STATE:	Michigan	
GRANT TITLE:	Comprehensive Invasive *Phragmites* Management Planning	
REPORT TYPE:	Final Performance Report - IS15-5004	
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Final Summary

The main goal of this project was to create an adaptive management plan for invasive *Phragmites* control that applies specific treatment techniques and time intervals (e.g., herbicide and cutting/burning schedule, and riparian buffering) based upon specific site conditions. We did this by integrating local and regional knowledge, high-resolution maps from remote sensing data, and modeling of nitrogen (N) loading and hydrological connectivity to identify the best *Phragmites* treatment and monitoring strategies. The outputs of this grant are products of multi-disciplinary integrative efforts between four universities (U Michigan, MSU, Texas A&M, and U Northern Iowa), USFWS, MDNR and the SB-CISMA.

Under this grant we have:

1) Researched and compiled information on the best treatment and monitoring protocols (Appendices 1 & 2);
2) Assembled an array of simple to complex protocols for monitoring in the field and compared costs, effort, and level of expertise needed (Table 1, Appendix 2);
3) Evaluated unmanned aerial vehicles (UAVs) for sampling in lieu of field collection, compared the information gained to field-sampled data (Table 1), and provided a report on lessons learned (section e);
4) Conducted analyses of multiple field-measured variables from the assembled monitoring protocols to understand the metrics collected 1 year post-treatment and how the data obtained from less intensive protocols compare to full biodiversity analyses, with implications for the most suitable protocols for different management goals (section k);
5) Developed a quick reference look-up table tool to aid managers in using MONDRIAN (Modes Of Nonlinear Dynamics, Resource Interactions, And Nutrient cycling) wetland ecosystem simulation model results to choose from 11 combinations of treatment strategies for their specific site conditions (**https://sites.google.com/uni.edu/phragmiteslookuptable**);
6) Conducted landscape modeling to determine the nitrogen loading of treatment sites for input into MONDRIAN and to conducted a riparian buffer analysis for the watersheds draining to our treatment sites (sections h and g; Billmire et al. 2018 in press);
7) Compared field sampled nitrogen to modeled results for validation (section i).
8) Modeled various treatment outcomes for our four treatment sites (Vanderbilt, Saganing River, Hampton, and Pine River) and provided management recommendations (section j);
9) Reviewed historical (1938 to present, Appendix 5) aerial imagery of these 4 sites to determine pre-invasion ecosystem type (wetland, beach, open water, etc.);

10) Mapped all sites with current pre-treatment (Worldview-2 August 2016) imagery as well as post-treatment imagery for the Hampton site (Figure 2; July 2017; cloud-free imagery was not available for other sites);
11) Tied management goals, treatments and monitoring protocols together for adaptive management approach (Appendix 3); and
12) Created a strategic plan with guiding principles for control of *Phragmites* for Saginaw Bay (Appendix 4).

Discussion of Accomplishments

Each of the tasks with accomplishments met during the course of this project is described below. Field photos and relevant figures and maps are attached as TIFs or JPEGs in a zip file. A table (Table 4) summarizing each task is presented at the end of Section 1 (status of project tasks). A summary of outreach activities, including press releases, peer-reviewed articles, conference presentations and websites and web viewers is listed at the end of the report.

1. Project Tasks Completed and Progress on Grant Goals

This project was focused on developing monitoring and modeling tools to aid in the adaptive management of the invasive plant *Phragmites australis* in the Saginaw Bay area. It was coupled with a sister grant to Bay County (PI-L. Ogar), which applied treatments and control to the four focus sites (Figure 1). The idea was to create a comprehensive *Phragmites* management plan for Saginaw Bay that both included adaptive management techniques and assessed individual site conditions and site-specific treatments. This project integrates landscape modeling of nutrients, wetland ecosystem modeling that includes management activities (e.g. herbicide, burning, mowing), local knowledge, and monitoring expertise from field and remote sensing.

We began the project by sitting down with local wetland managers to develop a working definition of success in terms of *Phragmites* management. Managers need to know ahead of time what their goals in *Phragmites* management are and thus when their efforts are successful. Then, we focused on developing monitoring plans for adaptive management, realizing that different managers have different goals, needs, and resources. For this component of the project, we needed to set up a comparison of monitoring techniques from remote sensing and field sampling that included estimates of information gained as well as equipment, expertise, and time requirements. We developed and tested three field monitoring protocols, ranging from a relatively simple photo-monitoring and questionnaire method (Tier 1, see section c for a full description of the 3 tiered protocols), with minimal effort and training required, to the most difficult (Tier 3) requiring botanical expertise along with significantly more time and effort. We also trained ten people in the monitoring protocols; four SB-CISMA monitoring staff implemented the protocols for this project with assistance from four MNFI and MTRI staff. We supplemented field monitoring activities with unmanned aerial vehicle (UAV) collections, conducted

Figure 1. Overview of treatment site locations from north to southeast: Pine River, Saganing River, Hampton, and Vanderbilt.

by certified unmanned pilots, over sites that were deemed too hazardous and too time-consuming for on-the-ground sampling. This allowed us to assess the utility of UAV data for monitoring - something that was not in the original proposed plan. This is a highly beneficial addition to the evaluation of various on-the-ground monitoring approaches since it is becoming increasingly available and more widely used. Further, by applying similar monitoring protocols developed for the MISGP sites to a concurrent EPA-funded project, which was focused on a study area in the proximity of the Saginaw River, south of the MISGP project, we were able to increase the treatment area sample size for greater statistical power in assessing treatment effects (including biodiversity comparisons pre- and post-treatment), information gained, and costs. This paired analysis also allowed for comparison between sites treated with glyphosate alone with the Cygnet Plus surfactant, then mowed (EPA project), and sites treated with glyphosate plus imazapyr and not mowed before the post-treatment field data were collected (this project). Some mowing was accomplished at the Ogar-led MISGP sites later and these data will be collected and analyzed for the EPA project report.

One of the outputs of this grant is a new site-specific modeled treatment look-up table (LUT), based on thousands of MONDRIAN model runs and using typical treatment scenarios, that allows review of modeled treatment outcomes based on site specific conditions. Hydrological connectivity modeling was also completed for the study sites to determine strategic locations for installing riparian buffers to reduce nitrogen loads to coastal areas (Billmire et al. 2018, in press). Several individuals at the participating universities were trained on the MONDRIAN model, and the SB-CISMA and partners from USFWS and MDNR were briefed on the LUT tool. A webinar scheduled for July 25, 2018 on the Great Lakes *Phragmites* Collaborative will be focused on the user-friendly version of MONDRIAN (funded by EPA) and the quick reference LUT. We connected with the USGS Great Lakes Science Center and the Great Lakes Commission about their State and Transition PAMF (*Phragmites* Adaptive Management Framework) tool. We are working on a document to explain the differences between these two models and how managers should use them. This one-page comparison will be linked from both the PAMF website and the MONDRIAN LUT website (**https://sites.google.com/uni.edu/*Phragmites*lookuptable**). We also obtained input on measures of success and treatment and monitoring efforts from active *Phragmites* managers, researchers and other stakeholders that was integrated into the compilation of measures of success and treatment and monitoring protocols for this project. Outreach efforts for the project included one press release, 8 conference presentations, 3 peer-reviewed journal articles (one in prep), course materials for 3 universities (that will train future modelers and land/resource managers), a project website, and a web-tool interface for the MONDRIAN quick reference look up table.

Detailed information on project accomplishments by task are described below, followed by appendices on: Compilation of Treatment Protocols (Appendix 1); Compilation of Monitoring Protocols with our Field Protocol and Field Sheets (Appendix 2); Tying Management Goals, Treatments and Monitoring Protocols Together for Adaptive Management (Appendix 3); Strategic Plan for Control of *Phragmites* for Saginaw Bay (Appendix 4); and Historical Aerial Imagery for Evaluation of Pre-treatment Conditions Compared to 2016 Treatment Area Maps (Appendix 5).

TASKS

a. Map *Phragmites* and other coastal wetlands in treatment areas: All treatment areas were mapped pre-treatment using August 2016 Worldview-2 sub-meter satellite imagery. Post-treatment maps for summer 2017 were incomplete due to cloudy conditions, and 2017 imagery was only available for one of the four treatment areas (Hampton). Figure 2 shows a comparison of pre- and post-treatment Worldview-2 imagery and mapping of the Hampton treatment area. Imagery from the summer of 2018 will be downloaded for the four sites, classified similar to Figure 2, and shared with L. Ogar (sister project), the SB-CISMA, and other interested stakeholders. A 17 May 2018 Worldview-2 image was downloaded, but it was too early in the spring to map vegetation. This May 2018 image shows the change after mowing last fall to open water across much of the Hampton site (Figure 3). Peak growing season post-treatment imagery provides needed information on the distribution of *Phragmites* killed, standing dead, mowed vegetation, as well as missed *Phragmites* and regrowing vegetation. This detailed site-level information is important for adaptive management; such a bird's eye view is particularly valuable for large areas.

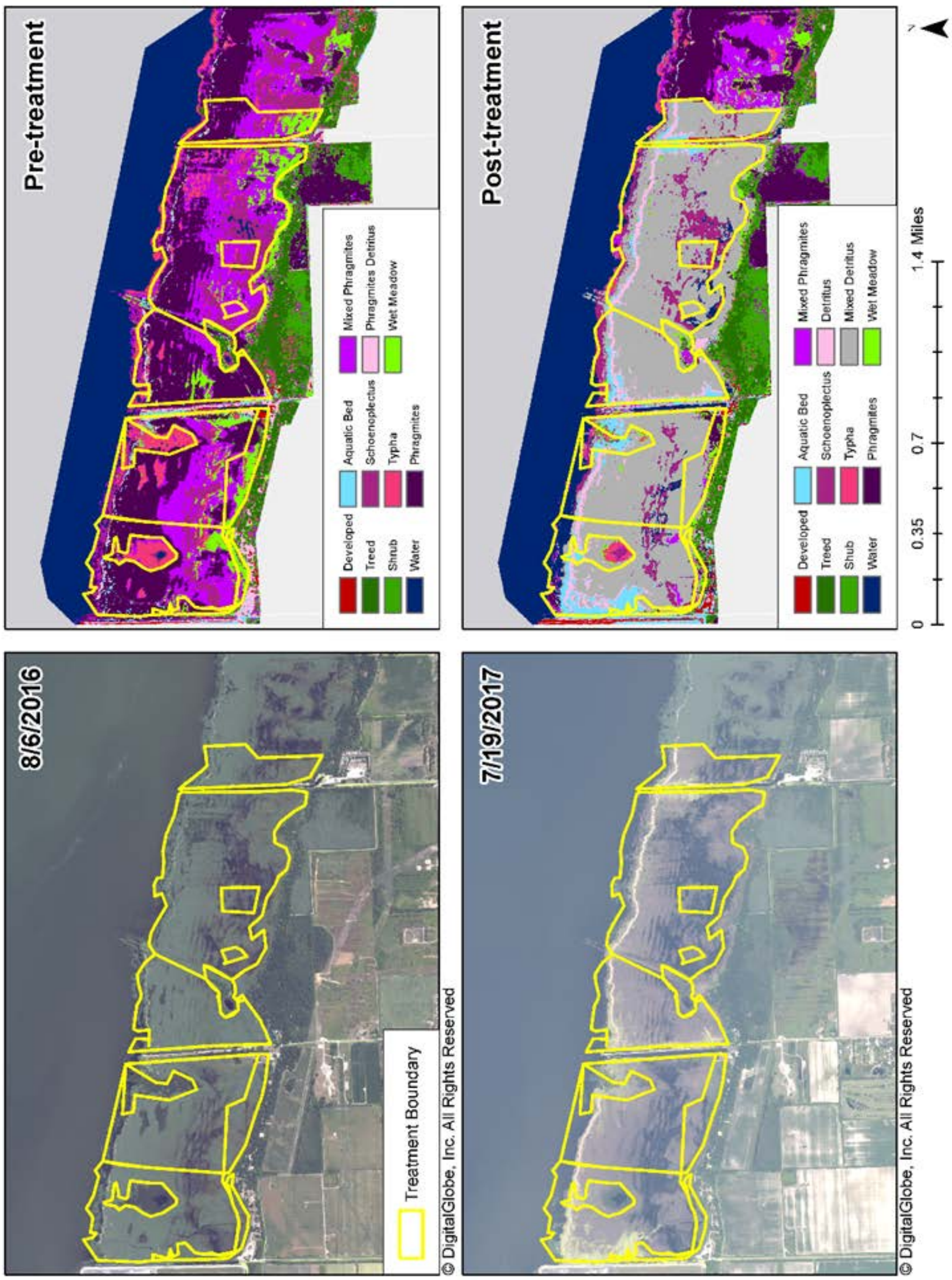

Figure 2. Worldview-2 imagery and corresponding map of Hampton treatment area pre-treatment (top row, 68.6% *Phragmites*/mixed *Phragmites* cover, 1.1% detritus) and post-treatment (bottom row, 3.4% *Phragmites*/mixed *Phragmites* cover, 72.7% detritus). Delineated are areas of live *Phragmites*, mixed *Phragmites* with other species (less than 50% *Phragmites*), *Phragmites* detritus, *Phragmites* detritus mixed with other dead plants, and several non-*Phragmites* vegetation cover types.

