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TECHNICAL ARTICLE

Restoration of a Lake Ontario-connected fen through invasive *Typha* removal

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Lake-level regulation that began in 1960 eliminated large fluctuations of Lake Ontario water levels, altering coastal wetland plant communities. More than a half century later, the altered hydroperiod supports dense, monotypic stands of invasive cattail (*Typha angustifolia* and *Typha* × *glauca*), which have diminished overall plant community diversity. As a result, Lake Ontario coastal wetlands are less capable of providing many of their traditional ecological functions. One such wetland is Buttonwood Fen, a floating, lake-connected peatland on Lake Ontario's southern shore near Rochester, NY. We implemented cattail-control measures from 2016 to 2018 with the goal of decreasing live and dead cattail biomass and increasing cover of native fen taxa. Site manipulation included removal of dead cattail biomass, cutting new cattail growth when rhizome carbohydrate reserves were at their lowest, and hand-wicking regrowth with herbicide in early fall. Results showed a decrease in live cattail stem density and cover and dead biomass cover, as well as an increase in cover of fen taxa. Although not a replicated study, our results suggest that removing dead cattail biomass and targeted treatment of live cattail stems via cutting and hand-wicking with glyphosate can reduce cattail and improve site quality.

Key words: fen, invasive species, Lake Ontario wetlands, restoration, *Typha* × *glauca*

Conceptual Implications

- Knowledge gaps exist regarding effective treatment of *Typha* × *glauca* in Great Lakes coastal fen communities.
- Manual removal of live and dead *Typha* is an effective treatment method in areas where more traditional methods are not feasible due to site access or areas with sensitive vegetation.
- Removal of dead *Typha* × *glauca* litter may be more expedient than attempts to remove live cattails.
- These results have implications for the few floating fens on Lake Ontario but also large areas of Lake Superior floating fens and other Great Lakes coastal wetlands being invaded by *Typha*.

Introduction

Invasive species are recognized as significant threats to natural ecosystems and biodiversity (Tsutsui et al. 2000), and wetlands are particularly vulnerable to invasion (Trebitz & Taylor 2007). Wetlands surrounding the Laurentian Great Lakes are susceptible to non-native species invasions. Years of commercial and recreational boating and development in neighboring watersheds have facilitated the introduction and spread of invasive species, which have been identified as a primary cause of ecosystem disruption in this region (Trebitz & Taylor 2007). One invader that has been degrading Great Lakes coastal wetlands is *Typha* × *glauca* Godr. (hereafter referred to as *Typha*) (Tuchman et al. 2009; Lawrence et al. 2016), an invasive hybrid of two parent species, *Typha latifolia* L. and *Typha angustifolia* L. (Bansal et al. 2019). Nearly 24% of Great Lakes coastal wetlands have been invaded by cattail (*Typha* spp.) (Bourgeau-Chavez et al. 2015) due to its rapid growth and highly competitive nature (Bansal et al. 2019).

The review by Bansal et al. (2019) reported that Lake Ontario has the greatest level of *Typha* invasion of the Laurentian Great Lakes. Lake-level regulation initiated in 1960 reduced fluctuations of Lake Ontario water levels (Wilcox & Xie 2007). The resultant altered hydroperiod and stabilization promotes dense, monotypic stands of *Typha* (Wilcox et al. 2008). *Typha* can be found in a variety of wetland types in Lake Ontario (Wilcox et al. 2008; Wilcox & Bateman 2018), including coastal peatlands. Great Lakes coastal peatlands are uncommon and account for only 4% of wetland area across the Great Lakes region (Bourgeois et al. 2012); most are located near Lake Michigan-Huron and Lake Superior (Bedford & Godwin 2003). Peatlands are of high conservation value (Larocque et al. 2016), which makes their protection from *Typha* encroachment of utmost importance.

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Control of *Typha* has long been a concern of wetland managers (Bansal et al. 2019); however, control of invasive cattail in peatlands is not well-understood (Bourgeois et al. 2012; Bansal et al. 2019). Although peatland restoration has become more common in the last few decades (Rochefort & Andersen 2016), knowledge gaps still exist, particularly regarding restoration of groundwater-fed fens (Chimner et al. 2016). Fens are the most diverse wetland types in the United States and support rare flora and fauna (Sampath et al. 2016); however, these groundwater-fed wetlands tend to be more heavily invaded by *Typha* because they have continual water supply (Wilcox et al. 1984). Floating, lake-associated fens are an even greater ecological rarity and are documented as being difficult to restore and often sustaining limited restoration success (van Zuidam et al. 2018). The development of effective *Typha*-removal strategies is paramount to conserve this unique wetland class.

