Initial Results from an Ecological Assessment of Invasive and Aggressive Plant Species in Coastal Wetlands of the Laurentian Great Lakes: A Combined Field-Based and Remote-Sensing Approach

[1]Ricardo D. Lopez, [1]Curtis M. Edmonds, [1]Anne C. Neale, [2]Terrence Slonecker, [1]K. Bruce Jones, [1]Daniel T. Heggem, [1]John G. Lyon, [3]Eugene Jaworski, Donald Garofalo, and David J. Williams

[1] U.S. EPA, Office of Research and Development, National Exposure Research Laboratory, Environmental Sciences Division, Landscape Ecology Branch - Las Vegas, NV 89119

[2] U.S. EPA, Office of Research and Development, National Exposure Research Laboratory, Environmental Sciences Division, Landscape Ecology Branch, Environmental Photographic Interpretation Center - Reston, VA 20192

[3] Eastern Michigan University, Department of Geography and Geology, Ypsilanti, MI 48197

1. Project Overview

The aquatic plant communities within coastal wetlands of the Laurentian Great Lakes are among the most biologically diverse and productive ecosystems of the world (summarized by Mitsch and Gosselink 1993). Coastal wetlands have been especially impacted by landscape conversions (Dahl 1990, Dahl and Johnson 1991), some of which having undergone a general decline in plant community biological diversity (e.g., Herdendorf et al. 1986, Herdendorf 1987, and Stuckey 1989). The loss of biological diversity in coastal wetland plant communities coincides with an increase in the presence and dominance of invasive (i.e., non-native and opportunistic) and aggressive (i.e., native and opportunistic) plant species. Research suggests that such invasive and aggressive plant species may be the result of general ecosystem stress (Elton 1958, Odum 1985). Such losses of biological diversity in the plant communities of Great Lakes coastal wetlands may be related to changes in the frequency of landscape disturbance within a wetland, or on the edges of wetlands [Miller and Egler 1950, Niering and Warren 1980], which may include fragmentation by roads, urban development, agriculture, or alterations in wetland hydrology. Little is known about such ecological relationships in the Great Lakes, especially at the lake-basin and multi-basin scales. The overall purpose of this study is to examine some of these landscape-scale ecological relationships by quantifying the extent and pattern of invasive and aggressive plant species, and testing for substantive relationships with local landscape disturbance.

Remote sensing technologies may offer unique capabilities to measure the extent of invasive and aggressive plant species over large areas. Our preliminary goal is to use ground-based vegetation sampling to calibrate remote sensing data, to develop spectral signatures of (1) the native opportunistic plant species *Phragmites australis* (Cav.) Steudel [common reed] and *Typha* spp. [cattail], and (2) the non-native opportunistic plant species *Lythrum salicaria* L. [purple loosestrife] in coastal wetlands of Lakes Erie, St. Clair, Huron, and Michigan (Figure 1).

Figure 1 (above). 13 wetland study sites in Ohio and Michigan coastal zone, lettered A - M. Sites were all sampled during July - August, 2001.

Figure 2 (above, inset). Magnified view of Point Mouillee wetland complex (Site E). Sample sites at Point Mouillee: P = *Phragmites australis*, T = *Typha* spp., L = *Lythrum salicaria*, N = non-target plant species, G = ground control point. Image is a false color infra-red IKONOS scene from August, 2001.

2. Great Lakes Wetland Sites

Thirteen coastal wetland study sites were selected, from a pool of approximately 125 wetland areas, along the coastal margins of western Lake Erie, Lake St. Clair, western Lake Huron, and eastern Lake Michigan (Figure 1). Sites were selected using aerial photographs, topographical maps (scale = 1:24 000), wetland inventory maps, the National Land Cover Dataset (NLCD), information from local wetland experts, and published accounts of coastal wetland studies in the areas (e.g., Lyon 1979, Herdendorf et al. 1986, Herdendorf 1987, Stuckey 1989, Lyon and Greene 1992). Sites were selected so that they (1) generally spanned the gradient of current landscape conditions along the coastline of the lakes, (2) were emergent wetlands (Cowardin et al. 1979), and (3) included both wetlands that are open to lake processes and wetlands protected from lake processes (e.g., diked wetlands or drowned river mouths) [Keough et al. 1999]. Sites were selected so that proportions of adjacent land cover generally varied among the 13 sites, using the NLCD and aerial photographs as a guide. These data indicated that the land cover adjacent to the study sites includes active agriculture, old-field agriculture, urban areas, and forest. Each of the 13 wetland sites was known *a priori* to contain at least one of the 'target taxa' (*Phragmites australis, Typha* spp., or *Lythrum salicaria*) somewhere within the wetland.