Hampton, Saginaw Bay

17 May 2018

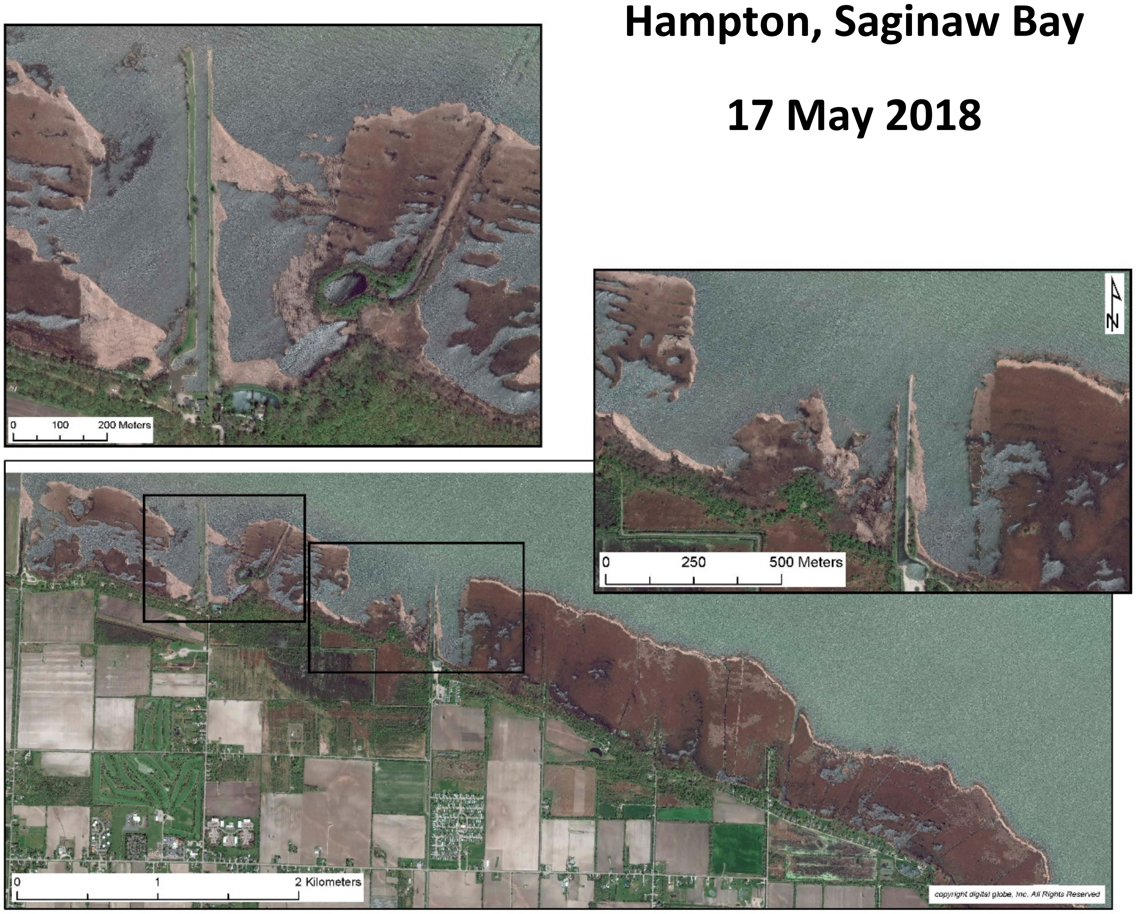

Figure 3. Worldview-2 image of Hampton Treatment Area collected May 17, 2018. Areas of dead *Phragmites* that were mowed during the winter are dominated by open water in this image, and dead mats of *Phragmites* are light colored areas along the pier and coastline, etc.

b. Compile treatment protocols: Treatment and monitoring efforts from active *Phragmites* managers, researchers and other stakeholders were identified through EPA funded stakeholder meetings, presentations/workshops at IAGLR and the Annual Stewardship Network Conference. In addition, peer-reviewed and gray literature were researched and monitored for new information on treatment options. See Appendix 1 for details.

c. Compile monitoring protocols: We interacted with active *Phragmites* managers through conferences (e.g. IAGLR *Phragmites* session in May 2017), workshops (e.g. USFWS workshop in Minnesota in September 2017, SB-CISMA training workshops), one-on-one conversations, and through meetings (e.g. SB-CISMA annual meeting) to review knowledge of monitoring literature and on-the-ground effort towards the goal of developing a broader set of management goals and a suite of monitoring protocols that will be made available to practitioners. We gathered additional feedback and input from a panel discussion we convened at the Stewardship Network Conference in January 2018 (funded by other projects, led by co-I Higman) and highlighted management concerns and novel ideas that are expressed by practitioners and other interested parties.

These recent efforts to engage managers, coupled with our previous efforts that included convening several meetings with the PAMF team to coordinate and exchange information (summer and fall 2016), our stakeholder meeting (February 2017) convened through the Bourgeau-Chavez EPA grant, as well as results from 2016 treatments through Fall/Winter 2017-18, were used to refine the suite of protocols developed for this project. The protocols were categorized as Level 1, 2 and 3 based upon complexity and cost of implementation (1-lowest, 3-highest). We continued to evaluate the tiered protocol system throughout the grant and added an intermediate Tier 1.5 protocol as well as a UAV-based monitoring method to the strategy that uses five generalized classes for dominant ground cover (*Phragmites*, undesirable plants, desirable plants, open water or bare). The protocols are defined here briefly and Tiers 1 -3 are presented in detail in Appendix 2.

The Tier 1 protocol asks the observer to collect a standardized set of site monitoring photos and record treatment details and monitoring photo numbers/filenames on a data sheet. The observer also selects from a handful of broad natural community types (e.g., emergent marsh, forested swamp) to characterize the site. Finally, the negative impacts of invasive species on the aesthetics, recreation, and safety of the treatment site are characterized as severe, moderate, or mild. This qualitative human impact assessment is based on the "human values" criteria in the MDEQ *Phragmites* Treatment/Management Prioritization Tool. A "Tier 1.5" modification to this protocol asks the observer to estimate the percent cover of *Phragmites*, other species that they consider undesirable, desirable vegetation cover, bare ground, and open water. These estimates are made from their photo-monitoring vantage point (no transects required), making this fieldwork the most accessible and least hazardous.

The Tier 2 protocol seeks to provide an intermediate option for managers who have specific vegetation goals, such as a return to pre-invasion vegetation types, and requires more detailed monitoring information to track their progress than can be obtained through a photo-monitoring protocol of Tier 1. This Tier 2 protocol is for those who do not have the resources for the species-level identification required by Tier 3 surveys. Our Tier 2 protocol consists of two parts: 1) a rapid belt transect is used which is the length of the wetland site perpendicular to the shoreline. Here information is recorded every 1 m along the transect including the definition of the vegetation zone (wet meadow, emergent or submergent), and characterization of the dominant cover using the same broad categories defined in Tier 1.5 (i.e. *Phragmites*, other undesirable species, desirable species, bare ground, or open water); and 2) five 1 m^2 quadrats are also spaced evenly along the same transect. Within each quadrat, *Phragmites* density, height, and stem diameter are recorded. The observer also counts the percent cover of different morphotypes (described below) and estimates the number of species within each morphotype, rather than identifying all individuals to species-level as in Tier 3. The belt transect approach is based on a US Fish and Wildlife monitoring protocol (Huffman et al. 2014) and the quadrats recording plant morphotypes is based on work by Abadie et al. (2007) on biodiversity monitoring with parataxonomy. Inclusion of the quadrat measurements enabled us to monitor the effect of treatment on not just *Phragmites* cover but also biomass (see subsection k).

For this project, each plant species was classified by its morphotype, or life form, into one of the following groups: rushes, bulrushes, sedges, grasses, forbs/herbs, woody plants, vines, other emergent plants, floating-leaved, and submerged plants. Percent cover of each morphotype and the number (<u>not</u> identity) of species in each morphotype group was counted in each plot. Where time and knowledge preclude identification to species, species richness can also be estimated based on reasonable guesses as to which specimens look so alike that they probably belong to the same species. These "morphospecies" can be used to compare sites as long as the criteria for distinguishing species (and preferably the observers making the determinations) are the same. This morphospecies richness is limited, though, in that richness values for separate studies or sites cannot be added together because the overlap between morphospecies is not clear (unless voucher specimens are collected). Use of morphospecies can underestimate the number of species present in some taxa, in which differences between species are subtle, and overestimate it in others with large intraspecific variation. Overall, though, morphotyping provides a means of comparing and tracking changes in biodiversity where more detailed survey work is not feasible

The Tier 3 protocol follows the Great Lakes Coastal Wetland Monitoring Protocol (GLCWMP, https://greatlakeswetlands.org/docs/QAPPs_SOPs/GLCWMP_Vegetation_SOP_June_4_2018.pdf). Transects are either established perpendicular to the elevation gradient as in Tier 2 or adjusted so as to maximize representative coverage of a patchy treatment area. Within each vegetation zone that is present, five 1 m^2 plots are spaced evenly along the transect within the zone (wet meadow, emergent and submergent). This yields a total of 10 or 15 plots per transect, as not all vegetation zones are present at all sites.

Advantages and Disadvantages of Tier 1-3 Protocols: Based on the implementation of these protocols for this project, it was certainly fastest to simply indicate undesirable, desirable, open water, or bare ground cover within the Tier 1.5 sampling strategy, compared to the time required for recording all species (Tier 3) or plant morphotypes (Tier 2). This approach was also more accessible to potential monitors, as the observer only needed to learn to identify 20 “undesirable” invasive species, and all other vegetation was grouped as “desirable plants”. This approach may be more realistic for some stakeholders in terms of time and training resources and perceived difficulty compared to Tier 2 or 3 sampling. It can be difficult to accurately count the number of different morphotypes without knowledge of grass, sedge, herb, and shrub identification.

Tier 2, by establishing transects, involves more effort than Tiers 1-1.5 but a similar level of botanical expertise. Tier 2 also provides greater spatial coverage than a Tier 1.5 estimate of cover from a single vantage point. This increased coverage in cases where a closer look at all parts of the treatment area is desirable; for example, it is critically important for determining potential secondary invasions of other non-native species like European frog-bit. The potential for secondary invasions was cited as a major concern by *Phragmites* managers at the stakeholder meeting and during one-on-one discussions throughout the project period. In addition, this study and others have shown that many *Phragmites* infestations are not 100% monotypic, but have a mosaic of other cover patches within them (see figure 2). Sampling along transects through the infestation will reveal this, whereas a Tier 1 assessment from a single vantage point usually will not, except for relatively small infestations. Finally, the Tier 2 protocol moves beyond simply assessing changes in *Phragmites* to providing a coarse scale measure of change in cover and diversity of desirable species. A fundamental concern echoed by managers during this study is that many monitoring efforts focus only on *Phragmites* kill, while ignoring other ecosystem variables. In many management scenarios, measurement of *Phragmites* kill is an inadequate measure of management success.

The use of morphotypes as part of Tier 2 was tested for this study to assess its utility when a high level of botanical expertise is lacking, as is commonly the case in *Phragmites* management scenarios. This method was also tested to determine whether data could be collected faster than using an all species approach. A prairie monitoring study (Grant et al., 2004), successfully showed that data gathered by non-experts using morphotypes was fast, efficient and more accurate than all species identification, and provided adequate data for adjusting management. They also state the following: “Few restorationists have adequate plant taxonomy skills required to document plant composition at this level [species], and misidentification of difficult taxa can make interpretation of results meaningless” (from Rooney and Rogers, 2002).

The Tier 3 protocol provides standard measures of plant diversity that can be compared pre- and post-treatment and between sites. It provides a measure of both *Phragmites* kill and ecosystem change, which can be used to determine if vegetation management goals are being achieved, or not. These data can be then be used effectively with the MONDRIAN LUT, to inform future management of the site—a key component of an adaptive management approach.

Some authors have suggested that generic or higher taxon richness correlates well with species-level richness in macrophytes (Mazaris et al. 2010), providing another "shortcut" option that was not pursued here. Further study is needed to determine if there are valuable morphotype groups that can be used to document the most relevant vegetation changes over time in *Phragmites*-treated sites. It is possible that there will be differences based on specific management goals for target plant and animal species.

Finally, **UAV aerial imagery** (~5 cm resolution) was collected in place of field data for some transects because they could not be traversed safely and in a reasonable amount of time. For some larger sites, the size and density of *Phragmites* patches would make it very difficult to get out of the field or for emergency services to reach someone in the event of an injury or emergency, which has likely dissuaded some managers from attempting any monitoring program. UAV mapping and classification with standard natural color (red / green / blue) imagery is generally limited to broad vegetation classes, with the exception of a handful of distinct, densely growing species such as *Phragmites*, *Typha*, and *Impatiens capensis* (spotted jewelweed). Diversity assessment based on these UAV data is limited to functional diversity, but it offers an option for rapid assessment of site conditions at a higher resolution than satellite mapping, with rapid deployment, and without the need for cloud-free sky conditions.

The protocol chosen by a given land manager will be dependent on their field skills, management goals, site conditions, funding and time. Please see subsections e, k and l for discussions of how an appropriate monitoring plan can be developed based on these considerations so that monitoring activities are achievable and the data collected demonstrate whether the management goals are being reached.

d. Worked with SB-CISMA on definitions of success: <u>Success</u> - The project teams for this project and the Ogar-funded MISGP sister project, established the following definition of success, based upon the collective experience of the group:

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.

To determine pre-invasion habitat/ecosystem, we demonstrated interpretation of aerial imagery available for Michigan's coast back to 1938 for two sites to determine the pre-invasion historic community type (see Appendix 5).