Land managers have used multiple techniques to restore *Typha*-invaded wetlands, including water-level manipulation, burning, cutting/mowing, nutrient management, herbicide, and detritus removal (Lishawa et al. 2015; Bansal et al. 2019), or combinations of these methods. However, removal methods may be limited in certain wetland types, such as fens, where native and rare species conservation is a management priority. Therefore, more selective methods, such as applying herbicide via hand-wicking, should be considered to avoid harming native vegetation (Wilcox et al. 2018). Site accessibility and stability may also prove to be problematic for certain removal methods. Wilcox et al. (2018) noted the inability to use heavy machinery for *Typha* removal in floating wetlands but found steel-bladed trimmers to be a practical solution.

The objective reported in this case study was to restore a Lake Ontario coastal fen using a combination of two cattail-control techniques: (1) removal of the thick *Typha* detritus layer (harvesting) followed by (2) cutting and herbicide treatment via hand-wicking of regrowth. We acknowledge the limitations of a non-replicated study. However, our intentions are to document the effects of treatment on *Typha* and plant communities in a specific, case-study site that has no similar sites accessible to use for replication. Davies and Gray (2015) noted that issues such as these are often unavoidable, particularly in case-based management studies. Despite these limitations, we believe that we provide valuable management recommendations to control cattail in habitats where traditional methods may not be feasible.

Methods

Site Description

Buttonwood Creek is a drowned river mouth tributary to Braddock Bay located on Lake Ontario's south shore near Rochester, NY (Fig. 1). In 2014, we found a rare peatland community concealed by invasive *Typha* × *glauca*. The site, which we refer to as Buttonwood Fen, is a floating, lake-connected fen in the Rochester Embayment Area of Concern. An initial site assessment revealed a well-defined circular pattern of *Typha* invasion.

Site Delineation

In 2016, we delineated the site to map the extent of fen vegetation and plan for restoration activities. We used Real-Time Kinematic (RTK) GPS to establish three concentric boundaries based on vegetation types and levels of *Typha* invasion. The interior portion (INT FEN) contained approximately 0.16 ha of relatively uninvaded fen community, and preliminary vegetation observations showed that the site contained endemic fen taxa such as *Sphagnum* spp., *Phragmites australis* ssp. *americanus*, *Vaccinium macrocarpon*, *Eriophorum virginicum*, *Drosera rotundifolia*, and *Morella pensylvanica*. The intermediate portion (INV FEN) was approximately 4.25 ha and contained several fen species in the understory but was invaded by a moderately dense stand of cattails. The Exterior Cattail (EXT CAT) zone surrounded the entire site and was approximately 12.75 ha in size. We used hydrologic and water chemistry data from nested piezometers to validate groundwater discharge, confirming that the site is a fen.

Cattail Removal

We implemented cattail-control measures in 2016, with restoration activities taking place over three consecutive growing seasons: 18 July–21 September 2016, 17 July–9 September 2017, and 2 July–2 October 2018. In the INV FEN and INT FEN zones, we harvested *Typha* litter and cut live *Typha* stems with steel-bladed weed cutters in July when carbohydrate reserves in rhizomes are low (Sodja & Solberg 1993), followed by annual herbicide treatments of resprouting cattail in September. The EXT CAT zone was used as a reference. Cut cattail stems were disposed of on-site in the EXT CAT zone.

Resprouting *Typha* stems were treated via hand-wicking (cloth glove over rubber glove) by a licensed applicator using an aquatic-labeled herbicide (i.e., Rodeo). The efficacy of herbicide for *Typha* control is seasonally dependent; as such, treatment was done in early fall when cattails are transporting carbohydrates to rhizomes. These methods were selected per recommendation of Wilcox et al. (2018) to reduce the thick layer of dead *Typha* litter and to kill *Typha* rhizomes, allowing for reduced competition for light for the short-stature, native fen species in the understory.

