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Chemical Control of Invasive Phragmites in a Great Lakes Marsh: A Field Demonstration

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PURPOSE: This field demonstration evaluated herbicide management techniques against the invasive wetland plant phragmites (*Phragmites australis* (Cav.) Trin. Ex Steud) that infests wetlands of Lake St. Clair; its purpose was to determine whether the techniques employed can play a role in the restoration of an ecologically important Great Lakes marsh vegetative community.

BACKGROUND: Lake St. Clair is a large freshwater lake that is situated approximately 10 km (6 miles) northeast of Detroit, Michigan. Its midline forms the boundary between Canada and the U.S. (Figure 1). With about 1114 Km^2 (430 square miles) of surface area, Lake St. Clair is part of the Great Lakes System. This waterbody connects Lake Huron with Lake Erie, and is fed from water flowing out of Lake Huron via the St. Clair River, emptying into Lake Erie via the Detroit River.

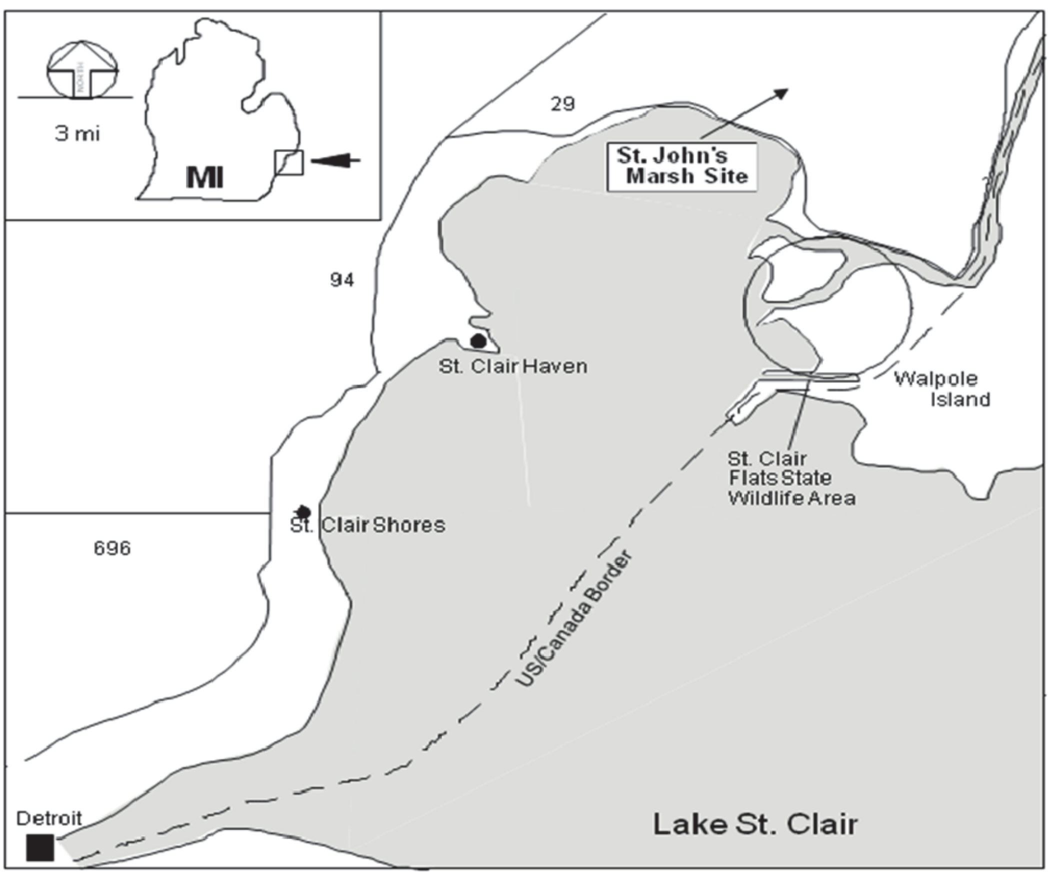

Figure 1. The Lake St. Clair region of Michigan. Lake St. Clair is fed with fresh water flowing out of Lake Huron to its north via the St. Clair River, which is the largest river delta within the Great Lakes system.

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Along the northeastern shore of Lake St. Clair is the St. John's Marsh Wildlife Area (SJMWA), a 1214 ha (3,000-acre) wetland dedicated to wildlife conservation and management (Figure 1). The vegetation of this area is characterized as Great Lakes Marsh, which is a wetland community restricted to the shoreline of the Great Lakes and their major connecting rivers. These marshes are productive natural systems and provide important habitat for migrating and breeding waterfowl, shore-birds, spawning fish, and medium-sized mammals, including many state threatened and endangered species such as the king rail (*Rallus elegans* Audubon), Foster's tern (*Sterna forsteri* Nuttall), least bittern (*Ixobrychus exilis* (Gmelin)), merlin (*Falco columbarius* Linnaeus), and Hine's emerald dragonfly (*Somatochlora hineana* Williamson). There are nine groups of the Great Lakes Marsh, and the SJMWA is part of the Lake Erie-St. Clair Lakeplain marsh group (Albert 2001). The St. Clair Lakeplain Marshes are currently threatened due to human habitat destruction, local changes in hydrology from drainage and ditching, shrub and tree encroachment, influxes of polluted water, and invasion by the non-native weed, phragmites (Tulbure and Johnston 2010). Phragmites (also known as common reed) has infested many Great Lakes marshes since 1945 (Wilcox et al. 2003).