Further work is needed to determine what optimal, desired thresholds of native/desirable species cover constitute success. (See Appendix 3 for further discussion.)

e. Worked with SB-CISMA <u>to provide</u> training <u>on</u> monitoring protocols & <u>implemented</u> pre- and post-treatment monitoring: MTRI, MNFI, and UNI provided training for field monitoring protocols in 2016 and 2017 for the SB-CISMA monitoring crew. Although the monitoring crew was trained in 2016, only one crew member was retained for 2017 and a new assistant was hired for summer/fall 2016. Therefore, we provided a refresher for the veteran crew member and new training for the new hire in spring 2017. Training was conducted in several field sites over 3 days and consisted of review of the Tier 1, 1.5, 2, and 3 protocols through direct implementation of the protocols. Review of common species encountered during monitoring, and plant and soil sampling were also conducted for model validation (see section i). Tier 3 monitoring was overseen by more highly trained project members from MTRI, MNFI, and UNI, as the monitoring crew was not confident in all of their species identifications after the 3-day training, highlighting a likely obstacle for other managers in following this protocol. Post-treatment field monitoring was then implemented by the SB-CISMA monitoring crew at the remaining transects for all sites treated (Hampton, Saganing River, Pine River and Vanderbilt, Figure 1). The same three-tiered protocol piloted in 2016 was followed in 2017, with the exception of a decision not to collect belt transect cover information every 1 m along the transect for Tier 2. This change was made because the project team felt that these belt transect data were difficult to analyze in a statistically rigorous way and the belt data were adding significant time to the field collection; therefore, sampling at the plot level was the focus of field sampling for Tier 2 in 2017 (see comparative analysis of monitoring protocols below).

In 2016, several of the sites were monitored with UAV imagery (September 2016, Figure 4). Those same sites were, therefore, monitored again with UAV post-treatment in early October 2017 and the data were processed and classified. A subset of sites was sampled with both UAV and tier 3 biodiversity sampling for comparison, as described below (section e-2). Classification of the UAV imagery was demonstrated using the same classification scheme applied to the Worldview-2 imagery using eCognition software for object-based image analysis. This resulted in high resolution (~5 cm) mapping of dominant species and good comparison to field plot data (Figure 5).

UAV Lessons Learned and Recommendations: Useful lessons learned during the UAV deployments include flying at heights to optimize vegetation mapping, and the areas that can be covered in single vs. combined flights. Several heights for UAV flying were tested during pre- and post-treatment mapping. For pre-treatment mapping of *Phragmites*, heights of approximately 38 m (125 feet) using a small UAV with a 12 megapixel (mp) camera such as the DJI Phantom 3 Advanced or Mavic Pro were appropriate for creating a complete combined aerial image (orthophoto) of a site using photogrammetric software such as Agisoft Photoscan. However, when flying over post-treatment sites that were dominated by dead *Phragmites* stems, this height did not produce imagery that could be combined into a single orthophoto to be used for use in mapping of the entire site. However, flying at a height of 100m (328 feet) produced images that could be combined into a single orthophoto for site mapping and inventory of post-treatment conditions. This produces imagery of approximately 5 cm resolution with the 12 mp camera of the Phantom 3 Advanced or Mavic Pro. Using a standard height of approximately 100m is recommended to ensure consistent mapping, assuming the onboard UAV camera is at least 12 mp in resolution.

Deployment of UAVs should also be convenient and rapid as part of field protocols. Current Federal Aviation Administration (FAA) rules implemented in August of 2016, known as “Part 107”, require those flying UAVs commercially, including researchers, to have an unmanned pilot’s certificate, obtainable through a 60-question, two-hour test that costs $150. The Michigan Tech team has three certified UAS pilots, and there were over 60,000 of them in the US as of September, 2017. FAA rules also require most UAV flights to be within line-of-sight of the pilot and with a maximum height of 122 m (400 feet), without additional permissions. Line-of-sight is somewhat subjective, but on a practical basis, Michigan Tech unmanned pilots have found that a practical limit is 1 km (½ mile) as the longest sight distance. The type of small quadcopter UAV used for field site mapping (Phantom 3 Advanced and Mavic Pro) cost $1300 at the time of purchase and can fly for approximately 20-25 minutes. Flying at 100 meters, a 15 hectare (38 acre) *Phragmites* treatment site was flown in 10 minutes, with sufficient imagery taken to create a composite site aerial map. Mapping sites at 5cm resolution for areas up to 30 ha (76 acres) is practical for a single flight.

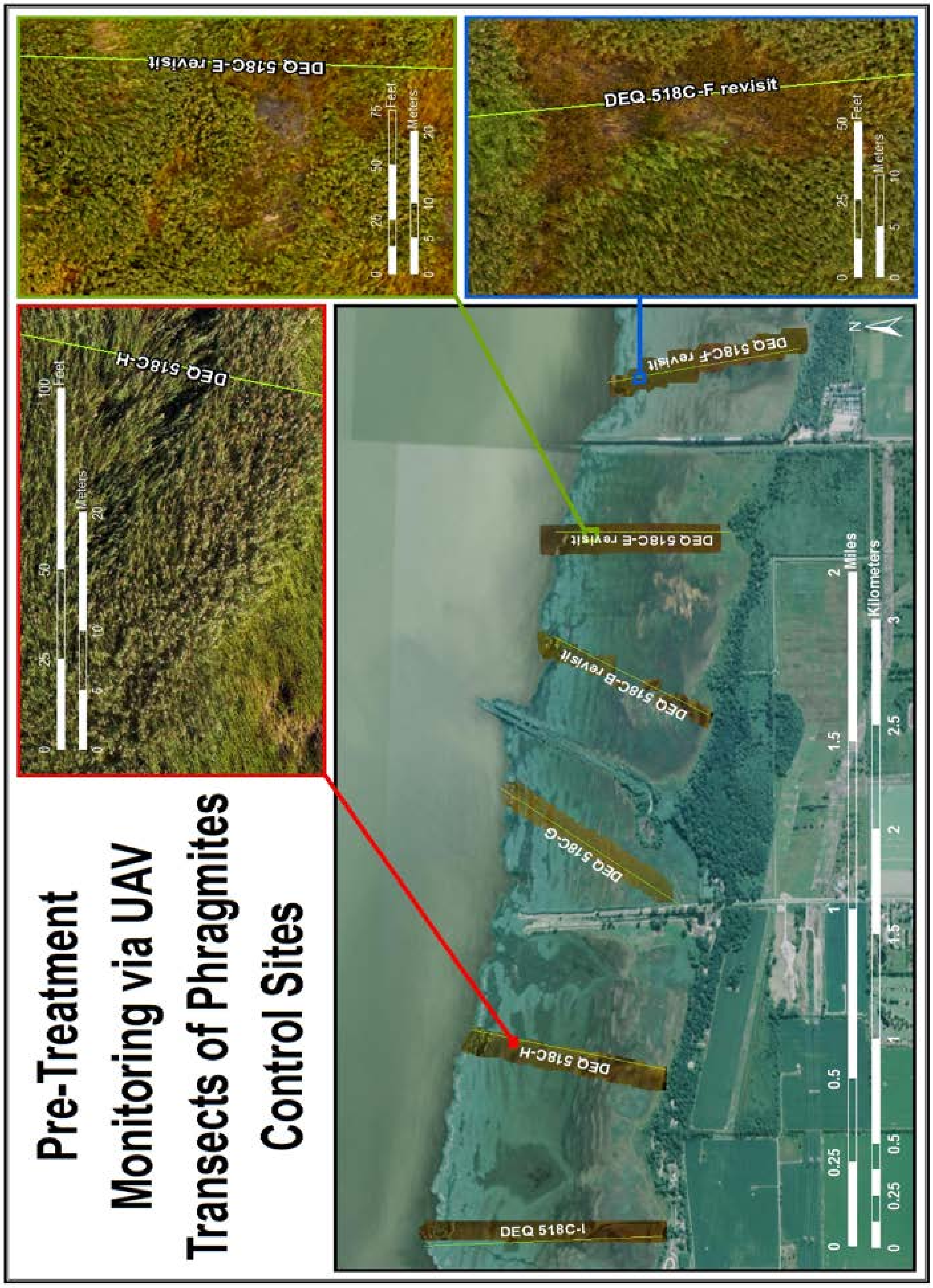

Figure 4. UAV 2016 transects for six areas collected in September pre-treatment over the Hampton treatment area

With new UAV site mapping applications, it is now possible to design flight plans that can cover larger areas than what can be covered in a single flight. The app “Precision Mapper” was tested, and for areas larger than a single flight, the software enables the UAV to land, have a battery swapped out, and then continue the rest of the aerial mapping mission. With Mavic Pro batteries currently costing $90, and Phantom 3 Advanced batteries costing $125, this means that larger missions can be collected, limited by ability to buy larger batteries and the FAA line-of-sight restriction. For example, a circle with a

1000 m radius is approximately 314 ha or 776 acres (about 1.2 km^2), meaning that a pilot could map up to that area if standing at the center of the collection location with 10 batteries available. Flying with a more practical set of four batteries should enable mapping of about 120 ha (just over 300 acres) in 40 minutes of flying from a single location. This is of sufficient area at the price points described above to make UAV flying a rapid and practical part of monitoring efforts.

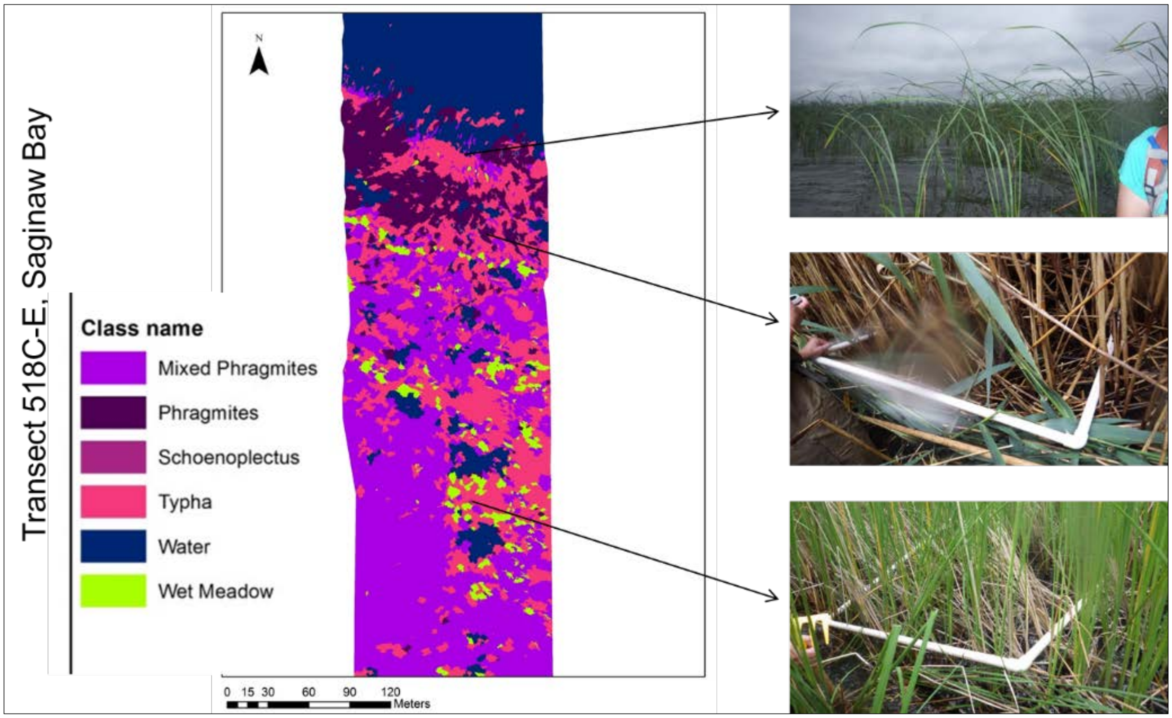

Figure 5. Comparisons of UAV classification of transect 518C-E in Hampton treatment area of Saginaw Bay to field data for validation.

e-1. Comparison of all Field Data Protocols – Data Value and Costs: The piloted monitoring protocols were compared on several bases: the data that each protocol provides, the utility of those data with respect to managing for particular goals, how well certain types of data collected using each approach compare to remotely sensed "ground truth" data, the hazard posed by the fieldwork involved in each protocol, and the resources (effort/time, skill, and equipment) required to implement each. Table 1 below summarizes the tradeoffs between the piloted monitoring protocols.

Table 1. Comparison of the 3 tiered field monitoring protocols to sampling via UAV or drones in terms of effort, skill, safety, cost, and various metrics of pre- and post-treatment condition for treatment effectiveness evaluation.

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/ sq m	Phragmites biomass	Species richness	Conservatism index	FQI
Tier 1	Low	Low	Low	Low	X	X							
Tier 1.5	Low	Med	Low	Low	X	X	X	X					
Tier 2	Med	Med	Med to High	Med		X	X	X	Estimate	X	Estimate		
Tier 3	High	High	Med to High	Med		X	X	X	X		X	X	X
Drones	Low	High	Low	High		X	X	X					

These different protocols collect varying types of information but can be compared directly on the basis of accuracy for monitoring *Phragmites* cover and treatment success, suitability for evaluating success with respect to different management goals, and the barriers to use posed by different skill and equipment requirements. The analysis of treatment success as measured using the various protocols is included here as subsection k, while suitability and barriers to use are discussed below.

Tier 1**:** The Tier 1 photomonitoring-based protocol generates the most anthropocentric monitoring data, consisting of photo documentation of aesthetic/structural changes, qualitative rankings of impacts on human values, and treatment success defined as *Phragmites* kill rate. For landscapes managed primarily for recreation or hunting, for example, rather than the quality of the natural area, Tier 1 can be an efficient way to evaluate the effects of *Phragmites* treatment. The primary benefits of Tier 1 monitoring are the low effort and skill level required (total time of approx. 10 minutes per site), low equipment costs (just a camera), and the protocol being one of the safest reviewed approaches because it is not necessary to traverse the wetland. The "Tier 1.5" addition of estimating percent cover of *Phragmites*, desirable cover and undesirable cover increases the required skill level somewhat, as observers need to be able to identify all undesirable/invasive species, but that is a manageable list, and many land managers are already familiar with at least most of these species. One might assume that the Tier 1.5 percent cover estimates, made from a single vantage point, would be less accurate than the transect-based estimates produced using the more intensive protocols, but as our data analysis presented later in this report shows, that isn't necessarily the case. Assuming that our satellite-based maps represent the most accurate estimate of site-wide percent cover, *Phragmites* cover estimates based on Tier 2 belt transects or field plots were generally more similar to the remote sensing values, but Tier 1 estimates compared reasonably well to remote sensing-based values for smaller sites (i.e., EPA sites Delta College and Dutch Creek). Presumably, estimates from a single vantage point are less accurate for larger areas.

