Long-term Spread and Control of Invasive, Common Reed (*Phragmites australis*) in Sheldon Marsh, Lake Erie

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Abstract. In 2001 the Ohio Department of Natural Resources (ODNR) initiated a long-term, herbicide-spraying control program of *Phragmites australis* (common reed), a highly invasive perennial grass, in Sheldon Marsh on Lake Erie's south shoreline. Controlling reed is a priority of many wetland managers because habitat homogenization from reed expansion may adversely affect wildlife habitat and waterfowl. Reed has historically been a minor part of wetland plant communities of the Laurentian Great Lakes but has spread rapidly since 2000 when lake water levels dropped. Here we examined ODNR records and aerial photographs using ArcGIS software and planimetry from 2000 to 2007 to (1) track annual changes in reed localities and areal coverage, (2) compare short-term effectiveness of glyphosate (Glypro® and AquaNeat®) and imazapyr (Habitat®) herbicides, and (3) estimate control costs. Reed first appeared in a small, isolated patch in 1998 but expanded to comprise approximately 18 percent of the marsh's emergent vegetation by 2001. Annual change in areal cover was not related to minor changes in already low Lake Erie water levels. However, reed amount decreased from 6.7 ha (= 14.8 percent of emergent vegetation) in 2004 to 2.5 ha in 2007 after a two- to three-fold annual increase in amount of herbicide used. Short-term, post-spraying necrosis (browning) was slower for *Phragmites* treated with a five percent Habitat® solution than with a 30 percent AquaNeat® solution. Slowed necrosis presumably prolongs photosynthesis and plant nutrient uptake and delays habitat deterioration for some wildlife, but provides time for vegetative spread. Seven years of herbiciding have contained reed to approximately six percent of the emergent plant cover. Estimated control expenditures from 2003 to 2007 were $8475 USD (average approximately $1700/year); a small cost to maintain system ecological diversity.

OHIO J SCI 108 (5):108-112, 2008

INTRODUCTION

Phragmites australis (Cav.) Trin. ex Steud., the common reed, is a tall (>2 m), perennial grass that has invaded and formed extensive monocultures in many North American brackish and freshwater marshes over the last approximately 80 years (Marks et al. 1994). Reasons for its spread and dominance probably include the introduction of a competitively superior genotype (haplotype M) from Europe (Galatowitsch et al. 1999, Saltonstall 2002), its ability to thrive in low water conditions and to quickly spread vegetatively by rhizomes and stolons into exposed mudflats (Marks et al. 1994, Amsberry et al. 2000), and its relative unpalatability to invertebrate herbivores (Polunin 1982, Graca et al. 2001).

Reed has historically been a minor component of wetland plant communities of the lower Laurentian Great Lakes, but has spread rapidly in the last approximately 10 years, as lake water levels have decreased (Wilcox et al. 2003). Controlling reed has become a priority of coastal wetland managers because decreases in plant diversity and habitat homogenization resulting from reed expansion can potentially adversely affect wildlife habitat and waterfowl (Marks et al. 1994). Control options have included cutting, burning, drowning, herbicides, and various combinations of each (Tewksbury et al. 2002, Russell and Kraaij 2008), but herbicides have become the principal control apparently because of their cost-effectiveness and relative ease of use in a variety of wetland types. Glyphosate herbicides, like Glypro® (Dow AgroSciences) and AquaNeat® (Riverdale Chemical), are widely used to eradicate *Phragmites*, in part, because they can be applied locally to invasive patches and have low toxicity to fish and aquatic invertebrates (Marks et al. 1994, Kulesza et al. 2008). The herbicide is mixed with a surfactant to facilitate penetration when applied to aboveground foliage and is transported to the root system where it inhibits amino acid production by inhibiting the enzyme EPSP synthase (Gunsolus and Curran 2002). Treated plants stop growing, wilt, become chlorotic and then necrotic, in approximately two weeks (Giesy et al. 2000). Habitat® (BASF Corporation), a systemic, imazapyr-containing herbicide recently registered for aquatic use in the United States (U.S. EPA 2003), is increasingly being used in aquatic plant management programs (Whyte et al. 2009). Imazapyr is absorbed and translocated to meristematic regions where, like glyphosates, it halts growth and causes necrosis by inhibiting amino acid synthesis (Entrix Inc. 2003). Habitat® is significantly more expensive than glyphosate herbicides, but more product may possibly be obtained from Habitat® given its greater dilution potential (Entrix Inc. 2003). It is unclear which of these herbicide types is better at controlling *Phragmites* and promoting plant community recovery. However, information on long-term effectiveness of any herbicide control plan is critical for assessing management actions and restoration progress.