Vegetation Surveys

We characterized vegetation three times during the restoration: 14–20 June 2016 (pre-restoration), 26 June–3 July 2018 (mid-restoration), and 11–16 July 2019 (1-year post-restoration). Vegetation sampling plot locations were randomly selected in different places each season using an RTK and ArcMap (Version 10.2.2). Sample plots were placed a minimum of 2.5 m apart in the smaller INT FEN and 10 m apart in the INV FEN and EXT CAT zones. We sampled vegetation in 25 $1-m^2$ quadrats in the INT FEN zone, 50 $1-m^2$ quadrats in the INV FEN, and 25 $1-m^2$ quadrats in the EXT CAT zone. Although the EXT CAT was the largest area, we justified collecting fewer samples there due to the nearly monotypic stands of *Typha*, which could be easily characterized by fewer samples.

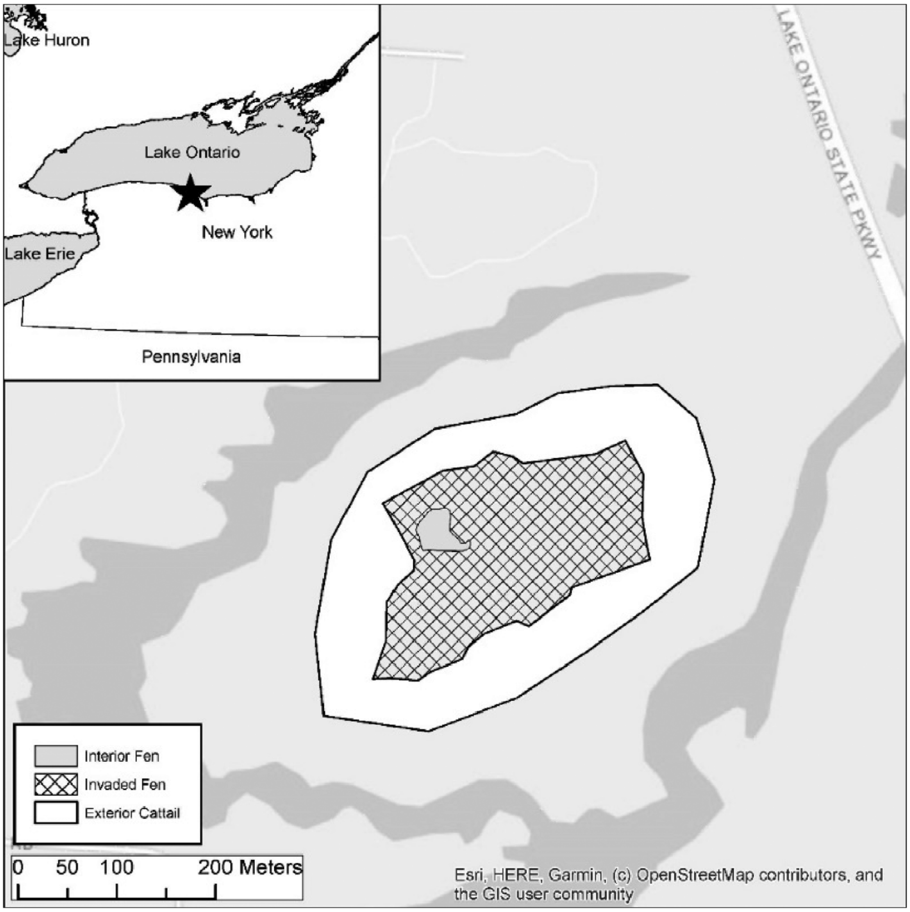

Figure 1. The study site at Buttonwood Fen, located within the Rochester Embayment of Concern on Lake Ontario's southern shore near Rochester, NY. Preliminary surveys showed that the interior portion of the fen (approximately 0.16 ha) was uninvaded by cattail, while the surrounding 4.25 ha contained fen heavily invaded by cattail. The entire site was encircled by 12.75 ha of cattail marsh.

Within each $1-m^2$ quadrat, we identified all plants to the lowest taxonomic level possible and visually estimated percent cover for each taxon every 1% up to 5% and then in 5% increments. We also conducted cattail stem counts in each quadrat.

Data Analyses

Not all data met the assumptions of normality, so non-parametric tests were used for analyses. We used Minitab (Version 18.1) to conduct a Mann–Whitney U test to compare the changes in live *Typha* cover, *Typha* dead litter cover, and *Typha* stem counts from 2016 to 2019 in each zone. We calculated the mean cover of live cattail and cattail litter in each individual zone from 2016 to 2019, and *Typha* stem counts were used to determine *Typha* density in each zone. We examined the change in percent cover of selected prominent native fen species in each zone from 2016 to 2019. Furthermore, we calculated Shannon Diversity Index (H') to show changes in native plant diversity pre- and post-*Typha* removal in the INT FEN and INV FEN zones.

