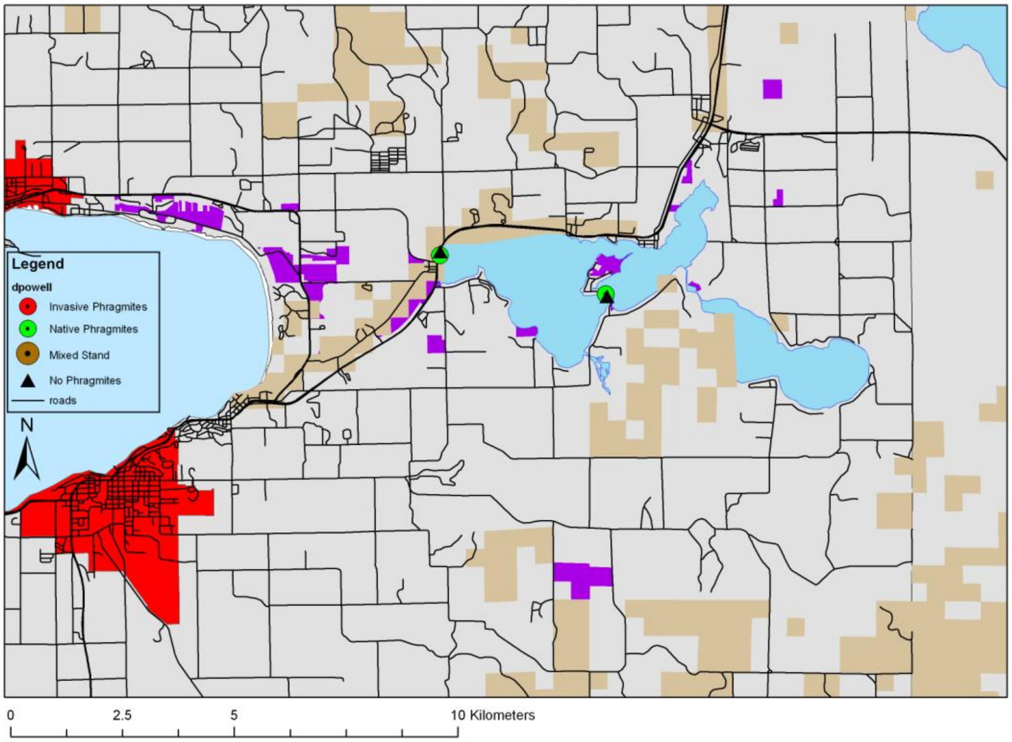
| | | | | | |
|---|---|---|---|---|---|
| Native (Only stand seen) | Cheboygan | Douglas Lake (North Fishtail Bay) | Inland freshwater lake w/ boat traffic | N of Pine Point, near North Fishtail Bay | Inland (near shore) wetland with *Myrica gale*, bordered by forest |
| Both (Several Native and Invasive stands seen, few or no mixed) | Emmett | Sturgeon Bay | Bay of Lake Michigan | Wilderness State Park | Sandy beach with some tidal pools |
| Invasive (Single stand seen) | Emmett | US Rt.31 | 2 lane highway | E side of road, S of Woodland Rd. | Roadside ditch, below elevation of highway, field to the E, forest NE |
| Both:Mixed (Only stand seen) Native mostly to the N, Invasive mostly S within stand | Cheboygan | Cheboygan Marsh | Marsh on Lake Huron (Gordon Turner Park) | Near parking area, overlooked by boardwalk | large *Typha spp.*-dominated marsh with Lake Huron shore to the E, tree fringe about 10m N of stand. |
| Both: Native stand and one large Invasive stand with a 1m Native stand inside (Several Native stands seen) | Cheboygan | Cheboygan State Park | Sandy shore of small Duncan Bay off Lake Huron | Near machine-smoothed sandy swimming beach (Native sampled stand N of beach, Invasive S) | vegetated area with Duncan Bay shore to the E |
| Native (Several Native stands seen) | Emmett | Lark's Lake | Inland freshwater lake w/ minimal boat traffic | Western end of lake, accessed by canoe from Pioneer Picnic Park. | Silty muck(?) lake, with patches of marl, depth usually less than 1m. Little shore development apparent. Only one small motorized boat seen. |

Appendix B: Location of study sites. GIS maps showing Phragmites invasive, native, and control sites in northern Michigan, and at a larger scale for Crooked Lake sites, and at the larger scale for sites at Duck Bay. Note: Cecil Bay Road (native site in Emmett Cty.) is excluded (Vande Kopple 2007).