Non-native phragmites is an aggressive weed, and its unchecked growth threatens the biological diversity, fish and wildlife habitat provided by Great Lakes wetland communities (Chambers et al. 1999, Findlay et al. 2003, Tulbure et al. 2007, Tulbure and Johnston 2010). Phragmites is a perennial grass that forms dense, monospecific stands. In Michigan, phragmites typically emerges in late May and by late July, a full canopy of developed and overwintering buds have formed on the rhizomes (Thompson and Shay 1985). Shoot carbohydrates start translocation to the rhizomes in May and continue until August prior to fall senescence (Asaeda et al. 2006). Phragmites will typically flower and set seed between July and September. Seeds are shed from November through January as shoots senesce (Marks et al. 1994). Although phragmites can grow to heights greater than 4 m (13 feet) (Blossey and McCauley 2000), 80% of its biomass is produced underground in the roots and rhizomes (Holm et al. 1977). Phragmites expands mostly through vegetative growth from rhizomes and stolons, which are viable for three to six years (Marks et al. 1994).

While small-scale operational projects (e.g., herbicide applications, disking, burning, flooding) have been undertaken to reduce the phragmites infestations at the SJMWA since 1994, a progression of field demonstrations were implemented in 2001 to document the effectiveness of control techniques on phragmites, which could be used to develop a long-term management plan for the St. Clair Lake Marsh community (Getsinger et al. 2006).

The first field demonstration (2001 to 2003) was conducted to compare the selective control of phragmites using specific herbicide applications and prescribed burning techniques on replicated small-scale plots. The systemic herbicides glyphosate (*N*-(phosphonomethyl) glycine) and imazapyr ((±)-2-(4,5-dihydro-4-methyl-4-(1-methylethyl)-5-oxo-1*H*-imidazol-2-yl)-3-pyridinecarboxylic acid) were selected for these demonstrations. These methods were based on previous reports from coastal Connecticut (Turner and Warren 2003), New Jersey (Teal and Peterson 2005), North Carolina (Kay 1995), and Chesapeake Bay (Ailstock et al. 2001). Results of these small-plot demonstrations provided 87 to 100% phragmites control one year posttreatment, and 67 to 95% control two years post treatment. Across years and sites, imazapyr applied alone and the combination of glyphosate + imazapyr provided slightly better control of phragmites than glyphosate applied alone (Getsinger et al. 2006). Recent reports of phragmites control with herbicides along Lake Erie (Carlson et al. 2009) and other areas verify these results (Derr 2008, Mozdzer et al. 2008, True et al. 2010).

The second effort, a series of large-scale demonstrations (2002 to 2005), included specific herbicide applications applied to large areas (0.8 to 24 ha or 2 to 60 acres) that had been previously burned, mowed, or flooded. The combination of herbicide broadcast applications (glyphosate, imazapyr or a combination glyphosate + imazapyr), followed by further flooding, dewatering, or burning provided the most consistent control of phragmites. Results showed that phragmites cover can be reduced by >85% for at least two years; however, growth and spread of phragmites begins to recover three years post treatment (Getsinger et al. 2006). Marks et al. (1994) and Monteiro et al. (1999) also reported phragmites recovery after three years of management using herbicides combined with other techniques.

Continuous management of phragmites enhances the establishment of non-target aquatic and wetland vegetation (Turner and Warren 2003). Carlson et al. (2009) found that native plants colonized areas treated with glyphosate followed by cutting, raking, or glyphosate spot-treatments for phragmites control. Information on selectivity and impact on non-target vegetation has not been reported for imazapyr or glyphosate + imazapyr combinations despite better phragmites control achieved with these herbicide treatments (Derr 2008, Mozdzer et al. 2008, True et al. 2010). The field demonstration summarized here evaluated the effect of a broadcast glyphosate + imazapyr combination treatment and a broadcast glyphosate treatment followed by secondary herbicide treatment on phragmites and the impact on the non-target plant community to realize the restoration of a Great Lakes Marsh.

MATERIALS AND METHODS: This field demonstration was conducted in three plots along the coast of Lake St. Clair in the SJMWA (Figure 1). This area is characterized as a Great Lakes Marsh, with plants that colonize emergent and wet meadow habitats of the Lake Erie-St. Clair Lakeplain Marsh (Albert 2001). Common species of the emergent zone include duckweeds (*Lemna* spp.), coontail (*Ceratophyllum demersum* L.), elodea (*Elodea canadensis* Michx.), arrowhead (*Sagittaria* spp.), bulrushes (*Schoenoplectus* spp.), and cattails (*Typha* spp.). The wet meadow is dominated by bluejoint (*Calamagrostis canadensis* (Michx.) P. Beauv.), reed canarygrass (*Phalaris arundinacea* L.), smartweeds (*Polygonum* spp.), narrowleaf cattail (*T. angustifolia* L.), as well as the pioneer species beggarticks (*Bidens* spp.) and jewelweed (*Impatiens capensis* Meerb.).

