Great Lakes PHRAGMITES COLLABORATIVE

WELCOME!

Remote Sensing Part I is available at bit.ly/GLPCwr18

Remote Sensing Series Part II:

Implementing practical field and remote sensing methods to inform adaptive management of non-native Phragmites australis in the Midwest

Colin Brooks, Michigan Technological Research Institute

December 10, 2015

The webinar is listen only. You can listen by phone or through your computer's speakers.
The webinar will be recorded and posted at greatlakesphragmites.net

We will begin shortly

MichiganTech Research Institute

CMU CENTRAL MICHIGAN UNIVERSITY

Applied Ecological Services, Inc.™

Implementing practical field and remote sensing methods to inform adaptive management of non-native *Phragmites australis* in the Midwest

http://www.mtri.org/treatment_effects_phragmites.html

MTRI: *Laura Bourgeau-Chavez, Colin Brooks, Amanda Grimm, Sarah Endres, Elizabeth Banda, Eleanor Serocki, Liz Schold, Michael Battaglia*

AES: *Jason Carlson, Steve Apfelbaum, Michael McGraw, Ry Thompson, Fugui Wang*

CMU: *Donald Uzarski*

Great Lakes Phragmites Collaborative Webinar

Remote Sensing Series Part II

10th December, 2015

WATER CENTER UNIVERSITY OF MICHIGAN

U-M Water Center award # 3002824402, Erb Family Foundation Grant # 534

Introduction

- Millions of dollars have been spent on treatment of *Phragmites* infested wetlands with herbicide and other control methods
- But, few studies or management efforts have included standardized monitoring or an assessment of the effectiveness of treatment in terms of habitat restoration
- Therefore, a standardized method for assessment of the effectiveness of treatment is needed for adaptive management and control
- Field and remote sensing data were analyzed in a nested design to help develop standardized methods for monitoring treatment success and provide recommendations
- ***Latest literature reviewed, adaptive management principles described: what do our field & remote sensing results mean for practical Phragmites management?***

Background to adaptive management discussion

- Uncertainty – inherent in all natural systems
- A single "historical precedent" has likely not existed
  - Ecosystems are flexible, esp. with species composition
- Not trying to manage to a historical, closed ecosystem
- Cannot completely know how an ecosystem will respond to intervention
- Need a process that enables new information to inform management
- Work towards specific goals rather than focus on specific treatments
- Be willing to change management practices as project progresses

Adaptive management background cont'd

- Adaptive management encourages reinvention of processes, flexibility in methods
  - Use best current knowledge
  - Change when new knowledge becomes available
  - "Active" AM – testing hypothesis, treatments to gain new info
  - "Passive" AM – info on "best" treatment is a side-effect, not main goal, but cheaper
- Well suited to addressing areas dominated by invasive Phragmites
- No "one best method" for treating Phragmites
- US Department of Interior actively integrating adaptive management into its invasive species control efforts (USGS example)
- Scientific literature is revealing new information, updated existing knowledge; our report reviews this for:
  - Nutrients, Climate Change
  - Management lessons, Agency Guides
  - Biological control
  - Monitoring methods, novel ecosystems

U.S. Department of Interior (US DOI): perspectives on adaptive management

- US DOI dealing with practical issues of effective *Phragmites* management
  - http://www.usgs.gov/sdc/adaptive_mgmt.html
- Ex: *Phragmites* control as part of integrated waterbird management & monitoring program (Moore et al. 2014)
- Important principles:
  - Dealing with uncertainty for transition states
  - Understanding constraints to management can exist in certain areas
  - Collect observations of results to inform decision making
  - Provide a decision support tool to help refuge managers in Phragmites control efforts
  - Enables gain in knowledge to improve performance of decision making over time

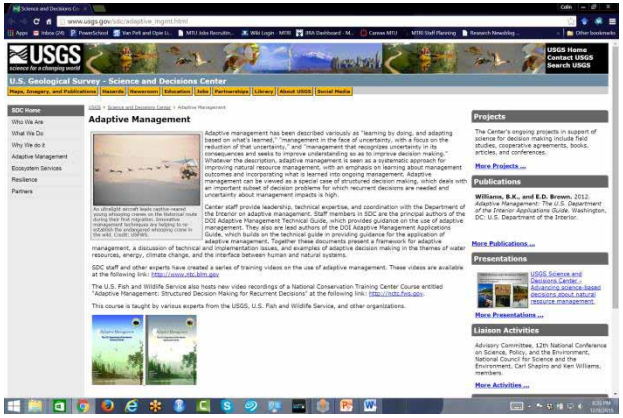


Table 4.2 Treatment menu of eight Phragmites treatment alternatives

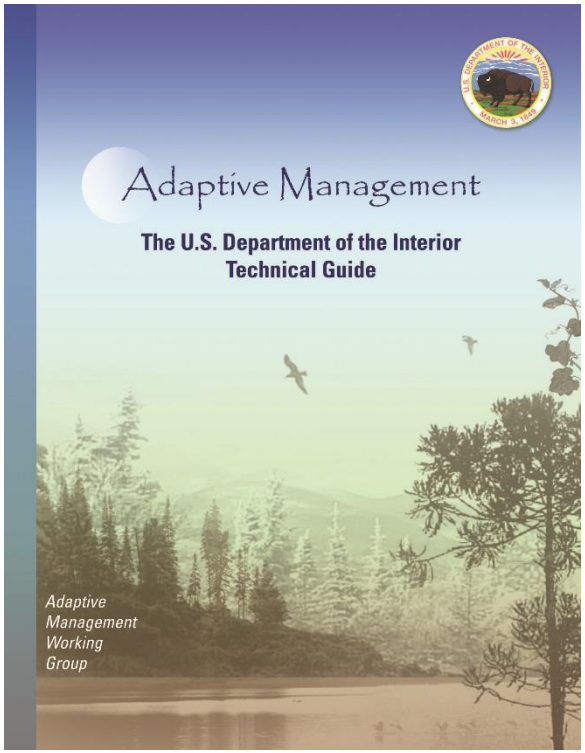
		Year 1						Year 2	
		Step 1		Step 2		Step 3		Step 1	
Prescrip.		Treat	Time	Treat	Time	Treat	Time	Treat	Time
1	G	Glyph	Su/F	NA		NA		Glyph Spot	Su/F
2	I	Imaz	Su/F	NA		NA		Imaz Spot	Su/F
3	SG	Stress*	Sp/Su	Glyph	Su/F	NA		Glyph Spot	Su/F
4	GF	Glyph	Su/F	Burn	Su/F or Sp	NA		Glyph Spot	Su/F
5	IF	Imaz	Su/F	Burn	Su/F or Sp	NA		Imaz Spot	Su/F
6	SGF	Stress*	Sp/Su	Glyph	Su/F	Burn	Su or Sp	Glyph Spot	Su/F
7	P	P/S	Sp	NA		NA		P/S	Sp/F
8	R	Rest		NA		NA		Rest	

Abbreviations:
Stress - a pre-chemical "stress" application (e.g., cutting, mowing, water manipulation, fire, grazing) intended to stress the plant, to promote vegetative growth, or to enhance uptake of the chemical.
Glyph – Glyphosate broadcast, Imaz – Imazapyr broadcast, P/S – Plant/Seed native perennials
Glyph Spot – Glyphosate spot treatment, Imaz Spot – Imazapyr spot treatment
Sp – Spring, Su – Summer, Su/F – Late Summer/fall

From Moore et al. 2014
Eight Phrag treatment alternatives

US DOI perspectives on adaptive management

- US DOI Adaptive Management Applications Guide, + Technical guide = useful resources
- Describes framework for managing responsive natural resources where uncertainty is present for impacts of management actions
  - Monitoring data can help reduce uncertainty
- Learning-based management
  - Provides flexible decision making environment
  - Can make changes to management methods based on careful monitoring data
- Adaptive management involves:
  - Clear statement of objectives
  - Identification of management alternatives
  - Precisions of management consequences
  - Recognition of uncertainties
  - Monitoring of resources responses
  - Learning
- Not an expensive "extra", but critical to understanding success of control efforts



Williams and Brown 2012

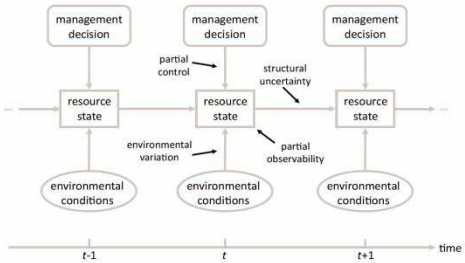


Figure 4.1. Uncertainty factors in natural resource management. Partial control limits the influence of management actions. Environmental variation affects resource system status and dynamics. Partial observability limits the recognition of system status. Structural uncertainty limits the ability to characterize system change.

Impacts of uncertainty on management

Nutrients literature

- Where nitrogen (N) is high, Phragmites has far higher biomass accumulation (Rickey & Anderson, 2004)
- High N – make it easier for Phrag to invade native wetlands, explain higher Phrag cover (Silliman & Bertness, 2004)
  - Reducing N could help reduce the spread of Phrag, increase effectiveness of management
    - Ex: New / enhanced stream buffers
  - N-focused management efforts likely to be more beneficial (Romero et al., 1999)
- Phragmites also impacts the N cycle
  - Lower processing of N-rich fertilizers through denitrification (Arce, 2009)

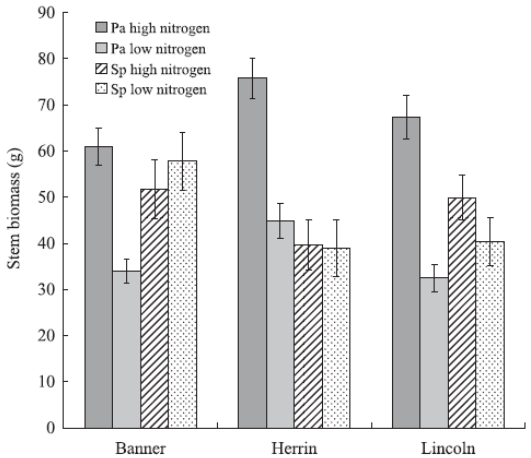
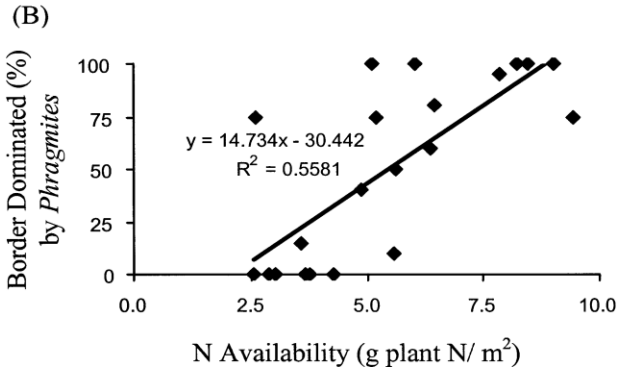


Fig. 2. Mean stem biomass ± 1 SE for *Phragmites australis* (Pa) and *Spartina pectinata* (Sp).

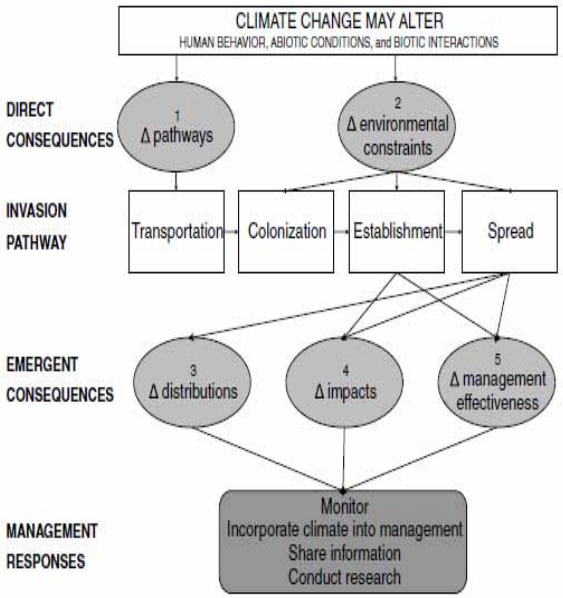
Rickey & Anderson 2004



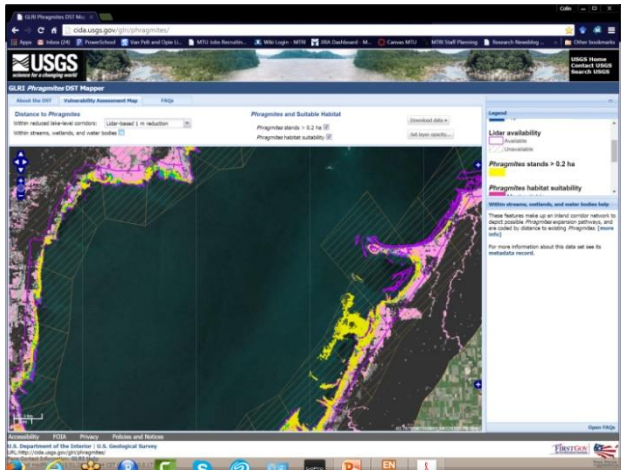
Silliman & Bertness 2004

Climate change

- Invasives often most suited to take advantage of a changing climate
- Changing water levels, removal of climatic barriers, increased nutrient deposition, stress on native veg – CC factors favoring Phrag (Dukes & Mooney, 1999; Hellmann et al. 2008)
- Invasive *Phragmites* less common in northern MI, historically rare in U.P.; may be changing (anecdotal info)
- Warmer temperatures, favors long distance reproduction (seeds) (Brisson et al. 2008)
- May need to monitor larger areas, not just neighboring wetlands
- USGS Great Lakes Science Center "GLRI Phragmites Decision Support Tool Mapper" – invasion risk related to existing large stands, changing water levels (Mazur et al. 2014)
  - http://cida.usgs.gov/glri/phragmites/



Hellman et al. 2008



Management lessons

- Treatments should be specified based on stand being treated (Currie et al. 2014)
- Multi-year treatment & monitoring needed
  - Hazelton et al. 2014 – "*Phragmites australis management in the United States: 40 years of methods and outcomes*"
  - Large scale treatments need to be followed up by yearly spot treating
- Beaver Island – address Phrag problem as a whole community (McDonough 2007, Grassmick 2011)
  - Local ordinance requiring "opt out"
  - Yearly contact with landowners
  - "Early detection, rapid response" (EDRR)
  - Volunteers critical to effort
  - Reduced extent from 27 to 3 acres, improved beach visibility

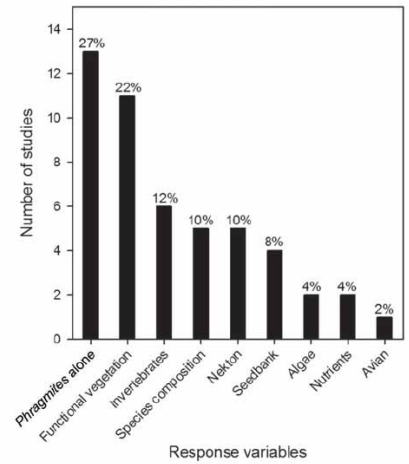


Figure 3. Response variables measured in reviewed studies. Functional vegetation represents only diversity, functional groups or species of interest, but not plant communities. Seedbank represents studies where germination trials were conducted.