3. Pilot: *Phragmites* Detection at Point Mouillee Wetlands

Point Mouillee (Monroe County, Michigan) is a wetland complex (Figure 2), located along the coastal margin of western Lake Erie, 8 kilometers south of the mouth of the Detroit River. The mouths of Mouillee Creek and the Huron River are at the mid-point of the coastal area of the wetland complex. A distinctive banana-shaped dike system distinguishes the offshore area of the current site. The extent of the onshore wetland study area is approximately 4 kilometers north and 2 kilometers south of the banana-shaped dike. In addition to *Phragmites*, *Typha*, and *Lythrum*, Point Mouillee supports diverse wetland plant and animal communities. Extensive damage occurred to these wetlands during the early 1950s and again in the early 1970s, a result of high water levels and storm surges in Lake Erie. Consequently, large areas of mudflat and vegetated marshland were lost in the 1950s and 1970s (Lyon and Greene 1992).

Figure 3 (above). Magnified view of initial study site at Point Mouillee where 2 patches were sampled in the field for vegetational and other ecological characteristics. Yellow = *Phragmites* edge and interior stand transects, White = *Typha* edge and interior stand transects, Black squares = points where quadrat sampling was conducted on edges and within the interior of each stand. Image is a natural color spatial subset of an ADAR scene, from August, 2001.

Preliminary data analyses were conducted to assess the utility of ADAR multispectral data and PROBE-1 hyperspectral data to detect relatively homogeneous areas of *Phragmites australis*, beginning at (one of our 13 study sites) the Point Mouillee wetland complex (Figure 2). In general, *Phragmites australis* (also referred to as "*Phragmites*") forms large monospecific "stands" that may predominate in wetland herbaceous plant communities, supplanting other plant taxa (Marks et al. 1994). Compared to other, more heterogeneous, plant communities, *Phragmites* stands are less suitable as animal habitat and, from a 'resource management' perspective, is difficult to manage because it is persistent, produces a large amount of biomass, propagates easily, and is very difficult to control with mechanical or chemical techniques. A combined field-based and remote sensing approach was used so that the detection of *Phragmites* can be automated with reasonable assurance that mapped areas are accurate.

Vegetation was sampled at Point Mouillee on August 7th and August 8th, 2001. Six 'target-species' stands were sampled (Figure 2), 2 stands of each target species. Two 'non-target' vegetation stands were sampled (minimum area = 0.8ha), for comparison to target-species stands.

Figure 5 (right). *Phragmites* stand, showing (A) a dense canopy layer and (B) the under-story layer. Stand edges and internal transects were mapped on the ground with a real-time-corrected GPS, resulting in a nominal mean spatial accuracy of 1 meter.

4. Remote Sensing Data

Point Mouillee was selected for comparison of spatial and spectral characteristics of several types of satellite and airborne remote sensing data. The following data were collected at Point Mouillee in August, 2001 for comparison and for the purpose of potential cross-sensor integration: Landsat Enhanced Thematic Mapper+, SPOT IMAGE, IKONOS, ADAR, RADARSAT (fine-beam mode), and PROBE-1. Historical Landsat