Tier 2**:** This tier was intended to provide an intermediate level of biodiversity monitoring data for those who have increasing native plant diversity as a goal but do not have the time and access to expertise needed for a Tier 3 monitoring program. Completing a transect following the Tier 2 protocol required approximately 2-4 hours for our sites, with transects that cross through standing *Phragmites* biomass requiring more time than transects through mowed or *Phragmites*-free areas. As can be seen in the summary table (Table 1), Tier 2 monitoring collects or estimates most of the values obtained from a Tier 3 protocol. This level of information gathering could be suitable for managers who are interested in the effect of treatment on biodiversity as a measure of natural area quality, but who aren't able or interested in conducting a Tier 3 intense program. An important part of this project was the comparison of Tier 2's morphotype-based estimates of diversity to Tier 3's more rigorous species diversity data. As Figure 6 shows, the Tier 2 data did not capture a significant change in morphospecies richness between 2016 and 2017, whereas the Tier 3 data do indicate declines in total and native species richness. Although morphospecies based assessments have been effective "shortcuts" for diversity monitoring in some systems (e.g. invertebrates, tropical terrestrial plants), these results show that this approach is not an effective alternative here. The Tier 2 protocol does provide a means of rapid assessment of land cover change for land owners/managers without access to UAV or satellite imagery, as well as *Phragmites* measurements that can be converted to allometry-based estimates of *Phragmites* above-ground biomass for the site, a unique feature among the protocols evaluated here. In summary, a manager interested in ground-based monitoring of land cover change and/or defining treatment success based on change in *Phragmites* biomass rather than percent ground cover could find the Tier 2 protocol to be an efficient approach to monitoring. Given that a *Phragmites* treatment resulting in some regrowth could accomplish a significant decrease in above-ground biomass while the dominant cover remains *Phragmites*, change in biomass may be a more sensitive measure of landscape change than dominant cover, especially in the initial years after treatment.

***Tier 3*:** The Tier 3 protocol is the most ecologically sophisticated, allowing for the calculation of an Adjusted Floristic Quality Index (FQI) that can be used to compare sites across space and time. Adjusted FQI is based on species diversity and Mean C, where the latter is the average conservatism coefficient of all species observed at a site. Conservatism coefficients, assigned by experts, range from 0 for invasive/highly generalist species to 10 for specialist endemic species, with the result that Mean C provides a measure of a site's tolerance for disturbance. Adjusted FQI, which includes but limits the effect of differences in species richness, has been suggested as a useful metric for comparing sites that differ in degradation/stressors, making it appropriate for the gradients of disturbance and invasion represented by our treatment sites; it is calculated as follows:

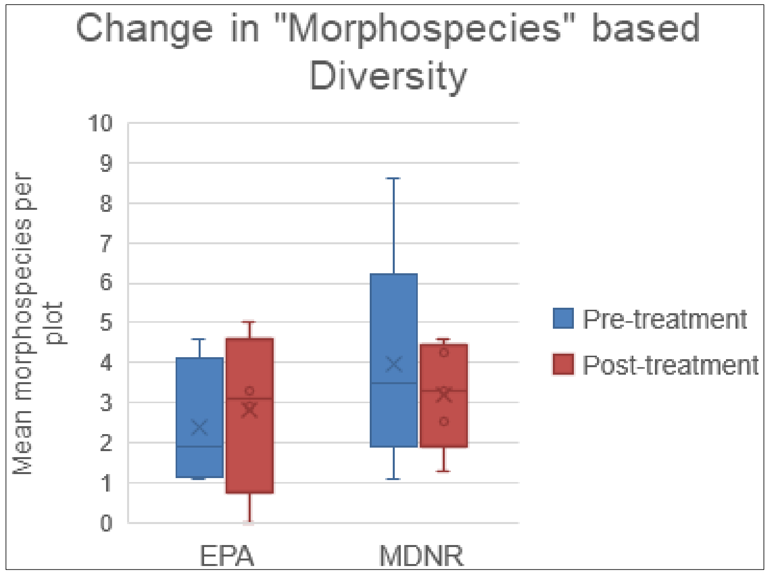

Figure 6: Pre- and post-treatment morphospecies diversity captured using the Tier 2 monitoring protocol for the treatment sites included in this project (MDNR) and in an EPA GLRI-funded project focused on *Phragmites* treatment along the Saginaw River (EPA).

$$\frac{\left(\sum_{i=1}^{n} C_i \Big/ N_n\right)}{10} \frac{\sqrt{N_n}}{\sqrt{N_a}}(100)$$

where $\sum_{i=1}^{n} C_i / N_n$ is Mean C, C_i is the conservatism coefficient assigned to species *i* observed at the site, N_n is native species richness, and N_a is total species richness. The information on ecological quality provided by the Tier 3 protocol is more detailed than any of the other options, and is the best choice for sites being managed specifically for their ecological value. The species-level data collected for Tier 3 also allows decision-makers to monitor particular species, for example if an endangered/threatened/special concern species is present at the site. However, the need for complete knowledge of wetland vegetation ID and the large amounts of time that can be required (transects generally take at least 4 hours to complete; some long transects through >1 km wide patches of *Phragmites* at the Hampton Twp site took > 12 hours to complete) will make this approach unfeasible or unappealing for managers who are less focused on ecology. Managers interested primarily in the relative coverage of native vegetation, *Phragmites* and other invasive species would most likely find the Tier 2 protocol a more efficient use of their time, a UAV approach if they have access to that equipment, or even Tier 1 monitoring for small sites.

e-2. Comparison of UAV to Field Data – Mapping and Biodiversity Analysis: As noted above, UAV data were collected in 2016 and again in 2017. Work was undertaken to determine if the UAV data (Figure 4) could provide useful vegetation biodiversity information, especially for unsafe and difficult to access locations. A comparison of field data with overlapping UAV data was completed for three different vegetation sites: a *Phragmites* dominated field plot (Figure 7), a *Typha*-dominated field plot (Figure 8) and a diverse, multiple species plot (Figure 9). For the *Phragmites* dominated site, the field sampling found a 40% cover of *Phragmites* with no other species present. A dominant *Phragmites* cover was also apparent in the UAV imagery with clear identification of individual *Phragmites* plants and individual plant inflorescences. For the *Typha*-dominated site, the field sampling reported the site to be *Typha*-dominant with other mixed vegetation and some *Phragmites* present. In the UAV imagery, we were able to see the *Typha* dominated patch and some mixed vegetation, but the species in the mixed patch could not be identified. We could also see a few individual *Phragmites* plants present in the area. For the mixed plot, the field sampling found a wide variety of species present at different cover percentages. In the UAV imagery, we could determine which areas had mixed emergent vegetation and could see rush/sedge/bulrush dominant areas. We could not identify specific species or exact cover percentages. We could also see some individual *Phragmites* plants in this area.

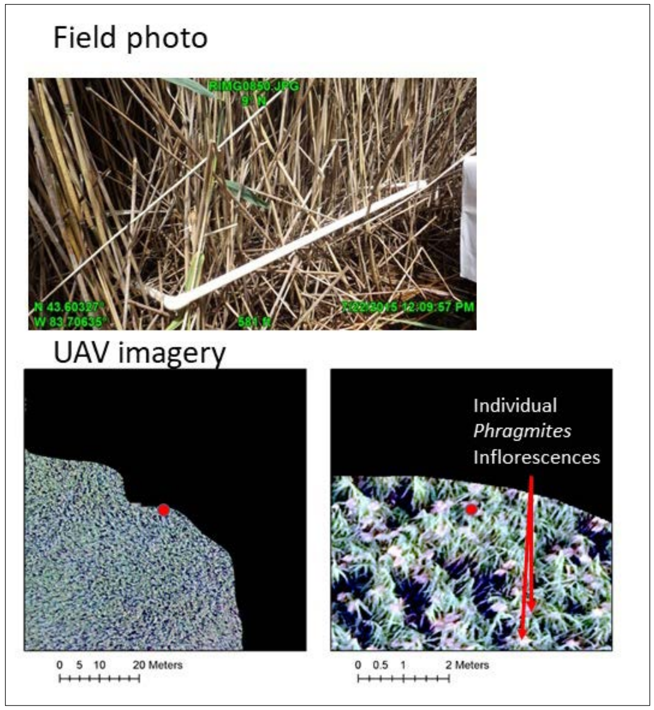

Figure 7. Comparison of field plot photo (517B-C plot 8) to UAV imaging data for a *Phragmites* dominated area of Hampton treatment area. Red dot shows the location of the center of the 1 x 1 m field plot in 5 cm imagery as you zoom in from left to right (bottom).

A summary of the uses of UAV data for vegetation biodiversity analysis:

- Pros of UAV sampling of *Phragmites* treatment areas
  - Different groups of vegetation can be differentiated, but usually not to species level (sometimes to family level if area is homogenous)
  - Can differentiate homogenous areas from mixed areas
  - Much more efficient for difficult-to-access sites
  - Able to see all pockets of different vegetation that might be missed with field transects
- Cons of UAV sampling of Phragmites Treatment Areas
  - Will not get species level of detail beyond monocultures of Typha, bulrush, or Phragmites or cover percentages from mixed species as is possible from field sampling
  - Only sampling top layer of vegetation, so could be missing understory or submergent vegetation
  - Missing information on small/sparse/rare vegetation

Our conclusion is that UAV sampling is a promising alternative for a quick estimate and an aerial view of extent of *Phragmites* and locations of more diverse patches within the *Phragmites* that should be omitted from treatment, but UAV sampling will not provide a quantitative statistical comparison of biodiversity (as expected).

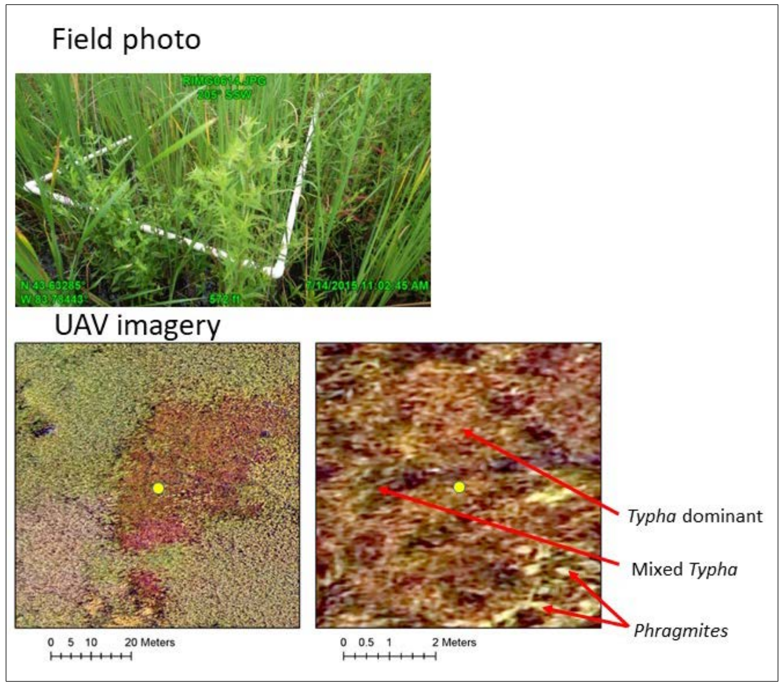

Figure 8. Comparison of field photo (518C-E plot 6) to UAV imaging for *Typha* dominated area of Hampton treatment area. Yellow dot shows the location of the center of the photographed 1 x 1 m field plot in 5 cm imagery as you zoom in from left to right (bottom). The field data for this plot indicate a mix of 20% *Typha* cover and shorter vegetation.