Three experimental plots were all within the boundaries of the SJMWA (Figure 2). Each plot was approximately 8 ha (20 acres) and placed in the middle of treatment areas, with enough buffer on all sides to prevent treatment overlaps (overspray). Plots 1 and 2 were located on the west side of state highway M-29 (Figure 2). These plots were within an area of the marsh that was heavily infested with phragmites and had never been treated with herbicides prior to 2010. Plot 1 received a glyphosate + imazapyr combination treatment in 2010 (Table 1). Plot 2 served as the reference and was not treated with herbicides. Plot 3 was located on the east side of state highway M-29 (Figure 2). This plot was also heavily infested with phragmites. It was chemically treated with glyphosate in 2009, with a follow-up glyphosate treatment in 2010 (Table 1).

Herbicide applications. In Plot 1, glyphosate (Eagre™, 53.8% active ingredient as the isopropylamine salt of glyphosate, SePRO Corporation, Carmel, IN) was aerially applied at 3.5 L per ha (3 pints of product per acre) in combination with imazapyr (Habitat®; BASF Corporation, Research Triangle Park, NC) using 3.5 L per ha in September 2010. In Plot 3, glyphosate (Eagre™, 53.8% active ingredient as the isopropylamine salt of glyphosate) was aerially applied at

7 L per ha (6 pints product per acre) in September 2009. The surfactant CygnetPlus™ (Cygnet Enterprises, Flint, MI), was added (0.5% v:v) to the tank-mix for all herbicide treatments.

Figure 2. Overview of phragmites control demonstration plots, St. John's Marsh Wildlife Area, Michigan, 2010-2011. Plot 1 was treated via helicopter with a herbicide combination of glyphosate + imazapyr in September 2010. Plot 2 was an untreated control (reference) and has never received any herbicide treatments. Plot 3 was treated via ground equipment with the herbicide glyphosate in September 2009, followed by small glyphosate treatments in 2010.

Table 1. Chemical treatments in 8-hectare plots to control phragmites at St. John's Marsh Wildlife Area, Michigan, 2009 to 2011.

	Plot 1	Plot 2	Plot 3
Location	St. John's Marsh Blue Water Isles	St. John's Marsh Blue Water Isles	St. John's Marsh W of Detroit Urban Railway dike
2009			
Phragmites infestation	100%	100%	100%
Treatment	None	None	Glyphosate (7 L/ha) Surfactant (0.5% v:v)
Application type	None	None	Aerial broadcast
2010			
Phragmites infestation	92%	100%	24%
Treatment	Glyphosate (3.5 L/ha) + Imazapyr (3.5 L/ha) Surfactant (0.5% v:v)	None	Glyphosate (7 L/ha) Surfactant (0.5% v:v)
Application type	Aerial broadcast	None	Ground broadcast

For the aerial application, herbicides were delivered evenly over the site as a broadcast application at a rate of 7.5 L per ha (8 gallons per acre) using a helicopter outfitted with a T-jet stainless steel boom with 80/10 fan nozzles. The helicopter applied the chemicals at an elevation of approximately 3 to 9 m (10 to 30 ft) above the top of the plant stand to minimize herbicide drift away from the treated zone. At the time of treatment, skies were clear, calm, and there was no standing water present in the plots.

In September 2010, Plot 3 received broadcast application treatments of glyphosate (7 L per ha using Eagre™, 53.8% active ingredient as the isopropylamine salt of glyphosate, SePRO Corporation, Carmel, IN) with surfactant (CygnetPlus™, 0.5% v:v). Herbicides were applied using an 8-track amphibious vehicle equipped with a spray-tower and spray boom mounted in the center of the vehicle. The sprayer was calibrated to deliver a total spray volume of 234 L per ha (25 gallons per acre), one to three feet above the plant canopy, with a swath width of approximately 12 m (40 feet).

Plant surveys. Plants in each treatment plot were surveyed before herbicide application (PRE; August 2010) and 1 year after herbicide applications (POST; August 2011) to evaluate effects on phragmites and non-target plant species. PRE and POST surveys were conducted by sampling along 5 permanent transects located within the plot. Each transect was 100 m (638 ft) in length. Every 20 m (66.5 ft), a quadrat (1 m^2 or 10.8 ft^2) was placed along the transect, and plant species within its boundaries were identified and recorded. Additionally, percent cover for each species was determined. For statistical analyses, cover classes were assigned to percent cover estimates using the following values: 1 (1-5%), 2 (6-25%), 3 (26-50%), 4 (51-75%), 5 (76-95%), and 6 (96-100%). The mean value for each cover class was used for statistical analysis. Voucher specimens of all plant species found in the test plots were collected, preserved, and verified by a plant taxonomist with expertise in Michigan native wet prairies.