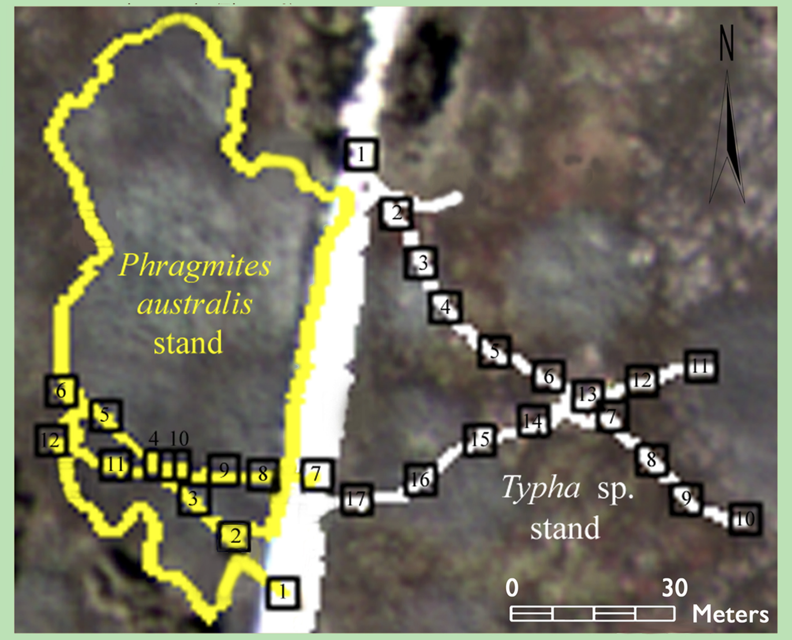

Figure 4 (above). Field data were collected in 12 quadrats of a *Phragmites* stand and 17 quadrats in a neighboring *Typha* stand (magnification of Figure 3)

MultiSpectral Scanner data and historical aerial photographs were also used to improve our understanding of change at the site and preliminary validation of classified areas of target species. Digital orthorectified aerial photographs (DOQs) [nominal, 1 meter spatial accuracy, USGS] were used in combination with GPS ground control points to georeference remote sensing data because the spatial accuracy of the acquired imagery is less (i.e., coarser) than the field-recorded GPS data. Of the data collected from these sensors, we initially used the ADAR data and the PROBE-1 data to assess *Phragmites* and *Typha* at Point Mouillee.

The **ADAR** System 5500 is a four camera, multispectral airborne sensor that acquires digital images in three visible and a single near infra-red band. ADAR data were acquired at Point Mouillee on August 14, 2001 (Average pixel size = $(0.75m)^2$. A single ADAR scene at Point Mouillee (Figure 3) was georeferenced using DOQs and GPS ground control points from field surveys, using ENVI image processing software v. 3.4 (RSI, Boulder CO). **PROBE-1** is an airborne hyperspectral scanner system with 128 bands of data and an average pixel size of $(4.8m)^2$. PROBE-1 data were acquired at Point Mouillee on August 29, 2001.

A supervised classification of the PROBE-1 scene (1 flightline) was performed using ENVI's Spectral Angle Mapper (SAM) algorithm, an automated processing technique for comparing image spectra to a spectral library. We collected a small number of spectra (12 pixels), using the PROBE-1 data, from the purest areas of *Phragmites australis*. The locations of purest *Phragmites* (and *Typha* for comparison) were determined by finding those areas along the field transects that had the greatest percent of non-flowering live plants, greatest stem density, and the least amount of other materials within a quadrat (see Figure 6). The SAM algorithm was used to determine the similarity between the spectra of each of the 12 "pure" *Phragmites* pixels and every pixel in the scene by calculating the spectral angle between them. The Spectral Angle Mapper classification resulted in 12 images, each with different areas mapped as potentially pure regions of *Phragmites*. Eleven of the 12 images were rejected because: (a) the mapped classes did not overlay on the core areas of known *Phragmites* sample areas or other known large *Phragmites* stands (Lopez, Jaworski, and Lyon personal observations), or (b) the mapped classes overlaid on areas that are known to not contain *Phragmites* (e.g., non-target survey areas or large areas on a golf course fairway).