We used vegetation relative frequency and relative mean percent cover to calculate importance values (IV) for all species within each concentric zone for 2016, 2018, and 2019. We used a non-metric multi-dimensional scaling (NMDS) ordination with Sorenson distance measure (PC-ORD Version 5.31) to evaluate species composition across treatment zones throughout the restoration process. Taxa used in the ordination included those found at least three times (spatially or temporally) and with IV ranging from 4 to 100 to focus on important wetland taxa. This approach eliminated 28 species and used 35 species in the analyses. Omitted species were not rare fen species and included saplings that did not contribute greatly to species composition. This metric was advantageous in determining the similarities of the most important vegetation types at each site. Axis scores were graphed to show groupings of taxa that occurred together and similarities and dissimilarities in species composition between each vegetation zone pre-, during, and post-restoration.

Results

Vegetation surveys at 100 sample plots across all zones at the study site detected 59 taxa in 2016 (pre-restoration) and 64 taxa in 2019 (post-restoration). Nine previously undetected species

Table 1. Results of Mann–Whitney *U* test showing a significant change in *Typha* percent cover, *Typha* biomass, and *Typha* stem density 2016 pre- to 2019 post-treatment in the INV FEN zone and a significant change in *Typha* biomass in the INT FEN zone from 2016 pre- to 2019 post-treatment.

	INT FEN	*INV FEN*	*EXT CAT*
Typha % cover (live)	Mann–Whitney $U = 710$ $n_1 = n_2 = 25$ $p = 0.151$ two tailed	**Mann–Whitney $U = 3{,}034$** **$n_1 = n_2 = 50$** **$p < 0.05$ two tailed**	Mann–Whitney $U = 594$ $n_1 = n_2 = 25$ $p = 0.400$ two tailed
Typha % litter (dead biomass)	**Mann–Whitney $U = 771$** **$n_1 = n_2 = 25$** **$p < 0.05$ two tailed**	**Mann–Whitney $U = 3{,}370$** **$n_1 = n_2 = 50$** **$p < 0.05$ two tailed**	Mann–Whitney $U = 645$ $n_1 = n_2 = 25$ $p = 0.892$ two tailed
Typha stem density (live)	Mann–Whitney $U = 638$ $n_1 = n_2 = 25$ $p = 0.992$ two tailed	**Mann–Whitney $U = 3{,}328$** **$n_1 = n_2 = 50$** **$p < 0.05$ two tailed**	Mann–Whitney $U = 684$ $n_1 = n_2 = 50$ $p = 0.372$ two tailed

Note: Bold values shows a significant difference pre-vs post-restoration.

were found post-restoration: *Carex lacustris*, *Cirsium muticum*, *Cyperus esculentus*, *Eragrostis spectabilis*, *Iris versicolor*, *Juncus tenuis*, *Lactuca serriola*, *Persicaria amphibia*, and *Verbena hastata*. Four species that had been surveyed in 2016 were not detected in 2019: *Cephalanthus occidentalis*, *Fraxinus nigra*, *Lysimachia terrestris*, and *Quercus rubra*.

We compared *Typha* cover, *Typha* litter cover, and *Typha* density pre-restoration (2016) and post-restoration (2019) individually in each zone. Results inherently differed among zones, which were in markedly different stages of invasion. In the INT FEN zone, we saw a significant decrease ($p < 0.05$) (Table 1) in dead biomass cover post-harvesting ($\bar{x} = 22.8$–4.6%) (Fig. 2A). Live *Typha* cover and stem counts changed little from pre- to post-restoration ($p = 0.15$ and $p = 0.92$, respectively) (Table 1; Fig. 2B & 2C), as there was only a small amount of *Typha* growing in the INT FEN zone initially. We saw an increase in several prevalent native species after restoration activities were completed (Table 2). *Thelypteris palustris* cover increased ($\bar{x} = 11.5$–27.9%) from 2016 to 2019. Similar patterns were seen with *E. virginicum* ($\bar{x} = 0.3$–2.3%), *Decodon verticillatus* ($\bar{x} = 0.6$–5.8%), and *D. rotundifolia* ($\bar{x} = 0.1$–2.7%). *Juncus canadensis* showed a modest increase from 4.1 to 5.4% mean cover from 2016 to 2019, while *C. lacustris* and *V. macrocarpon*, which were not detected pre-restoration, had respective mean cover of 2.6 and 8.3% in post-restoration 2019 (Table 2). Decreases in mean cover from 2016 to 2019 were observed for *Lysimachia thyrsiflora*, *M. pensylvanica*, *Osmundastrum cinnamomeum*, and *P. australis* ssp. *americanus* (Table 2). Overall, native plant diversity increased in the INT FEN zone from $H' = 1.8$ in 2016 to 2.0 after *Typha* removal.

