OFFICE OF REALTY AND ENVIRONMENTAL PLANNING

STATE OF ILLINOIS

FINAL REPORT

PROJECT NUMBER T-34-I-1

PROJECT TITLE Hennepin & Hopper Lakes Wetland Restoration and Research Project

OVERVIEW

The purpose of this project was to conduct research on how best to manage wetland invasive species *in the early stages of large-scale wetland restorations*. Our goal was to investigate management strategies for large-scale restorations that would put them on a developmental trajectory leading to a native and biologically diverse wetland flora. We evaluated different strategies for controlling the spread of eight species and one hybrid that can be extremely invasive: broad-leaved cattail (*Typha latifolia*), narrow-leaved cattail, (*T. angustifolia*), hybrid cattail (*T. x glauca*), common reed grass (*Phragmites australis*), reed canary grass (*Phalaris arundinacea*), purple loosestrife (*Lythrum salicaria*), eastern cottonwood (*Populus deltoides*), sandbar willow (*Salix interior*), and black willow (*Salix nigra*). The results of this investigation are being applied to the remaining wetlands on the Hennepin & Hopper Lakes site. The results of this study are also being prepared for submittal to a peer-reviewed journal.

Large-scale wetland restorations present significant challenges that do not apply to smaller scale projects, and in particular that of managing invasive species. Such projects are particularly vulnerable to invasion in the early stages of development, and standard management practices can prove as lethal to the developing natives as they do to the invasive targets (Moore et.al. 1999, Levine 2000). Without effective invasive control, such restorations can develop into monotypic or low diversity communities dominated by a few invasives (Wilson and Mitsch 1996, Kentula 2000). We are challenged with determining how best to manage such systems in order to promote the development of biologically diverse and native-dominated wetlands.

We hypothesized that early in development, such systems are at a tipping point between alternative stable states: one where the system is dominated by invasive species and one where the system is dominated by a diverse community of relatively conservative native species. Assembly rules theory as applied to restoration ecology suggests that it is critically important to develop community establishment trajectories that will achieve the desired restoration target (Temperton et. al. 2004). Although much work has been done in the past on wetland invasive management, and in particular on cattail control, no single or simple strategy has emerged to protect wetlands from being overrun by invasives short of ongoing, massive applications of herbicides or through a program of cutting and drowning by manipulating water levels for up to three years (Harris and Marshal 1963, Newman et.al. 1996, Ailstock et.al. 2001, Foster and Wetzel 2005). However, these strategies provide impractical solutions for large-acreage sites where invasives are interspersed with conservative native species.

In the 294 hectares of restored wetlands at the 1,117-ha Hennepin & Hopper Lakes Restoration Project (HHL; Figure 1), invasives have been competing with the more conservative native species since major restoration activities were concluded in 2003. When we began this study, much of the HHL wetland complex was at the tipping point between the two alternatives referenced above –biologically diverse wetlands supporting a diversity of wildlife, vs. a species poor mixture of exotic and/or native invasives with little wildlife habitat value. Because standard methodologies to accomplish this goal on a large scale – eliminating invasive impacts while promoting biological diversity - do not exist, there was a critical need to examine different strategies that may be applied at this and other sites to insure that developing wetland restorations fulfill their extraordinary potential.

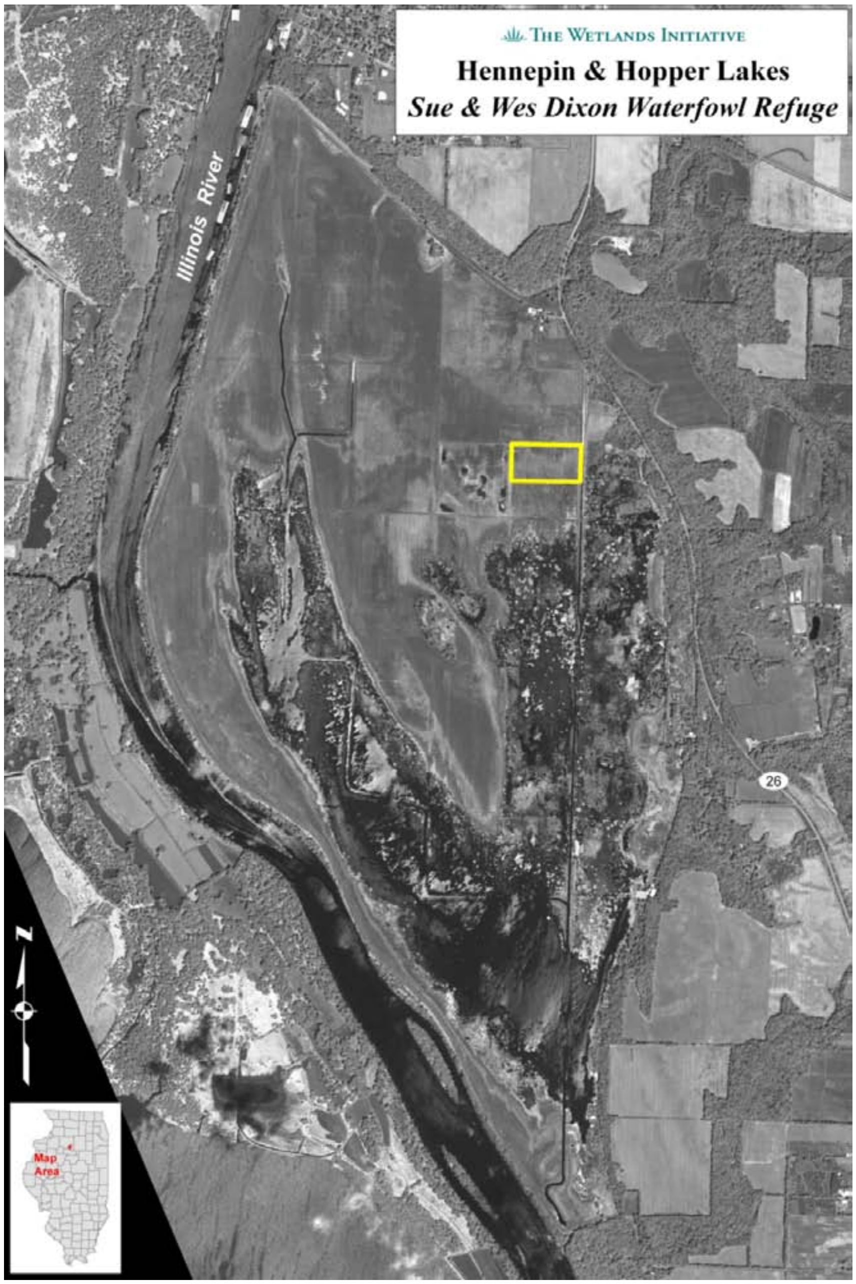

Figure 1. The 1,117-ha Hennepin & Hopper Lakes Restoration Project at the Sue & Wes Dixon Waterfowl Refuge south of Hennepin, IL on the east shore of the Illinois River. The 9.0-ha experimental treatment area at the north end of Hopper Lake is outlined in yellow.

METHODS

All research took place at the 1,117-ha Hennepin & Hopper Lakes Restoration site in north-central Illinois. The experimental work was conducted within a 9.0-ha (~22-acre) section of wetland bordering the north end of Hopper Lake (Figure 2). The experimental area consisted of two 3,000-m^2 experimental units (EU's) and an 8.4-ha experimental wetland testing area subdivided into seven experimental testing zones (EZ's). The two EU's were located on the ground in April 2007 in areas with a relatively even distribution of invasive species interspersed among a developing native wetland flora. The EZ's varied in size and shape based on local topography, hydrology, and species composition. Each EU and EZ was characterized at that time by the primary dominant invasives: either cattails or invasive woody vegetation. EU-1 was characterized by the presence of three tree species (*Populus deltoides*, *Salix interior*, and *Salix nigra*) growing in relatively high density (~3 individuals / m^2) among the grasses, sedges, and forbs typically found in a central Illinois wet meadow community. Tree height at that time varied between 30 and 220 cm (mean ht. ~130 cm). EU-2 was characterized by three cattail species (*Typha latifolia*, *Typha angustifolia*, and *Typha x glauca*) growing in relatively high density (>75% cover) among graminoids and forbs typically found in a central Illinois marsh / meadow community. Since overlapping phenotypes among the various cattails (two species and the hybrid) made field identification nearly impossible, no attempt was made to distinguish among them in the field and they were treated as a single species. These invasive species could be found in either community type, with reed canary grass, common reed grass, and/or purple loosestrife occurring primarily in the wet meadow.