5. Field Sampling Results

The sampled *Phragmites* stand at Point Mouillee (Figure 4) is bounded on the eastern edge by Point Mouillee Road (unpaved), with two small patches of trees/shrubs to the north (dogwood and willow) and to the south (willow). The western edge of the stand is bounded by a mixture of *Lythrum salicaria* and *Typha* sp. Soil in the *Phragmites* stand is dry and varies across the stand from clayey-sand, to sandy-clay, to a mixture of gravel and sandy-clay near the road. Percent cover of litter is 100% and constant across the sampled stand. Non-target plants in the canopy and understory (Figure 5) are smartweed (*Polygonum* spp.), jewel weed (*Impatiens* spp.), cattail (*Typha* sp.), mint (*Mentha* spp.), Canada thistle (*Cirsium arvense* L.), and an unidentifiable grass. Thus, the *Phragmites* stand is heterogeneous, with quadrat 4 located in the most, relatively, homogeneous area of live non-flowering *Phragmites* (Figure 6).

Comparatively, the sampled *Typha* stand at Point Mouillee (Figure 4) is bounded on the western edge by Point Mouillee Road, with soil, hydrologic, and percent litter cover conditions similar to the neighboring *Phragmites* stand, described above. Non-target plants in the canopy and the understory include *Lythrum salicaria*, *Phragmites australis*, *Polygonum* spp., bur-reed (*Sparganium* spp.), *Cirsium arvense*, and an unidentifiable grass. Thus, the *Typha* stand is also heterogeneous, with quadrat 8 located in the most, relatively, homogeneous area of live non-flowering *Typha* (Figure 6).

6. Remote Sensing Results

A series of reflectance spectra were collected, using PROBE-1 data, along *Phragmites* transect 2 (from quadrat 12 to 8) and along *Typha* transect 2 (from quadrat 17 to 11). To reduce the effect of plant community heterogeneity and number of similar spectra along each transect, the single nearest pixel to *Phragmites* quadrat-4 and *Typha* quadrat-8 was selected, then compared to each other. Initial spectral comparisons from the relatively pure pixels indicates several differences in reflectance of visible and near infra-red wavelengths between the two plant taxa. *Phragmites* reflects less in the green and near infra-red wavelengths than *Typha*, is similar to *Typha* in reflectance of red wavelengths, and reflects slightly more than *Typha* in the blue wavelengths (Figure 7).

PROBE-1 data analyses resulted in the selection of 12 relatively pure pixels of *Phragmites* at or around quadrat-4 (Figure 4). Supervised classification of the Point Mouillee PROBE-1 image indicates other areas of relatively homogeneous *Phragmites* (Figure 8). Several of these areas are located in the diked areas of the wetland complex, areas that are typically populated by large stands of *Phragmites* in other Lake Erie wetlands. Initial photo-interpretation, using stereo aerial photographs from September 2, 1999 and observations at the site during summer, 2001 suggests that the areas classified as *Phragmites* within the dikes are reasonably accurate. However, these are initial results and further field validation is required, scheduled for summer, 2002 at selected sites.

Because the ADAR data has a nominal spatial accuracy of 75cm, it is the most useful for viewing field GPS overlays, and is a convenient digital form of color infra-red aerial photographs. ADAR is 4-band multispectral data, thus is limited in its usefulness for developing spectral signatures for *Phragmites*. The relatively small ADAR data file (approximately 5Mb per 1.1km x 0.7km scene) allows for relatively fast georeferencing using image-to-image warping techniques. Positive Systems, Inc. offers an automated georeferencing software package that we will be evaluating to improve the efficiency of georeferencing the ADAR data.

Field data from quadrat sampling was an essential part of evaluating PROBE-1 data because of its nominal 1.0 meter spatial accuracy, by way of real-time-corrected GPS. Initial results demonstrate that "monospecific stands" of *Phragmites* and *Typha* can be very heterogeneous, as a result of variability in the underlying vegetation, litter, and soil conditions. The use of these detailed field data enabled us to select a 14.4m x 19.2m (3 pixel by 4 pixel) area of PROBE-1 image data containing the most homogeneous area of *Phragmites* within the sampled stand. Video and digital still images of each quadrat improved the decision making processes about which areas of the stand were dominated by live, non-flowering *Phragmites*.