In 2001, the Ohio Department of Natural Resources (ODNR), Division of Natural Areas and Preserves (DNAP), initiated a long-term, herbicide-based control program of reed at Sheldon Marsh on the south shore of Lake Erie. This initiative provided an opportunity to track the effectiveness of *Phragmites* control using only herbicides. We examined DNAP records and aerial photographs of the marsh from 2000 to 2007 to track annual changes in reed spread and areal coverage. We also compared short-term effectiveness of glyphosate herbicides and Habitat® and estimated the costs of controlling reed.

METHODS

Study Marsh

Sheldon Marsh Nature Preserve is located on the southwest shore of Lake Erie in Huron, Ohio (Erie County), approximately 112 km east of Toledo (Fig. 1). The preserve (latitude 41°41'02"N, longitude 82°60'78"W) is 188 ha, of which approximately 45 ha is emergent plant zone. Water levels in the marsh are directly affected by those of Lake Erie by a permanent approximately 25-m wide connection at the western end of a 1.8-km long barrier beach (Morang and Chader 2005). Reed was first detected in 1998 in a small patch

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in the northeast corner of the marsh, but did not proliferate until 2000 when marsh water levels dropped and mudflats were exposed (G. Obermiller, DNAP, personal communication). To control its spread, herbicides were applied yearly to patches from May to September since 2001 using backpack sprayers. From 2001 to 2006, only a 30 percent solution of Glypro® was used, however in 2007, either a 30 percent solution of AquaNeat® or a 5 percent solution of Habitat®, was used. These respective concentrations are strong, but often used to control reed (Giesy et al. 2000, Mozdzer et al. 2008). Another invasive, narrow-leaf cattail (*Typha angustifolia* L.), is a dominant hydrophyte in the marsh (J.R. Holomuzki and R.S. Whyte, personal observations), but is not controlled because it does not supposedly alter wetland structure and function, like reed (Findlay et al. 2002).

Long- and Short-Term Control

Long-term control effectiveness was assessed by annually tracking changes in reed amount and spread from 2000 to 2007. Aerial photographs of the preserve in August or early September were obtained from the Erie County Auditor (ECA) for 2001, 2003, 2005, and 2006 and from the ODNR for 2000, 2004, and 2007; photographs were not available for 2002. All maps from the ECA were black and white and in digital format. However, the 2000 and 2004 ODNR maps were black and white prints, whereas the 2007 map was a digitally-formatted, color infrared photograph. Reed patches in emergent zones were identified by texture and color, and through ground-truthing with Sheldon Marsh personnel who had applied the herbicide. Polygons were drawn around each patch for each year, and patch area was calculated using either ArcGIS software or planimetry, depending on map format. The same methods were used to estimate emergent zone areas each year. Areas of all reed patches were added and divided by total emergent area to estimate yearly changes in reed relative abundance.