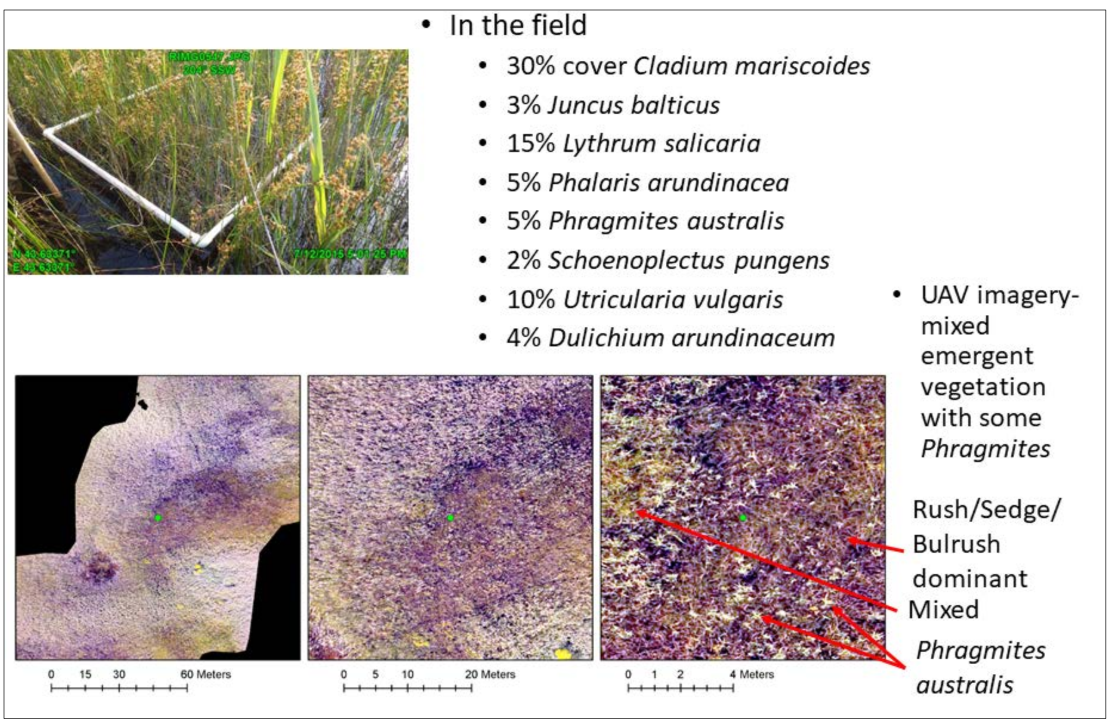

Figure 9. Comparison of field plot (518C-B plot 6) data to UAV imaging for mixed species area of Hampton treatment area. Green dot shows the location of the 1 x 1 m field plot in 5 cm imagery as you zoom in from left to right (bottom).

f. Implement Treatments – conducted under sister project to Ogar: Approximately 244.43 hectares were treated with herbicide (Imazapyr and Glyphosate) at sites including: Pine River, Vanderbilt, Hampton Township, and Saganing River. The treatment of the sites was completed in September 2016. Burning of Hampton by MDNR was delayed due to fire staff fighting fires out west and then deemed too unsafe due to wind and wave conditions along the shore. Hampton and Vanderbilt were mowed (in part) in winter 2018. Some sites had follow-up herbicide in fall 2017. May 2018 imagery shows the beneficial effects of mowing combined with the high water levels of 2018 (Figure 3).

g. Landscape modeling for riparian buffer analysis: Riparian buffer modeling for the watersheds that flowed into the treatment sites was completed. 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. These metrics are intended to be used as an informational resource for targeting areas where riparian buffer installation may be most effective.

The modeling 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. Geospatial modeling inputs 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 resolution SAR-derived landcover dataset. Methods and example outputs (Figure 10) were presented to The Nature Conservancy in December 2016.

Figure 10. Example outputs from the riparian buffer modeling. Left is the agricultural load estimate and right is the detention time/buffer effectiveness output.

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

Validation of the hydrological flow path-based metrics included use of both field visits/photos as well as 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 manuscript describing this analysis (Billmire and

Koziol 2018) is currently in press for the Journal of Great Lakes Research. Under the EPA grant to Bourgeau-Chavez, this approach was applied to all watersheds leading to the Saginaw Bay and a website was developed to present the results and inform managers (http://spatial.mtri.org/phrag-viewer/)

h. Landscape modeling for MONDRIAN **inputs**: Landscape modeling was used to produce estimates of water level, nitrogen loading and propagule pressure for each of the treatment sites, to be used as inputs for the MONDRIAN ecosystem model. Water levels were estimated by subtracting lake level observations from coastal elevation (as derived from LiDAR) at each site. Nitrogen modeling consisted of deriving estimates from three N sources: atmospheric deposition, overland runoff, and riverine delivery. A fourth source, groundwater upwelling, is thought to be a significant contributor to N loading in the study area but unfortunately there are insufficient data and/or modeling methods for which to produce estimates. Data and modeling resources used to produce these MONDRIAN inputs included USACE National Coastal Mapping Program Topobathy LiDAR, NOAA water level gauging stations, USGS NWIS and EPA STORET water quality monitoring network, National Atmospheric Deposition Program (NADP) (http://nadp.sws.uiuc.edu/ntn) NTN annual maps, Long Term Hydrologic Impact Analysis (L-THIA) non-point source pollution modeling, and SAR-derived wetlands maps produced under a previous NASA Great Lakes grant (PI Bourgeau-Chavez). Outputs from the landscape modeling included:

- CSV table of *atmospheric deposition N loading* (g/m^2) for each treatment site for each month for three different scenarios (LOW, MID, and HIGH estimates)
- CSV table *of N loading from other sources (overland runoff, riverine/lacustrine delivery)* (g/m^2) for each treatment site for each month for three different scenarios (LOW, MID, and HIGH estimates)
- CSV table of *water depth* (m) estimates for each treatment site for each month
- CSV table of *propagule pressure* (categorical LOW, MID, HIGH estimates) for each treatment site.
- Map of treatment sites and existing *Phragmites* stands highlighted that was used for estimating propagule pressure.

N loading inputs for MONDRIAN modeling were provided as LOW, MID, and HIGH scenarios because of the variability and uncertainty in the loading estimates. Table 2 provides a summary of output values from this work.

Table 2. Landscape modeling outputs produced for MONDRIAN modeling. N loading values are summarized here as annual MID values but were produced and provided as monthly LOW/MID/HIGH values.

		Annual N loading (g/m^3), MID scenario			
Site	Water level (m)	Overland	Atmospheric	Riverine	Propagule pressure
Hampton	0.07	0.25	0.44	0.78	HIGH
Pine River	0.14	0.27	0.42	1.72	LOW
Saganing River	0.10	0.21	0.36	1.12	LOW
Vanderbilt	0.10	0.41	0.39	1.06	HIGH

i. Integrate data and nitrogen modeling: To assess the landscape modeling efforts, in 2016 leaf and soil samples were collected from each of the treatment sites (prior to treatment) for analysis of N-content. The results confirm that the landscape modeling outputs accurately reflect conditions in the wetland, as shown in Figure 11**.** Note that data from the MISGP treatment sites in the bay and more southern sites along the Saginaw River (EPA funded treatment sites for PI Bourgeau-Chavez) were combined in these plots to show a greater range of 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. Leaf N content in green leaves collected from the treatment sites showed a clear positive relationship with modeled annual N inputs from the landscape model. Since green leaves provide the clearest indicator of immediate (current year) N inputs, this positive relationship provides confirmation that the landscape model accurately reflects conditions in the wetland. The Dutch Creek site (outlier in Figure 11A) did not show the same linear relationship as the remaining sites; however this is 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 this site), leaves cannot take up that much additional N, so one would expect to see the "leveling-off" displayed in Figure 11. Senesced leaves 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 is an adequate representation of on-the-ground conditions.

Finally, soil N content also showed a generally positive trend between modeled N input and observed soil N. 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 sampled soil N, indicating that for the most part, current conditions are likely a fair representation of conditions over the past couple of decades as well. There is one clear outlier however; the Saginaw River Mouth site has much higher soil N than expected. It is important to note that this site was not an outlier when examining leaf tissue N, indicating that modeled current conditions are 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.

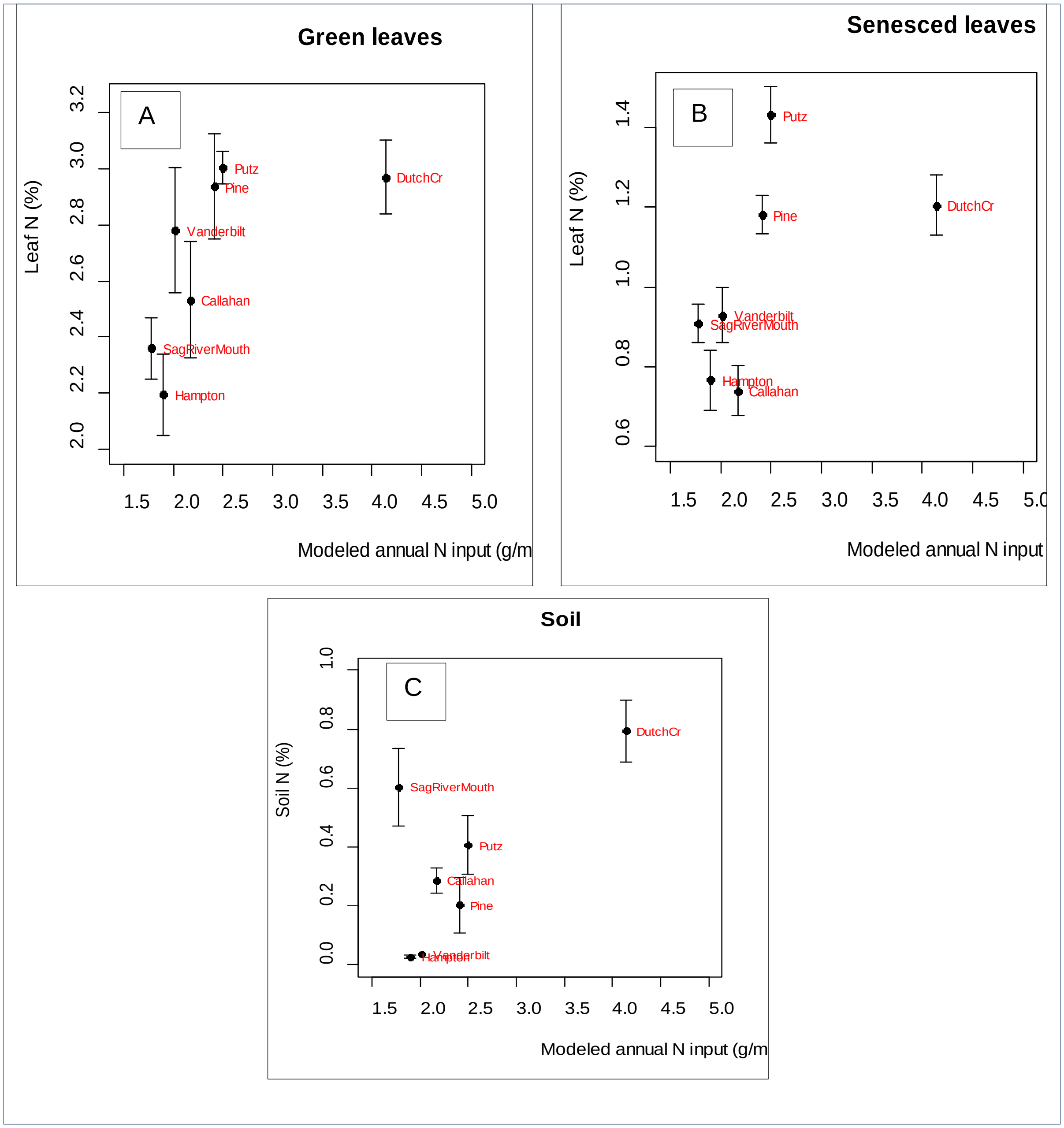

Figure 11. Plots of Modeled N input and (A) Green Leaf N; (B) Senesced leaf N; and; and (C) Soil N for each of the northern Lake Huron Saginaw bay sites treated under our sister- project (L. Ogar – Bay County- Vanderbilt, Hampton, Pine River, Saganing River Mouth) and including southern Saginaw River treated sites funded by an EPA grant (Putz Park, Dutch Creek, Callahan).

J. MONDRIAN modeling and Look Up Table: At the beginning of the grant period, the MONDRIAN modeling team used the landscape modeling outputs described above (site-specific water levels, N loading, and *Phragmites* propagule pressure) as inputs to the MONDRIAN model in order to simulate the Hampton, Saganing River, Vanderbilt and Pine River study sites. We simulated 7 different treatment options that were being considered for *Phragmites* control at each of these sites. The predicted outcomes of these treatment options (Figure 12) were shared via webinar with all project members in summer 2016, and project members considered these predicted outcomes, as well as other factors, in making decisions on how to treat each site.

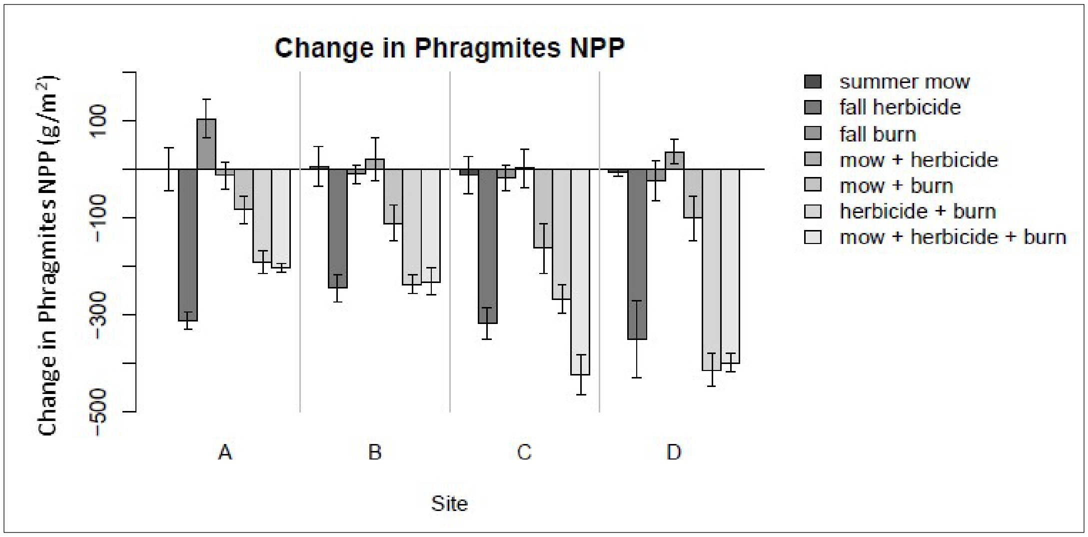

Figure 12. Predicted outcomes of the seven treatment options at each site. Negative numbers represent a reduction in *Phragmites* biomass due to the treatment.

