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Original Research

Control of Invasive *Phragmites* Increases Marsh Birds but not Frogs

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Abstract

The non-native invasive form of common reed (*Phragmites australis australis*; hereafter "invasive *Phragmites*") negatively affects certain flora and fauna throughout North America. As a result, much effort is spent in some locations controlling invasive *Phragmites*, although few estimates of the expected benefits of these efforts are available. We used data from Bird Studies Canada's Great Lakes Marsh Monitoring Program and Central Michigan University's Great Lakes Coastal Wetland Monitoring Program to estimate changes in 1) species richness, 2) total abundance, and 3) occurrence of 9 breeding marsh bird species and 8 breeding marsh frog species before and after control of invasive *Phragmites*. Our study took place between 2011 and 2018 throughout 3 Great Lakes coastal wetland complexes located on Lake Huron and Lake Erie in southern Ontario. We found at sample sites where invasive *Phragmites* was controlled that species richness of 5 breeding marsh bitterns (e.g., *Botaurus* sp.) and rails (e.g., *Rallus* sp.) of conservation concern increased by 1.1 species, and that total abundance of these species combined increased by 1.8 individuals. By contrast, we observed no change in these responses at nearby sample sites where no *Phragmites* control occurred. We found no change in occurrence of any frog species or species richness or crude calling frequency of all frog species combined in relation to control of *Phragmites*, although we lacked the ability to detect subtle changes in abundance of frogs, so more information would be helpful before firm conclusions can be made in relation to frogs and control of invasive *Phragmites* in our study system. Our study shows that control of invasive *Phragmites* has a significant positive effect on breeding marsh bird species of conservation concern and suggests that continued effort to restore habitat for these species is warranted, particularly in areas where former breeding marsh bird biodiversity was high.

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INTRODUCTION

The common reed (*Phragmites australis americanus*) is a perennial semi-aquatic grass native to North America (Clevering and Lissner 1999). During the 1800s, a non-native invasive form of the species (*P. australis australis* native to Europe and Asia) was introduced to North America (hereafter “invasive *Phragmites*”) (Saltonstall 2002). It is likely that this plant was inadvertently brought to North America by humans through an eastern Atlantic seaport (Saltonstall 2002). Since its introduction to eastern North America, invasive *Phragmites* has spread westwards to salt, brackish, and freshwater wetlands throughout much of the continent (Saltonstall *et al.* 2004). The seeds are small and easily transported long distances by wind, water, people, and possibly other animals including birds (Mal and Narine 2004; Brisson *et al.* 2008), and root sections contain enough energy to remain viable and re-sprout after natural and human-assisted long-distance transport (Catling and Mitrow 2011). Invasive *Phragmites* is most likely to get established in disturbed locations with exposed moist substrate, particularly those disturbed by humans, such as recently constructed highway margins, spoil piles, dikes, and receding shorelines (Trebitz and Taylor 2007; Wilcox 2012). Such locations provide favourable conditions for germination (Bart *et al.* 2006). As well, higher levels of nutrients from anthropogenic runoff (Saltonstall and Stevenson 2007; Kettenring *et al.* 2011) and increasingly favourable temperatures and precipitation due to global climate change (Guo *et al.* 2013) fuel growth and seed production in certain locations, contributing to the recent speed and extent of the spread. Some plant communities are also less resistant to invasion in some locations, particularly shallow-rooted plant assemblages, which are outcompeted by the deeply-rooted invasive *Phragmites* (Mozdzer *et al.* 2016). All of these factors have facilitated the spread of invasive *Phragmites* to certain areas and regions (Kettenring *et al.* 2012). The plant’s spread across North America accelerated after the 1960s, likely due to increased road and railway transportation networks that facilitated dispersal and subsequent establishment (Jodoin *et al.* 2008). Fueled by the above mechanisms, invasive *Phragmites* can be expected to increasingly affect sensitive biota, and in turn, the plant may increasingly warrant control and management in certain situations to achieve biodiversity and habitat management objectives (Hazelton *et al.* 2014).

Invasive *Phragmites* is considered by many to be a wetland pest in part due to its perceived or observed negative influence on certain flora and fauna (Kiviat 2013). For instance, some species of plants (Amatangelo *et al.* 2018), fish (Able and Hagen 2000), amphibians (Greenberg and Green 2013), reptiles (Markle and Chow-Fraser 2018), and birds (Whyte *et al.* 2015) occur at lower numbers and/or diversity within monotypic stands of invasive *Phragmites* compared to other available vegetation types. Invasive *Phragmites* also lowers reproductive success of some species, including at least 1 species of frog (Order Anura) (Greenberg and Green 2013) and 1 species of turtle (Bolton and Brooks 2010). For most species, it is the taller, denser growth of invasive *Phragmites* that is thought to cause negative affects by altering local conditions (Meyerson *et al.* 2000). This includes elimination of interspersed pools and ponds preferred by certain birds for feeding (Benoit and Askins 1999, Rehm and Baldassarre 2007) and lower light penetration and accumulation of larger amounts of sediments and detritus compared to other available wetland habitats, which prevents some plants from germinating or getting established (Minchinton *et al.* 2006). By contrast, some argue that invasive *Phragmites* has value because it provides ecosystem services, such as sequestering unwanted nutrients and pollutants, stabilizing desired shorelines or wetland edges, and providing a potential source of bioenergy (Kiviat 2013, Carson *et al.* 2018). In addition, some wetland species use monotypic stands of invasive *Phragmites* just as much or more than other available habitats, such as roosting blackbirds (e.g., *Agelaius phoeniceus*) and swallows (e.g., *Tachycineta bicolor*) (Meyer *et al.* 2010; Whyte *et al.* 2015) and some invertebrates (Holomuzki and Klarer 2010). Given the mixed responses and the ecosystem services beneficial to humans, some argue that efforts to control the plant may be unwarranted in some cases, or may be poor use of limited conservation resources (Weis and Weis 2003; Theuerkauf *et al.* 2017).

Nonetheless, there are some groups of organisms for which control of invasive *Phragmites* is warranted and effective in certain situations. Studies show that plant diversity is lower in monotypic *Phragmites* stands (Amatangelo *et al.* 2018), and that control of *Phragmites* restores native plant abundance and diversity (Carlson *et al.* 2009). This often occurs even without replanting, given viable seeds of native species typically remain in the seed bank in the substrate and germinate when favourable conditions return following control of invasive *Phragmites* (Ailstock *et al.* 2001). Thus, control of invasive *Phragmites* is warranted and effective for restoring plant biodiversity in situations where that is a desired conservation goal, and especially where the effort is part of an integrated restoration program that addresses most or all threats to better ensure ultimate success (Hazelton *et al.* 2014).

