Vegetation and marsh bird relationships with invasive *Phragmites australis* occurrence and management in Saginaw Bay, Lake Huron

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29 July 2022

MNFI Report No. 2022-15

Michigan Natural Features Inventory
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Suggested Citation:

Monfils, M. J., R. A. Hackett, P. J. Higman, and J. R. Heise. 2022. Vegetation and marsh bird relationships with invasive *Phragmites australis* occurrence and management in Saginaw Bay, Lake Huron. Michigan Natural Features Inventory, Report No. 2022-15, Lansing, MI.

Cover: Coastal marsh dominated by invasive *Phragmites australis* on Saginaw Bay. Photo by M. J. Monfils.

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EXECUTIVE SUMMARY

The rapid expansion of invasive common reed (*Phragmites australis* subsp. *australis*) in the Great Lakes region has raised concerns about impacts to plant and animal communities, wetland functioning, and ecosystem services. Despite these concerns, assessments of the effects of invasions and effectiveness of control efforts remain limited. Our goal was to investigate the effects of invasive *Phragmites* on plant communities and bird species of conservation concern and assess the success of control efforts through comparisons with reference wetlands on Saginaw Bay, Lake Huron. Three objectives guided our study: 1) compare plant diversity metrics and structural variables among managed *Phragmites*, unmanaged *Phragmites*, and reference wetlands; 2) compare marsh bird use among the same three wetland categories; and 3) explore potential associations between bird use and vegetation/wetland variables to help explain patterns among the three wetland categories. Knowledge gained from this study could inform future coastal wetland restoration efforts.

We implemented the study in managed *Phragmites*, unmanaged *Phragmites*, and reference wetlands within nine areas owned by governmental entities on Saginaw Bay. Vegetation and marsh bird surveys were conducted at 87 randomly selected points (35 managed, 27 unmanaged, and 25 reference points) separated by at least 400 m to ensure independence. We conducted vegetation sampling within three 0.25-m^2 quadrats randomly located within 25 m of each point. In each quadrat we measured water depth, organic soil depth, maximum vegetation height, percent cover of vegetation structural categories, percent cover of litter, percent cover of each species present, shrub density, and stem density of invasive *Phragmites*. We conducted three morning marsh bird surveys per year from early-May to mid-June at each point following the Standardized North American Marsh Bird Monitoring Protocols. We recorded detections of nine primary target species (e.g., grebes, bitterns, rails), and seven secondary target species (e.g., selected songbirds, marsh-nesting terns).

We examined patterns in plant species assemblages among sample points and wetland categories using non-metric multidimensional scaling (MDS) and compared individual vegetation variables among the three wetland categories using mixed-effect models. For bird data, distance sampling models were developed for six marsh bird species to assess the effect of distance from the observer and covariates on detection probability. We used mixed models to compare the abundance of eight bird species among the three wetland categories. Abundance-induced heterogeneity models, which incorporate imperfect detection probabilities, were used to estimate bird abundance and occupancy by wetland category for the same eight species. Finally, stepwise logistic regression was performed to evaluate the influence of vegetation covariates on bird species occurrence.

Over three years of data collection, we sampled 711 0.25-m^2 vegetation quadrats across the 87 points. Data from quadrats were averaged by sample point and year prior to analysis, resulting in 237 sample events at the 87 points over the three years. We identified 133 plant species across all years and wetland categories, with 102 species recorded at managed *Phragmites* points, 35 species at unmanaged *Phragmites* points, and 86 species at reference points. Our MDS analysis indicated most unmanaged *Phragmites* points were negatively associated with the first and second axes and positively associated with the third, indicating the dominance of invasive *Phragmites*. We observed substantial overlap across the three axes between managed *Phragmites* and reference points suggesting similar plant assemblages.

Our analyses revealed managed *Phragmites* points had more than double the percent cover of submersed plants than unmanaged *Phragmites* for all three years of sampling, and eight of the

top ten most abundant species at managed *Phragmites* points were submersed species. Percent cover of submersed species at reference points was similar to unmanaged *Phragmites* in 2018, but in 2019 and 2021, the percent cover of submersed species in reference plots more closely resembled that of managed *Phragmites*. Mixed-model analysis indicated no significant difference species richness (*S*) or percent cover of European frog-bit among wetland categories, but the other variables did differ by wetland category. We found greater invasive *Phragmites* percent cover and stem density at unmanaged *Phragmites* compared to the other categories, but the variables were similar between managed *Phragmites* and reference sites. Unmanaged *Phragmites* points had significantly lower mean Shannon diversity (*H'*) and floristic quality index (*FQI*) than the other two wetland categories. Managed *Phragmites* and reference sites had similar mean *H'* and *FQI* estimates. Our study indicates that *Phragmites* treatments in Saginaw Bay coastal wetlands were successful in reducing percent cover and stem density of *Phragmites* through four years post-treatment. Above-average Lake Huron water levels during and after herbicide treatments likely contributed to the successful reduction in *Phragmites* cover.

Across the three years of sampling, we conducted 646 marsh bird point counts at the 87 random points (286 at managed, 171 at unmanaged, and 189 at reference points). Fifteen primary and secondary target bird species were detected, with 14 species observed in managed *Phragmites* and reference wetlands and 13 species in unmanaged *Phragmites* sites. Abundances of American bittern, least bittern, common gallinule, marsh wren, and swamp sparrow were lower in managed compared to unmanaged *Phragmites* wetlands. Pied-billed grebe and common gallinule were most abundant at reference points, whereas abundances of American bittern, least bittern, Virginia rail, marsh wren, and swamp sparrow were similar between reference and unmanaged *Phragmites*. Swamp sparrow was the only species most abundant at our low-water reference points. Our findings indicate that *Phragmites*-dominated coastal wetlands on Saginaw Bay support several marsh-dependent species during high water levels at abundances similar reference sites. For some species, abundance in unmanaged *Phragmites* during this study was greater than what was detected at reference sites during low Lake Huron levels. Logistic regression indicated the occurrence of several bird species was associated with percent cover of open water, *Utricularia*, *Typha*, and *Phragmites*. Forster's tern occurrence was negatively related to percent cover of *Phragmites*, whereas occurrence of American bittern, least bittern, common gallinule, and marsh wren was positively associated with *Phragmites* cover. Our research suggests management followed by high lake levels and slow regrowth of emergent vegetation resulted in a short-term loss of nesting habitat for species requiring dense vegetation; however, given the similarity of plant assemblages between managed and reference sites, we expect marsh bird use at managed sites will increase to levels similar to reference wetlands as emergent plants regenerate.

This study highlights the challenges presented by invasive species management and assessment in degraded systems such as Saginaw Bay. Ecosystem attributes are likely interrelated with multiple invasive and native species, making evaluation of outcomes complicated. Without long-term monitoring, assessment of management over short periods could be difficult as ecological processes, such as water level fluctuations, could have greater influence on plant and animal populations. Though evaluations of management actions should include comparisons with reference ecosystems, it may not be possible to find references unaffected by invasive species and other impacts in degraded systems. We recommend invasive species management take a multispecies approach with a goal of functional eradication that is supported by concurrent long-term monitoring.

INTRODUCTION

Invasive populations of common reed (*Phragmites australis* subsp. *australis*, henceforth *Phragmites*) have been spreading across North America (Saltonstall 2002), with rapid expansion observed in Great Lakes coastal wetlands during an extended period of below average lake levels from the 1990s to mid-2010s (Tulbure et al. 2007, Whyte et al. 2008, Tulbure and Johnson 2010). The expansion of invasive *Phragmites* in the Great Lakes region has brought about dramatic changes to large coastal wetland complexes that provide an array of ecosystem services. Potential effects to these services have made *Phragmites* research, monitoring, and control efforts a priority in state and regional conservation plans (Wires et al. 2010, Michigan Department of Environmental Quality 2014, Derosier et al. 2015, Soulliere et al. 2018).

Despite concern about the effects of *Phragmites* to biodiversity and other wetland services in the Great Lakes, limited research has been completed on the ecosystem effects of invasions and effectiveness of control efforts. In a review of 34 studies completed in the United States to assess *Phragmites* management, only seven occurred in the Great Lakes region (Hazelton et al. 2014), of which five were in Lake Erie (Back and Holomuzki 2008, Kulesza et al. 2008, Carlson et al. 2009, Back et al. 2012, Lazaran et al. 2013), one in Lake St. Clair (Getsinger et al. 2006), and one in Lake Michigan (Plentovich 2008) coastal wetlands. Most invasive plant species management studies quantify the effectiveness of the treatment in terms of reduction of the target invasive species, including studies of invasive *Phragmites* treatment in the United States (Hazelton et al. 2014). Few studies have examined the restoration of habitat or related taxa of the managed areas relative to non-invaded reference areas (Neckles et al. 2002, Carlson et al. 2009, Kettering and Adams 2011, Abella 2014, Hazelton et al. 2014). The few studies that investigated bird use of invasive *Phragmites* in the Great Lakes region produced mixed results (Meyer et al. 2010, Lazaran et al. 2013, Lupien et al. 2015, Whyte et al. 2015, Robichaud and Rooney 2017).

Substantial expansions of *Phragmites* have occurred in Michigan's lakeplain prairies, wet meadows, and Great Lakes marshes, which are known to harbor rare plant and bird species. An influx of funding for wetland conservation provided by the Great Lakes Restoration Initiative and other sources has resulted in many control projects in Michigan's large wetland complexes, such as those along and near Saginaw Bay. However, these projects tend to occur ad hoc, lack coordinated landscape-scale planning, and rarely have clear goals or success metrics. Furthermore, funds for follow-up monitoring are limited, and when monitoring does occur, it often focuses on *Phragmites* only and ignores other ecosystem attributes. Ruiz-Jaen and Aide (2005) recommended studies of restoration success evaluate three ecosystem attributes (diversity, vegetation structure, and ecological processes) and include at least two reference sites. Research is needed to better understand the effects of invasive *Phragmites* on plant and bird communities and to determine if management is achieving desired outcomes.

We investigated the effects of invasive *Phragmites* on plant assemblages and bird species of management concern and the success of control efforts as compared to reference wetlands dominated by native plant species along the coast of Saginaw Bay, Lake Huron. Saginaw Bay was chosen as the study area for several reasons: 1) both well-established *Phragmites* stands and relatively unaffected reference sites were present; 2) the region supports unique plant communities and breeding marsh birds of conservation concern; and 3) there were active *Phragmites* control projects providing opportunities to assess management actions. We addressed three research objectives in this study: 1) compare plant composition and structural variables among managed *Phragmites*, unmanaged *Phragmites*, and reference wetlands; 2) compare marsh bird use among the same three wetland categories; and 3) explore potential associations between bird and plant variables and wetland characteristics to help explain patterns among the three wetland categories. Knowledge gained about the influence of *Phragmites* on plant and bird communities and success of control efforts could inform ongoing and future coastal wetland restoration efforts.

METHODS

Sample Design

We selected study sites in consultation with the Michigan Department of Natural Resources (DNR) and other partners working to manage invasive *Phragmites* in Saginaw Bay. Our goal was to identify a minimum of three areas within each of three wetland categories (≥ 9 sites total): managed *Phragmites*, unmanaged *Phragmites*, and reference. Managed wetlands sampled in this study were invasive *Phragmites* monocultures aerially treated with a combination herbicide of glyphosate and imazapyr in 2017 with standing dead stems removed prior to sampling, either through mechanical treatment, wave action, and/or ice scour. Unmanaged *Phragmites* sites were emergent wetlands dominated by invasive *Phragmites* (> 50% percent the total emergent cover) with no management occurring within the previous five years. Reference sites were emergent wetlands best representing conditions prior to invasion, having percent cover of invasive *Phragmites* less than 25% of the total emergent vegetation cover. Although other invasive species, such as narrowleaf cattail (*Typha angustifolia*) and hybrid cattail (*T.* ×*glauca*), occurred in the reference wetlands, these sites most closely resembled the structure and species composition of coastal marshes occurring before invasion. Wetlands with artificial water level control (e.g., dikes, control structures, pumps) were not included to avoid confounding factors that could influence plant and bird occurrence.

Sampling was conducted on several government-owned lands, which contained the largest wetland complexes on Saginaw Bay and where management efforts have been focused. We digitized potential study areas by wetland category using GIS and field visits. Sampling occurred within eight managed *Phragmites* ($\bar{x}$ = 41.3 ha, SE = 19.3 ha), three unmanaged *Phragmites* ($\bar{x}$ = 146.4 ha, SE = 27.4 ha), and seven reference ($\bar{x}$ = 36.4 ha, SE = 10.1 ha) sites (Figure 1). The closest distance separating two study areas was 0.8 km, with the average minimum separation distance between study areas being 2.5 km. Our study areas occurred in the following properties: Fish Point State Wildlife Area (SWA), Hampton Township Park, Nayanquing Point SWA, Pinconning County Park, Quanicassee SWA, Saginaw Chippewa Indian Tribe (SCIT) properties, Vanderbilt County Park, Wigwam Bay SWA, and Wildfowl Bay SWA (Figure 1).

We created random survey points within each study site polygon around which plant and bird sampling would occur, with a goal of having at least 25 points within each of the three wetland categories. For each potential survey point, we used aerial imagery to examine the wetland category, accessibility, and distance from other points (≥ 400 m spacing required [Conway 2011]). Preliminary points identified via GIS were then ground truthed in the field to confirm accessibility and the wetland category classification (i.e., managed *Phragmites*, unmanaged *Phragmites*, or reference). Survey points deemed unsuitable based on wetland classification or accessibility were dropped from the sample frame.

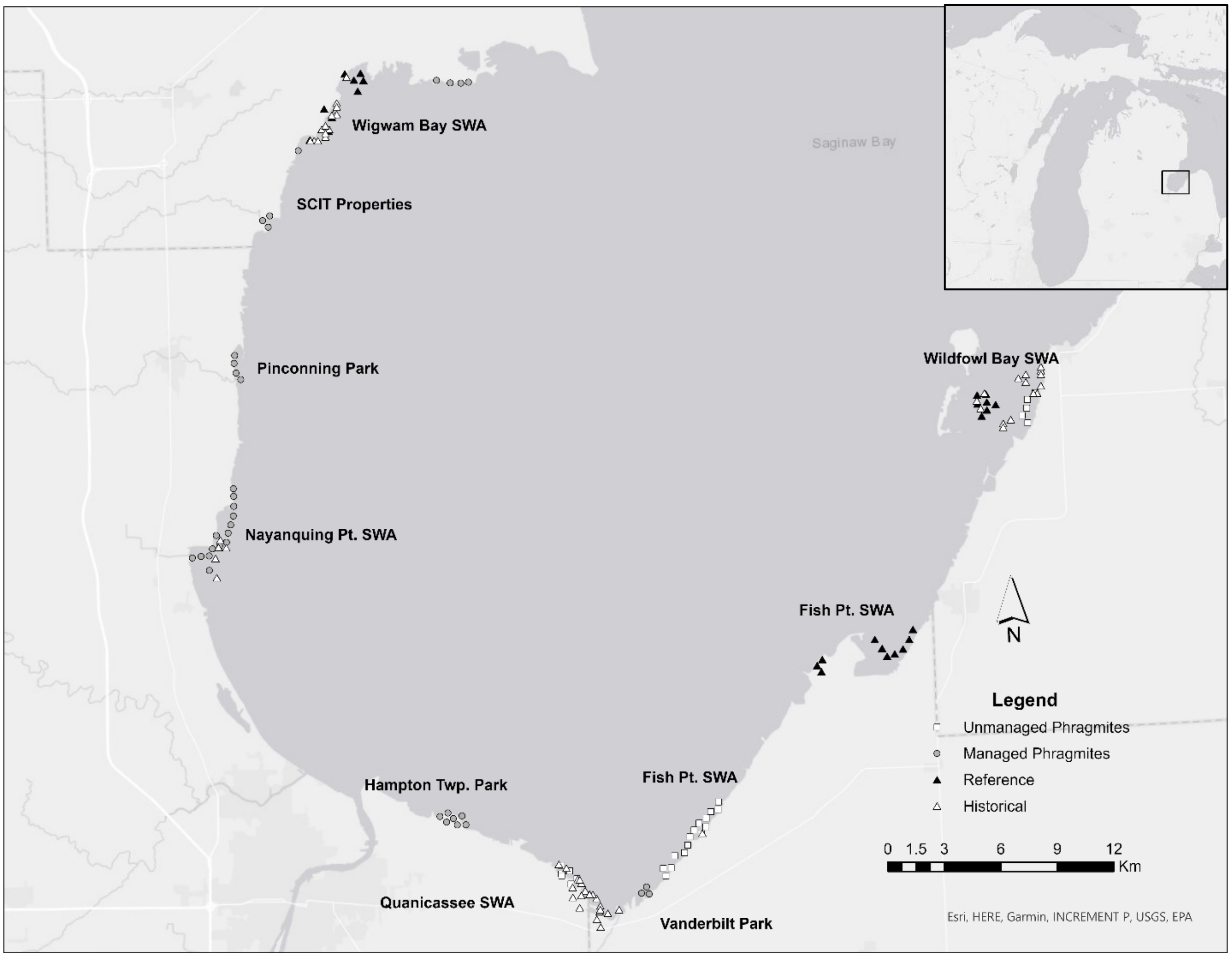

Figure 1. Locations surveyed for vegetation and marsh birds in Saginaw Bay, Lake Huron, coastal wetlands during 2018-2021 by wetland category.