Statistical analyses. All statistical tests were conducted with SigmaStat v3.1 (Systat Software Inc., Chicago, IL). Percent occurrence of plant species was calculated by dividing the number of points where a particular species was present by the total number of sample points in a plot (25). Frequency of phragmites and non-target plant species PRE and POST was compared using McNemar's Test ($p \leq 0.05$; Wersal et al. 2010) based on the actual number of points with and without that species at each sampling period. McNemar's Test uses dichotomous response variables that are not independent to assess differences in correlated proportions within a given data set, such as sampling the same points over time. Mean species per point (± 1 SE) was calculated as the average mean number of species present at each point in a plot. Phragmites or non-target mean species per point and mean cover class were compared PRE and POST using the nonparametric Wilcoxon Signed-Ranks Test (Wilcoxon, $p \leq 0.05$; Whitcraft and Grewell 2010), which tests for significant differences between the distributions of two non-independent samples involving repeated measures.

RESULTS AND DISCUSSION: One year after treatment, the combination of glyphosate + imazapyr reduced mean phragmites frequency from 92% PRE to 44% POST in Plot 1 (Table 2). This herbicide combination also reduced phragmites cover from 5.2 ± 0.3 (76 to 95%) to 0.6 ± 0.1 (1 to5%; Figure 3). Phragmites remained dominant in the reference plot (Plot 2) with 100% frequency at PRE and POST sampling periods (Table 3). Moreover, phragmites cover increased from 4.6 ± 0.2 (51 to 7%) to 5.2 ± 0.2 (76 to 95%; Figure 3). Although ground applications of glyphosate in Plot 3 did not further reduce phragmites frequency (24%; Table 4) or cover (1 to 5%; Figure 3) from earlier treatments, these treatments did not allow phragmites to regain dominance in this area.

Rates of glyphosate used in this demonstration provided 75% control, which was maintained for two years. This outcome corresponds to previous reports where glyphosate suppressed phragmites for at least two years (Mozdzer et al. 2008, True et al. 2010). Follow-up herbicide treatments have been recommended for prolonging control of phragmites (Marks et al. 1994, Moreira et al. 1999), which was evident in this evaluation.

The combination of imazapyr + glyphosate reduced phragmites by 50% based on frequency with a substantial reduction in cover (>75%). Reduced herbicide rates used in this combination were not as effective as other applications of glyphosate or imazapyr used alone (Mozdzer et al. 2008). Although better (or greater) phragmites control is achieved when herbicides are applied earlier in the growing season (Derr 2008, Mozdzer et al. 2008, True et al. 2010), non-target vegetation may be negatively affected by treatments in June or July, particularly since both glyphosate and imazapyr are broad spectrum systemic herbicides.

Although phragmites was the dominant species in all plots, 57 other species were present in the pre-treatment evaluation (Tables 2-4). Common plants were narrowleaf cattail and climbing nightshade (*Solanum dulcamara* L.), which are introduced species, as well as native beggarticks, sedges (*Carex* spp.), jewelweed, jointleaf rush (*Juncus articulates*), softstem bulrush (*S. tabernaemontani* (C.C. Gmel.) Palla), and broadfruit bur-reed (*Sparganium eurycarpum* Engelm.).

Table 2. Percent frequency of occurrence of wetland plant species surveyed in Plot 1 before herbicide application in 2010 (PRE) and after herbicide application in 2011 (POST) at St. John's Marsh Wildlife Area, Michigan. Plot 1 was treated via helicopter with an herbicide combination of glyphosate + imazapyr in September 2010. Asterisks indicate significant differences in plant occurrence before and after herbicide application (McNemar's Test, p≤0.05). Species with a 0 percent occurrence reported for either survey could not be analyzed.

Species[a]	Common Name	% Occurrence PRE	% Occurrence POST
Phragmites australis	Phragmites	92	44*
Non-Target Species			
Agrostis gigantea	Redtop	4	0
Alisma plantago-aquatica	European water plantain	0	4
Carex cryptolepis	Northeastern sedge	8	0
Carex stricta	Upright sedge	8	0
Carex sp.	Sedge	12	0
Circium arvense **I**	Canada thistle	12	0
Eleocharis erythropoda	Bald spikerush	12	4
Hypericum majus	Large St. Johnswort	8	0
Impatiens capensis	Jewelweed	36	0
Juncus articulates	Jointleaf rush	24	0
Juncus balticus	Baltic rush	16	0
Juncus brevicaudatus	Narrowpanicle rush	4	0
Lactuca sp.	Lettuce	4	20
Leersia oryzoides	Rice cut-grass	4	4
Lycopus uniflora	Northern bugleweed	8	0
Najas flexilis	Nodding waternymph	0	8
Onoclea sensibiles	Sensitive fern	4	0
Panicum capillare	Witchgrass	4	0
Potamogeton illinoensis	Illinois pondweed	0	4
Schoenoplectus acutus	Hardstem bulrush	8	0
Schoenoplectus tabernaemontani	Softstem bulrush	0	12
Scirpus sp.	Sedge	4	0
Scutellaria galericulata	Marsh skullcap	4	4
Solanum dulcamara **I**	Climbing nightshade	20	28
Solidago uglinosa	Bog goldenrod	4	0
Typha angustifolia **I**	Narrowleaf cattail	0	12
Zannichellia palustris	Horned pondweed	0	4
Number of non-target species		20	11