Field results at Point Mouillee demonstrate that a major impediment to automated detection of wetland vegetation is heterogeneity of biotic and abiotic characteristics of the plant community. Although water was not present at the selected Point Mouillee sample locations, the presence of water and variable soil moisture is a major factor in the heterogeneity at other sites (data in preparation). In this study we minimized the remote-sensing pitfalls of plant community heterogeneity by:

(1) selecting 3 plant taxa that are least likely (by definition) to exist in diverse, heterogeneous plant communities

(2) using GPS points with a nominal spatial accuracy that exceeds that of the acquired remote sensing data, for locating sampled quadrats, edges, and ground control points

(3) acquiring a sufficient variety of remote sensing data types that have appropriate spectral and/or spatial characteristics for detecting wetland plants

(4) collecting relevant field data that are most likely to explain differences in spectral reflectance among pixels

(5) collecting an abundance of field data to sufficiently account for phenological variability and variability among species, quadrats, stands, and wetlands

(6) collecting historical remote sensing data for contextual information about the site

(7) collaborating with local wetland experts to better understand the ecological processes of the sites, in a historical context

Spectra collected from PROBE-1 data demonstrate that a relatively pure pixel of *Phragmites* is quantitatively different from a relatively pure pixel of *Typha*, which may be the result of the greater leaf coverage, darker green leaves, and greater moisture content of *Typha*, relative to *Phragmites*. Although *Phragmites* and *Typha* are both tall monocots, their basic physical structure is quite different, in that *Typha* is primarily comprised of photosynthetic "shoots" that emerge from the base of the plant (at the soil surface). Comparatively, *Phragmites* has a main stem that is fibrous and non-photosynthetic (Figure 9), with branching leaves. *Phragmites* also has a large seed head that varies in color from a reddish-brown, to a brownish-black. *Typha* has a relatively small, dense flowering head, that resembles a hotdog on a stick. Thus, these structural differences are likely to contribute to the spectral differences observed between *Phragmites* and *Typha* at Point Mouillee.

The initial results from the 'Great Lakes Wetland Project' are the first steps toward investigating the landscape-ecological relationships between the extent and pattern of these plant species and wetland disturbance. Our results also build upon the ongoing efforts to develop new remote sensing techniques for mapping plant communities in Great Lakes wetlands. Our research may also lead to new techniques for identifying other plant communities, in other ecosystems. At the conclusion of this project, we will be able to quantify the cost-effectiveness of these techniques so that local, state, federal, and tribal agencies in the Great Lakes region can decide if these techniques are useful for their purposes.