Similarly, some studies document lower numbers of certain breeding marsh bird species within monotypic stands of invasive *Phragmites* compared to other available, more interspersed vegetation types (e.g., Benoit and Askins 1999; Schummer *et al.* 2012). For instance, abundance of marsh-dependent breeding Virginia rails (*Rallus limicola*) is similar in patches of relatively sparse invasive *Phragmites* compared to other available vegetation types (Lupien *et al.* 2014), but as the density of invasive *Phragmites* increases the abundance of Virginia rails decreases (Meyer *et al.* 2010, Tozer 2016), and finally Virginia rails disappear entirely from monotypic stands of invasive *Phragmites* (Robichaud and Rooney 2017). Indeed, a study of dozens of monotypic patches of invasive *Phragmites* at Long Point, Lake Erie in Ontario neglected to find any individuals of any breeding marsh bird species of conservation concern, although these species were found in other nearby vegetation types within the study area (Robichaud and Rooney 2017). Similarly, the spread of invasive *Phragmites* and other invasive plant species have been implicated in the decline of the black tern (*Chlidonias niger*) and other declining breeding marsh bird species in the Great Lakes region, and control of invasive *Phragmites* has been suggested as a worthy management action for restoring populations of these species (Schummer *et al.* 2012; Wyman and Cuthbert 2017). Therefore, control of invasive *Phragmites* is likely warranted as a conservation tool for certain breeding marsh birds. Furthermore, growth rates or reproductive success of some species of frogs may be negatively affected by invasive *Phragmites* (Greenberg and Green 2013; Perez *et al.* 2013), although other studies failed to find any differences in occurrence in patches of invasive *Phragmites* compared to other vegetation types (Mazerolle *et al.* 2014), or find a positive effect of invasive *Phragmites* on larval growth and development (Rogalski and Skelly 2012). Thus, control of invasive *Phragmites* may also be warranted as a conservation tool for some species of frogs, but the potential value is less clear than it is for breeding marsh birds. Demonstration and quantification of the effectiveness of the control of invasive *Phragmites* for conserving or restoring populations of breeding marsh birds and frogs of conservation concern is lacking, but would be useful for guiding conservation efforts to maintain or restore biodiversity (Hazelton *et al.* 2014).

In the southern Great Lakes basin, where our study took place, there is growing concern that the ongoing spread of invasive *Phragmites* is contributing to declines in biodiversity, particularly to population declines of breeding marsh birds (Tozer 2013, 2016; Wilcox *et al.* 2003), and other groups of animals and plants (Jung *et al.* 2017). As an example, occupancy of 7 marsh-dependent breeding bird species significantly declined in the region between 1996 and 2013, and invasive *Phragmites* is thought to be a contributing factor in at least some of these declines (Tozer 2016; Tozer and Beck 2018). As a result, conservation agencies have come together in the region to control invasive *Phragmites* in key areas where biodiversity was high historically, in an effort to restore and maintain populations of diverse species (e.g., Invasive *Phragmites* Control Centre 2019; Ontario *Phragmites* Working Group 2019). Control of invasive *Phragmites* to restore biodiversity has also been occurring for decades elsewhere primarily in the United States but also in Canada (Hazelton *et al.* 2014). This study contributes to these collective restoration efforts by filling in knowledge gaps regarding effectiveness of control of invasive *Phragmites* for benefiting populations of breeding marsh birds and frogs.

We used data from Bird Studies Canada's Great Lakes Marsh Monitoring Program and Central Michigan University's Great Lakes Coastal Wetland Monitoring Program to estimate the magnitude of the effectiveness of the control of invasive *Phragmites* for increasing the abundance or occurrence of breeding marsh birds and frogs. We quantified the change in abundance or occurrence of species or groups of species of these 2 animal groups before and after control of invasive *Phragmites* at locations with control and at nearby similar locations without control. We pursued our objective using data collected between 2011 and 2018 throughout 3 Great Lakes coastal wetland complexes located on Lake Huron and Lake Erie in southern Ontario where biodiversity restoration programs aiming to control invasive *Phragmites* were active. The assessment provided by our study will be useful for decisions regarding the utility of the control of invasive *Phragmites* as part of integrated wetland restoration efforts to meet biodiversity goals and targets (Kettenring *et al.* 2012; Hazelton *et al.* 2014).

METHODS

Study design

The study took place throughout 3 Great Lakes coastal wetland complexes located on Lake Huron and Lake Erie in southern Ontario (Figure 1). We chose these wetland complexes because they had active programs aiming to control invasive *Phragmites* in order to restore biodiversity (Ontario *Phragmites* Working Group 2019). The 3 wetland complexes also had breeding marsh bird and frog data available from 1-5 yrs before and 1-5 yrs after control of invasive *Phragmites* from 2 ongoing monitoring programs: Bird Studies Canada's Great Lakes Marsh Monitoring Program (Tozer 2013, 2016; Bird Studies Canada 2019) and Central Michigan University's Great Lakes Coastal Wetland Monitoring Program (Uzarski *et al.* 2017, 2019; Central Michigan University 2019). Our general approach was to