[a] **I** denotes an introduced species that is not native to Michigan

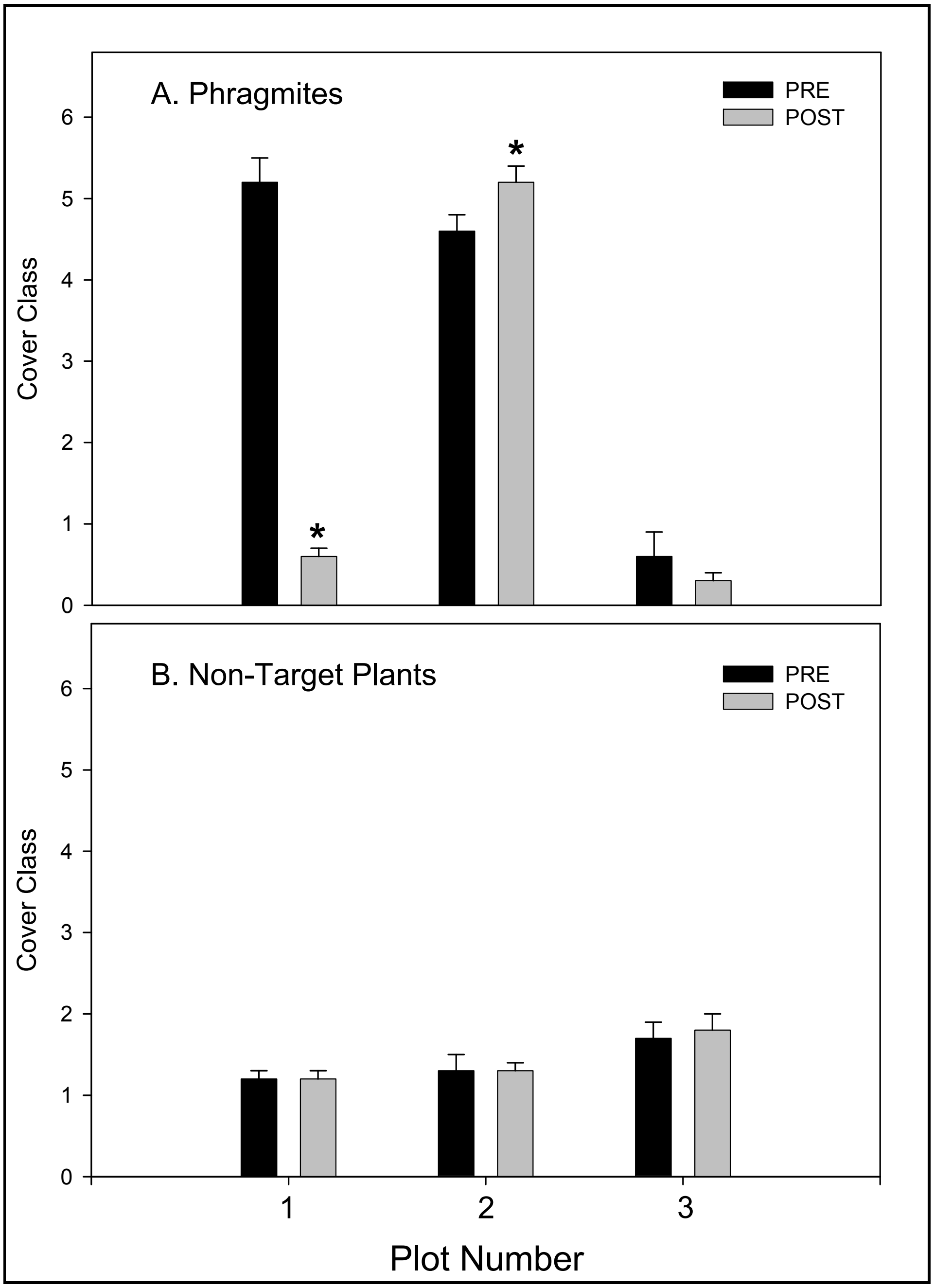

Figure 3. Mean (±1 SE) cover of A. Phragmites and B. Non-Target Plants before (PRE) and after (POST) herbicide application in phragmites demonstration plots in St. John's Marsh Wildlife Area, Michigan, 2010-2011. Plot 1 was treated via helicopter with an herbicide combination of glyphosate + imazapyr in September 2010. Plot 2 was an untreated control (reference) and has never received any herbicide treatments. Plot 3 was aerially treated with the herbicide glyphosate in September 2009, followed by broadcast ground applications of glyphosate in 2010. Cover was estimated using the following values: 1 (1-5%), 2 (6-25%), 3 (26-50%), 4 (51-75%), 5 (76-95%), and 6 (96-100%). Asterisks denote significant differences in cover PRE and POST treatment within a treatment plot (Wilcoxon, $p \leq 0.05$).

Table 3. Percent frequency of occurrence of wetland plant species surveyed in Plot 2 before herbicide application in 2010 (PRE) and after herbicide application in 2011 (POST) at St. John's Marsh Wildlife Area, Michigan. Plot 2 was an untreated control (reference) and has never received any herbicide treatments. Asterisks indicate significant differences in plant occurrence before and after herbicide application (McNemar's Test, p≤0.05). Species with a 0 percent occurrence reported for either survey could not be analyzed.

