EPA GRANT # GL 00E01929-0

INVASIVE SPECIES CONTROL PROGRAM

Project Title: Implementing Adaptive Management and Monitoring for Restoration of Invasive Phragmites

FINAL REPORT OUTLINE

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FINAL REPORT

USEPA - GREAT LAKES RESTORATION INITIATIVE

Grant Number: GL 00E01929-0

PROJECT TITLE: IMPLEMENTING ADAPTIVE MANAGEMENT AND MONITORING FOR RESTORATION OF INVASIVE *PHRAGMITES*

REPORTING PERIOD: APRIL 2016 TO NOVEMBER 2018

PRINCIPAL INVESTIGATOR: LAURA BOURGEAU-CHAVEZ

GOAL OF PROJECT

The goal of the project was to build a partnership between local land managers, researchers, remote sensing experts, and ecological modelers to develop a regional, long-term strategic plan for management and restoration of *Phragmites*-infested shoreline ecosystems and implement it in Saginaw Bay (Figure 1). Through integration of the local and regional knowledge, high resolution maps from remote sensing and best treatment strategies with modeling of N loading and hydrological connectivity we created an adaptive plan that targets specific treatment techniques and time intervals (e.g., herbicide and cutting/burning schedule and riparian buffering) based upon conditions of the site/region to be managed. This approach takes into account landscape position and conditions, including distribution of sources and pathways of *Phragmites* spread and environmental factors that influence vulnerability to invasion, e.g. N loading. The main objective was to develop a comprehensive plan tailored to site conditions for initial treatments, but included determining return intervals and quantifying costs for monitoring (materials, equipment, and time). Integral to the adaptive management plan was monitoring pre- and post-treatment to track effectiveness in terms of ecosystem restoration and conducting outreach and two-way knowledge transfer with managers and other stakeholders. We developed a suite of monitoring protocols to assess treatment success and ecosystem response in accordance with specific site restoration goals. Together these elements provide an innovative set of methods to address *Phragmites* management in a landscape scale context and work towards the goal of shoreline ecosystem restoration that can be transported to other coastal Great Lakes regions.

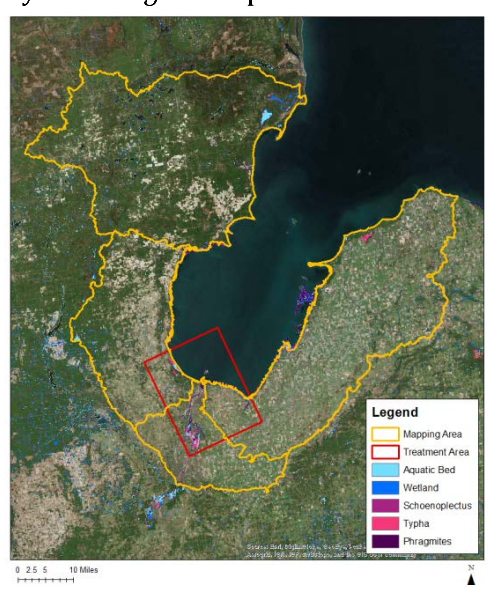


FIGURE 1. FOUR WATERSHEDS DRAINING TO SAGINAW BAY. *PHRAGMITES* TREATMENT STUDY AREA IN RED OUTLINE. WETLAND CLASSES ARE FROM THE LANDSAT-SAR 0.2 HA MMU CIRCA 2010 WETLAND MAP.

SUMMARY OF WORK ACCOMPLISHED, OUTCOMES AND OUTPUTS

This report provides the results and recommendations of the work accomplished. It has several different components, as described above and shown in Fig. 2. For ease of navigation, we have arranged this report by 5 main headings: 1) Treatments and Control; 2) Monitoring; 3) Modeling; 4) Outreach and Stakeholder Input; and 5) Long-term Comprehensive *Phragmites* Management Strategy. Integral to the decision making were the monitoring, both field and remote sensing, input from local stakeholders and modeling. We being with a description of the application study area and the treatments. The research on treatments from the literature is summarized in section 1 and fully described in Appendix C. Treatments evaluated include mechanical, chemical, combinations of these, as well as biocontrol. In section 2, we describe the monitoring protocols used in this project, both field and remote sensing. We provide single examples of the remote sensing and photo-monitoring, but comprehensive maps and photos for each site are detailed in Appendices A and B. Appendix D provides a full review of monitoring approaches from the literature and based on our interactions with managers and stakeholders. Importantly, we assess the various monitoring protocols (field, UAV) used in this project in the section "Analysis of the Monitoring for Assessing the Treatment Effectiveness" (see Table 3 for summary). In section 3 we describe the Landscape modeling and MONDRIAN plant competition modeling, including the webtools and user friendly version of MONDRIAN. The input from local stakeholders and our outreach is summarized in section 4. The full report from the Stakeholder Workshop is in Appendix E. Finally, based on this collaborative work, we developed a long-term strategic plan for the bay which is in section 5.

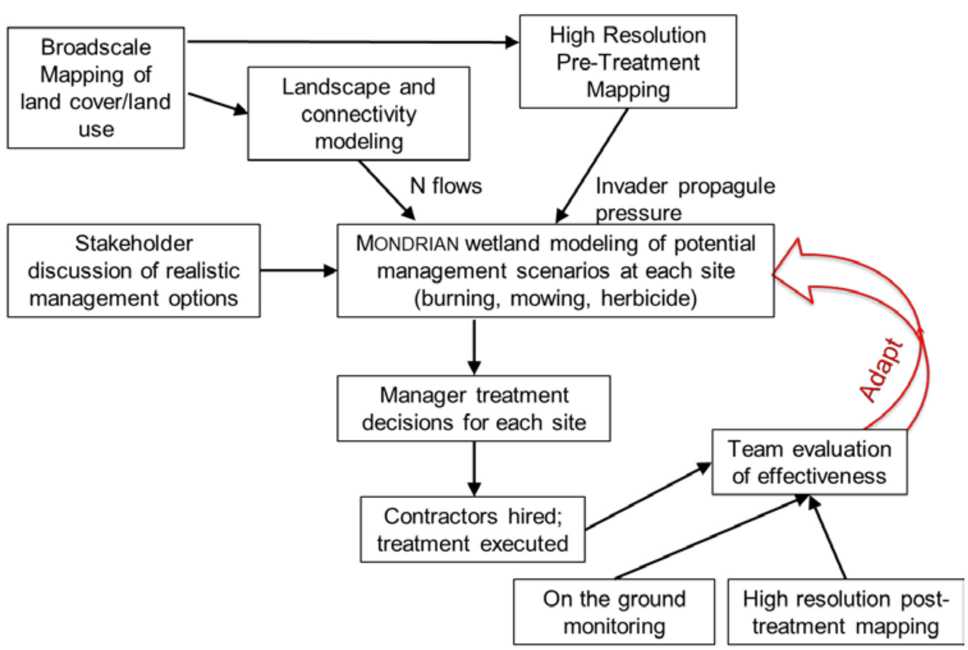


FIGURE 2. DIAGRAM SHOWING THE VARIOUS COMPONENTS OF THE COMPRENSIVE APPROACH TO *PHRAGMITES* CONTROL, INCLUDING STAKEHOLDER INPUT, MAPPING, LANDSCAPE AND MODRIAN MODELING, EVALUATIONS OF TREATMENT EFFECTIVENESS AND ADAPTATION OF MANAGEMENT.

APPLICATION STUDY AREA

The strategic management approach was built for all four watersheds of Saginaw Bay (Fig. 1) and treatment was implemented in the southern region of Saginaw Bay, including the coastal zone within the Southern Saginaw Bay Region of Michigan at the mouth of the Saginaw River (43.645179, -83.856563) including HUCs 040802 (Saginaw) and 040801 (Southwestern Lake Huron) and included portions of the Saginaw River to Crow Island State Game Area (Fig.3 - EPA treatment sites in green). This region was prioritized for several reasons. It has heavy invasions of *Phragmites* where clear priorities and best treatment techniques and regimes are not easily determined. Stakeholders are highly engaged and brought a variety of expertise and relevant information to the table for collaborative assessment of where and when treatment success is achievable.

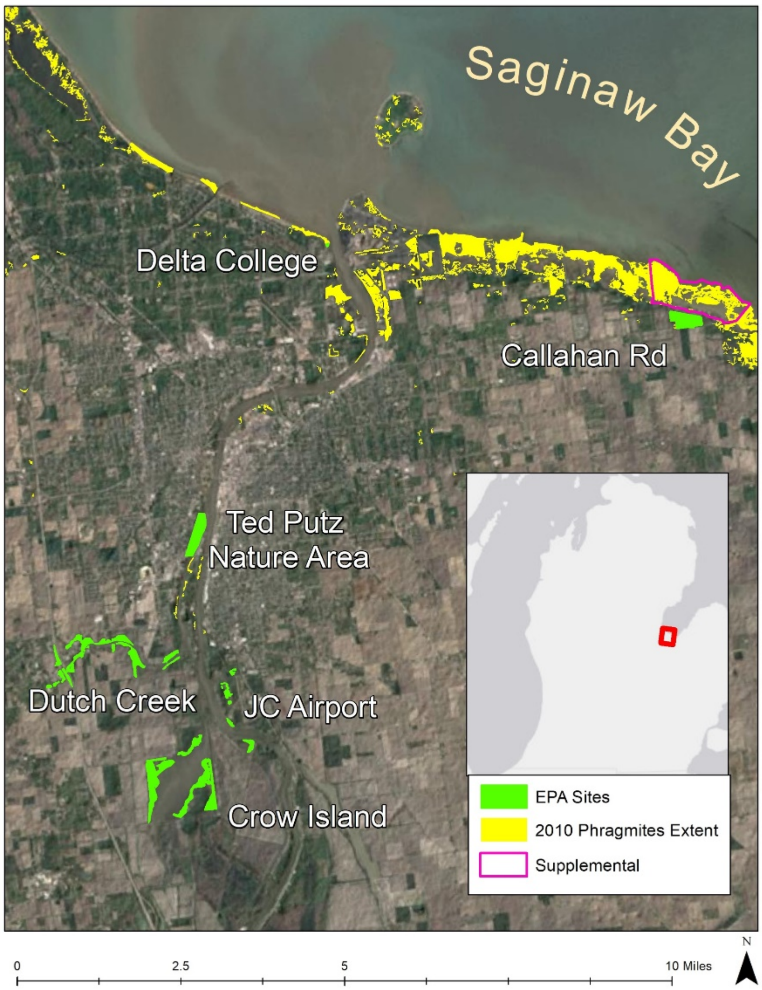


FIGURE 3: MAP OF PHRAGMITES TREATMENT AREAS (GREEN) IN THE SAGINAW BAY COASTAL AREA. THE SUPPLEMENTAL AREA (RED OUTLINE) WAS A TREATMENT AREA ADJACENT TO OUR CALLAHAN RD TREATMENT WHICH THE PROJECT SUPPLEMENTED IN OCTOBER 2018.

1. TREATMENT AND CONTROL

Treatment protocols in the literature and from the project stakeholder meeting held in February 2017, as well as interactions with local practitioners led to the protocols evaluated and implemented under this grant. Full details of that compilation is in Appendix C "Compilation of Treatment Protocols".

Under this grant, a total of 338.35 acres were under treatment and control for two or more years (2016-2018). In all cases an adaptive management approach was used that integrated the monitoring, modeling and local knowledge into the treatments as will be described in more detail in sections below. In addition the project provided a cost-share of herbicide of an additional 236.8 acres at the end of the grant (Fall 2018) for a neighboring *Phragmites* infested area to our Callahan Road Treatment area (see Fig. 2, pink outlined "supplemental" area which represents the Knodt Rd Neighborhood). In total, this project led to the new treatment of 575.15 acres. In addition, some of the 338.35 acres under treatment required retreatment in successive years. This is summarized here with details in Table

1. In 2017 45.4 acres were re-treated with herbicide and in 2018 51 acres were re-treated. For a total of 96.4 acres of secondary treatment. A summary of each EPA treatment area and treatment by year is in Table 1 and described below in more detail. Also, note that the EDR strike team of the SB-CISMA treated other *Phragmites* infestations as well as European frog-bit, Black swallow-wort, Japanese knotwood, and flowering rush as summarized in the subsection "EDR Strike Team" in Table 2.

TABLE 1: LIST OF TREATMENT SITES, AREA TREATED, TREATMENT BY YEAR. NOTE THAT CROW ISLAND AND JC AIRPORT HAD TREATMENT INITIATED IN 2017 WHILE ALL OTHER SITES WERE FIRST TREATED IN 2016. KNODT RD NEIGHBORHOOD WAS A SITE THAT THE PROJECT SUPPLEMENTED WITH INITIAL TREATMENT IN 2018.

Treatment area	Acres Treated	Initial Treatment Year	Treatment 2016	Treatment 2017	Treatment 2018
Callahan Field	51	2016	2% Glyphosate via boom sprayer/ mowing > 6 weeks after on all 51 acres	2% Glyphosate with marsh master-many patches of regrowth on 36.4 acres	spring 2018 burn all 51 acres- did not carry well Fall 2018 - treated with 1% glyphosate/1% imazapyr 43 acres
Delta College	0.7	2016	2% Glyphosate via boom sprayer/ mowing > 6 weeks after on 0.7 acres	2% Glyphosate with backpack sprayer- very small patches	very small Phrag was cut with a shovel belowground and harvested
Dutch Creek	101	2016	2% Glyphosate via boom sprayer/ mowing > 6 weeks after on all 101 acres	2% Glyphosate with marsh master-small patches over 5 acres	2% Glyphosate with Marsh master for some sparse regrowth at i_75 and M-84 – 1 acre
Putz Park	4	2016	2% Glyphosate via boom sprayer/ mowing > 6 weeks after on all 4 acres	2% Glyphosate with backpack sprayer/mulching of biomass on 4 acres	minimal regrowth cut with a spade and harvested - may need herbicide next year
Crow Island	169.27	2017	Not treated	2% Glyphosate via helicopter on 169.27 acres	Herbicide in sparse regrowth needed, but Marsh master could not get into steep banks
JC Airport	12.38	2017	Not treated	2% Glyphosate via boom sprayer/mulching 2 months later on 12.38 acres	2% Glyphosate on upland portions with marsh master boom sprayer and backpack sprayer over 7 acres
Knodt Rd Neighborhood	236.8	2018	not treated	not treated	2% Glyphosate with aerial spray on 236.8 acres

Fall 2016/Spring 2017

For Year 1 (2016) of the project, 4 areas were selected for treatment with a total acreage of 156.7: (Callahan Field: 51 acres; Delta College: 0.7 acres; Dutch Creek: 101 acres; Putz Park: 4 acres). Pre-treatment monitoring (field and satellite remote sensing – described in 2) Monitoring section) was conducted at all sites and used to determine treatments. *Phragmites* at Callahan Field, Delta College, Dutch Creek and Putz Park were treated using a 2% glyphosate solution and a Marsh Master boom sprayer. Starting six weeks after herbicide treatment, *Phragmites* was mowed using a Marsh Master with a mowing attachment. Burning did not take place as had been planned for spring 2017 due to wet conditions. At a few sites, the mowed unburned biomass was preventing water flow and encouraging algae growth. As an alternative to burning, mulching was a second choice and was applied at the Ted Putz Park site.

Fall 2017/Spring 2018

For year 2 (2017) of the project, post-treatment monitoring was implemented. Based on the monitoring of site conditions follow-up treatment decisions were made for those sites treated in 2016, and new treatment began at 2 additional sites: Crow Island and JC Airport.

For follow-up treatment, the *Phragmites* populations were small enough at the Ted Putz Park and Delta College sites to be treated using a backpack sprayer by the Saginaw Bay Cooperative Invasive Species Management Area (CISMA) strike team. Herbicide follow-up was needed at Callahan Field and parts of Dutch Creek. A marsh master with a boom sprayer was used at Callahan Field, which had dense, patchy regrowth. Herbicide treatment was applied at Callahan Field on September 28th, 2018. A marsh master with a sprayer wand was used at the Dutch Creek site, which had minimal regrowth throughout most of the site, but had heavy regrowth at one specific location near a bridge at M-84 (Westside Saginaw Rd.). Herbicide retreatment for Dutch Creek occurred on October 2nd, 2017. A burn was conducted on March 22, 2018 at the Callahan Field site. Our contractor found that the *Phragmites* was not dense enough and the site was too wet to effectively carry a burn. It was recommended in the future that burning be the first biomass removal effort at a site.

For the newly treated areas, 2% glyphosate solution was applied to Crow Island State Game Area (Crow Island: 169.27 acres) using helicopter, and to nearby James Clements Municipal Airport (JC Airport:12.38 acres, Fig. 3) using a Marsh Master with a boom sprayer in September and early October 2017. Crow Island was ranked #5 out of 165 in the DNR's priority scale for restoration. Due to weather conditions and prioritization, burning did not occur at Crow Island as planned in 2017. Over time, snow, ice and wind knocked a large portion of the *Phragmites* over, such that it is currently too sparse to carry a burn. Burning is not permitted at JC Airport for safety reasons, thus the biomass was mulched in December 2017.

Fall 2018

For year 3 of the project, post-treatment monitoring was implemented and all sites were mapped with Worldview-2 data collected in August/September (see section 2. Monitoring for details). Based on those aerial and field surveys, the planned treatment was determined and is shown below and in Table 1.