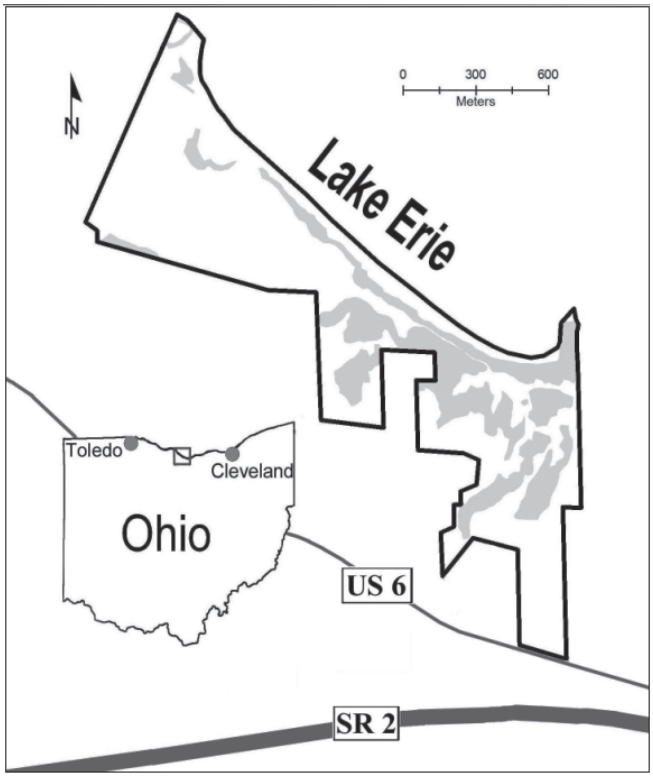

FIGURE 1. Locality and border outline of Sheldon Marsh in Huron, Ohio. Gray patches represent the emergent plant zone in the marsh.

DNAP records for short-term herbicide effectiveness were available for Glypro® treatments from 2001 to 2006 and for AquaNeat® and Habitat® treatments in 2007. Short term effectiveness was measured as the percent visual estimate of the reed patch that became chloritic, then necrotic (i.e., browning), after approximately three weeks post-treatment. Estimates were made by the same person from 2001 to 2003 and by the same two persons from 2004 to 2007, which provided between-year and between-herbicide continuity in the estimates. Browning (percentage) of leaves and shoots was estimated by walking around the periphery and in the interior of the patch along paths made when herbicide was applied.

Financial costs of reed control between 2003 and 2007 were estimated by determining the amount of field hours personnel spent treating reed, salary paid to employees for time treating reed, cost per unit volume of herbicide used, and the cost of equipment (e.g., sprayers). Cost information was not available for 2001 and 2002. Annual salary costs varied, in part, depending on how field time was proportioned between seasonal or full-time employees. Herbicide costs also differed. Glypro® and AquaNeat® were each purchased at $4.80/L, whereas Habitat® was $83.22/L. Equipment purchased for herbicide application between 2003 and 2007 was also included in management costs.

Statistics

We used multiple regression analysis (SYSTAT 9.0, SPSS Inc., Chicago, IL) to test whether total volume of herbicide used and Lake Erie water levels from 2003 to 2007 affected reed areal coverage in the marsh. Mean annual Lake Erie water levels for August (174.13 to 174.28 m) were used in the model and obtained from the U.S. Army Corps of Engineers, Detroit District. We compared short-term (approximately three weeks) browning estimates of reed by AquaNeat® and Habitat® in 2007 using ANOVA on arcsine transformed proportions.

RESULTS

Long-Term Control

In 2000, two years after invasion, reed was found in 14 patches (totaling approximately 2 ha; Fig. 2) spread over much of the emergent plant zone. By summer 2001, *Phragmites* covered 8.2 ha, or approximately 18 percent of the emergent zone (Figs. 2 & 3). Thereafter, herbicide treatments kept *Phragmites* cover to <7

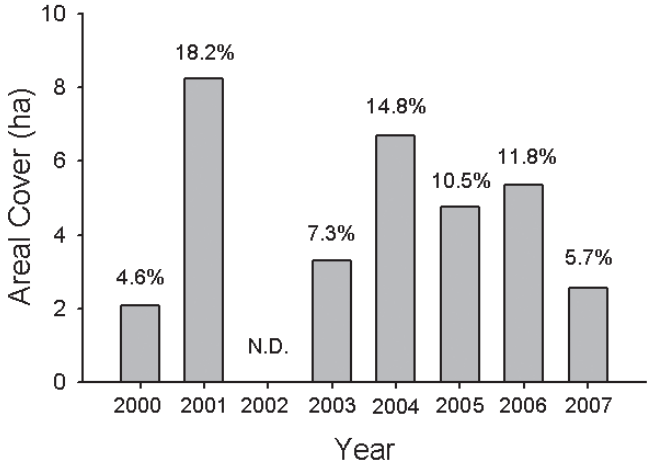

FIGURE 2. Areal cover of *Phragmites* in the marsh each year from 2000 to 2007. Numbers above bars represent the percentage of emergent vegetation comprised by reed. N.D. denotes no data available for that year.

ha per year (Fig. 2). New patch localities appeared annually (Fig. 3), particularly near sprayed patches in the previous year. Emergent zone area also shifted annually, ranging from approximately 39 to 45 ha. Multiple regression analysis showed that *Phragmites* areal cover was not related to minor annual changes in Lake Erie water levels and amount of herbicide used ($R^2_{adj} = 0.493$, $P = 0.254$).