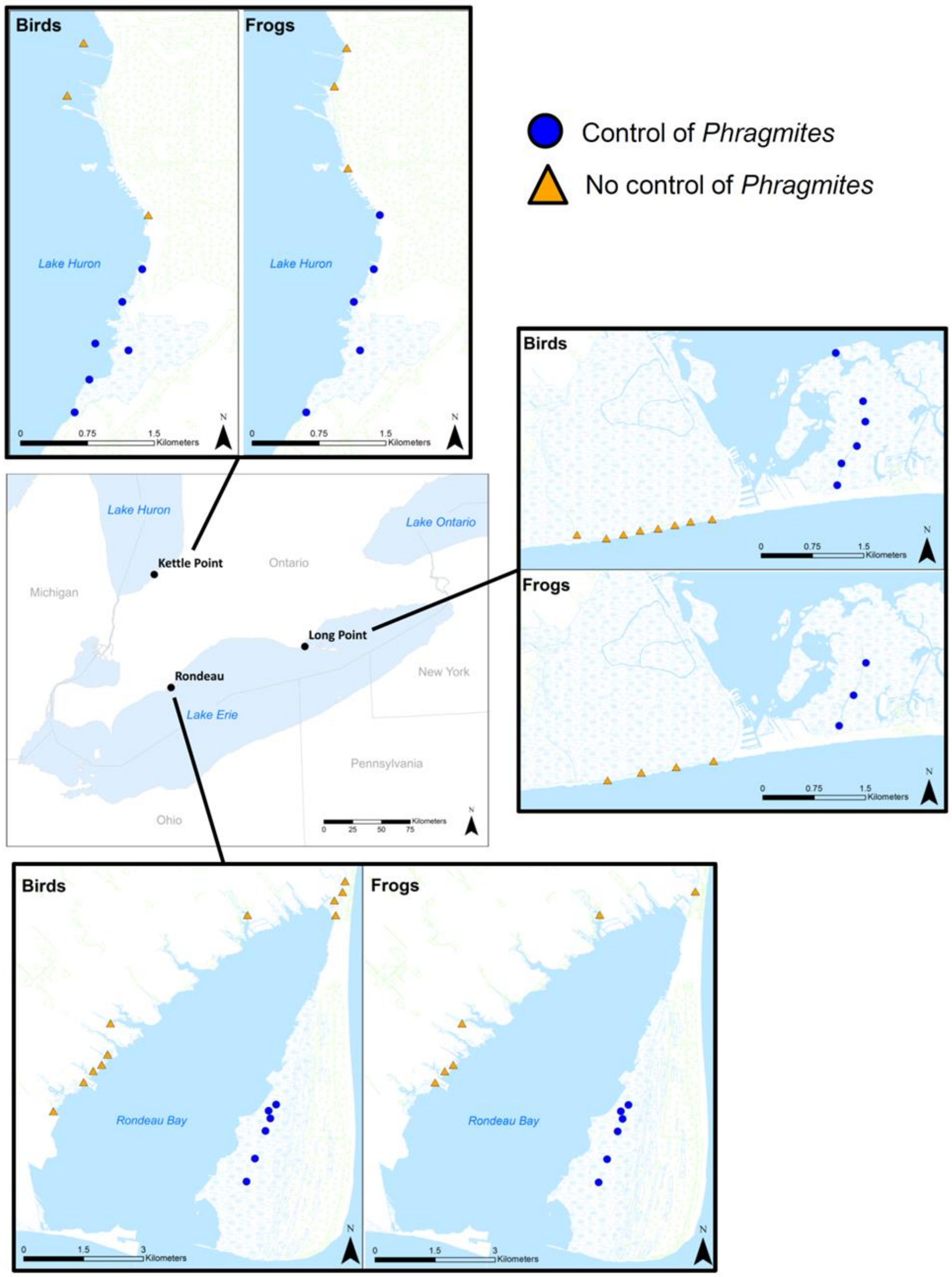

Figure. 1. Locations of sample sites used to estimate the effect of control of invasive *Phragmites* on breeding marsh birds and frogs within 3 wetland complexes on Lake Huron and Lake Erie in southern Ontario. Sample sites were located at and just south of Kettle and Stony Point First Nation (Kettle Point), in Rondeau Bay and Rondeau Provincial Park (Rondeau), and in Big Creek Marsh and the Crown Marsh at Long Point (Long Point).

compare indices of occupancy or abundance of breeding marsh birds and frogs before and after control of invasive *Phragmites* within 100-m-radius semicircular plots (hereafter "sample sites") where invasive *Phragmites* was controlled and nearby sample sites where invasive *Phragmites* was not controlled. This design is not a true before-after experimental control-impact or matched-pairs design, although it does account to a certain extent for confounding factors in both space and time. We note that a true before-after experimental control-impact design was not possible because control of invasive *Phragmites* occurred in different years among the wetland complexes, and because the areas where control of invasive *Phragmites* occurred were relatively large (e.g., 100s of ha) and were treated at the same time for efficiency. As such, sample sites where control did not occur were located by necessity at least a certain distance away from sample sites where control did occur. The complete separation of sample sites with control from sample sites without allows for potential confounding among the 2 areas due to other unknown influences, although as we note below we found no differences in any of the responses between the 2 areas before control of invasive *Phragmites*, which suggests that confounding was not an issue.

We used a 1-5-yr window before and after the control of invasive *Phragmites* to maximize the number of sample sites with data. As a consequence, control of invasive *Phragmites* (described in more detail below) and monitoring occurred in different years among and within the 3 wetland complexes. In nearly all cases (94-98%), sample sites were the same for birds and the same for frogs before and after control of invasive *Phragmites*, but in a relatively small number of remaining cases we selected the closest nearby alternative sample site located ~150-250 m away. Most (87%) of the sample sites for frogs were also sampled for birds. Populations of breeding marsh bird and frog species are known to fluctuate from year to year (Tozer 2013, 2016), and response of these species is known to vary with the amount of time since control of invasive *Phragmites* (e.g., Lazaran *et al.* 2013). We note that at sample sites with no control of *Phragmites* 95% confidence intervals overlapped among years and among the 3 wetland complexes for species richness and total abundance of birds and species richness and abundance index of frogs. Thus, we did not control in our modeling for the influence of year or wetland complex to keep models as simple as possible and in keeping with our sample size.

Control of invasive *Phragmites*

The timing of control of invasive *Phragmites* and the methods used for control differed among the 3 wetland complexes that we studied (Figure 1). At and just south of Kettle and Stony Point First Nation (hereafter "Kettle Point"), control occurred in different parts of the complex between 2011 and 2018 with glyphosate-based herbicide applied using custom-outfitted all-terrain vehicles and backpack sprayers in dry areas and cut-and-drown techniques using amphibious track machines and hand-held mechanical mowers in wet areas (see Ontario Ministry of Natural Resources 2011, Hazelton *et al.* 2014, and Invasive *Phragmites* Control Centre 2019 for further explanation of control techniques). Herbicide at Kettle Point was Roundup WeatherMax (Monsanto Canada, Winnipeg, Manitoba, Canada) mixed at 5% concentration in water plus 1% MSO (Methylated Seed Oil) Concentrate with Leci-Tech surfactant (Loveland Products Canada, Inc., Dorchester, Ontario, Canada) applied at 25.3 L/ha. Several weeks following herbicide application, some of the treated areas at Kettle Point were rolled to flatten the dead invasive *Phragmites* stalks, and then burned to reduce dead biomass to encourage subsequent re-growth of native vegetation by allowing more light to penetrate the surface and to facilitate access to new shoots of invasive *Phragmites* for follow-up control if needed. At Rondeau Bay and within Rondeau Provincial Park (hereafter "Rondeau") and within Big Creek Marsh and the Crown Marsh at Long Point (hereafter "Long Point"), control occurred in different parts of the 2 complexes between 2016 and 2018 with glyphosate-based herbicide applied to most sections using a helicopter as well as custom-outfitted all-terrain vehicles and backpack sprayers in wet and dry areas under special permit, given application of glyphosate over water was prohibited by law in Canada. Herbicide at Rondeau and Long Point was Roundup Custom (Monsanto Canada, Winnipeg, Manitoba, Canada) mixed at 12.5% concentration in water plus 1% AquaSurf surfactant (Norac Concepts, Inc., Guelph, Ontario, Canada) applied at 70 L/ha. Following herbicide application, some of the treated areas at Rondeau and Long Point were rolled and then burned for the same reasons cited above. In all cases, only monotypic stands or isolated stems of the non-native invasive form of *Phragmites* were targeted for control, which was achieved for aerial spraying of stands by helicopter with GPS mapping that informed precise on-board computer-controlled operation of the spray boom.