Our study was influenced by two factors beyond our control – Great Lakes water levels and the global coronavirus pandemic. The Great Lakes are dynamic systems with water levels varying seasonally, annually, and over longer-term climatic cycles, with fluctuations heavily influencing the biology and ecology of associated ecosystems. The years during which this study took place were some of the highest water levels in the Great Lakes in decades (Figure 2). Although not likely to affect established invasive *Phragmites*, some studies have shown flooding can reduce the spread of *Phragmites* and increase native plant species, whereas lower water levels that expose substrates can increase *Phragmites* invasion (Burdick et al. 1997, Warren et al. 2002, Buchsbaum et al. 2006, Konisky et al. 2006, Tulbure et al. 2007, Tulbure and Johnston 2010, Chambers et al. 2012, Diers and Richardson 2012, Buschsbaum 2021). Although water depths measured during habitat sampling differed by year, we found no significant difference in depths among wetland categories within a year (Figure 3). Treatment of our managed *Phragmites* sites occurred in 2017 during a period of above-average water levels that began in 2015 and continued through 2021 (Figure 2). Water levels observed in 2019 and 2020 approached the maximum water level recorded for Lakes Michigan and Huron in October 1986. Above-average water levels during this study likely affected plant and marsh bird assemblages across all sites, but especially at *Phragmites* treatment sites where deep water probably slowed the reestablishment of vegetation post management. Travel restrictions and administrative delays associated with the global pandemic forced us to postpone the third year of sampling planned for 2020 until 2021.

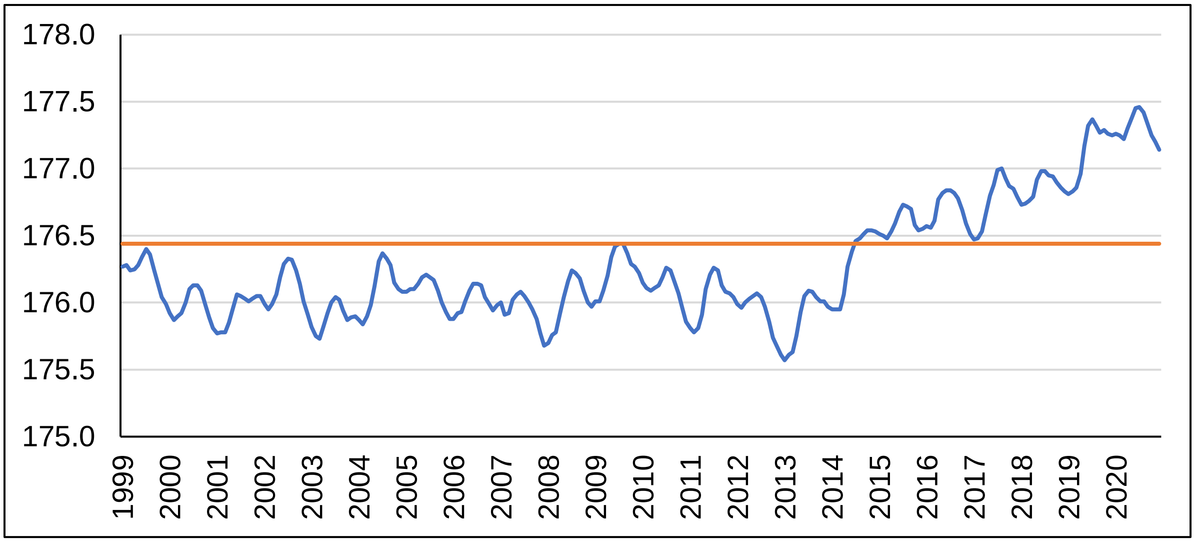

Figure 2. Average monthly water levels in meters (blue line, International Great Lakes Datum 1985) for Lakes Michigan and Huron during 1999-2020. The red line indicates the average annual mean (1918-2020). Source: NOAA Great Lakes Environmental Research Laboratory.

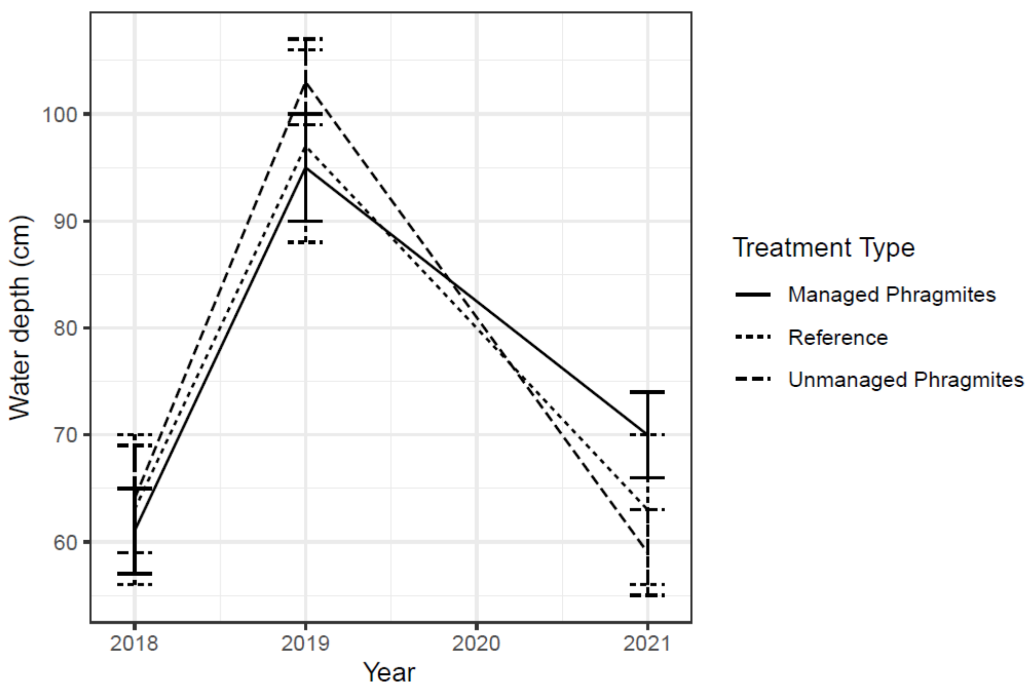

Figure 3. Variation of water depth among wetland categories across years of vegetation sampling. The whiskers at each year represent the standard error of the mean water depth by wetland type.

Vegetation and Wetland Characteristics

Vegetation and wetland characteristics were measured through onsite quadrat sampling according to Monfils et al. (2014a). Three randomly selected 0.50 m × 0.50 m (0.25 m^2) quadrats were sampled within 25 m of each randomly selected point. Quadrats were surveyed at a random distance between 1 m and 25 m along three compass bearings (i.e., 0°, 120°, and 240°). Sampling occurred in July or August in 2018, 2019, and 2021 after maturation of the plant community. We measured the following variables: water depth; depth of organic soil; maximum vegetation height; percent cover of vegetation structural categories (e.g., emergent, floating, submersed); percent cover of litter; percent cover of each species present; shrub density (> 2 m tall and within 2.5 m of quadrat center [Riffell et al. 2001]); and number of stems of invasive *Phragmites*, *Schoenoplectus*, and *Typha*. A complete list of data recorded can be found in Appendix A. Taxonomic nomenclature of plant species follows Michigan Flora (Reznicek et al. 2014). Algae species except for starry stonewort (*Nitellopsis obtusa*) were categorized as "Other". Starry stonewort was singled out because of its invasive status and abundance in the Saginaw Bay region.

Marsh Birds

We completed three marsh bird surveys each year during the breeding season (mid-May to late June) at the same randomly selected points at which vegetation sampling occurred. Surveys were conducted according to the Standardized North American Marsh Bird Monitoring Protocols (Conway 2011), which were tailored for use in the Michigan (MiBCI 2015). Surveys were done in the morning between 30 minutes before to 3 hours after sunrise. Point counts lasted 10 min and consisted of an initial five-min passive listening period followed by one-min broadcast periods for five secretive marsh bird species: Least bittern (*Ixobrychus exilis*), sora (*Porzana carolina*), Virginia rail (*Rallus limicola*), king rail (*Rallus elegans*), and American bittern (*Botaurus lentiginosus*,). Calls were broadcasted using an MP3 player and portable speaker (iMainGo 2, Ultimate Ears Wonderboom 2) at the recommended sound pressure of 80-90 dB at one meter from the speaker.

We recorded detections of nine "primary" target species (pied-billed grebe [*Podilymbus podiceps*], American bittern, least bittern, Virginia rail, sora, king rail, American coot [*Fulica americana*], common gallinule [*Gallinula galeata*], and Wilson's snipe [*Gallinago delicata*]), and seven "secondary" target species (Sandhill Crane [*Antigone canadensis*], Black Tern [*Chlidonias niger*], Forster's Tern [*Sterna forsteri*], Sedge Wren [*Cistothorus platensis*], Marsh Wren [*Cistothorus palustris*], Swamp Sparrow [*Melospiza georgiana*], and yellow-headed blackbird [*Xanthocephalus xanthocephalus*]). Observations of primary target species were recorded by individual bird across each minute of the 10-min survey and the distance at first detection was estimated to the nearest 5 meters with aid of a laser rangefinder. Secondary species were tracked at the species level, with only the period of first observation of the species noted and the total number of individuals were recorded within three distance bins (0-50 m, > 50-100 m, and > 100 m).

Analysis

Vegetation

Plant Species Assemblages: To visualize patterns in vegetation assemblages among the three wetland categories (i.e., managed *Phragmites*, unmanaged *Phragmites*, and reference), we analyzed the plant taxonomic species and mean percent cover per point per year using non-metric multidimensional scaling (MDS). To minimize the effects of rare species on the MDS analysis, species having less than 10 occurrences across all years of sampling were removed, and then points having no species in a given year were also removed (Appendix B). Percent cover values underwent arcsine square-root transformation to produce a more normal distribution. We used the Bray-Curtis dissimilarity distance matrix as it is recommended for use with community data (McCune and Grace 2002). McCune and Grace (2002) stated MDS models should have convergence and low stress values of less than 0.2 (on a scale from 0 to 1). A Monte Carlo permutation test was run to assess the significance of species in the MDS. MDS and related analyses were conducted using R package "vegan" and "vegan3d" using the statistical program R (v. 4.1.2; Oksanen et al. 2018, 2020, R Core Team 2021).

Mixed Models: Mixed models were used to examine differences in several plant community metrics among wetland categories while accounting for potential variation by location and year. For response variables, measurements taken among three vegetative quadrats at a point count in one year were pooled. The mean of those measurements was used in further analyses, except for invasive *Phragmites* stems present, which was summed. We analyzed the following variables: percent cover invasive *Phragmites*, number of invasive *Phragmites* stems, percent cover European frog-bit, percent cover submersed plants, total species richness (*S*), Shannon Diversity Index (*H'*; Shannon and Weaver 1949), and Floristic Quality Index (FQI; Herman et al. 2001). For FQI, non-native species were assigned a coefficient of conservatism value of zero.

Wetland category (i.e., managed *Phragmites*, unmanaged *Phragmites*, and reference) was a fixed effect in all our models. Three models were run and Akaike's Information Criterion (AIC) values compared: 1) linear model without any random effects, 2) linear mixed model with location as the random effect, and 3) linear mixed model with location:year as random effect. Location was recorded as the larger site or property in which the point was located, with Fish Point SWA split into northern and southern sections, which held reference and unmanaged *Phragmites* sites, respectively. In the best fit model, wetland categories were examined with repeated ANOVA and pairwise using Tukey Test. Linear, linear mixed model, and related analyses were conducted using R package "lme4" using the statistical program R (v. 4.1.2; Bates et al. 2015, R Core Team 2021).

Birds

Distance Sampling: For species for which we estimated exact distances to individuals (pied-billed grebe, bitterns, rails), we used distance sampling (Buckland et al. 2001) to assess the effect of increasing distance from the observer to detection probability. This analysis also allowed us to evaluate if covariates (e.g., wetland category, % cover of *Phragmites*) influenced detection functions. Six species had at least the 60-70 minimum detections recommended by Buckland et al. (2001) to conduct distance sampling: pied-billed grebe, American bittern, least bittern, sora, Virginia rail, and common gallinule. We did not have enough detections to permit analyses by year, so observations for each species were combined across years. We first compared four commonly used models (Thomas et al. 2010): uniform key with cosine adjustments, half-normal key with cosine adjustments, half-normal key with Hermite polynomial adjustments, and hazard-rate key with simple polynomial adjustments. The model type best supported by the data according to AIC value was incorporated into subsequent models. We then ran models with each of the following single detection covariates: wind (Beaufort index), ambient noise rating (0-4), wetland category (i.e., managed, reference, and unmanaged), water depth, percent cover of emergent vegetation, and percent cover of *Phragmites*. The final best-approximating model was selected using AIC. Models were developed and run using Distance 7.3 (Thomas et al. 2010).

Mixed Models: We used a linear mixed model to compare mean bird species abundance per point among our wetland categories. Sora, American coot, and black tern were excluded from this analysis as they were rarely detected (i.e., at < 5% of the points). To minimize the effects decreasing detection probability with increasing distance from the observer, we selected distance boundaries within which each species was readily detected according to our distance models. For pied-billed grebe, American bittern, and least bittern, we used 100-meter radius plot to summarize detections. A 50-meter radius plot was applied to all other species (rails, terns, songbirds). To help address the effects Great Lakes water levels on bird use, we included data from similar studies conducted during 2006-2013 (Monfils et al. 2014a, 2014b), a period of below-average Lake Huron levels (Figure 2). These past studies followed the same marsh bird survey protocol and we only included points meeting our definition for reference wetlands in the current study. Thus, these points served as a low-water reference to compare with bird use observed during this study.

The mixed model consisted of wetland category (i.e., managed *Phragmites*, unmanaged *Phragmites*, reference, and low-water reference) and survey period (i.e., early, mid, and late season) as fixed effects, and year and point as random effects. We used a repeated measures component to account for multiple surveys at the same point. Four commonly used covariance structures were evaluated for each species: variance components, autoregressive order 1, compound symmetric, and unstructured (Littell et al. 1996, Kincaid 2005). We compared models and selected the best-approximating model using AIC. If residuals from initial models using untransformed data were not normally distributed, we log transformed ($\log_e[x + 1]$ abundance in the final analysis. Models were run using SAS (PROC MIXED, SAS Institute, Cary, NC).

Abundance-induced Heterogeneity Models: We implemented the model described by Royle and Nichols (2003) to estimate abundance (λ, birds per point), occupancy (ψ), and detection probability (p) for eight species detected during repeated counts at our study sites. The same distance truncations used for bird detections in our mixed-model analyses were applied to these models. We combined all years into the same analysis because year was not a significant effect for any of the bird species in our mixed models ($P > 0.05$).

A multistep process was used to develop our candidate models. Because the Royle and Nichols (2003) model requires the use of an underlying distribution to estimate abundance, we first compared two null models lacking covariates, one using the Poisson distribution and the other a zero-inflated Poisson. The standard Poisson distribution was better supported by our data for all species and was used in subsequent models. Next, we modeled the detection probability parameter, first by comparing a model assuming constant detectability with another that allows for variable detection probability across visits. The best-supported configuration according to AIC value was included in subsequent models. We next compared models with single detection covariates – wind speed, noise rating, and wetland category. The best detection configuration was then used to model the abundance/occupancy parameter. Finally, we compared four models containing the following single abundance/occupancy covariates: wetland category, emergent vegetation percent cover, *Phragmites* percent cover, and water depth.

Logistic regression: To assess the local variables that might be associated with patterns in bird use across the sites, we conducted stepwise logistic regression analysis for eight of the target species detected during surveys. Sora, American coot, and black tern were excluded from the analysis because they were only occasionally detected (i.e., at < 5% of the points). We included data from similar studies conducted during below-average Lake Huron water levels (2006-2013) in wetlands representing reference conditions, unmanaged *Phragmites*, and intermediate between reference and *Phragmites*-dominated conditions. Past studies followed the same marsh bird survey and vegetation sampling procedures used in the current study, and we excluded any points inconsistent with our study design. We summarized data from vegetation quadrat sampling and after removing variables that occurred rarely (< 5% of the quadrats), identified 34 potential explanatory variables that could be included in the logistic regression, which was a combination of physical (e.g., vegetation height, water depth), structural (e.g., percent cover emergent vegetation), and taxonomic (e.g., percent cover of species/genera) variables. We assessed the collinearity of the variables using Pearson correlation analysis and removed variables correlated ($r \geq 0.50$) with other variables, resulting in a final set of 21 variables used in the analysis. We compiled bird detection data using the same distance cutoffs (i.e., 50 m or 100 m depending on species) used in other analyses. Bird detections were summarized by point and year; points having a species detected within the selected distance radius during at least one visit were assigned a “1”, whereas points lacking detections were given a “0”. Variables were selected using a forward stepwise procedure, with the maximum *P*-value for model entry being 0.20. Regression analyses were conducted using SAS (PROC LOGISTIC, SAS Institute, Cary, NC).

RESULTS

Vegetation

Plant Assemblages

We identified 133 plant species across 237 sampling events (i.e., sampling event consisted of three quadrats averaged at a point in one year) at the 87 points over the three years (Figure 4). Only 27 of those species were observed 10 or more times across all sampling events (Appendix B). Four vegetative sampling events were removed for lack of species, bringing the number of sampling events undergoing MDS analysis to 233. One point had two species of multicellular green algae (i.e., *Chara* sp., filamentous algae) together totaling 127%, because both species were classified as “Other”. The percentage was reduced to 100% to allow for statistical analysis. An acceptable stress value of 0.18 was reached at three dimensions with two convergent solutions found after 20 tries. The Monte Carlo permutation revealed that only *Typha* × *glauca* did not have a *P*-value less than 0.05 after 999 permutations ($P = 0.10$; Appendix C).