Hazelton et al. 2014

http://greatlakesphragmites.net/beaver-island-invasive-species-initiative/

"Volunteers disembarking on High Island, September 2013"

Integration of Wetland Ecosystem Modelling (MONDRIAN) of Treatment Scenarios

UM Water Center project conducted ecosystem modeling of the effects of various treatment scenarios in MONDRIAN modeling (PI Elgersma)

- Dr. Kenneth Elgersma's new work focused on understanding optimal # of years of treatment to control invasives (non-native *Typha, Phragmites*) informed by local N levels
- MONDRIAN modeling with varying N levels and treatments showed optimal treatment scenarios are dependent on N-loading, propagule pressure, hydrology and level of invasion

Elgersma *et al*. 2015 *in prep*

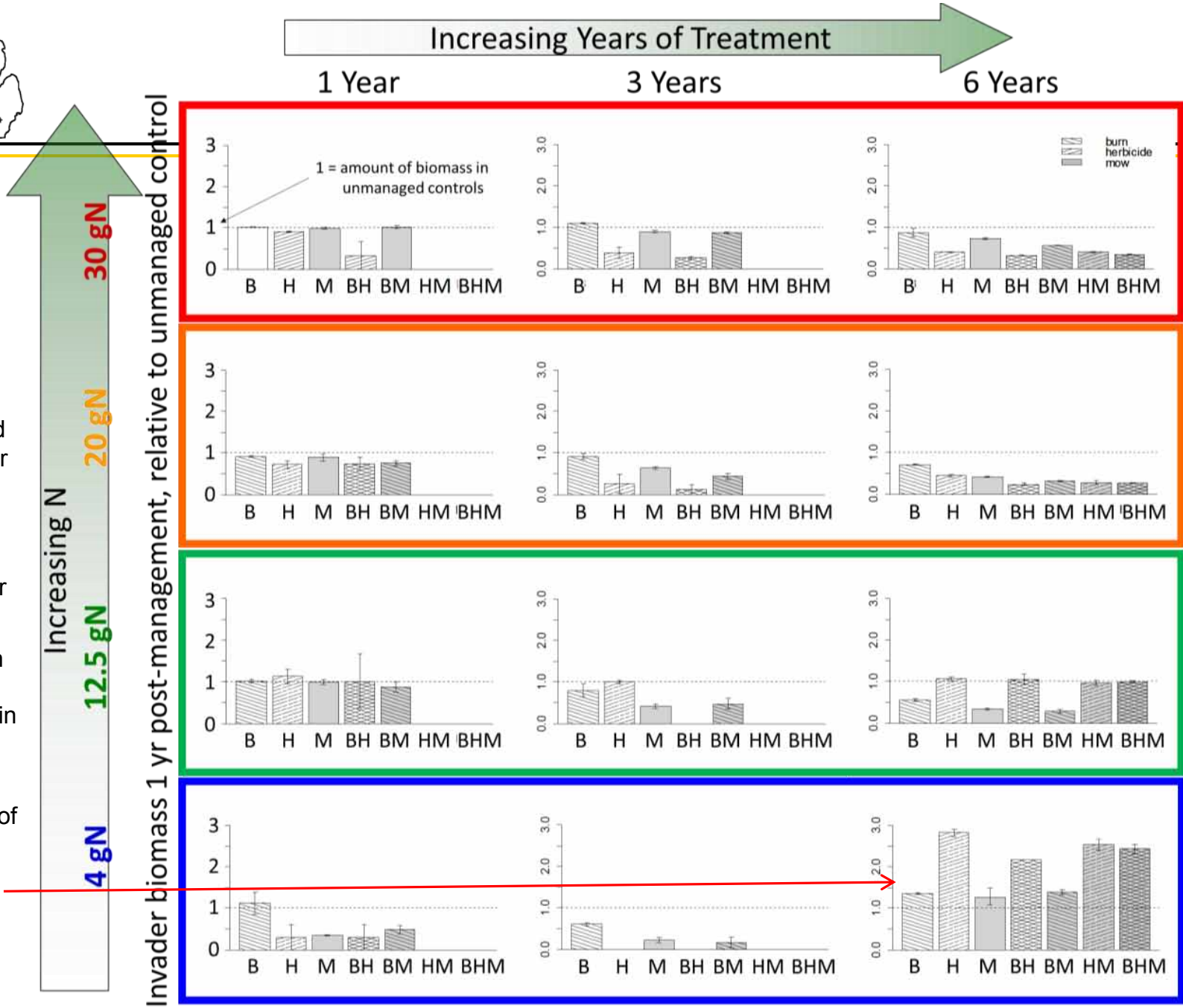
MONDRIAN Model Runs

B-Burned

H-herbicide

M-mowed

- Treatment should be appropriate for level of N in ecosystem
- HM, BHM most effective in higher N areas
- Model can be run for specific site conditions to aid in management strategies
- Too many years of treatment with lower N areas – negative effect



Elgersma *et al*. 2015 *in prep*

Integration of Wetland Ecosystem Modelling (MONDRIAN) of Treatment Scenarios

Results show that the effectiveness of treatments depends on how eutrophic the wetland is:

- Combined treatments, especially herbicide + mowing, are generally more effective than single treatments
- 3 years of combined management is often— but not always— better than 1 year, depending on the specific treatments used and how eutrophic the wetland is
- 6 years of management is seldom better than 3 years. In oligotrophic wetlands, 6 years of management actually *benefits* invasives due to stress on native plants
- N retention, C storage, and invader biomass recover relatively quickly after management ends.

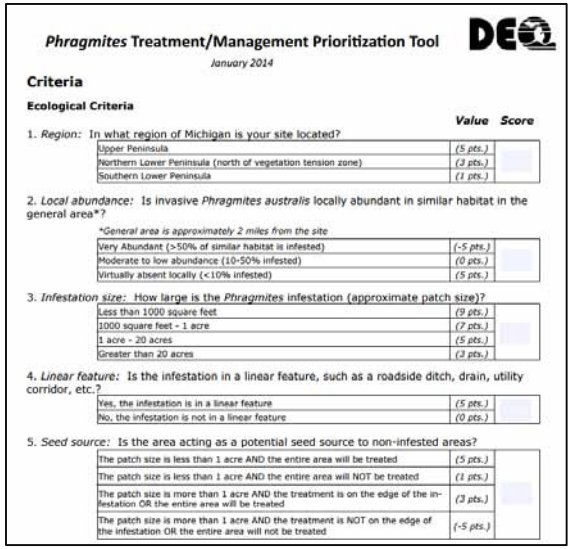
Elgersma *et al*. 2015 *in prep*

Complementary Work on Understanding Mechanisms of Invasion

- Land use/cover on adjacent watersheds influences
  - the structure and function of wetlands,
  - *Phragmites* expansion (King *et al.* 2007, Sillman and Bertness 2004, Chambers *et al.* 2012).
- Plant invasions are triggered by interacting factors including
  - disturbance, nutrients and propagule pressure (Colautti *et al.* 2006).
  - Propagule pressure includes the quality, quantity and frequency of the arrival of invading organisms at a site (e.g. via seeds or rhizomes).

Agency Guides

- Critical resource to many managers, from smallest local nature center to state & federal decision-makers
- Examples described:
  - Virginia
  - Ohio
  - Michigan
    - Prioritization Tool – based on patch size, treatment history, location: http://www.michigan.gov/deq/0,4561,7-135-3313_71151_71481_8314-178183--,00.html
    - 3rd Edition of "A Guide to the Control and Management of Invasive Phragmites" ("Green guide"): https://www.michigan.gov/documents/deq/deq-ogl-ais-guide-PhragBook-Email_212418_7.pdf
  - Anne Arundel Community College
  - USDA
  - Great Lakes Phragmites Collaborative
  - Ontario



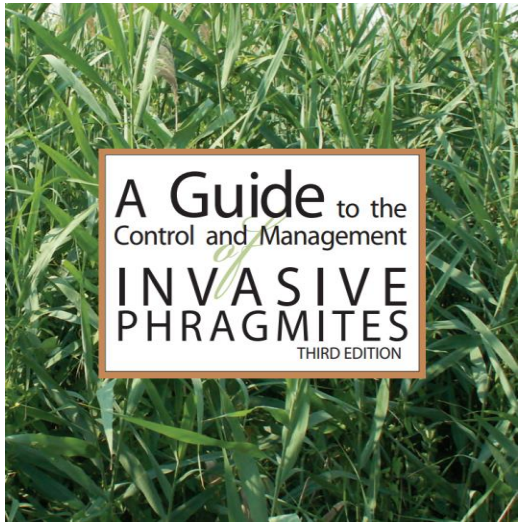
***Phragmites* Treatment/Management Prioritization Tool** DEQ

January 2014

Criteria

Ecological Criteria

	Value	Score
1. *Region:* In what region of Michigan is your site located?		
Upper Peninsula	(5 pts.)	
Northern Lower Peninsula (north of vegetation tension zone)	(3 pts.)	
Southern Lower Peninsula	(1 pts.)	
2. *Local abundance:* Is invasive *Phragmites australis* locally abundant in similar habitat in the general area*?		
*General area is approximately 2 miles from the site		
Very Abundant (>50% of similar habitat is infested)	(-5 pts.)	
Moderate to low abundance (10-50% infested)	(0 pts.)	
Virtually absent locally (<10% infested)	(5 pts.)	
3. *Infestation size:* How large is the *Phragmites* infestation (approximate patch size)?		
Less than 1000 square feet	(9 pts.)	
1000 square feet - 1 acre	(7 pts.)	
1 acre - 20 acres	(5 pts.)	
Greater than 20 acres	(3 pts.)	
4. *Linear feature:* Is the infestation in a linear feature, such as a roadside ditch, drain, utility corridor, etc.?		
Yes, the infestation is in a linear feature	(5 pts.)	
No, the infestation is not in a linear feature	(0 pts.)	
5. *Seed source:* Is the area acting as a potential seed source to non-infested areas?		
The patch size is less than 1 acre AND the entire area will be treated	(5 pts.)	
The patch size is less than 1 acre AND the entire area will NOT be treated	(1 pts.)	
The patch size is more than 1 acre AND the treatment is on the edge of the infestation OR the entire area will be treated	(3 pts.)	
The patch size is more than 1 acre AND the treatment is NOT on the edge of the infestation OR the entire area will not be treated	(-5 pts.)	



Agency Guides - summary

Guide	Publisher	Year	Link	Comments
Marsh Invader!	Virginia DCR	2007	http://www.deq.virginia.gov/portals/0/deq/coastalzonemanagement/task10-03-07.pdf	12 pg guide for land owners
Invasive Plants of Ohio	Ohio Invasive Plants Council	2010	http://www.oipc.info/uploads/5/8/6/5/58652481/5factsheetcommonreedgrass.pdf	2 pg fact sheet
Michigan "Green Guide"	Michigan DEQ	2014	https://www.michigan.gov/documents/deq/deq-ogl-ais-guide-PhragBook-Email_212418_7.pdf	46 pg guide on growth and control
Summary of Common Questions	Anne Arundel Community College	2006	http://home.comcast.net/~herringbay/pdfs/PhragQandA.pdf	8 pg FAQ for land owners
Plant Guide: Common Reed	USDA	2012	http://plants.usda.gov/plantguide/pdf/pg_phau7.pdf	5 pg guide on ID, and growth (no mgmt)
Phragmites Treatment Herbicide Quick Guide	Great Lakes *Phragmites* Collaborative	2015	http://greatlakesPhragmites.net/files/HerbicideQuickGuide.pdf	2 pg fact sheet on major herbicides with pros/cons
Invasive *Phragmites* BMPs	Ontario MNR	2011	http://www.nvca.on.ca/Shared%20Documents/Phragmites%20control%20-%20best%20practices.pdf	17 pg guide for land owners, note Canadian Herbicide legislation

Biological Control

- Biological control agents not yet released for Phrag control
- Parasitic European moth (*A. geminipuncta*) – appears promising
  - infects 2/3 of stands in native range, parasitizes up to 90% of stems (Blossey 2014)
  - Specific to invasive Phragmites (Hinz et al. 2014)
- 3 other moths tested – some potential effectiveness; 2 fly species – but impacted native Phrag as well (Lambert et al. 2007)
- Field testing must be completed, ensure that bio agents are safe, be cautious of unanticipated problems
- Should be assessed periodically for progress

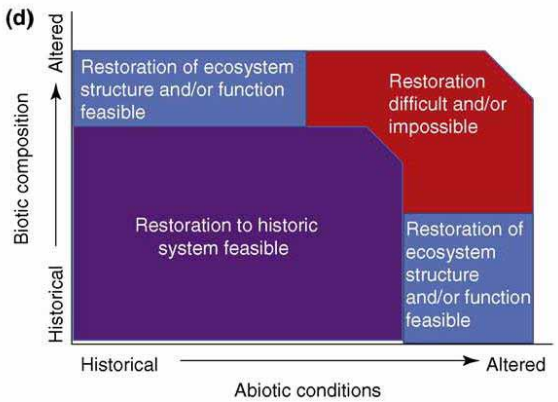
Archanara geminipuncta, a European moth currently being considered for Phragmites bio-control. (photo credit: Kevin Leighton, 2013)

Figure 2. Testing chamber

Blossey 2014

Novel ecosystems implications

- Not all Phragmites stands can be controlled everywhere
  - Remote non-natives that have integrated into local ecosystems challenging & not always desirable because they can provide some ecosystem services (Lugo 2013 – novel ecosystems theory example)
- In some situations, Phragmites can contribute to total function of an ecosystem & complete removal can negatively impact wetland function (Hershner & Havens 2008, Kiviat 2013)
- Can contribute to nutrient update, sediment retention (filter between upland areas & water)
- Stands can provide habitat / cover for some birds
- Select populations that pose greatest threat (ex: valuable wetlands, popular parks)



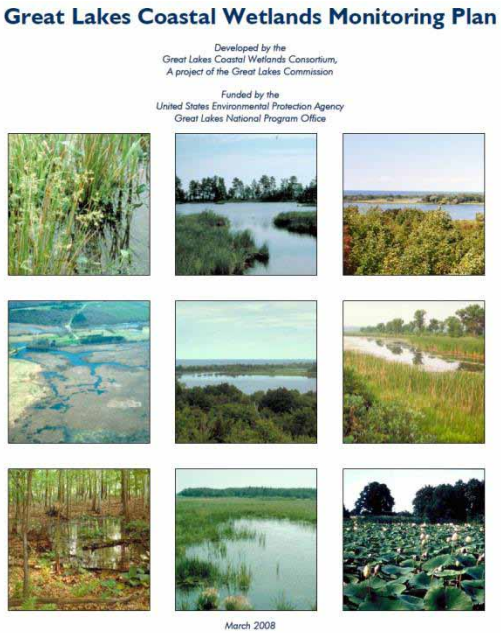
Hobbs et al. 2009
highly alterated ecosystems are difficult to restore

Figure 4. Birds nesting in *Phragmites*. Left: *Dendroica petechia* (yellow warbler) nest in *Rubus occidentalis* surrounded by Old World *P. australis*. Dry habitat on dredged material island, Hudson River. Right: *Quiscalus quiscula* (common grackle) nest in Old World *P. australis*. Freshwater tidal marsh, Hudson River. Photographs by Erik Kiviat.

Kiviat 2013 – birds nesting Phrag

Monitoring methodologies

- This project's methods derived from Great Lakes Commission's Great Lakes Coastal Wetlands Monitoring Plan
  - Burton et al. 2008:
  - http://glc.org/projects/habitat/coastal-wetlands/
  - D.Uzarski (CMU) GLRI coastal wetlands monitoring project
  - See also Wilcox et al. 2002 & Uzarski et al. 2004 for Index of Biological Integrity (IBI) background
  - See Bourgeau-Chavez et al. 2004, 2008 for remote sensing methods – combining optical & radar satellite imagery data provided mapping of Typha vs. Phragmites



Burton et al. 2008

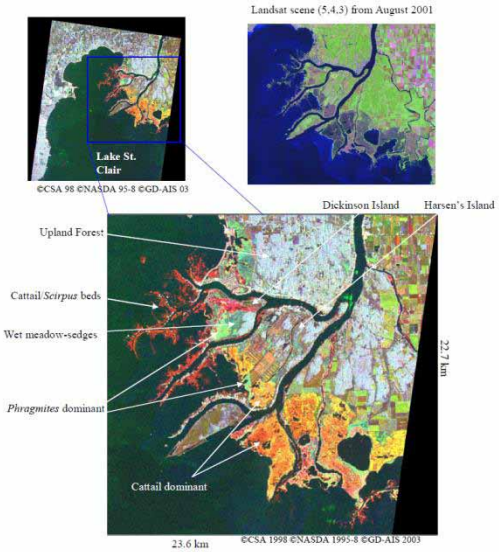


Figure 5. Lake St. Clair three date false color composite of Radarsat 3 Oct 98 (red), JERS 10 Aug 98 (green), and JERS 28 Mar 95 (blue). A 5,4,3 Landsat composite from August 2001 is shown for comparison.

Bourgeau-Chavez et al. 2004

Table 6-2. The approximate number of sites required to detect a difference in IBIs within an area of interest (e.g., Great Lakes basin, lake basin, state, region). IBIs are expressed out of 100 with higher scores indicating amphibian communities in better condition.