Bird surveys

Birds were sampled by observers standing at the midpoint of the flat side of each semicircular sample site. Each sample site was surveyed for 15 min on each of 2 occasions at least 10-15 d apart between 20 May and 5 July, which was the main avian breeding season in the region. During each survey at each sample site, participants recorded all species seen or heard within the sample site. Surveys occurred in either the morning (30 min before local sunrise to 10:00 hr local time) or evening (4 hr before local sunset to dark) and only under favourable weather conditions (no precipitation; wind: Beaufort 0-3, 0-19 km/hr). Observers broadcasted calls during surveys to entice individuals of elusive species to reveal their presence by approaching or responding vocally. Broadcasts occurred during the second 5-min period of each 15-min survey and consisted of 30 sec of vocalizations followed by 30 sec of silence for each of least bittern (*Ixobrychus exilis*), sora (*Porzana carolina*), Virginia rail, a mixture of American coot (*Fulica americana*) and common gallinule (*Gallinula galeata*), and pied-billed grebe (*Podilymbus podiceps*), in that order. Further details of the bird survey protocol are described in Bird Studies Canada (2009a) and Grabas *et al.* (2008).

Frog surveys

Frogs were sampled by observers standing at the midpoint of the flat side of each semicircular sample site. Each sample site was surveyed for 3 min on each of 3 occasions at least 15 d apart between late March and early July, which was the main anuran breeding season in the region. During each survey at each sample site, participants recorded an abundance code (0, 1, 2, or 3) for each species heard within the sample site: code 1, individuals could be counted, but calls were not simultaneous; code 2, calls were distinguishable, but some calls were simultaneous; and code 3, a full chorus where calls were continuous and overlapping. Surveys occurred at night starting at least 0.5 hr after local sunset and only under weather conditions that were favourable for detecting all species present (no persistent or heavy precipitation; wind: Beaufort 0-3, 0-19 km/hr). The first survey in the season was conducted when night-time air temperature had reached > ~5°C, the second when > ~10°C had been reached, and the third when > ~17°C had been reached. Further details of the frog survey protocol are described in Bird Studies Canada (2009b) and Timmermans *et al.* (2008).

***Phragmites* surveys**

Visual estimates of percent aerial coverage of invasive *Phragmites* were made by observers standing at the midpoint of the flat side of each semicircular sample site, an approach shown to generate results comparable to intensive quadrat-based sampling within each sample site (Crewe and Timmermans 2003). Vegetation surveys were completed once between late-May and mid-June, at a time when emergent vegetation had grown tall enough to yield accurate estimates of coverage, but not so tall as to restrict visibility of the sample site. Further details of the vegetation and habitat survey protocol are described in Bird Studies Canada (2009c).

Analysis

We used generalized linear models to estimate bird, frog, and vegetation responses to control of invasive *Phragmites*. We considered a single model for each response, which included 3 covariates: 1) a categorical variable referred to as "control of *Phragmites*" with 2 levels, control of invasive *Phragmites* or no control of invasive *Phragmites*; 2) a categorical variable referred to as "before-after" with 2 levels, before or after control of invasive *Phragmites*; and 3) an interaction term consisting of control of *Phragmites* x before-after. We note that we did not consider adjustments for imperfect detection because we felt that our sample sizes were too small to produce reliable estimates of detection. Instead, we relied on the strict guidelines imposed by the standardized marsh bird and frog field methods we followed to reduce possible differences in detection among the treatments. We also note that we considered mixed models with a random effect of wetland complex (i.e., Kettle Point, Long Point, or Rondeau), but results were very similar to models without the random effect, so we report results from the simpler models.

We used the models to quantify and illustrate the following responses as a function of control of invasive *Phragmites*: 1) species richness, 2) total abundance, and 3) occurrence of 9 breeding marsh bird species and 8 breeding marsh frog species. Species richness was the total number of species observed on any of the surveys at a sample site in a particular year. To calculate total abundance for birds, we first determined the maximum number of individuals of each species observed on any of the surveys at a sample site in a particular year, and then we summed the maximum counts across all of the species. To calculate an index of total abundance for frogs, we first determined the maximum calling code recorded for each species observed on any of the surveys at a sample site in a particular year, and then we summed the maximum calling codes across all of the species. Species richness and total abundance were modeled following a Poisson distribution with a log link, and occurrence was modeled following a binomial distribution with a logit link. The bird and frog species we considered were chosen because they were breeding marsh species that were observed on at least 1 occasion in more than 15% of sample sites. Five of the bird species were of particular interest because they are species of conservation concern in the region and invasive *Phragmites* is thought to be at least 1 of the threats affecting these species (Environment Canada 2014; Tozer 2016). We modeled the response of invasive *Phragmites* following a Gaussian distribution with an identity link. All models were run using the glm function of the R programming language (A language and environment for statistical computing, < https://www.r-project.org/ >, Foundation for Statistical Computing, Vienna, Austria). We considered differences to be significant when 95% confidence intervals did not overlap.

RESULTS

The dataset consisted of a grand total of 40 sample sites for birds and 27 sample sites for frogs (Figure 1; Table 1). We had data from 1-5 yrs before and 1-5 yrs after control of invasive *Phragmites* (Table 2) at 18 sample sites for birds and 14 for frogs, and 22 nearby sample sites for birds and 13 for frogs where no control of invasive *Phragmites* occurred. Before control, invasive *Phragmites* covered on average about half to three-quarters of the surface area of sample sites; after control, the coverage remained nearly equal at sample sites where no control occurred, but it was reduced to less than a quarter at sample sites where control did occur (Figure 2).