Herbicide application was conducted by licensed aquatic-label herbicide applicators. The herbicide applied by wicking was 33% aquatic label Glyphosate with a dye. The herbicide painted on stumps was 100% aquatic label Glyphosate. Herbicide was applied with a wick applicator in order to maximize coverage with minimal effect on the non-target and desirable native species. Since our ultimate goal was to influence community development, i.e., determine if an invasive community can be managed or eliminated in a manner that allows development of co-occurring native species, we decided to focus on wick application in order to selectively target invasives while avoiding natives. Cutting trees and applying herbicide to the stumps was tested as an alternative to wick application. We also planted plugs among EU experimental plots to test the impact of diversity on resistance to reinvasion. Diversity was enhanced across the EZ's by the planting of seed in the fall of project year 1 and 3.

The 8-foot long wick was constructed of 1-inch PVC pipe with a 1x1x¾-inch inlet tee located in the middle (4 feet from either end). Twelve 3/32-inch holes were drilled into the pipe at 8-inch intervals. The pipe was strengthened by attaching a 10-foot long, 1¼-inch dowel to the pipe with zip ties. Cotton fabric was wrapped loosely around the pipe with a 6- to 8- inch length hanging down to drape across vegetation as the wick was applied. Herbicide was pumped into the wick inlet from a back-pack sprayer and allowed to drip out of the holes onto the cotton fabric at a rate to maintain a saturated cotton wick. A two-person crew, one person on each end, walked the unit through the vegetation being wicked at a pace that transferred herbicide onto target vegetation at a rate similar to that at which it was leaving the pipe. The most effective walking rate was one that transferred herbicide to the vegetation while maintaining the cotton fabric in a saturated condition. The wick would be refilled by hand pumping as levels ran low, and the wick would be run over the vegetation until it ran out of herbicide, i.e., pumping would cease prior to the end of a run so that herbicide in the wick could be exhausted at the point the run was completed.

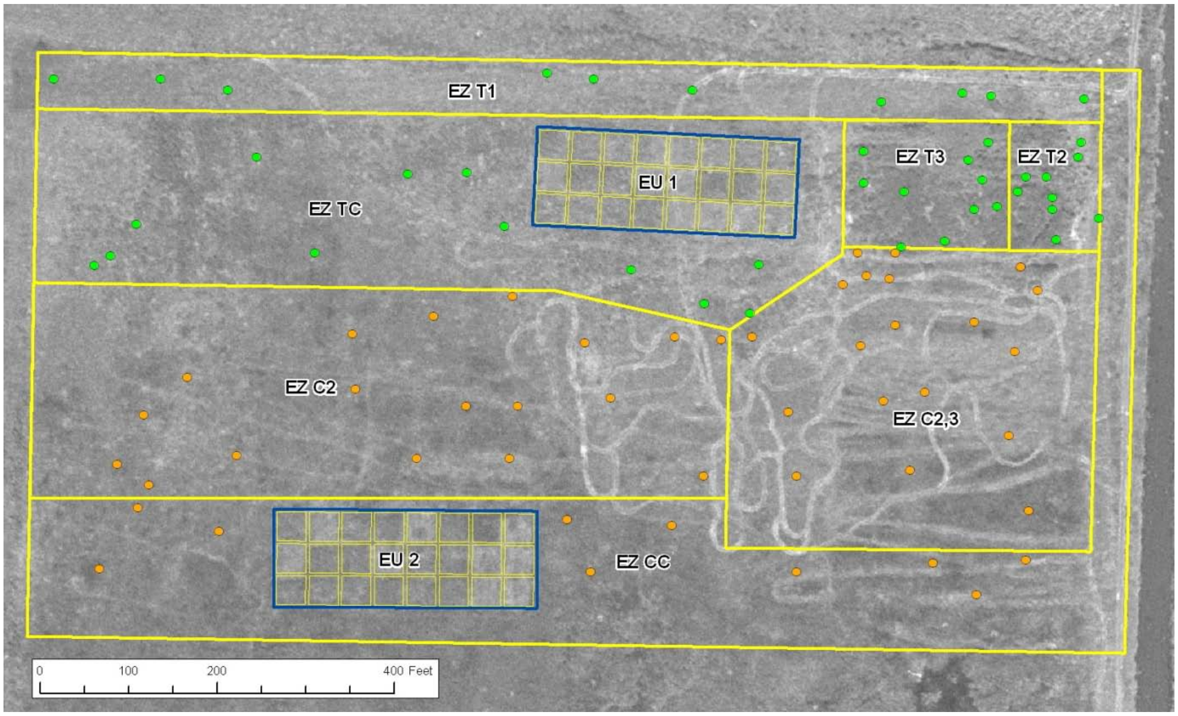

Figure 2. The 9.0-ha experimental area is comprised of two 3,000-m^2 experimental units (EU-1 and EU-2) and seven experimental testing zones (Table 1). The two EU's are comprised of 24 100-m^2 plots. In the experimental zones, randomly-located 1-m^2 sampling quadrats are designated by either green points (in tree zones) or orange points (in cattail zones).

Table 1. Subdivisions of the 9.0-ha experimental area (Figure 2) with map labels, dominant invasive group, and management treatment tested (experimental testing zones). For factorial experiment treatments, see Table 2.

Experimental Area	Map Label	Area (ha)	Primary Invasives Found	Treatment
experimental unit 1	EU-1	0.307	trees	3-year 2x3 factorial experiment
experimental unit 2	EU-2	0.306	cattails	3-year 2x3 factorial experiment
experimental zone	EZ-T1	0.692	trees	wick trees year 1
experimental zone	EZ-T2	0.139	trees	cut trees and paint stumps year 2
experimental zone	EZ-T3	0.252	trees	cut trees and paint stumps year 3
experimental zone	EZ-TC	1.403	trees	untreated tree control
experimental zone	EZ-C2	1.697	cattails	wick cattails year 2
experimental zone	EZ-C2,3	1.250	cattails	wick cattails years 2 & 3
experimental zone	EZ-CC	1.573	cattails	untreated cattail control

Experimental Units 1 and 2

The 3,000-m^2 experimental unit 1 (EU-1) is located in the northeast quadrant of the 9.0-ha experimental area at the north end of Hopper Lake, while EU-2 is located in the southwest quadrant of the experimental area (Figures 1, 2). The EU's were each divided into 24 100-m^2 plots (each 10m x 10m) with 1m-wide mowed buffering pathways. Six treatment combinations were replicated 4-fold and randomly assigned among the 24 plots in each 2 x 3 fully crossed factorial design. Planted and unplanted treatments were crossed with zero, one, and two years of selective herbicide treatment through wick application (Table 2).

Table 2. Factorial experimental design in each of the two 3,000-m^2 experimental units. Each of the six treatment combinations were replicated four times in the 2 x 3 fully crossed fixed factor design.

		Years of Wick Herbicide Application		
		0	1	2
Enhanced Diversity	Y	Y0	Y1	Y2
	N	N0	N1	N2

The invasives found in EU-1 were primarily cottonwood and willows (sandbar and black), with lesser coverage by cattails (broad-leaved, narrow-leaved, and hybrid), purple loosestrife, common reed grass, and reed canary grass. The invasives in EU-2 were primarily cattails (broad-leaved, narrow-leaved, and hybrid), with much lesser coverage by common reed grass and sandbar willow. The plots scheduled for one or multiple years of herbicide treatment were wick-treated in a single application in June of year 1. Plugs of 15 species were planted across the plots beginning in June of year 1 (Table 3). The plots scheduled for multiple years of herbicide treatment were wick-treated in June of year 2.

Table 3. Species planted as plugs in experimental units EU-1 and EU-2 to enhance diversity in year 1 of the experiment.

Species	EU-1	EU-2
Acorus americanus		X
Asclepias incarnata	X	
Carex aquatilis		X
Carex atherodes	X	X
Carex comosa	X	
Carex lacustris	X	
Carex pellita	X	
Cicuta maculata		X
Iris virginicus	X	
Scirpus acutus		X
Scirpus pungens		X
Sium suave	X	X
Sparganium eurycarpum		X
Spartina pectinata	X	
Vernonia fasciculata	X	

Wetland Experimental Zones

The 8.4-ha wetland experimental treatment area was divided into seven experimental zones: a year 1 tree wicking zone, a year 2 tree cutting and stump painting (N-(phosphonomethyl) glycine: glyphosate) zone, a year 3 tree cutting and stump painting zone, a tree control or untreated zone, a 1-year (year 2) cattail wicking zone, a 2-year (years 2 and 3) cattail wicking zone, and a cattail control or untreated zone (Table 1). Approximately 1.0 ha of the cattail control experimental zone EZ-CC was not sampled in 2008 or 2009 due to higher than anticipated water levels associated with elevated ground water inputs from greater than average rainfall and increased river levels throughout much of this period.