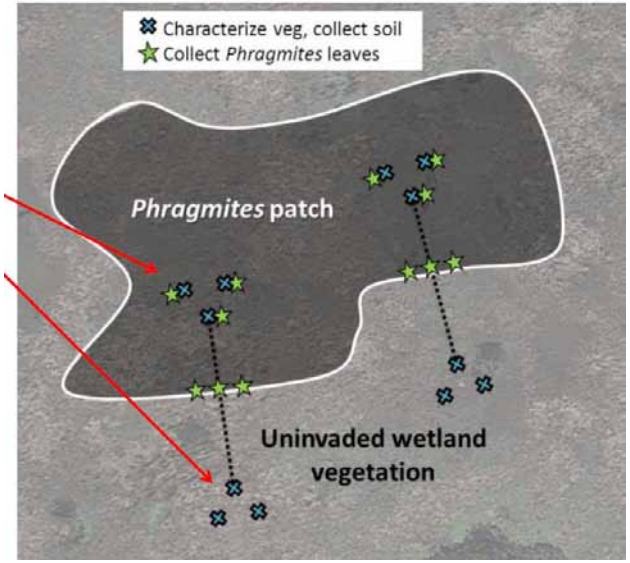
Number of sites required	Mean difference in IBI between paired sites
10	30
20	20
30	15
40	12

For example, if an agency wanted to detect a mean difference of 20 IBI points in a suite of sites sampled in a particular region, at least 20 sampling sites (wetlands) are recommended.

Uzarski et al. 2004

Other example monitoring protocols

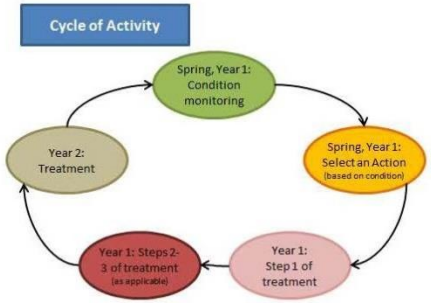
- PhragNet – Chicago Botanical Garden (CBG)
  - Series of transects per Phragmites patch, 3 points (edge, outside, 15m inside)
  - Leaf & soil samples
  - Simple to implement
  - Provides baseline information on a stand, but not focused on effectiveness of management
  - http://greatlakesphragmites.net/files/2.-PhragNet_6_5_2013FINAL.pdf



Hunt 2013 GLPC presentation

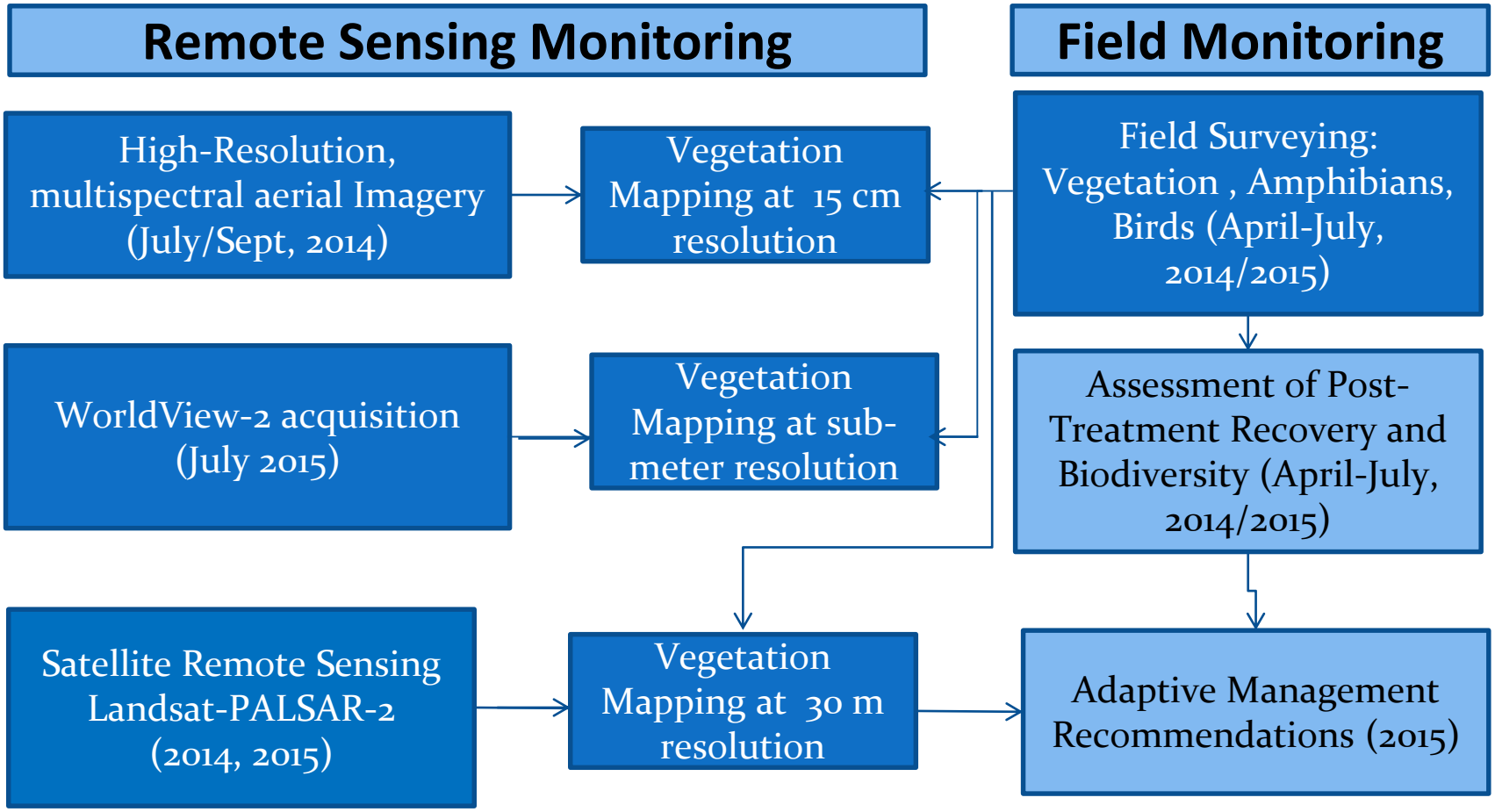
- USGS / CBG protocol for US Fish & Wildlife Service (Moore et al. 2014)
  - Uses transects
  - Landcover by category
  - Some training, wide application
  - Explicitly part of US DOI adapative management efforts

Figure 4.1 Activity cycle for eight action menu (Table 2)



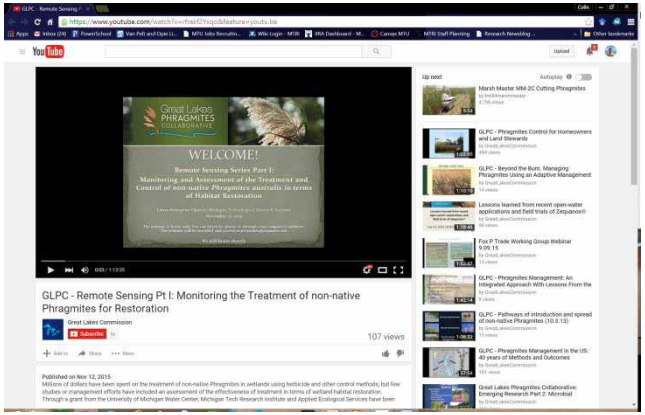
Moore et al. 2014

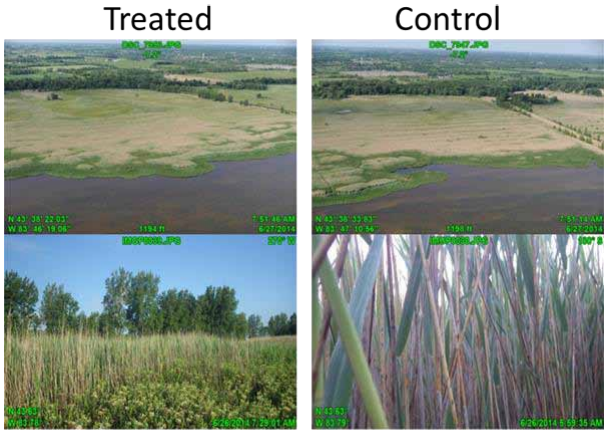
Our UM Water Center project…
Monitoring: A Tiered Approach



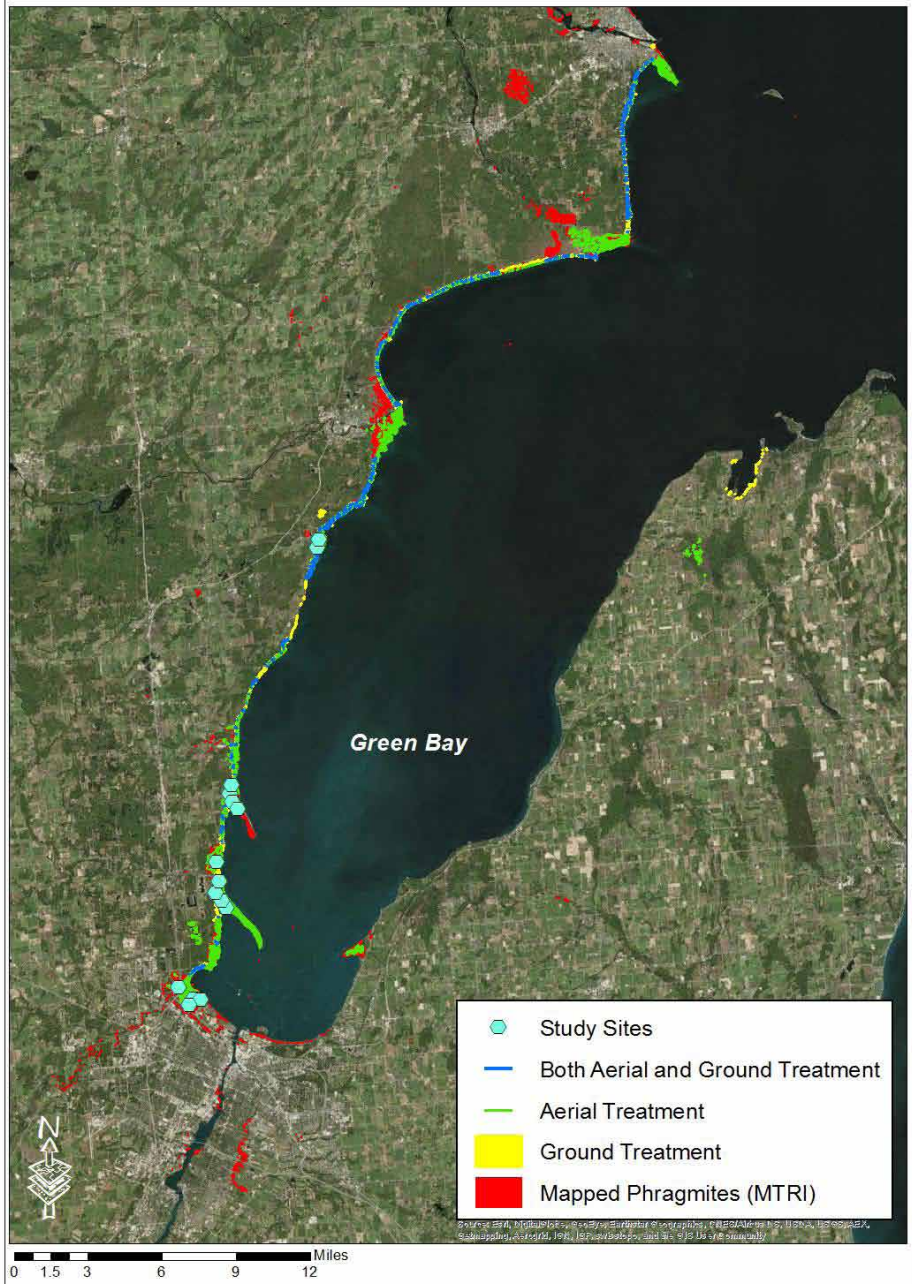
Remote sensing overview

- Described in detail in Part I: “Monitoring and Assessment of the Treatment and Control of non-native Phragmites australis in terms of Habitat Restoration” by Dr. Laura Bourgeau-Chavez (MTRI) and team.
- Available at GLPC webpage at http://greatlakesphragmites.net/resources/webinars-presentations/
- Full recording of Part I webinar available
- https://www.youtube.com/watch?v=rfrakf2Ysqo&feature=youtu.be
- Reviewed here:
  - Monitoring approach
  - Locations
  - Amphibians, bird results
  - Vegetation results (**NEW since Part I webinar**)
  - Remote sensing results

