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

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Introduction

1. Great Lakes Wetland 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 have 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).

2. Initial Focus: Integration of Sensor and Field Data to Detect *Phragmites*

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 reduce the overall biological diversity of wetlands. From a Great Lakes 'natural resource management' perspective, *Phragmites* 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. Relevant ecological data provided a measurable link between sensor data and information about the physical structure of *Phragmites*, soil characteristics, soil moisture content, and the presence of other plant taxa on the ground.

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.

Methods

1. Wetland Site Selection

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 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 area (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 included various levels of 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.

2. Point Mouillee Site Description

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 (below). 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.

3. Wetland Field Sampling

The following definitions were used for decision making in the field:

(a) Wetland: the transitional land between terrestrial and aquatic systems where the water table is usually at or near the surface, or the land is covered by shallow water. Area that supports or contains at least one of the following: (1) hydrophytes, (2) hydric soil, or (3) shallow water at some time during the growing season (after Cowardin et al. 1979)

(b) Target plant species: *Phragmites australis*, *Typha* spp., and *Lythrum salicaria* (per Voss 1972, 1985)

(c) Non-target plant species: any herbaceous vegetation other than target plant species

(d) Vegetation stand: a relatively homogeneous area of target plant species, with a minimum approximate size of 0.8ha

(e) Edge of vegetation stand: transition point where the percent canopy cover ratio of target:non-target species is 50:50

Vegetation was sampled at Point Mouillee on August 7th and August 8th, 2001. Prior to the vegetation sampling, aerial photographs (summer, 1999) were studied and on-site assessments were used to locate large stands of the target species (minimum area = 0.8ha). 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 2). To fully characterize the site, and for reference during image processing, digital video of each vegetation stand was recorded. Each vegetation stand was also mapped by a sketch in the field, noting the location and shape of vegetation stands, key landmarks that might be recognizable from remote sensing data, and any other information about the site that might be useful when trying to reconcile ground data with remotely sensed data. Transects along the edges of target-species stands were recorded using a real-time-corrected Global Positioning System (GPS) for sampled target species. Two non-target stands of vegetation were delineated with four GPS points, evenly spaced around the perimeter. Five GPS ground control points were collected at Point Mouillee, triangulating on sampled stands of vegetation (Figure 2). Each GPS point location was recorded with either a single digital photograph (edge quadrats and non-target vegetation stand), or multiple digital photographs (ground control points) to provide several views of each sample location. A written description of each ground control point was also recorded to assist in the georeferencing of imagery.

Within each target-species stand, a nested quadrat sampling method (after Mueller-Dombois and Ellenberg 1974, Barbour 1987) was used to sample herbaceous plants, shrubs, tree species, and other characteristics of target-species stands. Twelve to twenty (nested) 1-meter² and 3-meter² quadrats were evenly spaced along 2 intersecting transects, depending on the size of the stand (Figure 3). The approximate percent cover and specific epithet of trees and shrubs within a 15 meter radius was also recorded at each quadrat. Depending on the size of the stand, a transect might either cross the entire stand or penetrate deep into the stand of vegetation (Figure 3). Where appropriate, the terminal quadrat was placed outside of the target-species stand perimeter to characterize the immediately-adjacent land cover. An annotated corner of each 1-m² quadrat was delineated with a GPS. The perimeter (or accessible portion of the perimeter) of each stand of target species was recorded with a GPS and a still image of the full canopy height was recorded, at approximately 50 meter intervals (Figure 4). All GPS locations were recorded with a real-time-corrected (OmniStar) GPS (Trimble, XRS), with a nominal spatial accuracy of 1.0 meter. Within each of the quadrats, along each of the transects, the following data were recorded:

(a) within each nested 1-meter² quadrat: number of stems of each target species (live, dead, and flowering), water depth, litter depth, and mean stem diameter (N=5)

(b) within each nested 3-meter² quadrat: percent-cover of target species (live and dead) in the canopy, percent-cover of non-target species (live and dead) in the canopy, percent-cover of non-target species (live and dead) in the understory (Figure 4), percent-cover dead target species in the understory (i.e., senescent but not litter), percent-cover of exposed moist soil, percent cover of exposed dry soil, percent cover litter, percent-cover water, and general substrate type (e.g., sand, silt, or clay)