In spring 2017, the MONDRIAN modeling team again used the most recent fully tested version of the model (v 3.8) to simulate alternative management practices for summer/fall 2017 at the Hampton, Saganing River, Vanderbilt and Pine River study sites. This was a more thorough set of simulation runs compared to the previous year. For each site, we used site-specific values for both water levels and N loading to wetlands, and designed and completed a factorial set of model runs that included 2 options for herbicide treatment, 3 options for burning, 3 options for mowing, and 2 scenarios of propagule pressure. This amounted to approximately 760 model runs. The specific options for burning, mowing, and herbicide (what combinations are possible, timing, etc.) that we used in the model were derived from our conversations with Saginaw Bay CISMA wetland managers that we had earlier in 2017 in conference calls on this project. The results of this set of model runs were shared with wetland managers on this project via webinar in late spring 2017, prior to the summer/fall 2017 treatment period. Producing site-specific management recommendations from our MONDRIAN simulation runs accomplished a major project objective of the MONDRIAN modeling team.

All of the planned updates and enhancements to the MONDRIAN model code, as needed for this project, were completed by early fall 2017. A new model version (MONDRIAN v 4.0) was distributed to MONDRIAN team members for thorough beta-testing in fall 2017. The main model updates and enhancements in version 4.0 included the following:

i. A new ability to allow seasonal or interannual changes in wetland N inflows;
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; and
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 non-native *Phragmites*.

Thorough testing of these changes to the MONDRIAN model continued through late fall 2017. The MONDRIAN modeling team worked together to design a comprehensive set of test runs to ensure the new functionality of the model worked correctly without negatively affecting existing functionality. With the testing of v 4.0 of the model completed, in winter 2017-2018 the MONDRIAN team designed and executed a set of >5,000 model runs that were used for the basis of a look-up table that was produced in early 2018. The large set of model runs was analyzed and used to create an interactive, web-based tool intended to increase the accessibility of the look-up table's results for a broader audience.

The MONDRIAN look-up table (i.e. quick reference model) is a key output from this project. Originally, the look-up table was imagined as a standard reference table, but it was later created as an open access, web-based tool that allows for the consideration of multiple site characteristics simultaneously. To use this new tool, a wetland manager navigates to the website (http://phraglut.mtri.org) and selects four options that represent site characteristics:

1) a level of *Phragmites* propagule pressure from the surrounding area (from three options);
2) an estimate of the hydrologic regime / hydroperiod (from four options);
3) a level of N inflow (from four options – low, medium, high or very high);
4) a growing season length (from two options, long or short).

Once the user sets these four options, they are immediately presented with a graphical representation of the simulated reduction in *Phragmites* biomass (relative to control where no simulated treatment action occurred) after one year of treatment (Figure 13). The graphical representation summarizes the likely effects of 11 different combinations of management treatments (Table 3). It automatically highlights the most effective treatment combination in red and provides a written description of the most effective management treatment below the graphic. With its interactive immediacy and the fact that it shows the results across treatment options, this tool conveys a lot of information to the user. It shows the amount of variation in simulated treatment effectiveness, giving an indication of how much better one treatment combination is likely to be than another. If a manager is uncertain about the specific site conditions such as the degree of propagule pressure or level of N loading, the manager can quickly scroll down and select a different site condition and immediately see the comparison in simulated effectiveness. In this manner, the manager can see which combination of treatments is the most likely to be useful if there is uncertainty in their site conditions.

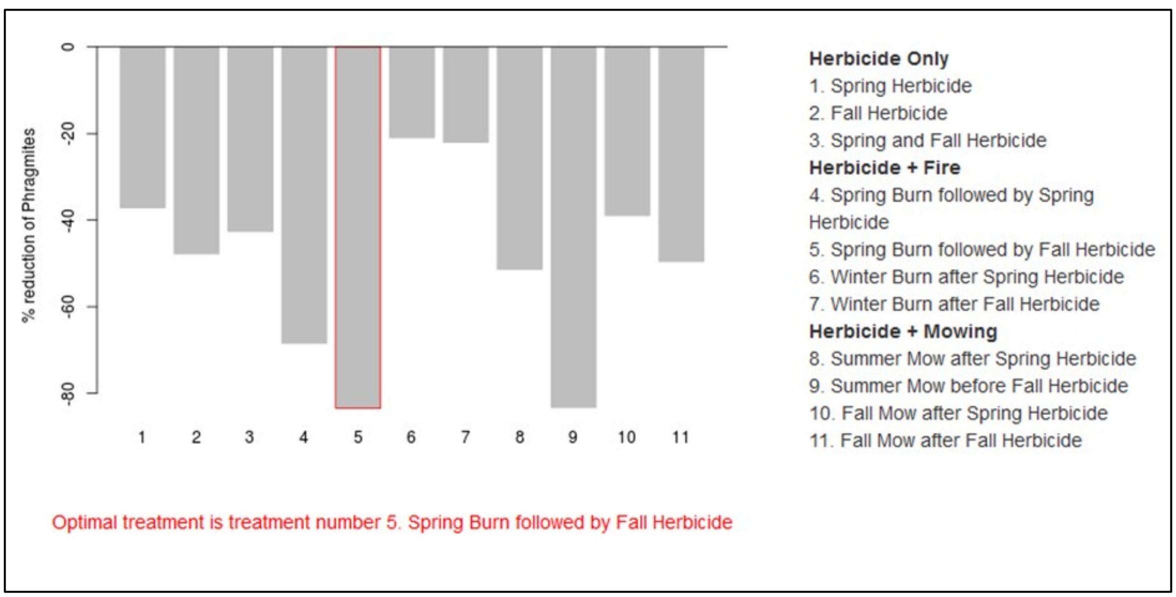

Figure 13. A sample result shown in the MONDRIAN look-up table tool: A graphical representation of the simulated effectiveness of a range of combinations (treatments are numbered as in Table 3) in reducing *Phragmites* biomass after one year of treatment.

Table 3. Options for combinations of management treatments in the MONDRIAN look-up table (quick reference model).

Option #	**Herbicide only**
1	Spring Herbicide
2	Fall Herbicide
3	Spring and Fall Herbicide
	Herbicide + fire
4	Spring Burn followed by Spring Herbicide
5	Spring Burn followed by Fall Herbicide
6	Winter Burn after Spring Herbicide
7	Winter Burn after Fall Herbicide
	Herbicide + mowing
8	Summer Mow after Spring Herbicide
9	Summer Mow before Fall Herbicide
10	Fall Mow after Spring Herbicide
11	Fall Mow after Fall Herbicide

The interactive look-up table can be used by land managers, conservation professionals, landowners, or any stakeholders interested in recommendations for the most effective combination of management treatments, according to the ecology-based MONDRIAN model simulations. The completion of the MONDRIAN look-up table marks the fulfillment of a major project outcome allowing managers to determine site-specific optimal treatment protocols for their specific site conditions.

In spring 2018, the MONDRIAN modeling team and other project participants met with members of the USGS GLRI PAMF (*Phragmites* Adaptive Management Program) project leads, trained them to use the MONDRIAN look-up table, and discussed similarities and differences with the PAMF state-transition model, which also provides concrete, site-specific advice to wetland managers to reduce *Phragmites* invasions. However, while MONDRIAN is based on ecology and plant-competition, PAMF State-Transition model learns from management actions. They are therefore complementary and provide modeled information from 2 different perspectives. The outcome of this meeting was a 1-page, web-based description of MONDRIAN and PAMF model similarities and differences, which will be completed in July 2018 and hosted at the Great Lakes Commission (GLC) website. We see this as being important for helping managers to recognize that the two tools have different strengths and weaknesses, and for use in future training sessions and webinars. A second outcome has been discussion about including the MONDRIAN outputs in future versions of PAMF.

k. Conduct data analysis to compare treatments in the sites:

k-1. Effects of treatment on Phragmites cover: To obtain estimates of treatment success from the field monitoring data, the measured pre-treatment *Phragmites* percent cover and the percentage of *Phragmites* cover that was dead during the 2017 surveys were compared across protocols. The satellite-based, site-wide land cover map was included in the comparison as the “ground truth”. Overall, the Tier 2 protocol produced estimates that were closer to the remotely sensed values than the Tier 1 estimates (mean percent error of 32.8% for Tier 2 vs. 43.1% for Tier 1, Figure 14). At the Saganing Casino Landing site, however, the placement of the Tier 2 transect did not intersect the small *Phragmites* patch, leading to an incorrect estimate of zero cover. Tier 1 “eyeball” estimates performed fairly well at small-area sites where most to all of the site was visible from the monitoring vantage point, with larger errors at larger sites.

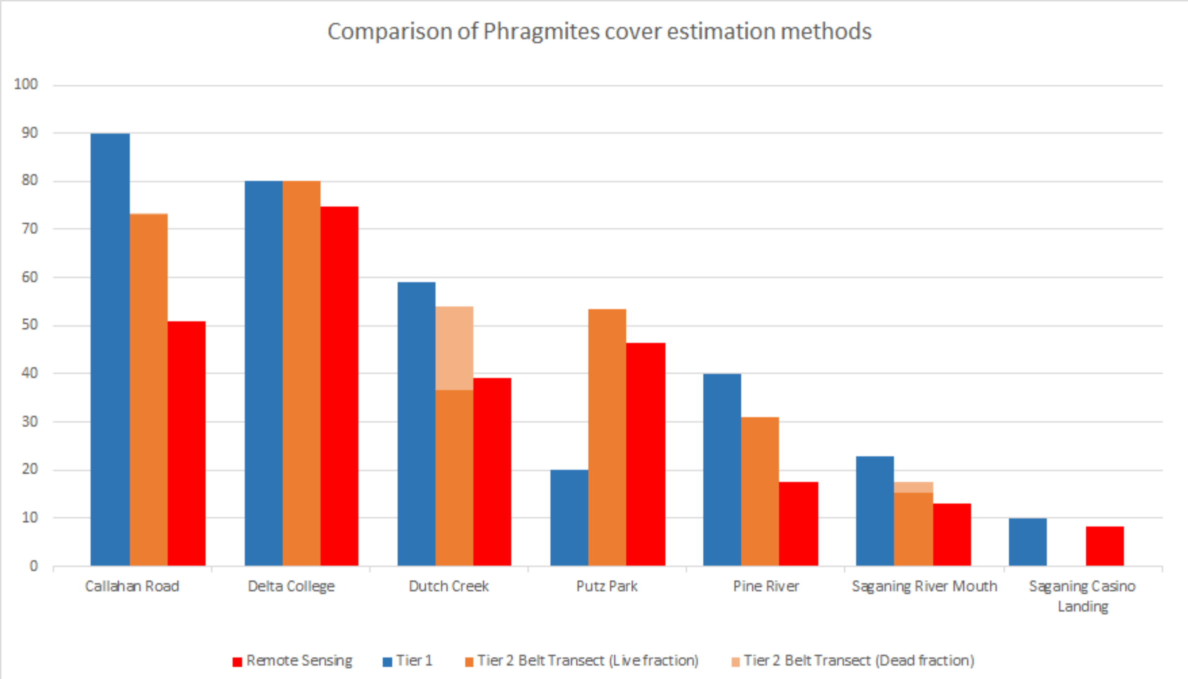

Figure 14. Comparison of *Phragmites* percent cover at study sites pre-treatment (2016) across different monitoring protocols and satellite-based "ground truth" for both MISGP and EPA sites (Callahan Rd, Dutch Creek, Delta College, and Putz Park).

Our working definition of treatment success required a reduction of *Phragmites* density by at least 60%. Across monitoring protocols, our results indicate that this goal was met for all treatment sites (Figure 15). Overall, the Tier 1 visual estimates of treatment success from a single vantage point on the ground were lower than transect-based estimates, perhaps indicating that observers are biased towards overestimating remaining *Phragmites* cover due to its height and visibility. Estimates of *Phragmites* kill were fairly consistent, though, (no significant differences) across estimation methods.

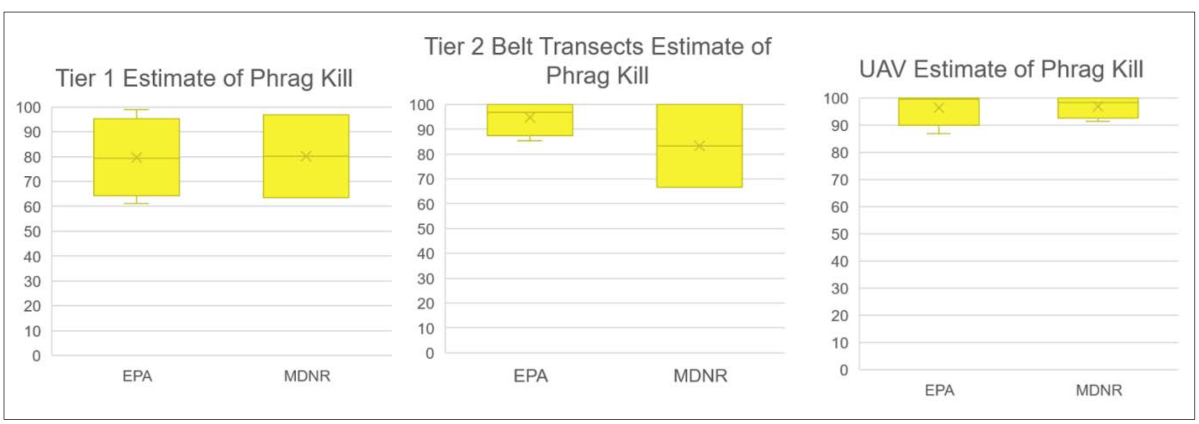

Figure 15. Estimates of *Phragmites* treatment success rates (percent) for this project (MDNR) and a related *Phragmites* treatment focused project in Saginaw Bay (EPA) based on Tier 1, Tier 2 and UAV data.