Invasive treatment by wick application followed the techniques that were tested in the experimental units. To provide an alternative treatment method for comparison, we cut trees and painted their stumps with herbicide, a potentially more effective method, but also more man-hour intensive. In order to enhance diversity and inhibit reinvasion within the treated areas, those with sufficient open space were seeded with a diverse mix of native wetland species in January of year 2 and December of year 3 (Table 4).

Table 4. List of species seeded in January 2008 and December 2009.

2008	2009	2009
Aster novae-angliae	*Acorus americanus*	*Eleocharis acicularis*
Carex crinita	*Agalinis tenuifolia*	*Hibiscus lasiocarpus*
Carex frankii	*Asclepias incarnata*	*Hypericum virginicum*
Carex lupulina	*Aster furcatus*	*Iris virginica shrevei*
Carex lurida	*Aster prealtus*	*Juncus nodosus*
Carex typhina	*Aster puniceus*	*Lathyrus palustris*
Chelone glabra	*Aster umbellatus*	*Lobelia siphilitica*
Decodon verticillatus	*Bromus ciliatus*	*Lobelia spicata*
Eleocharis palustris major	*Cacalia suaveolens*	*Lysimachia quadriflora*
Elymus virginicus	*Carex annectans*	*Lythrum alatum*
Iris virginica shrevei	*Carex crinita*	*Mentha arvensis villosa*
Liatris ligulistylis	*Carex frankii*	*Mimulus ringens*
Liatris spicata	*Carex granularis*	*Oxypolis rigidior*
Lobelia cardinalis	*Carex intumescens*	*Penstemon hirsutus*
Lobelia siphilitica	*Carex lacustris*	*Phlox glaberrima interior*
Penstemon digitalis	*Carex lurida*	*Physostegia angustifolium*
Physostegia virginiana	*Carex pellita*	*Pycnanthemum tenuifolium*
Pontederia cordata	*Carex retrorsa*	*Ranunculus hispidis*
Rudbeckia subtomentosa	*Carex squarrosa*	*Rudbeckia speciosa*
Scirpus cyperinus	*Carex stricta*	*Saxifraga pennsylvanica*
Solidago riddellii	*Carex tribuloides*	*Scirpus microcarpus*
Sparganium americanum	*Carex trichocarpa*	*Solidago flexicaulus*
Sparganium eurycarpum	*Chelone glabra*	*Spiraea tomentosa*
	Cicuta maculata	*Verbena hastata*

Data Collection

For each experimental unit (EU), data was collected beginning in June of year 2 and year 3. Each EU was divided into 24 treatment plots, with five $1m^2$ randomly located quadrats sampled in each plot (120 quadrats sampled per EU). For each plot, the outer perimeter (1 m in from the outer edge) was not sampled in an attempt to eliminate edge effects. Quadrats ($1m^2$) were also randomly located and sampled within each experimental zone (EZ). Quadrat locations for each EZ were determined by randomly choosing $1m^2$ cells in a GIS grid layer of each EZ (ArcMap 2009). Since community composition was not uniform with respect to the mix of invasives and desirable native species everywhere across the somewhat heterogeneous experimental area, quadrats could not be randomly located within the entire area of each experimental zone. Consequently, the number of quadrats sampled in each experimental zone varied based upon its size and the number of quadrats rejected in the field as inappropriate, ranging from 9 to 12 quadrats sampled among the zones being treated for invasive trees, and from 14 to 20 quadrats among the zones being treated for cattails.

For each quadrat, the presence of each species and its individual aerial cover was recorded. Cover was visually estimated and assigned to one of six cover classes (Table 5). Two observers identified species within each quadrat, with one observer (Gary Sullivan) estimating cover for all quadrats sampled over the two year sampling period.

Table 5. Cover classes were used to estimate the cover of individual species within each quadrat sampled. The cover value was the percent cover used for each species to calculate total cover, and for all statistical analyses.

Cover Class	1	2	3	4	5	6
Cover Range	>0% and ≤5%	>5% and ≤25%	>25% and ≤50%	>50% and ≤75%	>75% and ≤95%	>95% and ≤100%
Cover Value for Analyses	2.5%	15%	37.5%	62.5%	85%	97.5%

Statistical Analysis

For each of the experimental units, the results were analyzed to determine how plant communities under each treatment regime developed, particularly in regard to invasive cover, native cover, total cover, total richness, and the richness of desirable species. Differences among treatments were assessed through multifactorial analysis of variance (SYSTAT 2004). Differences between each level of herbicide treatment were assessed through Tukey's pairwise multiple comparisons utilizing the error mean square.

Differences among experimental zones were tested with one-way analysis of variance. Differences between individual experimental zones were assessed through Tukey's pairwise multiple comparisons utilizing the error mean square.

Milestones by Project Year

Project Year 1 (May 1, 2007 – April 31, 2008):

1. Conducted initial vegetation survey May 2007 to assess the distribution and relative density of invasives and to determine the location of experimental units at the north end of Hopper Lake.
2. Layout of two 3,000m^2 experimental units; each unit subdivided into 24 100m^2 experimental plots (4,800m^2 in total).
3. Randomly assigned treatments within experimental units based on a 2 x 3 fully crossed factorial design (planted and unplanted crossed with herbicide application in year 1, years 1 and 2, and in no years).
4. Applied herbicide by wick to the 8 100m^2 planted and 8 100m^2 unplanted treatment plots in each experimental unit beginning in May 2007.
5. Applied herbicide by wick to experimental zone EU-T1 in the 8.4-ha experimental area beginning in May 2007.
6. Installed plugs in the 12 plots to be planted in each experimental unit with native species beginning June 2007.
7. Planted plugs of native species across the wetland experimental zones beginning in June 2007.

8. Planted seed of native species in herbicided openings in the wetland restoration experimental zones in January 2008.
9. Burned plots March 2008 to remove standing vegetation.

Project Year 2 (May 1 2008 – April 31, 2009):

1. Applied herbicide by wick to the 8 multi-year treatment plots in each experimental unit (4 planted and 4 unplanted) beginning in May 2008.
2. Applied herbicide by wick to experimental zones EU-C2 and EU-C 2,3 in the 8.4-ha experimental area beginning in May 2008.
3. Conducted a species richness and cover survey of each plot in August 2008. Five randomly located 1m^2 quadrats were surveyed in each of the 24 treatment plots in each experimental unit (240 1m^2 quadrats sampled).
4. Cut trees and applied herbicide to the stumps in experimental zone EU-T2 in the 8.4-ha experimental area in December 2008.
5. Burned plots March 2009 to remove standing vegetation.

Project Year 3 (May 1, 2009 – December 31, 2009):

1. Applied a second year of herbicide by wick to experimental zone EU-C 2,3 in the 8.4-ha experimental area beginning in May 2009.
2. Conducted a species richness and cover survey in each of the 240 previously surveyed 1m^2 quadrats in August 2009.
3. Conducted a species richness and cover survey throughout all EZ's within the 8.4-ha experimental area beginning August 2009.
4. Planted seed of native species in herbicided openings in the wetland restoration experimental zones in December 2009.
5. Analyzed data for publication through December 31, 2009.
6. Submitted final report by March 31, 2010.

RESULTS AND DISCUSSION

The treatments were designed to evaluate differences in the response of invasive and native plant species to 1) the number and timing of herbicide wicking treatments (treatment in a single year vs. treatments in multiple years); 2) post-treatment community development with and without additional native species planted; and 3) the ability to translate experimental results to a large-scale wetland restoration. The results have already been used to develop a treatment strategy for managing the remaining complex of wetlands in the untreated areas surrounding Hennepin & Hopper Lakes.

All year 1 wicking activities were completed by the end of June 2007 in the experimental units (EU-1 and EU-2) and the tree-wicking experimental zone (EZ-T1). Cattails and trees began to wilt and turn brown within a few weeks. Based on visual observation, more than half of the cattails were affected and nearly all of the taller woody vegetation. It appeared that many of the shorter trees and cattails were not exposed to the wick due to lower stature. Conversely, some of the taller graminoids were unavoidably exposed to the wick due to their greater stature. Richness was enhanced by planting plugs of additional species by mid-summer 2007. The shorter cattails eventually grew to full size within the 2007 growing season and filled some of the space created by dying cattails. The shorter trees were less apparent in 2007, but had grown from 2 to 3 feet in additional height by spring 2008.

