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Controlling Cattail Invasion in Sedge / Grass Meadows

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ORIGINAL RESEARCH

Controlling Cattail Invasion in Sedge / Grass Meadows

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Abstract

As a result of water-level regulation, cattails have invaded sedge/grass meadow in all wetlands on Lake Ontario. Even with a change in water-level-regulation to a more natural hydrologic regime, restoration requires methods for active cattail management without the ability to manipulate water depths and without imperiling other vegetation. We conducted replicated studies at a wetland site with an active invasion front in zones of nearly mono-dominant cattail and transitional invasion. We tested various combinations of cutting cattail ramets when carbohydrate reserves were minimized, spraying cut stems with herbicide, slicing rhizomes to mimic tilling, and hand-wicking resprouted ramets with herbicide. We also collected companion environmental data. The most effective treatment in both zones was cutting during the period with reduced rhizome carbohydrates followed by hand-wicking resprouted ramets with herbicide in late summer, which allows the herbicide to be absorbed by the rhizomes. Two years of treatment provide the best results, reducing cattail stem counts and cover by more than 50%, but follow-up applications in ensuing years may be warranted to treat surviving cattails. Given the widespread problem of cattail invasion, these treatments may have broad application in wetlands where water levels cannot be manipulated.

Keywords Cattail control · Sedge/grass meadow · *Typha* · Cutting · Herbicide · Lake Ontario · Restoration

Introduction

Physical, chemical, and hydrologic disturbances in wetlands can open canopies, expose substrates, and reduce competition, thus allowing invasive plants to gain a foothold and potentially become dominant (e.g., Galatowitsch et al. 1999, Wilcox 2012). Less competitive species may thus be lost and diversity reduced (Wisheu and Keddy 1992; Boers et al. 2007). A prominent wetland invader is cattail (*Typha* spp.), which can exploit wetlands with increased nutrient availability (Woo and Zedler 2002), substrates exposed for seed germination (van der Valk and Davis 1978), and altered hydrology (e.g., Wilcox et al. 1984; Newman et al. 1998; Wilcox et al. 2008).

Regulation of water levels and flows on Lake Ontario and the St. Lawrence River since the St. Lawrence Seaway began

operation in 1960 resulted in compression of the range of water levels on Lake Ontario from approximately 1.5 m to 0.7 m (Wilcox and Xie 2007), with much of the loss of fluctuations due to lack of low lake levels (Wilcox et al. 2008). At higher elevations in the wetlands, sedge/grass meadow plants historically held a competitive advantage over cattails because they could better tolerate low soil moisture during low water years. Lack of low lake levels since the mid-1960s shifted the competitive advantage to the taller cattails, resulting in cattail invasion of all Lake Ontario wetlands and loss of large expanses of sedge/grass meadow (Wilcox et al. 2008). As a result, habitat for many fish and wildlife species has been lost and populations have been reduced (e.g., Farrell 2001; Desgranges et al. 2006; Toner et al. 2010; Gertzen et al. 2012).

Potential implementation of a new regulation plan for Lake Ontario that more closely mimics the natural hydrologic regime was suggested by the U.S.-Canadian International Joint Commission (IJC) in 2006 (Wilcox and Xie 2008), presenting the possibility for sedge/grass meadow plant species to compete with cattails in the future. However, sedge/grass species would likely not displace existing cattails in a reasonable time period without help, resulting in continued domination and potential expansion of cattails. Methods for reducing cattail cover in wetlands to promote restoration of sedge/grass meadow and other emergent communities need to be developed and tested before being implemented. If effective, they would have

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the potential to be applied to wetlands totaling more than 24,000 ha in area. Our objectives were to test several cattail-control methods that were compatible with hydrologic and other site characteristics of Lake Ontario wetlands at a site with an active zone of cattail invasion into sedge/grass meadow.

Control of cattails has been on the management and scientific agenda for many decades. Steenis et al. (1959) summarized early actions involving water-level manipulations and herbicide treatments. In-depth studies of cattail control methods followed (Nelson and Dietz 1966; Linde et al. 1976; Beule 1979), and other studies further narrowed the options for success (Weller 1975; Mallik and Wein 1986; Wilcox and Ray 1989; Ball 1990; Kostecke et al. 2004; Lawrence et al. 2016; Elgersma et al. 2017). Among methods tested were various combinations of hand-cutting or mowing or crushing of ramets, discing or rototilling of rhizomes, herbicide application, burning, covering with tarps, cattle-grazing, water-level manipulations, and explosives. Other larger scale mechanical methods have also been employed: weed-cutting boats (Hellsten et al. 1999), fangueo aquatic tractors (Osland et al. 2011), and a biomass harvester for bioenergy (Lishawa et al. 2015).

Many methods require physical alteration of habitat or control of water levels to force wintertime flooding conditions, which is not possible along the shores of the Great Lakes. However, less drastic methods are possible for reducing cattail dominance. Cutting cattails when storage carbohydrates reach their lowest concentration in rhizomes reduces the chance for survival, as storage reserves cannot be replenished without above-ground leaf tissue present to carry out photosynthesis (Sojda and Solberg 1993; Hall and Zedler 2010). Cut plants will resprout, however, so secondary treatments are necessary to reduce new photosynthesis and growth.