The estimated cost of employee time and product use for reed control from 2003 to 2007 was $7125 USD (Table 1). Equipment purchased solely for reed control between these years included two Birchemeire sprayers (ea. $275 USD), four solo sprayers (ea. $75 USD, three jet guns (ea. $150 USD), and a new nozzle ($50 USD); totaling $1350 USD. Thus, cost of reed control for these five years was $8475 USD. More field hours were devoted to reed control in 2007 than in other years, hence costs associated with employee salaries and product use were also higher that year (Table 1).

Short-Term Control

From 2001 to 2007, between 80 and 95 percent of Glypro®-treated reed patches browned within approximately three weeks (Table 2). Likewise in 2007, AquaNeat® killed, on average, approximately 95 percent of a patch. However, Habitat® caused significantly less short-term browning than AquaNeat® (ANOVA: $F_{1,9} = 5.255$, $P = 0.048$), and degree of browning between patches was highly variable (i.e., high SE) relative to the glyphosates (Table 2).

DISCUSSION

Long-Term Control of Reed

Multiple regression analysis suggested that reed areal cover was not related to minor changes in already low Lake Erie water levels and to amount of herbicide used from 2003 to 2007. However, a reduction in reed amount from 6.7 ha in 2004 to 2.5 ha in 2007 was associated with a two- to three-fold increase in herbicide use. Despite this increase, reed was not completely eradicated. Some reed patches went undetected each year, particularly those in localities with limited access, whereas others went untreated if they were not encroaching on areas with relatively high plant diversity (M.J. Grote, DNAP, personal communication). These reasons certainly contributed to the substantial amount of variability in *Phragmites* cover among years and to our inability to detect a relationship between *Phragmites* cover and amount of herbicide used. Moreover, new patch localities appeared annually (Fig. 3), and vegetative spread by stolons occurred from some patches where reed was not entirely eliminated. A single spray-application of glyphosate or Habitat® may kill approximately 70 to 98 percent of a patch one-year post-spraying (Caffrey 1996, Ailstock et al. 2001, Whyte et al. 2009), and the unkilled portion may vegetatively spread into multiple patches if left unchecked until the next growing season. Further, mini-patches within patches may simply be missed by the

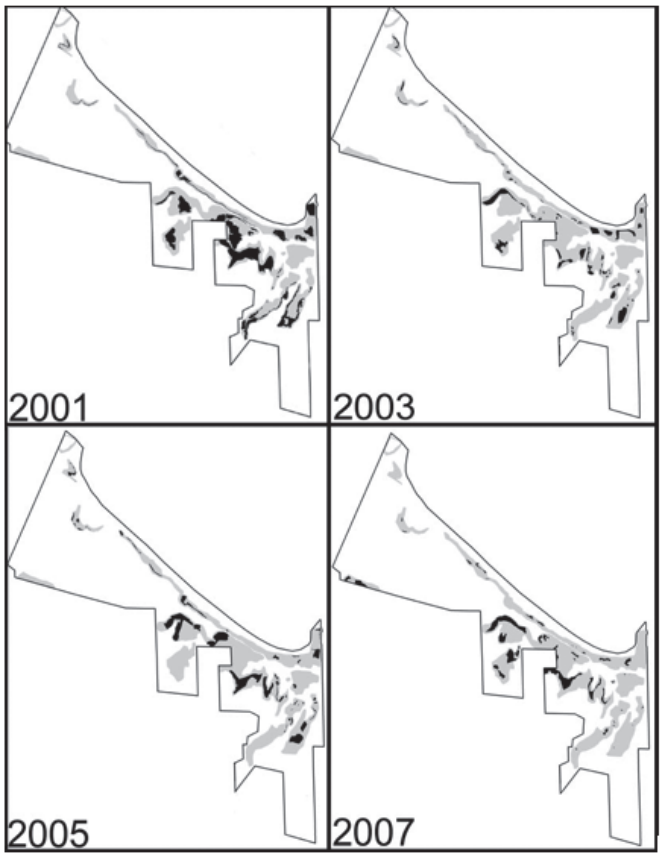

FIGURE 3. Annual changes in reed abundance and localities. Black represents reed patches and gray the emergent plant zone.