Regrowth at Delta College was sparse, and the plants were small. The plants were too small to effectively absorb herbicide, so they were cut below ground level using a shovel by the SB-CISMA strike team. This regrowth was collected in trash bags labeled “Invasive Species” and sent to the landfill. All regrowth at Delta College was along the shore, in the rip rap. No herbicide was used at this site in 2018.

Regrowth at Putz Park was also minimal, most of which was along the shore. Much of it was cut using a spade, however some will need to receive herbicide treatment. The cut *Phragmites* were collected in trash bags labeled “Invasive Species” and sent to the landfill. We found a large population of cut grass species growing in dead biomass.

Phragmites regrowth was denser at Callahan Road in the growing season of 2018 than in the growing season of 2017; we hypothesized that this may be due to glyphosate resistance. Thus in 2018 the site was treated using a mixture of 1% glyphosate with 1% imazapyr using a marsh master with a boom sprayer.

Phragmites regrowth was sparse around Dutch Creek, with the densest regrowth interfacing the intersection of I-75 and M-84. Dutch Creek was retreated using 2% glyphosate and a Marsh Master with a wand sprayer.

Crow Island saw a large population decline. The densest regrowth was in the easternmost treatment polygon. This polygon was to be retreated using a Marsh Master, however the contractor found he could not get the machine into the area due to steep slopes. It will need attention in 2019. Much of the dead *Phragmites* at the other polygons had been knocked down by wind and wave action, and we expect that they will sink on their own by the next growing season.

JC Airport also exhibited growth of a small patches of cut grass. Most of the *Phragmites* regrowth occurred on the upland portions of the site. These portions were retreated with a 2% glyphosate, a marsh master and a boom sprayer.

Due to weather issues (continual rain most of the fall of 2018), spraying of the herbicide before the project end date of 30 September 2018 was not possible for all sites. The herbicide needs to be sprayed during senescence of the *Phragmites* to achieve maximum absorption by the roots. Therefore, an extension through November 30, 2018 was requested and granted to allow for the full treatments to be implemented at all sites. Treatment was then completed in Oct 2018.

It was observed that, overall, *Phragmites* persisted where there was no standing water.

Knodt Rd Neighborhood

The Knodt Rd. Neighborhood reached out to the SB-CISMA for treatment in their neighborhood, which abuts the Callahan Rd treatment area and Lake Huron (Fig. 3). This neighborhood was heavily invaded by invasive *Phragmites australis*, and treatment of this adjacent property would reduce the propagule pressure on our treatment sites as well as the adjacent shoreline of Saginaw Bay. The EPA grant provided supplemental funds for treatment of this area with the neighborhood raising the majority of the funds. Total acres treated was 236.8. For this supplemental sitethe SB-CISMA collected Tier 1 data and trained the neighborhood in collecting the post-treatment data in

2019. Each landowner signed a contract with the CISMA stating that they would follow-up with biomass mowing or other form of removal and follow-up with monitoring.

EDR Strike Team

The EDR strike team for this project was established by staff at the SB-CISMA which encompasses 16 counties that are connected hydrologically to Saginaw Bay. MNFI provided environmental review for the EPA strike team treatment sites for flowering rush, European frog-bit, and Japanese knotweed by reviewing the MNFI Natural Heritage Database to assess the potential for impacts to listed species by treatment. No concerns were noted for our treatment sites.

In 2016 and 2017 the EDR strike team consulted with landowners to evaluate these invasives on their property and to determine whether the strike team had the capacity to treat for them. If they had the capacity they would treat it for them free of charge. Most frequently, the strike team dealt with Japanese knotweed and *Phragmites*. They participated in swallow-wort pulls in 2016 and 2017. In 2017 the EDR strike team treated some flowering rush. They also participated in frog-bit pulls in 2016, 2017 and 2018. A summary of the EDR strike team invasives control measures are below.

TABLE 2. SUMMARY OF EDR STRIKE TEAM TREATMENTS AND CONTROL IN 2016-17 OF INVASIVES IN THE 16 COUNTY AREA OF THE SB-CISMA. NOTE IN 2016 THE ACRES TREATED WERE NOT RECORDED AS THEY WERE IN 2017, SO ONLY THE GALLONS OF HERBICIDE ARE LISTED AS WELL AS TOTAL NUMBER OF INFESTATIONS IN BOTH YEARS.

Invasive species	Total # Infestations	Pounds of invasive removed	2016 Gallons of Herbicide	2017 Gallons of Herbicide	2017 Acres Treated
Flowering Rush	1		None	2.5	3
Japanese knotweed	38		183.5	81	2.03
Non-native Phragmites australis	77		533.5	526.75	70.76
Black swallow-wort	NM	15			
European frogbit	NM	2240			

2. Monitoring: Pre- and Post-treatment Field and remote sensing monitoring

A Framework for Monitoring the Success of *Phragmites* Management

Ideally, predefined management goals and objectives should drive the development of monitoring plans. Typical goals of *Phragmites* control include the maintenance or restoration of plant diversity, wildlife use, recreational use and ecological functioning. We understand that the monitoring plan ultimately implemented will be a function of not only management goals, but also available resources (e.g., funding, time, and expertise), characteristics of the *Phragmites* stands being treated (e.g., large vs. small area, dense vs. sparse cover), and availability, when needed, of reference sites for comparison. Although the complexity and therefore resources needed for monitoring may mean that optimal monitoring is not immediately possible at a given site, it is still important to consider upfront the optimal measures needed to assess progress towards your specified management goals. Trade-offs can then be made knowingly and wisely. It is particularly important to understand that success is not always or necessarily measured by percent *Phragmites* kill, and long-term success cannot be measured in the short time frame in which monitoring typically occurs (1-2 years). Managers should strive for the best measures for their management goals and long-term monitoring whenever possible. They should be prepared to change tactics based on monitoring results to ensure progress is being made towards their management goals. For our grants the definitions of success are described below, followed by the 3 tiered field monitoring protocols we applied and compare. In addition the remote sensing from Worldview-2 and UAV are also presented in this section.

SUITE OF DEFINITIONS FOR SUCCESS

Project teams for this project and two MISGP projects to Bourgeau-Chavez and Ogar teamed to develop a definition of success in restoring *Phragmites* infested sites for these projects. The team consisted of participants from Bay County (Ogar), Michigan DNR, MTRI, MNFI, USFWS and the SB-CISMA. Based on the consensus of the group, success in *Phragmites* treatment is defined for two types of sites:

1. Early detection sites (EDRR) – success is total eradication of *Phragmites* in isolated patches less than a ¼ acre in size.
2. Large connected stands of *Phragmites* – success is restoration of pre-invasion habitat/ecosystem (e.g. open water, sand beach, or marsh) with 60% reduction in *Phragmites* density in year 1. Site is stable if and when it no longer has to be treated with herbicide for 3 years. For the goal of marsh or other wetland restoration, it should have native vegetation returning.

FIELD MONITORING PROTOCOLS

A compilation of monitoring protocols was developed and evaluated before deciding on field monitoring protocols for this project. These are detailed in Appendix D "Compilation of Monitoring Protocols". Three tiers of field monitoring, as well as satellite and UAV monitoring were developed and applied to the application areas both pre- and post-treatment. This work was supplemented by complimentary work under two Michigan Invasive Species Grant Program (MISGP) projects, one to Laura Ogar of Bay county to treat the areas in orange in Fig. 4 and a "sister-project" to PI Bourgeau-Chavez for monitoring and modeling these MISGP treatment areas. Development of field monitoring and training of the Saginaw Bay Collaborative Invasive Species Management Area (SB-CISMA) field crew to collect field monitoring data was conducted in the EPA and MISGP sites. In the analysis of the field monitoring data, having a larger sample size of these combined projects was beneficial. It is also important to note that the treatments differed at the EPA and MISGP sites. With Glyphosate herbicide and biomass mowing before the next season for the EPA sites and a Glyphosate/Imazapyr mix for the MISGP sites, with partial mowing 1.5 years later at a couple sites.

These differences had an effect on post-treatment monitoring results as shown in the "Analysis of Monitoring Data for Assessing Treatment Effectiveness" section.

The three tiers of field monitoring were chosen to allow for flexibility in the needs and desired outcomes of resource managers, practitioners and stakeholders. The full evaluation and literature review of field monitoring protocols are described in Appendix D. Based on discussions with experts and testing different approaches for timing in the field, the MDNR's *Phragmites* Treatment and management Prioritization tool was chosen as the base protocol for the simplest (Tier 1) method and the Great Lakes Coastal Monitoring Program vegetation monitoring protocol was chosen as the most thorough evaluation of biodiversity (Tier 3). Tier 3 was also the most difficult. Realizing that Tier 1 may be too simple for some manager's needs but Tier 3 may be too intense, a Tier 2 approach was devised that did not require the expertise of a botanist but allowed field monitors to be trained on a much smaller set of desirable and undesirable species as well as identifying groups of plants (morphotypes). The 3 tiered system and UAV protocol are briefly described here and thoroughly at the end of Appendix D.

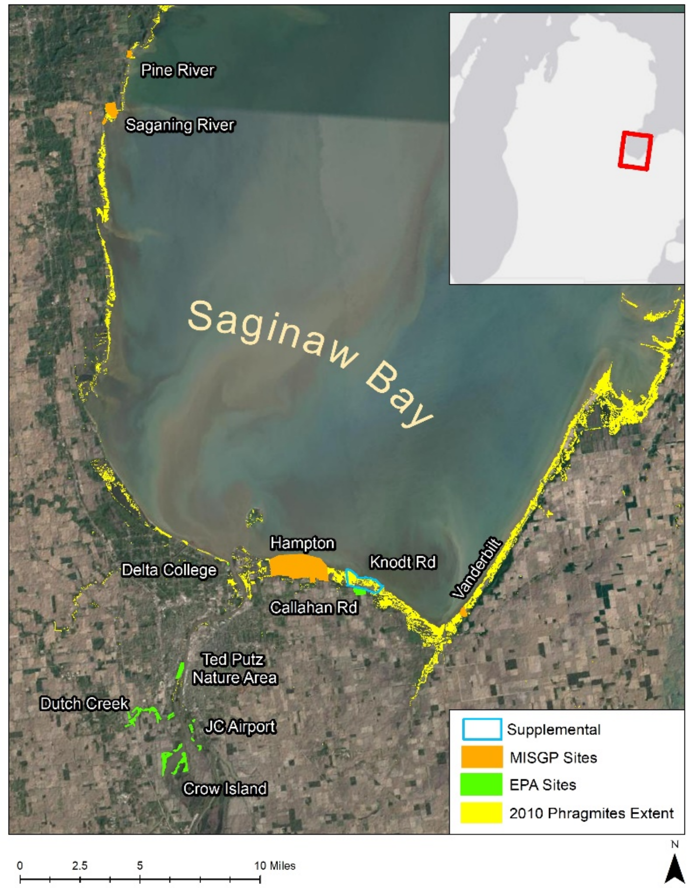


FIGURE 4: MAP OF PHRAGMITES TREATMENT AREAS FOR BOTH THE EPA PROJECT (GREEN) AND THE MISGP (ORANGE) IN THE SAGINAW BAY COASTAL AREA.

- Tier 1 monitoring is qualitative and does not require traversing a *Phragmites* infested site to conduct sampling and is the simplest and fastest protocol tested. It requires standardized photos with GPS maps or points of the treatment area and surrounding area, qualitative estimates of cover for *Phragmites* and desirable and undesirable species, and a one page question/answer sheet based on the DEQ's *Phragmites* Treatment and Management Prioritization tool. The SB-CISMA team developed a photo-monitoring protocol which allows for improved change comparisons between pre- and post-treatment photos which is described in Appendix D with an example in Fig. 5. Photos of all sites are in Appendix B.
- Tier 2 is more rigorous than tier 1, but less rigorous than tier 3. It can be conducted by the non-expert while Tier 3 requires botanical expertise. Tier 2 uses plant morphotypes and "desirable and undesirable" plant identification rather than identification of each species by name. This tier takes longer to implement than Tier 1, but is much quicker than Tier 3. Tier 2 is divided into monitoring plots (Tier 2a) and a belt transect (Tier 2b); each provides different information.

- Tier 3 is the most comprehensive protocol with detailed quantitative monitoring following the methodology of the Great Lakes Coastal Monitoring Program (led by CMU Uzarski). It requires a detailed sample of plant species that are present along transects and their percent cover. This tier is the most time consuming and requires plant species knowledge and expertise.

FIGURE 5. EXAMPLE OF PHOTOMONITORING USING TIER 1 PROTOCOL AT PUTZ PARK. TOP PHOTO WAS TAKEN IN AUGUST 2016 BEFORE TREATMENT, CENTER PHOTO WAS TAKEN IN SUMMER 2017 AFTER TREATMENT (HERBICIDE AND MOW) AND THE BOTTOM PHOTO WAS TAKEN IN JUNE 2018.

Tiers 1 and 2 sampling were implemented for pre-treatment monitoring of all the project treatment sites. Tier 3 sampling was conducted at a subset of the sites due to its need for botanical expertise. Training for the vegetation monitoring protocol of the Great Lakes Coastal Monitoring Program held at the University Biological Station was attended by MTRI staff in years 2015 and 2016. MNFI co-I Higman is an expert botanist and therefore, she and the MNFI field crew assisted the SB-CISMA in the Tier 3 monitoring. UAV monitoring was conducted at one of the Dutch Creek transects to assess the suitability for monitoring, in addition to several of the long transects (> 850 m) along the Saginaw Bay coast for the complementary MISGP project.

TRAINING FIELD MONITORING

MNFI and MTRI developed the field monitoring protocols and trained the SB-CISMA field monitoring crew in 2016. A refresher of the field training was conducted for the SB CISMA monitoring crew in years 2017 and 2018. The crew was comprised of a lead monitor who was initially trained in 2016 and a newly hired assistant each year. Plant identification training was conducted by visiting a variety of sites on the Bay to review common species encountered during monitoring. Review of the Tier 1, 2 and 3 protocols was conducted by working directly with the monitoring team to implement the protocols at several sites. MNFI, MTRI, and University of Northern Iowa project partners assisted with training while conducting actual monitoring in the *Phragmites* treatment sites (Fig. 6).

FIGURE 6: FIELD PHOTOS FROM BIODIVERSITY MONITORING TRAINING AT TREATMENT SITES.

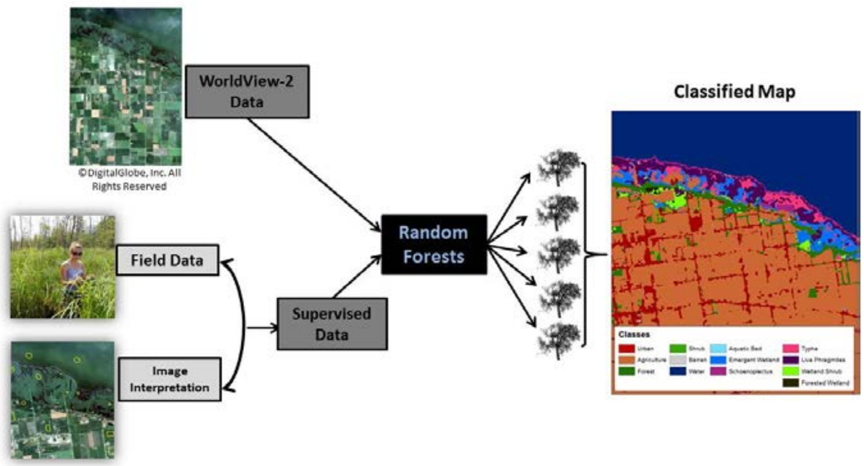


FIGURE 7: FLOW CHART SUMMARIZING THE INTEGRATED, SEMI-AUTOMATED APPROACH DEVELOPED BY PI BOURGEAU-CHAVEZ TO MAP THE EXTENT OF WETLAND PLANT INVASIONS.

Pre- and post-treatment mapping of *Phragmites* infested sites from a bird's eye view is essential for adaptive management. Especially for *Phragmites* infested stands, it is impossible to see the extent of infestation from a ground perspective due to the dense and tall nature of the invader. Both pre-treatment (2016) and post-treatment monitoring (2017 and/or 2018) was conducted for each treatment site using Worldview-2 imagery. Summer field sampling and Worldview-2 helped determined which treatment efforts were necessary at the treatment sites.