To meet our objectives, we considered the relative success and practicality of many of the methods described and evaluated by others in relation to environmental conditions present in Lake Ontario wetlands. The presence of floating cattail mats along the waterward edge of many wetlands makes treatments that require heavy equipment impractical there, and the mats would not be affected by water-level manipulations. Cutting ramets and flooding over winter, although effective, is not possible because lake levels are lowest in winter. Controlled burning was not considered because many Lake Ontario wetlands are adjacent to developed lands. Given the loss of sedge/grass meadow due to cattail invasion (Wilcox et al. 2008), the focus for testing was placed on the landward edge of the cattails where invasion of sedge/grass meadow is ongoing and might be reduced. To avoid destroying remnant sedge/grass meadow plants while controlling cattails, more selective methods were chosen for testing that targeted regeneration of cattails from rhizomes following cutting. We selected the following treatments for evaluation: 1) cutting cattail ramets, 2) hand-spraying cut stems with herbicide, 3) tilling rhizomes by hand, and 4) applying herbicide to re-sprouting cattail stems by hand-wicking to avoid affecting non-target plants.

Methods

Study Site

Kents Creek is a drowned river mouth wetland located at the east side of Lake Ontario about five kilometers south of Cape Vincent, New York, USA (44°5′4.03″N, 76°18′16.70″W) (Fig. 1). The 98,419 ha watershed drains primarily agricultural and forested lands. The lower creek meanders through a large flat basin and into Mud Bay, which connects the creek to Lake Ontario; water levels are controlled by the lake. Although most Lake Ontario wetlands are almost totally dominated by cattails, the 91-ha emergent marsh containing the study site has large areas of sedge/grass meadow that persist at slightly higher elevations provided by the broad, gently sloping basin morphology. The effects of long-term higher lake levels and increased soil moisture that have favored invasion of cattails (Wilcox et al. 2008) are thus avoided. The creek at the study site has long stretches with an obvious gradient of cattail density that thins from nearly mono-dominant along the shore to sporadic cattail individuals within the sedge/grass meadow.

Field Methods

This study was conducted in two parts – one in the nearly mono-dominant Cattail Zone and the other in the transitional Meadow Zone where estimated cattail cover in the sedge/grass meadow was 15–20%. Methods implemented in both zones were nearly identical, but a treatment to mimic tilling was also employed in the Cattail Zone, where few other taxa were present to be affected. Cattail-control treatments and data collection were conducted in two years (2010, 2011) in both zones, but a third year of data collection (2012) was added in the Meadow Zone to capture continued response to follow-up treatments.

Five replicate study areas for each zone, roughly parallel to the south shore of the creek, were selected following elevation surveys conducted to ensure similar hydrologic conditions. In late May 2010, prior to sprouting, the previous year's growth of cattail in the five study areas in each zone (5 m × 15 m in Meadow Zone, 5 m × 27 m in Cattail Zone) was cut with a steel-blade trimmer, and the cut material was completely removed from the study areas, along with the previous years' litter, so that sampling and treatments were not affected by the presence of dead *Typha* biomass. This also allowed each treatment block to be laid out accurately and increased light availability. Treatment and control plots inside each treatment

Fig. 1 Location and alignment (approx.) of the five treatment replicate blocks for the Meadow Zone (yellow) and Cattail Zone (blue) at Kents Creek, a drowned-river-mouth tributary to Lake Ontario. For ease of viewing, treatment blocks are not to scale
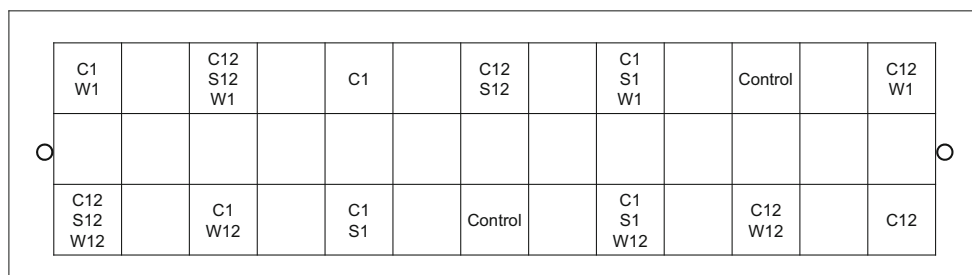

replicate block consisted of 1 m × 1 m plots that were staked with PVC pipe and separated by a 1 m × 1 m working area/ buffer (Fig. 2). Treatments were applied in a complete factorial, random block design.

Four treatments were tested. The primary treatment method was cutting *Typha* using hand-held loppers (C); cut stems were then removed from the treatment plots. This treatment included cutting in year 1 only or cutting in both years 1 and 2. The cutting treatments were conducted on 31 June 2010 and 11 July 2011 when energy reserves in the rhizomes were assumed to be at their lowest concentrations (Linde et al. 1976; Biesboer 1984); both dates fell within a three-week window from one week before to one week after the pistillate spikes were lime green and the staminate spikes were dark green (Sojda and Solberg 1993).