The INV FEN zone, which initially had greater active *Typha* invasion, demonstrated a reduction ($\bar{x} = 6.5$–4.1%) in *Typha* cover (live) ($p < 0.05$) (Table 1; Fig. 2B), a decrease ($\bar{x} = 50.1$–14.9%) in *Typha* litter ($p < 0.05$) (Table 1; Fig. 2A), and a decrease ($\bar{x} = 22.3$–10.9%) in *Typha* stems from 2016 to 2019 ($p < 0.05$) (Table 1; Fig. 2C). We saw increases in cover of native vegetation such as *D. verticillatus* ($\bar{x} = 0.02$–5.6%), *D. rotundifolia* ($\bar{x} = 0.4$–3.8%), and *T. palustris* ($\bar{x} = 19.9$–24.5%) (Table 2). *Carex lacustris* and *E. virginicum* were not detected pre-restoration but had a mean cover of $\bar{x} = 0.3\%$ and

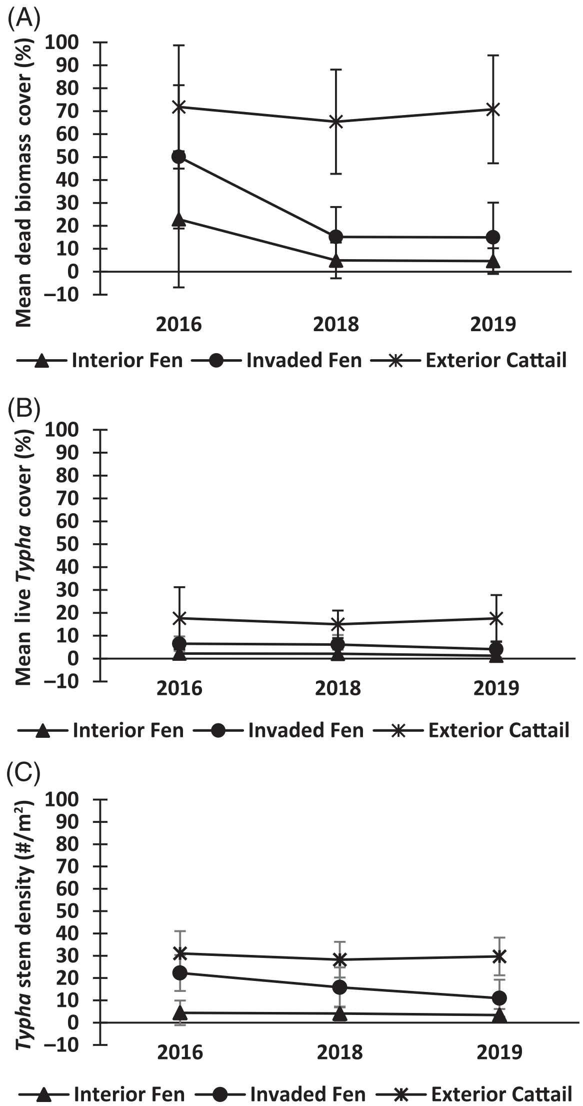

Figure 2. (A) The temporal trajectory of dead *Typha* biomass percent cover in Interior (INT) and Invaded (INV) Fen and External Cattail, (B) live *Typha* mean percent cover, and (C) *Typha* stem density across each concentric zone at Buttonwood Fen. Error bars represent ± SD, showing the variability in *Typha* cover (A and B) and stem counts (C) between sample plots.

Table 2. Mean percent cover of all taxa used in ordination in the Interior Fen (INT FEN), Invaded Fen (INV FEN), and Exterior Cattail (EXT CAT) zones from 2016 to 2019.