All year 2 wicking and tree removal activities were completed by mid-summer 2008. The trees missed in 2007 due to low stature appeared to have been successfully wicked in 2008 after having grown up to a susceptible height. The EU-2 cattail plots were subjected to higher water levels in 2008 due to greater than average precipitation throughout the spring and summer. The entire experimental unit was subject to water depths ranging from 6 to 16 inches in 2008, an increase from 2007 when water depth ranged from saturated soil to 8 inches depth. Some of the vegetation planted in the cattail plots in 2007 was lost in 2008 due to the extended period of inundation. All year 3 wicking and tree removal activities were completed by mid-summer 2009. Although data was collected within the experimental plots in 2008, only the results of the 2009 data analysis is reported below as that data better reflects the response of community development to the invasive management actions undertaken.

Experimental Unit 1

Strong differences among treatment plots in response to wicking woody vegetation were apparent by September 2009 (Figure 3). Significant differences in tree cover developed among the three treatments, where tree cover in the untreated plots exceeded 120%, while it was intermediate in the plots wicked only in 2007 (mean cover ~50%), and less than 2% in the plots having two years of wicking (Figure 4A, Table 6). Nearly all trees exposed to wicking were killed, but it was not possible to wick all trees as some were either too short, or they were protected from the wick by adjacent woody vegetation. A second round of wicking successfully eliminated nearly all of the remaining woody vegetation as it had grown tall enough to be exposed, or it was no longer guarded by other stems.

The decrease in woody vegetation in response to wicking was associated with a significant increase in forb cover (Figure 4B, Table 6). Forb cover in the plots with one year of wicking was greater than in the untreated plots, and it was greater in the plots with two years of wicking than in the plots with just one year of wicking. Greater forb cover was likely due to both a decrease in woody vegetation in the treated plots (increased forb cover in response to decreased shade in newly open plots), and the negative impact of shading in those plots with remaining tree cover (decreasing forb cover).

Despite the increase in forb cover associated with wicking woody vegetation, there was a significant decrease in total cover (forb plus woody vegetative cover) between the untreated plots and those having 2 years of wicking treatment (Figure 4C, Table 6). This suggests that forb and woody cover is not additive, i.e., the decrease in woody cover was not compensated with an equivalent increase in forb cover. Moreover, it is likely that forb cover would decrease further in time in response to increased shading in the developing tree canopy.

There were no differences among tree wicking treatments in overall species richness, indicating that richness did not increase where trees were either thinned or removed, and/or that richness did not decrease where a closed canopy was developing to shade out the understory (Figure 4D, Table 6). However, there was a significant increase in forb richness in response to the wicking treatments (Figure 4E, Table 6). Forb richness increased between the untreated plots and those receiving two years of wicking, and between those plots receiving one and two years of wicking. This appears to be due to the loss of forb species in those plots being shaded by trees.

Although one of our primary questions was whether the spread or impact of invasive species could be reduced or eliminated by increasing the diversity of native species, differences among plots where richness was enhanced by planting additional species were not significant (Table 6). However, forb cover and total cover were greater in the richness enhanced plots receiving one year of wicking, and less in the richness enhanced plots with two years of wicking (a significant treatment x planting interaction, Table 6). This suggests that forb cover may be negatively affected by occasional unintended herbicide contact (personal observation), but that forb cover may rebound and eventually increase in response to the positive effects of invasive tree loss. Since all of the species planted were observed in at least some of the plots, the lack of difference between the planted and unplanted plots suggests the overall density and distribution of the introduced species among plots may have been relatively low. If enhanced diversity or richness

A)

B)

Figure 3. Photos taken 09 September 2009 of EU1 plots having A) 2 years of tree wicking (foreground) and 1 year of wicking (background), and B) 2 years of treatment (foreground) and 0 years of treatment (background). The view in A is into the 1-year wicking plot, while the view in B is the corner of a control plot with another control plot in the far background.

is going to have a positive impact on community development (decreased invasive persistence or reinvasion potential), it may take more than 2 or 3 years for this effect to become apparent as these species may need more time to spread throughout an already developing community.

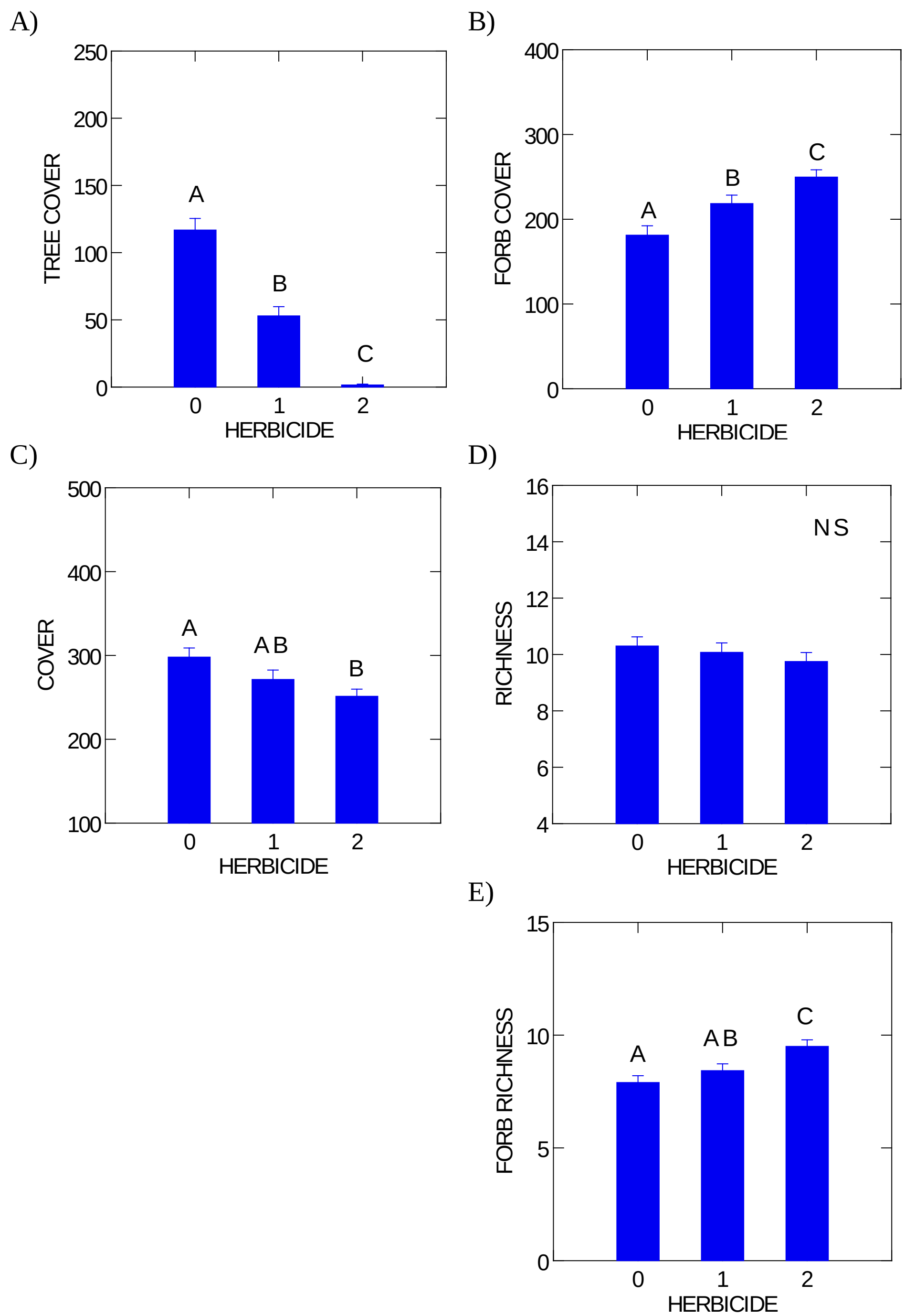

Figure 4. Effects of zero, one, and two years of wicking trees in experimental unit EU-1 in the third year of the experiment (2009), reporting means + 1 s.e. for A) tree cover, B) forb cover, C) cover, D) richness, and E) forb richness. Bars sharing no letters in common differ significantly from each other (Tukey's multiple comparisons, $\alpha < 0.05$). See Table 6.

Table 6. Results of the two-factor analysis of variance crossing herbicide treatment with richness enhancement (planting) in the tree management plots in experimental unit EU-1. Results of the Tukey's multiple comparisons on the number of years of herbicide wicking were calculated using the error mean square. α = 0.05, DNT = did not test.