Table 1. Number of sample sites used to estimate the effect of control of invasive *Phragmites* on breeding marsh birds and frogs within 3 wetland complexes on Lake Huron and Lake Erie in southern Ontario. Sample sizes are given as a function of wetland complex (Kettle Point, Rondeau, Long Point) and control (Con.) or no control (No con.) of invasive *Phragmites*. See Figure 1 for spatial arrangement of the sample sites.

	Kettle Point		**Rondeau**		**Long Point**		**TOTAL**	
Taxon	**Con.**	**No con.**	**Con.**	**No con.**	**Con.**	**No con.**	**Con.**	**No con.**
Birds	6	3	6	11	6	8	18	22
Frogs	5	3	6	6	3	4	14	13

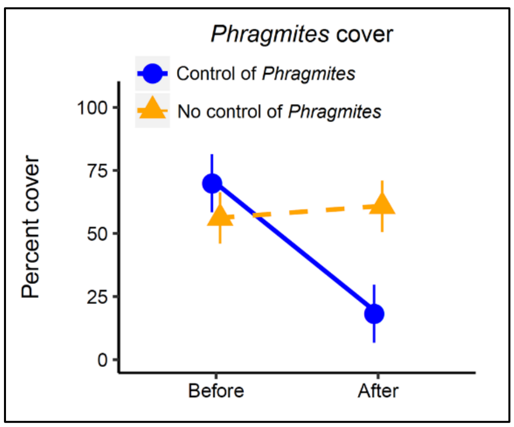

Figure 2. Aerial coverage (percent cover) of invasive *Phragmites* 1-5 years before and 1-5 years after control of invasive *Phragmites* at sample sites with control of invasive *Phragmites* (Control of *Phragmites*) and at nearby sample sites without control (No control of *Phragmites*) within 3 wetland complexes on Lake Huron and Lake Erie in southern Ontario between 2011 and 2018. Error bars are ± 95% confidence intervals.

At sample sites where invasive *Phragmites* was controlled, species richness of 5 breeding marsh bitterns and rails of conservation concern increased significantly by 1.1 species, and the total abundance of these species combined increased significantly by 1.8 individuals (Figure 3). By contrast, there was no significant change in these responses at nearby sample sites where no control of *Phragmites* occurred (Figure 3). Due to low occupancy and small sample size, we were unable to reliably estimate species-level effects for breeding marsh birds of conservation concern, although we note that all of these species, including American bittern (*Botaurus lentiginosus)*, responded positively albeit non-significantly to control (Figure 4). By contrast, we found no significant change in occurrence of 3 of 4 relatively common breeding marsh songbird species: common yellowthroat *(Geothlypis trichas*), red-winged blackbird (*Agelaius phoeniceus*), and swamp sparrow (*Melospiza georgiana*); occurrence of marsh wren (*Cistothorus palustris*) significantly increased at sample sites with control of *Phragmites* but not at nearby sample sites without control (Figure 5). We found no significant change in occurrence of any of 8 frog species (Figure 6): American toad (*Bufo americanus*), American bullfrog (*Rana catesbeiana*), western chorus frog (*Pseudacris triseriata*), green frog (*Rana clamitans*), eastern gray treefrog (*Hyla versicolor*), northern leopard frog (*Rana pipiens*), spring peeper (*Pseudacris crucifer*), and wood frog (*Rana sylvaticus*). We also found no significant change in species richness or crude calling frequency of all frog species combined in relation to control of invasive *Phragmites* (Figure 7).

Table 2. Median year of sampling among sample sites used to estimate the effect of control of invasive *Phragmites* on breeding marsh birds and frogs within 3 wetland complexes on Lake Huron and Lake Erie in southern Ontario. Median year is given as a function of wetland complex (Kettle Point, Rondeau, Long Point) and before or after control of invasive *Phragmites*.

	Kettle Point		Rondeau		Long Point	
Taxon	**Before**	**After**	**Before**	**After**	**Before**	**After**
Birds	2012	2016	2013	2018	2011	2018
Frogs	2013	2015	2013	2018	2011	2018

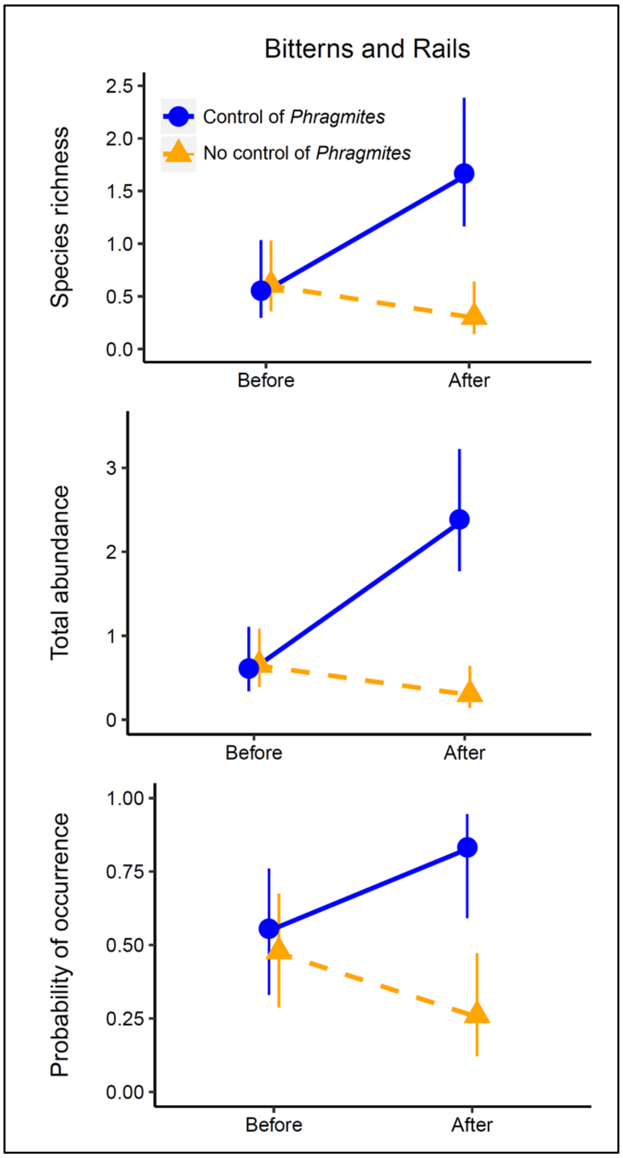

Figure 3. Response of breeding marsh bitterns and rails of conservation concern 1-5 years before and 1-5 years after control of invasive *Phragmites* at sample sites with control of invasive Phragmites (Control of *Phragmites*) and at nearby sample sites without control (No control of *Phragmites*) within 3 wetland complexes on Lake Huron and Lake Erie in southern Ontario between 2011 and 2018. Error bars are ± 95% confidence intervals.