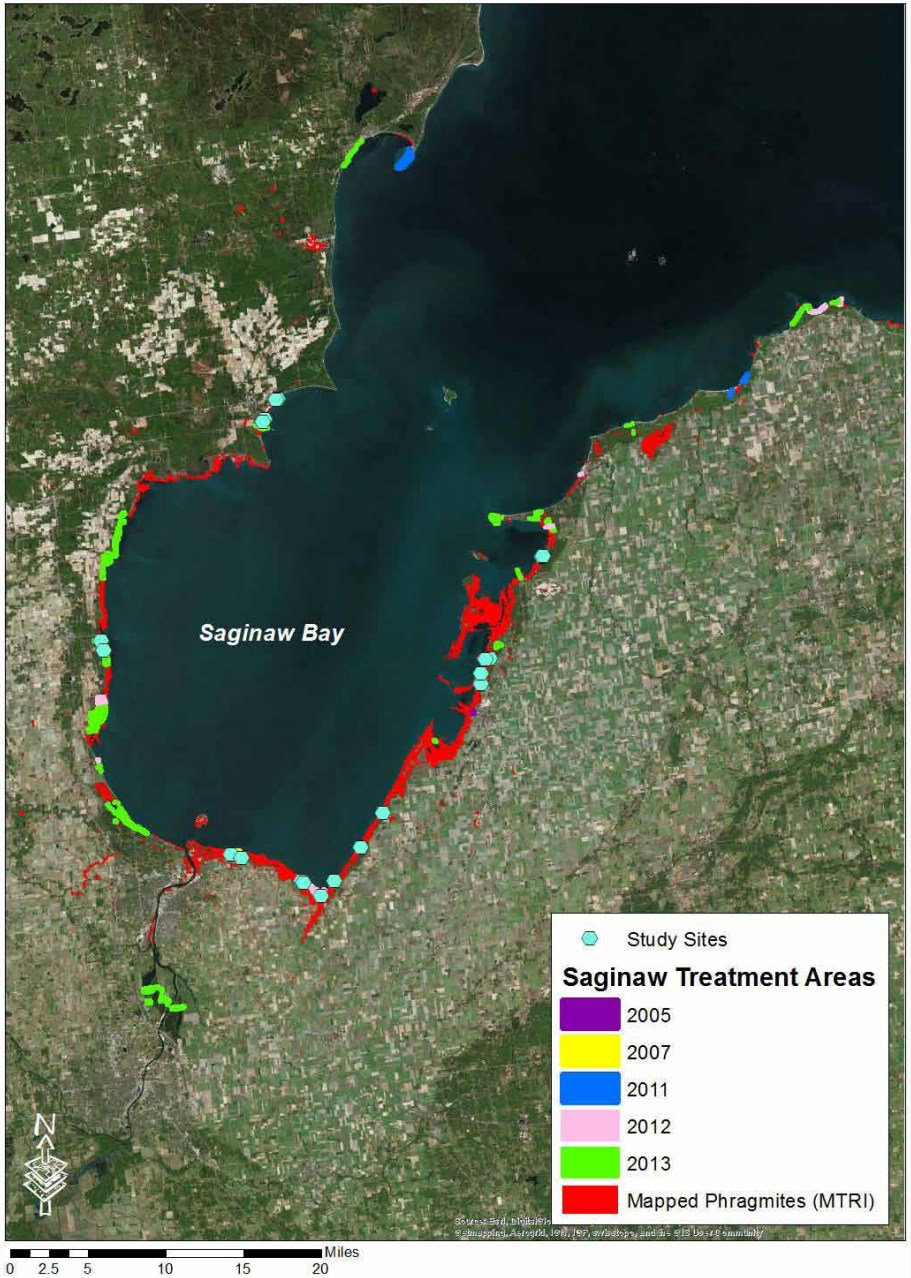




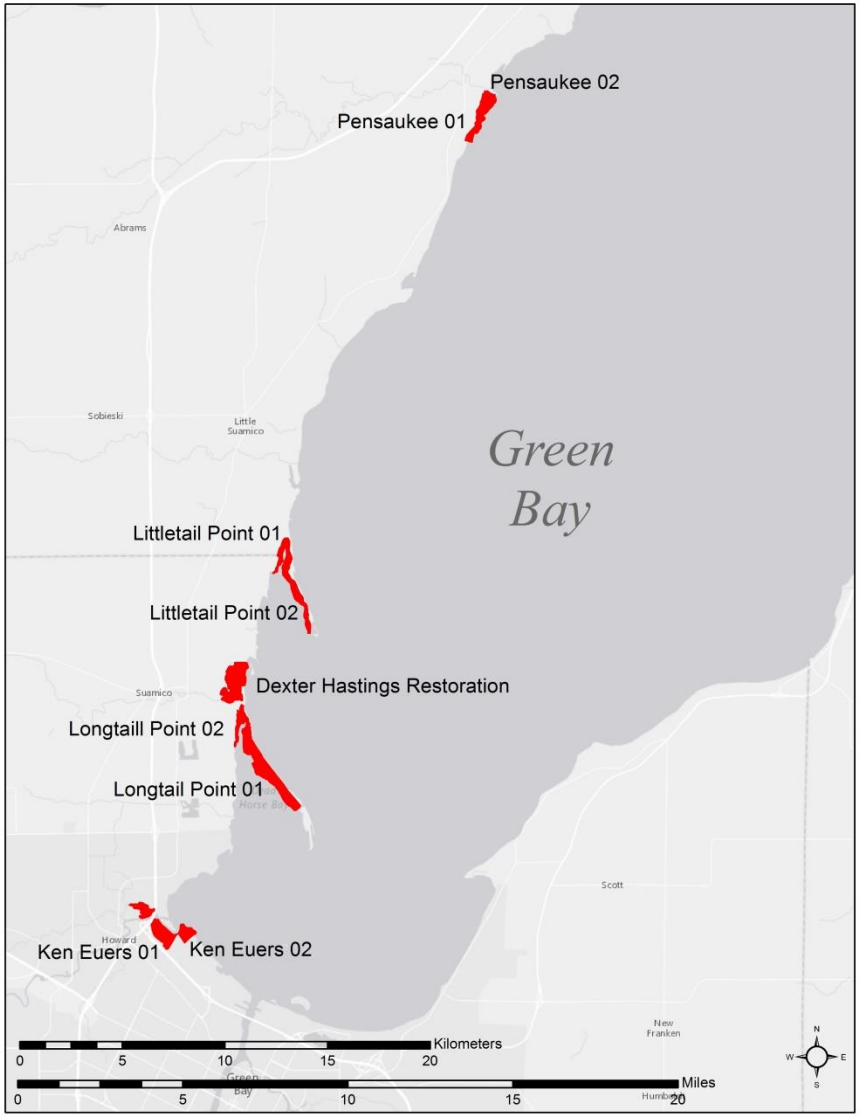
Green Bay Phragmites australis Treatment 2011 - 2012



Saginaw Bay Phragmites australis Treatment 2011 - 2013



Study site locations



Field Monitoring in Green and Saginaw Bays

- Biodiversity Data Collection and Processing
  - Amphibian and bird diversity
    - Surveyed using point count protocols
    - Calculated Indices of Biotic Integrity (IBIs) developed and recommended by the GLCWC for assessing community condition
    - Also analyzed simple species diversity for anurans
  - Vegetation diversity
    - Calculated the GLCWC vegetation IBI (standardized measure of community condition), native species diversity, site-wide *Phragmites* cover, *Phragmites* cover in the emergent plant zone, mean conservatism index (measure of community intactness) and mean conservatism ratio (measures degradation of the site by invasions)

Field Monitoring in Green and Saginaw Bays

Site Name	Amphibians		Birds		Vegetation	
	Pre-treatment	Post-Treatment	Pre-treatment	Post-Treatment	Pre-treatment	Post-Treatment
Saginaw Bay						
499A		2014, 2015		2014, 2015		2014, 2015
761C	2011*	2014, 2015		2014, 2015		2014, 2015
517Awest	2012*	2014, 2015	2012*	2014, 2015	2012*	2014, 2015
517Aeast	2012	2014, 2015	2012	2014, 2015	2012*	2015
522A	2011	2014, 2015	2011	2014, 2015	2011	2014, 2015
518Ceast		2014, 2015		2014, 2015		2014, 2015
461A	2012	2014, 2015	2012	2014, 2015	2012	2014, 2015
761A		2014, 2015	2011*	2014, 2015		2014, 2015
515A		2015		2015		2015
Green Bay						
KE		2013, 2014		2013, 2014, 2015		2014
PE		2013, 2014		2013, 2014, 2015		2014
LO01	2011*	2014	2011*	2014, 2015		2014
LO02	2011*	2014	2011*	2014, 2015	2011*	2014
LI01		2014		2014, 2015		2014
DXT	2011*	2013*, 2014*, 2015*	2011*	2013, 2014*, 2015*	2011*	2014*

*data only available for treated site, not control

Field Monitoring in Green and Saginaw Bays

- Amphibian Diversity: Before After Control Impact (BACI) Design
  - Mean BACI effect (estimated by two-factor mixed-effect ANOVA) was not significant for IBI or species diversity
- Amphibian Monitoring Takeaways
  - Species diversity, but not IBI, shows significant decrease over time – **choice of indicator metric is important**!
  - *Phragmites* treatment appears to have no significant effect on amphibian diversity for the two years of study
  - **Highlights value of control sites**: looking at change over time in treated sites alone, we might assume a negative effect of treatment, but control sites show this is not the case



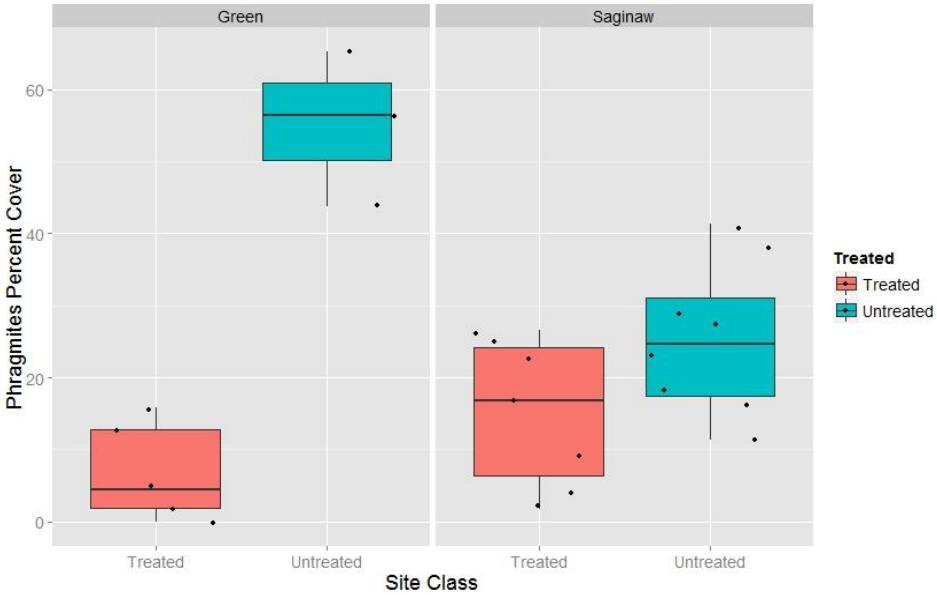
Field Monitoring in Green and Saginaw Bays


Bird Monitoring Takeaways

- Large year-to-year variations require either more surveys per year (pseudo-replicates) or more years of surveys to increase statistical power
- Indicator taxa respond differently and on different timescales.
- The GLCWC bird IBI emphasizes cryptic marsh nesting obligate species (rails, bitterns), which may benefit from *Phragmites* treatment over the long term but not the short term if mowing removes the thick emergent vegetation they prefer.
- More suitable sampling approach may be applied when monitoring begins prior to treatment

Vegetation Monitoring in Green and Saginaw Bays

- Measuring success: Is *Phragmites* cover lower in treated sites compared to similar, nearby untreated sites?



In Green Bay, Yes

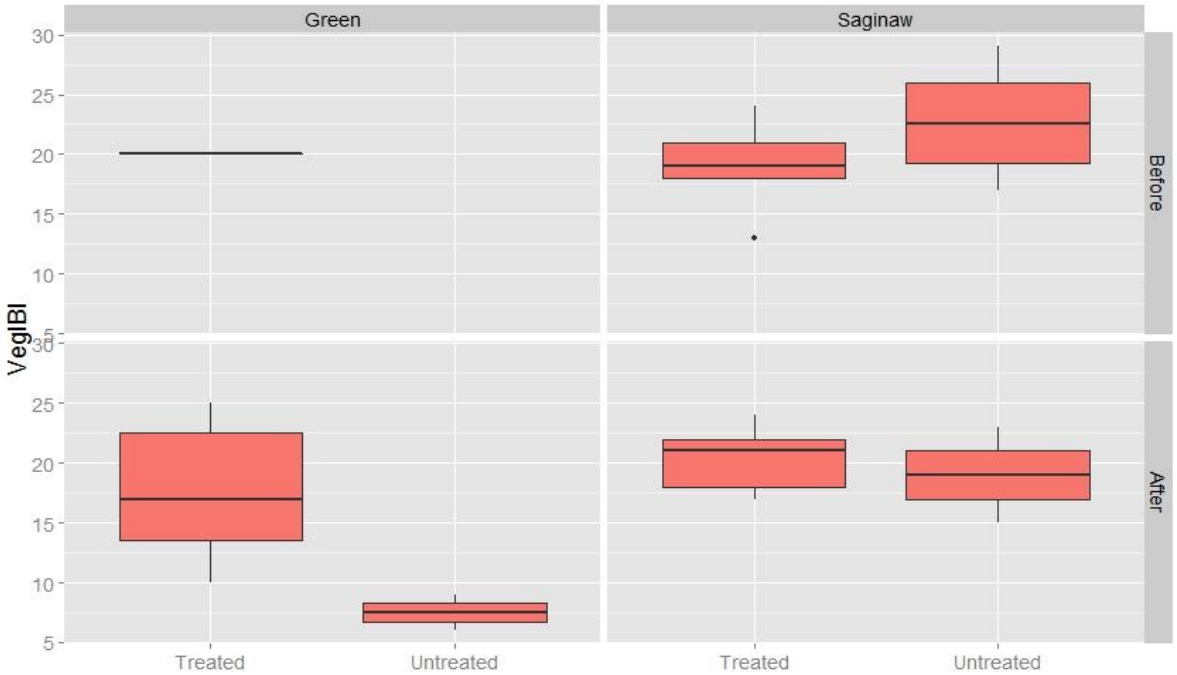
In Saginaw Bay, No

Vegetation Monitoring in Green and Saginaw Bays

- Measuring success: Is *Phragmites* cover lower in treated sites compared to similar, nearby untreated sites?
  - In Green Bay, where *Phragmites* was treated with aerial spraying followed by ground-based touch-up treatment the next year, live *Phragmites* cover decreased following treatment at all sites with both pre- and post-treatment survey data
  - In Saginaw Bay, live *Phragmites* cover actually increased following treatment at three of the four sites for which pre-treatment data were available
    - Treatment at all of these sites consisted of a single year of ground-based herbicide application (one site mowed) with no followup treatment in subsequent years

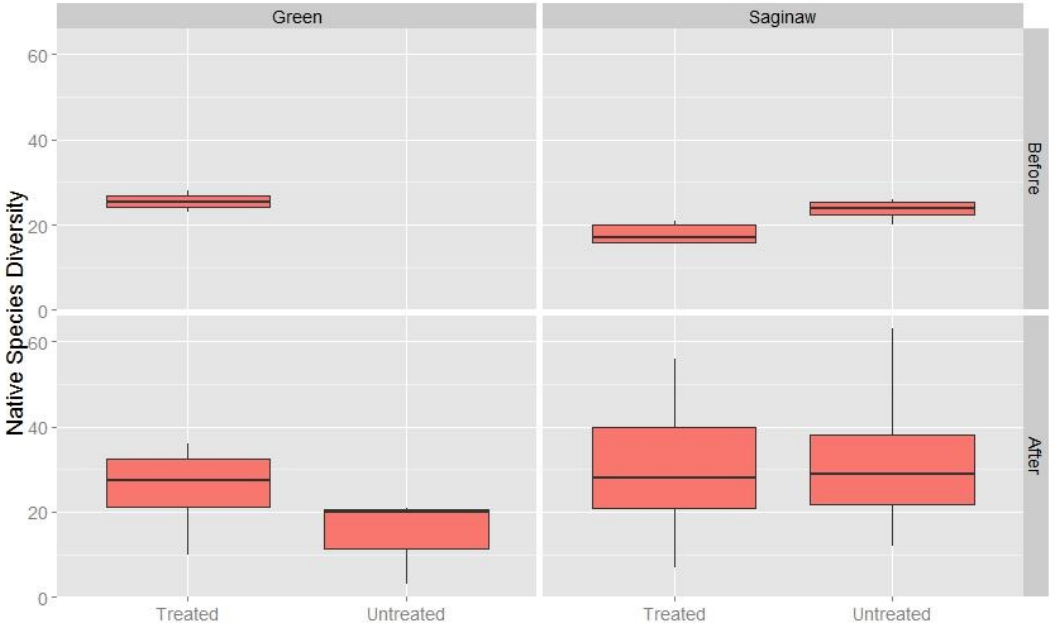
Field Monitoring in Green and Saginaw Bays

- Vegetation Community Condition
- Three indicator metrics:
  - Vegetation IBI was developed by the GLCWC and reflects the conservatism of the native species present and the number and cover of invasive species present in 3 vegetation zones



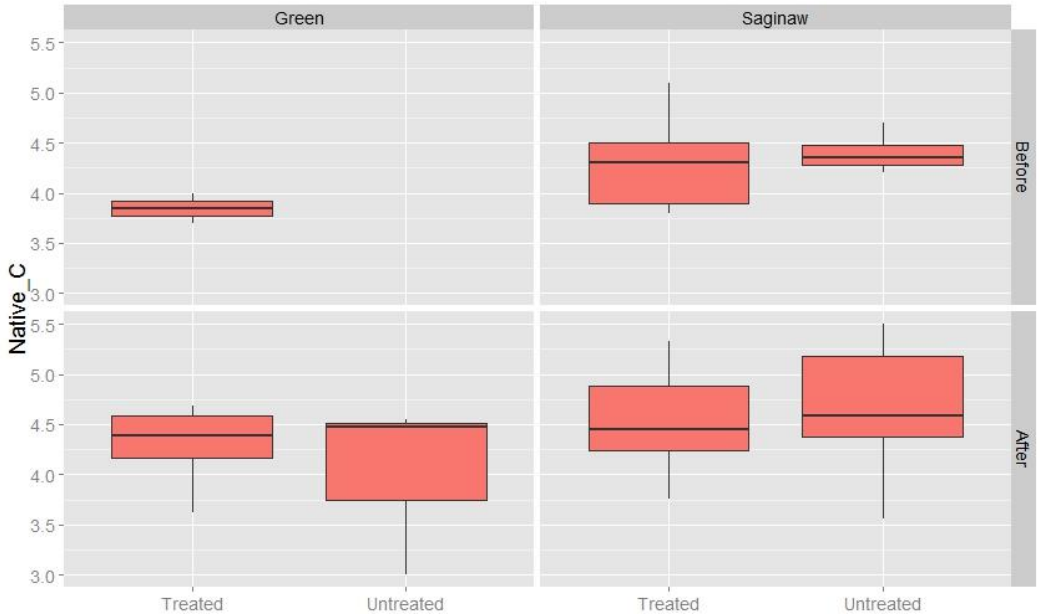
Field Monitoring in Green and Saginaw Bays

- Vegetation Community Condition
- Three indicator metrics:
  - Native diversity is the number of native macrophyte species recorded in the 45 quadrats measured per site