Pre-treatment mapping from high resolution Worldview-2 imagery from 7/26/2015 and 8/6/2016 using the Random Forests classifier was conducted for the entire Saginaw Bay coastline (Fig. 6). Supervised training data were created from field data and air photo interpretation as shown in the diagram of Figure 5. All treatment areas were mapped as well as the entire Saginaw Bay coastline. The pre-treatment maps provide baseline data to

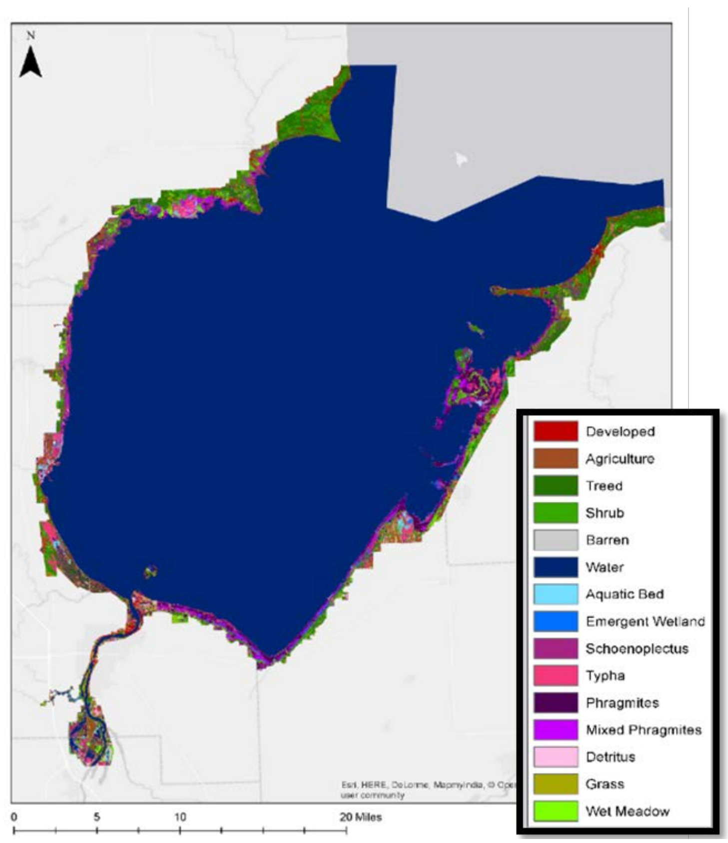


FIGURE 6: SAGINAW BAY COASTAL WETLAND MAP INCLUDING INVASIVE PHRAGMITES, MIXED PHRAGMITES WITH OTHER SPECIES, DEAD PHRAGMITES AND CUT/PHRAGMITES DETRITUS. SEE FIGURES 7 AND 8 FOR DETAILS OF THIS MAPPING WITH WORLDVIEW-2.

monitor treatment effectiveness, as well as providing early detection of outliers. The entire Saginaw Bay coastline that was mapped for this project (Fig. 6) is available for viewing and download request here: https://geodjango.mtri.org/coastal-wetlands/. A few areas of the bay were covered by clouds in the 2016 imagery, so the gaps were filled with 2016 NAIP. Although NAIP does not have as large a range of spectral bands as Worldview-2, it provided the best available substitute. In addition to providing pre-treatment *Phragmites* distribution maps for planning the project's treatments and to provide acreage for bid requests from contractors, this map was useful in the modeling to address propagule pressure specific to each treatment site. The map was produced for the entire bay to aid practitioners in targeting outliers, targeting additional treatment areas and protecting rare ecosystems such as Lake Plain prairie. An example of how this Bay map was used for the Knodt Rd neighborhood (Fig. 7) in determining acreage of *Phragmites*, is shown in Fig. 7. Most of this area was treated in Fall 2018 by the neighborhood association, supplemented by this project's treatment funds (see section above on Knodt Rd Treatment in 2018).

FIGURE 7: MAP OF KNODT RD NEIGHBORHOOD WITH EXTENSIVE PHRAGMITES. TOP MAP SHOWS ALL VEGETATION TYPES AND THE DELINEATED AREA, BOTTOM MAP SHOWS JUST THE PHRAGMITES EXTENT.

Post-treatment maps help determine the success of treatments implemented. In 2017 cloud-free Worldview-2 imagery was available for only 2 sites: Delta College and Callahan Rd sites, 1 year post treatment. In 2018, Worldview-2 data were available for all sites listed in table 1 and post-treatment maps were produced (see Fig. 8 for an example and Appendix A for all pre- and post-treatment maps of all EPA sites).

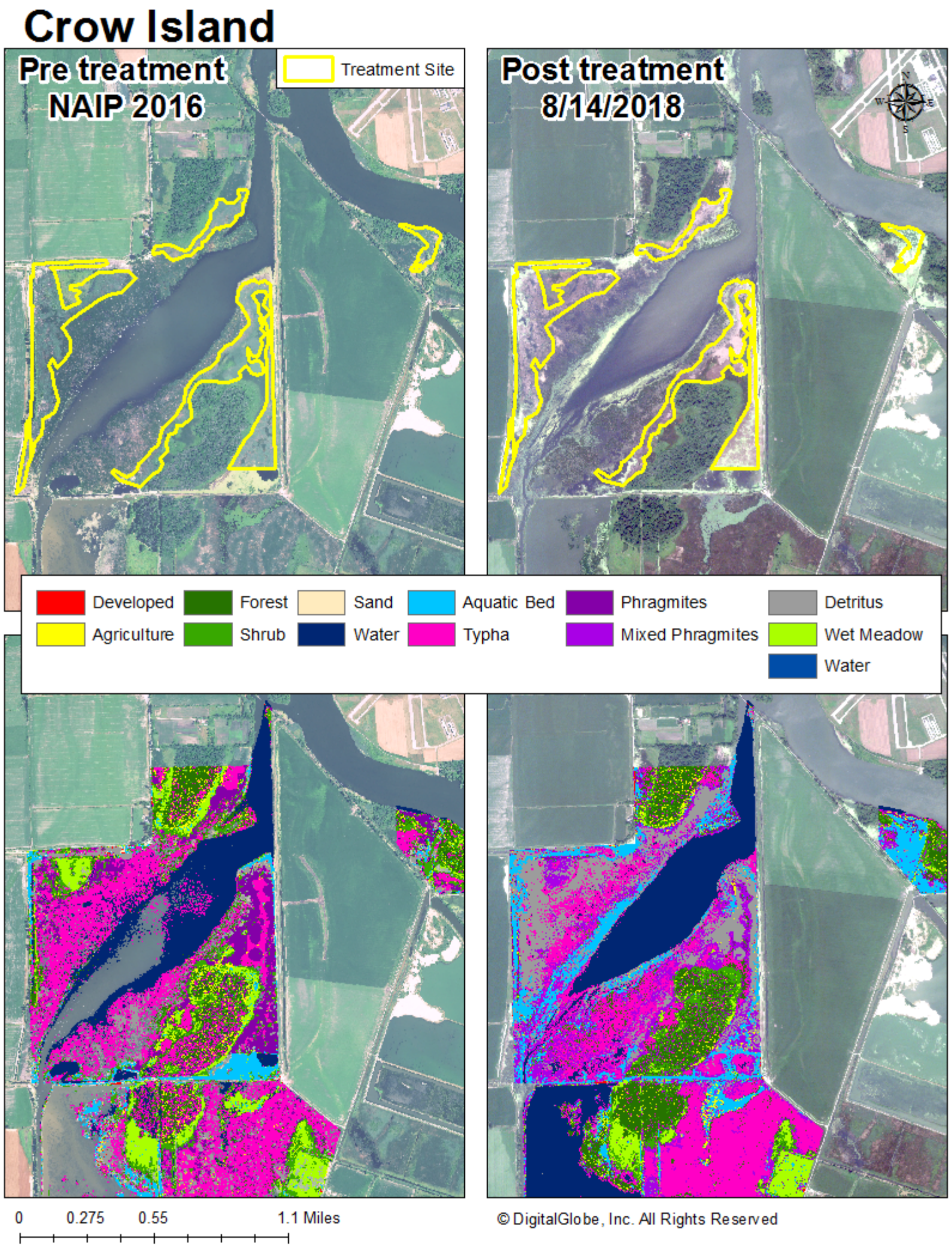


FIGURE 8: PRE- (2016) AND POST-TREATMENT (2018) IMAGERY (TOP ROW) AND CORRESPONDING MAPS (BOTTOM ROW) OF THE CROW ISLAND STATE GAME AREA.

UAV-BASED MONITORING

UAV monitoring is an option for monitoring that has become more practical with advancements in technology and flight rules. Based on field testing of UAVs over areas of fairly homogeneous *Phragmites* (both before and after treatment), a flying height of 100m (328 feet) was selected as the best elevation that lead to consistent creation of base maps to allow identification of *Phragmites* extent. UAV settings for data collection were optimal at 70% forward and side overlap, with a maximum mission speed of 10 m/s (22 mph). Using a DJI Mavic Pro UAV, an area of 16 ha 40 acres) can be imaged with these settings in a single 15-minute flight. Larger areas can be covered by dividing up data collections into missions that use multiple batteries. All Federal Aviation Administration (FAA) rules on maintaining line of sight, staying below 122m (400 feet), and not in controlled airspace will need to be followed unless further FAA permissions are obtained.

For some coastal wetlands in Saginaw Bay, sites can be too large and/or contain *Phragmites* that is too dense for upland-to-open-water field transects to be undertaken reasonably and safely. Given some training data, small unmanned aerial vehicles (UAVs) can be used to quickly map the dominant vegetation type along field transects. This was done for Transect H at the Dutch Creek treatment site in

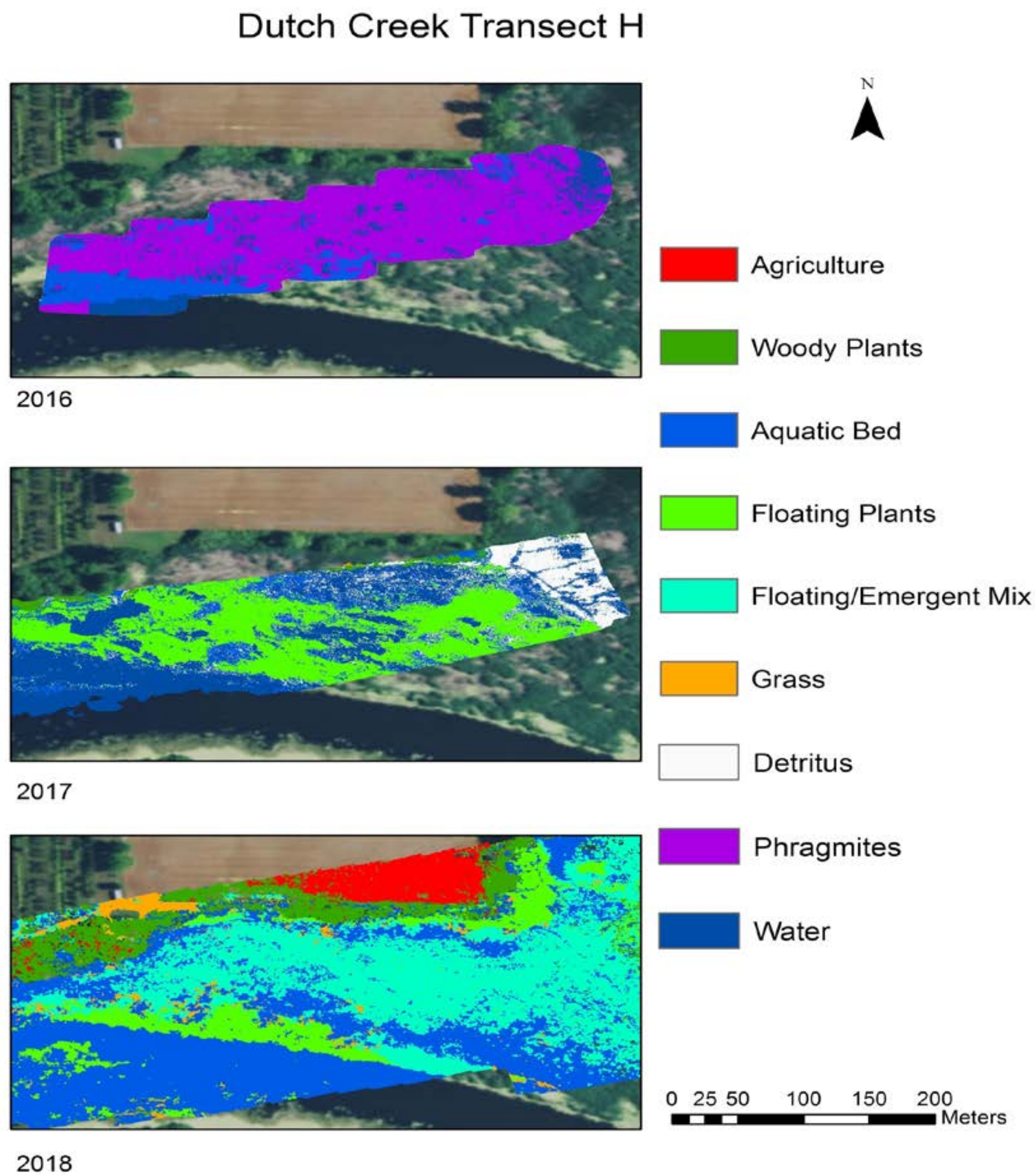


FIGURE 9: CLASSIFIED UAS IMAGERY COLLECTED ALONG TRANSECT H AT THE DUTCH CREEK TREATMENT SITE IN 2016, 2017 AND 2018.

September 2016, October 2017, and August 2018 (Figure 9). This UAV imagery cannot be used to extract detailed biodiversity information, but provides a flexible and safe way to identify dominant cover types and can be deployed as needed, including under cloud cover. UAV imagery was also collected at some of the MISGP sites which were 850 m to 1 km of *Phragmites* from upland/wetland interface to open water. A comparison of the UAV monitoring to the Tier 1, 2 and 3 is provided below.

Analysis of Monitoring Data for Assessing Treatment Effectiveness

One of the goals of this project was to quantify the costs and identify the pros and cons of a suite of monitoring protocols appropriate for different management scenarios and available resources (i.e. Tiers 1, 2, 3 and UAV monitoring), as well as to determine optimal monitoring return intervals. Specific concerns for these sites to evaluate through monitoring, identified from previous management efforts, were that imazapyr could negatively affect the native seed bank and that glyphosate alone is not sufficient to achieve desired *Phragmites* removal. The required expertise, time and cost effectiveness vs. statistical power and information gained for each monitoring approach were also evaluated. The monitoring tiers are described in brief above in the section 2 and in detail in Appendix D.

The changes in the treatment sites for this project were compared to those observed for the concurrent MISGP-funded project (sites were north of the EPA study sites, Fig. 4), and results showed no significant difference in *Phragmites* control success between projects. The MISGP sites were treated with a combination of imazapyr and glyphosate, while the EPA sites were treated with glyphosate and Cygnet Plus surfactant. However, results did show a substantial decrease in the monitored “impacts to human use values” at the EPA project’s treatment sites (Fig. 10) and no change at the MISGP sites. This is most likely because the treatment for the EPA project sites included biomass mowing post-herbicide, whereas those for the MISGP project were left with standing dead biomass. The Hampton and Vanderbilt MISGP sites (Fig. 4, aka MDNR sites) were partially mowed in winter 2017/2018, 1.5 years post-treatment.

Imagery collected with small unmanned aerial vehicles (UAVs) in 2016 ,17 and 18 along the transects that were unsafe or logistically difficult to survey on foot were processed and composited into mosaics for each transect (see example Fig. 9). The imagery was classified, via an object-based image analysis approach using eCognition software, into seven classes (*Phragmites*, mixed *Phragmites*, *Schoenoplectus*, *Typha*, aquatic bed, wet meadow, and open water). A combination of field observations and image interpretation was used to train the classifier. We evaluated what information we could reliably obtain from the UAV classifications in comparison to the field surveys.

One way to compare the monitoring protocols (Tiers 1,2, 3 and UAV) was to compare the estimated percent *Phragmites* cover from each protocol to the satellite-derived classifications (Worldview-2, Appendix A). Because the Worldview-2 imagery covers the entire treatment sites at a high resolution (sub-meter) and the accuracy of *Phragmites* classification has been validated as very high for the satellite classification, it can be used as “ground truth” for comparison. The results of this comparison showed that Tier 2b and UAS data were most similar to the satellite-based map, followed by Tier 2a, Tier 3, and Tier 1 (Fig. 11). Given the relative levels of effort required, this suggests that where monitoring change in *Phragmites* cover is a management priority, UAS-based monitoring is efficient when a small UAS and pilot are available, especially when transects would be long and difficult or unsafe to traverse, and that a Tier 2b (belt transect) approach provides a rapid and accurate estimate for traversable sites.

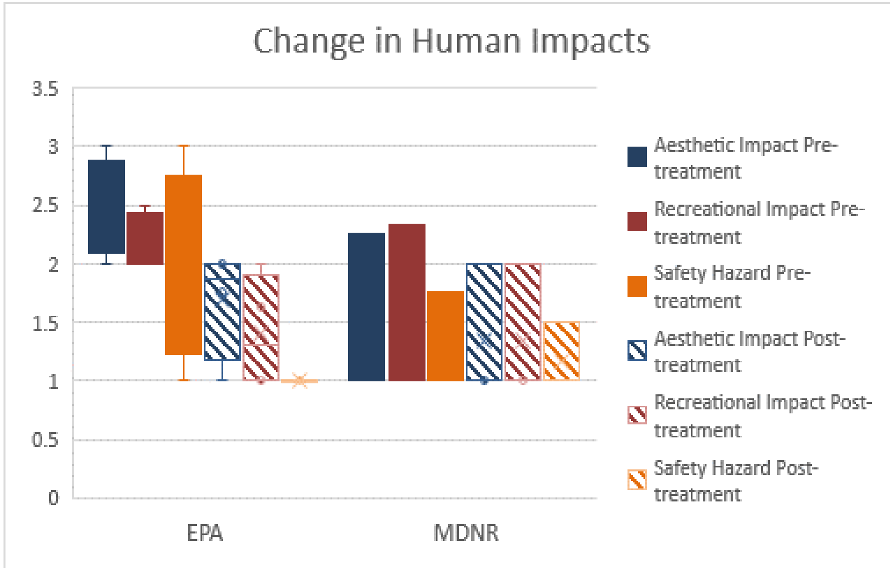


FIGURE 10: ESTIMATED AESTHETIC, RECREATIONAL AND SAFETY HAZARD "HUMAN IMPACTS" OF *PHRAGMITES* PRESENCE AT TREATMENT SITES, BEFORE (SOLID BARS) AND AFTER TREATMENT (HASHED BARS). TREATMENT SITES FOR THIS PROJECT (EPA) WERE COMPARED TO THOSE OF THE CONCURRENT MDNR MISGP-FUNDED *PHRAGMITES* MANAGEMENT PROJECT.