Tree Management Plots (EU-1) Two-Factor ANOVA					Tukey's Multiple Comparison *P*		
Source of Variation	**df**	**MS**	***F***	***P***	**0 - 1**	**1 - 2**	**0 - 2**
Tree Cover							
Herbicide Treatment	2	133,346.46	83.64	0.000	0.000	0.000	0.000
Richness Enhancement	1	762.55	0.48	0.491			
H x R	2	1,630.83	1.02	0.363			
error	114	1,594.37					
Forb Cover							
Herbicide Treatment	2	47,125.68	13.54	0.000	0.015	0.050	0.000
Richness Enhancement	1	2,167.50	0.62	0.432			
H x R	2	26,687.97	7.67	0.001			
error	114	3,479.61					
Cover							
Herbicide Treatment	2	21,940.78	5.66	0.005	0.140	0.324	0.003
Richness Enhancement	1	358.80	0.09	0.762			
H x R	2	20,878.18	5.38	0.006			
error	114	3,878.28					
Richness							
Herbicide Treatment	2	3.06	0.72	0.488	DNT	DNT	DNT
Richness Enhancement	1	0.08	0.02	0.894			
H x R	2	2.58	0.61	0.547			
error	114	4.24					
Forb Richness							
Herbicide Treatment	2	26.61	7.55	0.001	0.426	0.031	0.001
Richness Enhancement	1	0.41	0.12	0.734			
H x R	2	2.56	0.73	0.486			
error	114	3.53					

Experimental Unit 2

Significant differences in cattail cover developed in response to the herbicide wicking treatments (Figure 5A, Table 7). Cattail cover in the untreated plots was nearly 95% in 2009, while it was approximately 66% in the plots treated for just one year (2007) and slightly less than 50% for the plots treated for two years (2007 and 2008). Although differences among the treatments were strong, cattails were not only unable to be eliminated, they appear able to at least partially recover given sufficient time. Since cattails grow relatively tall early in the growing season, wicking took place beginning in late spring so that they would be treated before other, desirable vegetation grew tall enough to be impacted. Although a high percentage of the wicked cattails died in response to treatment, a number of shorter, late emerging shoots were not impacted due to their shorter stature. Despite apparent belowground rhizomatous connections with the dying shoots, the unimpacted shoots eventually developed into a spreading rhizomatous, reproductive individual. It remains to be seen whether the cattails treated twice will eventually recover to the levels observed in the untreated plots, i.e., we do not yet know whether there will be a lasting effect of cattail treatment.

Cattail cover was exceeded in all plots by the combined cover of all other species (Figure 5B), although nearly all of these species were individually much shorter in stature and comprised less biomass (e.g. rice cut grass (*Leersia oryzoides*) and mud plantain (*Alisma subcordatum*)). The only species to compete with cattails in stature or biomass was river bulrush (*Scirpus fluviatilis*), a less widely distributed member of the community. The cover of species other than cattails increased significantly across the wicking treatments, exceeding 200% in plots treated for two years, indicating a strong response to reduced cattail presence (Table 7). Despite the increase in non-cattail cover, differences among treatments in total cover were not significant (Figure 5C, Table 7).

Although total species cover did not increase across the wicking treatments, overall species richness and non-cattail species richness increased significantly in response to cattail wicking (Figures 5D and E, Table 7). The increase in overall richness was primarily due to the increase in non-cattail richness, which in turn appears to have resulted in the increase in non-cattail cover. The decrease in cattail cover with a second year of wicking left more open space into which the other forbs were apparently able to colonize and/or expand. However, the difference in richness between the untreated plots and the plots treated twice was only one species, which may not be enough to inhibit cattail reinvasion.

There was a positive effect of enhanced richness (planting additional species) on total cover and on cattail cover (Table 7). The increase in total cover was due to both cattails and species other than cattails in the planted plots. Since many of the plants that were installed to enhance richness did not survive the prolonged high water levels that took place in 2008 and 2009, the increase in cattail cover may reflect their better ability to colonize space previously occupied by the inundated plants.

There also was a significant interaction between cattail wicking and enhanced richness (planting additional species) in both overall richness and the richness of forbs other than cattails (Table 7). This was due to a disproportionate loss of forbs other than cattails in the plots treated once in 2007 that received additional plantings (a mean of four species in the single wicked unplanted plots vs. a mean of three species in the single wicked planted plots). Why there should be one less forb in the planted plots wicked for just one year is not intuitive and may be due to spurious differences in the initial distribution of species across the plots.

Our goal was to determine if cattail management could alter the development of a wetland community and put it on the path towards a stable native flora dominated by species other than cattails. Although we were able to significantly reduce cattail cover and increase the cover and richness of other forbs, we were unable to eliminate cattails or achieve the level of control achieved in treating woody vegetation. Wicking cattails early in the growing season proved to be an effective means of reducing cattail cover, but multiple wicking events within a single growing season may be needed to effectively kill the later growing shoots that are too short in stature to be treated in the initial wicking. One or more additional wick applications later in the growing season, e.g. once the individuals have begun bolting inflorescences, may effectively treat those cattails not killed in the first application. A multiple application strategy may be more effective than a single focused application to a dense stand later in the season since the overall height of the community by late June makes effective navigation nearly impossible, and the density of shoots at that stage causes many shoots to be shielded from the wick. This dynamic would not develop if the canopy has been stunted in growth or thinned by an early season application.

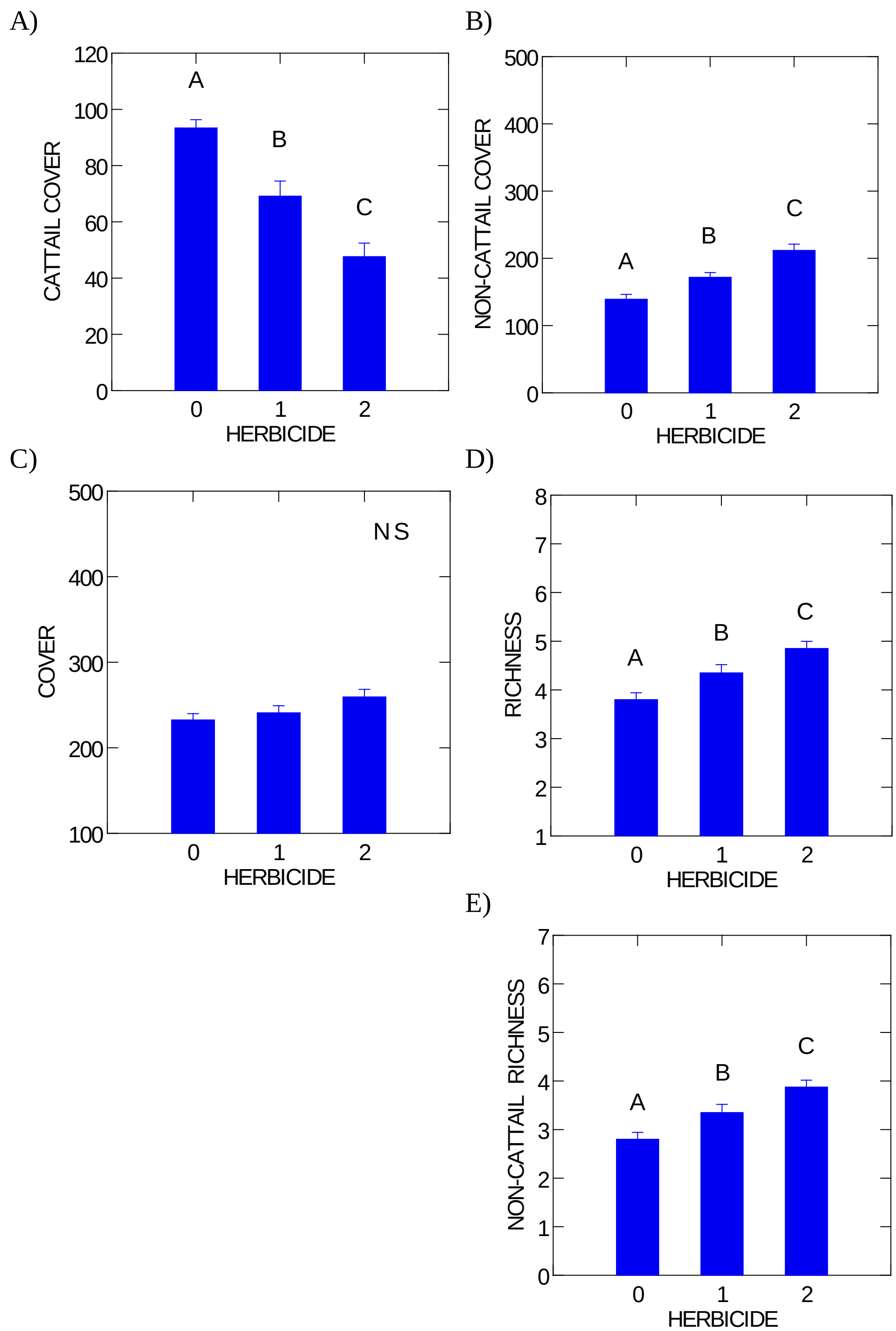

Figure 5. Effects of zero, one, and two years of wicking cattails in experimental unit EU-2 in the third year of the experiment (2009), reporting means + 1s.e. for A) cattail cover, B) non-cattail cover, C) total cover, D) richness, and E) non-cattail richness. Bars sharing no letters in common differ significantly from each other (Tukey's multiple comparisons, $\alpha < 0.05$). See Table 7.