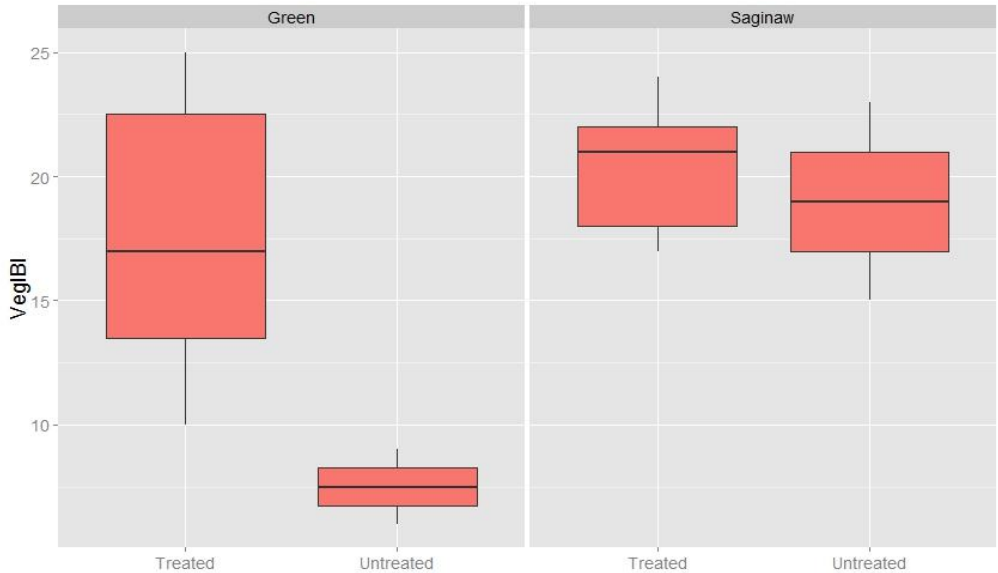
Field Monitoring in Green and Saginaw Bays

- Vegetation Community Condition
- Three indicator metrics:
  - Mean Native C is the “mean coefficient of conservatism” of the native species recorded at the site; species with greater habitat specificity and lower tolerance to disturbance have higher C



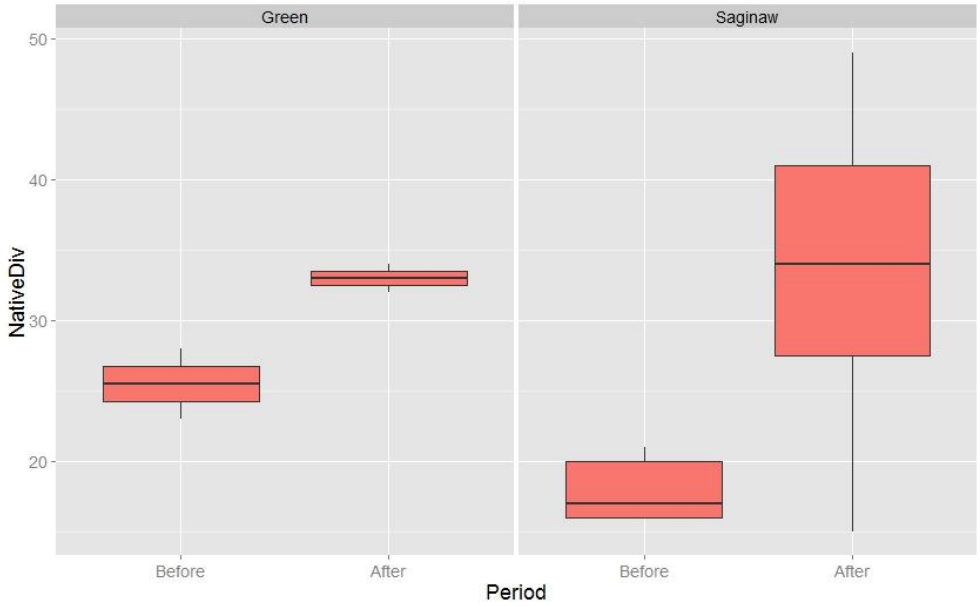
Field Monitoring in Green and Saginaw Bays

- Vegetation Diversity: Spatial Matched-Pairs Design
  - No significant differences in vegetation diversity or mean native C between control and treated sites post-treatment
  - Vegetation IBI varied significantly between bays with a significant interaction between bay and site class (treated/untreated)
  - Pairwise comparisons: treated and untreated sites were significantly different in Green Bay but not Saginaw Bay



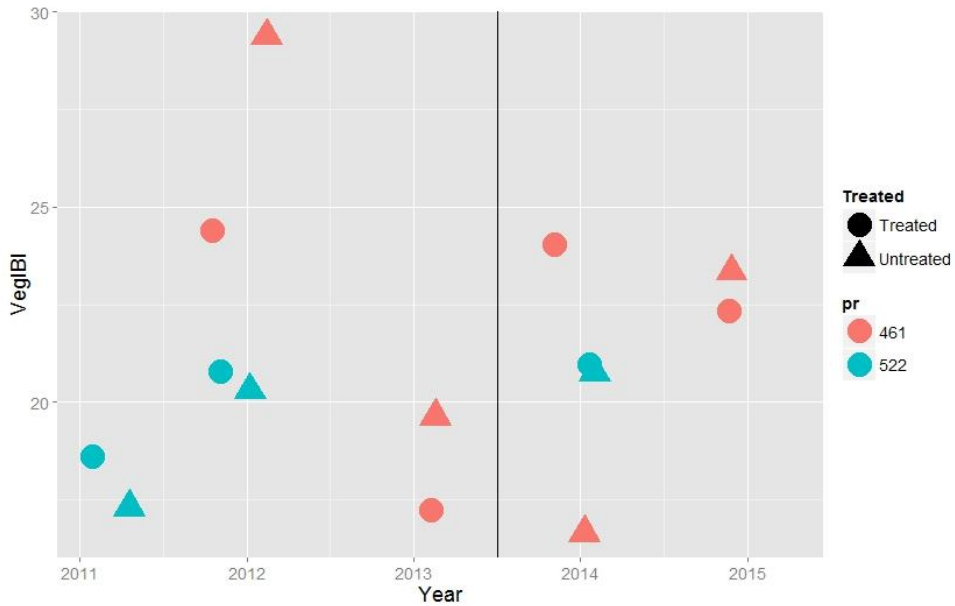
Field Monitoring in Green and Saginaw Bays

- Vegetation Diversity: Temporal Baseline Design
  - Compared values before and after treatment at the same sites
  - No significant differences for vegetation IBI or mean native C
  - Native species diversity significantly higher after treatment in both bays



Field Monitoring in Green and Saginaw Bays

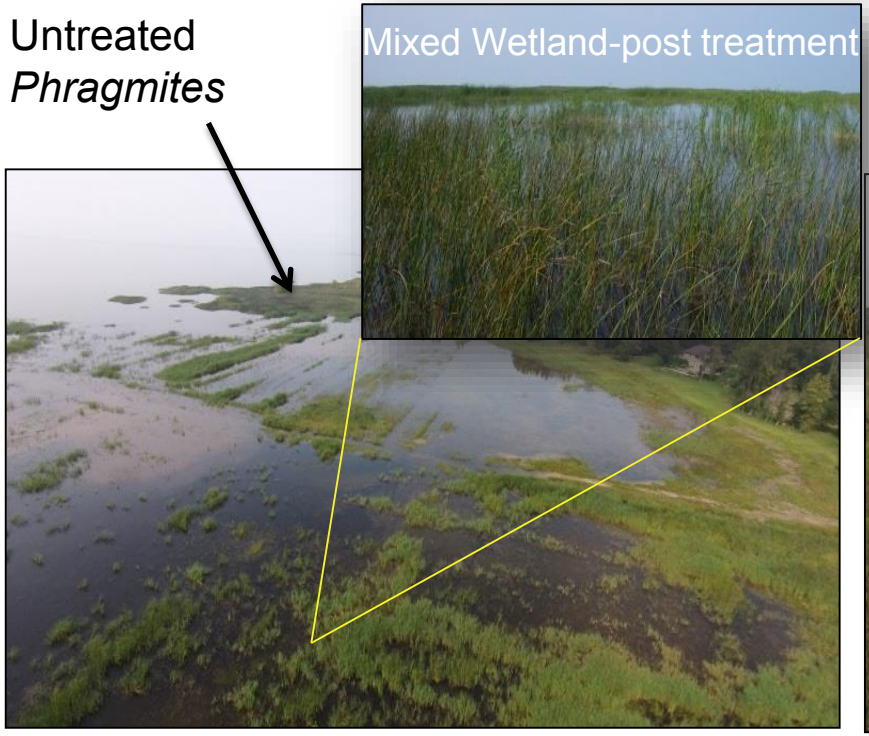
- Vegetation Diversity: BACI Design
  - Two pairs of sites with complete data, not enough pairs for significant results
  - Treatment appeared to have no effect on vegetation IBI for pair 522, but may have caused a short-term boost for pair 461

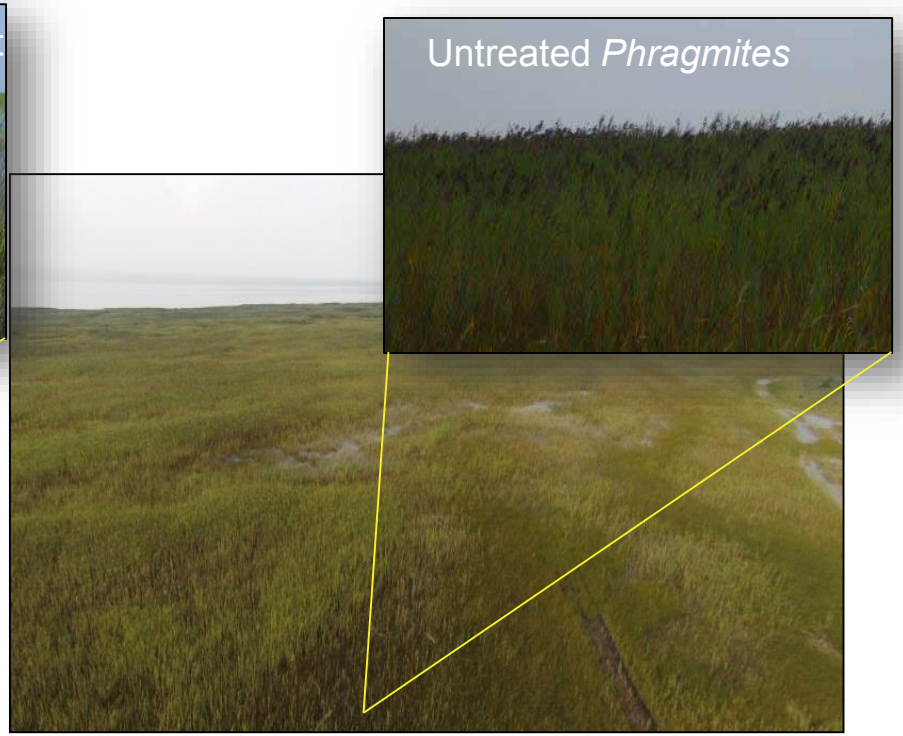


Field Monitoring in Green and Saginaw Bays

- Vegetation Monitoring Takeaways
  - Spatial-matched pairs results suggest that aerial herbicide spraying in Green Bay, which had a stronger effect on reducing *Phragmites* cover, also had a stronger effect on increasing vegetation diversity than the piecemeal ground-based treatment in Saginaw Bay
  - On average, native species diversity increased at treated sites in both bays
  - Large variations in vegetation metrics from year to year and between sites
    - Annual weather conditions, ice/wave scour, slope, bathymetry, and surrounding land use are all likely to have strong influences on both invasive species cover and the native species assemblage present at a site
    - Before/after data and inclusion of control sites provides the best opportunity to distinguish treatment effects from other sources of variation

September 2015 UAV and Field Reconnaissance Saginaw Bay Shoreline





40 acre Treated site

- mowed since late 1990s and
- herbicide treated for 4 years (2010-2014)

Paired control site with untreated *Phragmites*

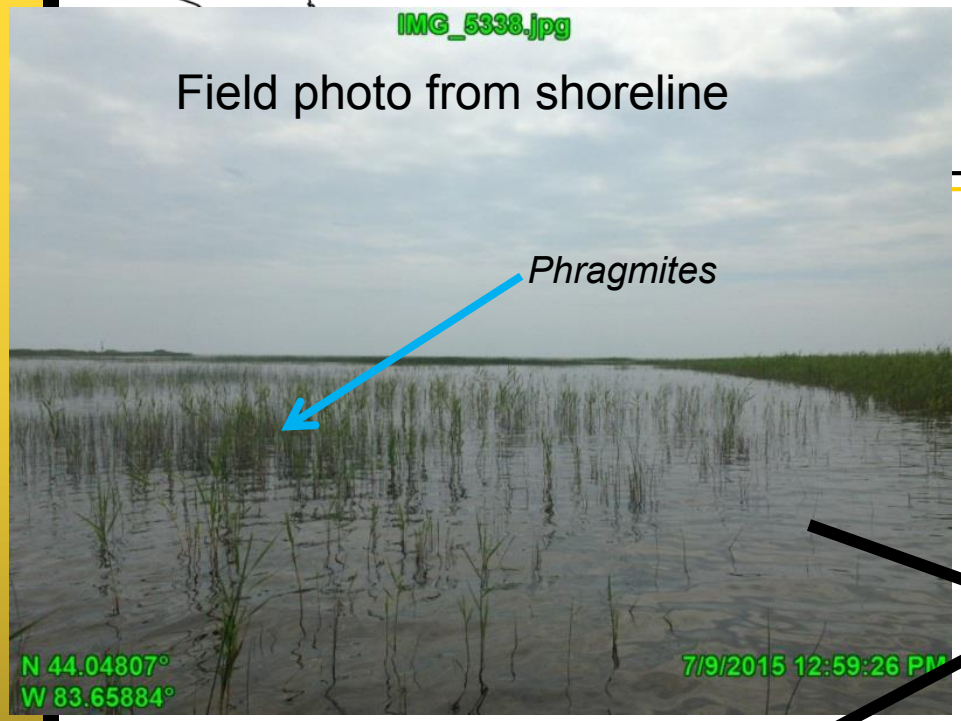
Remote Sensing

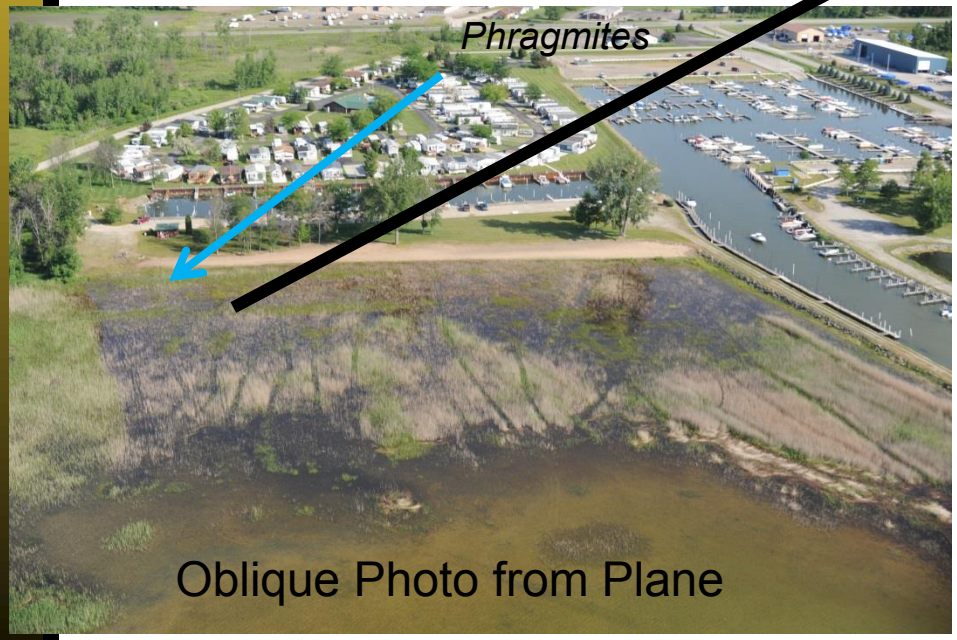
- **Satellite Sensors**
  - Radar
    - ~24 cm wavelength L-band PALSAR-2 (10 m resolution)
    - ~5.6 cm wavelength C-band Radarsat-2 (5 m resolution)
  - Optical multi-wavelength
    - Landsat 8 (30 m resolution)
    - Worldview-2 (1 to 2 meter resolution)
    - RapidEye (5 m resolution)
- **Aerial Imaging**
  - AES multi-wavelength system
    - 15 cm resolution
    - Includes near-infrared bands (visible + NIR = 4 total)
    - Timely collections
  - AES oblique images for field site assessment, paired site imagery, monitoring tool
  - Tested small UAVs for field site imaging