Table 1
Estimated costs of employee salaries and herbicide used for reed control from 2003 to 2007.

Year	Field Time (hrs)	Salary (USD)	Herbicide Active Ingredient Used (L)	Herbicide Cost (USD)	Total (USD)
2003	37	444	69.3	311	754
2004	19	228	34.1	153	381
2005	48	768	90.3	405	1173
2006	39	616	87.4	392	1008
2007	136	2176	106.7*	1633	3809
Total	279	4232	387.8	2894	7125

* 92.0 L of AquaNeat® was used from 22 May to 24 July, and 14.7 L of Habitat® was used from 17 July to 21 September.

Table 2
Mean percent (± 1SE) browning of reed patches approximately three weeks after herbicide treatment from 2001 to 2007

Year	Herbicide	Patches Treated	Browning
2001	30% Glypro®	5	81 ± 2
2002	30% Glypro®	9	82 ± 5
2003	30% Glypro®	11	94 ±3
2004	30% Glypro®	5	88 ± 6
2005	30% Glypro®	10	94 ± 3
2006	30% Glypro®	10	91 ± 2
2007*	30% Glypro®	6	96 ± 2
2007*	5% Habitat®	5	59 ± 20

* Browning data are unavailable for seven other sprayed patches (three with AquaNeat® and four with Habitat®) in 2007.

sprayer, particularly in tall, dense beds. Thus, to effectively reduce reed spread, we recommend at least two spraying episodes per patch in a growing season, targeting live areas/stems in the second spraying. The second touch-up treatment is critical for patches that were sprayed early in the summer, prior to the appearance of seed heads, and should preferably be done within 30 days of the first treatment to prevent vegetative spread (Cross and Fleming 1989). Although it is recommended that spraying not occur until mid- to late-summer when seed heads appear and herbicide is translocated to the roots (Entrix Inc. 2003), such timing may not allow for a second treatment, particularly in wetlands with expansive areas of reed and personnel shortages.

Multiple control options may not be possible at Sheldon Marsh, and many other Lake Erie coastal wetlands. For example, an herbicide-burn combination may be impractical, given these wetlands are usually surrounded by suburban residential and commercial buildings. Further, a fire may not burn hot enough to kill the approximately two-m deep root system in water-saturated soils (Kohzu et al. 2003). Herbicides and drowning, or cutting and drowning, may be feasible in some diked marshes, where water levels can be finely controlled, but not in natural marshes with widely fluctuating, uncontrollable water levels. Thus, the best control option in natural, Great Lake coastal wetlands like Sheldon's is to carefully locate and track reed patches using GPS and treat the same patches twice a year over two consecutive years, if possible, with herbicide. Follow-up treatment the second year should selectively target individual plants or small patches by spot-spraying or hand-wicking (Cross and Fleming 1989, Norris et al. 2002) to prevent injury to native plants (e.g., burweed [*Sparganium eurycarpum* Engelm.], arrowhead [*Sagittaria latifolia* Willd.], and cattail [*Typha latifolia* L.]; M.J. Grote, personal communication) beginning to re-establish in treated areas.

Comparing Glyphosate and Habitat® Short-Term Effectiveness

Browning was significantly slower for *Phragmites* treated with a five percent Habitat® solution than with a 30 percent AquaNeat® solution. A 1.5-2.0 percent solution of Habitat® supposedly causes significant browning of reed in two to four weeks when applied during warm, rain-free conditions (Entrix Inc. 2003). Indeed, these conditions existed when both herbicides were applied in 2007 (M.J. Grote, personal communication). Habitat®-treated reed in the nearby Old Woman Creek National Estuarine Research Reserve (Huron, Erie County) also appears to brown more slowly than Glypro®-treated (five percent solution) stands (D.M. Klarer, ODNR, personal communication). Browning equates to necrosis of aboveground growth and eventual root deterioration (Gunsolus and Curran 2002), and timing and extent of browning certainly depends on herbicide concentration. However, delayed necrosis may have significant ramifications on ecosystem function and reed spread in a growing season. For example, reed patches treated with slower-acting Habitat® may possibly uptake nutrients longer, and provide better short-term habitat for birds, terrestrial insects, and aerial life stages of aquatic insects, than those treated with faster-acting, highly concentrated glyphosates. However, delayed necrosis may also allow for prolonged photosynthetic activity, which may enable a reed patch to spread vegetatively by rhizomes and stolons. Given the relative newness of Habitat® use in aquatic systems, long-term data on its effectiveness and benefits is sparse, although Habitat® appears better at reducing reed abundance than glyphosates (Rodeo®) one to two years post-treatment when concentration formulations are similar (Mozdzer et al. 2008).