In addition to treatment success, each monitoring protocol provided additional information about the effects of treatment on the site. For Tier 1, this was primarily photo-based, along with the observer's judgement about the severity of the invasion's impacts on human use of the site, characterized as aesthetic and recreational impacts along with the severity of the safety hazard posed by the *Phragmites* patches (1 = mild impact, 2 = moderate, 3 = severe impact). These human impact values were not significantly affected before vs. 1 year after *Phragmites* treatment for the sites treated as part of this project (Figure 16, "MDNR"). This is in contrast with the sites treated as part of the separate EPA GLRI project, which exhibited significant decreases in impact severity across all three categories ("EPA"). We attribute this difference to biomass removal; the EPA sites were mowed after treatment and before the 2017 surveys were conducted, whereas the MDNR sites were not mowed prior to the 2017 monitoring.

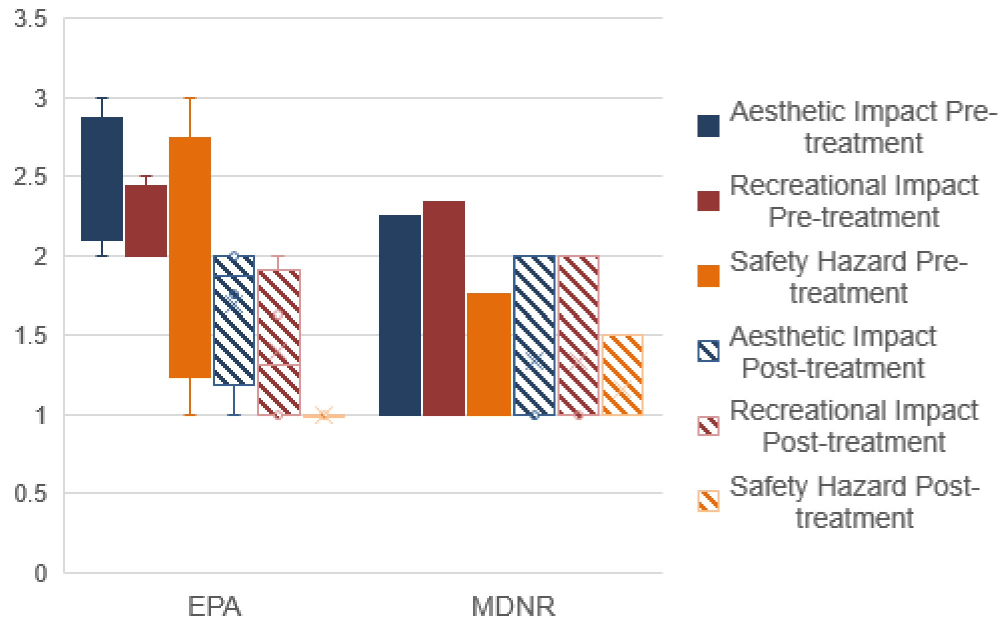

Figure 16. Observer-estimated severity of impacts on human use values caused by *Phragmites* presence for this project (MDNR) and another *Phragmites* treatment project that took place at a separate set of Saginaw Bay sites over the same period (EPA).

As discussed above in subsection e, the morphospecies-based diversity estimation included in the Tier 2 protocol as a simpler option for tracking change in diversity did not indicate a significant change in diversity between 2016 and 2017. The Tier 2 data also found no significant change in the percent cover of desirable (i.e., not invasive) vegetation (Figure 17).

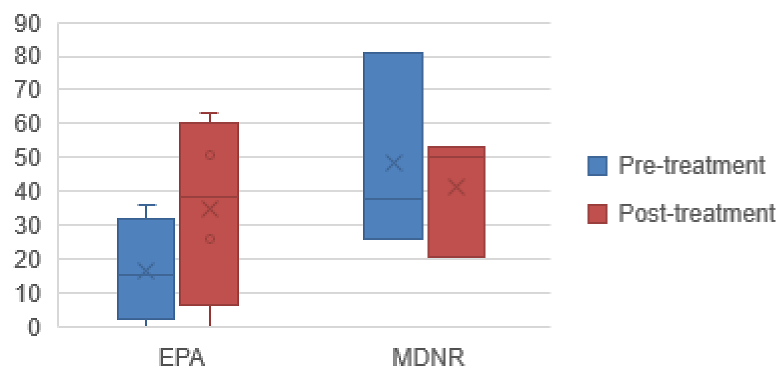

Figure 17. Percent cover of desirable vegetation estimated from Tier 2 protocol data. Percent cover did not change significantly between 2016 and 2017 for either treatment group.

Perhaps the most useful component of the Tier 2 protocol was the quadrat-based measurements of *Phragmites* stem count, height and stem diameter. Training observers on the collection of these measurements is simple, and these data can provide quantitative information about changes in *Phragmites* stem density and estimated above-ground biomass, which may be more sensitive metrics than percent cover. Above-ground biomass was estimated from the field measurements using an allometric equation developed for *Phragmites australis* by SERC (Lu et al. 2016). For our treatment areas, the biomass estimates indicate that although some *Phragmites*-dominated areas remained in 2017, the above-ground biomass had been almost completely eliminated relative to the initial values (Figure 18). However, long term control of *Phragmites* ultimately depends on depletion of the underground biomass (rhizomes), and effective measurement of the below ground biomass have not been perfected to date.

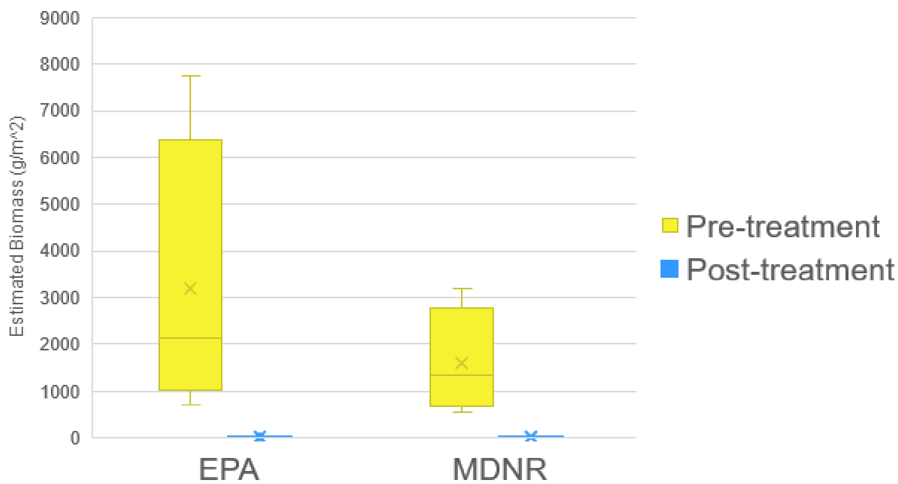

Figure 18. Changes in above-ground biomass of *Phragmites* at treatment sites 1 year after treatment.

With the detailed Tier 3 protocol monitoring data collected for the Hampton Twp, Saganing River and Vanderbilt sites, we can track more specific components of biodiversity in a reliable, replicable way. First, the Tier 3 data indicate that both total species richness and native species richness declined in the year following treatment for all three sites (Figure 19). This points to the value of longer-term monitoring datasets, as biodiversity increases can be expected to become apparent over a longer time scale where the native seed bank responds to *Phragmites* removal. During this study, many managers consistently remarked on the viability of the seedbank after removal of *Phragmites*, except in cases where imazapyr use had created "dead zones". However, it is important to monitor native species recovery in order to determine if additional action, such as native seeding may be needed. This has been the case for some sites in Utah, for example (Martin and Kettenring, 2018). The need for better understanding and clarification of the conditions and contexts for effective use of imazapyr is discussed further in Appendix 1.

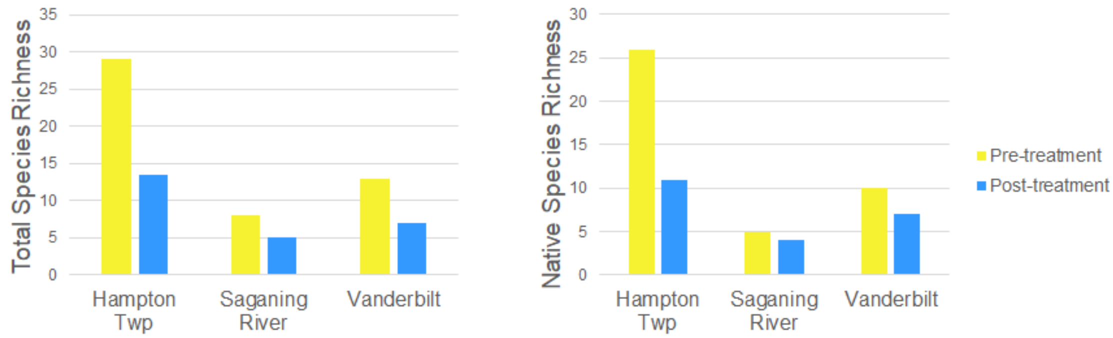

Figure 19. Total and native species richness at sites monitored using the Tier 3 protocol before and after treatment.

Natural areas can also be characterized by mean conservatism coefficient (Mean C) where species are assigned conservatism coefficients of 0 (generalists, invaders) to 10 (specialists, E/T/SC species) and the values of all species present are averaged. On this basis, *Phragmites* treatment did not appear to have a significant impact on the vegetation community (Figure 20). In other words, before treatment the assemblage of vegetation species present at these sites was moderately to highly tolerant of disturbance (Mean C ~ 2 to 5), and shortly after *Phragmites* treatment, fewer species were observed but they represented a similar disturbance tolerance. If these conservatism coefficients for individual species are weighted by their observed percent cover on the landscape, the pattern remains largely the same (Figure 20).

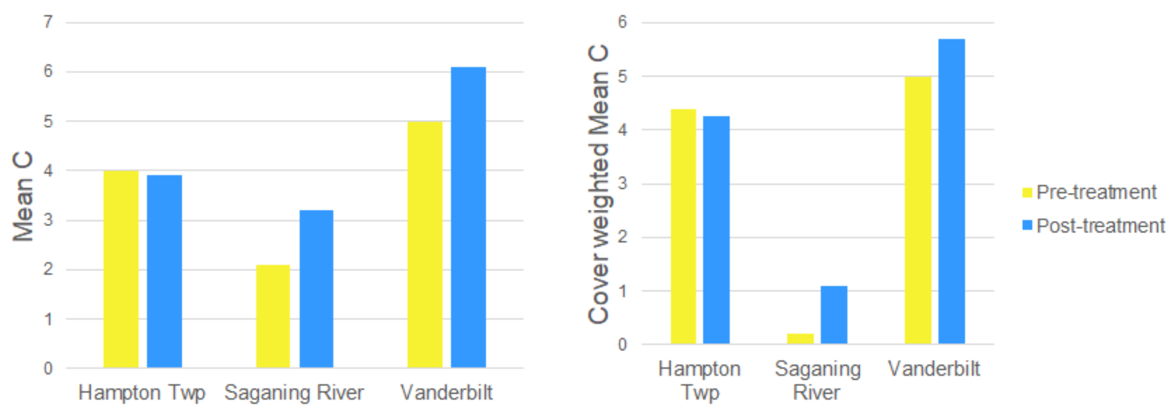

Figure 20. Mean C and cover-weighted Mean C at the Tier 3-monitored sites in 2016 and 2017.

Finally, the Adjusted Floristic Quality Index (FQI) may be the most appropriate single metric for assessing the response of the ecosystem to *Phragmites* treatment, as discussed in subsection e. For this project's treated and monitored sites, adjusted FQI appeared to increase slightly the year after treatment across all sites (Figure 21). More generally, managers interested in increasing the ecological quality of their lands could collect an initial year of pre-treatment data, then set a management goal for a specific increase in the initial adjusted FQI values. Adjusted FQI can also be integrated into an adaptive management framework, where a decrease in adjusted FQI following treatment would be a "red flag", signaling the need to adjust management because the current course of treatment is causing excessive disturbance such that native species recovery is diminished. Ideally, the MONDRIAN LUT could also be used to help refine management activities.

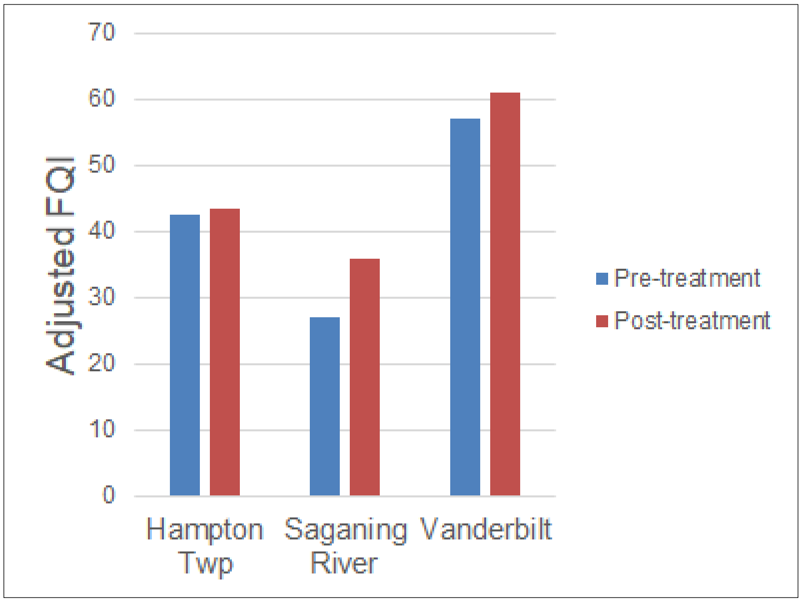

Figure 21. Comparison of adjusted FQI at the Tier 3-monitored sites before and after treatment.

l. Develop strategic prioritized plan for Saginaw Bay: The tasks of this project have allowed us to review the literature, conduct analyses of monitoring data collected pre- and post-treatment, consult stakeholders, and model connectivity and ecosystem outcomes from treatment to better understand the interactions. The outcomes of these activities that include expertise from field ecologists, remote sensing and geospatial analysts, land managers, stakeholders and modelers of landscapes and plant competition and response have led us to a set of guidelines for strategically managing the Saginaw Bay region, which is detailed in Appendix 4. A watershed approach is suggested that addresses both reducing nutrient loading while controlling invasive *Phragmites*. The guiding principles emphasize 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. We suggest use of the MONDRIAN look up table for best treatment strategies for site specific conditions and have specific guidelines for different types of infestation (i.e. outliers and leading edges, high restorability areas, low restorability areas, etc.). See Appendix 4 for full details.