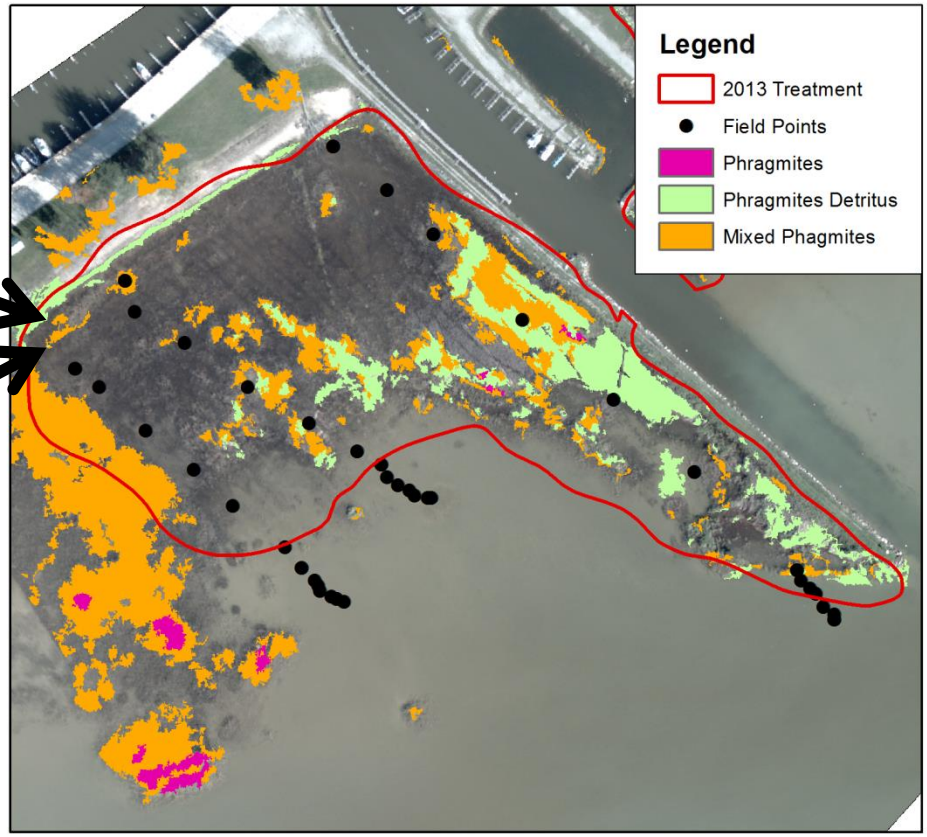
Importance of Mapping in Management

- Identify where *Phragmites* stands are including leading edges and the surrounding landscape
- Determine outliers, pathways, and possible sources
- Allows for strategic planning of locations to treat and the best type of treatment
- Annual (frequent) map updates can monitor treatment success and identify areas needing additional treatment
- Maps provide information on the level of invasion (density) and degree of regrowth post treatment

High resolution aerial imagery classification used to identify areas of *Phragmites* regrowth post treatment







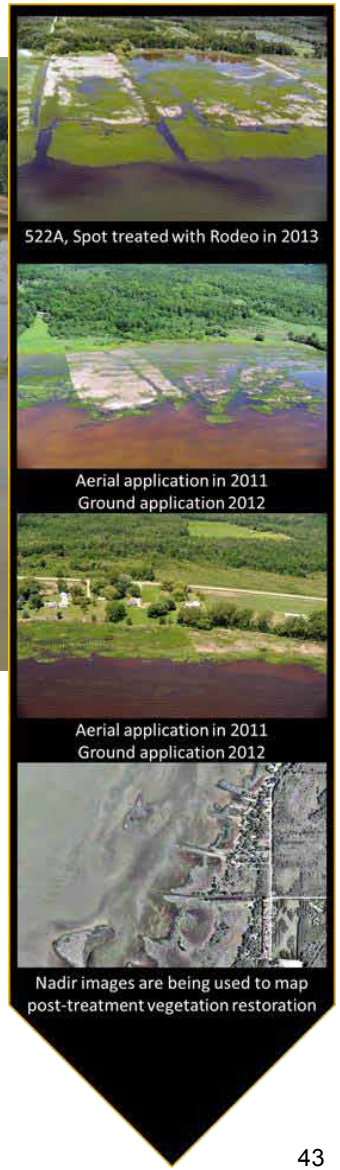
UAV-enabled field site imaging

- UAV-enabled sensing provides **a quick overview** of field sites & useful images for monitoring sites
- Can be done with systems in the **$600 - $1000 range** for rapid aerial images (not mapping grade)
  - Systems can fly from 300' to 2500' feet away, with first-person viewer (FPV) capabilities
  - DJI Phantom 2 Vision shown
- **Hobbyists can fly now (w/in certain limits** – below 400', not near airports, within line of sight, during daytime)
- **Can be done commercially with FAA Section 333 exemption** under similar rules
  - Public agencies: Certificates of Authorization (COA), or partner with existing operator
- **New rules coming from FAA in 2016/2017** making this more practical (no pilot's license, just a $300 UAV operator's permit)

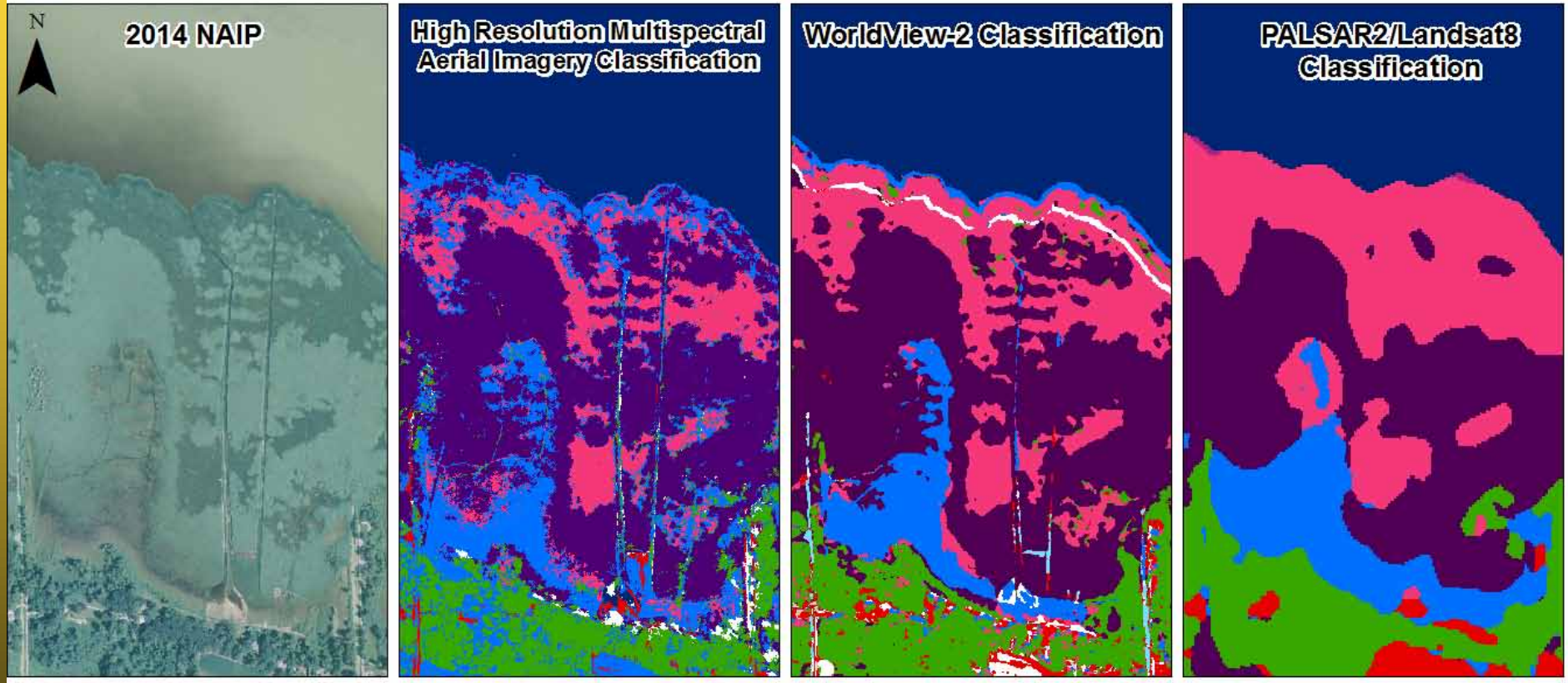
AES Oblique 2014 Aerial Images (from airplane)

- Site 515B treated

- Site 515A untreated



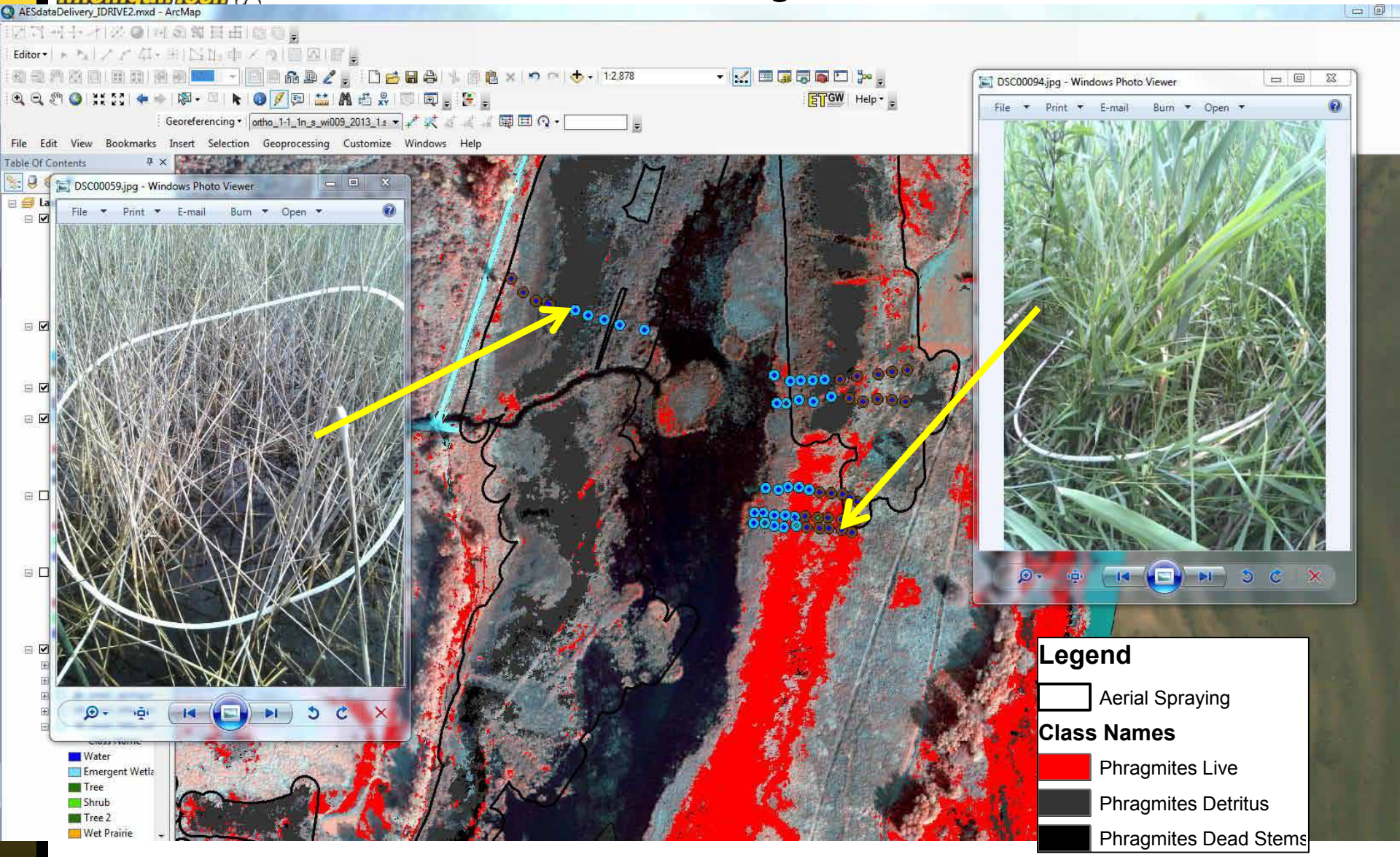
15 cm Aerial Imagery compared to Worldview and Landsat/PALSAR-2 Mapping



Classes

- Phragmites
- Wet Meadow/Emergent
- Barren
- Developed
- Typha
- Water
- Tree/Shrub