	INT FEN		*INV FEN*		*EXT CAT*	
Taxa	*2016*	*2019*	*2016*	*2019*	*2016*	*2019*
Acer rubrum	0.00	0.16	0.08	0.41	0.00	0.16
Andropogon virginicus	1.36	0.56	0.00	0.16	0.00	0.00
Asclepias incarnata	0.00	0.00	0.02	0.00	0.32	0.37
Boehmeria cylindrica	0.28	0.84	1.16	2.03	1.70	2.13
Calamagrostis canadensis	0.84	0.70	0.06	0.26	0.00	0.00
Carex lacustris	0.00	2.64	0.00	0.34	0.00	0.00
Cicuta bulbifera	0.00	0.00	0.00	0.00	0.16	0.58
Comarum palustre	0.36	0.82	0.02	0.14	0.52	0.89
Decodon verticillatus	0.60	5.84	0.02	5.64	0.70	0.61
Drosera rotundifolia	0.10	2.74	0.44	3.77	0.00	0.00
Epilobium coloratum	0.00	0.12	0.00	0.59	0.12	1.18
Eriophorum virginicum	0.28	2.28	0.00	2.82	0.00	0.00
Galium sp.	0.00	0.00	0.01	0.31	0.00	0.00
Hydrocharis morsus-ranae	0.00	0.00	0.00	0.00	1.08	0.24
Impatiens capensis	0.06	0.00	0.83	0.77	0.52	1.29
Juncus canadensis	4.06	5.36	0.00	1.30	0.00	0.00
Juncus effusus	0.00	0.64	0.00	0.00	0.08	0.11
Lycopus americanus	0.20	0.78	0.10	1.48	0.96	0.45
Lycopus uniflorus	0.98	0.96	0.14	0.78	0.02	0.97
Lysimachia thyrsiflora	7.22	3.48	1.35	1.29	1.38	0.97
Lythrum salicaria	0.08	0.04	0.20	0.04	1.92	0.18
Morella pensylvanica	23.60	7.04	3.10	1.18	0.00	0.00
Onoclea sensibilis	0.00	0.24	3.10	2.50	6.78	2.08
Osmundastrum cinnamomeum	6.06	2.60	1.87	0.64	0.14	0.00
Phragmites australis	2.56	0.80	0.06	0.00	0.00	0.00
Rosa palustris	0.12	0.60	0.40	0.14	0.52	0.50
Scutellaria galericulata	0.00	0.48	0.15	0.02	0.62	0.42
Solidago rugosa	1.14	0.00	0.02	0.70	0.00	0.00
Sphagnum sp.	67.24	88.00	53.70	62.56	3.84	0.00
Spiraea alba	0.22	0.48	0.16	0.00	0.08	0.55
Thelypteris palustris	11.52	27.88	19.88	24.52	14.84	15.12
Triadenum fraseri	5.38	11.80	1.62	2.40	0.52	2.32
Typha × *glauca*	2.22	1.26	6.52	4.08	17.64	17.56
Vaccinium macrocarpon	0.00	8.32	0.00	0.23	0.40	0.00
Viburnum dentatum	0.94	0.88	0.46	0.59	0.12	0.42

$\bar{x} = 2.8\%$, respectively, post-restoration (Table 2), while *C. palustre* increased slightly from 2016 to 2019 (Table 2). Decreases in mean cover from 2016 to 2019 were observed *for Impatiens capensis*, *L. thyrsiflora*, and *M. pensylvanica* (Table 2). Native plant diversity increased in this zone from $H' = 1.4$ in 2016 to 1.9 after *Typha* removal.

There were no significant differences in *Typha* cover ($p = 0.40$), *Typha* litter ($p = 0.89$), or *Typha* stem density ($p = 0.37$) in the EXT CAT zone where no removal efforts were conducted (Table 1). Few native species were found growing in the *Typha* understory in this zone, and only a few species had a mean cover of 1.5% or greater: *T. palustris*, *Onoclea sensibilis*, *Boehmeria cylindrica*, *Triadenum fraseri*, *Sphagnum* sp., and *Lythrum salicaria* (Table 2).

The NMDS ordination plotted by taxa from the plant community data (Table S1) highlights the differences in species response to *Typha* treatment. Taxa were grouped visually and are depicted by ellipses in Figure 3A. These visual groupings were determined based on similarity of occurrence as shown in Table 2. Group 1 species were only found in the EXT CAT zone or were more abundant in this area than the other treatment areas. Group 2 taxa increased in the INT FEN zone post-treatment but were also common in the EXT CAT understory during all years. Plants in group 3 showed a decrease in the INT FEN and INV FEN zone post-treatment. *Typha* also decreased post-treatment but was dominant in the EXT CAT zone all years, which explains why it grouped with other EXT CAT zone dominant plants. Group 4 are taxa that increased in both INT FEN and INV FEN treatment zones because of *Typha* removal. The one exception is *Sphagnum*, which essentially demonstrated no change but was one of the dominant species in these zones each year. Group 5 are the most dominant taxa in the INT FEN and INV FEN zones before, during, and after treatment (Fig. 3A).