The second treatment method was spraying newly-cut *Typha* stems with glyphosate (Rodeo) using a hand-held sprayer (S) to avoid spraying other (non-target) plants. This treatment was conducted only in combination with cutting in year 1 or years 1 and 2. The third treatment consisted of

wicking herbicide (W) manually to re-sprouted *Typha* plants in late August with a cloth glove doused in glyphosate worn over a rubber glove. The glove was run from the bottom of each leaf to the top and on both sides of the leaf to ensure complete leaf application. Wicking of re-sprouted stems was selected over spraying to avoid affecting other plants. In the Meadow Zone, this treatment was either not conducted, done in year 1, or done in both years 1 and 2. In the Cattail Zone, the wicking treatment, if conducted, was done only in year 1. The additional treatment to mimic tilling (T) in the Cattail Zone, if conducted, was done only in year 1. *Typha* rhizomes were cut manually using a trenching shovel forced into the ground around every *Typha* stem, as this produced a result similar to tilling with larger equipment.

The different combinations of these techniques resulted in 12 different treatments in the Meadow Zone (2x2x3 block design: Cutting $n = 2$, Spraying $n = 2$, Wicking $n = 3$) and 16 treatments in the Cattail Zone (2x2x2x2 design: Cutting n = 2, Spraying n = 2, Wicking n = 2, Tilling n = 2) (Table 1). Two control plots were also randomly assigned to each of five

C1 W1	C12 S12 W1	C1	C12 S12	C1 S1 W1	Control	C12 W1
C12 S12 W12	C1 W12	C1 S1	Control	C1 S1 W12	C12 W12	C12

Fig. 2 Example study design layout for placement of 12 treatment combinations and 2 controls (as identified in Table 1) in the Meadow Zone at Kents Creek. Circles at the ends of the panel represent placement of the water-table wells. The space between each treatment plot represents a 1-m working buffer, which also extended around the perimeter. The Cattail Zone design was similar but included 16 treatments

Table 1 Treatment combinations implemented in Meadow Zone and Cattail Zone in *Typha*-control study at Kents Creek

Meadow zone	Cattail zone
C1	C1
C1S1	C1S1
C1W1	C1W1
C1W12	–
C1S1W1	C1S1W1
C1S1W12	–
–	C1T1
–	C1S1T1
–	C1W1T1
–	C1S1W1T1
C12	C12
C12S12	C12S12
C12W1	C12W1
C12W12	–
C12S12W1	C12S12W1
C12S12W12	–
–	C12T1
–	C12S12T1
–	C12W1T1
–	C12S12W1T1

C, cut; *S*, spray; *W*, wick; *T*, till; *1*, year 1; *12*, years 1 and 2

treatment blocks in both zones, in which previous years' growth and litter had been removed but no treatments applied, for a total of 32 plots – 14 in the Meadow Zone and 18 in the Cattail Zone (Fig. 2).

To evaluate treatment responses, vegetation was sampled twice each year. Sampling entailed identifying each plant present in the plot to species level and estimating percent cover. Individual *Typha* plants were identified to species level using a combination of indicators that differentiate *Typha* x *glauca* Godr. from *Typha angustifolia* L. (Gertz et al. 1994). *Typha latifolia* L. was never encountered. In addition, *Typha* stems were counted within each 1 m^2 plot to show direct effects of treatments. Primary vegetation sampling occurred on 9–11 July 2010 and 30 June 2011, before each round of treatments was applied. Cutting and spraying treatments were applied immediately following primary sampling. Secondary sampling occurred on 22–23 August 2010 and 25 August 2011 and involved the same parameters as in the primary sampling. Following secondary sampling, the wick treatment was applied to re-sprouting *Typha* plants in applicable treatment plots. Follow-up vegetation sampling in the Meadow Zone was conducted on 28 August 2012 to note further changes in the overall plant community. All vegetation surveys were conducted by the same trained individuals in each zone in all years.

Environmental factors were measured during the growing season to help understand the underlying variables related to

Typha control and sedge/grass meadow restoration. Water-table wells were installed at both ends of each treatment block (Fig. 2) to measure the variability of ground-water elevations. Percent soil moisture measurements were taken with a Dynamax TH20 Moisture Probe in each plot to relate treatment success to soil-moisture levels. Water-table and soil-moisture readings were taken weekly throughout the growing season in 2010 and bi-monthly in 2011. Soil moisture was also measured in 2012 in the Meadow Zone.

In the spring of 2010, sediment depths of each treatment and control plot in both zones were measured using a soil auger to reach the underlying clay layer. Two surface soil cores were also collected per treatment block in 2010 to measure bulk density and percent soil organic matter. Bulk density analysis was conducted using methods described by Grossman and Reinsch (2002). Following bulk density analysis, percent loss on ignition was used to estimate percent organic matter using methods described by Storer (1984).