Table 7. Results of the two-factor analysis of variance crossing herbicide treatment with richness enhancement in the cattail management plots in experimental unit EU-2. Results of the Tukey's multiple comparisons on the number of years of herbicide wicking were calculated using the error mean square. α = 0.05, DNT = did not test.

Cattail Management Plots (EU-2) Two-Factor ANOVA					Tukey's Multiple Comparison *P*		
Source of Variation	**df**	**MS**	***F***	***P***	**0 - 1**	**1 - 2**	**0 - 2**
Cattail Cover							
Herbicide Treatment	2	20,955.83	28.95	0.000	0.000	0.000	0.001
Richness Enhancement	1	7,680.00	10.61	0.001			
H x R	2	1,275.63	1.76	0.176			
error	114	723.85					
Non-Cattail Cover							
Herbicide Treatment	2	52,925.21	22.59	0.000	0.009	0.001	0.000
Richness Enhancement	1	1,452.55	0.62	0.433			
H x R	2	7,126.46	3.04	0.052			
error	114	2,342.87					
Cover							
Herbicide Treatment	2	7,564.38	3.02	0.053	DNT	DNT	DNT
Richness Enhancement	1	15,812.55	6.31	0.013			
H x R	2	2,375.21	0.95	0.391			
error	114	2,506.43					
Richness							
Herbicide Treatment	2	11.03	13.37	0.000	0.021	0.040	0.000
Richness Enhancement	1	2.70	3.27	0.073			
H x R	2	4.90	5.94	0.004			
error	114	0.83					
Non-Cattail Richness							
Herbicide Treatment	2	11.56	14.42	0.000	0.019	0.027	0.000
Richness Enhancement	1	3.01	3.75	0.055			
H x R	2	4.76	5.94	0.004			
error	114	0.80					

Invasive Tree Management: Experimental Zones T1, T2, T3, and TC

The work in these experimental zones was to determine how well the wicking strategy being investigated in the experimental plots could be applied to a larger area (EZ-T1). We also wished to examine the efficacy of wicking invasive trees vs. cutting the trees and herbiciding (painting) the stumps. Unexpectedly, the amount of disturbance associated with the cutting and painting activity (primarily trampled plants) resulted in an apparent loss of cover and diversity. Consequently, a second year of cutting and painting was conducted in an adjacent plot to quantitatively assess the treatment year impact (EZ-T3) and potential recovery after one year (EZ-T2).

Both the herbicide wicking treatment and the cutting and painting treatments resulted in significantly lower woody vegetative cover than in the control areas (Figure 6A, Table 8). Although differences among the three treatments were not significant, there were slightly more

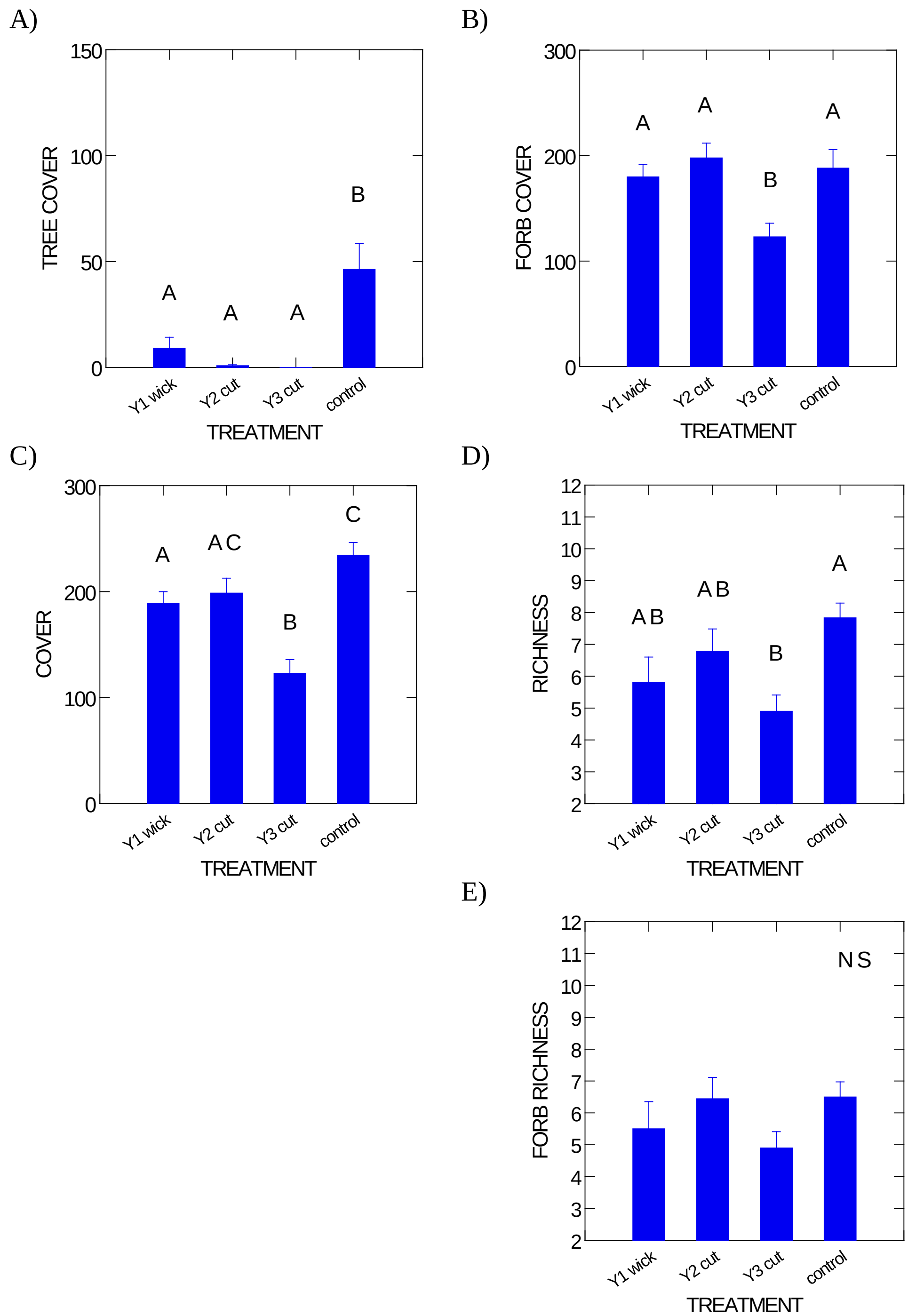

Figure 6. Effects of herbicide treatments in the experimental zones impacted by invasive trees: EZ-T1 (year 1 wick treatment), EZ-T2 (year 2 cut trees & paint stumps treatment), EZ-T3 (year 3 cut trees & paint stumps), and EZ-TC (an untreated control), reporting means + 1 s.e. for A) tree cover, B) forb cover, C) total cover, D) species richness, and E) forb richness. Bars sharing no letters in common differ significantly from each other (Tukey's multiple comparisons, $\alpha < 0.05$). See Table 8.

trees and more tree cover in the wicked quadrats sampled. This was likely due to the longer period of time that area had to recover following the single wicking treatment in year 1, i.e., there was more time for any small trees missed in the wicking treatment to grow and increase aerial coverage. Although differences were not significant, it appeared that a single cutting and painting of stumps was slightly more effective than a single wicking in regard to killing trees, and in particular the smaller trees missed by a wick passing 60 to 90 cm above the ground surface. This result was similar to the results of wicking for just one year in the experimental plots. Lower tree cover in experimental zone EZ-T1 (year 1 wicking) than in the experimental plots with one year of wicking (~10% vs. ~50% respectively) is likely due to the lower overall tree density (on average) at the beginning of the experiment outside of the experimental plots.

Table 8. Results of the single factor analysis of variance testing herbicide treatments in the tree management experimental zones. Results of Tukey's multiple comparisons on differences between herbicide treatments were calculated using the error mean square. Y1W = year 1 wicking (EZ-T1), Y2C = year 2 cut and paint stumps (EZ-T2), Y3C = year 3 cut and paint stumps (EZ-T3), and C = a no-treatment control (EZ-TC). α = 0.05, DNT = did not test.