A summary of the project tasks, who was responsible and the accomplishments is below.

Table 4. Project tasks, responsible investigator and task accomplishments. Italicized tasks are led by sister MISGP project to PI- Ogar.

Task	Responsible Investigator	Accomplishments
Kick-off Team Meeting – sister projects	All	Held in Bay City May 16, 2016
Quarterly team meetings via phone or in person	All	Quarterly webinars or in-person meetings were held throughout the project
Mobilize EDR Strike Team	*CISMA*	An Early Detection and Response (EDR) node was developed through the Bourgeau-Chavez EPA grant. This is housed on the MISIN and outreach was conducted in each year to Saginaw Bay stakeholders.
Map *Phragmites* and other coastal wetlands in treatment areas	Bourgeau-Chavez	Pre-treatment mapping completed for treatment sites, post-treatment mapping complete for Hampton. Need cloud free imagery for other sites, will be completed in summer 2018 as imagery becomes available. *A 2016 map was completed for the rest of the coastal bay through Bourgeau-Chavez EPA grant and is available for viewing and request for download here: http://geodjango.mtri.org/coastal-wetlands/*
Landscape modeling for watersheds with treatment sites	Billmire, Bourgeau-Chavez	N-loading and water level modeling was completed for all sites, connectivity modeling for determining riparian buffers was also completed for all sites. *Under EPA grant to Bourgeau-Chavez, a web viewer for locations of optimal riparian buffers across the bay and a publication (Billmire et al. in press) were produced.*
MONDRIAN **management modeling for treatment areas**	Elgersma, Martina, Currie	MONDRIAN look up table from large number of model runs was completed and web app developed. http://phraglut.mtri.org
Compile treatment protocols	Higman, Cronk, Vander Haar	Review of monitoring literature and discussions among land managers and project investigators was conducted throughout the project. Stakeholder meeting convened with funds from EPA grant to Bourgeau- Chavez gathered direct input from key managers in Great Lakes. Summary of meeting is posted on **http://mtri.org/phragmiteswetlandmanagementandscience.html** website . Overall summary of treatment protocols is in Appendix 2.
Work with CISMA to *Compile*	*CISMA, VanderHaar*	*A working definition of success was developed under EPA grant to Bourgeau-Chavez with the CISMA. Input provided from the EPA funded stakeholder meeting*

Task	Responsible Investigator	Accomplishments
Definitions of success		*confirmed that clear management goals and measures of success are often lacking and most only consider Phragmites kill.*
Compile monitoring protocols	Higman, MTRI, VanderHaar	Literature searches, discussions with project investigators, USGS GLRI PAMF project leads and managers were compiled. Input was also gathered from stakeholder meeting convened under Bourgeau-Chavez EPA grant. Summary of monitoring protocols reviewed is provided in Appendix 3. Meeting to tweak and finalize protocols for 2017 was convened in July 2017. Supplemented with EPA grant to Bourgeau-Chavez
Integrate model and data	All	2016 field data were integrated into the models.
Work with CISMA partners in monitoring protocols	Higman, Bourgeau-Chavez	Each year, training of CISMA was conducted by MNFI and MTRI. UAV imagery was collected for very long transects pre- and post-treatment.
Implement pre-treatment monitoring	*CISMA, MTRI, MNFI*	*Completed for 2016 treatments*
Implement Treatments	*CISMA*	*Herbicide in Sept 2016.*
Implement post-treatment monitoring	*CISMA, MTRI, MNFI, UNI*	*Completed July-August 2017*
Conduct follow-up treatments	*CISMA*	*Follow-up herbicide in Fall 2017, mowing of Hampton and Vanderbilt in winter 2018, burning was deemed unsafe for coastal bay sites.*
Process/analyze plant/soil samples	Elgersma (UNI)	Samples were dried by Delta College and processed and analyzed by UNI; results integrated into modeling.
Conduct data analysis to compare treatments in the sites	Grimm (MTRI)	Results presented during the May 2018 webinar and summarized in this report. Compilation with 2018 data from southern Saginaw Bay sites of EPA Grant to Bourgeau-Chavez will occur in Sept. 2018 and manuscript written for peer review.
Integrate results into the MISIN	Higman, MNFI	Treatment data from 2016-17 was entered into the MISIN.
Develop strategic prioritized plan for Saginaw Bay	All	Complete, presented in this report.
Document suite of definitions for success and monitoring protocols	Higman	Working definitions of success complete. Summary of monitoring protocols and corresponding analyses for a broad set of management goals. Input from the stakeholder meeting convened under the Bourgeau-Chavez EPA grant; follow-up discussions with meeting

Task	Responsible Investigator	Accomplishments
		participants and research colleagues, as well as results from 2016 treatments-Fall/Winter 2017-18, were used to refine the suite or protocols for this project. Additional input was sought during a panel discussion convened at The Stewardship Network Conference in January 2017 by co-Is Higman, Currie and Bourgeau-Chavez (under EPA grant to Bourgeau-Chavez).
Share project results	All	Data were shared between sister projects and other interested groups. 3 presentations were given at the 2017 IAGLR conference in May. Presentation was given at CISMA annual meeting in June 2017 and to DNR-DEQ- MDARD Quality of Life Core Team in Oct. 2017. 3 presentations were given at the Stewardship Network workshop in January 2018, one presentation at IAGLR in 2018 by Grimm and 2 webinars are planned for July and Fall 2018 with Great Lakes *Phragmites* Collaborative.
Write final report	Bourgeau-Chavez, All	Complete

2. *Discuss problems encountered during the grant period and how that interfered with meeting program/project objectives. [List N/A if no problem exists.]*

Some desired treatments were not conducted due to environmental, physical and/or safety constraints, e.g., fire was deemed unsafe for some sites, underwater cutting was not possible due to lack of contractors with scarce, expensive equipment. We learned that the logistics of getting land owner permissions, getting contractors lined up to do the work, and weather variables can alter the desired plans and most likely will alter them. We also learned of the potential for lack of timely access to commercial satellite imagery; some imagery was collected during cloud conditions that limited our ability to interpret and map the distribution of *Phragmites*.

3. *List remedies of the problem(s) indicated in item 2 and how they may be avoided in the future. [List N/A if not applicable]*

Alternate treatments were employed such as mowing instead of prescribed fire or treatments were conducted later than initially planned or in some cases, sites will be reassessed for next treatment cycle. Planning early is the best way to avoid issues with contractors and getting permissions. Bringing more landowners on board will require continued work to demonstrate the value of and the ability to conduct successful *Phragmites* control. Timely access to Imagery will likely get better in the future as additional platforms are launched.

4. *Discuss the rate of expenditure versus progress on project. Did your original budget allow you to accomplish the goals of the project? Please describe any budgetary problems you encountered and how those could be alleviated in the future.*

There were no issues with the project progress and rate of expenditure, other than the need for an extension to give one of the sub-awardees, who transferred to a new University mid-project, additional time to complete the work.

5. *Provide information on equipment purchased for the grant and how it was utilized to meet project goals. NA*

6. *Discuss steps taken to ensure activities conducted did not contribute to the spread of invasive species*.

The CISMA monitoring staff was trained in decontamination procedures and implemented them during monitoring. Following MDEQ, MDARD, and MDNR decontamination protocol "Invasive Species Decontamination for Field Operations in Michigan", we determined that our risk of spread is low this year because all sites were infested. We followed the recommended protocol for low risk decontamination, which is as follows:
We pulled off all visible vegetation possible from ourselves and our equipment.
We carried a 5 gallon container of water, a rubber horse trough and a scrub brush with us, so we could stand in the trough and use the water and scrub brush to wash off any vegetation or sediment from our waders.
We had Clorox wipes to carefully wipe off sensitive equipment like GPS, cameras and compasses.

7. *Describe any post-completion activities that will be the responsibility of the GRANTEE*.

Worldview-2 imagery will be downloaded for summer 2018 when and if cloud free imagery becomes available for all 4 study sites and post-treatment map classifications will be produced and shared with stakeholders including the SB-CISMA and PI Ogar for the sister project.

Data from EPA grant sites south of the MISGP study area will be collected this summer on biodiversity and UAV imagery over one transect of Dutch Creek. These data along with the MISGP site data will be used to do a final analysis of the biodiversity changes post-treatment and written in journal article form and submitted for peer review in the fall (see Grimm et al. in prep, below).

Webinars will be held with the Great Lakes *Phragmites* Collaborative on (1) the MONDRIAN model (Look up table and user friendly version of the full model produced under the EPA grant to PI Bourgeau-Chavez); 2) Results of this and the EPA grants including the tools created, monitoring protocols developed and the outcomes of the biodiversity analysis. The first webinar is scheduled for July 25, 2018.

8. *Describe any plans for continuing activities funded under this grant in the future.*

Beyond the EPA grant funded through September 2018, we continue to look for grant opportunities to continue to develop the tools and apply the holistic approach to the watershed scale in *Phragmites* infested areas. We are working with TNC in areas where they are reducing nutrient loading to test the idea that reduction of N-loading will improve management outcomes in the long term. We continue to have relevant discussions with TNC, USGS, Bay County, USFWS, DNR and other collaborators and folks working on restoring *Phragmites* infested areas to pre-invasion systems and reducing nutrient loads to the Bay. We are currently implementing a GLFWRA-funded project to compare the effects of managed *Phragmites* and unmanaged *Phragmites* on 16 vulnerable coastal wetland birds. We will compare the use of monitoring protocols tied to our management goal of sustaining or increasing bird use and plant diversity, to those tested in this grant. We met in June with USGS and GLC on PAMF and how the two projects and the MONDRIAN LUT tool in particular could and should be incorporated into PAMF in the future. PAMF uses a state-transition model to learn from management actions, whereas MONDRIAN is an ecosystem, plant competition model rooted in ecology and focused on understanding mechanisms of invasion. They provide two different aspects for control of invasive *Phragmites* control and are complementary to each other.

GRANTEE Statement of Project Completion

Statement	Signature of GRANTEE
All relevant data uploaded to MISIN	
All other required documents attached or located in project file	
Project completed in accordance with the DEPARTMENT-approved Budget and Work Plan	

DEPARTMENT Statement of Project Completion

Statement	Signature of DEPARTMENT representative(s)
I have received and approved the GRANTEE's Final Report Documents, including the Final Performance Report, Financial Status Report, and Final Reimbursement Request. I certify that the project has been completed within the project period and as described in the executed grant agreement (including any amendments executed between the DNR and the grantee).	
	Technical: Signature, Division, Department (Final Report)
	Date
	Grants Management (Financial Status/Final Reimbursement)
	Date

Outreach Materials

University Course Material

- **University of Northern Iowa**: Designed / implemented a Biostatistics lab for students at Univ. of Northern Iowa to understand and interpret MONDRIAN model results
- **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.
- **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.
- **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.

Articles/Press Release/Conference Presentations

Online Article/Press Release

- **Fighting invaders with drones and fungi**. By Natasha Blakely | September 30, 2016. Great Lakes Echo. **http://greatlakesecho.org/2016/09/30/fighting-invaders-with-drones-and-fungi/**

Conference Presentations and Workshops

- **International Association of Great Lakes Research (IAGLR) conference in Detroit, MI,** 15-19 May 2017 Three oral presentations in the special session on "Binational and regional cooperation on invasive plant management - the case of *Phragmites*"
  - 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.
  - 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.
  - 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.
- **International Association of Great Lakes Research (IAGLR) conference in Toronto, ON, CA,** 18-22 June 2018
  - 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. International Association of Great Lakes Research (IAGLR) conference in Toronto, ON, CA, 18-22 June 2018.
- **Core Team Presentation**
- Bourgeau-Chavez, L.L., P.J. Higman. Comprehensive Invasive *Phragmites* Management. October 31, 2017.
- **Stewardship Network Workshop – 3 presentations**
  - Higman, P.J., L.L. Bourgeau-Chavez, W.S. Currie. Sharing Insights on *Phragmites* Management. 1. Introduction to EPA and MISGP projects, 2. Using high resolution drones and satellite imagery and drones to monitor *Phragmites* treatments, 3. MONDRIAN wetland modeling, 4. Tiered monitoring protocols, followed by discussion.

Peer-reviewed Articles

- Billmire, M., B. Koziol. (**in press**). Landscape and flow path-based nutrient loading metrics for evaluation of in-stream water quality in Saginaw Bay, Michigan. Journal of Great Lakes Research.
- 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.
- 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.

Project Website:
http://mtri.org/misgp-phrag-management-planning.html

Comparison of MISGP to EPA project:
http://mtri.org/*Phragmites*wetlandmanagementandscience.html

URL for MONDRIAN **Quick Reference/LUT:**

https://sites.google.com/uni.edu/*Phragmites*lookuptable

Direct temporary link to the interactive tool:

http://phraglut.mtri.org/

Attached are appendices as listed below**:**

References:

Abadie, J.C., Andrade, C., Machon, N. and Porcher, E., 2008. On the use of parataxonomy in biodiversity monitoring: a case study on wild flora. *Biodiversity and Conservation*, *17*(14), pp.3485-3500.

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Martin, Emily and K. Kettenring. 2018. Seed-based revegetation following *Phragmites australis* control. Webinar presented by of Utah State University for the Great Lakes *Phragmites* Collaborative, live on March 28. https://www.greatlakesphragmites.net/resources/webinars/

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