The ordination plotted by zone/year showed few changes from 2016 to 2019 in the EXT CAT zone where no treatments were conducted (Fig. 3B), with all years in the upper left. There were several community-level changes in the INT FEN zone from

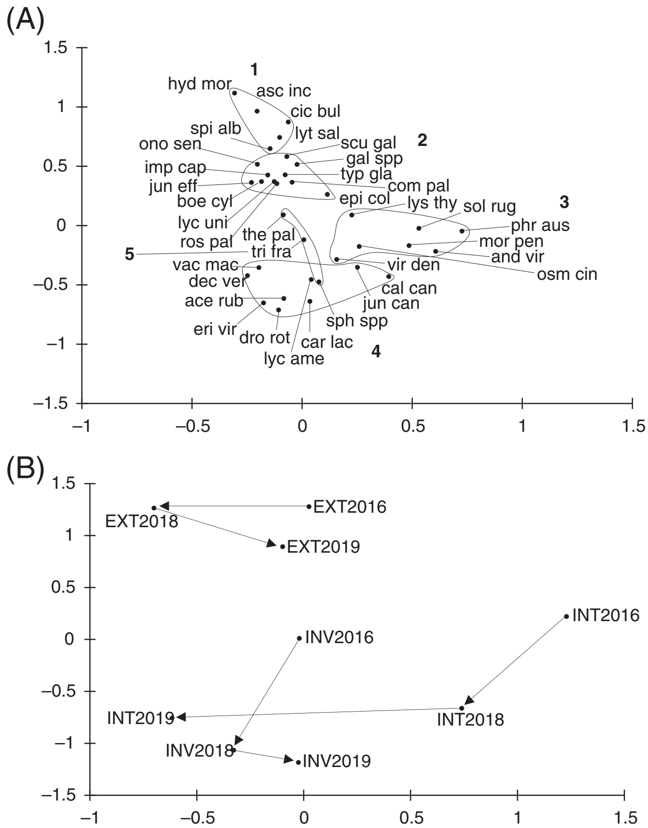

Figure 3. Two-dimensional plot of NMDS ordination of (A) selected plant taxa IV from Buttonwood Fen (autopilot on, Sorenson [Bray-Curtis] distance measure, no species weighting, final stress = 0.067, number of iterations = 23). Plants labeled in groupings 1–5 based on growing location and response to *Typha* treatment. Full species list can be found in Table S1. (B) Zones shown from 2016 to 2019 based on dominant species found growing in each sample location and response to *Typha* treatment, with arrows showing trajectories.

2016 and 2018 to 2019 (plots moving from middle right to lower left) as a result of the decrease in species such as *M. pensylvanica* and *P. australis* ssp. *americanus* and increases in *D. verticillatus*, *E. virginicum*, *V. macrocarpon*, and *D. rotundifolia* (Fig. 3A). Changes in the INV FEN zone from 2016 to 2018 and 2019, as shown by moving to lower right, are a function of increased *Acer rubrum*, *E. virginicum*, *D. verticillatus*, *Lycopus americanus*, and *D. rotundifolia*, and decreased *Typha*, *I. capensis*, *and L. thyrsiflora*. In 2016, INV FEN zone more closely resembled plots for EXT CAT, driven by greater presence of *Typha*. However, by 2018 and 2019, reductions in cattail and changes in other taxa caused INV FEN to plot near INT2019, where changes had also occurred since 2016 (Fig. 3B).