Tree Management Area: Single Factor ANOVA					Tukey's Multiple Comparison *P*				
Source of Variation	**df**	**MS**	***F***	***P***		**Y1W**	**Y2C**	**Y3C**	**C**
Tree Cover					**Y1W**	1.000			
Herbicide Treatment	3	5,366.90	9.68	0.000	**Y2C**	0.874	1.000		
error	37	554.63			**Y3C**	0.828	1.000	1.000	
					C	0.004	0.001	0.000	1.000
Forb Cover					**Y1W**	1.000			
Herbicide Treatment	3	11,235.71	5.65	0.003	**Y2C**	0.815	1.000		
error	37	1,990.48			**Y3C**	0.035	0.004	1.000	
					C	0.971	0.961	0.008	1.000
Cover					**Y1W**	1.000			
Herbicide Treatment	3	23,024.82	15.89	0.000	**Y2C**	0.942	1.000		
error	37	1,449.08			**Y3C**	0.002	0.001	1.000	
					C	0.039	0.162	0.000	1.000
Richness					**Y1W**	1.000			
Herbicide Treatment	3	17.35	4.95	0.005	**Y2C**	0.670	1.000		
error	37	3.51			**Y3C**	0.707	0.147	1.000	
					C	0.071	0.582	0.004	1.000
Forb Richness					**Y1W**	DNT			
Herbicide Treatment	3	6.17	1.70	0.185	**Y2C**	DNT	DNT		
error	37	3.64			**Y3C**	DNT	DNT	DNT	
					C	DNT	DNT	DNT	DNT

There were no differences detected in forb cover among the year 1 wicking zone, the year 2 cutting and painting zone, and the untreated control zone, although forb cover was significantly lower in the year 3 cutting and painting zone than in any of the others (Figure 6B). This suggests that both management strategies were equally effective in promoting forb development, although neither resulted in higher forb cover than in the untreated control zone. Unlike the results in the experimental plots, it appears that three years was insufficient time for the negative impact of increasing tree cover to become apparent on forb cover given the initially lower average tree density in areas outside of the experimental plots. The ~75% lower forb cover in the year 3 cutting and painting experimental zone EZ-T3 indicates the extent of disturbance associated with that management strategy, although that difference disappeared after the one year of recovery in EZ-T2.

Total cover (forbs and woody vegetation) was greater in the control zone (EZ-TC) than in the wicking zone (EZ-T1) or the year 3 cutting and painting zone (EZ-T3), although differences between the control and the year 2 cutting and painting zone (EZ-T2) were not significant (Figure 6C).

There were no differences in species richness among the year 1 wicking zone, the year 2 cutting and painting zone, and the untreated control zone (Figure 6D), suggesting that those treatments did not have a negative effect on the number of species present. Richness was lower in the year 3 cutting and painting zone than in the control, although not lower than in the other treated zones. This indicated that although cover was significantly reduced in EZ-T3 relative to the other treatment zones, the number of species present wasn't affected, which is likely why overall cover and forb cover were both able to rebound after one year of recovery (EZ-T2 vs. EZ-T1 and EZ-TC). The greater richness in the control zone EZ-TC relative to EZ-T3 is likely due to the presence of trees, which were undetected in EZ-T3.

There were no differences in forb richness among the four treatment zones (Figure 6E), again suggesting that forbs were not impacted by any of the treatments, or by the presence of trees in the untreated control zone.

Invasive Cattail Management: Experimental Zones C2, C2,3, and CC

These analyses were designed to test, on a larger scale, the management strategy of wicking cattails, and consequently our ability to positively impact desirable native elements of a developing wetland community within a restoration context. Ultimately, we wanted to determine if cattail management could alter the course of community development away from a wetland dominated by cattails to a stable community dominated by forbs other than cattails.

Both of the treated experimental zones (with either one or two years of wicking) had significantly less cattail cover by the third year of the experiment (Figure 7A, Table 9). However, differences between the experimental zone treated once in year 2 (EZ-C2) and the area treated once in each of years 2 and 3 (EZ-C2,3) were not significant ($P = 0.055$), despite a nearly 20% difference in mean cattail cover (39% vs. 19% respectively). This appears due to the relatively large amount of variation among individual sampling quadrats throughout these areas, where cattail cover ranged from 0 to 97.5% in EZ-C2 and from 0 to 85% in EZ-C2,3. The data suggest that the wicking was successful in significantly reducing cattail cover, but not in eliminating cattails, even after two years of wicking. The reduction of cattail cover in the wicked experimental zones was somewhat lower than in the experimental plots due to the lower overall initial density of cattails across the larger, more heterogeneous landscape in the experimental zones.

The cover of forbs other than cattails was significantly greater in the experimental zone wicked once in year 2 (EZ-C2) than in the control zone (EZ-CC; Figure 7B). However, non-cattail cover in the experimental zone wicked in years 2 and 3 (EZ-C2,3) was not greater than in EZ-C2 or in EZ-CC. This appears to be due to the occurrence of some collateral damage to desirable native vegetation from herbicide unintentionally dripping from the wick. Inadvertent contact between herbicide and desirable vegetation occurred in both treated zones, but the native

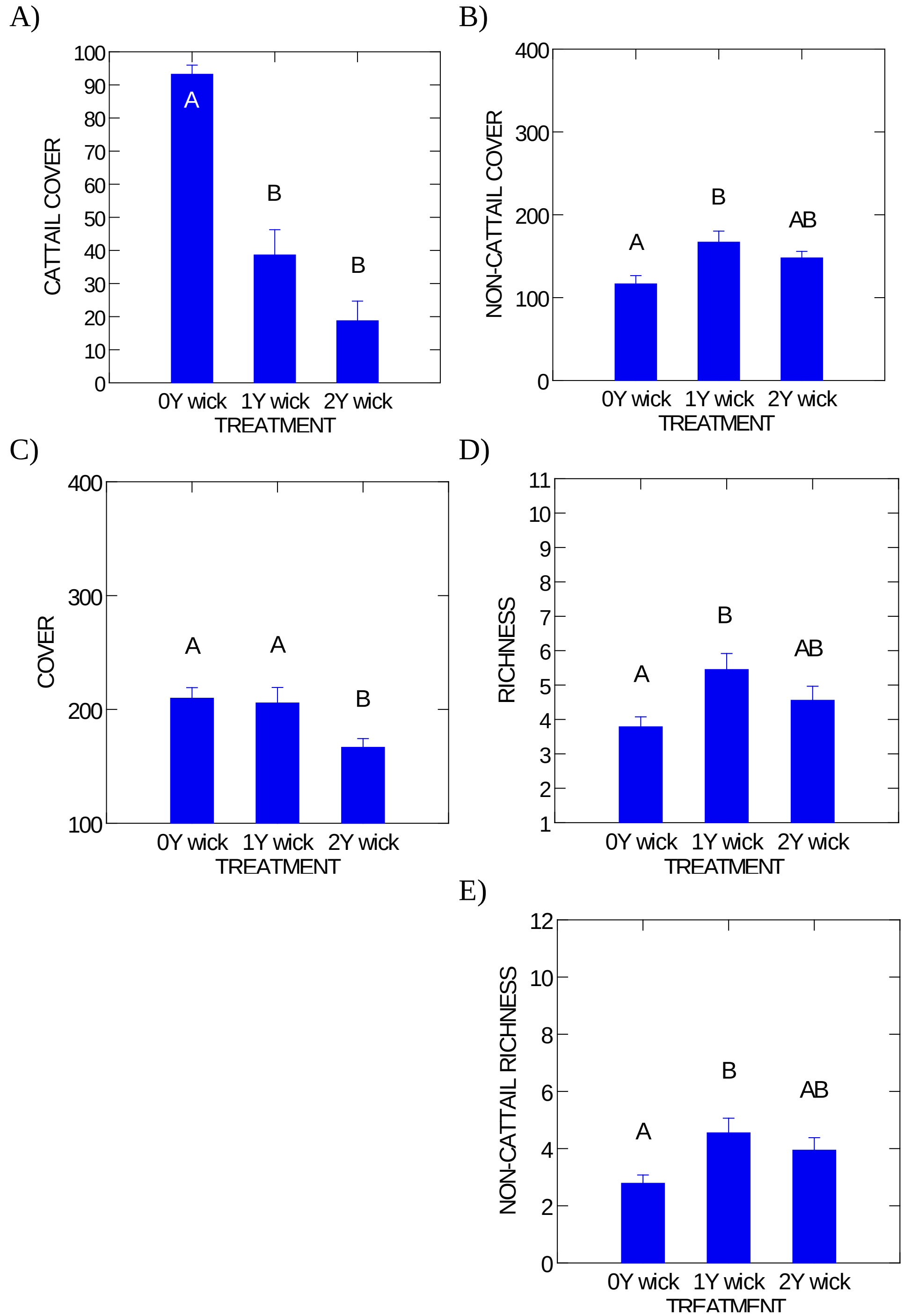

Figure 7. Effects of herbicide treatments in the experimental zones impacted by invasive cattails: EZ-C2 (cattails wicked once in year 2), EZ-C2,3 (cattails wicked once in years 2 and 3), and EZ-CC (an untreated control), reporting means +1 s.e. for A) cattail cover, B) non-cattail cover, C) total cover, D) richness, and E) non-cattail richness. Bars sharing no letters in common differ significantly from each other (Tukey's multiple comparisons, $\alpha < 0.05$). See Table 9.

community in EZ-C2 had a year more time in which to recover. Moreover, it was apparent in field testing that herbicide dripping onto non-target vegetation was more difficult to control in the second year of application since the target vegetation, which received most of the herbicide in the first round of application, was much less dense in the second round and unable to absorb all of the herbicide coming from the wick.