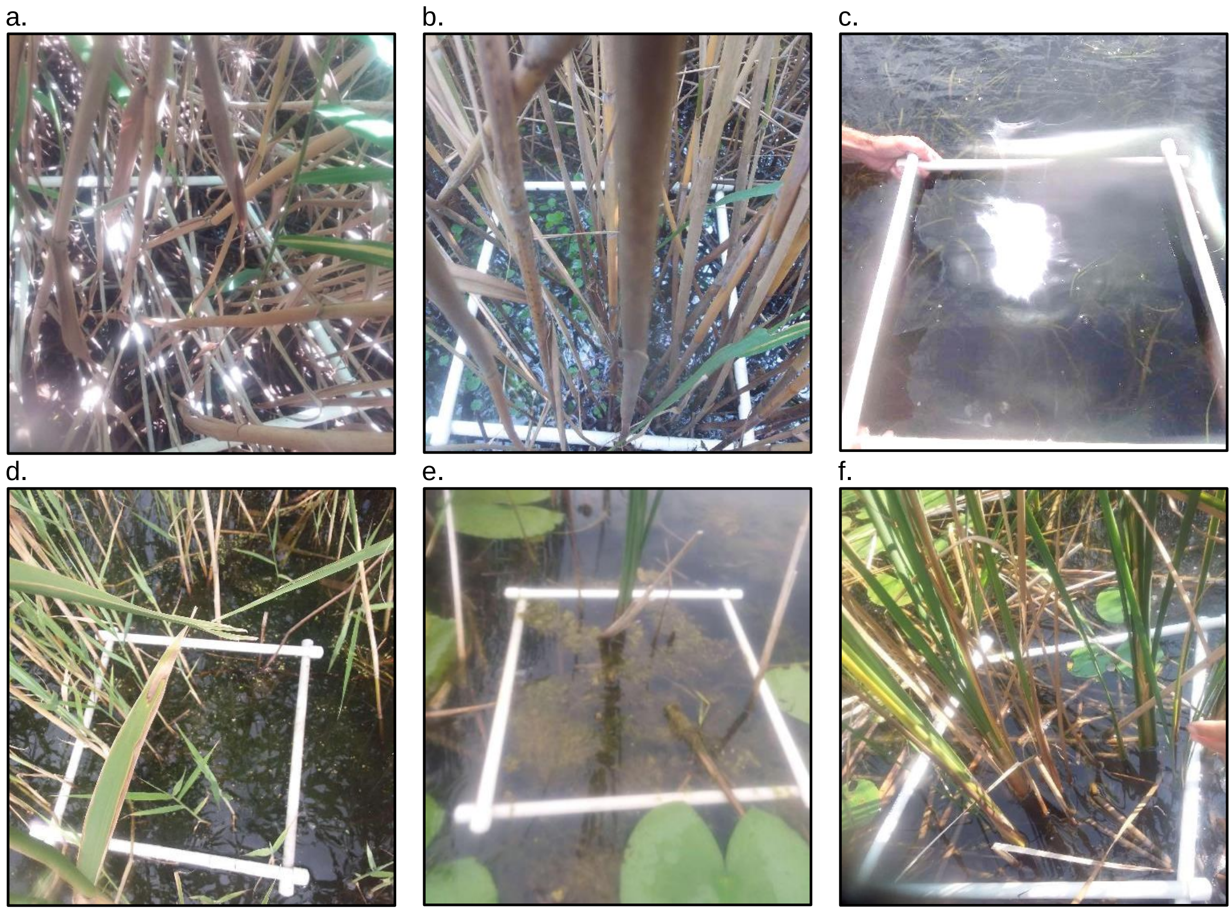

Figure 4. Photograph examples of each wetland category: a) unmanaged *Phragmites* at Quanicassee State Wildlife Area in 2018; b) unmanaged *Phragmites* at Quanicassee State Wildlife Area in 2021; c) managed *Phragmites* at Vanderbilt County Park in 2021; d) managed *Phragmites* at Vanderbilt County Park in 2021; e) reference site at Fish Point State Wildlife Area in 2018; and f) reference wetland at Fish Point State Wildlife Area in 2018.

Nearly all the unmanaged *Phragmites* points were clustered near the quadrant with negative values on the MDS 1 and 2 axes and positive values on the MDS 3 axis (Figure 5). Invasive *Phragmites* (*Phragmites australis* subsp. *australis*) was the only species to have its center in that quadrant (Table 1, Figure 5). Managed *Phragmites* and reference vegetative points were intermixed and scattered among the other quadrants of the MDS (Figure 5), indicating similar plant assemblages. Although overall they were not separated into separate groups, many of the reference points were positively associated with axis 2 (MDS 2) and negatively associated with axes 1 and 3 (MDS 1 and 3; Figure 5), which suggests an association with greater abundance of *Typha angustifolia* and *Persicaria amphibida* (Table 1). Concentrations of managed *Phragmites* points were found near points of submersed species such as water-milfoil (*Myriophyllum* spp.), pondweed (*Potamogeton richardsonii*), eel-grass (*Vallisneria americana*), and coontail (*Ceratophyllum demersum*; Figure 5).

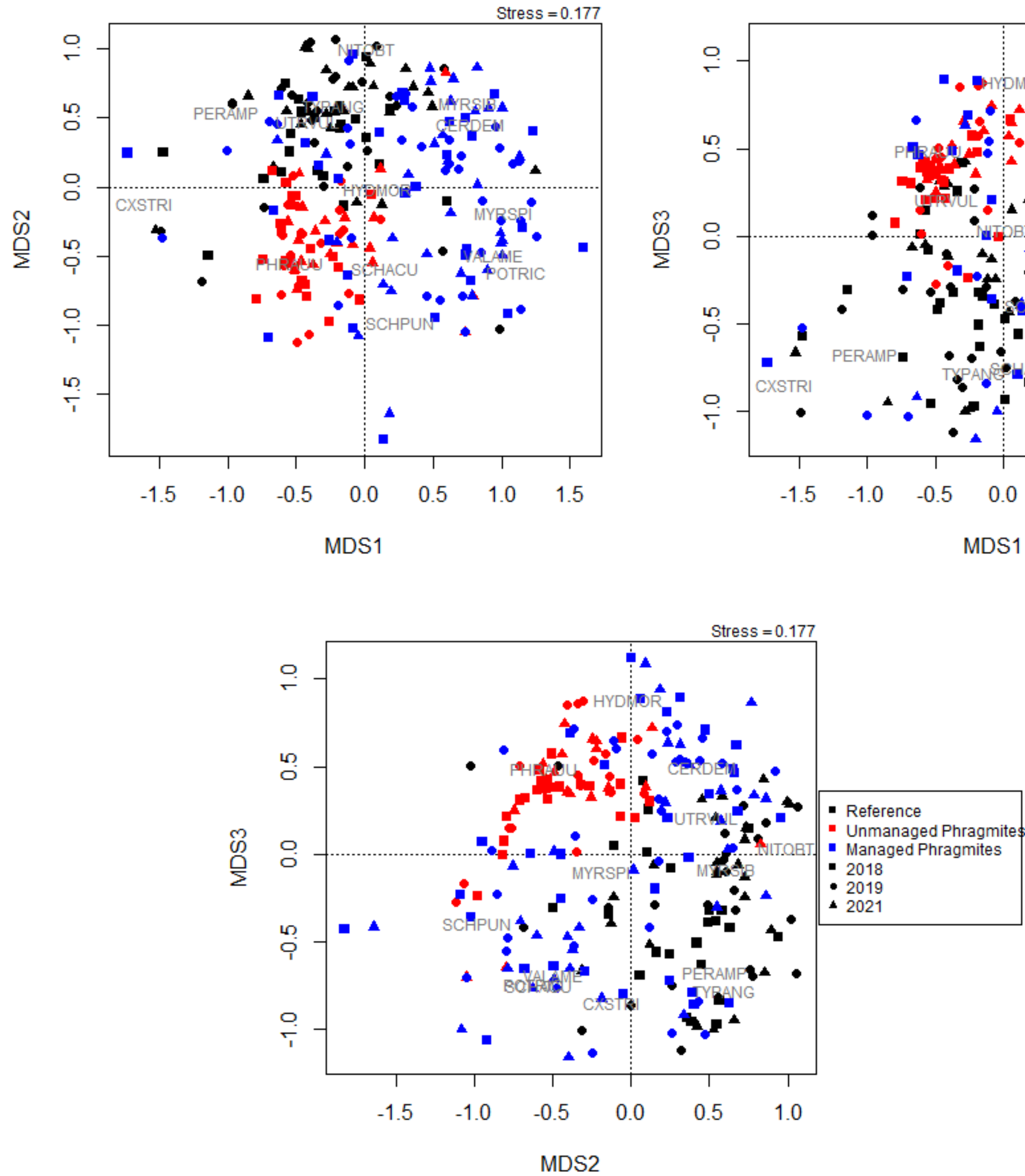

Figure 5. Non-metric multidimensional scaling of the vegetation sampling events, categorized by wetland category and year. Black symbols are reference points, red are unmanaged *Phragmites* points, and blue are managed *Phragmites* points; square symbols were surveyed in 2018, circles in 2019, and triangles in 2021. Species scores are indicated by six-letter code (see Appendix C).

Table 1. Description of species clustered in each MDS quadrant.

MDS1	MDS2	MDS3	Description
+	+	+	Four submerged species, including one non-native; 2 emergent *Schoenoplectus*: Eurasian water-milfoil (*Myriophyllum spicatum*), slender naiad (*Najas flexilis*), Richardson's pondweed (*Potamogeton richardsonii*), eel-grass (*Vallisneria americana*), hardstem bulrush (*S. acutus*), three-square bulrush (*S. pungens*)
+	+	-	Three floating one of which was non-native; one emergent non-native: European frog-bit (*Hydrocharis morsus-ranae*), red duckweed (*Lemna turionfera*), hybrid cat-tail (*Typha* × *glauca*), common water meal (*Wolffiella columbiana*)
+	-	+	Three native species: one submerged, one floating-leaved, one floating-leaved/emergent. Spiked water-milfoil (*Myriophyllum sibiricum*), sweet-scented waterlily (*Nymphaea odorata*), stiff arrowhead (*Sagittaria rigida*)
+	-	-	Submerged, floating, and algae species, including one non-native algae: coontail (*Ceratophyllum demersum*), common waterweed (*Elodea canadensis*), star duckweed (*Lemna trisulca*), starry stonewort (*Nitellopsis obtusa*), Other (e.g., *Chara* sp. filamentous algae), greater duckweed (*Spirodela polyrhiza*), Sago pondweed (*Stuckenia pectinata*)
-	+	+	Two emergent, native species: blue-joint grass (*Calamagrostis canadensis*), tussock sedge (*Carex stricta*)
-	+	-	One non-native emergent species: invasive Phragmites (*Phragmites australis* subsp. *australis*)
-	-	+	Two emergent species: one native, one non-native. Water smartweed (*Persicaria amphibida*), narrow-leafed cat-tail (*Typha angustifolia*).
-	-	-	Two native submerged/floating *Utricularia* species: humped bladderwort (*U. gibba*), common bladderwort (*U. vulgaris*)

Mixed Models

Of the 237 sampling events (i.e., 3 quadrats per point per year) completed during the three years of the study, 100 were categorized as managed *Phragmites*, 64 as unmanaged *Phragmites*, and 73 as reference. Species richness (*S*) across all managed *Phragmites* points was 102, unmanaged *Phragmites* 35, and reference 86 (Table 2). The best-fit model for submersed plants was the linear mixed model with the location:year as random effect. For invasive *Phragmites* percent cover, invasive *Phragmites* number of stems, European frog-bit percent cover, and *S*, the best-supported model was the linear mixed model with location as a random effect. We found the linear model with no random effects was the best fit for the diversity metrics *H'* and FQI.

The was no significant difference in European frog-bit percent cover and *S a*mong wetland categories, but the other variables examined all differed by wetland category (Table 3). As would be expected, we found greater invasive *Phragmites* percent cover and stem density at unmanaged *Phragmites* compared to the other categories, but estimates were similar between managed *Phragmites* and reference points (Table 3). For *H'*, unmanaged *Phragmites* points had significantly lower values than the other two wetland categories (Table 3). The *H'* and were not significantly different between managed *Phragmites* and reference points. The *FQI* followed the same patterns as *H'*.

Percent cover of submersed plants was informative to how *Phragmites* treatment combined with above-average water levels may change habitat (Figure 6): managed *Phragmites* points had more than double the percent cover of submersed plants than unmanaged *Phragmites* for all three years of sampling. There were 21 submersed species found across 100 plots. Eight of the top ten most abundant species across all managed *Phragmites* plots were submersed species (Table 2). Unmanaged *Phragmites* plots had less than 20% cover of submersed plants and 13 submersed species found across the 64 sampling events. Four of the top ten most abundant species across all unmanaged *Phragmites* points were submersed species (Table 2). The most common assemblage at unmanaged *Phragmites* points was invasive *Phragmites* with some floating-leaved species (e.g., European frog-bit, greater duckweed). Percent cover of submersed species at reference points did not differ from that of unmanaged *Phragmites* in 2018, but in 2019 and 2021, the percent coverage of submersed species at reference points more closely resembled managed *Phragmites* (Figure 6). There were 17 submersed species observed across the 73 sampling events at reference points. Six of the top 10 most abundant species at reference points were submersed species (Table 2).

Table 2. Ten most abundant plant species by percent cover across all points and years by wetland category during vegetation sampling conducted in Saginaw Bay, Lake Huron coastal wetlands during 2018-2021. Scientific names are listed in parentheses and non-native species are capitalized.

	Managed Phragmites	**Unmanaged Phragmites**	**Reference**
1	Coontail (*Ceratophyllum demersum*)	INVASIVE PHRAGMITES (*Phragmites australis* subsp. *australis*)	STARRY STONEWORT (*Nitellopsis obtusa*)
2	EUROPEAN FROG-BIT (*Hydrocharis morsus-rane*)	EUROPEAN FROG-BIT (*Hydrocharis morsus-rane*)	NARROW-LEAVED CAT-TAIL (*Typha angustifolia)*
3	Eel-grass (*Vallisneria americana*)	Common bladderwort (*Utricularia vulgaris*)	Common bladderwort (*Utricularia vulgaris*)
4	Common bladderwort (*Utricularia vulgaris*)	STARRY STONEWORT (*Nitellopsis obtusa*)	Other (e.g., *Chara* sp., filamentous algae)
5	Other (e.g., *Chara* sp., filamentous algae)	Coontail (*Ceratophyllum demersum*)	Coontail (*Ceratophyllum demersum*)
6	Common waterweed (*Elodea canadensis*)	Greater duckweed (*Spirodela polyrhiza*)	Sweet-scented waterlily (*Nymphaea odorata*)
7	STARRY STONEWORT (*Nitellopsis obtusa*)	Red duckweed (*Lemna turionifera*)	INVASIVE PHRAGMITES (*Phragmites australis* subsp. *australis*)
8	Spiked water-milfoil (*Myriophyllum sibericum*)	Other (e.g., *Chara* sp., filamentous algae)	Spiked water-milfoil (*Myriophyllum sibericum*)
9	Richardson's pondweed (*Potamogeton richarsonii*)	Small bladderwort (*Utricularia minor*)	Eel-grass (*Vallisneria americana*)
10	Red duckweed (*Lemna turionifera*)	Flat-leaved bladderwort (*Utricularia intermedia*)	Blue-joint grass (Calamagrostis canadensis)

Table 3. Comparison of habitat measures and diversity metrics by wetland category in Saginaw Bay, Lake Huron coastal wetlands, 2018, 2019, and 2021. Bolded *P*-values indicate significant differences ($P < 0.05$) by wetland category in mixed-effects model analyses unless noted. Estimates followed by the same letter were not significantly different ($P > 0.05$).

Response Variable	**Managed Phragmites (*n* = 100)**		**Unmanaged Phragmites (*n* = 64)**		**Reference (*n* = 73)**		***P*-value**
Invasive *Phragmites* percent cover	2.14 (2.67)	A	50.1 (3.40)	B	1.26 (3.06)	A	**<0.001**
Invasive *Phragmites* stems	3.86 (5.39)	A	84.6 (6.87)	B	0.81 (5.97)	A	**<0.001**
European frog-bit percent cover	6.21 (3.13)	A	7.76 (3.94)	A	6.05 (3.38)	A	0.900
Submersed plants *	40.5 (4.83)	A	14.4 (6.05)	B	42.7 (5.45)	A	**<0.001**
S	6.82 (0.63)	A	4.87 (0.80)	AB	6.08 (0.70)	A	0.100
H' ‡	1.13 (0.05)	A	0.69 (0.06)	B	1.16 (0.06)	A	**<0.001**
FQI ‡	9.93 (0.35)	A	6.78 (0.44)	B	9.23 (0.41)	A	**<0.001**

* Linear mixed model with random effect of location:year interaction was the best fit model for variable

‡ Linear regression model was the best fit model for variable

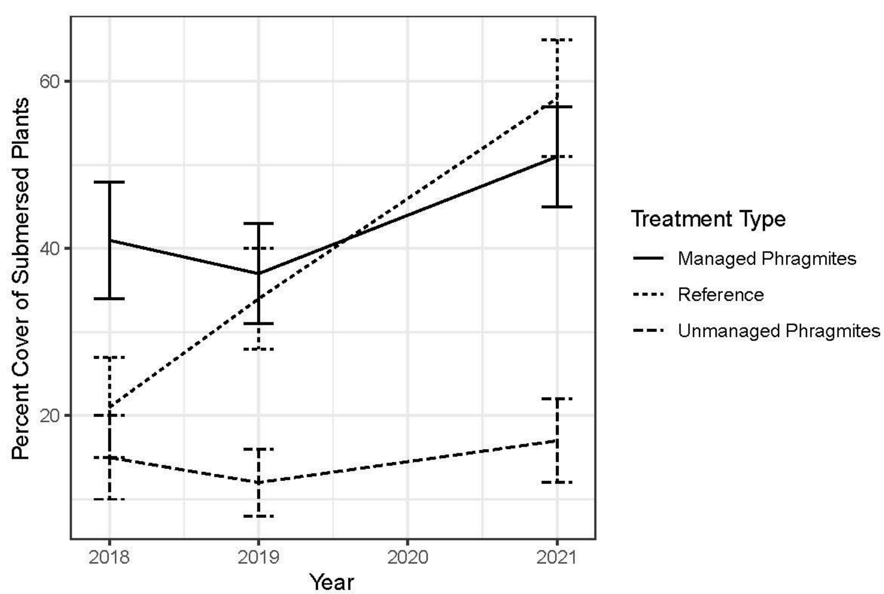

Figure 6. Mean percent cover of submersed plants across three years of sampling in Saginaw Bay, Lake Huron coastal wetlands. The whiskers at each year represent the standard error of the mean by wetland category.