Species[a]	Common Name	% Occurrence PRE	% Occurrence POST
Phragmites australis	Phragmites	100	100
Non-Target Species			
Campanula aparaniodes	Bluejoint grass	8	4
Carex comosa	Longhair sedge	0	8
Carex lasiocarpa	Woollyfruit sedge	12	16
Carex stricta	Upright sedge	16	0
Carex sp.	Sedge	16	12
Cladium mariscoides	Smooth sawgrass	8	0
Cornus amomum	Silky dogwood	4	0
Cornus sericea	Redosier dogwood	4	0
Eleocharis erythopoda	Bald spikerush	0	4
Glyceria striata	Fowl mannagrass	8	8
Hypericum majus	Large St. Johnswort	8	0
Impatiens capensis	Jewelweed	8	8
Juncus articulatus	Jointleaf rush	16	0
Juncus balticus	Baltic rush	4	0
Juncus brevicaudatus	Narrowpanicle rush	4	0
Lycopus americana	American water horehound	12	8
Lythrum salicaria **I**	Purple loosestrife	12	0
Onoclea sensibiles	Sensitive fern	0	4
Parthenocissus quinquefolia	Virginia creeper	4	0
Polygonum sp.	Smartweed	8	0
Potomageton illinoensis	Illinois pondweed	8	4
Potamogeton sp.	Pondweed	0	8
Schoenoplectus acutus	Hardstem bulrush	12	12
Schoenoplectus tabernaemontani	Softstem bulrush	0	4
Solanum dulcamara **I**	Climbing nightshade	4	4
Solidago altissima	Canadian goldenrod	8	8
Thelypteris palustris	Eastern marsh fern	12	12
Triadenum fraseri	Fraser's marsh St. Johnswort	0	8
Typha angustifolia **I**	Narrowleaf cattail	20	20
Number of non-target species		23	18

[a] **I** denotes an introduced species that is not native to Michigan

Table 4. Percent frequency of occurrence of wetland plant species surveyed in Plot 3 before herbicide application in 2010 (PRE) and after herbicide application in 2011 (POST) at St. John's Marsh Wildlife Area, Michigan. Plot 3 was aerially treated with the herbicide glyphosate in September 2009, followed by broadcast ground applications of glyphosate in 2010. Asterisks indicate significant differences in plant occurrence before and after herbicide application (McNemar's Test, p≤0.05). Species with a 0 percent occurrence reported for either survey could not be analyzed.

Species[a]	Common Name	% Occurrence PRE	% Occurrence POST
Phragmites australis	Phragmites	24	24
Non-Target Species			
Agrostis hyemalis	Redtop	8	12
Alisma plantago-aquatica	European water plantain	0	4
Aster sp.	Aster	4	0
Bidens cernuus	Nodding bur marigold	44	0
Bidens comosa	Threelobe beggarticks	20	0
Bidens fondosa	Devil's beggartick	8	0
Bidens sp.	Beggarticks	0	4
Calamagrostis canadensis	Bluejoint	16	4
Campanula aparaniodes	Marsh bellflower	4	0
Carex comosa	Longhair sedge	0	8
Carex sp.	Sedge	28	0
Cicuta bulbifera	Bulblet-bearing water hemlock	4	4
Circium arvense **I**	Canada thistle	28	16
Cyperus strigosus	Straw-colored flatsedge	12	4
Daucus carota **I**	Queen Anne's lace	0	4
Eleocharis erythopoda	Bald spikerush	0	8
Epilobium coloratum	Purpleleaf willowherb	8	0
Galium trifidum	Threepetal bedstraw	4	4
Impatiens capensis	Jewelweed	24	8
Lactuca sp.	Lettuce	0	8
Lathyrus palustris	Marsh pea	4	8
Leersia oryzoides	Rice cut-grass	20	32
Lemna minor	Common duckweed	0	28
Lemna trisulca	Star duckweed	0	4
Lycopus americana	American water horehound	4	4
Lycopus uniflora	Northern bugleweed	4	0
Lythrum salicaria **I**	Purple loosestrife	0	4
Mentha sp.	Mint	8	4
Muhlenbergia sp.	Muhly	4	0
Panicum capillare	Witchgrass	8	0
Parthenocissus quinquefolia	Virginia creeper	12	0
Phalaris arundinacea	Reed canarygrass	0	16
Polygonum convolvulus	Black bindweed	0	8

Polygonum pensylvanicum	Pennsylvania smartweed	32	0
Polygonum punctatum	Dotted smartweed	16	12
Polygonum sagittatum	Arrowleaf tearthumb	32	12
Polygonum scandens	Climbing false buckwheat	4	0
Ranunculus recurvatus	Blisterwort	0	4
Sagittaria latifolia	Broadleaf arrowhead	0	12
Sagittaria sp.	Arrowhead	4	0
Schoenoplectus tabernaemontani	Softstem bulrush	32	44
Scirpus sp.	Bulrush	4	12
Scutellaria galericulata	Marsh skullcap	8	8
Solanum dulcamara **I**	Climbing nightshade	0	4
Solidago altissima	Canadian goldenrod	16	16
Solidago sp.	Goldenrod	4	4
Sparganium eurycarpum	Broadfruit bur-reed	52	52
Typha angustifolia **I**	Narrowleaf cattail	40	40
Typha latifolia	Broadleaf cattail	0	4
Verbena hastate	Swamp verbena	8	0
Vitus riparia	Riverbank grape	24	0
Number of non-target species		36	35