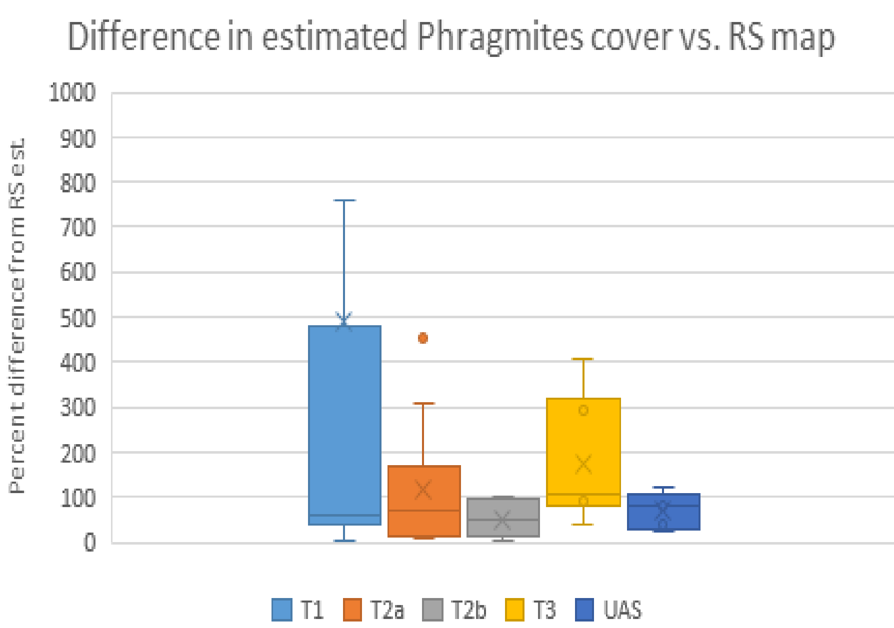


FIGURE 11: DIFFERENCE IN ESTIMATED *PHRAGMITES* PERCENT COVER BETWEEN EACH FIELD MONITORING PROTOCOL AND THE WORLDVIEW-2 SATELLITE-DERIVED COVER MAP.

Because Tier 2a includes *Phragmites* stem counts and measurements of height and diameter, it allows for estimation of changes in live *Phragmites* above-ground biomass (AGBM). This can be useful for understanding the effects of *Phragmites* invasion and treatment on carbon cycling, and serves as an alternative measure of treatment effectiveness where treatment results in live *Phragmites* that is sparser but still present. Before treatment, *Phragmites* biomass at the EPA sites averaged slightly more than 2 kg dry weight per square meter and 1.5 kg dw/m^2 at the comparison MISGP project sites (Fig. 12). Both one and two years after treatment, live *Phragmites* biomass was negligible at both sets of sites, as any live *Phragmites* that remained was small and occurred at a much lower density than pre-treatment.

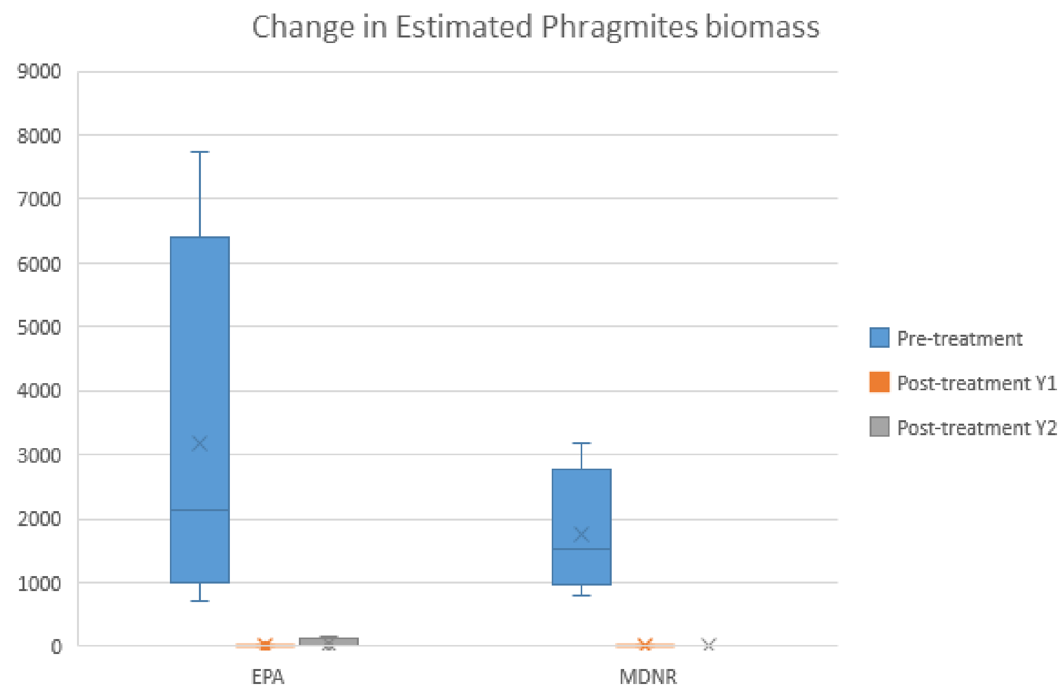


FIGURE 12: ESTIMATED ABOVE-GROUND BIOMASS (GRAMS PER SQUARE METER) OF LIVE *PHRAGMITES* AT EPA AND MDNR (MISGP) PROJECT TREATMENT SITES PRE-TREATMENT AND 1 AND 2 YEARS FOLLOWING TREATMENT.

Next, with respect to the recovery of native wetland vegetation, which formed part of the definition of treatment success for these sites, the belt transect monitoring data show that the percent cover of desirable vegetation increased from an average of approx. 15% pre-treatment to 40% Y1 post-treatment and >60% Y2 post-treatment (Fig. 13). In comparison, native vegetation at the MISGP project's treatment sites has responded more slowly despite similar pre-treatment native cover, and reached 40% only at Y2. This is likely another effect of the delayed and incomplete biomass removal at the MISGP sites.

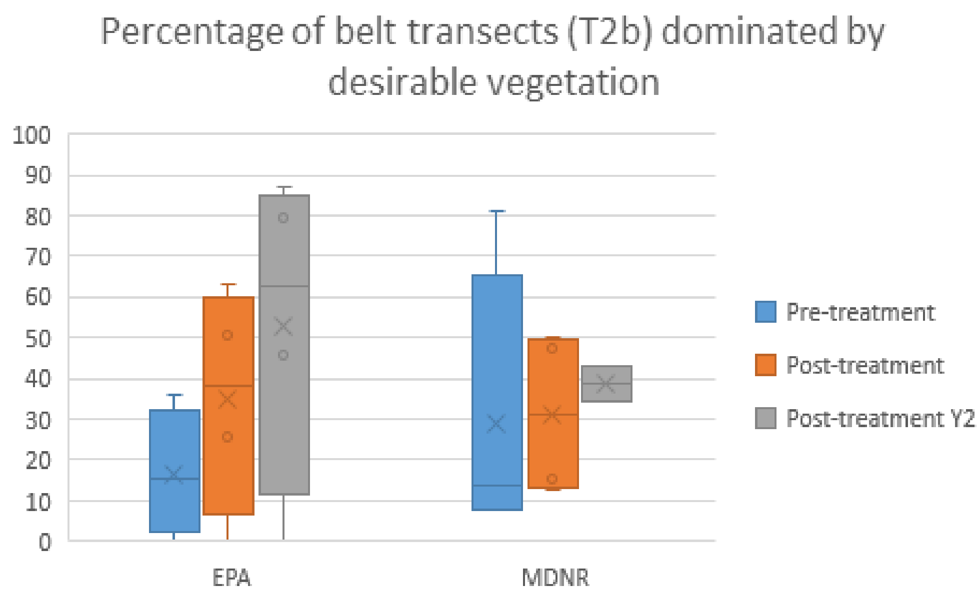


FIGURE 13: COMPARISON OF PERCENT DESIRABLE VEGETATION PRE-TREATMENT (BLUE) AND YEAR 1 POST-TREATMENT (ORANGE) AND YEAR 2 POST-TREATMENT (GRAY) FOR BOTH THE EPA AND MDNR (MISGP) SITES.

The identification of "morphotypes" in Tier 2a plots, i.e., the number of different rush, sedge, floating, etc. species that appear to be present, was evaluated as a potential means of obtaining some information about changes in native biodiversity when a botanist is not available to identify all individuals to the species level. These data indicate an increasing trend in native biodiversity at the EPA sites but not at the MISGP sites (Fig 14). The pattern for the MISGP sites is consistent with the Tier 3 monitoring performed for selected MISGP site transects, which showed an initial drop in total and native species richness after treatment with little change between Y1 and Y2 after treatment (plot not shown).

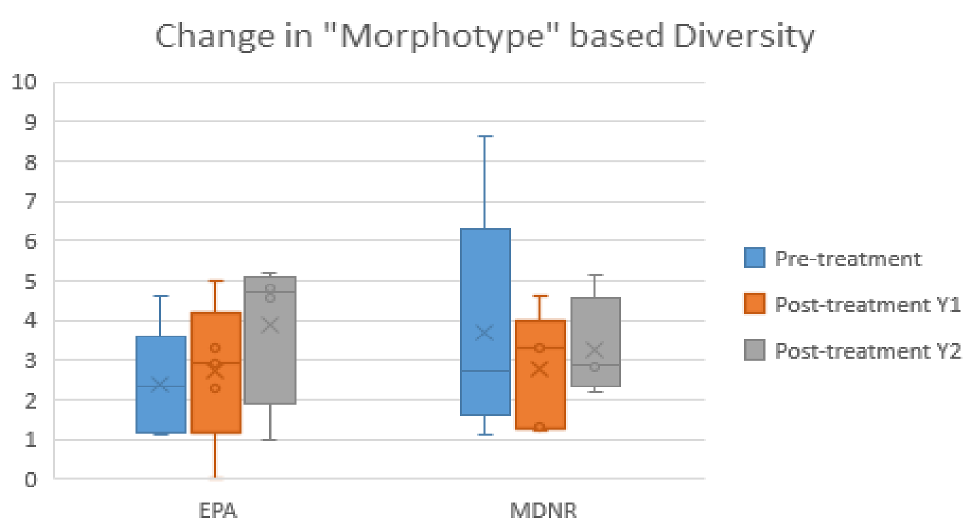


FIGURE 14: COMPARISON OF BIODIVERSITY BASED ON PLANT MORPHOTYPES IN THE EPA VS. MDNR (MISGP) TREATMENT SITES IN THE PRE-TREATMENT YEAR (BLUE) AND YEAR 1 AND 2 POST-TREATMENT (ORANGE AND GRAY, RESPECTIVELY).

Overall, the monitoring data indicate that the treatment approach for this project of glyphosate + surfactant followed by mowing was successful at removing most of the live *Phragmites* from the sites with resulting low regrowth two years after treatment. The changes in native cover and diversity are less immediate than the reduction in *Phragmites*, but both are moving in the desired direction. Monitoring the first and second years after treatment were very useful for assessing *Phragmites* kill and detecting any blooms of secondary invaders. However, a longer monitoring period is required to capture the long-term effect of treatment on the native vegetation community; a follow-up approximately 5 years after treatment would provide more useful information.

Tier 1 monitoring requires the least time and training (Table 3), and is certainly preferable to no monitoring, but provided the least accurate estimates of *Phragmites* cover and little information on native cover and diversity. Without walking through the plot, important observations of secondary invasions following treatment could also be missed. However, the photo-monitoring results (Fig. 5 and Appendix B) provide useful documentation of site changes.

Tiers 2a and 2b provide complementary information on changes in biomass and diversity (2a) and in overall cover (2b); because these are compatible for collecting along a single transect, the monitoring crew found it fairly fast and straightforward to combine the two. This combined approach provides information on both the cover and density/biomass of *Phragmites*, as well as trends in native cover and diversity, all of which can be useful for determining future treatment plans in an adaptive management approach. Tier 3 requires the highest levels of skill and effort as well as the most time, but provides information on species composition, conservation value and diversity that can't be replicated using the "easier" protocols. For sites with specific biodiversity goals for management, or where endangered/threatened/special concern plant species are present, Tier 3 may be the best approach to evaluating treatment effects. Outside of those contexts, some combination of Tiers 1/2a/2b is likely to be sufficient.

Finally, UAS-based monitoring is a rapid means of assessing inaccessible sites when UAS resources are available, and can provide estimates of dominant vegetation cover similar to belt transect data more rapidly and at less risk. However, by imaging from above, understory layers of vegetation are not observed, and information on small/sparse/rare vegetation types is lost.

The need for more practical monitoring methods in large, dense infestations was demonstrated during this project, where on-the-ground monitoring of large stands (> 800 m) across the gradient from wet meadow to submergent zone in the Great Lakes coastal zone) was prohibitively time-consuming and even sometimes unsafe to implement during typical *Phragmites* treatment efforts. Fortunately, remote sensing imagery options have improved dramatically, and using World View-2 Digital Globe imagery (60 cm resolution) during this project, even small patches of *Phragmites* dead and live stems could be detected before and after treatment. In addition, some biodiversity measures could also be detected (i.e. mixed vegetation vs monotypic *Typha, Phragmites* or *Schoenoplectus*, for example). The use of unmanned aerial vehicles is improving as well and will almost certainly be more routinely employed for treatment monitoring. The drones used during this study were able to distinguish *Phragmites* from non-*Phragmites* but did not allow identification of non-*Phragmites* taxa to the species level other than *Typha*, even at 5 cm resolution with a natural color camera. Further differentiation may be possible with multi-band cameras.

TABLE 3: SUMMARY OF MONITORING PROTOCOL COMPARISON.

Protocol	Effort	Skill	Safety Hazard	Equipment cost	Effect on human impact	Phragmites cover/kill rate	Change in total undesirable veg	Change in desirable veg	Native species/sqm	Phragmites biomass	Species richness	Conservatism index	FQI
Tier 1	Low	Low	Low	Low	X	X							
Tier 2 belt transects	Medium	Medium	Medium to High	Medium		X	X	X					
Tier 2 plots	Medium	Medium	Medium to High	Medium		X	X	X	X	X			
Tier 3	High	High	Medium to High	Medium		X	X	X	X		X	X	X
Drones	Low	High	Low	High		X	X	X					

Guidelines for Tying Management Goals, Treatments, and Monitoring Protocols together for Adaptive Management

It is of critical importance to assess site specific conditions and determine explicit management goals prior to implementing management activities. These will dictate the best treatment methods and sequences for achieving success, as well as the best monitoring protocols to measure progress. Only then can adaptive management be truly implemented, where monitoring results inform subsequent management activities, and are adapted accordingly. Consistent documentation of management goals, treatments implemented, and monitoring results not only will improve management at the site scale, but it also allows these data to be easily shared to inform a broader management and restoration community. Compiling site level data across many sites will also have implications at larger landscape scales. Coordinated landscape, regional and site-scale management and learning are needed for optimal management of *Phragmites* throughout Saginaw Bay.

Factors to Consider in Developing a Monitoring Plan

Monitoring Goals

The goals of monitoring should be framed by the overall management goals and underlying specific objectives (Table 4). For example, the simplest monitoring goal would be evaluation of management actions in reducing *Phragmites* occurrence (e.g., percent cover, frequency, density, and/or stem diameters) within a wetland where management occurred. If the management goal is to restore a functioning Great Lakes marsh ecosystem, then monitoring would require measures of plant and animal communities and ecosystem functioning as related to reference wetlands. Although evaluating the effects of management on plant/animal communities and ecosystem functioning should provide increased knowledge to inform future management, such monitoring often requires substantial resources, including money, time, and expertise (Table 4). However, the

TABLE 4: TYPICAL MONITORING GOALS WHEN ASSESSING THE SUCCESS OF MANAGEMENT ACTIONS TARGETED AT INVASIVE *PHRAGMITES*.

Typical Monitoring Goals	Scientific value increases, as does complexity and resources required.
Evaluate the success of management actions in reducing *Phragmites* occurrence within the wetland	
Assess the effects of management actions on the overall plant community (plant diversity measures)	
Investigate the effects of management on both plant and selected animal communities (e.g., birds, amphibians, reptiles, fish, invertebrates)	
Assess the success of management actions in achieving ecosystem restoration (e.g., plant and animal communities, ecosystem functioning). NatureServe (Comer & FaberLangendoen 2017) is developing ecosystem-based templates for measuring progress towards wetland mitigation site goals that considers ecosystem composition, structure and function. The latter requires an understanding of the fundamental ecosystem processes that drive the ecosystem and a way to determine if they are occurring.	

addition of at least one or more measures that go beyond % *Phragmites* kill, are highly desirable in most management scenarios to better assess progress towards specific management goals – and they are not always cost-prohibitive. For example, simple qualitative visual estimates of the total % cover of all "desirable" and "undesirable" species can be made relatively easily with limited expertise, assuming clear definitions of the estimation categories are developed and communicated. Similarly, simply setting a threshold level of *Phragmites* cover that is believed acceptable for the persistence of a specific plant and/or animal populations could also be easily measured. In the latter case, monitoring data would be more valuable if they included some measure of other species (desirable and undesirable).