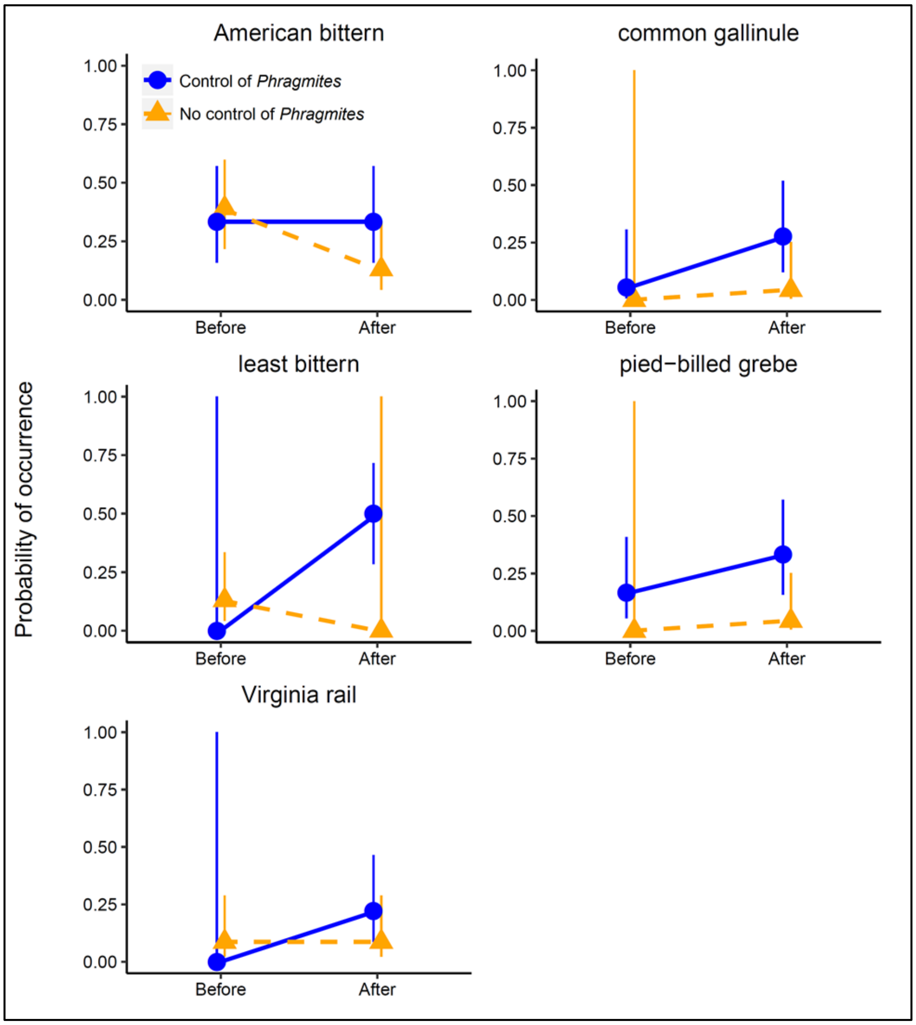

Figure 4. Occurrence of breeding marsh bitterns and rails of conservation concern 1-5 years before and 1-5 years after control of invasive *Phragmites* at sample sites with control of invasive *Phragmites* (Control of *Phragmites*) and at nearby sample sites without control (No control of *Phragmites*) within 3 wetland complexes on Lake Huron and Lake Erie in southern Ontario between 2011 and 2018. Error bars are ± 95% confidence intervals.

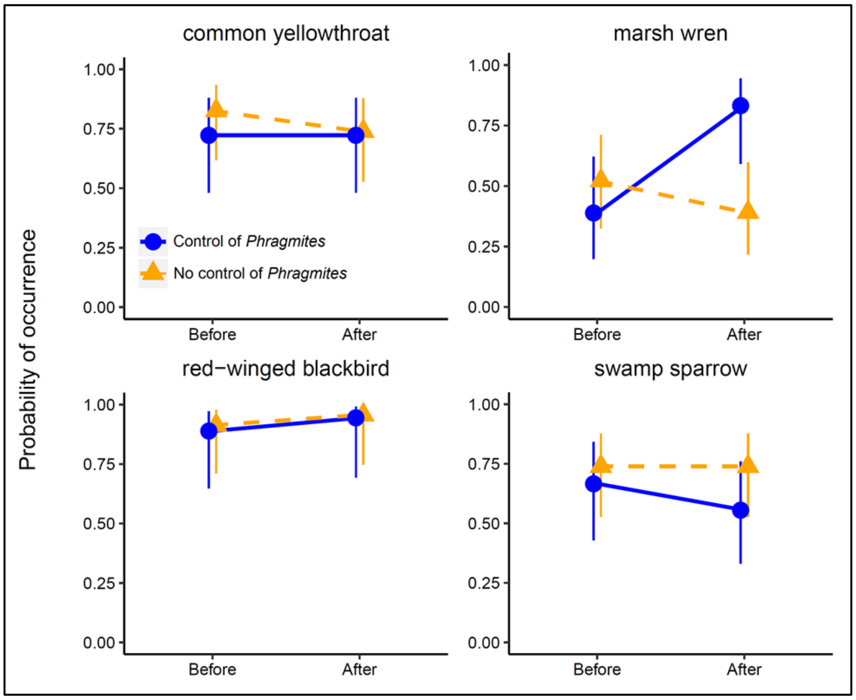

Figure 5. Occurrence of relatively common breeding marsh songbird species 1-5 years before and 1-5 years after control of invasive *Phragmites* at sample sites with control of invasive *Phragmites* (Control of *Phragmites*) and at nearby sample sites without control (No control of *Phragmites*) within 3 wetland complexes on Lake Huron and Lake Erie in southern Ontario between 2011 and 2018. Error bars are ± 95% confidence intervals.

DISCUSSION

We found that control of invasive *Phragmites* had a significant positive effect on occurrence of breeding marsh bird species of conservation concern. Our results show that both species richness and total abundance of these species increased significantly by 1.1 species and 1.8 individuals, respectively, in response to techniques that are typical of those used to control invasive *Phragmites* throughout North America (Hazelton *et al.* 2014). Our findings are some of the first to document the effectiveness of the control of invasive *Phragmites* for increasing biodiversity of breeding marsh birds. The results of our study suggest that the use of conservation resources to control invasive *Phragmites* is warranted in order to meet biodiversity goals and targets for breeding marsh birds. Such efforts will be especially warranted if they are applied in areas that are known to have had high biodiversity historically, and that are part of integrated restoration programs that address most or all threats to better ensure ultimate success (Hazelton *et al.* 2014).