Statistical Analyses

Paired T-tests were used to compare response variables (*Typha* stem counts, *Typha* percent cover) before (2010) versus after (2012) treatment to test the significance of individual treatments or treatment combinations. Some datasets were non-normal, so the non-parametric alternative, the Wilcoxon signed-ranks test, was used. Paired T-tests were also used to test for significant differences in pre- and post-cattail treatment cover of *Carex lacustris* Willd. and *Calamagrostis canadensis* (Michx.) P. Beauv., which were the two most dominant sedge/grass meadow species present in the Meadow Zone in all five treatment areas. The Kruskal-Wallis non-parametric alternative to ANOVA was used to test for differences in soil moisture among the five treatment replicates within each of the sampling years in both zones. One-way ANOVAs with Tukey's multiple comparisons were used to test for differences in sediment depth, mean bulk density, and mean percent organic matter among the five treatment replicates in both zones.

Results

Meadow Zone

Typha

The effectiveness of the various treatment combinations (e.g., C1S1W1) was evaluated based on their ability to reduce *Typha* stem counts and percent cover over the three-year study period (pre-treatment 2010 vs. post-treatment 2012 vegetation sampling). Seven treatment combinations significantly reduced the mean number of *Typha* stems across all plots over

that period: C1W1, C1W12, C1S1W12, C12, C12S12, C12W12, and C12S12W1 (Table 2). Six of those seven treatments more than halved the mean number of stems from 2010 to 2012. The remaining treatment combinations (C1, C1S1, C1S1W1, C12W1, C12S12W12) resulted in lower *Typha* stem counts, but the differences were not significant. *Typha* in the control treatment plots fluctuated throughout the study and lost an average of 1.2 stems over the three-year period.

Five treatment combinations resulted in significant reductions in mean *Typha* percent cover by more than 50% across all plots from 2010 to 2012: C1S1W12, C1W12, C12S12, C12W1, and C12W12 (Table 3). Of these treatments, all but C12W1 were among the seven treatments that significantly reduced *Typha* stem counts. Although the remaining treatment combinations (C1, C1S1, C1W1, C1S1W1, C12, C12S12W1, C12S12W12) also reduced *Typha* percent cover, the reduction was not statistically significant. Percent cover of *Typha* in control plots fluctuated slightly throughout the study but was relatively unchanged at the end of the study.

No treatment combination showed an increase in either *Typha* stem count or percent cover. With the exception of C12 and C12S12, all treatment combinations that significantly reduced *Typha* stem counts and percent cover had the wick treatment in year 1 or years 1 and 2. However, not all treatments with wick application showed a significant effect. These exceptions may be related to outliers among replicate blocks with different environmental conditions. However, statistical analysis of soil moisture, the most important environmental factor measured, revealed no difference across the full range of all treatment blocks. Although treatments had widespread success at reducing *Typha* stem counts across replicates, they had varied success at reducing percent cover across replicates. Across treatments, blocks 1, 2, 3, and 4 had

significantly greater decreases in mean *Typha* stem counts at the end of the study (August 2012) compared to the beginning (July 2010), while treatment block 5 had the smallest mean reduction of *Typha* stem count.

Sedge/Grass

The mean cover of *C. lacustris* in treatments that showed a significant reduction in *Typha* percent cover was 21.7% in pre-treatment July 2010 and 14.0% in post-treatment August 2012; this difference was not significant. In treatments with no significant decrease in *Typha* cover, the mean cover of *C. lacustris* was reduced from 23.6% in 2010 to 14.1% in 2012 ($T = 3.298$, $p = 0.016$). In control plots, the mean cover of *C. lacustris* decreased from 37% to 15.5% from July 2010 to August 2012. The mean cover of *C. canadensis* in treatments with *Typha* reduction increased from 26.4% in 2010 to 50.0% in 2012 ($T = -9.667$, $p = 0.001$), while in treatments with no *Typha* reduction, it increased from 24.3% in 2010 to 45.4% in 2012 ($T = -8.106$, $p = 0.000$). In the control plots, *C. canadensis* increased from 21% to 36% mean cover from July 2010 to August 2012. Loss of *Typha* cover created little open space because much of the cover was in overstory.

Environmental Conditions

Water-table elevations in monitoring wells closely followed Lake Ontario gauged water-level data (NOAA 2012). In 2010, the water table peaked in July at 74.97 m (IGLD1985) and steadily decreased throughout the growing season. In 2011, the water table rose sharply in the spring and stayed elevated during May, June, and July (75.23, 75.33, and 75.14 m, respectively). The water table then fluctuated

Table 2 Mean stem counts of *Typha* across all replicates in the Meadow Zone at Kents Creek before and after treatments

Treatment	Mean stems before	Standard error	Mean stems after	Standard error	Percent stem change	p-value	T-value
C1	17.2	5.9	13.2	2.6	−23.2	0.217	
C1S1	10.8	3.5	7.0	1.0	−35.2	0.129	
C1W1	13.6	3.6	5.0	2.3	−63.2	0.031*	2.35
C1W12	12.6	2.2	5.2	1.0	−58.7	0.003*	3.21
C1S1W1	12.0	4.1	8.2	1.3	−31.7	0.179	
C1S1W12	10.4	2.8	4.6	0.8	−55.8	0.040*	2.85
C12	13.8	3.3	6.4	1.4	−53.6	0.026*	2.23
C12S12	16.0	2.6	4.2	1.0	−73.8	0.002*	2.83
C12W1	14.8	4.2	6.0	1.2	−59.5	0.074	
C12W12	12.4	1.3	3.8	1.7	−69.4	0.007*	3.33
C12S12W1	9.8	2.3	5.4	0.8	−44.9	0.036*	4.25
C12S12W12	8.2	2.5	2.6	0.7	−68.3	0.067	
Control	9.8	1.3	8.6	1.2	−12.2	0.247	