(c) at each quadrat location, the approximate distance, direction, and total canopy cover (area) of woody shrubs and trees that occurred within 15 meters of the sampling location were recorded

Field spectroradiometry measurements (FieldSpec Pro FR and FieldSpec HandHeld; ASD, Inc.) were conducted at 4 of the 13 wetlands (sites A, B, F, and H), during August, 2001 to provide calibration of the PROBE-1 data and to contribute to overall spectral library field spectra for plant taxa (Figure 5).

4. Remote Sensing Data Selection, Acquisition, and Processing

Point Mouillee was selected for comparison of the spatio-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 MultiSpectral Scanner data and historical aerial photographs were also used to improve our understanding of change at the site, for preliminary validation of classified areas of target species. Digital orthorectified aerial photographic (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 than the field-recorded GPS data (1.0 meters). 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.

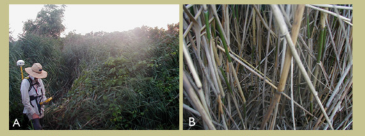

Figure 4 (above). *Phragmites* stand edge, showing (A) a dense canopy and (B) understory layer. Stand edges and internal transects were mapped with a real-time-corrected GPS.

Figure 5 (above). Field spectroradiometry sampling was conducted at 4 wetland sites during August, 2001. The procedure involved recording (A) white reference spectra and (B) vegetation spectra during mid-day solar illumination.

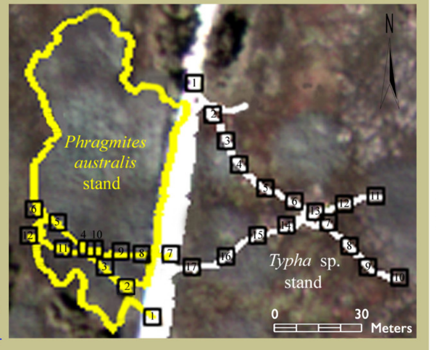

Figure 6 (above). Field data were collected in 12 quadrats of a *Phragmites* stand and 17 quadrats in a neighboring *Typha* stand (magnification of Figure 3)

ADAR System 5500 is a four camera, multispectral airborne sensor that acquires digital images in three visible and a single near infra-red band. At Point Mouillee (August 14, 2001) approximate operating altitude of the twin-engine aircraft was 1890 meters above ground level at 150 knots, flying north-to-south, resulting in an average pixel area of 75cm². A single ADAR scene at Point Mouillee (Figure 3) was georeferenced using DOQs and GPS ground control points from field surveys with ENVI image processing software v3.4 (RSI, Boulder CO), total RMS error of less than 0.6.

PROBE-1 is an airborne, hyperspectral, opto-mechanical, whisk-broom scanner system with a rotating axe-head scan mirror that sequentially generates cross-track scan-lines on both sides of nadir to form a raster image cube. Incident radiation is dispersed onto four 32-channel detector arrays. The PROBE-1 data are calibrated to reflectance by means of a NIST-traceable laboratory radiometric calibration procedure, providing 128 channels of reflectance data from the visible through the short wave infrared wavelengths (435.7nm - 2481.6nm). The instrument carries an on-board lamp for recording in-flight radiometric stability, collected along with shutter-closed (dark current) measurements on alternate scan lines.

At Point Mouillee (August 29, 2001) operating altitude of the 2-crew-member Aerocommander, twin-engine aircraft was 2170 meters above ground level at 147 knots, flying north-to-south (visibility 50km), resulting in an average pixel area of 4.8m². The data collection rate was 14 scanlines per second (pixel dwell time of 0.14 milliseconds) and the 4.80km flightline resulted in a total ground coverage of 13km². The PROBE-1 scene in this study of *Phragmites* at Point Mouillee was georeferenced using onboard GPS data, DOQs, and GPS ground control points from field surveys with ENVI v3.4 image processing software (RSI, Boulder CO), total RMS error of less than 0.6.