The best measures for some management goals and objectives may not yet be known, but implementing deliberate, consistent monitoring over time, along with on-going studies by the research community, will help improve our understanding of these measures. It is possible, for example that specific ecosystem structural measures, such as percentage of plants in certain height categories, would be highly informative for some coastal wetland nesting bird species.

Wetland ***restoration*** is another common goal of *Phragmites* control efforts but requires monitoring beyond measuring *Phragmites* kill and plant diversity to evaluate success. Monitoring efforts rarely assess the success of restoration efforts – again, typically because of limited resources and expertise. Determining restoration success may seem simple, but in reality, requires substantial planning and careful sampling that includes ***ecological reference sites***. The Society for Ecological Restoration (SER) identified nine indicators of restoration success (SER 2004): 1) similar species composition as reference site; 2) native species are present; 3) appropriate functional groups are present; 4) sustains reproducing populations of species; 5) functions normally (ecosystem processes are intact); 6) site is integrated into the landscape; 7) potential threats reduced or eliminated; 8) withstands natural disturbances; and 9) site can sustain itself indefinitely. Recognizing it is unlikely that resources are available to evaluate all nine indicators, Ruiz-Jaen and Aide (2005) provided more realistic suggestions for evaluating restoration projects. The authors recommended assessments include the measurement of at least two variables within each of three ecosystem attributes (diversity, vegetation structure, and ecological processes) and comparison with at least two reference sites.

Sample Design

Based on the management and monitoring goals, the sample design should be determined before management actions are implemented. Whether you are monitoring *Phragmites* alone, various plant/animal communities, or measures of ecosystem functioning, some basis for comparison is required. For example, to assess the effects of management on *Phragmites* at a particular site, measures of *Phragmites* occurrence (e.g., percent cover, density, spatial extent) would need to be compared between separate time periods, sites, or both. Simply measuring *Phragmites* metrics at the management site after actions have occurred provides no basis for comparison and therefore, no way to evaluate success. The most statistically robust design would include both temporal (i.e., sampling before and after management) and spatial (i.e., sampling at both management and reference sites) replication (Table 5). This allows for a before-after-control-impact robust statistical analysis. Because species and ecosystems typically vary greatly over time and space, replication of sampling (e.g., years and sites sampled) should be maximized as much as possible.

TABLE 5: SAMPLE DESIGN CONSIDERATIONS WHEN ASSESSING THE SUCCESS OF MANAGEMENT ACTIONS TARGETED AT INVASIVE *PHRAGMITES*.

Sample Design	Examples of Implementation	Scientific value increases, as does complexity and resources required
Temporal Comparisons	Compare metrics during 1 growing season before and 1 season after management	
	Compare metrics during 1 growing season before and multiple seasons after management	
Spatial Comparisons	Compare metrics at management site to reference site	
	Compare metrics at multiple management sites to multiple reference sites	
Both Temporal and Spatial Comparisons	Compare metrics between the management site and a reference site during 1 growing season before and 1 season after management	
	Compare metrics between multiple management sites and multiple reference sites during 1 growing season before and multiple seasons after management	

STAND CHARACTERISTICS

A Guide to the Control and Management of Invasive Phragmites (MDEQ, 2014) describes specific management strategies based on the size and density of *Phragmites* stands. Similarly, the size and density of stands, as well as other characteristics, will influence the resources required and methods to be employed for monitoring. If the same on-ground sampling methods are used across sites, monitoring costs increase substantially with stand size and density (Table 6) and in some cases may not be feasible due to safety concerns. It is likely that limited resources will require different monitoring approaches be used at large dense stands compared to smaller and sparser stands (Table 7).

TABLE 6: SAMPLE DESIGN CONSIDERATIONS WHEN ASSESSING THE SUCCESS OF MANAGEMENT ACTIONS TARGETED AT INVASIVE *PHRAGMITES*.

Stand Size	Stand Density	Monitoring costs and resources required increase.
Small	Sparse	
Small	Dense	
Large	Sparse	
Large	Dense	

TABLE 7: EXAMPLES OF POSSIBLE SAMPLING APPROACHES BASED ON MONITORING GOALS AND STAND CHARACTERISTICS. THESE APPROACHES COULD BE APPLIED USING ANY SAMPLE DESIGN (E.G., TEMPORAL COMPARISONS, SPATIAL COMPARISONS, AND BOTH TEMPORAL AND SPATIAL COMPARISONS). GRAY SHADED CELLS INDICATE POTENTIAL MONITORING APPROACHES FOR LISTED MONITORING GOALS, STAND SIZE, AND STAND DENSITY. GREEN-SHADED CELLS INDICATE A RECOMMENDED METHOD TO USE IN ADDITION TO OR WHEN RESOURCES ARE LACKING FOR HIGHER LEVEL MONITORING, BUT THAT IS NOT OPTIMAL ALONE. THE ORANGE SHADED CELLS INDICATE STAND CONDITIONS WHERE REMOTELY SENSED SATELLITE IMAGERY TESTED IN THIS PROJECT CAN BE HELPFUL.

Monitoring Goal	**Stand Size**	**Stand Density**	**Photo-monitor/ Tier 1**	**Mapping – on-the-ground**	**Mapping – remote sensing**	**Plot/transect – *Phragmites****	**Plot/transect – plant community***	**Animal surveys**	**Ecosystem functioning**
Evaluate the success of management actions in reducing *Phragmites* occurrence within the wetland	Small	Sparse							
	Small	Dense							
	Large	Sparse							
	Large	Dense							
Assess the effects of management actions on the overall plant diversity	Small	Sparse							
	Small	Dense							
	Large	Sparse							
	Large	Dense							
Investigate the effects of management on both plant and selected animal communities	Small	Sparse							
	Small	Dense							
	Large	Sparse							
	Large	Dense							
Assess the success of management actions in achieving ecosystem <u>restoration</u>	Small	Sparse							
	Small	Dense							
	Large	Sparse							
	Large	Dense							

* The same transects and plots can be used for both *Phragmites* and plant diversity response.

** Generally small sites are those with transects spanning the water gradient that are less than 200 m in length in a large water body; large includes sites where transects are over 500 m in length in large water body.

3. Modeling

Landscape Modeling

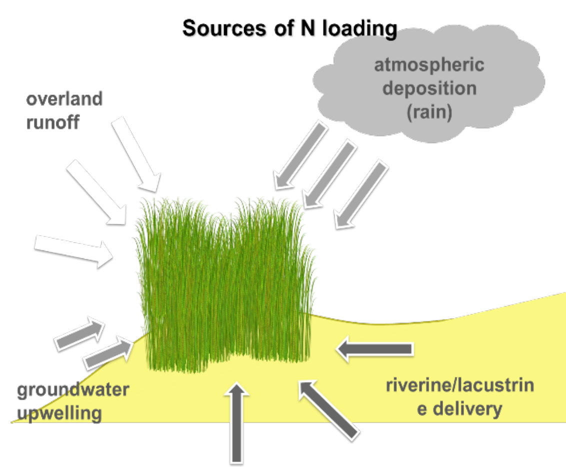
Landscape modeling metrics for input to MONDRIAN

Landscape modeling metrics for use in MONDRIAN modeling were produced for each treatment site. Metrics included 1) water levels, 2) nitrogen load, and 3) propagule pressure estimates. Water level and nitrogen loading inputs were provided as monthly estimates. Nitrogen loading inputs included low, moderate, and high estimates due to uncertainty in the modeling data inputs and methods. Details on the modeling methodology for each metric are provided below.

1) *Water levels* were calculated by taking river/lake level – site elevation. Unfortunately, for the treatment sites of interest, water level data was not available. There is a single USGS gage station with a history of monthly Saginaw River level observations near the Crow Island site, but these levels never exceed LiDAR-derived ground-elevation levels. Additionally, the Crow Island site is diked and so may not be significantly influenced by changing river levels regardless. In lieu of available water level data, the treatment sites were assigned a mean water level of 0.09 m; this value was derived by modeling water levels for *Phragmites* treatment sites in nearby Saginaw Bay where both water level and LiDAR elevation data are more readily available to produce depth estimates.

2) *Nitrogen Load*: There are potentially four major sources of *N loading* to wetland sites:

   - Overland runoff
   - Atmospheric deposition
   - Riverine/lacustrine delivery
   - Groundwater upwelling



   Overland runoff: surface flow (typically following a precipitation event) that moves sediment and nutrients from their source to lower elevation sinks. For overland runoff estimates, we used Long Term Hydrologic Impact Analysis (L-THIA) modeling available via the Great Lakes Watershed Management System (GLWMS; http://lthia.agriculture.purdue.edu/). L-THIA estimates non-point source pollution using climate, soil hydrological group, and land use parameters.

   Using L-THIA via GLWMS, we derived annual N loading estimates for each HUC12 catchment. Each of the treatment sites were assigned the HUC12(s) that contained the site. These annual estimates were then up-sampled to monthly estimates based on distribution of mean monthly precipitation (according to 1981-2010 climate normals).

   Atmospheric deposition: nutrients delivered to sites via direct precipitation. For atmospheric deposition estimates, we used National Atmospheric Deposition Program (NADP) National

Trends Network (NTN) annual maps. These maps are produced annually as raster data at ~3 km resolution.

For each site catchment (i.e. proximate upland area flowing into the site), we extracted annual N deposition values for 2005-2014. We calculated annual mean and standard deviation from these values. As with the overland flow estimates, we up-sampled the annual estimates to monthly estimates by using the distribution of mean monthly precipitation (again, according to 1981-2010 climate normals).

Riverine/lacustrine delivery: nutrients/sediment delivered via creeks, rivers, or lakes adjacent to the site. This is one of the largest components of N loading and it is also one of the most uncertain (due to the sparse network of water quality measurements and lake level data). To calculate riverine/lacustrine N loading:

N delivery (g m-2) = N concentration (g m-3) * water level (m)

N concentration (g m-3) data were derived from NWIS/STORET water quality monitoring stations. NWIS and STORET are collections of field data from disparate sources and collection regimes that span several decades. The stations with long-term records of NO_3 and NH_4 concentrations that are closest to sites were used to derive monthly values. N concentration is then multiplied by site-specific water level (described above) to get total N loading for each site.

Groundwater upwelling: nutrients delivered via groundwater infiltration. This is a potentially significant source of N loading; many wetlands in the area have large groundwater inputs (David Hyndman & Anthony Kendall, personal communication), but unfortunately, there are no field data or modeling methods available to make spatially explicit estimates for these sites.

The NWIS and STORET station networks have some historic concentration data for wells, but there are no wells anywhere near the treatment sites, and the well data that are available are extremely sporadic and limited both spatially and temporally (i.e. the data usually represent a single one-time measurement rather than a time-series).

3) *Propagule pressure* was estimated for each treatment site based on visual interpretation of *Phragmites* extent upstream of the sites using SAR-Optical derived wetlands maps produced under a previous NASA Great Lakes grant (PI Bourgeau-Chavez https://geodjango.mtri.org/coastal-wetlands/).

RIPARIAN BUFFER MODELING AND WEB-APPLICATION DEVELOPMENT

Riparian buffer modeling for the full Saginaw Bay watershed was completed as planned. The purpose of this modeling was to map locations where riparian buffers might be most effective in mitigating the amount of agricultural runoff entering streams. It involved the calculation of two geospatial metrics: a metric indicating where and how much agricultural runoff enters streams and a metric indicating how effective a buffer would be, given soil and topographic conditions at the site (Fig. 15). Geospatial inputs to the modeling included linear hydrography (modified from NHD+ Version 2 according to aerial imagery to better match landscape), SSURGO-derived soil metrics, USGS NED 10m DEM, and a 12.5m SAR-derived landcover dataset. Methods and example outputs (below) were presented to The Nature Conservancy in early December 2017 and were documented in a peer-reviewed manuscript published in the Journal of Great Lakes Research (Billmire and Koziol 2018).

There were limitations in the precision of the NHD hydrography layers (linear features were frequently 20–40 m offset from actual locations according to aerial imagery), and limitations in the accuracy of the landcover layer (which does not always pick up existing natural vegetation buffers along linear features). It is, therefore, recommended that the outputs not be used to identify locations for precise buffer placement but rather be used (possibly in the form of spatially aggregated mean values) to target and prioritize areas for further assessment via field surveys and aerial imagery.

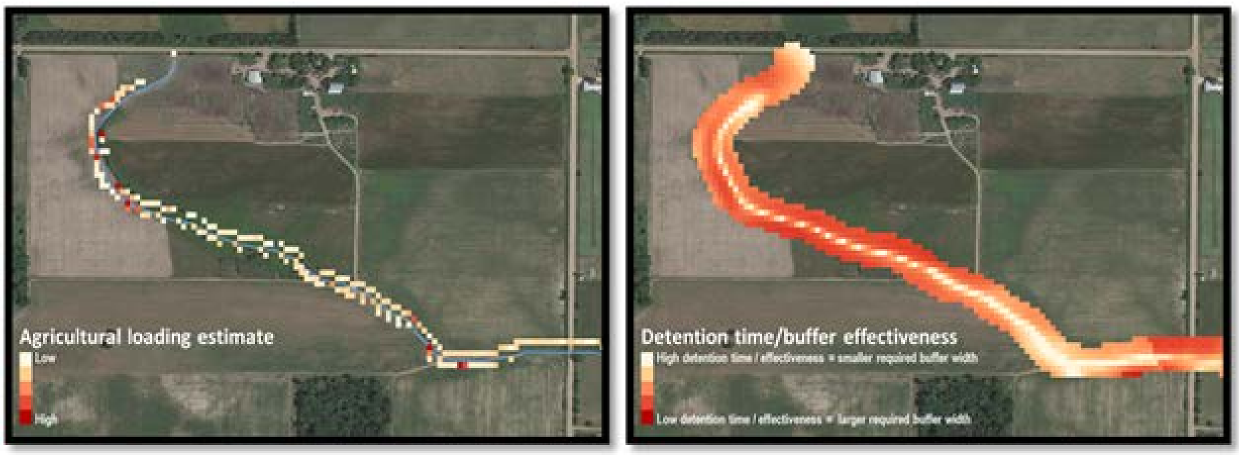


FIGURE 15: MODELING OF AGRICULTURAL LOADINGS AND DETENTION TIME/BUFFER EFFECTIVENESS.

Validation of the hydrological flow path-based metrics included use of both field photos and archived USGS NWIS and EPA STORET in-stream nutrient concentration observations. The loading metric was validated via statistical analysis comparing the loading values to in-stream inorganic N concentrations during high flow conditions. The analysis showed that the loading metric is a better predictor of in-stream N concentrations than simpler landscape metrics that indicate proportion of cropland within a catchment (or drainage basin) and proportion of cropland within a fixed-width riparian zone within the catchment. The buffer effectiveness metric did not contribute predictive power to the in-stream nutrient concentration models.

A web mapping application was developed to facilitate visualization and exploration of the riparian buffer modeling output products. The application uses Leaflet.js for web mapping and GeoServer for serving the spatial data layers (Fig. 16). The web mapping application for displaying the riparian buffer modeling outputs can be accessed here: http://spatial.mtri.org/phrag-viewer/

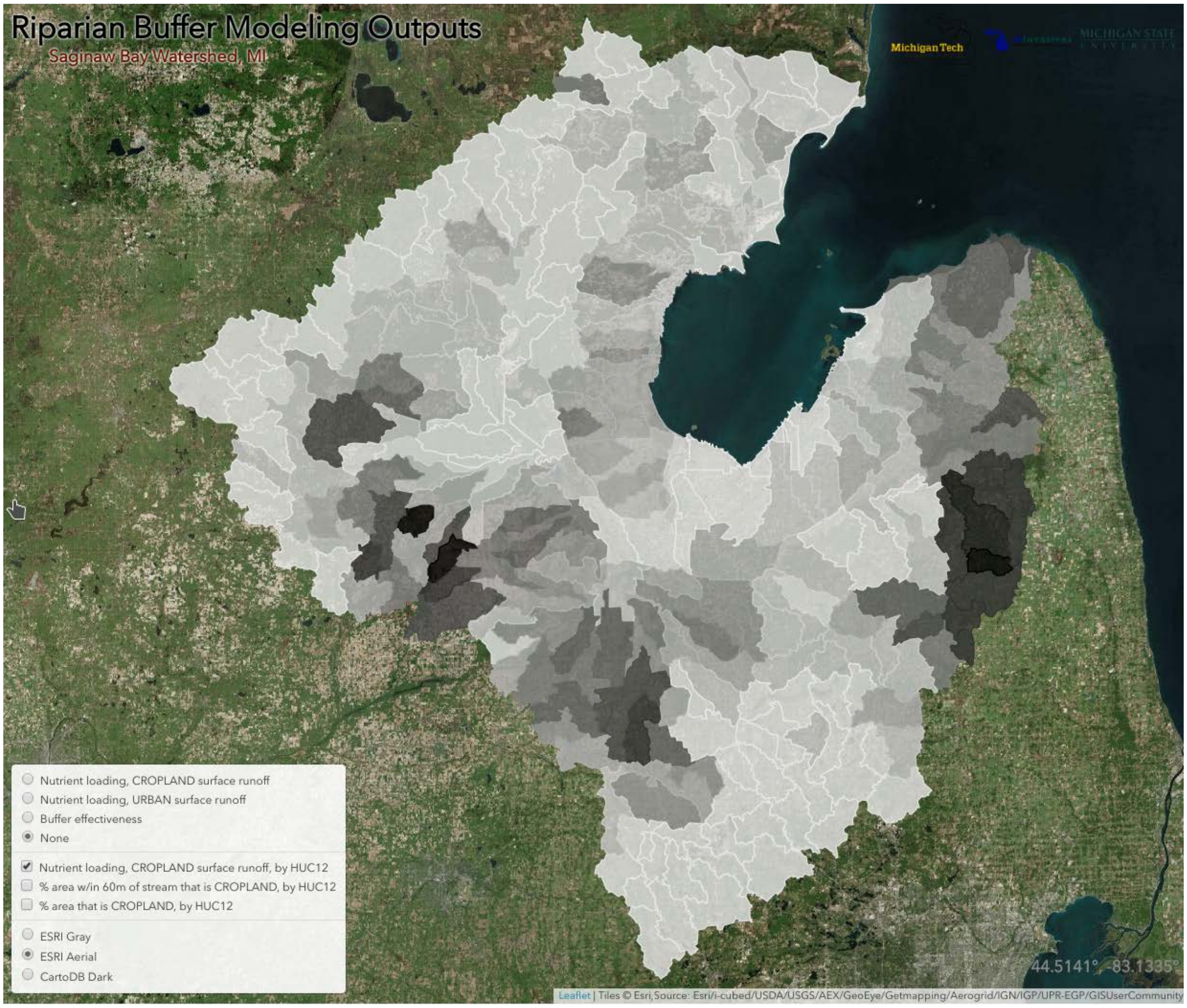


FIGURE 16: SCREENSHOT OF THE WEB-APPLICATION FOR DISPLAYING RIPARIAN BUFFER MODELING OUTPUTS. IN THE DISPLAYED DATASET, DARK COLORS REPRESENT HIGH NUTRIENT LOADING DUE TO CROPLAND SURFACE RUNOFF AND LIGHT COLORS REPRESENT LOW CROPLAND SURFACE RUNOFF.