Previous studies have found that breeding marsh bird species of conservation concern drop out and eventually even disappear from increasingly monotypic patches of invasive *Phragmites* (Meyer *et al.* 2010; Lupien *et al.* 2014; Tozer 2016; Robichaud and Rooney 2017). Thus, one might have expected beforehand that these species would respond positively to the control of invasive *Phragmites*, as we found in this study. We suspect that monotypic patches of invasive *Phragmites* exclude these species because the stems fill in the interspersed pools and small openings that the birds prefer for feeding (Rehm and Baldassarre 2007). By contrast, monotypic patches of invasive *Phragmites* may be used by these species for hiding and supporting their nests (Benoit and Askins 1999). In some cases, some of these species place their nests within monotypic patches of invasive *Phragmites* and probably feed at the edge of the *Phragmites* or in nearby patches of other available vegetation (Dupuis-Désormeaux *et al.* 2017). Thus, in situations where control of invasive *Phragmites* is not possible, efforts to increase interspersion of open water pools within dense patches of invasive *Phragmites* might yield positive responses by breeding marsh birds (Schummer *et al.* 2012). These ideas may be fruitful for further research.

Notably, Robichaud and Rooney (2017) at Long Point on Lake Erie in Ontario failed to find any breeding marsh bird

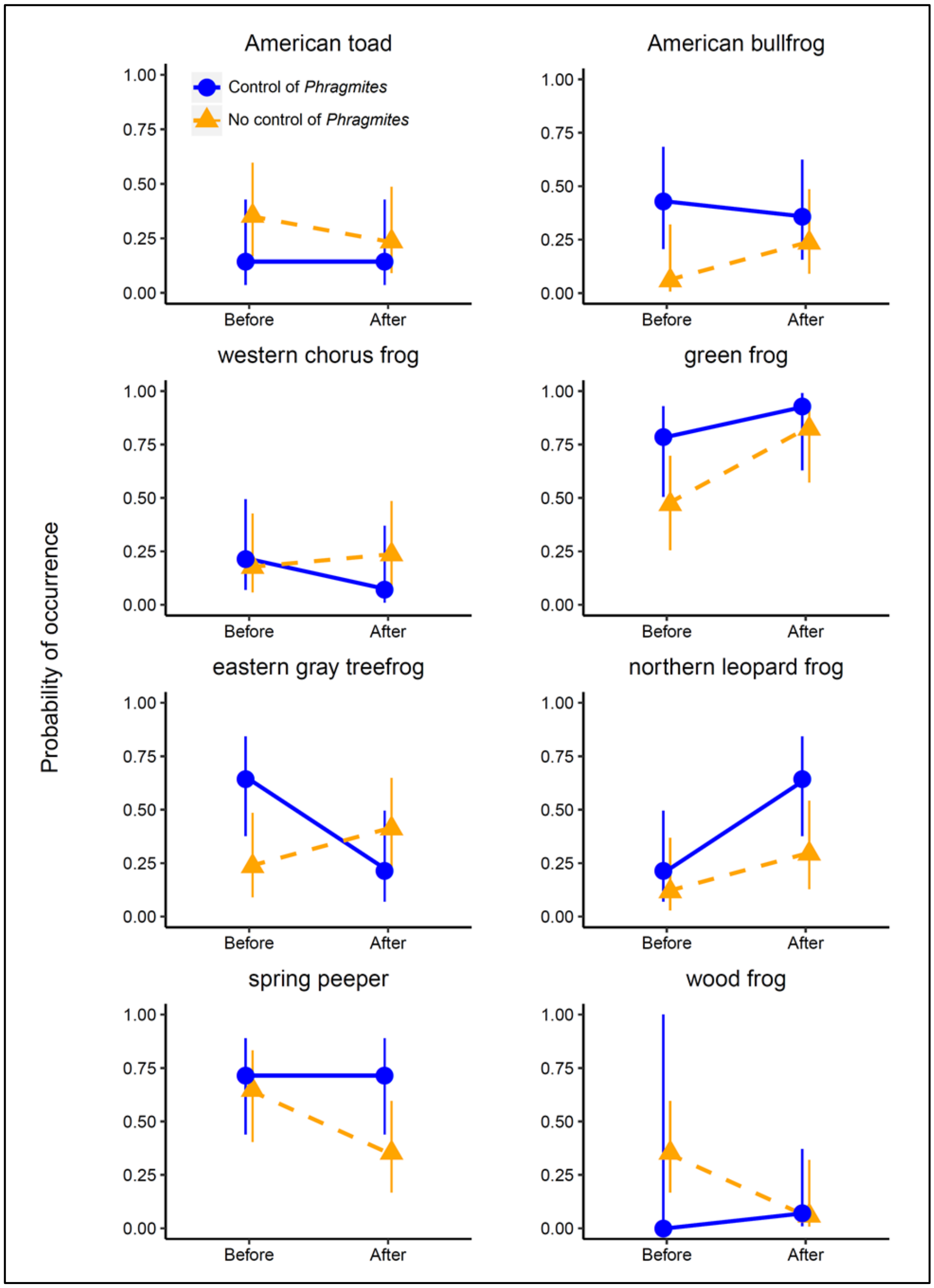

Figure 6. Occurrence of breeding marsh frogs 1-5 years before and 1-5 years after control of invasive *Phragmites* at sample sites with control of invasive *Phragmites* (Control of *Phragmites*) and at nearby sample sites without control (No control of *Phragmites*) within 3 wetland complexes on Lake Huron and Lake Erie in southern Ontario between 2011 and 2018. Error bars are ± 95% confidence intervals.

species of conservation concern within patches of monotypic invasive *Phragmites*, even though they found these species within other nearby vegetation types. By contrast, before control of invasive *Phragmites* in our sample sites, we found ~0.5 species and a little less than 1 individual on average of these species in patches of invasive *Phragmites*, some of which were in the same marshes as those studied by Robichaud and Rooney (2017). We suspect that the difference in results for these species between the 2 studies was due, at least in part, to differences in the size of sample sites. We used a 100-m-radius semicircular sample plot (1.6 ha), whereas Robichaud and Rooney (2017) used a 25-m-radius circular sample plot (0.2 ha). As such, the surface area of the relatively small plots studied by Robichaud and Rooney (2017) were almost completely covered by monotypic invasive *Phragmites*, whereas the much larger plots in our study were covered prior to control by about half to three-quarters by invasive *Phragmites*. This difference in coverage of invasive *Phragmites* likely explains why breeding marsh bird species of conservation concern were present in our sample plots at relatively low numbers prior to control of invasive *Phragmites*, whereas these species were entirely absent in the study by Robichaud and Rooney (2017).