CONCLUSION

Seven years of herbicide treatments have contained reed to approximately 2.5 ha, or approximately six percent of the emergent plant cover in the marsh. We estimate the cost of reed control in Sheldon Marsh from 2003 to 2007 to be $8475 USD, which averages approximately $1700 per year. We believe this cost is well worth the benefit of preventing reed expansion and maintaining plant diversity and macrofaunal habitat. In freshwater marshes, *Phragmites* expansion can decrease red wing blackbird (*Agelaius phoeniceus*) populations by reducing nesting habitat (Bernstein and McLean 1980), and decrease muskrat (*Ondantra zibethicus*) numbers by reducing the abundance of carbohydrate-rich cattail rhizomes (*Typha* spp.) (Kadlec et al. 2007). Yet, other work suggests that *Phragmites* does not necessarily detrimentally affect benthic macroinvertebrate and juvenile fish community structure and diversity (Kulesza et al. 2008) and soil macroinvertebrate diversity (Ailstock et al. 2001). Thus, the effects of *Phragmites* cover on trophic structure and faunal abundance patterns in the Great Lakes coastal wetlands are not entirely clear, but determining these effects has relevance to management approaches in these systems. It seems clear, however, that system-wide replacement of native flora by *Phragmites* causes major shifts in faunal community composition, at least in brackish wetlands (Benoit and Askins 1999, Meyerson et al. 2000, Angradi et al. 2001, Robertson and Weis 2005). We propose that future studies elucidate the "critical" amount at which marsh spatial and trophic structure is disrupted by reed, given 100 percent eradication of reed is probably impractical and ecologically unnecessary.

Acknowledgements. We thank Steve Harvey, Mike Grote, and Gary Obermiller (DNAP) for their help delineating reed localities on maps, Melissa Moser (DNAP) for providing reed browning records, and Ningchuan Xiao (OSU-Columbus) for GIS consultation. This work was supported in part by a contract to JRH through award NA09NOS4190080 from the National Oceanic and Atmospheric Administration, administered by the Ohio Department of Natural Areas and Preserves through the Ohio Coastal Management Program.

LITERATURE CITED

Ailstock, M.S., C.M. Norman, and P.J. Bushmann. 2001. Common reed *Phragmites australis*: control and effects upon biodiversity in freshwater nontidal wetlands. Restoration Ecology 9:49-59.

Amsberry, L.M., A. Baker, P.J. Ewanchuk, and M.D. Bertness. 2000. Clonal integration and the expansion of *Phragmites australis*. Ecological Applications 10:1110-1118.

Angradi, T.R., S.M. Hagan, and K.W. Able. 2001. Vegetation type and the intertidal macroinvertebrate fauna of a brackish marsh: *Phragmites* vs. *Spartina*. Wetlands 21:75-92.

Benoit, L.K. and R.A. Askins. 1999. Impact of the spread of *Phragmites* on the distribution of birds in Connecticut tidal marshes. Wetlands 19:194-208.

Bernstein, N.P. and E.B.McLean. 1980. Nesting of red-winged blackbirds in cattails and common reed grass in Mentor Marsh. Ohio Journal of Science 80:14-19.

Caffrey, J.M. 1996. Glyphosate in fisheries management. Hydrobiologia 340:259-263.

Cross, D.H. and K.L. Fleming. 1989. Control of *Phragmites* or common reed. Fish and Wildlife Leaflet 13.4.12. U.S. Fish and Wildlife Service, Washington D.C., 5 p.

Entrix Inc. 2003. Ecological risk assessment of the proposed use of the herbicide imazapyr to control invasive cordgrass (*Spartina* spp.) in estuarine habitat of Washington State. Prepared for Washington State of Agriculture. Project No. 3000901.