INTEGRATING FIELD AND MODEL DATA

The leaf and soil samples collected in fall 2016 were analyzed and used to assess the landscape modeling efforts. The results provided confirmation that the landscape modeling provided a reasonably accurate reflection of conditions in the wetland**.**

N-loading: Since nitrogen availability is an important parameter that is being fed from the landscape modeling into the MONDRIAN model, this provides an assessment of the accuracy of one component that links these two modeling frameworks. Results are shown in the Figure 17 below. Note that these measurements were taken for both this project and the MISGP project sites (Fig. 4).

Leaf N content in green leaves showed a clear positive (non-linear) relationship with modeled annual N inputs (Figure 17 panel A). Since green leaves are the clearest indication of immediate (current year) N inputs, this positive relationship provides confirmation that the landscape modeling is accurately reflecting current conditions in the wetland. The non-linear relationship, evident in the Dutch Creek site where extremely high modeled annual N input did not result in commensurately higher leaf N, was expected because there is an upper physiological bound on the amount of N that leaf tissue can contain. When N is supplied in excess (as the landscape model suggests is happening at the Dutch Creek site), leaves cannot take up that much additional N, resulting in the asymptotic relationship displayed in this figure.

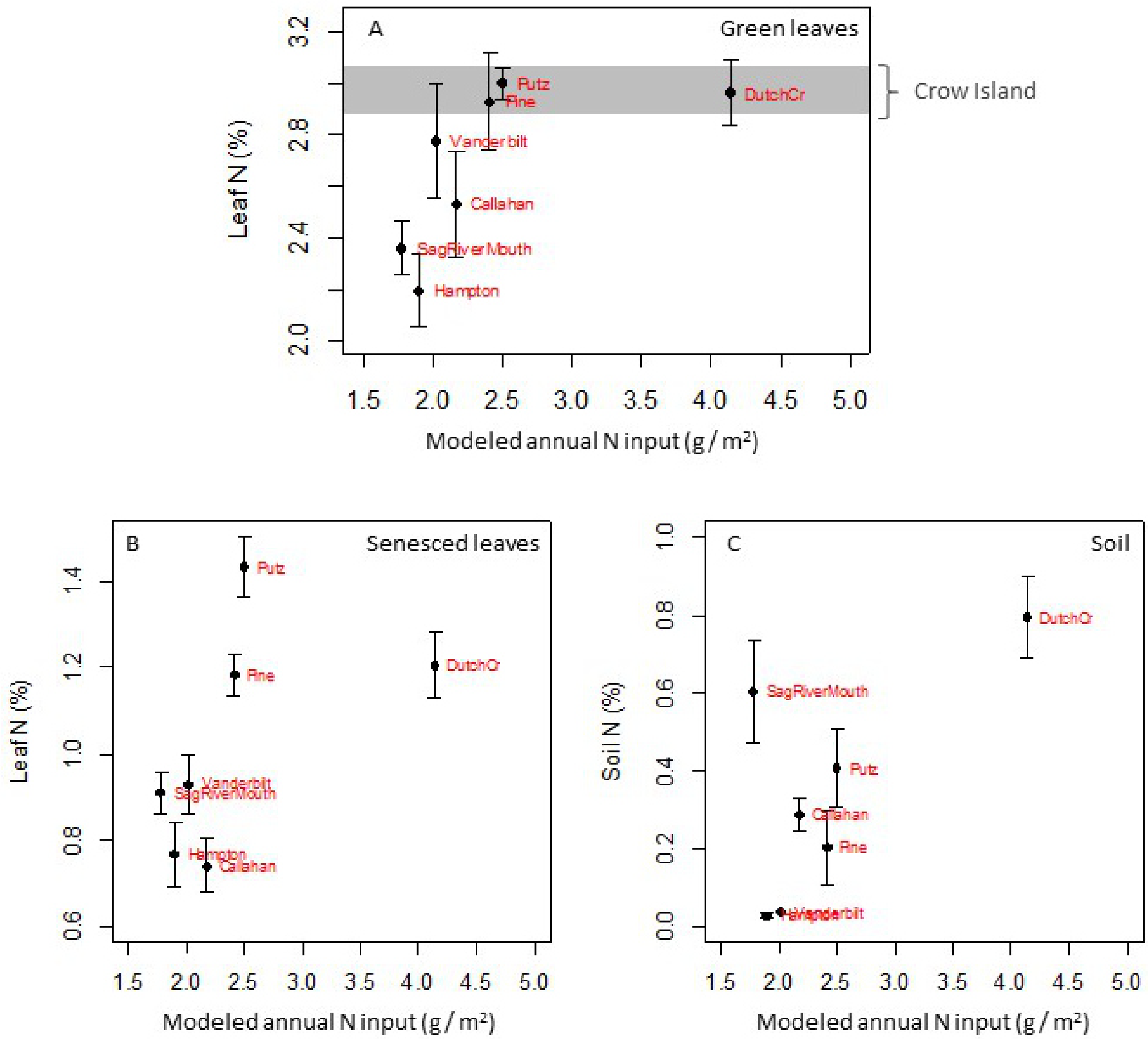


FIGURE 17: MODELED N INPUT AND A. GREEN LEAF N; B. SENESCED LEAF N; AND C. SOIL N FOR EACH OF THE SOUTHERN SAGINAW RIVER TREATED SITES FOR THIS PROJECT IN 2016 (PUTZ PARK, DUTCH CREEK, CALLAHAN) AND NORTHERN LAKE HURON SAGINAW BAY SITES TREATED UNDER MISGP FUNDING (L. OGAR – BAY COUNTY-VANDERBILT, HAMPTON, PINE RIVER, SAGANING RIVER MOUTH). POINTS SHOW A NONLINEAR RELATIONSHIP BETWEEN MODELED NITROGEN INPUT INTO WETLANDS AND *PHRAGMITES* LEAF TISSUE NITROGEN CONTENT IN THOSE WETLANDS. THE SHADED REGION INDICATES THE RANGE OF TYPICAL VALUES (MEAN +/- STANDARD ERROR) FOR *PHRAGMITES* LEAF NITROGEN CONTENT AT CROW ISLAND. WHILE ANNUAL N INPUT HAS NOT BEEN MODELED FOR THIS SITE, THE EMPIRICAL LEAF NITROGEN DATA SUGGEST HIGH NITROGEN INPUTS AT THIS SITE.

Additional leaf samples were collected from new treatment sites at Crow Island and elsewhere in late summer 2017 in order to assess the nitrogen content of *Phragmites* leaves and compare the Crow Island site to the other study sites. The range of leaf tissue N content measured at Crow Island, indicated by the shaded band in Figure 17 panel A, demonstrated high tissue N content at the Crow Island site. Because previous sites' leaf tissue N content was correlated to the modeled N inputs, these results suggest that Crow Island has high N inputs as well.

Senesced leaves (Figure 17 panel B) showed a similar overall relationship between modeled annual N input and leaf N tissue. This is expected because when N is in low supply, plants resorb a higher proportion of their leaf N during the process of leaf senescence. Thus, the senesced leaf tissue data provide further confirmation that the landscape modeling was an adequate representation of on-the-ground conditions.

Finally, soil N content also showed a generally positive trend between modeled N input and soil N (Figure 17 panel C). Whereas leaf N represents plant responses to current conditions, soil N is more accurately understood as an indicator of past conditions; soil accretion is a slow process occurring over the course of decades to centuries. These data therefore represent an effort to understand past nutrient inputs into these sites. The data also show a generally positive linear trend between modeled current N inputs and soil N, indicating that current conditions are likely a fair representation of conditions over the past decades. There is one clear outlier however; the Saginaw River Mouth site has much higher soil N than expected based on its current (modeled) N input. It is important to note that this site was not an outlier when examining leaf tissue N, indicating that modeled current conditions were still valid. The high soil N may therefore be an indication that this site received much higher N inputs in the past, or perhaps other factors have influenced past soil deposition at this particular location. Because this site contains higher N stocks, management approaches at this site may need to address this additional source of N if standard management practices are not effective alone.

MONDRIAN MODELING

USING MONDRIAN TO INFORM INITIAL SITE SELECTION AND MANAGEMENT

Results from the landscape modeling were used as site-specific inputs to the MONDRIAN model in spring 2016 in order to model site-specific outcomes of 8 potential treatment options (burning, mowing, herbicide, and all combinations thereof, or no treatment) in each of the candidate sites for restoration. We ran five stochastic replicate model runs for each treatment scenario in each site, resulting in hundreds of model runs. In all cases, we modeled the effects of one year of treatment at each site on the net primary productivity (NPP) of invasive *Phragmites* and NPP of native wetland emergent plants to determine how effectively each treatment reduced *Phragmites* NPP (expressed both in absolute terms and as a proportion of total NPP) in the first year. Based on these results, we made recommendations to the management treatment team on which sites would be most responsive to treatment, and which treatments would likely be most effective in the first year, including the likely most effective dates for treatment based on MONDRIAN model simulations. We presented these results to the group in a project meeting on July 29, 2016. Based on these recommendations and other considerations, the group worked together to select sites and treatment options and to solicit bids for implementing management treatments. For all five sites, the predicted optimal treatment approach involved fall herbicide combined with a spring or summer treatment beforehand, with the specific treatment varying from site to site. For Delta College, Callahan Road, and Crow Island, the optimal treatment was a spring burn, summer mowing, and fall herbicide (treatment #23). This was also one of the two optimal treatments identified for Dutch Creek, where fall herbicide and mowing combined with a spring burn (treatment #24) was predicted to be about equally effective at reducing *Phragmites* growth. This same treatment (treatment #24) was recommended for Ted Putz Park, but there the model predicted that combining spring and fall herbicide application (treatment #4) would be about as effective. Spring and fall herbicide was also predicted to be successful at Crow Island.

USING MONDRIAN TO INFORM FOLLOW-UP MANAGEMENT

Through questionnaires and conversations with managers in early 2017, the MONDRIAN team refined the set of possible treatments modeled in order to better reflect the types of treatments managers would want to implement. This narrowed down management approaches to two options for herbicide treatment, three options for burning, and three options for mowing (including the timing and dates of treatments). The two herbicide options were alone or with another follow-up herbicide application. The three burning options were alone, combined with follow-up burning, or combined with mowing. The three mowing options were alone, combined with burning, or combined with follow-up mowing.

We modeled all of these options, separately and in combination with each other, as well as a "no-management" control option, for each of the specific sites being managed in this project in order to provide recommendations for second-year (spring, summer and fall 2017) treatments at each site. Comparison of the outcomes of various simulated treatment options against the outcome of the no-management control case allowed us to quantify the expected effectiveness of each treatment option. This resulted in a very large number of possible treatment options (Fig. 18), so we condensed and shared our results and recommendations with the full group, including the management implementation team, through a webinar.

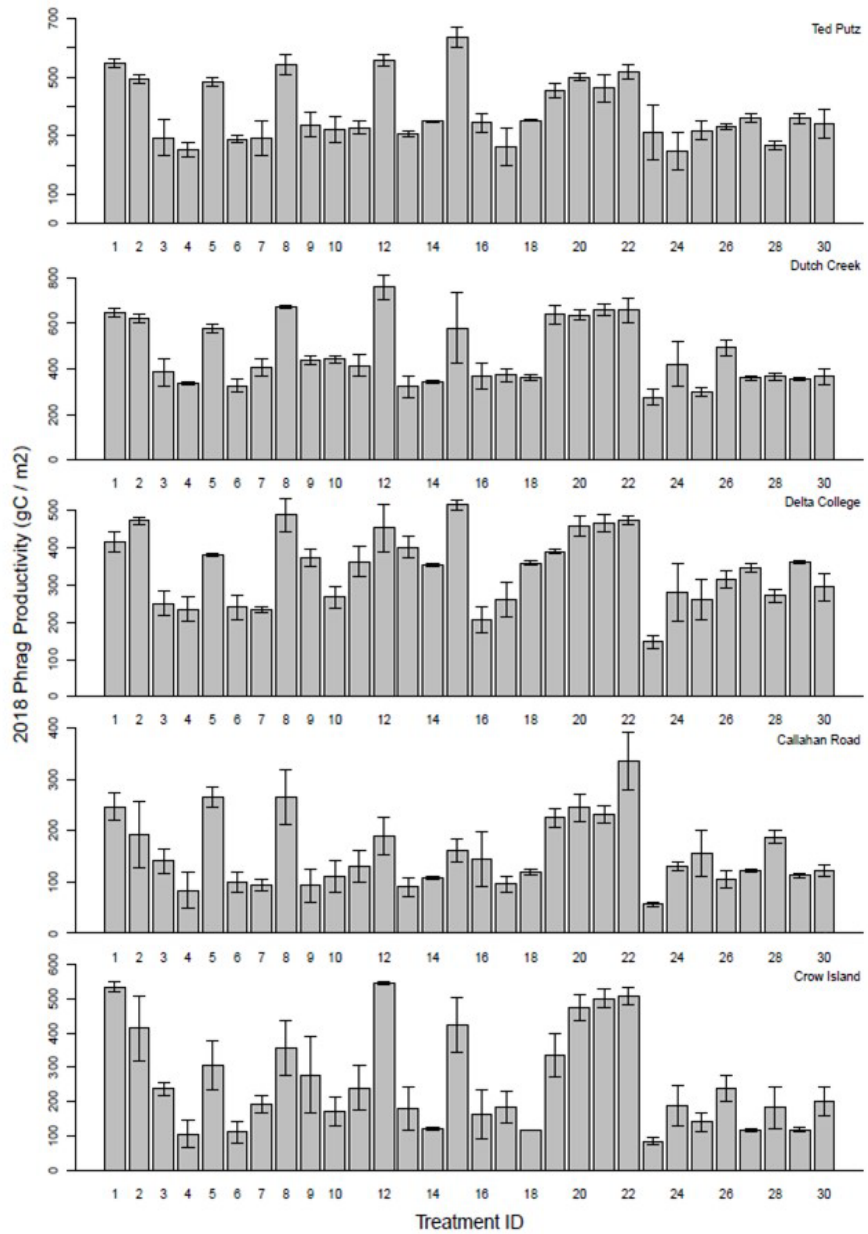


FIGURE 18: MONDRIAN PREDICTED THE SIMULATED, EXPECTED PRODUCTIVITY OF *PHRAGMITES* IN 2018 (ONE YEAR FOLLOWING MANAGEMENT TREATMENTS) FOR EACH OF THE FIVE SITES UNDER 30 DIFFERENT SIMULATED 2017 TREATMENT OPTIONS, PRIOR TO TREATMENT IN 2017. TREATMENT OPTIONS WERE: 1. CONTROL, 2. SPRING HERBICIDE, 3. FALL HERBICIDE, 4. SPRING & FALL HERBICIDE, 5. SPRING BURN + SPRING HERBICIDE, 6. SPRING BURN + FALL HERBICIDE, 7. SPRING BURN + SPRING & FALL HERBICIDE, 8. WINTER BURN + SPRING HERBICIDE, 9. WINTER BURN + FALL HERBICIDE, 10. WINTER BURN + SPRING & FALL HERBICIDE, 11. WINTER & SPRING BURN + SPRING & FALL HERBICIDE, 12. SUMMER MOW + SPRING HERBICIDE, 13. SUMMER MOW + FALL HERBICIDE, 14. SUMMER MOW (8/15) + SPRING & FALL HERBICIDE, 15. FALL MOW + SPRING HERBICIDE, 16. FALL MOW + FALL HERBICIDE, 17. FALL MOW + SPRING & FALL HERBICIDE, 18. SPRING & FALL MOW + SPRING & FALL HERBICIDE, 19. SUMMER MOW + SPRING BURN + SPRING HERBICIDE, 20. FALL MOW + SPRING BURN + SPRING HERBICIDE, 21. SUMMER MOW + WINTER BURN + SPRING HERBICIDE, 22. FALL MOW + WINTER BURN + SPRING HERBICIDE, 23. SUMMER MOW + SPRING BURN + FALL HERBICIDE, 24. FALL MOW + SPRING BURN + FALL HERBICIDE, 25. SUMMER MOW + WINTER BURN + FALL HERBICIDE, 26. FALL MOW + WINTER BURN + FALL HERBICIDE, 27. SUMMER MOW + SPRING BURN + SPRING & FALL HERBICIDE, 28. FALL MOW + SPRING BURN + SPRING & FALL HERBICIDE, 29. SUMMER MOW + WINTER BURN + SPRING & FALL HERBICIDE, 30. FALL MOW + WINTER BURN + SPRING & FALL HERBICIDE.