Birds

We completed 646 point counts at the 87 random points across the three years sampled (286 at managed, 171 at unmanaged, and 189 at reference points). Fifteen primary and secondary target bird species were recorded across all survey points and years. The number of bird species detected was similar among the three wetland categories, with 14 species observed in managed *Phragmites* and reference wetlands and 13 species in unmanaged *Phragmites* points (Table 4). The small differences in bird species detected by wetland category were accounted for by uncommon species observed sporadically. Sedge wren and yellow-headed blackbird were recorded at some managed *Phragmites* and reference points but not unmanaged *Phragmites* points, whereas Wilson's snipe was only detected at unmanaged *Phragmites* points.

Table 4. Primary and secondary target species detected (indicated by "X") by wetland category during marsh bird surveys conducted in Saginaw Bay, Lake Huron coastal wetlands during 2018-2021.

Common Name	Scientific Name	Managed Phragmites (*n* = 286)	Unmanaged Phragmites (*n* = 171)	Reference (*n* = 189)
Pied-billed Grebe	*Podilymbus podiceps*	X	X	X
American Bittern	*Botaurus lentiginosus*	X	X	X
Least Bittern	*Ixobrychus exilis*	X	X	X
Virginia Rail	*Rallus limicola*	X	X	X
Sora	*Porzana carolina*	X	X	X
Common Gallinule	*Gallinula galeata*	X	X	X
American Coot	*Fulica americana*	X	X	X
Sandhill Crane	*Antigone canadensis*	X	X	X
Wilson's Snipe	*Gallinago delicata*		X	
Black Tern	*Chlidonias niger*	X	X	X
Forster's Tern	*Sterna forsteri*	X	X	X
Sedge Wren	*Cistothorus platensis*	X		X
Marsh Wren	*Cistothorus palustris*	X	X	X
Swamp Sparrow	*Melospiza georgiana*	X	X	X
Yellow-headed Blackbird	*Xanthocephalus xanthocephalus*	X		X

We developed distance sampling models for six of the primary target species (see Appendix D for model results). The hazard-rate key with simple polynomial adjustments was the best-supported model for three of the species (common gallinule, sora, and Virginia rail). The best-approximating model for least bittern and pied-billed grebe was the half-normal key with cosine adjustments. The half-normal key with Hermite polynomial adjustments was the best-supported model for American bittern. Only two of the best-approximating models contained covariates. Least bittern detection probability was negatively associated with percent cover of emergent vegetation. The pied-billed grebe model best supported by the data contained wetland category (i.e., managed, unmanaged, and reference) as a categorical variable. None of the best-supported models indicated a relationship between detection and percent cover of *Phragmites*.

We used the estimated effective distance radius (EDR) from our models to inform how we compiled data for other analyses. The EDR was 94 m (95% confidence interval [CI] 90 – 98 m) for Pied-billed grebe, 130 m (95% CI 112 – 150 m) for American bittern, and 91 m (95% CI 85 – 98 m) for least bittern, so we used detections within a circular plot radius of 100 m for these three species in our abundance and occupancy models. We used a 50-m radius plot for our analyses of other species, as common gallinule had a EDR of 43 m (95% CI 36 – 53 m), sora an EDR of 32 m (95% CI 14 – 77 m), and Virginia rail an EDR of 34 m (95% CI 21 – 56 m).

We conducted mixed-model analyses to evaluate if abundances (i.e., detections per point) of eight bird species varied among our wetland categories. For all but one species, Virginia rail, abundance significantly differed by wetland category (Table 5). Mean abundances of pied-billed grebe and common gallinule were greatest at reference points compared to other categories. Three species, American bittern, least bittern, and marsh wren, had similar abundance between unmanaged *Phragmites* and reference points, which was significantly greater than abundance at managed *Phragmites* points. Mean abundance of foraging Forster's terns was similar between managed and reference points and greater than abundance at unmanaged *Phragmites* points. Swamp sparrow was the only species with greatest abundance at our low-water reference points.

Table 5. Comparison of mean bird abundance (detections per point; standard error in parentheses) by wetland category for eight marsh bird species detected in Saginaw Bay, Lake Huron coastal wetlands, 2006-2021. Bolded *P*-values indicate significant differences (P < 0.05) by wetland category in mixed-effects model analyses. Estimates followed by the same letter were not significantly different (P > 0.05).

Species	**Managed Phragmites (*n* = 286)**		**Unmanaged Phragmites (*n* = 171)**		**Reference (*n* = 189)**		**Low-water Reference (*n* = 114)**		***P*-value**
Pied-billed grebe	0.18 (0.06)	A	0.18 (0.06)	A	0.52 (0.06)	B	0.02 (0.06)	A	**<0.001**
American bittern	0.03 (0.02)	A	0.15 (0.03)	B	0.15 (0.03)	B	0.03 (0.03)	A	**<0.001**
Least bittern	0.05 (0.03)	A	0.16 (0.03)	B	0.20 (0.03)	B	0.01 (0.03)	A	**<0.001**
Virginia rail	0.02 (0.02)	A	0.05 (0.03)	A	0.07 (0.03)	A	0.09 (0.02)	A	0.191
Common gallinule	0.07 (0.05)	A	0.18 (0.05)	B	0.35 (0.05)	C	0.02 (0.05)	A	**<0.001**
Forster's tern	0.17 (0.03)	A	0.03 (0.04)	BC	0.17 (0.04)	A	0.08 (0.04)	AC	**0.019**
Marsh wren	0.16 (0.14)	A	0.85 (0.15)	B	1.01 (0.14)	B	0.79 (0.13)	B	**<0.001**
Swamp sparrow	0.16 (0.10)	A	0.35 (0.11)	B	0.24 (0.11)	AB	0.98 (0.10)	C	**<0.001**

We estimated marsh bird abundance, occupancy, and detection probability following Royle and Nichols (2003) and used point estimates to calculate mean estimates by wetland category (i.e., managed, unmanaged, and reference) for each species. Wetland category was a detection covariate in all the top models except for swamp sparrow. Swamp sparrow detection probability was negatively associated with wind speed (Table 6). Water depth was an abundance covariate in the best-supported model of five species, with pied-billed grebe, common gallinule, and Forster's tern abundance being positively related to water depth, whereas abundance of Virginia rail and swamp sparrow showed a negative association with water depth. The top models for least bittern and marsh wren contained wetland category as an abundance covariate. American bittern was the only species with percent cover of *Phragmites* in its best-approximating model; abundance was positively related to *Phragmites* cover.

Table 6. Covariates included in best-approximating abundance and occupancy models for marsh bird species detected in Saginaw Bay, Lake Huron coastal wetlands during 2018-2021. Covariates included are indicated by an “X” or where appropriate by a positive or negative sign to indicate direction of association with detection probability or occupancy/abundance.

Covariate	**Pied-billed grebe**	**American bittern**	**Least bittern**	**Virginia rail**	**Common gallinule**	**Forster’s tern**	**Marsh wren**	**Swamp sparrow**	**Total no. species**
Detection:									
Survey period		X	X			X	X	X	5
Wetland category (managed, unmanaged, and reference)	X	X	X	X	X	X	X		7
Wind level								–	1
Noise Level									0
Abundance:									
Wetland category (managed, unmanaged, and reference)			X				X		2
Water depth	+			–	+	+		–	5
% cover emergent plants									0
% cover *Phragmites*		+							1

Our best-approximating pied-billed grebe, Virginia rail, common gallinule, Forster’s tern, and swamp sparrow models suggested average abundances (bird detections per point) and occupancy probabilities were similar among the wetland categories (Table 7). The American bittern models best supported by our data indicated greatest mean abundance and occupancy at unmanaged *Phragmites* points. Models for least bittern and marsh wren indicated similar average abundance and occupancy between unmanaged *Phragmites* and reference points and lowest estimates for managed *Phragmites* points, which was consistent with the patterns observed in our mixed-effects models estimates.

Table 7. Naïve or observed occupancy and estimated mean abundance (λ, birds per point), estimated occupancy probability (ψ), and detection probability (*p*) by wetland category from our best-approximating abundance-induced heterogeneity models for marsh birds detected in Saginaw Bay, Lake Huron coastal wetlands, 2018-2021.

		Managed Phragmites (*n* = 286)		**Unmanaged Phragmites (*n* = 171)**		**Reference (*n* = 189)**	
Species	**Parameter**	**Mean**	**SE**	**Mean**	**SE**	**Mean**	**SE**
Pied-billed grebe	naïve occupancy	0.164	(0.021)	0.164	(0.028)	0.428	(0.036)
	occupancy (ψ)	0.585	(0.079)	0.575	(0.078)	0.567	(0.079)
	detectability (*p*)	0.298	(0.060)	0.287	(0.060)	0.733	(0.046)
	abundance (λ)	0.863	(0.164)	0.846	(0.161)	0.881	(0.179)
American bittern	naïve occupancy	0.038	(0.011)	0.192	(0.030)	0.185	(0.036)
	occupancy (ψ)	0.459	(0.084)	0.656	(0.136)	0.463	(0.084)
	detectability (*p*)	0.054	(0.025)	0.189	(0.071)	0.301	(0.104)
	abundance (λ)	0.735	(0.228)	1.138	(0.422)	0.741	(0.228)
Least bittern	naïve occupancy	0.045	(0.012)	0.192	(0.030)	0.243	(0.031)
	occupancy (ψ)	0.118	(0.044)	0.575	(0.128)	0.630	(0.111)
	detectability (*p*)	0.193	(0.078)	0.147	(0.080)	0.174	(0.092)
	abundance (λ)	0.130	(0.053)	1.032	(0.475)	1.276	(0.569)
Virginia rail	naïve occupancy	0.024	(0.009)	0.053	(0.017)	0.069	(0.018)
	occupancy (ψ)	0.187	(0.073)	0.191	(0.075)	0.219	(0.086)
	detectability (*p*)	0.115	(0.074)	0.184	(0.086)	0.270	(0.148)
	abundance (λ)	0.233	(0.112)	0.235	(0.112)	0.286	(0.145)
Common gallinule	naïve occupancy	0.080	(0.016)	0.199	(0.031)	0.328	(0.034)
	occupancy (ψ)	0.498	(0.067)	0.486	(0.067)	0.494	(0.064)
	detectability (*p*)	0.119	(0.037)	0.327	(0.078)	0.539	(0.076)
	abundance (λ)	0.761	(0.159)	0.738	(0.154)	0.813	(0.180)
Forster’s tern	naïve occupancy	0.161	(0.022)	0.012	(0.008)	0.122	(0.024)
	occupancy (ψ)	0.561	(0.082)	0.541	(0.081)	0.565	(0.067)
	detectability (*p*)	0.133	(0.072)	0.033	(0.024)	0.098	(0.057)
	abundance (λ)	1.367	(0.722)	1.319	(0.696)	1.491	(0.798)
Marsh wren	naïve occupancy	0.129	(0.020)	0.532	(0.038)	0.577	(0.036)
	occupancy (ψ)	0.273	(0.054)	0.835	(0.055)	0.815	(0.051)
	detectability (*p*)	0.413	(0.089)	0.393	(0.090)	0.465	(0.087)
	abundance (λ)	0.337	(0.083)	2.019	(0.482)	1.967	(0.407)
Swamp sparrow	naïve occupancy	0.115	(0.019)	0.281	(0.034)	0.217	(0.030)
	occupancy (ψ)	0.343	(0.044)	0.355	(0.045)	0.374	(0.041)
	detectability (*p*)	0.374	(0.075)	0.387	(0.075)	0.384	(0.074)
	abundance (λ)	0.539	(0.105)	0.540	(0.102)	0.759	(0.167)

We ran logistic regression models for eight bird species to help us understand the small-scale variables that might be associated with bird use patterns across the wetland categories. Of the 21 potential habitat variables included in the analysis, 17 were selected in at least one species' model. *Utricularia* spp., or bladderwort, was the variable most often selected, with all species except common gallinule having it in their final model. Although Forster's tern was negatively associated with *Utricularia* cover, the remaining species showed a positive relationship. Percent cover of open water was included in six of the models, with occurrence of all but swamp sparrow showing a positive relationship. *Typha* spp. cover was positively associated with the occurrence of pied-billed grebe, American bittern, least bittern, common gallinule, Forster's tern, and marsh wren (Table 8). Five species had percent cover of *Phragmites* in their models; Forster's tern occurrence was negatively related, whereas American bittern, least bittern, common gallinule, and marsh wren were positively associated with *Phragmites* cover. Virginia rail, marsh wren, and swamp sparrow were negatively related to submersed plant cover and common gallinule showed a positive association. Occurrence of four species, pied-billed grebe, Virginia rail, common gallinule, and Forster's tern, was positively associated with percent cover of *Myriophyllum* spp. (Table 8). Pied-billed grebe, least bittern, and common gallinule occurrence was positively related with *Nitellopsis obtusa*, whereas swamp sparrow showed a negative association. Pied-billed grebe and common gallinule occurrence was positively related to *Nymphaea odorata* cover, but swamp sparrow had a negative association with the species. The remaining variables were only included in one or two of the species models (Table 8).

Table 8. Parameter estimates for variables (SE in parentheses) included in final stepwise logistic regression models for marsh bird species detected in Saginaw Bay, Lake Huron coastal wetlands during 2006-2021.

Parameter	Pied-billed grebe	American bittern	Least bittern	Virginia rail	Common gallinule	Forster's tern	Marsh wren	Swamp sparrow	Total No. Species
Intercept	-4.2 (0.5)	-4.3 (0.5)	-4.7 (0.6)	-2.8 (0.3)	-6.4 (0.7)	-5.0 (0.8)	-0.9 (0.1)	1.3 (0.2)	
Organic soil depth			3.0 (1.0)	2.4 (1.0)					2
% cover variables:									
Open water	2.8 (0.6)	1.4 (0.5)	1.3 (0.5)		3.0 (0.7)	3.2 (0.9)		-2.3 (0.3)	6
Bare substrate									0
Litter		1.1 (0.4)			1.5 (0.5)				2
Submersed plants				-3.8 (1.2)	1.3 (0.4)		-0.5 (0.3)	-1.9 (0.6)	4
Grasses (Poaceae)									0
Carex spp.				2.5 (1.5)					1
Eleocharis spp.						2.3 (1.3)	-4.4 (2.0)		2
Hydrocharis morsus-ranae			2.5 (0.7)	-8.3 (3.7)					2
Lemna spp.	-6.0 (3.1)			5.3 (1.3)					2
Myriophyllum spp.	2.1 (1.0)		3.6 (1.1)		2.9 (1.1)	3.3 (1.0)			4
Najas spp.								7.2 (2.8)	1
Nitellopsis obtusa	1.8 (0.4)		1.3 (0.5)		1.6 (0.5)			-6.2 (3.2)	4
Nymphaea odorata	5.1 (1.4)				5.7 (1.5)			-24.6 (12.4)	3
Phragmites australis		1.5 (0.5)	2.3 (0.5)		2.0 (0.6)	-6.6 (2.3)	1.6 (0.4)		5
Potamogeton spp.									0
Sagittaria spp.									0
Schoenoplectus spp.	-45.2 (16.0)						3.5 (1.8)		2
Typha spp.	3.6 (0.8)	1.8 (1.0)	2.7 (1.0)		4.9 (0.9)	2.6 (0.9)	5.3 (0.8)		6
Utricularia spp.	1.2 (0.5)	1.5 (0.5)	2.3 (0.7)	4.4 (1.4)		-2.2 (1.0)	2.3 (0.6)	1.2 (0.8)	7
Vallisneria americana							-4.5 (1.8)	-6.7 (3.1)	2

DISCUSSION

Vegetation

Our assessment of *Phragmites* treatments at multiple points in Saginaw Bay coastal wetlands indicates that they were successful in reducing percent cover and stem density of *Phragmites* through four years post-treatment. Managed points had greater diversity and quality indices compared to unmanaged *Phragmites* points and similar to reference wetlands, which was supported by the MDS species composition analysis. The above-average Lake Huron water levels that coincided with herbicide treatments and follow-up assessment likely contributed to the successful reduction in *Phragmites* cover, as several authors have indicated flooding can reduce the spread of *Phragmites* and increase native plant species (Burdick et al. 1997, Warren et al. 2002, Buchsbaum et al. 2006, Konisky et al. 2006, Tulbure et al. 2007, Tulbure and Johnston 2010, Chambers et al. 2012, Diers and Richardson 2012, Buschsbaum 2021). Similar results were seen in Uddin and Robinson (2017) and Zimmerman et al. (2018), although those studies compared managed *Phragmites* to only one other wetland category. The variability observed in vegetation metrics across the sample points could be related to the variable habitats and abiotic characteristics (e.g., fetch) found in wetlands in Saginaw Bay as location was a significant random effect in most mixed models. Our submersed plant cover model was the only one containing the random location:year variable. This may be indicative of the influence of yearly fluctuations in Great Lakes water levels to the establishment of submersed plants post-treatment.