Significance based on paired t-tests for pre-treatment 2010 vs. post-treatment 2012 results

*Treatments with *p*-value less than 0.05

Table 3 Mean percent cover of *Typha* across all replicates in the Meadow Zone at Kents Creek before and after treatments

Treatment	Mean percent cover before	Standard error	Mean percent cover after	Standard error	Percent mean cover change	p-value	T-value
C1	21.4	7.6	17.0	3.4	−20.6	0.214	
C1S1	21.0	7.5	10.0	1.6	−52.4	0.085	
C1W1	17.0	4.9	11.2	4.2	−34.1	0.158	
C1W12	17.4	4.8	6.4	1.6	−63.2	0.037*	4.05
C1S1W1	15.0	5.2	14.0	2.9	−6.7	0.440	
C1S1W12	17.0	4.3	6.0	1.0	−64.7	0.020*	2.54
C12	18.0	3.7	13.0	3.0	−27.8	0.071	
C12S12	21.0	4.3	8.0	1.2	−61.9	0.020*	2.81
C12W1	17.0	1.2	8.0	2.0	−52.9	0.011*	2.61
C12W12	19.0	2.5	6.0	1.0	−68.4	0.003*	3.54
C12S12W1	13.4	4.6	7.0	1.2	−47.8	0.115	
C12S12W2	12.4	3.8	5.4	1.3	−56.5	0.117	
Control	14.9	2.8	15.0	2.4	+0.7	0.487	

Significance based on paired t-tests for pre-treatment 2010 vs. post-treatment 2012 results

*Treatments with *p*-value less than 0.05

throughout the remainder of the sampling season. In 2012, the water table steadily decreased throughout the sampling period, from 74.91 m in May to 74.90 in June, 74.79 m in July, and 74.76 m in August.

There were no significant differences in mean percent soil moisture among all treatment plots across all replicate blocks for each of the three sampling seasons (Kruskall-Wallis: 2010 $H_{12} = 11.46$, $p = 0.490$; 2011 $H_{10} = 8.11$, $p = 0.618$; 2012 $H_{12} = 16.58$, $p = 0.166$). Based on this result, any differences in *Typha* response to treatments were likely not in response to differing soil moisture regimes. However, median soil moisture at block 5 was only 78.1% and ranged from 85.3 to 90.8% at the other block in 2010. So, block 5 may have been drier, although differences were less pronounced in extremely wet 2011 and drier 2012.

Sediment depth to clay at block 3 (32.6 cm) was significantly less (ANOVA: $F_4 = 3.50$, $p = 0.012$) than at the other blocks (ranging from 35.1 to 38.3 cm). Mean soil bulk density was significantly greater (ANOVA: $F_4 = 7.96$, $p = 0.021$) at block 5 (0.52 g/cm^3) than at the other blocks, which ranged from 0.17 to 0.29 g/cm^3. Percent soil organic matter ranged from a low of 18.7 at block 5 to as high as 56.3% at block 2, but the differences were not significant.

Cattail Zone

Typha

In the Cattail Zone, the effectiveness of the various treatment combinations was evaluated over a two-year study period (pre-treatment 2010 vs. post-treatment 2011 vegetation sampling). Six treatment combinations significantly reduced the number of *Typha* stems: C1W1, C1S1W1, C1W1T1, C12S12W1, C12W1T1, and C12S12W1T1 (Table 4). The latter three treatments reduced the number of stems by over 42% between 2010 and 2011. The remaining treatment combinations (C1, C1S1, C1T1, C1S1T1, C1S1W1T1, C12, C12S12, C12W1, C12T1, and C12S12T1) did not significantly reduce stem counts, which increased in some treatments. The control treatment plots gained an average of 13.4 *Typha* stems through the two years of the study.

Four of the six treatments that significantly reduced *Typha* stem counts also significantly reduced *Typha* percent cover: C1S1W1, C12S12W1, C12W1T1, and C12S12W1T1 – the latter three by more than 65% (Table 5). The other two treatments that significantly reduced *Typha* cover were C12 and C12W1. The remaining treatment combinations (C1, C1S1, C1W1, C1T1, C1S1T1, C1W1T1, C1S1W1T1, C12S12, C12T1, and C12S12T1) did not reduce *Typha* cover significantly or showed an increase. Treatments C12S12 and C12S12T1 reduced *Typha* cover substantially, but this was not significant. In the control plots, mean *Typha* cover increased by 28% over the two years of study.

Treatment combinations that were significant in reducing both *Typha* stems and percent cover through both years of the study had the wick treatment (W1) in common. All treatment plots, with the exception of C1, C1S1, C1T1, and C1S1T1 (all with cutting in year 1 only) had fewer *Typha* stems and less percent cover. Plots with only cutting in year 1 (C1) showed increases in *Typha* from August 2010 to June 2011 (e.g., C1S1 treatment). Initial reductions of *Typha* stems occurred, but lack of treatments in the following year allowed re-expansion.