Field Work: Biodiversity-> Amphibian, Bird, Vegetation



Using Maps to Inform Adaptive Management

Legend

Aerial Spraying

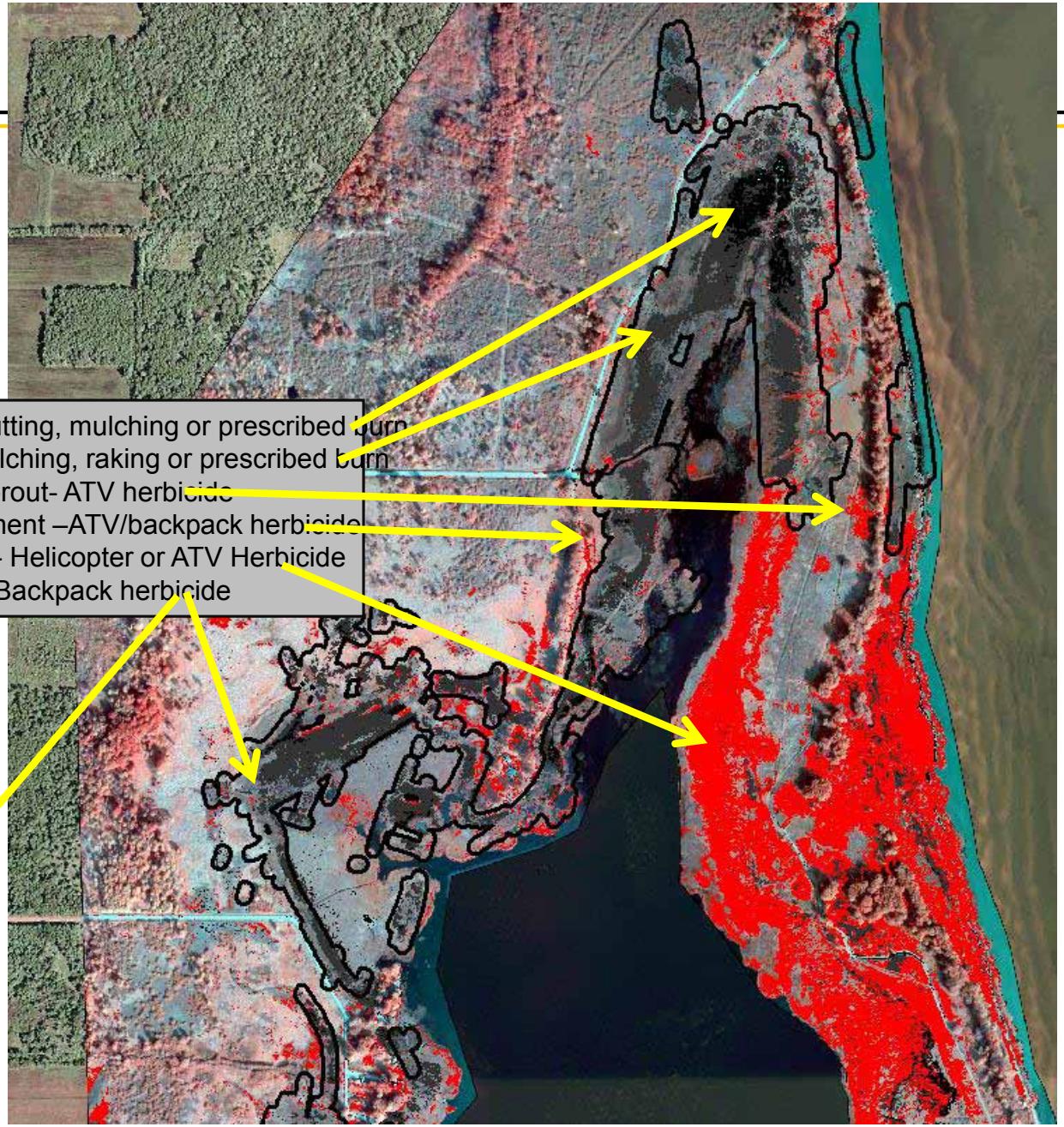
Class Names

Phragmites Live

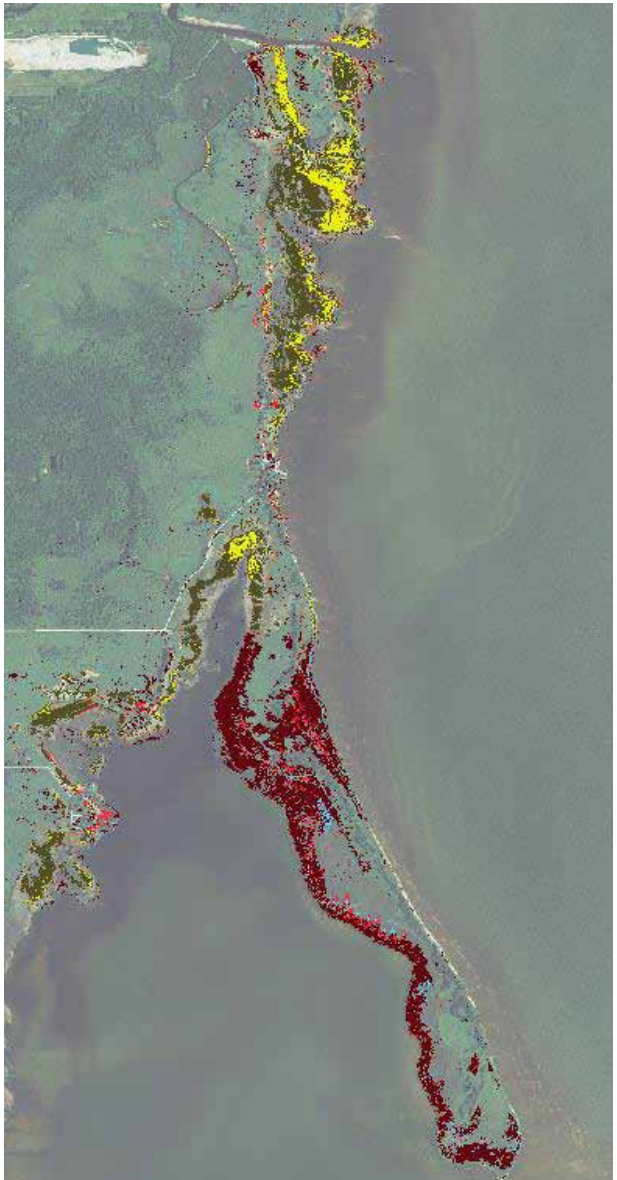
Phragmites Detritus

Phragmites Dead Stems

- Areas of standing dead Phrag- cutting, mulching or prescribed burn
- Areas of dense thatch require mulching, raking or prescribed burn
- Medium sized areas Phrag Re-sprout- ATV herbicide
- Edges missed by herbicide treatment –ATV/backpack herbicide
- Large Areas of dense Live Phrag- Helicopter or ATV Herbicide
- Small areas of Phrag Re sprout- Backpack herbicide



Using Maps to Inform Adaptive Management



Ph_Treat
ADMANAGE
- Cut, Mulch or Burn -Year 1
- Effective Herbicide, Cut, Mulch or Burn -Year 2
- Effective Herbicide, Mulch or Burn -Year 2
- Herbicide Live Phrag -Year 1 Helicopter or ATV Herbicide
- Mulch or Burn -Year 1
- Re-herbicide Live Phrag- Year 2 ATV/backpack herbicide

- Planning with WI DNR (AES)
- Map describes what needs to be done
- Based on remote sensing results
- Turns mapping results into treatment plan

Comparison of Benefits/Limitations of Remote Sensing/Mapping at various scales

Source	Resolution	MMU	Capture Leading edges?	Cost of Imagery (High-Low)	Timeliness/ limitations
Aerial Imaging	15 cm	15 cm	All	Medium	High
World-view 2	1.85 m	2 m	many	Free for Federal Agencies	Cloud cover and satellite orbits
Rapid Eye/ Radarsat-2	5-8 m	0.05 ha	many	High	Cloud cover and satellite orbits
Landsat/ PALSAR-2	10-30 m	0.12 Ha	some	Landsat-free; PALSAR-2 (high)	Cloud cover for Landsat and satellite orbits/collection plans
UAV	1 cm+	3 cm+	All	Low	High for viewing/ mapping more difficult

Implications of results for adaptive management

- Set of indicators needed to measure & understand success of management efforts
  - Vegetation IBI most clearly showed impacts of treatment, can become part of adaptive management efforts
- Longer-term monitoring, with pre-treatment measurements – really needed to…
  - Understand relative effect of treatment (BACI analysis)
  - Provide quantitative measures of effectiveness of treatments
  - Understand "half life" of treatments – how long are they effective? (rapid re-invasion risk)
    - Reduce risk of public perception of "wasted dollars"
  - Also confirm that rare species are not adversely affected

Surveying treatment site, Saginaw Bay

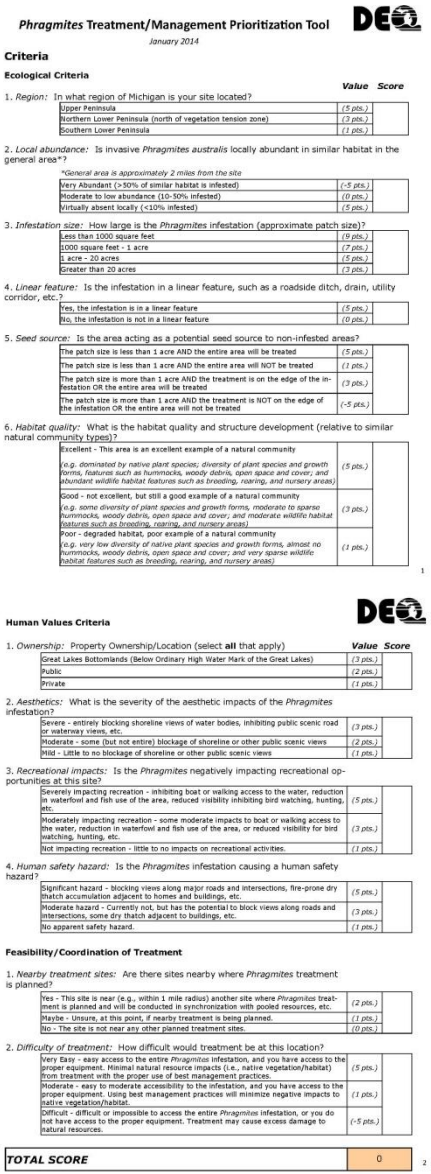
Project protocol points in light of adaptive management principles

- Spatial-matched pairs, temporal baseline results showed reduction in Green Bay Phrag cover (regional scale spraying), lack of strong effect at Saginaw Bay (patchwork of properties issue; need for follow-up spot treatments)
- Large variations in year-to-year Phrag cover; remote sensing can help with this
- Faster protocol by not sampling submergent zone (no Phrag)
- Survey just wet meadow, emergent plant zones
- Anuran data – unclear results in short time period after control (1-2 years not long enough to show effect); better for rare species evaluation than strong IBI indicator
- Bird data – mowing in short-to-medium term could negatively affect marsh nesting obligates; can confirm no rare species impacted; not characterizing breeding success but presence from a wider contributing region; mow in sections!
- "The responses of wildlife species to Phragmites invasion and control are individualistic & complex." – Brooks et al. 2015 (forthcoming report to go with this briefing
- Vegetation IBI data showed strongest effect of treatment – both Bays showed statistically significant increase in mean species diversity of native plants; focus on increasing diversity if complete control is unlikely (Carlson et al. 2009)
- Need longer-term monitoring, beyond 1-2 years after treatment to really understand response, information Adaptive Management (three to five years, depending on site); not "AM-Lite" (Fischman & Ruhl 2015)

Implications of results to management guidelines / tools

- Potential update to Michigan DEQ Phragmites Treatment/Management Prioritization Tool
  - Add a new Criteria category called “Planning and Monitoring” with these example questions:

1. Pre-control monitoring: Has monitoring taken place before control efforts, to establish a baseline for understanding control impacts:
   a. Yes, there was a pre-control monitoring program using an established protocol: +2 points
   b. Yes, there was pre-control monitoring, but using informal methods: +1 point
   c. No, pre-control monitoring did not take place : +0 points
2. Plans for monitoring: Do monitoring plans exist to evaluate impacts and success of control efforts:
   a. Yes, using identified methods for at least 5 years: +3 points
   b. Yes, using identified methods for at least 3 years: + 1 point
   c. No, monitoring plans do not exist: -1 point
3. Management plan: Has a formal management plan been created for the site undergoing Phragmites control:
   a. Yes, and it uses the principles of adaptive management: +3 points
   b. Yes, but it does not explicitly include adaptive management: +1 point
   c. No, a management plan does not exist: 0 points



***Phragmites* Treatment/Management Prioritization Tool**

January 2014

Criteria

Ecological Criteria

	Value	Score
1. *Region:* In what region of Michigan is your site located?		
Upper Peninsula	*(5 pts.)*	
Northern Lower Peninsula (north of vegetation tension zone)	*(3 pts.)*	
Southern Lower Peninsula	*(1 pts.)*	
2. *Local abundance:* Is invasive *Phragmites australis* locally abundant in similar habitat in the general area*? **General area is approximately 2 miles from the site*		
Very Abundant (>50% of similar habitat is infested)	*(-5 pts.)*	
Moderate to low abundance (10-50% infested)	*(0 pts.)*	
Virtually absent locally (<10% infested)	*(5 pts.)*	
3. *Infestation size:* How large is the *Phragmites* infestation (approximate patch size)?		
Less than 1000 square feet	*(9 pts.)*	
1000 square feet - 1 acre	*(7 pts.)*	
1 acre - 20 acres	*(5 pts.)*	
Greater than 20 acres	*(3 pts.)*	
4. *Linear feature:* Is the infestation in a linear feature, such as a roadside ditch, drain, utility corridor, etc.?		
Yes, the infestation is in a linear feature	*(5 pts.)*	
No, the infestation is not in a linear feature	*(0 pts.)*	
5. *Seed source:* Is the area acting as a potential seed source to non-infested areas?		
The patch size is less than 1 acre AND the entire area will be treated	*(5 pts.)*	
The patch size is less than 1 acre AND the entire area will NOT be treated	*(1 pts.)*	
The patch size is more than 1 acre AND the treatment is on the edge of the infestation OR the entire area will be treated	*(3 pts.)*	
The patch size is more than 1 acre AND the treatment is NOT on the edge of the infestation OR the entire area will not be treated	*(-5 pts.)*	
6. *Habitat quality:* What is the habitat quality and structure development (relative to similar natural community types)?		
Excellent - This area is an excellent example of a natural community *(e.g. dominated by native plant species; diversity of plant species and growth forms, features such as hummocks, woody debris, open space and cover; and abundant wildlife habitat features such as breeding, rearing, and nursery areas)*	*(5 pts.)*	
Good - not excellent, but still a good example of a natural community *(e.g. some diversity of plant species and growth forms, moderate to sparse hummocks, woody debris, open space and cover; and moderate wildlife habitat features such as breeding, rearing, and nursery areas)*	*(3 pts.)*	
Poor - degraded habitat, poor example of a natural community *(e.g. very low diversity of native plant species and growth forms, almost no hummocks, woody debris, open space and cover; and very sparse wildlife habitat features such as breeding, rearing, and nursery areas)*	*(1 pts.)*	

1

Human Values Criteria

	Value	Score
1. *Ownership:* Property Ownership/Location (select **all** that apply)		
Great Lakes Bottomlands (Below Ordinary High Water Mark of the Great Lakes)	*(3 pts.)*	
Public	*(2 pts.)*	
Private	*(1 pts.)*	
2. *Aesthetics:* What is the severity of the aesthetic impacts of the *Phragmites* infestation?		
Severe - entirely blocking shoreline views of water bodies, inhibiting public scenic road or waterway views, etc.	*(3 pts.)*	
Moderate - some (but not entire) blockage of shoreline or other public scenic views	*(2 pts.)*	
Mild - Little to no blockage of shoreline or other public scenic views	*(1 pts.)*	
3. *Recreational impacts:* Is the *Phragmites* negatively impacting recreational opportunities at this site?		
Severely impacting recreation - inhibiting boat or walking access to the water, reduction in waterfowl and fish use of the area, reduced visibility inhibiting bird watching, hunting, etc.	*(5 pts.)*	
Moderately impacting recreation - some moderate impacts to boat or walking access to the water, reduction in waterfowl and fish use of the area, or reduced visibility for bird watching, hunting, etc.	*(3 pts.)*	
Not impacting recreation - little to no impacts on recreational activities.	*(1 pts.)*	
4. *Human safety hazard:* Is the *Phragmites* infestation causing a human safety hazard?		
Significant hazard - blocking views along major roads and intersections, fire-prone dry thatch accumulation adjacent to homes and buildings, etc.	*(5 pts.)*	
Moderate hazard - Currently not, but has the potential to block views along roads and intersections, some dry thatch adjacent to buildings, etc.	*(3 pts.)*	
No apparent safety hazard.	*(1 pts.)*	

Feasibility/Coordination of Treatment

1. *Nearby treatment sites:* Are there sites nearby where *Phragmites* treatment is planned?		
Yes - This site is near (e.g., within 1 mile radius) another site where *Phragmites* treatment is planned and will be conducted in synchronization with pooled resources, etc.	*(2 pts.)*	
Maybe - Unsure, at this point, if nearby treatment is being planned.	*(1 pts.)*	
No - The site is not near any other planned treatment sites.	*(0 pts.)*	
2. *Difficulty of treatment:* How difficult would treatment be at this location?		
Very Easy - easy access to the entire *Phragmites* infestation, and you have access to the proper equipment. Minimal natural resource impacts (i.e., native vegetation/habitat) from treatment with the proper use of best management practices.	*(5 pts.)*	
Moderate - easy to moderate accessibility to the infestation, and you have access to the proper equipment. Using best management practices will minimize negative impacts to native vegetation/habitat.	*(1 pts.)*	
Difficult - difficult or impossible to access the entire *Phragmites* infestation, or you do not have access to the proper equipment. Treatment may cause excess damage to natural resources.	*(-5 pts.)*	
TOTAL SCORE	0	

2

Implications & suggestions for state monitoring recommendations

- Treatment: Likely need for 3 years, but not more than six (Elgersma analysis)
- Include “key activities” of adaptive management (based on Williams & Brown 2012 – US DOI guide)
  - Stakeholder engagement
  - Resource monitoring
  - Modeling
- Monitoring:
  - At least three years, five recommended after control (site dependent)
  - Monitor for at least a year before control, providing information on evaluating impacts & success of treatment efforts
  - Include remote sensing imagery to understand effects of treatment, locate/monitor remaining areas needing further control
- Michigan example:
  - 3rd edition of Michigan Phragmites control & management guide explicitly references need for monitoring to inform management; detailed monitoring plan; provides the data needed to determining success & types of control methods needed.

Where do we go from here?

- Complete & publish adaptive management report that includes recommendations for monitoring and adaptive management based on literature/research (*due Dec. 2015*)
- Working with land managers to develop a strategic approach to adaptive management for *Phragmites* control and restoration that includes mapping, monitoring and modeling (*continuing applied research projects*)
- Seeking project partners, field sites, collaborations (future projects)

Closing thoughts…

We recognize the limitations on invasive species control funding, but success should be measured by more than the amount of a controlled area (such as '87 acres of Phragmites were controlled in 2013').

Being able to measure if vegetation diversity is definitely improving, and continuing to improve more than a year or two after control, is important.

Monitoring efforts provide the key data to adaptively manage a resource based on informed decision making.

Limited funding has the opportunity to be spent more wisely, and with greater effect, by following the principles of adaptive management.

(*from forthcoming accompanying Brooks et al. report*)

MichiganTech Research Institute

Thank you

Questions?