Diversity measures such as species richness and Shannon's Diversity Index are helpful to better understand communities, but they do not take into account the origin of the species. Establishment of invasive versus native species in managed *Phragmites* points needs to be examined. Invasive species treatment often leaves habitat open to the establishment of other non-native plant species (Kettering and Adams 2011, Abella 2014). The reestablishment of vegetation in the managed *Phragmites* wetlands consisted of both native and non-native vegetation. Invasive *Phragmites* was observed to be reinvading some managed points (see Figure 4d) and invading some reference points. Anecdotal accounts of European frog-bit (*Hydrocharis morsus-ranae*) invasion after treatment of invasive *Phragmites* or *Typha* populations in Saginaw Bay have increased over the years and are worth investigating (Phyllis Higman, personal communication); however, we found no significant difference in percent cover of frog-bit among wetland categories. Although the *Phragmites* treatments we sampled appear successful in the short-term, longer-term monitoring and retreatment as needed is recommended (Kettering and Adams 2011, Uddin and Robinson 2017, Zimmerman et al. 2018).

We note that although our reference areas offered the best available representation of pre-invasion conditions or uninvaded wetlands, especially regarding vegetation structure, the plant assemblages had been degraded. *Typha angustifolia*, *T*. x *glauca*, and *Nitellopsis obtusa* were common and invasive *Phragmites* represented enough percent cover over the years to be one of the ten most abundant species. Thus, despite our analyses indicating similar plant assemblages between managed and reference wetlands, this success must be put in the context of Saginaw Bay being a degraded system. Reid et al. (2009) suggested post-treatment success should not be measured only by the removal of the target species, but also the restoration trajectory of other components of the ecosystem. For example, although we documented control of *Phragmites* at the managed points, we found no significant difference in percent cover of European frog-bit across our wetland categories and the invasive *Nitellopsis obtusa* was one of the most common species detected at managed points (Table 2). Full recovery of the plant communities of managed wetlands will not be possible without taking the other invasive plant species population into account.

Birds

Our study design allowed us to assess the effects of *Phragmites* management to abundance/occupancy of several target marsh bird species through comparisons with unmanaged *Phragmites* points, while also evaluating the effects of *Phragmites* invasion to these same species via comparisons with reference wetlands where *Phragmites* was not dominant. Five of the eight species we analyzed, American bittern, least bittern, common gallinule, marsh wren, and swamp sparrow, had lower abundance at managed points compared to unmanaged *Phragmites* wetlands. This is likely due to the reduced amount of emergent vegetation of the managed points. Lazaran et al. (2013) documented impacts to marsh wren productivity in Lake Erie coastal wetlands receiving broadscale herbicide applications to control *Phragmites*. Virginia rail was the only species that showed no difference in abundance across wetland categories in our study. Pied-billed grebe abundance was similar between managed and unmanaged wetlands but greatest in reference wetlands. Abundance of Forster's tern was greater in managed compared to unmanaged points and similar to reference sites; however, Forster's tern detections consisted of birds foraging over open water areas resulting from management. We only observed Forster's tern nesting colonies in *Typha* and *Schoenoplectus* patches in or near reference areas. Our findings suggest that management followed by high lake levels and slow regrowth of emergent vegetation has caused a short-term loss of nesting habitat for species requiring dense vegetation, such as American bittern, least bittern, common gallinule, marsh wren, and swamp sparrow. However, the abundances of American bittern, least bittern, and common gallinule we observed in managed *Phragmites* were similar to abundances recorded in reference wetlands during low lake levels (2006-2013). Given the similarity of vegetation assemblages between managed and reference points, we expect future marsh bird use will become more similar to reference wetlands as emergent plants regenerate.

In assessing the potential effects of *Phragmites* expansion on marsh-dependent species, we compared use among our three wetland categories, as well as with data collected during low-water levels (2006-2013) on Saginaw Bay (Monfils et al. 2014a, Monfils unpublished data). Two of the eight species analyzed, pied-billed grebe and common gallinule, were most abundant at reference points, whereas abundances of American bittern, least bittern, Virginia rail, marsh wren, and swamp sparrow were similar between reference and unmanaged *Phragmites*. Swamp sparrow was the only species to be most abundant at our low-water reference points, which could be due to greater shrub cover and denser emergent vegetation during lower water levels. Our findings indicate that *Phragmites*-dominated coastal wetlands on Saginaw Bay support several marsh-dependent species during high water levels similar to reference sites. For some species, abundance in unmanaged *Phragmites* was greater than what was recorded at reference sites during low lake levels. Our results are consistent with those of Lupien et al. (2015), who found that despite major structural differences between *Phragmites* stands and marsh vegetation assemblages dominated by other plant species (e.g., *Schoenoplectus*, *Typha*, *Carex*), there was a little difference in abundance, richness, diversity, and site occupancy of birds. In a study of Lake Erie coastal wetlands at Long Point, Ontario, Meyer et al. (2010) found total relative abundance and species richness of birds were greater in *Phragmites* compared to *Typha* or meadow marsh habitats, yet relative abundance of marsh-nesting birds was greater in meadow marsh than the other habitat types during summer. Subsequent research at Long Point indicated invasive *Phragmites* excluded many marsh-nesting species, including those of conservation concern, and instead provided habitat for shrub-nesting, and ground and foliage gleaners (Robichaud and Rooney 2017).

To augment our comparisons of bird abundance across wetland categories, we explored potential associations between bird occurrence and variables gathered during plant sampling. Occurrence of most of the eight species analyzed showed relationships with percent cover of

Utricularia, open water, and *Typha*, with nearly all associations being positive except for Forster's tern (negative with *Utricularia*) and swamp sparrow (negative with open water). We did not include water depth in our analyses because it was highly correlated (r = 0.75) with percent cover of open water. Our logistic regression analyses included samples during low and high Lake Huron levels across a range of *Phragmites* occurrence, from dominant to absent or sparse, yet only one species, Forster's tern, had a negative relationship between occurrence and percent cover of *Phragmites*. Conversely, occurrence of American bittern, least bittern, common gallinule, and marsh wren was positively associated with *Phragmites* cover. Use of coastal wetlands by marsh birds is unlikely to be explained by *Phragmites* alone, as our study suggests it results from complicated relationships among native and invasive species, physical structure, and ecological processes (e.g., water level fluctuations). Large-scale, or landscape-level factors not considered in our analyses have also been shown to influence marsh bird occurrence (e.g., Naugle et al. 1999, Fairbairn and Dinsmore 2001, DeLuca et al. 2004, Smith and Chow-Fraser 2010) and warrant further exploration. Though difficult to implement, research also needs to go beyond abundance and occurrence to determining if breeding bird use of *Phragmites*-dominated wetlands results in nest success, survival, and recruitment rates at levels similar to or different from reference wetlands.

Conclusions

This study highlights the complexity of invasive species management and assessment of success in Great Lakes coastal wetlands. Informed by the recommendations of Ruiz-Jaen and Aide (2005) and others (e.g., Society for Ecological Restoration 2004), we attempted to compare multiple ecosystem attributes (e.g., plant diversity, abundance of bird species of conservation concern) among managed *Phragmites*, unmanaged *Phragmites*, and reference wetlands. On the surface, our study design seemed rather straightforward, yet its implementation revealed complexities: 1) evaluating success in controlling an invasive species is difficult when the system contains multiple interacting invasive and native species; 2) without long-term monitoring, short-term assessments of management success could be "washed out" by overarching ecological processes (e.g., Great Lakes water levels); and 3) with widespread degradation of ecosystems, finding proper reference ecosystems may not be possible. Management actions monitored in this study were successful in treatment of *Phragmites* over a 4-5 year period, yet other invasives (European frog-bit, starry stonewort) were common and similar to unmanaged *Phragmites* wetlands. Assessment of success is more complicated when considering marsh birds, as management likely reduced habitat for several species for the short-term, yet the managed sites appear on a trajectory toward similarity with reference areas and we expect marsh bird use would follow over the long-term. In addition, abundance of several species was similar between unmanaged *Phragmites* and reference areas. Because the managed sites evaluated in this study were relatively small within the vast wetland complexes of Saginaw Bay, we do not believe the loss of some habitat resulted in serious impacts to marsh bird populations. However, detrimental effects may occur if similar management were undertaken in larger or more isolated areas of coastal wetlands. We suggest management of large wetland areas be implemented in staggered way over multiple years, so that some emergent habitat is maintained over time to minimize possible negative effects to breeding marsh birds. If done in a manner that increases the interspersion of open water and vegetation, management could increase wetland bird diversity and density (Weller and Spatcher 1965, Weller and Fredrickson 1973, Kaminski and Prince 1981a, b, Murkin et al. 1982). Our findings, both for plants and birds, likely would have been different if the management and research occurred during a period of low Lake Huron levels. Similarly, with Saginaw Bay being a degraded system overall, our results may have been different if our reference area were more representative of pristine conditions.

The complexities presented here can be overwhelming to both researchers and managers, who are looking for guidance on where and how best to manage habitats for a myriad of species and objectives. Given the common occurrence of multiple invasive species in the same ecosystems, such as *Phragmites*, *Typha angustifolia*, *Hydrocharis morsus-ranae*, and *Nitellopsis obtusa* in Saginaw Bay, we suggest management consider multiple, high-priority species and objectives at the same time. Although this approach would undoubtedly reduce the spatial area covered, it could result in more meaningful restoration. For example, if plant diversity and marsh bird habitat were high priorities, a plan for managing multiple invasive species could be undertaken in a part of Saginaw Bay known to support high plant diversity, rare plant species, and marsh birds of management concern (e.g., areas with overlapping occurrences of natural communities, rare plants, and birds). Eradication of these species within Saginaw Bay is unlikely, so we would suggest managers focus on “functional” eradication as described by Green and Grosholz (2020), which focuses on determining invader levels at which impacts become unacceptable and planning management to keep invasive species below those thresholds. Concurrent, long-term monitoring of aspects of the system to assess success and inform adaptive management would be essential, but could perhaps be implemented periodically versus annually to reduce costs and better coincide with large-scale processes such as Great Lakes water levels.

ACKNOWLEDGEMENTS

Funding support was provided by the U.S. Fish and Wildlife Service (USFWS), Great Lakes Fish and Wildlife Restoration Act Grant Program. Rick Westerhof (USFWS) provided administrative support for the project. We appreciate the support and cooperation provided by local land managers: Pat Brickel (Michigan Department of Natural Resources [DNR]), Brandy Dybas-Berger (DNR), Tim Gierman (DNR), and Barry Sova (DNR). Steve Beyer (DNR) served as the state agency sponsor for USFWS grant proposal and project. Brian Klatt, Ashley Adkins, Sarah Carter, and Nancy Tobin of MNFI provided administrative support for the study.

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Appendix A: Data dictionary for vegetation and wetland sampling

Table A-1. Descriptions of each field of data and meta-data to be collected. "Table" refers to the level of data collected and spreadsheet it is found on. "Display name" is the name used in surveys and most correspondence; "Field Name" is the true name used in tables and analyses. Italics indicate a Field Name whose data is repeated from the Plot Table to help with organization and data analysis among different levels of data. "Data Type" is the class of data of the spreadsheet generated by the Survey123 app.

Table	**Display Name**	**Field Name**	**Definitions and Values**	**Example**	**Data Type**
Plot	Year:	eventYear	Year of survey	2021	Date
Plot	Date:	eventDate	The day, month, and year of survey	08/17/2021 16:00	Date
Plot	Time:	time	Time survey began	10:12	Time
Plot	Surveyor name:	recordedBy	Names of the surveyors conducting the sampling	Rachel Hackett; Mark Hamlyn	String
Plot	Survey period:	survey_period	Number corresponding to which seasonal sampling period the survey event took place during Values: 1 - Spring (mid-May to late June), 2 - Early summer (late June to late July), 3 - Late summer (late July to September), 0 - Other	3	String
Plot	Explain other:	survey_period_other		New period 09/2020	String
Plot	Location ID:	locationID	Name abbreviations of site location Values: Wigwam Bay SWA (WBSWA), Bay County Pinconning Park (BCPP), Nayanquing Point SWA (NPSWA), Hampton (HAMP), Quanicassee SWA (QSWA), Vanderbilt County Park (VCP), Fish Point SWA South (FPSWAS), Fish Point SWA North (FPSWAN), Wildfowl Bay SWA (WFBSWA), Saganing River (SCTSR), Other	WFBSWA	String
Plot	Explain other:	locationID_other	To input a site name not listed in locationID above	City Park	String
Plot	Marsh bird plot:	locationID_plot	Unique identifier of bird point count station used in both bird and vegetative surveys	529N	String

Table	Display Name	Field Name	Definitions and Values	Example	Data Type
Plot	Bearing from plot center:	bearing	The directional bearing of vegetative plot from bird point count station center on 0-359 degree scale (0 = north)	120	Integer
Plot	Distance from plot center:	distance	Distance of vegetative plot from bird point count station center Values: 1-25	4	Integer
Plot	image_count	image_count	Number of attached images counted by Survey123 form based on Photo Table	1	String
Plot	How many muskrat houses are within 25 m of the quadrat?	muskrat_houses	Number of muskrat houses observed within 25 m circular plot around bird point count station center	1	Integer
Plot	Water depth:	water_depth	Depth of water from top of substrate to water surface in centimeters	90	Double
Plot	Are the Phragmites rhizomes too dense to accurately measure organic layer?	dense_phrag_rhizomes	Surveyor(s) determine of the viability of measuring depth of organic layer due to the thickness of Phragmites rhizomes in substrate Values: yes, no	no	String
Plot	Depth of organic Layer:	organic_layer_depth	Depth from top of substrate to bottom of detected substrate layer in centimeters	4	Double
Plot	Maximum vegetation height:	vege_height	Height of tallest vegetation from top of substrate to vertical height of plant in centimeters	304	Double
Plot	percent_cover_all	percent_cover_all	Calculated sum of percent covers of percent_cover_emergent, percent_cover_submersed, percent_cover_floating, percent_cover_woody, percent_cover_water, percent_cover_bare_ground, percent_cover_litter, percent_cover_other. Often greater than 100% due to three-dimensional nature of vegetative plot	181	String
Plot	Emergent plants	percent_cover_emergent	Estimate of percent cover of all emergent class vascular plants in vegetative plot, both alive and dead	55	Double
Plot	Submersed plants	percent_cover_submersed	Estimate of percent cover of all submersed class vascular plants in vegetative plot	30	Double

Table	Display Name	Field Name	Definitions and Values	Example	Data Type
Plot	Floating-leaved plants	percent_cover_floating	Estimate of percent cover of all floating-leaved/unrooted class vascular plants in vegetative plot	0	Double
Plot	Woody plants	percent_cover_woody	Estimate of percent cover of all woody plants in vegetative plot	0	Double
Plot	Water	percent_cover_water	Estimate of percent cover of surface water in vegetative plot including floating-leaved and submersed plants	90	Double
Plot	Bare ground	percent_cover_bare_ground	Estimate of percent cover of exposed substrate in vegetative plot	0	Double
Plot	Litter	percent_cover_litter	Estimate of percent cover of all litter (i.e., detritus, dead vegetative matter at less than 45 degree angle, trash) in vegetative plot	1	Double
Plot	Other	percent_cover_other	Estimate of percent cover of items that do not fall into above categories in vegetative plot (e.g., algae, liverwort, moss)	5	Double
Plot	Explain other(s)	percent_cover_other_notes	Description of any “others” indicated in percent_cover_other	algae	String
Plot	species_richness	species_richness	Number of species in vegetative plot calculated by Survey123 form based on Species Table	2	String
Plot	How many woody stems > 2 m tall within 2.5 m of quadrat center?	number_woody_stems	Number of woody stems, both dead and alive, greater than 2m from ground within 2.5 m of vegetative plot center	1	Integer
Plot	species_richness_shrub	species_richness_shrub	Number of shrub species within 2.5 m of vegetative plot center	1	String
Plot	Additional Notes:	additional_notes	Remarks by surveyor(s) about vegetative plot that were not captured elsewhere	On muskrat hut	String
Plot	Treatment Type	treatmentType	Values: Managed Phragmites, Reference, Unmanaged Phragmites	Reference	String
Plot	Longitude	x	Longitudinal coordinate of vegetative plot in decimal degrees (WGS84)	-83.62074789	Geometry
Plot	Latitude	y	Latitudinal coordinate of vegetative plot in decimal degrees (WGS84)	43.6278377	Geometry