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. Because the PROBE-1 overflights occurred three weeks *after* field sampling, there was a possibility that trampling from the field crew could have altered the reflectance signature of *Phragmites* within the exact pixel located by GPS. For this reason, and because of inherent georeferencing inaccuracies of the data, we selected the immediately adjacent pixels around the field-recorded purest point in each stand (a total of 12 pixels, in a 3-pixel by 3-pixel block). The SAM algorithm was then 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 (threshold = 0.07 radians). SAM treats the spectra as vectors in an N-dimensional space, equal to the number of bands (i.e., a 128-dimension space for the PROBE-1 data). The SAM classification resulted in 12 images, each with different areas mapped as potentially pure regions of *Phragmites*. Ten 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 vegetation areas or large areas on a golf course fairway).

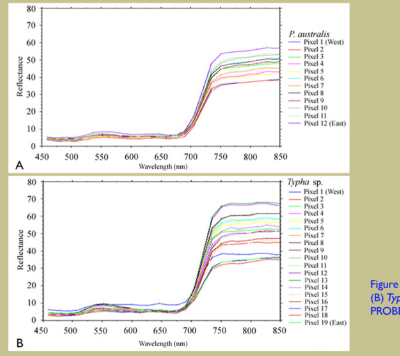

Figure 8 (left). Spectral variability of (A) *Phragmites australis* (from quadrat 12 to 8) and (B) *Typha* spp. (from quadrat 17 to 11), sampled at Point Mouillee (August, 2001), with PROBE-1 data (450nm - 850nm spectral subset).

Results

1. Vegetation Stand Physical Characteristics

The sampled *Phragmites* stand at Point Mouillee (Figure 6) 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 the understory include 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 7).

Comparatively, the sampled *Typha* stand at Point Mouillee (Figure 6) 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 7).

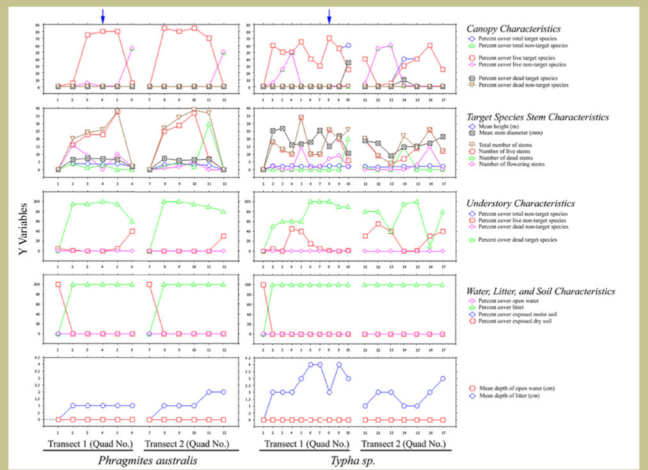

Figure 7. The heterogeneity of canopy, stem, understory, soil, and litter characteristics in *Phragmites* and *Typha* stands was used to calibrate the PROBE-1 data, initially for the purpose of detecting relatively homogeneous areas of *Phragmites*. Blue arrows indicate relatively homogeneous areas of each target-species.

2. Vegetation Stand Spectral Characteristics

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). The variability of spectra among pixels within stands of *Phragmites* and *Typha* (Figure 8) is noticeable by visual inspection of the spectra, with *Typha* generally having greater reflectance in the green and near infra-red wavelengths. 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 comparison of *Phragmites* and *Typha* spectra 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 9).

3. Automated Detection of other Relatively Homogeneous Stands of *Phragmites*

Analyses of field data from Figure 7, digital still photographs, digital video images, field sketches, and field notes resulted in the selection of 12 relatively pure pixels of *Phragmites* at or around quadrat-4 (Figure 6). Supervised classification of the Point Mouillee PROBE-1 image indicates other areas of relatively homogeneous *Phragmites* (Figure 10). 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 (personal observations). Initial photo-interpretation, using stereo aerial photographs from September 2, 1999 (scale = 1:15 840), 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 validation is required on site, in summer, 2002.