The effectiveness of the treatments varied among treatment blocks in the *Typha* zone also. Treatment blocks 1 and 3 had

Table 4 Mean stem counts of *Typha* across all replicates in the Cattail Zone at Kents Creek before and after treatments

Treatment	Mean stems before	Standard error	Mean stems after	Standard error	Percent stem change	p-value	T-value
C1	29.6	2.1	35.4	4.6	+19.6	0.368	
C1S1	27.8	1.7	29.3	2.9	+5.4	0.822	
C1W1	26.7	2.4	20.6	3.4	−22.8	0.048*	2.29
C1S1W1	26.1	3.0	17.9	2.2	−31.4	0.013*	3.33
C1T1	21.8	2.4	31.0	3.8	+42.2	0.041[†]	
C1S1T1	30.6	3.6	32.3	2.6	+5.6	0.59	
C1W1T1	30.4	2.5	22.4	1.8	−26.3	0.018*	3.33
C1S1W1T1	23.8	1.9	19.6	2.1	−17.6	0.181	
C12	22.8	1.5	19.5	3.4	−14.5	0.391	
C12S12	26.4	3.3	18.0	8.5	−31.8	0.475	
C12W1	27.5	2.8	21.1	1.8	−23.3	0.059	
C12S12W1	28.7	3.0	16.5	2.6	−42.5	0.020*	2.81
C12T1	27.8	2.1	30.0	10.5	+8.9	0.776	
C12S12T1	34.6	4.0	29.3	7.4	−15.3	0.587	
C12W1T1	31.0	3.0	15.1	1.9	−51.3	0.005*	4.34
C12S12W1T1	28.2	1.9	15.3	3.3	−45.7	0.002*	5.03
Control	27.3	3.4	40.7	4.1	+49.1	0.000[†]	

Significance based on paired t-tests for pre-treatment 2010 vs. post-treatment 2011 results

*Treatments with p-value less than 0.05. [†] Significant increase in *Typha* stems

significantly lower mean *Typha* stem counts at the end of the study (August 2011) compared to the beginning (July 2010).

Treatment block 3 reduced the largest average amount of both *Typha* stem counts and percent cover.

Table 5 Mean percent cover of *Typha* across all replicates in the Cattail Zone at Kents Creek before and after treatments. Significance based on paired t-test for pre-treatment 2010 vs. post-treatment 2011 results

Treatment	Mean percent cover before	Standard error	Mean percent cover after	Standard error	Percent mean cover change	p-value	T-value
C1	32.6	4.4	45.0	7.7	+38.0	0.234	
C1S1	37.6	3.2	45.0	3.1	+19.7	0.433	
C1W1	33.1	3.7	31.0	6.2	−6.3	0.707	
C1S1W1	32.1	2.9	25.6	3.8	−20.2	0.040*	2.51
C1T1	35.6	3.2	46.3	8.4	+30.1	0.278	
C1S1T1	34.4	4.8	50.0	0.0	+45.3	0.211	
C1W1T1	39.9	2.3	35.5	4.3	−11	0.246	
C1S1W1T1	32.2	2.2	26.9	4.2	−16.5	0.494	
C12	28.0	3.7	13.8	3.4	−50.7	0.049*	3.22
C12S12	36.6	4.8	8.7	4.1	−76.2	0.136	
C12W1	37.7	3.4	16.7	2.8	−55.7	0.001*	5.20
C12S12W1	38.0	1.7	12.5	2.4	−67.1	0.000*	9.14
C12T1	34.2	3.7	31.3	15.5	−8.5	0.886	
C12S12T1	42.2	4.4	23.3	6.8	−44.5	0.172	
C12W1T1	32.7	3.6	10.9	1.6	−66.7	0.002*	5.20
C12S12W1T1	35.5	2.7	12.3	4.9	−65.4	0.014*	[a]
Control	31.3	3.6	59.3	6.3	+89.5	0.000[†]	

*Treatments with p-value less than 0.05. [†] Significant increase in *Typha* percent cover

[a] Wilcoxon signed-ranks test statistic = 36.0

Sedge/Grass

Carex lacustris and *C. canadensis* were also the primary sedge/grass meadow species present in the Cattail Zone. *Carex lacustris* was found in every treatment block, while *C. canadensis* was randomly distributed in the study area and did not occur in every block. The mean percent cover of *C. lacustris* was 3.8% in pre-treatment July 2010 and increased to 18.4% in post-treatment August 2011 ($T = -6.956$, $p = 0.001$) in those treatments that showed a significant reduction in *Typha* percent cover. In treatments with no significant decrease in *Typha* cover, the mean cover of *C. lacustris* increased from 3.8% in 2010 to 17.5% in 2011 ($T = -6.157$, $p = 0.012$). In control plots, the mean cover of *C. lacustris* increased from 3.3% to 12.8% from July 2010 to August 2011. In treatments with significant *Typha* reduction, the mean cover of *C. canadensis* increased from 4.6% in 2010 to 10.8% in 2011 ($T = -3.192$, $p = 0.024$), while in treatments with no *Typha* reduction, it increased from 2.7% in 2010 to 8.2% in 2011 ($T = -4.392$, $p = 0.002$). In the control plots, *C. canadensis* increased from 11.7% to 15% mean cover from July 2010 to August 2011.