We found no influence of control of invasive *Phragmites* on occurrence or abundance of breeding marsh frogs. One previous study concluded that invasive *Phragmites* fills in, shades, and eliminates the sparsely-vegetated, sandy-bottomed pools required by breeding Fowler's toads (*Bufo fowleri*), which likely causes the near elimination of the toads as the plant spreads throughout an area (Greenberg and Green 2013). Although we note that we did not detect Fowler's toad in our study. Another study found that growth of larval wood frogs is slower within patches of invasive *Phragmites*, perhaps due to lower amounts of food, yet there is no negative effect on survival (Perez *et al.* 2013). By contrast, there appears to be no negative influence of invasive *Phragmites* on any life stage of the green frog or Leopard Frog (Mazerolle *et al.* 2014), and invasive *Phragmites* has positive effects on mass, development, and survival of the American bullfrog (Rogalski and Skelly

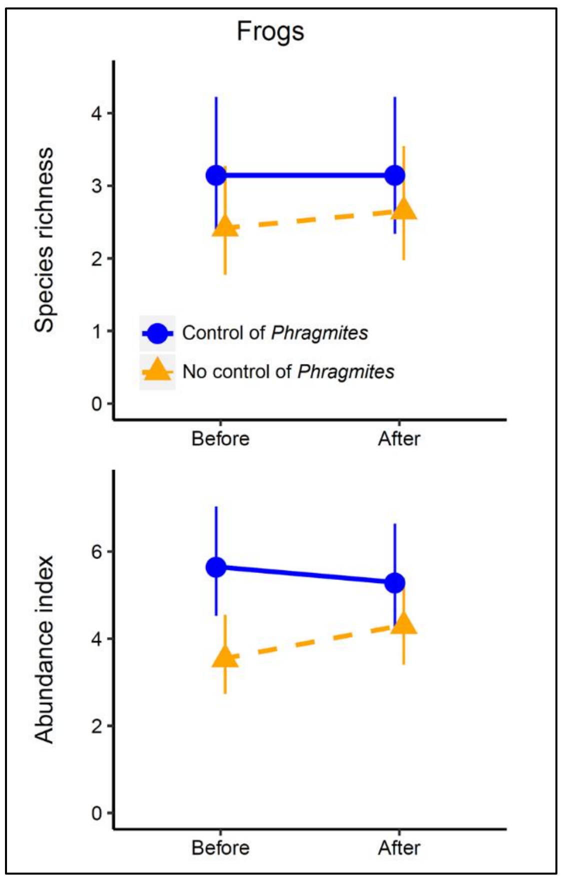

Figure 7. Response of breeding marsh frogs 1-5 years before and 1-5 years after control of invasive *Phragmites* at sample sites with control of invasive *Phragmites* (Control of *Phragmites*) and at nearby sample sites without control (No control of *Phragmites*) within 3 wetland complexes on Lake Huron and Lake Erie in southern Ontario between 2011 and 2018. Error bars are ± 95% confidence intervals.

2012). Therefore, it may be that the spread of monotypic patches of invasive *Phragmites* has significant negative effects on frog species like the Fowler's toad that require sparsely-vegetated pools for breeding (Greenberg and Green 2013), whereas any negative effects of invasive *Phragmites* on most other frog species is small enough, if it exists, that there is little, if any, influence on occurrence or crude calling frequency, as we found in this study. This idea should be verified by further research, particularly of species that require sparsely-vegetated shallow water pools, which are typically entirely eliminated by invasive *Phragmites*. It seems possible that populations of species like the Fowler's toad will respond positively to control of invasive *Phragmites* if it results in the restoration of sparsely-vegetated, sandy-bottomed pools that the species requires for breeding.

Alternatively, we lacked the ability to detect subtle changes in abundance of frog populations, if they occurred, in relation to the control of invasive *Phragmites*. Unlike marsh birds, our standardized point count field protocol for frogs meant that we were only able to collect information on occurrence and crude calling frequency and not exact numbers of detected individuals. It is possible that changes in frog abundance occurred within the areas where *Phragmites* was controlled in our study, possibly including initial reductions in numbers due to lethal effects of glyphosate-based herbicide (Relyea *et al.* 2005; Krynak *et al.* 2017), but that individuals quickly dispersed back into the treated areas thereafter from populations in surrounding untreated areas. As such, there could have been changes in numbers of individual frogs before and after control of *Phragmites* that we were unable to detect. Although the standardized field protocol that we followed is efficient for sampling points for occurrence and crude calling frequency of frogs, it might be a fruitful area for future research to collect additional more-detailed information on numbers of individual frogs at various stages in their life cycle in relation to control of invasive *Phragmites*.

CONCLUSION AND IMPLICATIONS FOR MANAGEMENT

There is growing concern that the ongoing spread of invasive *Phragmites* is contributing to declines in biodiversity, and particularly to population declines of breeding marsh birds (Tozer 2013, 2016). As a result, conservation agencies have been controlling invasive *Phragmites* for decades primarily in the United States but also in Canada in order to restore or maintain biodiversity. To date, few estimates have been available of the magnitude of the presumed positive effects of control of invasive *Phragmites* on breeding marsh birds and frogs. In this study, we helped fill this knowledge gap by showing that control of invasive *Phragmites* has a significant positive effect on occurrence of breeding marsh bird species of conservation concern. By contrast, we found no influence of control of invasive *Phragmites* on occurrence, species richness, or crude calling frequency of breeding marsh frogs, although as noted above, we lacked the ability to detect subtle changes in abundance of frogs, so more information would be helpful before firm conclusions can be made in relation to frogs and control of invasive *Phragmites* in our study system. We note that control of invasive *Phragmites* is likely effective for frog species that require sparsely-vegetated pools for breeding such as the Fowler's toad, which was not present in our study (Greenberg and Green 2013). We conclude that control of invasive *Phragmites* is effective for increasing populations of breeding marsh bird species of conservation concern, and that such efforts will be especially effective if they are applied in areas where breeding marsh bird biodiversity was high historically, and that are part of integrated restoration programs that address most or all threats to better ensure ultimate success (Hazelton *et al.* 2014).

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