Colin Brooks, MEM; Senior Research Scientist

Environmental Sciences Lab Manager, MTRI

cnbrooks@mtu.edu 734-913-6858

www.mtri.org

http://www.mtri.org/treatment_effects_phragmites.html

References (1)

- (2008). Marsh Invader! . V. D. o. C. a. Recreation. Richmond, Virginia.
- (2013). Phragmites Treatment/Management Prioritization Tool Frequently Asked Questions and User Guide. D. o. E. Quality. Lansing, MI, State of Michigan.
- (2013). Phragmites Treatment/Managment Prioritization Tool D. o. E. Quality. Lansing, MI.
- (2014). A guide to the control and management of invasive Phragmites. Lansing, MI, Michigan Department of Environmental Quality.
- (2015). Phragmites Treament Herbicide Quick Guide. G. L. P. Collaberitive. Ann Arbor, MI**:** 1-2.
- (2015). Phragmites Treatment Herbicide Quick Guide. G. L. P. Collaberative. Ann Arbor, MI**:** 1-2.
- Ailstock, M. S. (2006). Summary of Common Questions Concerning *Phragmites* Control, Ann Arundel Community College**:** 8.
- Ailstock, M. S., et al. (2001). "Common reed Phragmites australis: control and effects upon biodiversity in freshwater nontidal wetlands." Restoration Ecology **9**(1): 49-59.
- Albert, D. A., et al. (2005). "Hydrogeomorphic classification for Great Lakes coastal wetlands." Journal of Great Lakes Research.
- Arce, M. I., et al. (2009). "Effects of" Phragmites australis" growth on nitrogen retention in a temporal stream." Limnetica **28**(2): 229-242.
- Avers, B. (2007). A guide to the control and management of invasive Phragmites, Michigan Department of Environmental Quality.
- Bertness, M. D., et al. (2002). "Anthropogenic modification of New England salt marsh landscapes." Proceedings of the National Academy of Sciences **99**(3): 1395-1398.
- Blossey, B. (2014). Identification, Development, and Release of Insect Biocontrol Agents for the Management of Phragmites australis, DTIC Document.
- Board, C. T. P. M. A. (2010). Clay Township Phragmites Management Plan. C. T. Board.
- Bourgeau-Chavez, L., et al. (2004). Final Report to the Great Lakes Commission: Remotely Monitoring Great Lakes Coastal Wetlands using a Hybrid Radar and Multi-spectral Sensor Approach. Project no WETLANDS2-WPA-06, http://www.glc.org/wetlands/pdf/GD-landscapeReport.pdf**:** 82 pp.
- Bourgeau-Chavez, L. L., et al. (2013). "Mapping invasive Phragmites australis in the coastal Great Lakes with ALOS PALSAR satellite imagery for decision support." Journal of Great Lakes Research **39**: 65-77.
- Bourgeau-Chavez, L. L., et al. (2008). Remotely monitoring Great Lakes Coastal wetlands with multi-sensor, multi-temporal SAR and multi-spectral data. Geoscience and Remote Sensing Symposium, 2008. IGARSS 2008. IEEE International, IEEE.
- Brisson, J., et al. (2008). "Evidence of sexual reproduction in the invasive common reed (Phragmites australis subsp. australis; Poaceae) in eastern Canada: a possible consequence of global warming." Rhodora **110**(942): 225-230.
- Burton, T. M., et al. (2008). Great Lakes coastal wetlands monitoring plan, Great Lakes Commission.
- Carlson Mazur, M. L., et al. (2014). "Assessment of suitable habitat for Phragmites australis (common reed) in the Great Lakes coastal zone." Aquatic Invasions **9**(1): 1-19.
- Carlson, M. L., et al. (2009). "Promoting species establishment in a Phragmites-dominated Great Lakes coastal wetland." Natural Areas Journal **29**(3): 263-280.
- Carlson, M. L., et al. (2009). "Promoting species establishment in a Phragmites-dominated Great Lakes coastal wetland." Natural Areas Journal **29**(3): 263-280.
- Chambers, R. M., et al. (2012). Ecology of Phragmites australis and responses to tidal restoration. Tidal Marsh Restoration, Springer**:** 81-96.
- Colautti, R. I., et al. (2006). "Propagule pressure: a null model for biological invasions." Biological Invasions **8**(5): 1023-1037.
- Crowl, T. A., et al. (2008). "The spread of invasive species and infectious disease as drivers of ecosystem change." Frontiers in Ecology and the Environment **6**(5): 238-246.
- Currie, W. S., et al. (2014). "Emergence of nutrient-cycling feedbacks related to plant size and invasion success in a wetland community–ecosystem model." Ecological Modelling **282**: 69-82.
- Davis, M. A. (2003). "Biotic globalization: does competition from introduced species threaten biodiversity?" Bioscience **53**(5): 481-489.
- Davis, M. A., et al. (2011). "Don't judge species on their origins." Nature **474**(7350): 153-154.
- DeSante, D. F. (1990). "The role of recruitment in the dynamics of a Sierran subalpine bird community." American Naturalist: 429-445.
- Dukes, J. S. and H. A. Mooney (1999). "Does global change increase the success of biological invaders?" Trends in Ecology & Evolution **14**(4): 135-139.
- Elgersma, K. J., et al. (2014). Assessing Ecosystem Services Provided by Restored Wetlands Under Current and Future Land-Use Scenarios. Poster. University of Michigan Water Center Annual Meeting.
- Fischman, R. L. and J. B. Ruhl (2015). "Judging adaptive management practices of US agencies." Conservation Biology.
- Galatowitsch, S. M., et al. (1999). "Invasiveness in wetland plants in temperate North America." Wetlands **19**(4): 733-755.
- Gannon, J. J., et al. (2013). Native Prairie Adaptive Management: a multi region adaptive approach to invasive plant management on Fish and Wildlife Service owned native prairies, US Geological Survey.
- George, L. T., et al. (1992). "Impacts of a severe drought on grassland birds in western North Dakota." Ecological Applications: 275-284.
- Grassmick, P. (2011). Successful collaboration of local governments, landowners, and the Michigan DNRE in eradicating phragmites populations on Beaver Island through rapid response. Phragmintes Invasions in Michigan: A Symposium to Build Capacity for Managment, East Lansing, MI, The Great Lakes Commision.
- Guo, W., et al. (2013). "Invasion of Old World Phragmites australis in the New World: precipitation and temperature patterns combined with human influences redesign the invasive niche." Global change biology **19**(11): 3406-3422.

References (2)

- Häfliger, P., et al. (2006). "Comparison of biology and host plant use of Archanara geminipuncta, Archanara dissoluta, Archanara neurica, and Arenostola phragmitidis (Lepidoptera: Noctuidae), potential biological control agents of Phragmites australis (Arundineae: Poaceae)." Annals of the Entomological Society of America **99**(4): 683-696.
- Hazelton, E. L. G., et al. (2014). "Phragmites australis management in the United States: 40 years of methods and outcomes." AoB plants **6**: plu001.
- Helander, M., et al. (2012). "Glyphosate in northern ecosystems." Trends in plant science **17**(10): 569-574.
- Hellmann, J. J., et al. (2008). "Five potential consequences of climate change for invasive species." Conservation Biology **22**(3): 534-543.
- Hershner, C. and K. J. Havens (2008). "Managing invasive aquatic plants in a changing system: strategic consideration of ecosystem services." Conservation Biology **22**(3): 544-550.
- Hiland, N. (2013). Invasive Plants of Ohio: Common Reed Grass. O. I. P. Council. columbus, Ohio, Ohio Department of Natural Resrouces.
- Hinz, H., et al. (2014). Complete Host Testing with a Potential Biological Control Agent on Common Reed in View of Submitting a Petition for Field Release in Winter 2014/15, DTIC Document.
- Hobbs, R. J., et al. (2009). "Novel ecosystems: implications for conservation and restoration." Trends in Ecology & Evolution **24**(11): 599-605.
- Host, G. E., et al. (2011). "High-resolution assessment and visualization of environmental stressors in the Lake Superior basin." Aquatic Ecosystem Health & Management **14**(4): 376-385.
- Hunt, V. (2013). "PhragNet Protocol." Retrieved 1 Dec, 2015, 2015, from https://sites.google.com/site/phragmitesnet/protocol.
- Kettenring, K. M., et al. (2012). "Moving from a regional to a continental perspective of Phragmites australis invasion in North America." AoB plants **2012**: pls040.
- Kettenring, K. M., et al. (2011). "Mechanisms of Phragmites australis invasion: feedbacks among genetic diversity, nutrients, and sexual reproduction." Journal of Applied Ecology **48**(5): 1305-1313.
- Kettenring, K. M. and C. Reinhardt Adams (2011). "Lessons learned from invasive plant control experiments: a systematic review and meta-analysis." Journal of Applied Ecology **48**(4): 970-979.
- King, R. S., et al. (2007). "Threshold effects of coastal urbanization onPhragmites australis (common reed) abundance and foliar nitrogen in Chesapeake Bay." Estuaries and coasts **30**(3): 469-481.
- Kiviat, E. (2013). "Ecosystem services of Phragmites in North America with emphasis on habitat functions." AoB plants **5**: plt008.
- Knutson, M. G., et al. (1999). "Effects of landscape composition and wetland fragmentation on frog and toad abundance and species richness in Iowa and Wisconsin, USA." Conservation Biology **13**(6): 1437-1446.
- Kowalski, K. P., et al. (2015). "Advancing the science of microbial symbiosis to support invasive species management: A case study on Phragmites in the Great Lakes." Frontiers in Microbiology: 0.
- Lambert, A. M., et al. (2007). "Distribution and impact of exotic gall flies (Lipara sp.) on native and exotic Phragmites australis." Aquatic Botany **86**(2): 163-170.
- Lazaran, M. A., et al. (2013). "Impacts of Phragmites management on Marsh Wren nesting behavior." The Wilson Journal of Ornithology **125**(1): 184-187.
- Lugo, A. E. (2013). "Novel tropical forests: Nature's response to global change." Tropical Conservation Science **6**(3): 325-337.
- Martin, L. J. and B. Blossey (2013). "The runaway weed: costs and failures of Phragmites australis management in the USA." Estuaries and coasts **36**(3): 626-632.
- Mazerolle, M. J., et al. (2014). "Common reed (Phragmites australis) invasion and amphibian distribution in freshwater wetlands." Wetlands Ecology and Management **22**(3): 325-340.
- McDonough, E. P., E. (2007). Victory over Phragmites: How Beaver Island defined the odds. Michigan Out of Doors. Lansing, MI, Michigan United Concervation Clubs.
- Meyerson, L. A., et al. (2010). "Hybridization of invasive Phragmites australis with a native subspecies in North America." Biological Invasions **12**(1): 103-111.
- Minchinton, T. E. and M. D. Bertness (2003). "Disturbance-mediated competition and the spread of Phragmites australis in a coastal marsh." Ecological Applications **13**(5): 1400-1416.
- Moore, C. T., et al. (2014). Implementing Adaptive Management for Control of *Phragmites australis* on National Wildlife Refuges in the Northeast Region and Model Development to Support the Integrated Waterbird Management and Monitoring Program. U. S. G. Survey. Athens, GA, U.S. Geological Survey**:** 24.
- Moore, C. T., et al. (2013). "Spatial education: improving conservation delivery through space-structured decision making." Journal of Fish and Wildlife Management **4**(1): 199-210.
- O'Neill, R. V. (2001). "Is it time to bury the ecosystem concept? (With full military honors, of course!) " Ecology **82**(12): 3275-3284.
- Pagter, M., et al. (2005). "Tolerance and physiological responses of Phragmites australis to water deficit." Aquatic Botany **81**(4): 285-299.
- Parker, A. K. (2002). Methods for Evaluating Wetland Condition:# 4 Study Design for Monitoring Wetlands, US Environmental Protection Agency, Office of Water.
- Perez, A., et al. (2013). "Effects of exotic common reed (Phragmites australis) on wood frog (Lithobates sylvaticus) tadpole development and food availability." Journal of Freshwater Ecology **28**(2): 165-177.
- Peter, C. R. and D. M. Burdick (2010). "Can plant competition and diversity reduce the growth and survival of exotic Phragmites australis invading a tidal marsh?" Estuaries and coasts **33**(5): 1225-1236.
- Pieterse, A. H. and K. J. Murphy (1990). Aquatic weeds: the ecology and management of nuisance aquatic vegetation, Oxford University Press.
- Policanski, D. (1991). Ecological Knowledge and Environmental Problem-Solving. Abstracts of Papers of the American Chemical Society, 16TH ST, NW, WASHINGTON, DC 20036.
- Price, S. J., et al. (2007). "Are anurans of Great Lakes coastal wetlands reliable indicators of ecological condition?" Journal of Great Lakes Research **33**: 211-223.

References (3)

- Pulliam, H. R. (1988). "Sources, sinks, and population regulation." American Naturalist: 652-661.
- Reznicek, A. A., et al. (2014). "Michigan Floristic Quality Assemssment Database." from http://michiganflora.net.
- Rickey, M. A. and R. C. Anderson (2004). "Effects of nitrogen addition on the invasive grass Phragmites australis and a native competitor Spartina pectinata." Journal of Applied Ecology **41**(5): 888-896.
- Romero, J. A., et al. (1999). "Interactive effects of N and P on growth, nutrient allocation and NH 4 uptake kinetics by Phragmites australis." Aquatic Botany **64**(3): 369-380.
- Schwarts, C. J. (2015). Analysis of BACI Experiments. Course Notes for Beginning and Intermediate Statistics.
- Silliman, B. R. and M. D. Bertness (2004). "Shoreline development drives invasion of Phragmites australis and the loss of plant diversity on New England salt marshes." Conservation Biology **18**(5): 1424-1434.
- Tilley, D. and L. St. John (2012). Plant Guide to Common Reed (*Phragmites australis*). D. o. Agriculture. Aberdeen, ID, USDA-Natural Resource Conservation Service**:** 5.
- Tulbure, M. G. and C. A. Johnston (2010). "Environmental conditions promoting non-native Phragmites australis expansion in Great Lakes coastal wetlands." Wetlands **30**(3): 577-587.
- Uzarski, D., et al. (2004). "Validation and performance of an invertebrate index of biotic integrity for Lakes Huron and Michigan fringing wetlands during a period of lake level decline." Aquatic Ecosystem Health & Management **7**(2): 269-288.
- Van Horne, B. (1983). "Density as a misleading indicator of habitat quality." The Journal of Wildlife Management: 893-901.
- Walters, C. J. (1986). Adaptive management of renewable resources. Cadwell, NJ, The Blackburn Press.
- Walters, C. J. and C. S. Holling (1990). "Large-scale management experiments and learning by doing." Ecology **71**(6): 2060-2068.
- Welch, B. A., et al. (2006). "Dominant environmental factors in wetland plant communities invaded by Phragmites australis in East Harbor, Ohio, USA." Wetlands Ecology and Management **14**(6): 511-525.
- Wilcox, D. A., et al. (2002). "Hydrologic variability and the application of index of biotic integrity metrics to wetlands: a Great Lakes evaluation." Wetlands **22**(3): 588-615.
- Wilcox, K. L., et al. (2003). "Historical distribution and abundance of phragmites australis at Long Point, Lake Erie, Ontario." Journal of Great Lakes Research **29**(4): 664-680.
- Williams, B. (2011). Stewardship approach in fighting phragmites invasions on Harsen's Island. Phragmintes Invasions in Michigan: A Symposium to Build Capacity for Managment, East Lansing, MI, The Great Lakes Commision.
- Williams, B. K. and E. D. Brown (2012). Adaptive management: The US Department of the Interior applications guide, US Department of the Interior, Adaptive Management Working Group.
- Williams, B. K., et al. (2007). Adaptive management: the US Department of the Interior applications guide, US Department of the Interior, Adaptive Management Working Group.
- Wilson, J. (2012). DNREC's Phragmites Control Program Treats more than 6,700 acres, including 5,720 acres in Bayshore region. D. o. N. Resources. dnrec.delaware.gov.
- Works, J. M., C. (2008). Peaine Township Phragmites Ordinance. P. Township. Peaine Township, MI**:** 4.

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Q & A

Colin Brooks

Manager of Environmental Science Laboratory
Senior Research Scientist
Adjunct Lecturer in the Department of Biological Sciences
Michigan Technological University
Michigan Tech Research Institute

3600 Green Ct. Suite 100
Ann Arbor, MI 48105
(734) 913-6858

cnbrooks@mtu.edu

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www.greatlakesphragmites.net

phragmites@glc.org

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