Environmental Conditions

Levels in the water-table wells tracked gauged Lake Ontario water levels (NOAA 2012) and also followed the pattern shown in the Meadow Zone. In 2010, median soil moisture ranged from 72.3% in drier block 3 to greater than 99% in blocks 2 and 5. In wetter 2011, median soil moisture ranged from 90.6% in block 3 to 100% in blocks 2 and 5. For both years, block 3 was likely the cause for significant differences in soil moisture among the five treatment blocks (Kruskal-Wallis: 2010 $H_4 = 29.25$, $p = 0.000$; 2011 $H_4 = 16.3$, $p = 0.003$).

Sediment depth to clay differed significantly (ANOVA: $F_4 = 170.12$, $p = 0.000$) among the five treatment blocks, ranging from 36 to 37 cm at blocks 1 and 3 to 63 cm at block 4 and 73 cm at block 5. Mean soil bulk density in block 3 (0.38 g/m^3) was significantly greater than in the other blocks (0.12 to 0.24 g/cm^3) (ANOVA: $F_4 = 18.96$, p = 0.003). Although there were differences among blocks for percent organic matter, ranging from 20.8% in block 3 to 23.4–59.7% in the other blocks, they were not significant.

Discussion

Our objectives were to test cattail-control methods tested or suggested by others but adapted for hydrologic and environmental conditions present in Lake Ontario wetlands, which include winter low and summer high lake levels, inability to control water levels, floating cattail mats along the waterward edge, adjacent developed lands, and the presence of sedge/grass meadow species among the cattails. Cutting or mowing in June–July was tested by Nelson and Dietz (1966), Weller (1975), Linde et al. (1976), and Beule (1979); Lawrence et al. (2016) and Elgersma et al. (2017) later tested cutting also. Those studies generally found that lasting effectiveness required secondary treatments, such as herbicide application (Nelson and Dietz 1966; Weller 1975; Elgersma et al. 2017) or tilling/discing (Wilcox and Ray 1989; Kostecke et al. 2004). We designed our studies around their methodologies and conclusions, and we base our treatment recommendations on evaluation of the effectiveness of our results, as suggested by significance of treatment combinations shown in Tables 2, 3, 4, and 5.

Most Effective Treatment Combinations

Reduction of *Typha* stems and percent cover was dependent on the combination of treatments, but some general observations can be made. In the Meadow Zone, the treatments in which glyphosate was applied by wicking the regrowth of *Typha* ramets in late summer of one or both years were generally the most successful (Tables 2 and 3). In the Cattail Zone, wicking seemed to be the most important treatment as well, as it was included in every treatment combination that significantly reduced *Typha* stems and in all but one combination that reduced *Typha* cover (Tables 4 and 5). More importantly, the wick treatment combined with cutting was the only treatment that significantly reduced *Typha* stems without other secondary treatments (i.e., spraying or tilling). In the Meadow Zone, some combinations of cutting and wicking significantly reduced *Typha* stem counts (C1W1, C1W12, C12W12) and *Typha* cover (C1W12, C12W1, C12W12). Combined cutting and wicking was also effective in the Cattail Zone, where C1W1 reduced *Typha* stems, and C12W1 reduced cover. Although C12W1 also reduced stem counts in both zones, the results were not significant. The wicking treatment was applied in late summer, thereby allowing the herbicide to be absorbed by the plant and eventually into the rhizomes. For effective control, Cole (1985) noted the importance of applying herbicides later in the year, which is when cattails are actively metabolizing and transporting carbohydrates to their rhizomes. Herbicide has been shown to be effective in previous modeling and field studies (Lawrence et al. 2016; Elgersma et al. 2017).

Less Effective Treatment Combinations

Treatments involving only cutting in year 1 (C1) or cutting and spraying in year 1 (C1S1) were not successful in reducing either *Typha* stem counts or percent cover and even resulted in increases of both in the Cattail Zone. The increase is likely because cutting did not stress the rhizome and may only have

served to increase sunlight penetration. Spraying was ineffective because, during early summer, *Typha* is not re-establishing carbohydrate reserves in the rhizomes. Treatments C12 and C12S12 were not effective in the Cattail Zone, but the second year of treatment did reduce *Typha* in the Meadow Zone, so perhaps a second year of cutting was more effective at slightly drier elevations.

In the Cattail Zone, the tilling treatment, combined with the other treatments, had variable success at reducing *Typha* stems and cover but was effective only when applied in combination with wicking. An individual *Typha* genet may be several square meters in size (Travis et al. 2010, 2011). Therefore, any treatment method that targets only individual *Typha* ramets or fails to isolate treated rhizomes is not likely to be effective. In this study, T-treatment tilling was conducted blindly by feeling for rhizomes with a trenching shovel and then slicing the rhizome around each ramet. In most cases, the rhizome surrounding an individual ramet was isolated, but likely not in all cases. Cutting cattail ramets in the C treatment may only have affected a fraction of the larger *Typha* organism that could extend well beyond the treatment plots via the extensive rhizome system. The uncut stems outside the plots are part of the larger *Typha* genet and supply carbohydrates to the rhizome system.