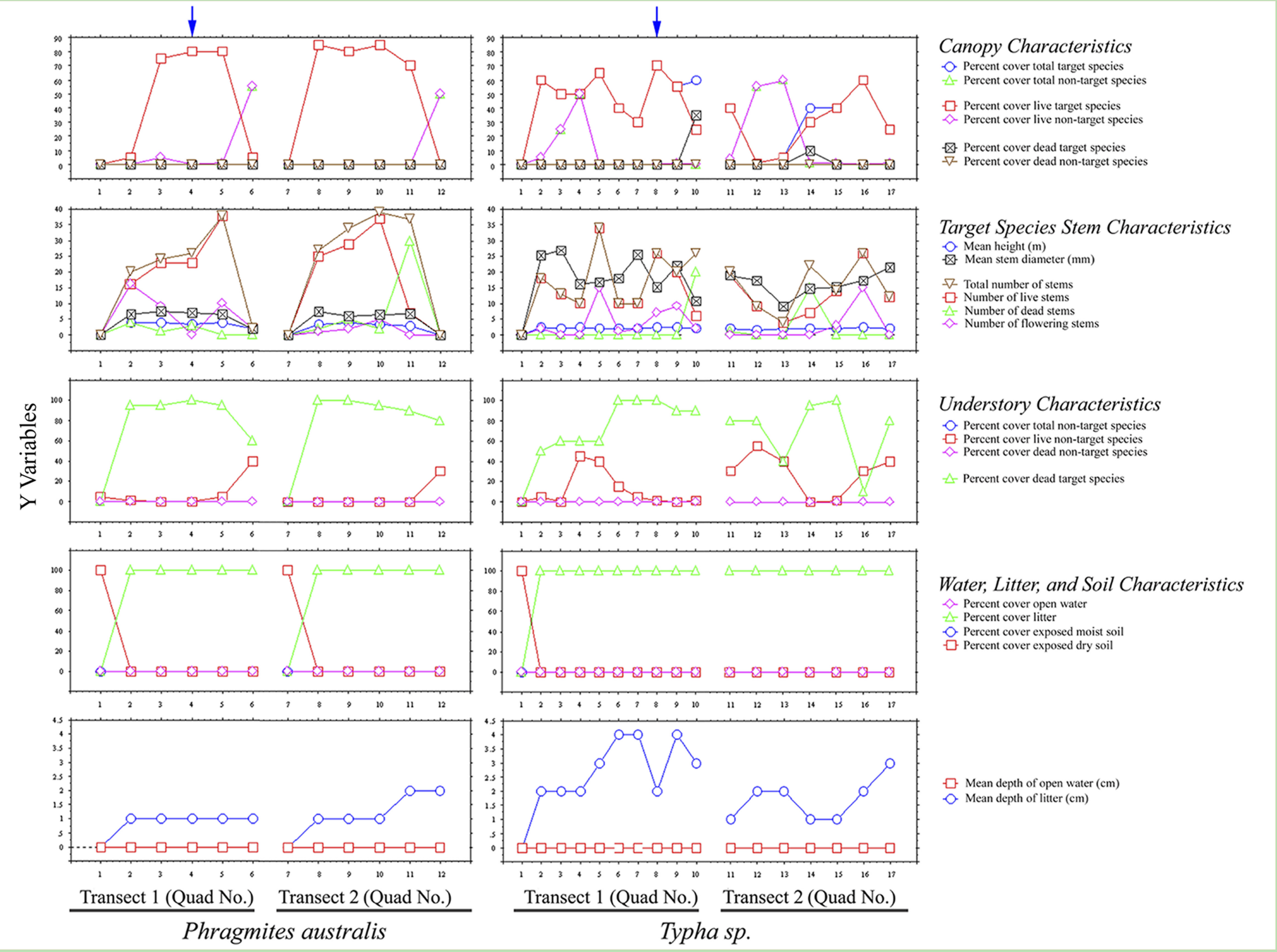

Figure 6. The heterogeneity of canopy, stem, understory, soil, and litter characteristics in *Phragmites* and *Typha* stands was used to calibrate the PROBE-1 data, initially for the purpose of detecting relatively homogeneous areas of *Phragmites*. Blue arrows at top of figure indicate the transect location of relatively homogeneous areas of *Phragmites* (Quadrat 4) and *Typha* (Quadrat 8).

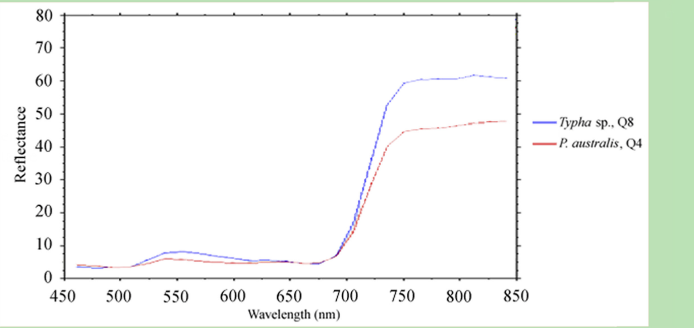

Figure 7. Spectra of *Phragmites australis* and *Typha* spp. in a single, relatively homogeneous 4.8m x 4.8m area of each taxa, using PROBE-1 data (450nm - 850nm spectral subset). Spectral samples are from the approximate location of field-sampled *Phragmites* quadrat-4 and *Typha* quadrat-8, in their respective stands (shown in Figure 6).

Literature Cited

Cowardin, L.M., V. Carter, F.C. Gollet, and E.T. LaRoe. 1979. *Classification of Wetlands and Deepwater Habitats of the United States*. FWS/OBS-79/31. U.S. Fish and Wildlife Service, Washington, D.C.

Dahl, T.E. 1990. *Wetlands Losses in the United States, 1780s to 1980s*. U.S. Department of the Interior, Fish and Wildlife Service. Washington, D.C.