Developing user-friendly version of Mondrian model and Training

Model Development

Many structural changes and model developments were made to Mondrian throughout the course of this grant. These changes included:

(i) A new ability to allow seasonal or interannual changes in wetland N inflows and water levels;

(ii) The ability to simulate different lengths of the growing season to allow comparison among wetlands at different latitudes and to simulate this important effect of climate change;

(iii) the ability to simulate flooding mortality of wetland plants. The flooding mortality in the model differentiates among species, including native emergent marsh plants and invasive plant species, allowing the model to simulate the effects of changes in Great Lakes water levels on changes in plant community composition, including accelerated invasion by invasive *Phragmites*.

(iv) the ability for clonal branching architecture in the species modeled, based on plant branching traits, for both the native wetland plant species and invasive plants including *Phragmites*. The clonal branching architecture allowed a more realistic simulation of plant competition and biotic resistance of the native community to invasion under certain conditions.

All of these changes were extensively tested. The Mondrian modeling team worked together to design and a comprehensive set of test model runs in stages, and to apply the comprehensive model testing after each major model change. The model testing process both ensured the new functionality of model augmentations as well as correct, continued functionality of the pre-existing model.

User-friendly version

An important output from this project is a user-friendly version of the Mondrian community-ecosystem model of coastal Great Lakes wetlands along with a detailed and comprehensive user guide. In addition, under funding from the MISGP and EPA projects, a "look-up table" has also been produced that summarizes the results from thousands of model runs of the Mondrian plant community-ecosystem model. Through the overall grant period, we completed the following:

a) Finalized the user guide for the user friendly version of Mondrian and made it available for free download at http://williamcurrie.net/current-projects/.
b) Trained a broader range of land and wetland managers to use the Mondrian look-up table on the internet: Webinar given as part of the Great Lakes *Phragmites* Collaborative webinar series on July 25, 2018. https://youtu.be/0zdCGcKXU6I
c) Coordinated with another research group actively modeling *Phragmites* treatment options (USGS Great Lakes Science Center) to produce a user-friendly high-level summary document describing similarities and differences between the two modeling approaches. This summary document is published online and can be accessed at https://www.greatlakes*Phragmites*.net/wp-content/uploads/2018/11/PAMF_Mondrian_Comparison_11.27.18.pdf.
d) Trained a new postdoctoral scholar (funded on a separate project) and three new graduate students at the University of Michigan School for Environment and Sustainability to use the Mondrian model.

e) Developed a lecture and series of two labs for undergraduate students enrolled in a Restoration Ecology class at the University of Northern Iowa (UNI) to learn and use the MONDRIAN model. Students learned about wetland invasive plants, developed hypotheses on best approaches to invasive control under different wetland conditions, and test these hypotheses using MONDRIAN simulations. This series of labs has been useful not only to teach students and give them hands-on experience, it also helped us to identify major roadblocks and obstacles with the model for inexperienced beginning users. Following the testing of the undergraduate classroom use of MONDRIAN at UNI, it was used in an undergraduate class at the University of Michigan, Environ 305 Sustainability Issues in the Great Lakes Region.

MONDRIAN LOOK-UP TABLE

In addition to making use of the full version of the MONDRIAN model more accessible, we also made a wide array of model outcomes accessible to users who do not have the ability or do not wish to run the full model. These results are accessible online as a "look-up table" accompanied by a front-end user interface, instructions, and website. This lookup table can be accessed at https://phraglut.mtri.org. The site has been visited by 41 unique users from the United States and Canada since we began tracking this metric in July 2018; unfortunately this number does not capture all unique users because tracking began several months after the site was initiated and advertised.

4. OUTREACH AND STAKEHOLDER INPUT

EARLY DETECTION AND ALERT SYSTEM

MNFI worked with the MISIN and the Saginaw Bay CISMA to develop a ***Saginaw Bay Watchers*** Project on the MISIN Web Site (https://www.misin.msu.edu/projects/saginawbaywatchers/), where early detectors for the Bay can log on and report detections of new infestations of *Phragmites* and high threat secondary invaders in the region. The program was unveiled at the Saginaw Bay CISMA annual meeting on July 11, 2017 in a presentation on the EPA *Phragmites* project and the importance of early detection of invasions, the threat of secondary invaders after *Phragmites* treatment, and how citizens can help. Additional public outreach was provided at two CISMA coordinated flowering rush workshops in Bay City and Saginaw on October 4th and 23rd. These presentations provided an overview of the invasion curve, the importance of early detection and priority species to look for and report. Specific instructions were also provided for using the MISIN website and their phone apps to report invasive species sightings, and how to use the invasive species identification modules. These introductions led into a discussion about a USFS-funded project to map and treat flowering rush along a stretch of the Saginaw River. Excerpts from the web page for the Early Detection and Alert System are shown below in Figure 18. The featured priority species include flowering rush, European frog-bit, water hyacinth, and water lettuce, all of which have been documented in SE Michigan. The latter two have not yet been confirmed overwintering in Michigan, but have been found in significant numbers during the growing season and are thought to originate from water gardens.

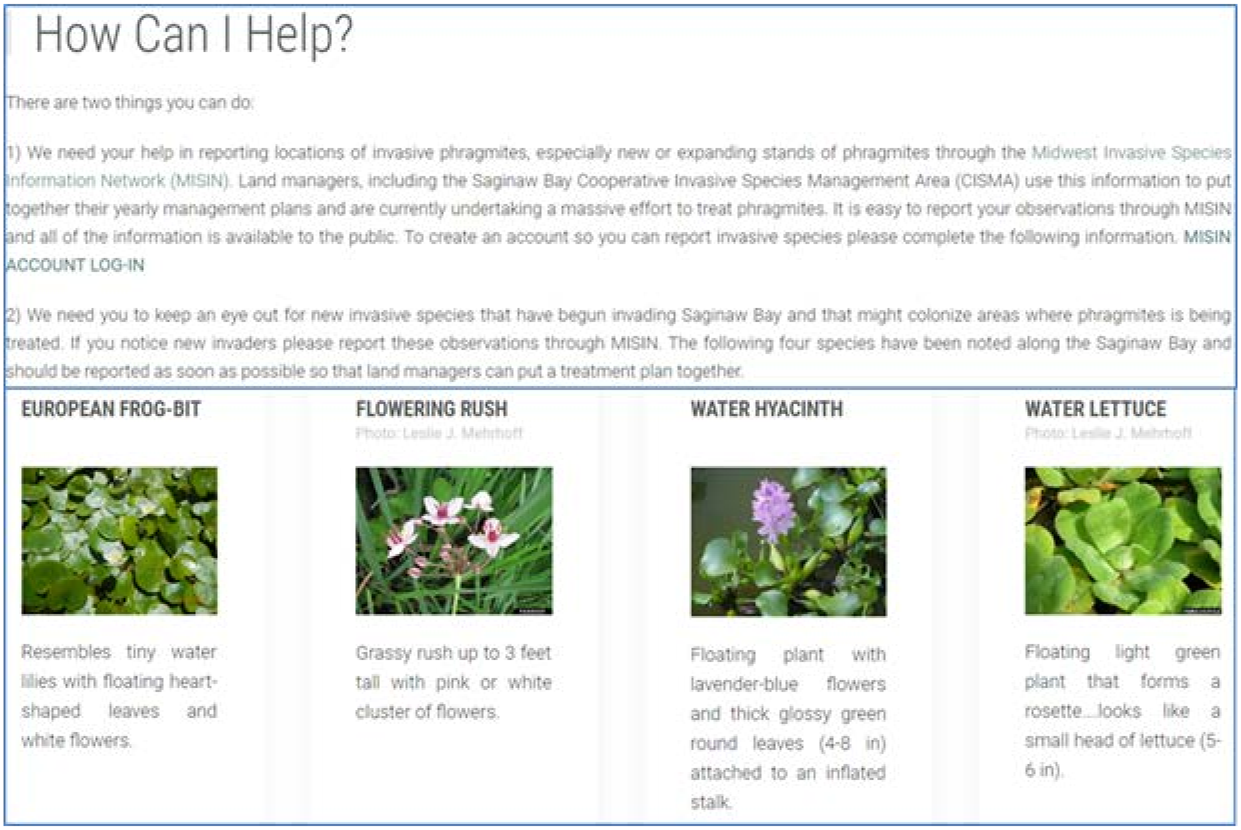


FIGURE 18. EXCERPTS FROM THE SAGINAW BAY WATCHERS MISN WEBSITE, WHERE EARLY DETECTORS FOR THE BAY CAN LOG ON AND REPORT DETECTIONS OF NEW INFESTATIONS OF *PHRAGMITES* AND HIGH THREAT SECONDARY INVADERS IN THE REGION

STAKEHOLDER WORKSHOP

A summary of the stakeholder meeting convened on February 1, 2017 has been completed and is provided in Appendix E. The purpose of the meeting was to gather insights from current practitioners about managing invasive *Phragmites.* Thirty-two practitioners attended the workshop including wetland managers from Saginaw Bay and other regions of the Great Lakes (e.g. USFWS, MDNR, MDEQ and USGS representatives working on *Phragmites* control (Appendix E - Table 7)). The intent was to obtain input from practitioners with real-life experiences treating *Phragmites* to help inform and improve currently published best control practices and to identify gaps in information. The workshop was focused on 4 key topic areas: 1) measures of success and monitoring; 2) prioritizing management action and sustaining management over time; 3) control methods and unintended impacts; and 4) pathways, re-invasion, secondary invasion and decontamination.

Website, Publications and Presentations

Websites

1. Project website: http://mtri.org/*Phragmites*wetlandmanagementandscience.html Changes to this website are under development to improve the communication of this complex multi-faceted project. It will also include the Appendices of this report.

2. High resolution *Phragmites* distribution map of the Saginaw Bay coastal zone wetlands has been posted to the website: http://geodjango.mtri.org/coastal-wetlands/ This map allows for pre-treatment *Phragmites* extent estimation in the coastal Saginaw Bay from 2016 Worldview 2 imagery. It was used by the SB-CISMA and other stakeholders to define new areas for treatment, including the Knodt Road area that was treated in Fall 2018. *Note that the webpage also displays the binational coastal wetlands map from circa 2010 SAR-Optical satellite imagery at 0.2 ha minimum mapping unit. MTU will also be posting an update to the SAR-Optical satellite-based map using circa 2016 imagery also funded by GLRI through USGS Great Lakes Science Lab*.
3. Connectivity Modeling Website. The web mapping application for displaying landscape connectivity modeling outputs, including where to target installation of riparian buffers is here http://spatial.mtri.org/phrag-viewer/.
4. MONDRIAN *Phragmites* Management Tool http://phraglut.mtri.org/ A simplified version of the MONDRIAN model to aid stakeholders in decision making
   - The MONDRIAN -PAMF comparison document is listed on the PAMF page under the resources tab. A link to the document also went out in the PAMF fall/winter newsletter. https://www.greatlakes*Phragmites*.net/wp-content/uploads/2018/11/PAMF_Mondrian_Comparison_11.27.18.pdf
5. User friendly version of MONDRIAN is available for free download at http://williamcurrie.net/current-projects/

Peer-Review Articles & Manuscripts

Two manuscripts have been published

- Billmire, M., B. Koziol. (2018). Landscape and flow path-based nutrient loading metrics for evaluation of in-stream water quality in Saginaw Bay, Michigan. Journal of Great Lakes Research 44 (5): 1068-1080.
- Elgersma, K.J., J.P. Martina, W.S. Currie, and D.E. Goldberg. 2017. Effectiveness of cattail (Typha spp.) management techniques depends on exogenous nitrogen inputs. Elementa: Science of the Anthropocene (5): 19. DOI: http://doi.org/10.1525/elementa.147.

***Two manuscripts are being written based on this work**.* The first manuscript in preparation is on the comparison of monitoring methods and biodiversity analysis pre- and post-treatment (Grimm et al. in prep). The second focuses on the integration of the modeling, monitoring and management from an adaptive management perspective (Currie et al. in prep).

- Grimm, A., L. Bourgeau-Chavez, S. Grelik, P. Higman, E. Schaefer. (in prep). Comparing wetland monitoring protocols for assessing the effects of *Phragmites* treatment on wetland biodiversity.
- Currie, W. S., J. Martina, K. Elgersma, S. Sharp, M. Vanderhaar, and P. Higman. (in prep.) Wetland process modeling and remote sensing in the development of an adaptive management framework: Restoration of *Phragmites*-invaded coastal wetlands in the Great Lakes region. To be submitted June 2019 for a special issue of Ecological Informatics entitled "Environmental Modelling and Adaptive Management Implementation".

Online Article/Press Release

http://www.mtu.edu/news/stories/2016/august/fighting-invasive-species-michigan.html

Conference Presentations and Workshops

1. ***Stakeholder Workshop February 2, 2017 – Kiva, Michigan Tech Research Institute, Ann Arbor, MI*** This was an interactive workshop with stakeholders and practitioners on *Phragmites* control (see Stakeholder Report in Appendix E)
2. ***An interactive session at The Stewardship Network's "The Science, Practice and Art of Restoring Native Ecosystems 2018" in East Lansing MI*** Three presentations on work accomplished from this project were made at the conference in East Lansing, MI on January 12, 2018 during the interactive session titled "Sharing Insights on Invasive *Phragmites* Management". Co-Is Higman, Currie, and Bourgeau-Chavez each gave short presentations and fielded questions from the participants.
   A) Co-I, Phyllis Higman presented on implementing adaptive management and monitoring towards the goal of restoration of wetlands invaded by *Phragmites*.
   B) The MONDRIAN modeling team gave a presentation on their modeling of *Phragmites* invasion and management scenarios for wetland restoration. Co-I Bill Currie delivered the oral presentation.
   C) PI Laura Bourgeau-Chavez presented on the remote monitoring at multiple scales (from UAV to satellite).
3. ***Two presentations at the International Association of Great Lakes Research (IAGLR) conference in Toronto, ON, CA, 18-22 June 2018***
   A) Grimm, A., Bourgeau-Chavez, L. Endres, S., Brooks, C., Higman, P. Schaefer, E. (2018). Comparing wetland field protocols for practical, informative monitoring of invasive species.
   B) Bourgeau-Chavez, P. Higman., A. Grimm, S.L. Endres 2018. Developing a Framework for Monitoring Coastal Wetlands with High Resolution Satellite Imagery
4. ***Presentation at the Wetlands Remote Sensing State of Science Workshop, International Joint Commission, March 26-27, 2018, Burlington, ON Canada***
   A) Bourgeau-Chavez, L.L., and M.J. Battaglia. Mapping and Monitoring the U.S. and Canadian Coastal Great Lakes Wetlands.
5. ***Presentation at the 39th Canadian Symposium on Remote Sensing (CSRS2018) held on***

19-21 June in Saskatoon, Saskatchewan, Canada

A) Battaglia, M.J., L.L. Bourgeau-Chavez, Invasive Species Monitoring in the Great Lakes.

6. ***Presentation at the State of Lake Superior Conference. Houghton, MI. 9-12 October 2018.***

   A) Bourgeau-Chavez, L.L., M. J. Battaglia, A. Grimm, M.E. Miller. 2018. Monitoring Coastal Wetland Types and Invasive Plants with High Resolution Satellite Imagery.

7. ***Presented project results on monitoring to a graduate level class at University of Michigan, Ann Arbor Campus on November 06, 2017. "Remote Sensing for decision support" in course "NRE 639: Coastal Wetlands of the Great Lakes: Ecology and Management"***

   PI, Bourgeau-Chavez gave a presentation on the satellite and UAV imagery used for monitoring in this research to the NRE 639 class. The presentation was followed with an hour long discussion of the use of remote sensing for decision support of *Phragmites* management.