Outlier Treatment Combinations

Despite the apparent importance of the wicking treatment, several treatment combinations that did include wicking failed to reduce *Typha* stem counts and/or cover significantly in one or both of the zones, perhaps because individual replicate blocks showed little or no response due to environmental conditions. For example, Meadow Zone block 5 was slightly higher in elevation than the other blocks, and cattails were initially less dense all across block 5 in response to the lower soil moisture (Wilcox et al. 2008). Thus, there were fewer regrowth *Typha* ramets to wick with herbicide, and the underlying rhizomes, which could extend beyond the treatment plots, were not treated as effectively. Block 5 showed no significant reduction in *Typha* stems across all treatment combinations in the Meadow Zone. In the Cattail Zone, block 2 was slightly lower in elevation and had increased percent soil moisture, which apparently affected treatment efficacy. Across all treatment combinations in the Cattail Zone, block 2 showed no significant reduction in *Typha* stems.

Sedge/Grass Response

Reduction in percent cover of *Typha* leads to the expectation of increases in percent cover of sedge/grass meadow species at a site such as Kents Creek. In the Meadow Zone, *Carex lacustris* decreased and *Calamagrostis canadensis* increased in plots of all treatment combinations and control plots, suggesting that the resultant habitat following pre-study cutting of standing dead *Typha* favored *Calamagrostis* (Costello 1936; Ashworth 1997). In the wetter Cattail Zone, *C. lacustris* increased substantially in plots of all treatments and controls, and *C. canadensis* increased moderately. These results in both zones suggest that, rather than treatments, the positive response of sedge/grass meadow species was related to opening of the canopy during preliminary cutting and removal of cattail litter to set up the study (van der Valk 1986; Farrer and Goldberg 2009; Vaccaro et al. 2009; Hall and Zedler 2010). *Carex lacustris* was favored under wetter conditions in the Cattail Zone (Ashworth 1997; Yetka and Galatowitsch 1999).

Treatment Recommendations

The findings of this study suggest the possibility of an effective treatment for *Typha* control in Lake Ontario wetlands and other applicable locations where water-level manipulation is not possible. Cattail litter from previous years' growth should first be reduced prior to the growing season to open the canopy for sedge/grass species. New cattail ramets should then be cut when carbohydrate reserves in rhizomes are minimized (late June to early July) and followed with wicking of the resprouted stems with herbicide in late August to early September. The cutting and wicking treatments should be implemented for at least two consecutive years. If funds and/or personnel are available, follow-up application of cutting and wicking treatments in additional years to reduce or eliminate surviving cattails would be advisable. The spray treatment and tilling do not seem effective without wicking and are not recommended.

Treatments performed on small scales, such as in this study, are feasible with a small group of workers; however, all *Typha* stems must be treated to ensure that the entire genet is targeted, rather than just a few ramets of the larger organism. Cutting with a steel-blade trimmer is labor- and time-intensive, but it is the most effective way to cut cattails without heavy machinery that is often impractical in saturated/inundated conditions.

In larger areas, cattail litter could be mowed in winter using a tractor on substantial, thick ice; in spring, a brush-hog attached to a long-arm excavator operating on mats made from railroad ties could be used. Controlled burns are another option in areas with acceptable adjacent land use and adequate access for control equipment and personnel (Ponzio et al. 2004; Tian et al. 2010). To cut new growth of cattails in summer, a Marshmaster © tracked-amphibious vehicle equipped with a brush hog can mow in places a conventional tractor cannot go. Wicking of *Typha* with glyphosate (Rodeo) should only be done by hand if other native vegetation is present. In *Typha* stands lacking native understory vegetation, herbicide could be applied to resprouted cattails with backpack sprayers. For large monocultures of *Typha*, the Marshmaster can be

equipped with spraying equipment to apply herbicide more quickly.

In anticipation of the new Plan 2014 for regulation of Lake Ontario water levels (IJC 2014) that was approved in December 2016 and went into effect in January 2017, large wetland restoration projects on NYS Department of Environmental Conservation lands on the south shore of the lake were initiated using these methods. The restoration areas were 6.5, 1.7, 4.25, and 1.7 ha in size. Equipment used consisted of brush hogs, long-arm excavators, a Marshmaster, and steel-blade trimmers. Herbicide was hand-wicked under contract by an approved herbicide-application firm within a few days at each site. Post-treatment data collection at all of these restoration sites is on-going. Conclusions drawn from this study and these on-site applications will provide land managers with a cattail-management strategy that may effectively reduce the size and density of cattail stands that have taken over Lake Ontario wetlands and should aid in restoration of sedge/grass meadow communities that have been lost (Wilcox et al. 2008). Cattail invasion is rampant in wetlands throughout the Great Lakes (e.g., Friezwyk et al. 2007; Frieswyk and Zedler 2007; Lishawa et al. 2010) and elsewhere (Galatowitsch et al. 1999), so this strategy may have very broad applications.

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