Dahl, T.E. and C.E. Johnson. 1991. *Status and Trends of Wetlands in the Conterminous United States, Mid-1970s to Mid-1980s*. U.S. Department of Interior, Fish and Wildlife Service. Washington, D.C.

Elton, C.S. 1958. *The Ecology of Invasions by Animals and Plants*. Methuen, London, UK.

Herdendorf, C.E. 1987. *The Ecology of the Coastal Marshes of Western Lake Erie: A Community Profile*. Biological Report 85(7.9). U.S. Fish and Wildlife Service, Washington, D.C.

Herdendorf, C.E., C.N. Raphael, E. Jaworski, and W.G. Duffy. 1986. *The Ecology of Lake St. Clair Wetlands: A Community Profile*. Biological Report 85(7.7). U.S. Fish and Wildlife Service, Washington, D.C.

Keough, Thompson, Guntenspergen, and Wilcox. 1999. Hydrogeomorphic factors and ecosystem responses in coastal wetlands of the Great Lakes. *Wetlands*. 19:821-834

Lyon, J.G. 1979. Remote sensing analyses of coastal wetland characteristics: The St. Clair Flats, Michigan. *Proceedings of the Thirteenth International Symposium on Remote Sensing of Environment,* April 23-27, Ann Arbor, Michigan.

Lyon, J.G. and R.G. Greene. 1992. Use of aerial photographs to measure the historical areal extent of Lake Erie coastal wetlands. *Photogrammetric Engineering and Remote Sensing*. 58:1355-1360.

Marks, M., B. Lapin, and J. Randall. 1994. *Phragmites australis* (*P. communis*): threats, management, and monitoring. *Natural Areas Journal*. 14:285-294.

Miller, W. and F. Egler. 1950. Vegetation of the Wequetequock-Paw-catuck tidal marshes, CT. *Ecological Monographs*. 20:147-171.

Mitsch, W.J. and J.G. Gosselink. 1993. *Wetlands* (second edition). Van Nostrand Reinhold. New York, New York.

Niering, W.A. and R.S. Warren. 1980. Vegetation patterns and processes in New England salt marshes. *BioScience*. 30:301-307.

Odum, E.P. 1985. Trends expected in stressed ecosystems. *Bioscience*. 35(7):419-422.

Stuckey, R.L. 1989. *Western Lake Erie Aquatic and Wetland Vascular-Plant Flora: Its Origin and Change in Lake Erie Estuarine Systems: Issues, Resources, Status, and Management*. National Oceanographic and Atmospheric Administration, Washington, D.C.

Figure 8. Results of a preliminary Spectral Angle Mapper (supervised) classification of PROBE-1 airborne data, indicating likely areas of relatively homogeneous stands of *Phragmites australis* (solid blue). Field-sampled areas of *Phragmites australis* are within the 2 yellow polygons. Preliminary validation of likely areas of *Phragmites*, using aerial photo interpretation, indicates that a large majority of the classified areas are correct. The areas of agreement between aerial photos and the classified image are in the general vicinity of a yellow "P". Field validation of selected areas is scheduled for summer, 2002.