[a] **I** denotes an introduced species that is not native to Michigan

There were significant reductions in mean non-target species number per point between the PRE and POST sampling in Plot 1 receiving the imazapyr + glyphosate combination treatment (Figure 4); however, canopy cover remained the same (1 to 5%; Figure 3). In the reference (Plot 2) non-target plant cover was similar PRE and POST (1 to 5%; Figure 3), but mean non-target species number per point decreased (Figure 4). Neither canopy cover nor mean species number per point changed with the glyphosate spot treatments in Plot 3 (Figures 3-4). Except for phragmites, the occurrence of many species either stayed the same or changes were statistically insignificant before or after herbicide application (Tables 2-4). It should be noted that many changes in frequency of occurrence could not be analyzed using the McNemar's Test since percent occurrence was zero at either the PRE or POST sampling period. While frequency and cover of phragmites was significantly reduced, or kept at low levels, frequency and cover of non-target vegetation was generally constant. Significant increases in non-target species may require more than one or two years of phragmites management (Turner and Warren 2003).

Submersed, floating, and emergent plants increased in cover after applications of glyphosate and the glyphosate + imazapyr combination, which reduced phragmites cover in the emergent zone. Common duckweed (*Lemna minor* L.) frequency of occurrence increased from 0% PRE to 28% POST in Plot 3 (Table 4). Broadfruit bur-reed, another submersed species, continued to be a large part of the plant community before (52%) and after (52%) herbicide application in Plot 3. Pondweeds (*Potamogeton* spp. and *Zannichellia palustris* L.) were present in all treatment plots at the POST sampling. Submersed plants are an important part of the St. Clair River Delta and contribute to its uniqueness within the Great Lakes system, since many of the St. Clair River Delta wetlands are lacustrine estuaries (Albert 2001).

Narrowleaf cattail and bulrushes are also characteristic of the Lake Erie-St. Clair Lakeplain Marsh emergent zone (Albert 2001). Narrowleaf cattail occurrence was not adversely affected by herbicide treatments with 40% frequency at both PRE and POST sampling periods in Plot 1 (Table 2) and 0% frequency at PRE sampling and 12% at POST sampling in Plot 3 (Table 3). Although narrowleaf cattail frequency was 20% at both PRE and POST sampling periods in the reference (Table 3), percent cover decreased (data not shown). Bulrush (*Schoenoplectus* spp.) occurrence was maintained in all treatment plots, including the reference, before and after herbicide application. Other rush species (*Juncus* spp.) were reduced in the plot receiving the glyphosate + imazapyr combination and the reference.

Herbicide applications may have negatively affected species that inhabit the wet meadow zone more than those that inhabit the emergent zone (Tables 2, and 4). For example, jewelweed frequency was 36% at the PRE sampling period, but 0% at the POST sampling in Plot 1, and 24% PRE and 8% POST in Plot 3. Beggarticks (*Bidens* spp.) were a large component of Plot 3 before glyphosate application in 2010, but were not present after spot treatments in 2011 (Table 4). Likewise, sedges (*Carex* spp.) were part of the plant community in Plot 1 before glyphosate + imazapyr application, but were not present in 2011 (Table 2). Although direct herbicide phytotoxicity could have played a role in the elimination of these species (Whitcraft and Grewell 2011), seedling recruitment and native species establishment may have been suppressed by dead phragmites litter (van der Valk 1986). Removal of phragmites litter through raking and burning after herbicide application promotes species establishment and increases species richness (Getsinger et al. 2006, Carlson et al. 2009).

The decline in species richness after broadcast herbicide application of glyphosate + imazapyr in Plot 1 (Figure 4) may have been due to the lack of a secondary or follow-up treatment to remove phragmites litter in the wet meadow zone. Carlson et al. (2009) found that litter removal was essential to seedling recruitment in drier areas more than in saturated ones. Glyphosate spot treatments in Plot 3 kept phragmites cover thin (Figure 3), which maintained non-target species richness (Figure 4). In the reference, the decrease in species richness (Figure 4) may be attributed to the increase in phragmites cover (Figure 3). Phragmites is notorious for shading out native plant species with its tall canopy and preventing establishment of more desirable plants due to its dense rhizomes (Marks et al. 1994).