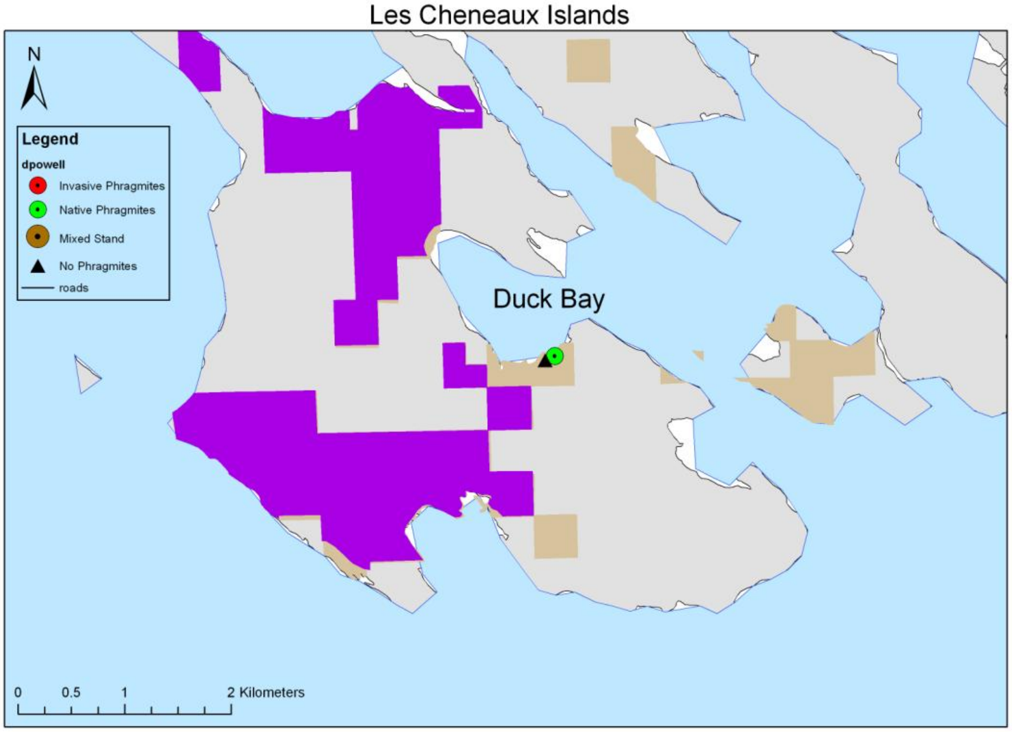
Phragmites in Northern Michigan



Crooked Lake




Les Cheneaux Islands



## Appendix C: Procedure for soil inorganic Nitrogen analysis

1. Keep soils in zip-lock bags in refrigerator until analysis. Wear gloves throughout procedure to prevent contamination.
2. Sieve each sample through 2mm soil sieve to homogenize soil and remove roots, rocks, and other large debris, which can be discarded. Return sieved portion to bag. Final rinse sieve with d.I. water between samples
3. Measure 10g (accurate within 0.1g) of each sieved sample into acid washed labeled centrifuge tube, reserving extra soil.
4. Pipette 40mL 2M KCl into each tube, invert several times. Pipette 40mL into empty tube for a blank.
5. Shake mechanically for 1 hour
6. Centrifuge at ½ setting for 5 minutes.
7. Pour fluid (avoiding pellet material) through G8 Glass Fiber Filter Circles; diameter = 2.5, Fisher Cat. No. 09-804-25D or bigger vacuum filter. Pour into labeled acid washed bottles. Rinse flask with d.I. water between samples.
8. Freeze samples and blank until analysis.
9. Analyze extractions for nitrogen ($NO_3$) and ammonium ($NH_4$).
10. Calculate dry mass and ash mass from reserved soil samples, drying 10g (accurate within 0.1g and recording to the fourth decimal) of each sample in drying oven for 24 hours at 100 degrees C, then in muffle furnace for 2 hours at 550 degrees C.
11. Calculate nitrogen and ammonium in mg/g of dry mass.