Table	Display Name	Field Name	Definitions and Values	Example	Data Type
Photo	Direction from plot, which photograph was taken	image_direction	Direction from plot which the photograph was taken Values: Above, North, East, South, West, Other	Above	String
Photo	Explain other:	image_other	Explanation by surveyor(s) as to why “Other” was selected for image_direction.		String
Photo	image_locationID	image_locationID	Name abbreviations of site location Values: Wigwam Bay SWA (WBSWA), Bay County Pinconning Park (BCPP), Nayanquing Point SWA (NPSWA), Hampton (HAMP), Quanicassee SWA (QSWA), Vanderbilt County Park (VCP), Fish Point SWA South (FPSWAS), Fish Point SWA North (FPSWAN), Wildfowl Bay SWA (WFBSWA), Saganing River (SCTSR), Other	WFBSWA	String
Photo	image_locationID_plot	image_locationID_plot	Unique identifier of bird point count station used in both bird and vegetative surveys.	529N	String
Photo	image_eventDate	image_eventDate	The day, month, and year of survey	2021-07-12	String
Photo	Bearing from plot center:	image_bearing2	The directional bearing of vegetative plot from bird point count station center on 0-359 degree scale (0 = north)	120	Integer
Photo	image_distance	image_distance	Distance of vegetative plot from bird point count station center. Values: 1-25	4	String
Species	Scientific name	nomenclaturalCode	Species acronym for plant species in the vegetative plot. Used six-letter acronyms for the scientific name for Michigan species as per Herman et al. 2001. If species was not on list, "Other" was available	SCHPUN	String
Species	scientificName	scientificName	Scientific name of the species using taxonomy Reznicek et al. 2014	*Schoenoplectus pungens*	String
Species	vernacularName	vernacularName	Common or vernacular name of the species	bulrush	String
Species	family	family	Family name of the species	Cyperaceae	String
Species	nativeNonNative	nativeNonNative	Species’ native/non-native status in Michigan using Reznicek et al. 2014	native	String
Species	genus	genus	Genus name of the species	*Schoenoplectus*	String

Table	Display Name	Field Name	Definitions and Values	Example	Data Type
Species	physiognomy	physiognomy	Physiognomic class or physical appearance and shape of the species	sedge	String
Species	coefficient_of_conservatism	coefficient_of_conservatism	Coefficient of conservatism is numeric value assigned regionally to plant species to indicate their sensitivity to anthropogenic disturbance. Coefficients range from 0 to 10 and represent an estimated probability that a plant is likely to occur in a landscape relatively unaltered from what is believed to be pre-European colonization (Herman et al. 2001, Reznicek et al. 2014)	5	String
Species	coefficient_wetness	coefficient_wetness	Coefficient of wetness is the estimated probability for which a species occurs in wetlands. Coefficients range from -5 to 5. Positive numbers indicate drier habitat while negative number indicate wet habitat (Herman et al. 2001, Reznicek et al. 2014)	-5	String
Species	life_duration	life_duration	Life duration or life span category of the species Values: annual, biennial, perennial	perennial	String
Species	Explain other:	species_other	Explanation by surveyor(s) as to why “Other” was selected for nomenclaturalCode	*Riccia* sp.	String
Species	Percent cover	percent_cover_species	Estimate of percent cover of species in vegetative plot	2	Double
Species	Number of stems	stem_density	Number of stems at angles greater than 45 degrees in vegetative plot. Only counted for species of genera Phragmites, Schoenoplectus, and Typha.	21	Integer
Species	Are you certain in your species identification?	scientificName_id_certain	Surveyor(s)’s certainty of species identification Values: yes, no	yes	String
Species	Explain your identification uncertainty	scientificName_id_cert_notes	Explanation by surveyor(s) if they indicated uncertainty in species identification	likely, possibly hybrid	String
Species	Notes:	occurenceRemarks	Remarks by surveyor(s) about species that were not captured elsewhere	Fruits present	String

Table	Display Name	Field Name	Definitions and Values	Example	Data Type
Species	species_vege_locationID	species_vege_locationID	Name abbreviations of site location Values: Wigwam Bay SWA (WBSWA), Bay County Pinconning Park (BCPP), Nayanquing Point SWA (NPSWA), Hampton (HAMP), QuanicasseeSWA (QSWA), Vanderbilt County Park (VCP), Fish Point SWA South (FPSWAS), Fish Point SWA North (FPSWAN), Wildfowl Bay SWA (WFBSWA), Saganing River (SCTSR), Other	WFBSWA	String
Species	species_vege_locationID_plot	species_vege_locationID_plot	Unique identifier of bird point count station used in both bird and vegetative surveys.	529N	String
Species	species_vege_eventDate	species_vege_eventDate	The day, month, and year of survey	2021-07-12	String
Species	species_vege_bearing	species_vege_bearing	The directional bearing of vegetative plot from bird point count station center on 0-359 degree scale (0 = north)	120	String
Species	species_vege_distance	species_vege_distance	Distance of vegetative plot from bird point count station center. Values: 1-25	4	String
Shrub	Scientific name	nomenclaturalCode_shrub	Species acronym for woody species within 2.5 m of vegetative plot center. Used six-letter acronyms for the scientific name for Michigan species as per Herman et al. 2001. If species was not on list, "Other" was available	CORSER	String
Shrub	scientificName	scientificName_shrub	Scientific name of the species using taxonomy Reznicek et al. 2014	*Cornus sericea*	String
Shrub	vernacularName	vernacularName_shrub	Common or vernacular name of the species	red-osier	String
Shrub	family	family_shrub	Family name of the species	Cornaceae	String
Shrub	nativeNonNative	nativeNonNative_shrub	Species’ native/non-native status in Michigan using Reznicek et al. 2014	native	String
Shrub	genus	genus_shrub	Genus name of the species	*Cornus*	String
Shrub	physiognomy	physiognomy_shrub	Physiognomic class or physical appearance and shape of the species	shrub	String

Table	Display Name	Field Name	Definitions and Values	Example	Data Type
Shrub	coefficient_of_conservatism	coefficient_of_conserv_shrub	Coefficient of conservatism is numeric value assigned regionally to plant species to indicate their sensitivity to anthropogenic disturbance. Coefficients range from 0 to 10 and represent an estimated probability that a plant is likely to occur in a landscape relatively unaltered from what is believed to be pre-European colonization (Herman et al. 2001, Reznicek et al. 2014)	2	String
Shrub	coefficient_wetness	coefficient_wetness_shrub	Coefficient of wetness is the estimated probability for which a species occurs in wetlands. Coefficients range from -5 to 5. Positive numbers indicate drier habitat while negative number indicate wet habitat (Herman et al. 2001, Reznicek et al. 2014)	-3	String
Shrub	life_duration	life_duration_shrub	Life duration or life span category of the species Values: annual, biennial, perennial	perennial	String
Shrub	Explain other:	species_other_shrub	Explanation by surveyor(s) as to why “Other” was selected for nomenclaturalCode	*Cornus florida*, not on list	String
Shrub	Are you certain in your species identification?	scientificName_shrub_id_cert	Surveyor(s)’s certainty of species identification Values: yes, no	yes	String
Shrub	Explain your identification uncertainty	scientificName_id_cert_notes	Explanation by surveyor(s) if they indicated uncertainty in species identification	genus certain, likely species	String
Shrub	Distance from plot center	distance_shrub	Distance in meters of nearest shrub of species from vegetative plot center	1.7	Double
Shrub	Shrub height:	height_shrub	Height in meters of nearest shrub of species from vegetative plot center	1	Double
Shrub	Notes:	occurenceRemarks_shrub	Remarks by surveyor(s) about species that were not captured elsewhere	2 more of the same species, taller, 4 m	String

Table	Display Name	Field Name	Definitions and Values	Example	Data Type
Shrub	species_shrub_locationID	species_shrub_locationID	Name abbreviations of site location Values: Wigwam Bay SWA (WBSWA), Bay County Pinconning Park (BCPP), Nayanquing Point SWA (NPSWA), Hampton (HAMP), QuanicasseeSWA (QSWA), Vanderbilt County Park (VCP), Fish Point SWA South (FPSWAS), Fish Point SWA North (FPSWAN), Wildfowl Bay SWA (WFBSWA), Saganing River (SCTSR), Other	WFBSWA	String
Shrub	species_shrub_locationID_plot	species_shrub_locationID_plot	Unique identifier of bird point count station used in both bird and vegetative surveys.	529N	String
Shrub	species_shrub_eventDate	species_shrub_eventDate	The day, month, and year of survey	2021-07-12	String
Shrub	species_shrub_bearing	species_shrub_bearing	The directional bearing of vegetative plot from bird point count station center on 0-359 degree scale (0 = north)	120	String
Shrub	species_shrub_distance	species_shrub_distance	Distance of vegetative plot from bird point count station center. Values: 1-25	4	String

Appendix B: Data alterations of vegetation assemblages for MDS analysis.

Table B-1. Species removed from MDS analysis, because they were observed (obs.) less than 10 times across all years of sampling (n = 106). The six-letter acronym scheme was developed in Herman et al. (2001). Several characteristics of each species are listed: native/non-native status, Family, Physiognomy, and Coefficient of Wetness (W).

Scientific Name	Acronym	Native/ Non-native	Family	Physiognomy	W	Obs.
Acer rubrum	ACERUB	native	Sapindaceae	tree	0	1
Alisma triviale	ALITRI	native	Alismataceae	forb	-5	1
Ambrosia artemisiifolia	AMBART	native	Asteraceae	forb	3	1
Apios americana	APIAME	native	Fabaceae	vine	-3	2
Apocynum cannabinum	APOCAN	native	Apocynaceae	forb	0	2
Barbarea vulgaris	BARVUL	non-native	Brassicaceae	forb	0	1
Bidens connata	BIDCON	native	Asteraceae	forb	-3	3
Bidens trichosperma	BIDTRI	native	Asteraceae	forb	-5	3
Boehmeria cylindrica	BOECYL	native	Urticaceae	forb	-5	4
Bolboschoenus fluviatilis	BOLFLU	native	Cyperaceae	sedge	-5	2
Calystegia sepium	CALSEP	native	Convolvulaceae	vine	0	2
Campanula aparinoides	CAMAPA	native	Campanulaceae	forb	-5	6
Centaurea stoebe	CENSTO	non-native	Asteraceae	forb	5	1
Cicuta bulbifera	CICBUL	native	Apiaceae	forb	-5	7
Cinna arundinacea	CINARU	native	Poaceae	grass	-3	1
Cladium mariscoides	CLAMAR	native	Cyperaceae	sedge	-5	7
Clematis virginiana	CLEVIR	native	Ranunculaceae	vine	0	1
Clinopodium vulgare	CLIVUL	native	Lamiaceae	forb	5	1
Conyza canadensis	CONCAN	native	Asteraceae	forb	3	1
Cornus amomum	CORAMO	native	Cornaceae	shrub	-3	3
Cornus foemina	CORFOE	native	Cornaceae	shrub	0	1
Cornus sericea	CORSER	native	Cornaceae	shrub	-3	2
Carex aquatilis	CXAQUA	native	Cyperaceae	sedge	-5	3
Carex buxbaumii	CXBUXB	native	Cyperaceae	sedge	-5	2
Carex hystericina	CXHYST	native	Cyperaceae	sedge	-5	1
Carex lacustris	CXLACU	native	Cyperaceae	sedge	-5	7
Carex lasiocarpa	CXLASI	native	Cyperaceae	sedge	-5	9
Carex pellita	CXPELL	native	Cyperaceae	sedge	-5	5
Carex prairea	CXPRAI	native	Cyperaceae	sedge	-3	3
Carex pseudo-cyperus	CXPSEU	native	Cyperaceae	sedge	-5	1
Carex sartwellii	CXSART	native	Cyperaceae	sedge	-5	3
Carex utriculata	CXUTRI	native	Cyperaceae	sedge	-5	3
Cyperus engelmannii	CYPENG	native	Cyperaceae	sedge	-5	1
Cyperus esculentus	CYPESC	native	Cyperaceae	sedge	-3	1
Elodea nuttallii	ELONUT	native	Hydrocharitaceae	forb	-5	1
Equisetum fluviatile	EQUFLU	native	Equisetaceae	fern	-5	1
Erechtites hieraciifolius	EREHIE	native	Asteraceae	forb	3	3
Euthamia graminifolia	EUTGRA	native	Asteraceae	forb	0	1
Fraxinus pennsylvanica	FRAPEN	native	Oleaceae	tree	-3	4
Galium asprellum	GALASP	native	Rubiaceae	vine	-5	1
Galium labradoricum	GALLAB	native	Rubiaceae	forb	-5	4
Galium tinctorium	GALTIN	native	Rubiaceae	forb	-5	4
Galium trifidum	GALTRD	native	Rubiaceae	forb	-3	1
Heteranthera dubia	HETDUB	native	Pontederiaceae	forb	-5	4
Hypericum majus	HYPMAJ	native	Hypericaceae	forb	-3	2

Scientific Name	Acronym	Native/ Non-native	Family	Physiognomy	W	Obs.
Impatiens capensis	IMPCAP	native	Balsaminaceae	forb	-3	4
Iris versicolor	IRIVER	native	Iridaceae	forb	-5	1
Juncus balticus	JUNBAL	native	Juncaceae	rush	-5	1
Lathyrus palustris	LATPAL	native	Fabaceae	vine	-3	3
Leersia virginica	LEEVIR	native	Poaceae	grass	-3	1
Lycopus americanus	LYCAME	native	Lamiaceae	forb	-5	1
Lycopus uniflorus	LYCUNI	native	Lamiaceae	forb	-5	3
Lycopus virginicus	LYCVIR	native	Lamiaceae	forb	-5	1
Lysimachia thyrsiflora	LYSTHY	native	Myrsinaceae	forb	-5	3
Lythrum salicaria	LYTSAL	non-native	Lythraceae	forb	-5	8
Melilotus albus	MELALB	non-native	Fabaceae	forb	3	1
Najas guadalupensis	NAJGUA	native	Hydrocharitaceae	forb	-5	1
Onoclea sensibilis	ONOSEN	native	Onocleaceae	fern	-3	1
Persicaria hydropiper	PERHYR	native	Polygonaceae	forb	-5	1
Persicaria hydropiperoides	PERHYS	native	Polygonaceae	forb	-5	1
Phalaris arundinacea	PHAARU	native	Poaceae	grass	-3	8
Phragmites australis var. *americanus*	PHRAUM	native	Poaceae	grass	-3	6
Pilea pumila	PILPUM	native	Urticaceae	forb	-3	4
Poa palustris	POAPAS	native	Poaceae	grass	-3	1
Pontederia cordata	PONCOR	native	Pontederiaceae	forb	-5	3
Potentilla anserina	POTANS	native	Rosaceae	forb	-3	2
Potamogeton crispus	POTCRI	non-native	Potamogetonaceae	forb	-5	2
Potamogeton foliosus	POTFOL	native	Potamogetonaceae	forb	-5	7
Potamogeton gramineus	POTGRM	native	Potamogetonaceae	forb	-5	7
Potamogeton illinoensis	POTILL	native	Potamogetonaceae	forb	-5	3
Potamogeton obtusifolius	POTOBT	native	Potamogetonaceae	forb	-5	1
Potamogeton zosteriformis	POTZOS	native	Potamogetonaceae	forb	-5	9
Proserpinaca palustris	PROPAL	native	Haloragaceae	forb	-5	6
Ranunculus recurvatus	RANREC	native	Ranunculaceae	forb	-3	1
Rubus strigosus	RUBSTR	native	Rosaceae	shrub	0	3
Rudbeckia fulgida	RUDFUL	native	Asteraceae	forb	-5	1
Sagittaria cristata	SAGCRI	native	Alismataceae	forb	-5	1
Sagittaria latifolia	SAGLAT	native	Alismataceae	forb	-5	9
Salix discolor	SALDIS	native	Salicaceae	shrub	-3	1
Salix exigua	SALEXI	native	Salicaceae	shrub	-3	1
Salix nigra	SALNIG	native	Salicaceae	tree	-5	1
Schoenoplectus tabernaemontani	SCHTAB	native	Cyperaceae	sedge	-5	2
Scirpus cyperinus	SCICYP	native	Cyperaceae	sedge	-5	2
Scutellaria galericulata	SCUGAL	native	Lamiaceae	forb	-5	2
Sium suave	SIUSUA	native	Apiaceae	forb	-5	1
Solidago gigantea	SOLGIG	native	Asteraceae	forb	-3	1
Sonchus arvensis	SONARV	non-native	Asteraceae	forb	3	1
Sparganium emersum	SPAEME	native	Typhaceae	forb	-5	1
Sparganium eurycarpum	SPAEUR	native	Typhaceae	forb	-5	1
Spartina pectinata	SPAPEC	native	Poaceae	grass	-3	1
Symphyotrichum boreale	SYMBOR	native	Asteraceae	forb	-5	1
Symphyotrichum lanceolatum	SYMLAN	native	Asteraceae	forb	-3	3
Symphyotrichum lateriflorum	SYMLAT	native	Asteraceae	forb	0	1
Taraxacum officinale	TAROFF	non-native	Asteraceae	forb	3	1

Scientific Name	Acronym	Native/ Non-native	Family	Physiognomy	W	Obs.
Teucrium canadense	TEUCAN	native	Lamiaceae	forb	-3	1
Thelypteris palustris	THEPAL	native	Thelypteridaceae	fern	-3	6
Toxicodendron radicans	TOXRAD	native	Anacardiaceae	vine	0	1
Trifolium dubium	TRIDUB	non-native	Fabaceae	forb	3	1
Triadenum fraseri	TRIFRA	native	Hypericaceae	forb	-5	1
Typha latifolia	TYPLAT	native	Typhaceae	forb	-5	3
Urtica dioica	URTDIO	native	Urticaceae	forb	0	1
Utricularia intermedia	UTRINT	native	Lentibulariaceae	forb	-5	7
Utricularia minor	UTRMIN	native	Lentibulariaceae	forb	-5	9
Verbena hastata	VERHAS	native	Verbenaceae	forb	-3	1
Vitis riparia	VITRIP	native	Vitaceae	vine	0	1
Zizania palustris	ZIZPAL	native	Poaceae	grass	-5	1

Table B-2. Pooled vegetative plots per year removed for absence of non-rare species. The 16 species present in 387N in 2018 had less than 10 observations across all vegetative plots and years. A key to the acronyms used for rare species can be derived from Table A1 (Appendix A).