Discussion

In the INT FEN where live *Typha* occurred at low density, the increase in native plants suggests that the significant decrease in *Typha* litter from harvesting was responsible for increases in native plants. Several studies have shown that accumulation of *Typha* litter, rather than live *Typha* cover, is a key component of negative plant community changes at invaded sites (Farrer & Goldberg 2009; Tuchman et al. 2009; Keyport et al. 2019). Farrer and Goldberg (2009) noted that the removal of the litter layer may make *Typha* reinvasion less likely. Dense accumulation of *Typha* litter has been shown to enrich soil nutrients at invaded sites, creating positive feedbacks that facilitate its dominance (Lawrence et al. 2016) and allowing the continuation of buildup over time (Keyport et al. 2019). Litter accumulation increases nitrogen and decreases light, which creates ideal *Typha* habitat and promotes additional *Typha* growth (Farrer & Goldberg 2009). Furthermore, thick layers of *Typha* reduce light availability and diminish native seed germination (Farrer & Goldberg 2009; Lawrence et al. 2016), resulting in a decline in native plant communities (Farrer & Goldberg 2009; Tuchman et al. 2009; Keyport et al. 2019). Harvesting *Typha* litter has multiple advantages (Lawrence et al. 2016). It diminishes the positive feedback loop, decreasing *Typha's* capability to invade (Lishawa et al. 2015; Keyport et al. 2019); and it opens the canopy, allowing light to penetrate the understory, resulting in increased plant diversity (Farrer & Goldberg 2009; Lishawa et al. 2015; Lawrence et al. 2016; Keyport et al. 2019). Opening of the canopy by removing *Typha* litter in the INV FEN likely contributed to the increase of *T. palustris*, *D. verticillatus*, *D. rotundifolia*, *C. lacustris*, *E. virginicum*, and *C. palustre* in this zone. These species are often found in fens; they prefer moist soils, open habitats, and abundant sunlight.

While we cannot tease apart the individual impacts of harvesting, live stem-cutting, and hand-wicking in the INV FEN zone, our results suggest that the combination of these treatments effectively reduced aboveground *Typha* biomass, resulting in increased native taxa cover by means of "opened" canopy. Other studies have outlined the efficacy of herbicide treatment to control *Typha* (Lawrence et al. 2016; Wilcox et al. 2018); however, repetitive treatments are often necessary (Wilcox et al. 2018; Bansal et al. 2019). Fewer studies have assessed the combination of cutting followed by herbicide via hand-wicking. Our results in the INV FEN zone corroborate those of Wilcox et al. (2018), who found that herbicide application via hand-wicking after cutting was an effective means of *Typha* stem removal and reduction in *Typha* cover in a Lake Ontario coastal marsh. Like the Wilcox et al. (2018) study, we conducted the hand-wicking treatment in early fall, timed with stem regrowth and done when carbohydrates are being transported to the rhizomes. This allows the herbicide to be absorbed into the rhizomes (Wilcox et al. 2018), which may be more effective than spraying aboveground stems alone. Furthermore, this type of treatment is targeted to individual plants, diminishing the likelihood of native species being affected (Wilcox et al. 2018). Removing *Typha* biomass and slowing active invasion in this zone should reduce further *Typha* invasion in the INT FEN zone.

No treatments were conducted in the EXT CAT zone, explaining the lack of statistical differences between *Typha* cover, *Typha* litter, and *Typha* stem density pre- versus post-treatment. However, these variables also did not show an increase from 2016 to 2019, suggesting that cattail may have reached its peak density, although cattail invasion farther onto the floating mat may be continuing. Without long-term management, it is likely that *Typha* will continue to proliferate from this zone back into the treated INV FEN and INT FEN zones.

The results of our study suggest that there are effective *Typha* treatment options in sensitive habitats where standard methods (i.e., foliar spraying, water-level manipulation, mechanical harvesting) may not be feasible, including floating fens where flooding does not occur. We recommend development of a long-term management plan for *Typha*, which should be site-specific. Although cutting and herbicide treatments were effective in reducing *Typha* cover and stem counts, in low-light environments created by abundant *Typha* cover, the removal of *Typha* litter is paramount. Not only does this open the canopy, it reduces nutrient loads, breaking the *Typha* feedback loop, and results in increased light penetration, thus allowing for greater native recruitment and improved wildlife habitat (Lawrence et al. 2016). In areas of active invasion, we suggest the removal of biomass via cutting of live *Typha* stems. This should be timed to periods when carbohydrate reserves are low (Sojda & Solberg 1993) and followed by hand-wicking regrowth from the cut stems with an aquatic-approved herbicide, if necessary. Ultimately, *Typha* control should be viewed as a long-term process with continued active removal efforts.

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Supporting Information

The following information may be found in the online version of this article:

Table S1. Importance values for selected taxa used in the NMDS ordination for each zone at Buttonwood Fen pre- and post-restoration.

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