SUMMARY: Herbicide applications to areas dominated by phragmites either significantly reduced its occurrence and cover or prevented its expansion. A broadcast application of a glyphosate + imazapyr combination reduced phragmites frequency of occurrence by 48% and cover by >75%. Phragmites frequency of occurrence remained at 24% while cover was 1 to 5% before and after spot treatments of glyphosate, which were conducted one year following a broadcast application. Although both herbicides used in this evaluation are broad spectrum systemic products, non-target plant cover was unchanged before and after treatment. Overall, cover remained the same; however, some species declined after treatment, while others increased. Species diversity was maintained after repeated glyphosate treatments by keeping phragmites cover thin. Reduction in species diversity after the glyphosate + imazapyr combination may be a result of herbicide phytotoxicity and/or suppression of species establishment by dense phragmites litter. A secondary treatment following broadcast herbicide applications may promote growth of native species. Long-term control efforts that effectively reduce phragmites while increasing species diversity are imperative for restoration of a Lake Erie-St. Clair Lakeplain Marsh.

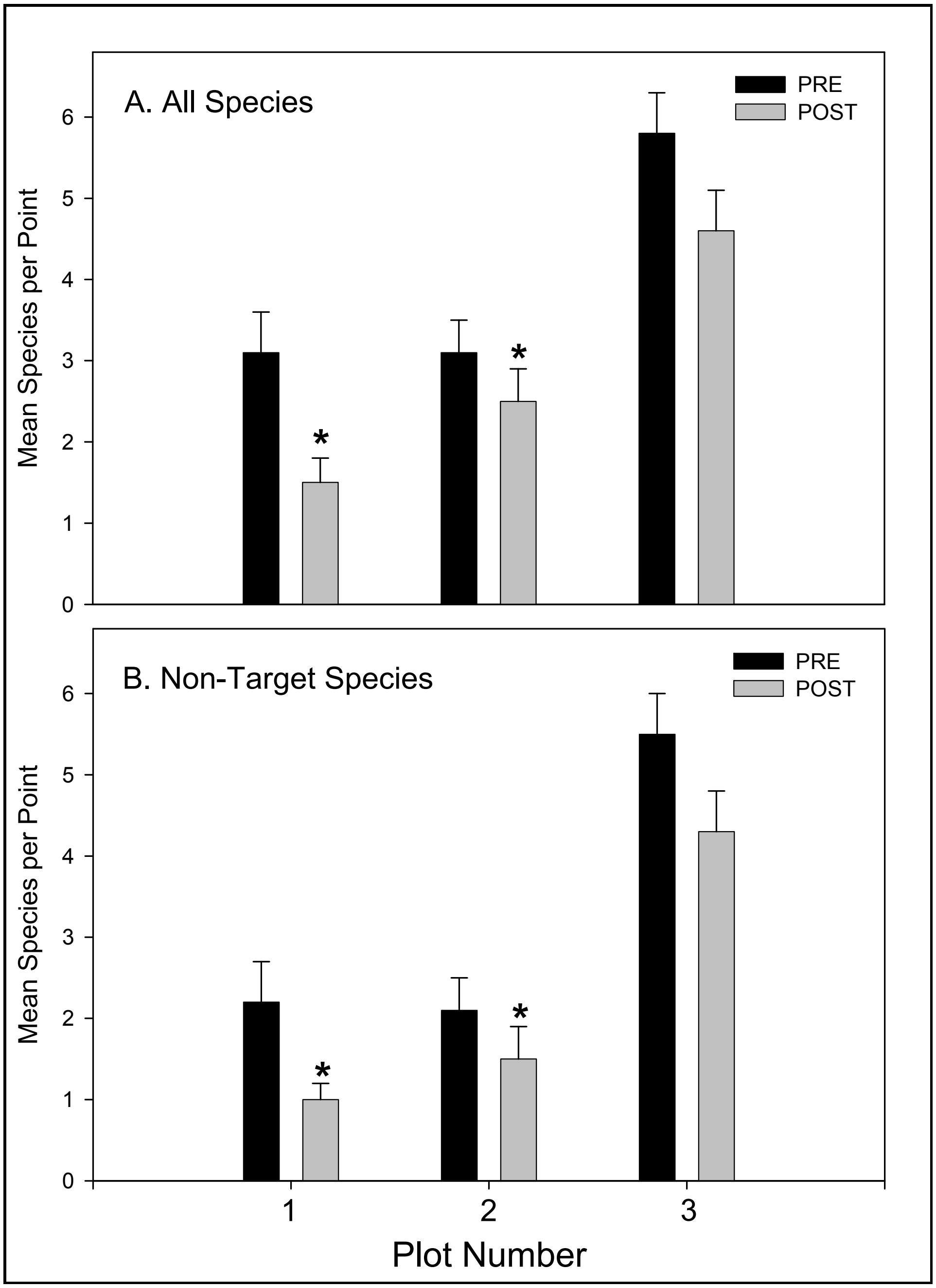

Figure 4. Mean (±1 SE) species per point of A. All species, and B. Non-Target Species before (PRE) and after (POST) herbicide application in phragmites demonstration plots, St. John's Marsh Wildlife Area, Michigan, 2010-2011. Plot 1 was treated via helicopter with an herbicide combination of glyphosate + imazapyr in September 2010. Plot 2 was an untreated control (reference) and has never received any herbicide treatments. Plot 3 was aerially treated with the herbicide glyphosate in September 2009, followed by broadcast ground applications of glyphosate in 2010. Asterisks denote significant differences in cover PRE and POST treatment within a treatment plot (Wilcoxon, $p \leq 0.05$).

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