Location	Point Identifier	Year	Wetland Type	Species Present
Wigwam Bay State Wildlife Area	387N	2018	Reference	16[1]
Wigwam Bay State Wildlife Area	PM02	2019	Managed Phragmites	0
Nayanquing Point State Wildlife Area	PM10	2019	Managed Phragmites	0
Nayanquing Point State Wildlife Area	PM10	2021	Managed Phragmites	0

[1]ACERUB, CORAMO, CORSER, CXPELL, CXPRAI, CXSART, GALTIN, LYCAME, PHAARU, POTANS, RUDFUL, SONARV, SYMBOR, SYMLAN, TAROFF, TRIDUB.

Appendix C: Non-metric multidimensional scaling results.

Non-metric multidimensional scaling (MDS) results for vegetative plot assemblage of each bird count station per year (n = 233). Rare species with less than ten observations across all bird count stations per years were removed (Appendix B), leaving 27 plant species in analysis. The resulting MDS had three dimensions and a stress value of 0.18. Percent coverage of species were arcsine square-root transformed prior to analysis. The results categorized by wetland category can be seen in Figure 5.

Table C-1. Monte Carlo results for MDS of species assemblage of 27 plant species across 233 vegetative plots. MDS had three dimensions and a stress value of 0.18. Coverage estimates of species were arcsine square-root transformed prior to analysis.

Scientific Name	**Acronym**	**MDS1**	**MDS2**	**MDS3**	**r^2**	**$P_r(>r)$**
Calamagrostis canadensis	CALCAN	-1.330	0.091	0.615	0.1862	0.001
Ceratophyllum demersum	CERDEM	0.773	-0.455	-0.496	0.3792	0.001
Carex stricta	CXSTRI	-1.604	0.118	0.844	0.1606	0.001
Elodea canadensis	ELOCAN	0.860	-0.438	-0.238	0.1806	0.001
Hydrocharis morsus-ranae	HYDMOR	0.098	0.017	-0.884	0.3016	0.001
Lemna trisulca	LEMTRI	0.597	-0.571	-0.335	0.1543	0.001
Lemna turionifera; L. minor	LEMTUR	0.158	0.096	-0.443	0.0603	0.003
Myriophyllum sibiricum	MYRSIB	0.756	-0.609	0.084	0.1831	0.001
Myriophyllum spicatum	MYRSPI	1.015	0.189	0.101	0.0738	0.001
Najas flexilis	NAJFLE	0.765	0.114	0.644	0.0908	0.001
Nitellopsis obtusa	NITOBT	0.015	-0.997	-0.036	0.2218	0.001
Nymphaea odorata	NYMODO	0.410	-0.516	0.323	0.0867	0.001
Other (e.g., *Chara* sp. *Riccia* sp., filamentous algae)	OTHER	0.285	-0.335	-0.289	0.0887	0.001
Persicaria amphibia	PERAMP	-1.008	-0.542	0.672	0.1402	0.001
Phragmites australis var. *australis*	PHRAUU	-0.541	0.551	-0.486	0.5366	0.001
Potamogeton richardsonii	POTRIC	1.108	0.621	0.737	0.2444	0.001
Sagittaria rigida	SAGRIG	0.662	-0.404	0.338	0.0406	0.015
Schoenoplectus acutus	SCHACU	0.158	0.588	0.745	0.0640	0.004
Schoenoplectus pungens	SCHPUN	0.263	0.981	0.397	0.1854	0.001
Spirodela polyrhiza	SPIPOL	0.159	-0.064	-0.363	0.0985	0.001
Stuckenia pectinata	STUPEC	0.227	-0.384	-0.300	0.0380	0.027
Typha angustifolia	TYPANG	-0.219	-0.594	0.775	0.4687	0.001
Typha × glauca	TYPGLA	0.376	0.117	-0.448	0.0231	0.133
Utricularia gibba	UTRGIB	-0.651	-0.697	-0.319	0.0797	0.001
Utricularia vulgaris	UTRVUL	-0.420	-0.476	-0.209	0.2844	0.001
Vallisneria americana	VALAME	0.944	0.496	0.685	0.3728	0.001
Wolffia columbiana	WOLCOL	0.154	0.496	-0.724	0.0336	0.048

Table C-2. Coordinates of vegetative point location on MDS. Bird point count station identifier per year is abbreviated “Point ID – YEAR”. MDS had three dimensions and a stress value of 0.18.

Point ID-Year	Location	Wetland Category	MDS1	MDS2	MDS3
PM04-2018	Bay City Pinconning Park	Managed Phragmites	-0.083	1.022	0.358
PM04-2019	Bay City Pinconning Park	Managed Phragmites	-0.199	0.860	0.229
PM04-2021	Bay City Pinconning Park	Managed Phragmites	0.192	0.753	0.073
PM05-2018	Bay City Pinconning Park	Managed Phragmites	-0.123	0.642	-0.003
PM05-2019	Bay City Pinconning Park	Managed Phragmites	0.590	-0.118	0.419
PM05-2021	Bay City Pinconning Park	Managed Phragmites	0.456	0.490	-0.014
PM39-2018	Bay City Pinconning Park	Managed Phragmites	0.107	-0.393	0.792
PM39-2019	Bay City Pinconning Park	Managed Phragmites	0.864	0.099	-0.604
PM39-2021	Bay City Pinconning Park	Managed Phragmites	0.824	-0.016	0.090
PM40-2018	Bay City Pinconning Park	Managed Phragmites	-0.335	-0.152	0.197
PM40-2019	Bay City Pinconning Park	Managed Phragmites	-0.109	-0.311	-0.540
PM40-2021	Bay City Pinconning Park	Managed Phragmites	0.508	-0.314	-0.625
CM97-2018	Fish Point State Wildlife Area	Reference	-0.214	-0.547	0.973
CM97-2019	Fish Point State Wildlife Area	Reference	-0.370	-0.318	1.115
CM97-2021	Fish Point State Wildlife Area	Reference	-0.248	-0.421	0.980
CM98-2018	Fish Point State Wildlife Area	Reference	-0.534	-0.387	0.957
CM98-2019	Fish Point State Wildlife Area	Reference	-0.345	-0.554	0.816
CM98-2021	Fish Point State Wildlife Area	Reference	-0.285	-0.527	1.000
PR14-2018	Fish Point State Wildlife Area	Reference	-0.736	-0.058	0.688
PR14-2019	Fish Point State Wildlife Area	Reference	-0.739	0.144	0.302
PR14-2021	Fish Point State Wildlife Area	Reference	-0.850	-0.658	0.948
PR15N-2018	Fish Point State Wildlife Area	Reference	-0.366	-0.501	0.322
PR15N-2019	Fish Point State Wildlife Area	Reference	0.232	-0.587	0.032
PR15N-2021	Fish Point State Wildlife Area	Reference	0.183	-0.537	-0.207
PR17-2018	Fish Point State Wildlife Area	Reference	-0.173	-0.449	0.629
PR17-2019	Fish Point State Wildlife Area	Reference	-0.016	-0.760	0.661
PR17-2021	Fish Point State Wildlife Area	Reference	-0.118	-0.722	0.247
PR18N-2018	Fish Point State Wildlife Area	Reference	-0.061	-0.493	0.389
PR18N-2019	Fish Point State Wildlife Area	Reference	0.083	-1.019	0.371
PR18N-2021	Fish Point State Wildlife Area	Reference	0.041	-0.892	0.432
PR19-2018	Fish Point State Wildlife Area	Reference	-0.573	-0.750	-0.149
PR19-2019	Fish Point State Wildlife Area	Reference	0.580	-0.857	-0.180
PR19-2021	Fish Point State Wildlife Area	Reference	0.353	-0.726	-0.081
PR20-2018	Fish Point State Wildlife Area	Reference	0.015	-0.943	0.470
PR20-2019	Fish Point State Wildlife Area	Reference	-0.209	-1.067	-0.262
PR20-2021	Fish Point State Wildlife Area	Reference	-0.282	-0.847	-0.426
PR22N-2018	Fish Point State Wildlife Area	Reference	0.015	-0.359	0.933
PR22N-2019	Fish Point State Wildlife Area	Reference	-0.233	-0.777	0.697
PR22N-2021	Fish Point State Wildlife Area	Reference	-0.158	-0.548	0.100

Point ID-Year	Location	Wetland Category	MDS1	MDS2	MDS3
514-2018	Fish Point State Wildlife Area	Unmanaged Phragmites	-0.676	-0.118	-0.301
514-2019	Fish Point State Wildlife Area	Unmanaged Phragmites	-0.522	-0.083	-0.345
514-2021	Fish Point State Wildlife Area	Unmanaged Phragmites	0.040	0.442	-0.568
515N-2018	Fish Point State Wildlife Area	Unmanaged Phragmites	-0.506	0.599	-0.364
515N-2019	Fish Point State Wildlife Area	Unmanaged Phragmites	-0.590	0.568	-0.418
515N-2021	Fish Point State Wildlife Area	Unmanaged Phragmites	-0.512	0.596	-0.367
518-2018	Fish Point State Wildlife Area	Unmanaged Phragmites	-0.035	0.818	0.003
518-2019	Fish Point State Wildlife Area	Unmanaged Phragmites	-0.407	1.069	0.167
518-2021	Fish Point State Wildlife Area	Unmanaged Phragmites	0.793	0.795	0.643
522-2019	Fish Point State Wildlife Area	Unmanaged Phragmites	-0.577	0.540	-0.400
522-2021	Fish Point State Wildlife Area	Unmanaged Phragmites	-0.378	0.564	-0.518
529N-2018	Fish Point State Wildlife Area	Unmanaged Phragmites	-0.421	0.792	-0.214
529N-2019	Fish Point State Wildlife Area	Unmanaged Phragmites	-0.614	0.779	-0.147
529N-2021	Fish Point State Wildlife Area	Unmanaged Phragmites	-0.495	0.745	-0.248
533-2018	Fish Point State Wildlife Area	Unmanaged Phragmites	-0.456	0.676	-0.317
533-2019	Fish Point State Wildlife Area	Unmanaged Phragmites	-0.497	1.121	0.276
533-2021	Fish Point State Wildlife Area	Unmanaged Phragmites	0.733	1.050	0.702
PU06-2018	Fish Point State Wildlife Area	Unmanaged Phragmites	-0.435	0.708	-0.308
PU07-2018	Fish Point State Wildlife Area	Unmanaged Phragmites	-0.575	0.535	-0.422
PU07-2019	Fish Point State Wildlife Area	Unmanaged Phragmites	-0.547	0.489	-0.386
PU08-2019	Fish Point State Wildlife Area	Unmanaged Phragmites	-0.183	0.337	-0.861
PU08-2021	Fish Point State Wildlife Area	Unmanaged Phragmites	0.592	-0.826	-0.055
PU09-2018	Fish Point State Wildlife Area	Unmanaged Phragmites	-0.791	0.811	-0.074
PU10-2018	Fish Point State Wildlife Area	Unmanaged Phragmites	-0.605	0.320	-0.394
PU10-2019	Fish Point State Wildlife Area	Unmanaged Phragmites	-0.557	0.551	-0.369
PU10-2021	Fish Point State Wildlife Area	Unmanaged Phragmites	-0.487	0.387	-0.342

Point ID-Year	Location	Wetland Category	MDS1	MDS2	MDS3
PU11N-2019	Fish Point State Wildlife Area	Unmanaged Phragmites	-0.179	-0.040	-0.654
PU11N-2021	Fish Point State Wildlife Area	Unmanaged Phragmites	0.058	0.547	-0.428
PU12-2019	Fish Point State Wildlife Area	Unmanaged Phragmites	-0.601	0.345	-0.011
PU12-2021	Fish Point State Wildlife Area	Unmanaged Phragmites	-0.202	0.411	-0.353
PU13-2018	Fish Point State Wildlife Area	Unmanaged Phragmites	-0.260	0.978	0.242
PU14-2018	Fish Point State Wildlife Area	Unmanaged Phragmites	-0.186	0.583	-0.479
PU14-2019	Fish Point State Wildlife Area	Unmanaged Phragmites	-0.116	0.767	-0.147
PU14-2021	Fish Point State Wildlife Area	Unmanaged Phragmites	-0.254	0.489	-0.468
PM25-2018	Hampton Township Park	Managed Phragmites	0.278	-0.683	-0.242
PM25-2019	Hampton Township Park	Managed Phragmites	1.086	-0.171	0.040
PM25-2021	Hampton Township Park	Managed Phragmites	0.625	0.191	0.822
PM26-2018	Hampton Township Park	Managed Phragmites	0.604	-0.234	-0.206
PM26-2019	Hampton Township Park	Managed Phragmites	1.134	-0.189	-0.250
PM26-2021	Hampton Township Park	Managed Phragmites	0.990	0.332	0.417
PM27-2018	Hampton Township Park	Managed Phragmites	-0.661	0.169	-0.508
PM27-2019	Hampton Township Park	Managed Phragmites	-0.642	-0.457	-0.664
PM27-2021	Hampton Township Park	Managed Phragmites	0.319	-0.088	-1.086
PM28-2018	Hampton Township Park	Managed Phragmites	-0.624	-0.663	-0.465
PM28-2019	Hampton Township Park	Managed Phragmites	0.981	-0.288	-0.528
PM28-2021	Hampton Township Park	Managed Phragmites	0.895	0.602	0.465
PM29-2018	Hampton Township Park	Managed Phragmites	-0.191	-0.061	-0.885
PM29-2019	Hampton Township Park	Managed Phragmites	0.687	-0.133	-0.571
PM29-2021	Hampton Township Park	Managed Phragmites	1.006	-0.573	-0.188
PM30-2018	Hampton Township Park	Managed Phragmites	-0.434	-0.316	-0.890
PM30-2019	Hampton Township Park	Managed Phragmites	0.345	-0.578	-0.518
PM30-2021	Hampton Township Park	Managed Phragmites	1.128	-0.219	-0.295
PM32-2018	Hampton Township Park	Managed Phragmites	-0.378	-0.653	-0.488
PM32-2019	Hampton Township Park	Managed Phragmites	0.621	-0.171	-0.313
PM32-2021	Hampton Township Park	Managed Phragmites	0.627	-0.618	-0.028
CM67-2018	Nayanquing Point State Wildlife Area	Managed Phragmites	0.299	0.046	0.799
CM67-2019	Nayanquing Point State Wildlife Area	Managed Phragmites	-0.123	-0.429	0.841
CM67-2021	Nayanquing Point State Wildlife Area	Managed Phragmites	-0.207	0.398	1.159
PM06N-2018	Nayanquing Point State Wildlife Area	Managed Phragmites	0.623	-0.474	-0.708
PM06N-2019	Nayanquing Point State Wildlife Area	Managed Phragmites	0.618	-0.339	-0.530

Point ID-Year	Location	Wetland Category	MDS1	MDS2	MDS3
PM06N-2021	Nayanquing Point State Wildlife Area	Managed Phragmites	0.484	-0.764	-0.865
PM07-2018	Nayanquing Point State Wildlife Area	Managed Phragmites	0.952	-0.673	-0.624
PM07-2019	Nayanquing Point State Wildlife Area	Managed Phragmites	0.232	-0.652	-0.037
PM07-2021	Nayanquing Point State Wildlife Area	Managed Phragmites	0.478	-0.857	-0.316
PM08-2018	Nayanquing Point State Wildlife Area	Managed Phragmites	1.235	-0.403	0.859
PM08-2019	Nayanquing Point State Wildlife Area	Managed Phragmites	0.996	0.246	1.132
PM08-2021	Nayanquing Point State Wildlife Area	Managed Phragmites	1.002	0.493	0.712
PM09-2018	Nayanquing Point State Wildlife Area	Managed Phragmites	0.377	-0.001	-1.120
PM09-2019	Nayanquing Point State Wildlife Area	Managed Phragmites	0.705	-0.224	-0.699
PM09-2021	Nayanquing Point State Wildlife Area	Managed Phragmites	0.903	-0.571	-0.363
PM10-2018	Nayanquing Point State Wildlife Area	Managed Phragmites	0.781	0.677	0.651
PM11-2018	Nayanquing Point State Wildlife Area	Managed Phragmites	0.738	-0.501	-0.345
PM11-2019	Nayanquing Point State Wildlife Area	Managed Phragmites	0.952	-0.438	-0.531
PM11-2021	Nayanquing Point State Wildlife Area	Managed Phragmites	0.644	-0.783	-0.334
PM12-2018	Nayanquing Point State Wildlife Area	Managed Phragmites	0.603	-0.228	-0.811
PM12-2019	Nayanquing Point State Wildlife Area	Managed Phragmites	0.413	-0.296	-0.739
PM12-2021	Nayanquing Point State Wildlife Area	Managed Phragmites	0.572	-0.374	-0.507
PM13-2018	Nayanquing Point State Wildlife Area	Managed Phragmites	0.296	-0.626	0.852
PM13-2019	Nayanquing Point State Wildlife Area	Managed Phragmites	1.213	0.112	-0.648
PM13-2021	Nayanquing Point State Wildlife Area	Managed Phragmites	0.807	-0.547	0.303
PM14-2018	Nayanquing Point State Wildlife Area	Managed Phragmites	1.152	0.294	0.669
PM14-2019	Nayanquing Point State Wildlife Area	Managed Phragmites	0.455	0.787	0.476
PM14-2021	Nayanquing Point State Wildlife Area	Managed Phragmites	1.001	0.389	0.653
PM15-2018	Nayanquing Point State Wildlife Area	Managed Phragmites	0.751	0.448	0.252
PM15-2019	Nayanquing Point State Wildlife Area	Managed Phragmites	0.552	0.814	-0.591
PM15-2021	Nayanquing Point State Wildlife Area	Managed Phragmites	0.178	1.640	0.414