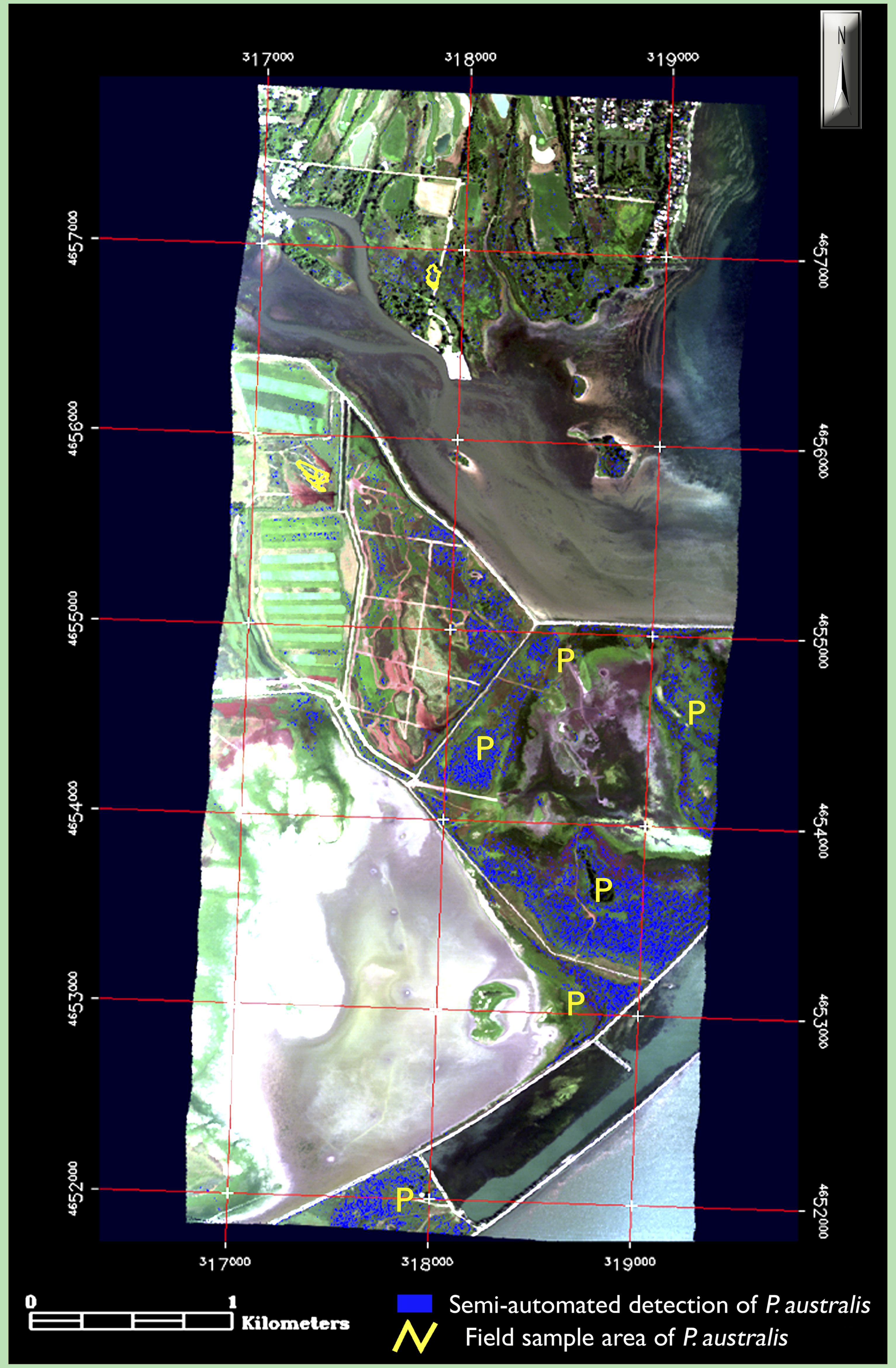

Figure 9. Illustrations of *Phragmites* and *Typha*, demonstrating the basic structural differences between the plants. Illustrations provided by IFAS, Center for Aquatic Plants, University of Florida, Gainesville.

Acknowledgements

The project was funded by U.S. EPA Region 5 and U.S. EPA's Regional Environmental Monitoring and Assessment Program. Our sincere thanks go to Joe D'Lugosz, John Schneider, and the Great Lake National Program Office for their support of this project. We thank Karl Leavitt, Marco Capo diVacca, Joe Robison, Nita Tallent-Halsell, Chad Cross, Don Ebert, Mary Moffett, Clay Lake, Susan Jackson, Lee Bice, Audrey Rager, Larry Tinney, Tim Ehli, Donna Sutton, Kim Johnson, Rosie Chelot, Joann Menke, Ruth Christianson, Brenda Harris, Susan Braun, Mark Silverstein, and John Baker for their professional assistance during this study. We also thank the Moxley Family, the Little River Band of Ottawa Indians, the U.S. Fish and Wildlife Service, the Michigan Department of Natural Resources, the Ohio Department of Natural Resources, and the U.S. Army Corps of Engineers (Detroit District) for logistical assistance. For more information about this project and other wetland projects in the Great Lakes, visit our website at: http://www.epa.gov/nerlesd1/land-sci/wetlands.htm.