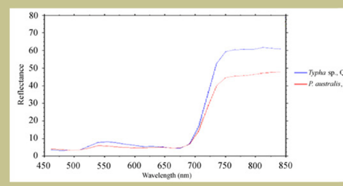

Figure 9. Spectra of *Phragmites australis* and *Typha* spp. in a single, relatively homogeneous 4.8m x 4.8m area of each taxa, using PROBE-1 data (450nm - 850nm spectral subset). Spectral samples are from the approximate location of field-sampled *Phragmites* quadrat-4 and *Typha* quadrat-8, in their respective stands (shown in Figure 6).

Discussion

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. Because it is 4-band multispectral data, it 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 14.4m (3 pixel by 3 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*.

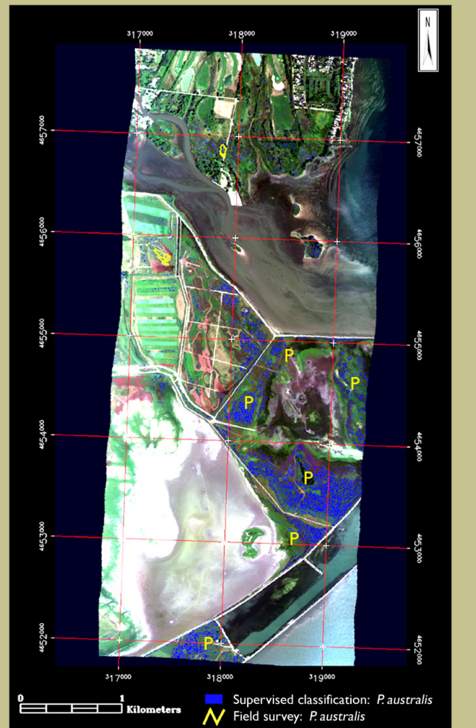

Figure 10. Results of a preliminary Spectral Angle Mapper (supervised) classification, indicating likely areas of relatively homogeneous stands of *Phragmites australis*, using PROBE-1 data (437.5nm - 2512.0nm) and field-based ecological data. Likely *Phragmites* stands (blue) are overlain on a natural-color PROBE-1 image of Point Mouillee wetland complex. P = preliminary field and aerial photo validation of *P. australis*.

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). We minimized the potential 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 11), 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 SAM-classified PROBE-1 results suggest where there are other large stands of relatively homogeneous *Phragmites australis* plants at Point Mouillee. This is a preliminary classification, the result of a search for solely the purest areas of *Phragmites* (i.e., a conservative classification). Thus, there is a reasonable likelihood of finding additional areas of *Phragmites*, mixed with other plant species (e.g., non-target species in the understory) or *Phragmites* mixed with different underlying soil and hydrologic conditions adjacent to the pure areas shown in the classified image. Because these are preliminary classification results, there is a likelihood that some areas are incorrectly classified as *Phragmites* To complete our assessment activities, during summer of 2002, we will return to selected sites to field-assess the accuracy of classified images, similar to Figure 10. Research is ongoing at Point Mouillee and the other 12 wetland study sites, developing new techniques for detecting pure and mixed stands of the target species, other plant taxa, and other plant communities. The immediate research foci are separating signal from noise in the PROBE-1 data, measuring correlations between imagery data and field data, calibrating the sensor data with field-collected spectra, and cross-sensor techniques for automated detection of the target plant species.

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 such efforts are useful for their own monitoring programs.

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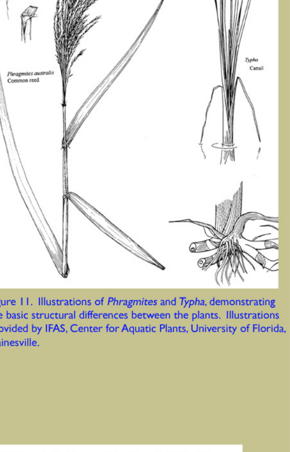

Figure 11. Illustrations of *Phragmites* and *Typha*, demonstrating the basic structural differences between the plants. Illustrations provided by IFAS, Center for Aquatic Plants, University of Florida, Gainesville.