Point ID-Year	Location	Wetland Category	MDS1	MDS2	MDS3
PM16-2018	Nayanquing Point State Wildlife Area	Managed Phragmites	0.742	0.492	0.639
PM16-2019	Nayanquing Point State Wildlife Area	Managed Phragmites	0.852	0.472	0.762
PM16-2021	Nayanquing Point State Wildlife Area	Managed Phragmites	0.787	0.789	0.652
PM17-2018	Nayanquing Point State Wildlife Area	Managed Phragmites	0.787	-0.370	0.022
PM17-2019	Nayanquing Point State Wildlife Area	Managed Phragmites	1.138	0.248	0.260
PM17-2021	Nayanquing Point State Wildlife Area	Managed Phragmites	0.823	-0.863	0.240
PM41-2018	Nayanquing Point State Wildlife Area	Managed Phragmites	0.516	0.949	-0.068
PM41-2019	Nayanquing Point State Wildlife Area	Managed Phragmites	0.733	1.050	0.702
PM41-2021	Nayanquing Point State Wildlife Area	Managed Phragmites	-0.045	1.080	1.000
PU16-2018	Quanicassee State Wildlife Area	Unmanaged Phragmites	0.050	0.058	-0.663
PU16-2019	Quanicassee State Wildlife Area	Unmanaged Phragmites	0.114	0.237	-0.533
PU16-2021	Quanicassee State Wildlife Area	Unmanaged Phragmites	0.064	0.225	-0.646
PU17-2018	Quanicassee State Wildlife Area	Unmanaged Phragmites	-0.394	0.451	-0.383
PU17-2019	Quanicassee State Wildlife Area	Unmanaged Phragmites	-0.157	0.311	-0.874
PU17N-2021	Quanicassee State Wildlife Area	Unmanaged Phragmites	-0.478	-0.095	-0.384
PU20N-2018	Quanicassee State Wildlife Area	Unmanaged Phragmites	-0.740	0.528	-0.314
PU20N-2019	Quanicassee State Wildlife Area	Unmanaged Phragmites	-0.319	0.406	-0.852
PU20N-2021	Quanicassee State Wildlife Area	Unmanaged Phragmites	-0.090	0.422	-0.744
PU21-2018	Quanicassee State Wildlife Area	Unmanaged Phragmites	-0.590	0.568	-0.418
PU21N-2019	Quanicassee State Wildlife Area	Unmanaged Phragmites	-0.494	0.134	-0.444
PU21N-2021	Quanicassee State Wildlife Area	Unmanaged Phragmites	-0.294	0.246	-0.657
PU23-2018	Quanicassee State Wildlife Area	Unmanaged Phragmites	-0.232	0.503	-0.572
PU23-2019	Quanicassee State Wildlife Area	Unmanaged Phragmites	-0.185	0.162	-0.571
PU23-2021	Quanicassee State Wildlife Area	Unmanaged Phragmites	-0.144	0.223	-0.599
PM33-2019	Saginaw-Chippewa Tribe – Saganing River	Managed Phragmites	0.301	-0.677	-0.370
PM34-2019	Saginaw-Chippewa Tribe – Saganing River	Managed Phragmites	-0.118	-0.918	-0.475

Point ID-Year	Location	Wetland Category	MDS1	MDS2	MDS3
SC12-2019	Saginaw-Chippewa Tribe – Saganing River	Managed Phragmites	-1.481	0.366	0.522
PM36-2018	Vanderbilt County Park	Managed Phragmites	-0.704	1.091	0.234
PM36-2019	Vanderbilt County Park	Managed Phragmites	0.273	-0.341	-0.531
PM36-2021	Vanderbilt County Park	Managed Phragmites	0.605	-0.183	-0.938
PM37-2018	Vanderbilt County Park	Managed Phragmites	1.597	0.445	0.000
PM37-2019	Vanderbilt County Park	Managed Phragmites	1.258	0.360	-0.106
PM37-2021	Vanderbilt County Park	Managed Phragmites	0.997	0.404	0.474
PM42-2018	Vanderbilt County Park	Managed Phragmites	-0.256	0.388	-0.686
PM42-2019	Vanderbilt County Park	Managed Phragmites	-0.098	0.364	-0.712
PM42-2021	Vanderbilt County Park	Managed Phragmites	-0.282	-0.235	-0.634
PM01-2018	Wigwam Bay State Wildlife Area	Managed Phragmites	0.137	1.828	0.425
PM01-2019	Wigwam Bay State Wildlife Area	Managed Phragmites	-1.005	-0.261	1.016
PM01-2021	Wigwam Bay State Wildlife Area	Managed Phragmites	0.700	0.623	0.767
PM02-2018	Wigwam Bay State Wildlife Area	Managed Phragmites	1.050	0.916	1.062
PM02-2021	Wigwam Bay State Wildlife Area	Managed Phragmites	0.131	0.707	0.383
PM03-2018	Wigwam Bay State Wildlife Area	Managed Phragmites	-0.084	-0.959	-0.212
PM03-2019	Wigwam Bay State Wildlife Area	Managed Phragmites	1.138	0.889	-0.019
PM03-2021	Wigwam Bay State Wildlife Area	Managed Phragmites	0.205	0.374	0.543
PM35-2019	Wigwam Bay State Wildlife Area	Managed Phragmites	0.718	0.792	0.550
PM38-2018	Wigwam Bay State Wildlife Area	Managed Phragmites	-1.732	-0.244	0.719
PM38-2019	Wigwam Bay State Wildlife Area	Managed Phragmites	-0.699	-0.473	1.027
PM38-2021	Wigwam Bay State Wildlife Area	Managed Phragmites	-0.636	-0.334	0.915
387N-2019	Wigwam Bay State Wildlife Area	Reference	-1.493	0.316	1.004
387N-2021	Wigwam Bay State Wildlife Area	Reference	-1.525	0.314	0.663
PR03-2018	Wigwam Bay State Wildlife Area	Reference	-0.339	-0.113	-0.256
PR03-2019	Wigwam Bay State Wildlife Area	Reference	0.185	-0.660	0.208
PR03-2021	Wigwam Bay State Wildlife Area	Reference	0.489	-0.582	-0.330
PR16-2018	Wigwam Bay State Wildlife Area	Reference	-0.184	-0.581	0.324
PR16-2019	Wigwam Bay State Wildlife Area	Reference	-0.415	-0.609	0.096
PR16-2021	Wigwam Bay State Wildlife Area	Reference	0.297	-0.853	0.677
PR21N-2018	Wigwam Bay State Wildlife Area	Reference	0.602	0.105	-0.048
PR21N-2019	Wigwam Bay State Wildlife Area	Reference	0.982	1.025	-0.506
PR21N-2021	Wigwam Bay State Wildlife Area	Reference	1.248	-0.119	0.517
PR23N-2018	Wigwam Bay State Wildlife Area	Reference	0.110	-0.164	0.559
PR23N-2019	Wigwam Bay State Wildlife Area	Reference	-0.299	-0.002	0.864
PR23N-2021	Wigwam Bay State Wildlife Area	Reference	0.126	0.126	0.397
PR27-2018	Wigwam Bay State Wildlife Area	Reference	0.185	-0.565	0.833
PR27-2019	Wigwam Bay State Wildlife Area	Reference	0.014	-0.261	0.748
PR27-2021	Wigwam Bay State Wildlife Area	Reference	-0.090	-0.722	0.133
PR28-2018	Wigwam Bay State Wildlife Area	Reference	-0.550	-0.255	0.078
PR28-2019	Wigwam Bay State Wildlife Area	Reference	-0.391	-0.485	0.284

Point ID-Year	Location	Wetland Category	MDS1	MDS2	MDS3
PR28-2021	Wigwam Bay State Wildlife Area	Reference	0.062	-0.732	-0.152
PR29-2018	Wigwam Bay State Wildlife Area	Reference	-0.180	-0.420	0.506
PR29-2019	Wigwam Bay State Wildlife Area	Reference	-0.129	-0.153	0.287
PR29-2021	Wigwam Bay State Wildlife Area	Reference	0.462	-0.684	0.060
PR38N-2018	Wigwam Bay State Wildlife Area	Reference	-0.153	0.139	0.340
PR38N-2019	Wigwam Bay State Wildlife Area	Reference	0.567	0.466	-0.503
PR38N-2021	Wigwam Bay State Wildlife Area	Reference	-0.056	0.111	0.245
PR04-2018	Wildfowl Bay State Wildlife Area	Reference	-0.462	-0.542	0.382
PR04-2019	Wildfowl Bay State Wildlife Area	Reference	-0.398	-1.051	0.678
PR04-2021	Wildfowl Bay State Wildlife Area	Reference	-0.433	-1.010	-0.282
PR05-2018	Wildfowl Bay State Wildlife Area	Reference	-0.605	-0.104	-0.011
PR05-2019	Wildfowl Bay State Wildlife Area	Reference	-0.614	-0.712	-0.280
PR05-2021	Wildfowl Bay State Wildlife Area	Reference	-0.411	-0.996	-0.298
PR06-2018	Wildfowl Bay State Wildlife Area	Reference	-0.483	-0.632	0.420
PR06-2019	Wildfowl Bay State Wildlife Area	Reference	-0.533	-0.667	0.319
PR06-2021	Wildfowl Bay State Wildlife Area	Reference	-0.575	-0.547	0.049
PR07-2018	Wildfowl Bay State Wildlife Area	Reference	-0.301	-0.080	-0.420
PR07-2019	Wildfowl Bay State Wildlife Area	Reference	-0.213	-0.805	-0.088
PR07-2021	Wildfowl Bay State Wildlife Area	Reference	-0.464	-0.451	-0.314
PR08-2018	Wildfowl Bay State Wildlife Area	Reference	-1.141	0.500	0.308
PR08-2019	Wildfowl Bay State Wildlife Area	Reference	-1.186	0.685	0.418
PR09N-2019	Wildfowl Bay State Wildlife Area	Reference	-0.964	-0.597	-0.119
PR09N-2021	Wildfowl Bay State Wildlife Area	Reference	-0.670	-0.145	0.065
PR31-2018	Wildfowl Bay State Wildlife Area	Reference	-1.471	-0.248	0.568
PR31-2019	Wildfowl Bay State Wildlife Area	Reference	-0.964	-0.610	-0.007
PR31-2021	Wildfowl Bay State Wildlife Area	Reference	-0.412	-0.543	0.112
PU01-2018	Wildfowl Bay State Wildlife Area	Unmanaged Phragmites	-0.572	-0.028	-0.205
PU01-2019	Wildfowl Bay State Wildlife Area	Unmanaged Phragmites	-0.457	0.344	-0.450
PU01-2021	Wildfowl Bay State Wildlife Area	Unmanaged Phragmites	0.116	-0.133	-0.722
PU02N-2018	Wildfowl Bay State Wildlife Area	Unmanaged Phragmites	-0.530	0.063	-0.399
PU02N-2019	Wildfowl Bay State Wildlife Area	Unmanaged Phragmites	-0.563	0.126	-0.351
PU02N-2021	Wildfowl Bay State Wildlife Area	Unmanaged Phragmites	-0.363	0.319	-0.406
PU04-2018	Wildfowl Bay State Wildlife Area	Unmanaged Phragmites	-0.540	0.135	-0.358
PU04-2019	Wildfowl Bay State Wildlife Area	Unmanaged Phragmites	-0.469	0.325	-0.393
PU04-2021	Wildfowl Bay State Wildlife Area	Unmanaged Phragmites	-0.464	0.540	-0.400
WL313-2018	Wildfowl Bay State Wildlife Area	Unmanaged Phragmites	-0.503	0.066	-0.214

Point ID-Year	Location	Wetland Category	MDS1	MDS2	MDS3
WL313-2019	Wildfowl Bay State Wildlife Area	Unmanaged Phragmites	-0.481	0.715	-0.503
WL313-2021	Wildfowl Bay State Wildlife Area	Unmanaged Phragmites	-0.452	0.148	-0.376
WL349-2018	Wildfowl Bay State Wildlife Area	Unmanaged Phragmites	-0.611	0.265	-0.387
WL349-2019	Wildfowl Bay State Wildlife Area	Unmanaged Phragmites	-0.545	0.523	-0.377
WL349-2021	Wildfowl Bay State Wildlife Area	Unmanaged Phragmites	-0.561	0.254	-0.324

Appendix D. Results of distance sampling modeling.

Table D-1. Results of distance models ran for primary marsh bird species detected during surveys conducted in Saginaw Bay, Lake Huron, coastal wetlands in 2018-2021. Abbreviations as follows: K = number of parameters; EDR = effective detection radius (meters); P = detection probability; D = density (detection per point); LCL = lower confidence limit (95%); and UCL = upper confidence limit (95%).

Species	Model Name[1]	K	AIC	Δ AIC	EDR	P	P LCL	P UCL	D	D LCL	D UCL
American bittern	hnher	1	372.28	0.00	129.72	0.75	0.56	1.00	0.04	0.03	0.05
	hnher_phragmites	2	373.70	1.42	129.13	0.74	0.67	0.82	0.04	0.03	0.04
	hnher_emergent	2	374.14	1.86	129.54	0.75	0.68	0.82	0.04	0.03	0.04
	hnher_depth	2	374.25	1.98	129.65	0.75	0.68	0.82	0.04	0.03	0.04
	hnher_wind	5	375.38	3.11	126.82	0.71	0.62	0.82	0.04	0.03	0.05
	hnher_type	3	375.67	3.40	129.38	0.74	0.67	0.83	0.04	0.03	0.04
	hnher_noise	4	376.68	4.41	126.62	0.71	0.00	1.00	0.04	0.00	15.18
Common gallinule	hrsim	2	1137.07	0.00	43.32	0.08	0.06	0.12	0.89	0.59	1.34
	hrsim_emergent	3	1191.33	54.26	72.99	0.24	0.22	0.26	0.31	0.26	0.37
	hrsim_depth	3	1191.35	54.29	72.97	0.24	0.22	0.26	0.31	0.26	0.37
	hrsim_phragmites	3	1191.40	54.33	73.01	0.24	0.22	0.26	0.31	0.26	0.37
	hrsim_noise	5	1195.39	58.32	72.98	0.24	0.22	0.26	0.31	0.26	0.37
	hrsim_wind	6	1197.34	60.27	72.98	0.24	0.22	0.26	0.31	0.26	0.37
	hrsim_type	4	1207.50	70.43	73.21	0.24	0.22	0.26	0.31	0.26	0.37
Least bittern	hncos_emergent	2	483.11	0.00	91.49	0.37	0.32	0.43	0.09	0.07	0.11
	hncos_phragmites	2	484.10	0.99	91.73	0.37	0.33	0.43	0.09	0.07	0.11
	hncos	1	485.00	1.90	92.54	0.38	0.31	0.47	0.09	0.07	0.11
	hncos_depth	2	485.93	2.82	92.25	0.38	0.33	0.43	0.09	0.07	0.11
	hncos_type	3	487.25	4.15	92.09	0.38	0.33	0.43	0.09	0.07	0.11
	hncos_noise	3	487.43	4.32	92.19	0.38	0.33	0.43	0.09	0.07	0.11
Pied-billed grebe	hncos_type	3	1065.10	0.00	94.28	0.40	0.36	0.43	0.18	0.15	0.22
	hncos_phragmites	2	1071.93	6.83	95.48	0.41	0.37	0.44	0.18	0.15	0.21
	hncos_emergent	2	1075.75	10.64	95.78	0.41	0.37	0.44	0.18	0.15	0.21
	hncos	1	1078.23	13.13	96.33	0.41	0.36	0.48	0.18	0.14	0.22
	hncos_depth	2	1079.88	14.78	96.27	0.41	0.38	0.45	0.18	0.15	0.21
	hncos_noise	4	1080.00	14.89	95.80	0.41	0.37	0.44	0.18	0.15	0.21

Species	Model Name	K	AIC	Δ AIC	EDR	P	P LCL	P UCL	D	D LCL	D UCL
Sora	hrsim	2	205.61	0.00	32.47	0.05	0.01	0.22	0.26	0.06	1.26
	hrsim_depth	3	221.06	15.44	78.61	0.27	0.22	0.35	0.05	0.03	0.07
	hrsim_emergent	3	221.14	15.52	78.71	0.28	0.22	0.35	0.05	0.03	0.07
	hrsim_phragmites	3	221.21	15.60	78.58	0.27	0.22	0.35	0.05	0.03	0.07
	hrsim_type	4	222.99	17.37	79.07	0.28	0.22	0.36	0.04	0.03	0.06
	hrsim_wind	6	227.02	21.41	78.97	0.28	0.21	0.36	0.04	0.03	0.07
	hrsim_noise	6	227.06	21.45	79.08	0.28	0.21	0.37	0.04	0.03	0.07
Virginia rail	hrsim	2	248.84	0.00	34.44	0.05	0.02	0.14	0.29	0.11	0.77
	hrsim_phragmites	3	266.90	18.06	68.49	0.21	0.17	0.26	0.07	0.05	0.10
	hrsim_depth	3	266.90	18.06	68.49	0.21	0.17	0.26	0.07	0.05	0.10
	hrsim_emergent	3	266.91	18.07	68.85	0.21	0.17	0.26	0.07	0.05	0.10
	hrsim_type	4	268.90	20.06	68.49	0.21	0.17	0.26	0.07	0.05	0.10
	hrsim_noise	5	270.83	21.99	69.07	0.21	0.17	0.27	0.07	0.05	0.10
	hrsim_wind	6	272.90	24.06	68.49	0.21	0.17	0.26	0.07	0.05	0.10

[1]Model abbreviations: hnher = half-normal with Hermite polynomial adjustments; hncos = half-normal with cosine adjustments; and hrsim = hazard rate with simple polynomial adjustments.