Findlay, S., S. Dye, and K.A. Kuehn. 2002. Microbial growth and nitrogen retention in litter of *Phragmites australis* compared to *Typha angustifolia*. Wetlands 22:616-625.

Galatowitsch, S.M., N.O. Anderson, and P.D. Ascher. 1999. Invasiveness in wetland plants in temperate North America. Wetlands 19:733-755.

Giesy, J.P., S. Dobson, and K.R. Solomon. 2000. Ecotoxicological risk assessment for Roundup herbicide. Reviews of Environmental Contamination and Toxicology 167:35-120.

Graca, M.A.S., C. Cressa, M.O. Gessner, M.J. Feio, K.A. Callies, and C. Barrios. 2001. Food quality, feeding preferences, survival and growth of shredders from temperate and tropical streams. Freshwater Biology 46:947-957.

Gunsolus, J.L. and W.S. Curran. 2002. Herbicide mode of action and injury symptoms. North Central Regional Extension Publication, No. 377. 19 p.

Kadlec, R.H., J. Pries, and H. Mustard. 2007. Muskrats (*Ondantra zibethicus*) in treatment wetlands. Ecological Engineering 29:143-153.

Kohzu, A., K. Matsui, T. Yamada, A. Sugmoto, and N. Fujita. 2003. Significance of rooting depth in mire plants: Evidence for natural ^{15}N abundance. Ecological Research 18:257-266.

Kulesza, A.E., J.R. Holomuzki, and D.M. Klarer. 2008. Benthic community structure in stands of *Typha angustifolia* and herbicide-treated and untreated *Phragmites australis*. Wetlands 28:40-56.

Marks, M., B. Lapin, and J. Randall. 1994. *Phragmites australis* (*P. communis*): Threats, management, and monitoring. Natural Areas Journal 14:285-294.

Meyerson, L.A., K. Saltonstall, L.Windham, E. Kiviat, and S. Findlay. 2000. A comparison of *Phragmites australis* in freshwater and brackish marsh environments in North America. Wetlands Ecology and Management 8:89-103.

Morang, A. and S. Chader. 2005. Geology and historical evolution of Sheldon Marsh Nature Preserve, Lake Erie, Ohio. U.S. Army Corps of Engineers, Engineer Research and Development Center, Coastal and Hydraulics Laboratory, Vicksburg, MS.

Mozdzer, T.J., C.J. Hutto, P.A. Clarke, and D.P. Field. 2008. Efficacy of imazapyr and glyphosate in the control of non-native *Phragmites australis*. Restoration Ecology 16:221-224.

Polunin, N.V.C. 1982. Processes contributing to the decay of reed (*Phragmites australis*) litter in fresh water. Archiv für Hydrobiologie 94:182-209.

Robertson, T.L. and J.S. Weiss. 2005. A comparison of epifaunal communities associated with the stems of salt marsh grasses *Phragmites australis* and *Spartina alterniflora*. Wetlands 25:1-7.

Russell, I.A. and T. Kraaij. 2008. Effects of cutting *Phragmites australis* along an inundation gradient, with implications for managing reed encroachment in a South African estuarine lake system. Wetlands Ecology and Management 16:383-393.

Saltonstall, K. 2002. Cryptic invasion by a non-native genotype of the common reed, *Phragmites australis*, into North America. Proceedings of the National Academy of Sciences of the USA 99:2445-2449.

Tewksbury, L., R. Casagrande, B. Blosey, P. Hafliger, and M. Schwarzlander. 2002. Potential for biological control of *Phragmites australis* in North America. Biological Control 23:191-212.

U.S. EPA. 2003. Office of Pesticide Programs. Work plan for the registration of conventional pesticides.

Whyte R.S., J.R. Holomuzki, and D.M. Klarer. 2009. Wetland plant and macroinvertebrate recovery in *Phragmites australis*-dominated stands after herbicide (Habitat®) treatment. Verhandlungen der Internationalen Vereinigung für theoretische und angewandte Limnologie 30:725-730.

Wilcox, K.L., S.A. Petrie, L.A. Maynard, and S.W. Meyers. 2003. Historical distribution and abundance of *Phragmites australis* at Long Point, Lake Erie, Ontario. Journal of Great Lakes Research 29:664-680.