Table 9. Results of the single factor analysis of variance testing the number of years of herbicide wicking in the cattail management Experimental Zones. Results of the Tukey's multiple comparisons on differences between the number of treatment years were calculated using the error mean square. 0Y = a no wicking control in EZ-CC, 1Y = one year of wicking (year 2) in EZ-C2, and 2Y = two years of wicking (years 2 and 3) in EZ-C2,3. α = 0.05.

Cattail Management Area: Single Factor ANOVA					Tukey's Multiple Comparison *P*			
Source of Variation	**df**	**MS**	***F***	***P***		**0Y**	**1Y**	**2Y**
Cattail Cover					**0Y**	1.000		
Herbicide Treatment	2	22,826.20	34.41	0.000	**1Y**	0.000	1.000	
error	49	663.30			**2Y**	0.000	0.055	1.000
Non-Cattail Cover					**0Y**	1.000		
Herbicide Treatment	2	10,472.86	5.15	0.009	**1Y**	0.007	1.000	
error	49	2,032.00			**2Y**	0.136	0.400	1.000
Cover					**0Y**	1.000		
Herbicide Treatment	2	9,813.75	4.84	0.012	**1Y**	0.961	1.000	
error	49	2,026.36			**2Y**	0.026	0.028	1.000
Richness					**0Y**	1.000		
Herbicide Treatment	2	11.66	4.03	0.024	**1Y**	0.019	1.000	
error	49	2.89			**2Y**	0.419	0.248	1.000
Non-Cattail Richness					**0Y**	1.000		
Herbicide Treatment	2	12.90	3.85	0.028	**1Y**	0.021	1.000	
error	49	3.35			**2Y**	0.188	0.569	1.000

The reduced cover of forbs other than cattails (Figure 7B) had a strong impact on overall cover, where cover in experimental zone EZ-2,3 was significantly lower than in either of the other two zones (Figure 7C). Total cover appears to be lower in the EZ-C2,3 due to the combined effect of wicking cattails twice and the effect of inadvertently wicking non-target vegetation. Based on personal observation, it appears that both cattails and non-target vegetation are already beginning to recover.

The pattern of response in both overall species richness and in the richness of forbs other than cattails is nearly identical (Figure 7D and E). In each analysis, richness is greater in the experimental zone wicked once in year 2 (EZ-C2) than in the control zone (EZ-CC), while no differences were found between richness in the experimental zone wicked in years 2 and 3 (EZ-C,3) and either EZ-C2 or EZ-CC. This appears due to the same dynamic affecting the cover of non-cattail forbs: inadvertent contact between herbicide and those desirable species in the relatively open cattail canopies during the second round of wicking. The unintentional contact with herbicide appears to not only have reduced the cover of non-target species, but to have eliminated some of them as well.

Conclusions

One of our primary goals was to determine if the trajectory of community development in a relatively new restored wetland could be altered away from an assemblage of species dominated by invasives and towards a more stable community dominated by desirable native species. In the two wetland community types examined (a wet meadow community composed of sedges, grasses, forbs, and invasive trees, and a marsh edge community composed of forbs, sedges, and cattails), the wick application of herbicide has returned mixed results.

Wicking in the wet meadow community was very effective in eliminating cottonwoods, sandbar willows, and black willows, although a second year of application was necessary to achieve a nearly-complete kill due to younger trees being sheltered by lower-growing non-target species. The development of a dense stand of underlying herbaceous vegetation has so far been able to inhibit the establishment of additional trees. Enhanced diversity appears to have played little role in this dynamic as the additional species are not currently a major component of the restored community, although that may change in time if and when these species establish themselves more firmly and increase their relative importance value.

In comparing the efficacy of wicking trees vs. cutting and painting stumps, both methods proved to be quite effective in achieving the desired goal. However, the additional man-hours required to both cut trees and herbicide stumps makes that a more costly management strategy. It also is a strategy that results in more incidental damage to the non-target herbaceous community, although the data suggest the community may recover given sufficient time.

Another consideration in employing this strategy is the age and/or size of the woody vegetation to be eliminated. Wicking proved effective in a relatively young, establishing tree community with maximum height less than 3.0 m, the type of circumstance one might expect in a newly restored wetland. Attempts to wick older trees in other areas proved much more difficult due to their greater height and stem rigidity, both of which rendered the handheld wick much less effective. In addition, larger trees have more biomass both above and below ground, a condition that necessitates a greater volume of herbicide reaching the plant, and more of the stems (which are better shielded by their neighbors) being contacted with the wick. Cutting taller woody vegetation and painting stumps with herbicide may be a much more effective means of managing stands greater than 2.5 to 3.0 m in height. This ephemeral two to five year window of opportunity to manage woody vegetation in newly restored wetlands through strategic wicking underscores the importance of adaptive management.

Wicking in the marsh community was effective in reducing cattail cover and in enhancing the cover and richness of forbs other than cattails. However, unlike in the wet meadow community, cattails were not eliminated, and appear to be recovering from the effects of wicking. The cover and richness of non-cattail species was also impacted by the wicking, and they too appear to be recovering. It remains to be seen whether the desirable marsh species have been given sufficient advantage to compete with the recovering cattails. Regardless, two years of wicking were insufficient to achieve our goal of altering the developmental trajectory of a recently restored marsh community towards a wetland composed of and dominated by species other than cattails.

Careful wicking in late spring or early summer while cattails were relatively low in stature (but taller than nearly all other species) failed to impact late growing shoots that were too short to reach without damaging the species we were trying to promote. Since cattail recovery appears to have been driven by these surviving, lower-stature shoots, better results might be had with a second or even third wick application later in the growing season. The primary reason to avoid late-season wicking is that once cattails grow more than five to six feet tall, they become too dense for effective application. However, after an initial early season application, cattail growth is inhibited and shoot density remains low, both of which are conditions that are conducive to a more effective late-season wicking.

It was more difficult to ascertain the impact of enhancing diversity where cattails were treated in the marsh. As in the wet meadow areas, more time would be needed before the additional species could establish themselves effectively. Moreover, many of the plantings failed to survive due to the unexpectedly high water throughout the growing season of 2008 and much of 2009. However, it remains likely that enhancing diversity would eventually improve the community's ability to resist invasion or reinvasion by undesirable species, especially considering the inherently low diversity of the many marsh communities.

A secondary goal of this project was to reduce or eliminate other invasive species potentially having a negative impact on wetland community development. These other invasive species (common reed, reed canary grass, and purple loosestrife) were all herbaceous species primarily occurring in the wet meadow zones. Of these, only common reed was negatively impacted by the wick application of herbicide, primarily due to its greater stature. Purple loosestrife and reed canary grass were too low in stature at the time of wicking to be effectively contacted by herbicide. Consequently, we are attempting other means to manage these species across the site, including the use of backpack sprayers to treat small clumps or individuals, and the release of an insect herbivore that has adapted specifically to purple loosestrife in summer 2010.

The wick application of herbicide has proven to be an effective tool to reduce or eliminate some invasive species. Like any tool, it is most effective when used as part of a well-considered program of adaptive management. When used in a newly restored wetland, it can be very effective in altering the developmental trajectory of a wet meadow community being invaded by woody vegetation towards an alternative, stable endpoint: an herbaceous-dominated community of forbs and graminoids. It also can be used in marsh communities being invaded by cattails to reduce their numbers and their impact on other marsh vegetation. Further testing will be required before we can determine if wicking can eliminate cattails and/or alter a marsh from becoming a cattail-dominated, low-diversity wetland community.

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