8. ***Presented on Early Detection and Alert System***

   The development of the Saginaw Bay-Watchers Early Detection and Alert System was previewed at the Annual CISMA meeting at Bay City State Park on July 11, 2017. Two additional presentations were given after completion; oneein Bay City on 10/4/17 and one in Saginaw on 10/12/17. See Early Detection and Alert System,

9. ***Three oral presentations in the special session on "Binational and regional cooperation on invasive plant management - the case of Phragmites" at the International Association of Great Lakes Research (IAGLR) conference in Detroit, MI, 15-19 May 2017***

   A. Higman, P.J., L.L. Bourgeau-Chavez, K.J. Elgersma, W.S. Currie, K.R. Cronk, and M.A. Vander Haar. *Implementing Adaptive Management and Monitoring for Restoration of Wetlands Invaded by Phragmites* Oral presentation, International Association of Great Lakes Researchers (IAGLR), Detroit, MI, May 15-19, 2017.
   B. Currie, W.S., K. J. Elgersma, J. P. Martina, and L.L. Bourgeau-Chavez. *The* MONDRIAN *Model: a Tool to Develop an Adaptive Management Framework to Restore Invaded Wetlands* Oral presentation, International Association of Great Lakes Researchers (IAGLR), Detroit, MI, May 15-19, 2017.
   C. Bourgeau-Chavez, L.L., Endres, S.L, Brooks, C.N., Serocki, E., Carlson, J., Wang, F. Battaglia, M.J., and Higman, P.J. *Monitoring the Control of Invasive Phragmites australis to Inform Adaptive Management* IAGLR 2017, Detroit, MI May 15-19.

WEBINARS HOSTED AND COMING SOON THROUGH THE GREAT LAKES *PHRAGMITES* COLLABORATIVE

A. Currie, WS, JP Martina, & KJ Elgersma. 2018. *A primer on the user-friendly MONDRIAN model for wetland ecology and invasive species management. July 25, 2018.* https://youtu.be/0zdCGcKXU6I

B. Grimm, A., Higman, P. and L. Bourgeau-Chavez. Spring 2019. *Evaluation of monitoring protocols for assessing effectiveness of Invasive Phragmites treatments. TBA.*

UNIVERSITY COURSE MATERIAL

1. **University of Northern Iowa**: Designed / implemented a Biostatistics lab for students at Univ. of Northern Iowa to understand and interpret MONDRIAN model results
2. **University of Northern Iowa**: Designed / implemented a lecture and a series of two labs in a Restoration Ecology class for students at Univ. of Northern Iowa to understand wetland invasion dynamics, develop hypotheses about invasion and managing invasive species, and test these hypotheses using MONDRIAN.
3. **Texas A&M**: Martina presented two guest lectures on the management practices of *Phragmites* and *Typha* in the Great Lakes region to an introduction to ecology course for non-majors (Title: Ecological principles of conservation and management) and a wetland ecology course for majors (Title: Adaptive management of invasive species) at Texas A&M University, College Station, TX.
4. **University of Michigan**. Currie used the MONDRIAN model and its role in this project as a case study in a graduate course in Applied Ecosystem Modeling, winter term 2017. Currie also used the MONDRIAN model and its role in this project as a case study in the undergraduate course Environ 305, Sustainability Issues in the Great Lakes Region, fall 2018.

QUARTERLY WEBINARS

Quarterly webinars were hosted by MTU-MTRI to keep the teams and stakeholders of Saginaw Bay apprised of the work accomplished and outcomes and to gain local knowledge and feed back. Participants included stakeholders and project team members including MISGP teams, SB-CISMA, USFWS, MDNR, UM, UNI, Texas A&M, Bay County, MSU-MNFI, MTU-MTRI. The final webinar was held the second week of February 2019 with A. Grimm presenting the results of the Analysis of Monitoring Data.

5. LONG-TERM COMPREHENSIVE *PHRAGMITES* MANAGEMENT STRATEGY

Plant invasions are triggered by interacting factors of disturbance, nutrients (e.g. from agricultural runoff) and nearby invasive plant presence (Colautti *et al.* 2006), including *Phragmites* and new invaders that continue to arrive over time. The best approach for *Phragmites* management across a region such as the Saginaw Bay is at the watershed scale. Ideally, both the source of the problem, nutrient loading, and the symptom, *Phragmites* invasion, should be addressed at the same time. However, we recognize that this can be challenging logistically, economically and politically, and near-term control actions will be needed while long-term abatement of causes progresses. Land use changes and increasing nutrients, particularly the limiting nutrient nitrogen (N), have been documented as causational to large, perennial clonal species such as *Phragmites*, *Typha* and other non-native plant invasions (Currie et al. 2014, Kettenring et al. 2011, King *et al.* 2007, Martina et al. 2016, Silliman and Bertness 2004). Currie et al. 2014 and Martina et al. 2016 have shown that above a threshold of N loading of 4 $g/m^2/yr$, the invasive plants, *Phragmites* and *Typha* angustifolia, and *T*. X*glauca*., are able to outcompete native plants and grow to extreme heights and densities. As long as N pollution continues to be a problem, efforts to control invasive plants like *Phragmites* will be ongoing and costly, with repeated reinfestations of either the problem plant or a secondary invader.

A prototype solution to ultimately improve ecological health of coastal wetlands is an integrative approach to control the invasive plants, restore wetland habitat and improve water quality by holistically treating the entire watershed. Within the watershed, individual invasions need to be assessed for site specific conditions and treatment plans designed accordingly. Best treatments vary by site specific conditions and need to be assessed annually. It is critical to monitor treated sites and conduct follow-up treatments as needed, applying an adaptive management strategy. The whole watershed prototype includes measuring and modeling N loading, working to improve water quality and reduce nitrogen pollution to below the threshold of 4 $g/m^2/yr$ and further developing and implementing wetland ecosystem modeling tools (MONDRIAN [this study}and PAMF [GLC et al. 2017]). These tools are needed for determining the best site-specific treatment scenarios, including the timing and sequence of methods (herbicide, mowing, biomass removal, burning, etc.). Best treatment practices are not one size fits all, but vary by water levels, N-loading, stand age and distribution of invaders surrounding the site (Elgersma et al 2017).

The guiding principles below are suggested with emphasis on knowing your landscape and site conditions, setting goals for what success will look like and implementing adaptive management. Monitoring is critical to assess your site pre-treatment and for follow-up assessment and treatment plans. Long-term data sets are particularly important to inform models.

GUIDING PRINCIPLES:

- Learn the entire Saginaw Bay landscape and integrate prioritization, management and monitoring with the CISMAs and other partners to achieve the desired goals.
- Take a watershed approach and work to install buffers or implement other practices to reduce N loading while treating *Phragmites*. See website for strategic location of buffers based on hydrologic connectivity modeling http://spatial.mtri.org/phrag-viewer/
- Use principles of adaptive management:
    - Set management goals and define the desired future condition before treatment begins.
    - Plan treatment and monitoring for multiple years into the future.
    - Conduct pre- and post-monitoring; this will depend on budgets, but the management goals should define the level and specific measurable parameters of monitoring. implement adaptive management based on monitoring results.
    - Share results widely to improve *Phragmites* management region wide and broaden support from scientists, funders and the public.
- Prioritize:
    - Evaluate *Phragmites* invasion at landscape, regional and local scales before prioritizing; involve stakeholders where possible.
    - Use informative data layers (maps of *Phragmites* distribution, high value and priority sites including high quality natural communities and rare species occurrences, MONDRIAN modeling and look-up table, PAMF treatment recommendations, invasion pathways, Great Lakes decision support tools) effectively in advance of selecting treatment areas.
    - Use MDEQ *Phragmites* prioritization tool to help select treatment areas.

    - Size, quality and desired condition, safety, aesthetics, recreation, adjacency of treatments.
  - Consider outliers, pathways and sources.
    - Control outliers first to stop them from expanding; (strong evidence for greater genetic diversity and increased viable seed production in outliers - Kettenring et al. 2016, Hazleton et al. 2015, Kettenring et al. 2011, McCormick et al. 2010).
    - Block pathways, minimize/eliminate sources where feasible (cost-effective approach).
    - Push large infestations from leading edges towards their centers.
  - Consider unanticipated outcomes including secondary invasions; e.g., will *Phragmites* treatment alter hydrology of adjacent high-quality lakeplain prairie, is flowering rush or European frog-bit in the surrounding area?).
  - Assess feasibility and likelihood of management success (adequate knowledge and resources); don't focus resources where success is not likely.
  - Update maps and other resources frequently based on new knowledge gained.

- Understand and consider the role of nitrogen.
  - Work with partners to reduce inputs into the basin (plant buffer strips, two-stage ditches, etc.).
  - Prioritize control of sites where nitrogen levels are low (not facilitating *Phragmites* expansion) so that native species can compete effectively.

- Stakeholder collaboration and support:
  - Educate all landowners and partners on the deterioration of wetlands, habitat, recreational access, aesthetics, and property values from invasion.
  - Showcase successful control efforts including pre- and post-treatment comparisons.
  - Consider cost-sharing options, especially for first time treatments which are often cost-prohibitive for private landowners.
  - Consider millage or other methods of attaining adequate funding for treatment.

- Stay abreast of scientific literature:
  - Consider and evaluate novel approaches and tools (e.g. different chemicals, endophytes, gene silencing, biocontrol), new understanding of mechanisms of invasion, and modes of nutrient reduction, frequently;

- Be prepared to seize opportunities:
  - Budgets, people and environments are unpredictable; if a new unplanned opportunity arises that meets treatment criteria, consider it by conducting a risk-benefit assessment.

- Be prepared to shift priorities and management approach if treatment is unsuccessful.

STRATEGY:

I. Know your Landscape and the distribution of *Phragmites* across the region; prepare data layers

A. Map *Phragmites* throughout basin using high resolution imagery (e.g. WorldView, air photos, RapidEye or other source); Ideally need resolution of 2 m or better; 5 m resolution maximum to detect outliers and leading edges (Bourgeau-Chavez *et al.* 2016, see table 7 below); apply to all watersheds leading to Saginaw Bay.
B. Identify and map high value and priority areas within each watershed (biodiversity, cultural, economic, public visibility, public access, pathways of spread).
C. Identify and map nitrogen levels (high, med, low) throughout basin.
D. Identify and map landscape connectivity throughout basin (This was completed for the entire basin under the EPA grant to Bourgeau-Chavez and is located on this website: http://spatial.mtri.org/phrag-viewer/
E. Identify and assess high to low restorability sites using tools such as the Great Lakes Coastal Wetland Decisions Support Tool (GLCWDST) or the Great Lakes Coastal Wetland Restoration Assessments: https://www.greatlakeswetlands.org/DST/Home.vbhtml ; https://lccnetwork.org/resource/great-lakes-coastal-wetland-restoration-assessments

PRIORITIZE TREATMENT AREAS BY WATERSHED

A. PHRAGMITES OUTLIERS

a. Set management goals and identify what constitutes success, e.g., for this study:
    i. Determine goals based upon desired future condition.
    ii. Desirable future condition may be determined from historical cover but could differ depending upon site conditions and goals.
b. Example: [X]% *Phragmites* kill; [X]% desirable species; [X]% undesirable species.Use MONDRIAN tool to determine best treatment method for specific site conditions https://sites.google.com/uni.edu/phragmiteslookuptable For sites that are enrolled in PAMF, compare treatment recommendations to inform decision-making.
c. Conduct pre-monitoring at the site scale; determine what level of information is needed based on management goals; biodiversity for habitat restoration (Tier 3) or minimally percent *Phragmites* kill (Tier 1) or something in between or more specific to management goals, such as the change in breeding birds using the site.
d. Treat outliers using site specific treatment prescription.
e. Conduct post-monitoring at the same Tier as pre-treatment, assess site condition, determine success of treatment.
f. Adapt management based on monitoring results and MONDRIAN tool recommendations, and re-treat if needed; re-assess management goals. For sites that are enrolled in PAMF, compare treatment recommendations to inform decision-making.
g. Repeat sequence until management goals are achieved or shift priorities if management is not likely to succeed.

B. High value areas with high restorability and low nitrogen levels (ecological, social, economic, public visibility & access, pathways of dispersal),

a. Set management goals:

   i. Determine goals based upon desired future condition.

   ii. Desirable future condition may be determined from historical cover but could differ depending upon site conditions and goals.

   iii. Example: [X]% *Phragmites* kill; [X]% desirable species; [X]% undesirable species.

b. Use Mondrian tool to determine best treatment method for specific site conditions https://sites.google.com/uni.edu/phragmiteslookuptable For sites that are enrolled in PAMF, compare treatment recommendations to inform decision-making.

c. Conduct pre-monitoring at the site scale; determine what level of information is needed based on management goals; e.g., biodiversity for habitat restoration (Tier 3) or minimally percent *Phragmites* kill (Tier 1) or something in between or more specific to management goals such as change in breeding birds using the site.

d. Consider whether success is likely; if not, reconsider management goals.

e. If success is likely, implement treatment using site specific treatment prescription.

f. Conduct post-monitoring at the same Tier as pre-treatment, assess site condition, determine success of treatment.

g. Adapt management based on monitoring results and Mondrian tool, and re-treat if needed; re-assess management goals. For sites that are enrolled in PAMF, compare treatment recommendations to inform decision-making.

h. Repeat sequence until management goals are achieved or shift priorities if management is not likely to succeed.

C. High value areas with moderate restorability and low to medium nitrogen levels

a. Set management goals

   i. Determine goals based upon desired future condition.

   ii. Desirable future condition may be determined from historical cover but could differ depending upon site conditions and goals.

   iii. [X]% *Phragmites* kill; [X]% desirable species; [X]% undesirable species.

b. Use Mondrian tool to determine best treatment method for specific site conditions https://sites.google.com/uni.edu/phragmiteslookuptable For sites that are enrolled in PAMF, compare treatment recommendations to inform decision-making.

c. Conduct pre-monitoring at the field scale; determine what level of information is needed based on management goals: biodiversity for habitat restoration (Tier 3) or minimally percent *Phragmites* kill (Tier 1) or something in between or more specific to management goals such change in breeding birds using the site.

d. Consider whether success is likely, if not, reconsider management goals.

e. Conduct post-monitoring at the same Tier as pre-treatment, assess site condition, determine success of treatment.

f. Adapt management based on monitoring results and MONDRIAN tool, and re-treat if needed; re-assess management goals. For sites that are enrolled in PAMF, compare treatment recommendations to inform decision-making.

g. Repeat sequence until management goals are achieved or shift priorities if management is not likely to succeed.

C. HIGH VALUE AREAS WITH LOW RESTORABILITY AND HIGH NITROGEN LEVELS (TO MAINTAIN GENETIC DIVERSITY UNTIL N LEVELS ARE REDUCED AND/OR BETTER TREATMENTS BECOME AVAILABLE)

a. Consider if it is an exceptionally high value area where minimizing devastating levels of infestation is likely to sustain important native gene pools; if so, move to next step; if not, move to step g.

b. Set management goal (what constitutes success)

   i. Determine goals based upon desired future condition.

   ii. Desirable future condition may be determined from historical cover but could differ depending upon site conditions and goals.

   iii. [X]% *Phragmites* kill; [X]% desirable species; [X]% undesirable species

c. Use Mondrian tool to determine best treatment method for specific site conditions https://sites.google.com/uni.edu/phragmiteslookuptable For sites that are enrolled in PAMF, compare treatment recommendations to inform decision-making.

d. Conduct pre-monitoring at the site scale; determine what level of information is needed based on management goals; e.g., biodiversity for habitat restoration (Tier 3) or minimally percent *Phragmites* kill (Tier 1) or something in between or more specific to management goals such as change in the number of breeding birds using the site.

e. Consider whether success is likely; if not, reconsider management goals.

f. If success is likely, implement treatment using site-specific treatment prescription.

g. Conduct post-monitoring at the same Tier as pre-treatment, assess site condition, determine success of treatment.

h. Adapt management based on monitoring results and Mondrian tool, and re-treat if needed; re-assess management goals. For sites that are enrolled in PAMF, compare treatment recommendations to inform decision-making.

i. If management is not likely to sustain genetic pools or has undesirable impacts, use funds for education, promoting and installing buggers or other means of nitrogen reduction instead of treatment.

TABLE 7. REMOTE SENSING FOR MONITORING GUIDE FROM BOURGEAU-CHAVEZ 2016.

	Field Surveys	**Aerial Imaging**	**World-view 2**	**Rapid Eye/ Radarsat-2**	**Landsat/ PALSAR-2**
Use for…	- Assessing species diversity changes - Ground-truth of remote sensing data	- Planning treatment strategies - Monitoring effects of treatment - Implementing adaptive management	- Planning treatment strategies - Monitoring effects of treatment - Implementing adaptive management	- Planning treatment strategies - Monitoring effects of treatment - Implementing adaptive management	Quick, large-scale mapping to understand broadscale distribution of *Phragmites* invasion
Capabilities	- Make direct observations	- Determine location and percentage of *Phragmites* - Measure *Phragmites* within "mixed stands" - Determine if *Phragmites* is live, standing dead, or detritus	- Determine location and percentage of *Phragmites* - Determine if *Phragmites* is live, standing dead, or detritus	- Determine location of *Phragmites* patches	- Determine landscape-level distribution of *Phragmites*
Timeliness/ Limitations	-	Collection plans	Cloud cover and satellite orbits	Cloud cover and satellite orbits	Cloud cover and satellite orbits/collection plans
Resolution; MMU	-	15 cm; 15 cm	0.6 - 1.85 m; 2 m	5-8 m; 0.05 ha	10-30 m; 0.12 ha
Capture Leading Edges?	-	All	Many	Many	Some
Cost of Imagery	-	$31.11/km^2$	Free for Federal Agencies, Otherwise: $19/km^2$ *min. 25km²*	Rapid Eye: $1.17/km^2$ *min. 625km²* RADARSAT-2: $0.93/km^2$ *min. 4500 km²*	Landsat - Free; PALSAR-2: $0.71/km^2$ *min.4000 km²*

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