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Efficacy of Imazapyr and Glyphosate in the Control of Non-Native *Phragmites australis*

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Abstract

The cosmopolitan common reed (*Phragmites australis*) has been expanding into previously unoccupied wetland habitats throughout North America. This invasion by a non-native haplotype of *Phragmites* has become a major concern due to a reduction in plant diversity, reduction of faunal biodiversity, and changes in ecosystem structure. A randomized complete block design was used to compare the efficacy of two herbicides, glyphosate (Rodeo, Dow AgroSciences, IN, U.S.A.) and imazapyr (Habitat, BASF Corporation, NC, U.S.A.), on 1-ha *Phragmites* monoculture in a shallow borrow pit. Six foliar experimental treatments were applied consisting of (1) 2% glyphosate formulation, June application; (2) 2% glyphosate formulation, September application; (3) 2% imazapyr formulation, June application; (4) 2% imazapyr formulation, September application; (5) 5% imazapyr formulation, June application; and (6) 5% imazapyr, September application. Experimental plots were monitored yearly for two years after treatment. Relative importance values (RIV) were determined to assess the efficacy of herbicide treatments. We report that imazapyr foliar application is statistically superior to glyphosate in reducing *Phragmites* RIV, with no significant differences between the 2 and 5% formulations. Both herbicides are more effective in reducing *Phragmites* RIV if applied early in the growing season (June). No significant differences in non-*Phragmites* plant recolonization were observed between herbicide treatments over the two-year time course. These results suggest that imazapyr is superior in reducing *Phragmites* RIV, and that earlier applications of herbicides may be more effective on *Phragmites*. However, managers must note that adjacent nontarget plant species may be negatively affected by earlier treatments.

Key words: glyphosate, habitat restoration, herbicide, imazapyr, phragmites, wetlands.

Introduction

The common reed (*Phragmites australis* (Cav.) Trin. Ex Steud.) has been described as one of the most widely distributed angiosperms in the world (Holm et al. 1977; Clevering and Lissner 1999). It is commonly found in freshwater and brackish wetlands and along the upland edges of tidal marshes. Although historically a natural component of the wetland community, over the past 100 years, *Phragmites* has increased in proportion in both tidal and nontidal wetlands in North America and has become a major concern to wetland ecologists (Chambers et al. 1999; Findlay et al. 2002; Windham and Meyerson 2003). Genetic research has demonstrated that although 11 haplotypes of *Phragmites* are endemic to the North American continent, an introduced haplotype is responsible for the recent population explosion (Saltonstall 2002). This expansion of *Phragmites* has resulted in changes in both wetland structure and function. For example, expansion of *Phragmites* into salt marshes reportedly caused a five-fold decrease in plant species richness (Bertness et al. 2002), reductions in microtopography (Windham and Lathrop 1999, Raichel et al. 2003), and reductions in biodiversity (Chambers et al. 1999).

To date, several strategies have been utilized to eradicate *Phragmites*, with differing levels of success (Ailstock et al. 2001). Of these strategies, multiyear application of the herbicide glyphosate has been the most effective when applied in early fall after native plants have senesced. Unfortunately, glyphosate usually requires multiple applications over successive years to be effective after which restoration areas enter an indeterminate maintenance phase requiring periodic follow-up treatments.

United States Environmental Protection Agency approval of the imazapyr salt in September 2003 packaged under the trademarked name, Habitat, has provided land managers with an alternate choice of herbicide for the control of *Phragmites*. The objective of our study was to compare the efficacy of these two herbicides, glyphosate (Rodeo) and imazapyr (Habitat), in the reduction of non-native *Phragmites* by manipulating herbicide concentrations and seasonality of applications.

Methods

The study was conducted within Kiptopeke State Park (lat 37.169°N, long 75.971°W), Northampton County, Eastern

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* The restoration community misses Curtis J. Hutto, who suffered a heart attack and passed away while working on a *Phragmites* remediation site on September 26, 2005.

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Shore of Virginia, United States. Experimental plots were located in a well-established 1-ha stand of untreated *Phragmites* surrounded by a coastal plain pine-hardwood forest. A randomized complete block design was used to compare the efficacy of two herbicides, glyphosate (Rodeo) and imazapyr (Habitat), on a 1-ha *Phragmites* monoculture in a shallow borrow pit. Six foliar experimental treatments were applied to individual 100-m^2 macroplots. Treatments consisted of (1) 2% glyphosate formulation, June application; (2) 2% glyphosate formulation, September application; (3) 2% imazapyr formulation, June application; (4) 2% imazapyr formulation, September application; (5) 5% imazapyr formulation, June application; and (6) 5% imazapyr, September application. Two experimental 1-m^2 plots within each macroplot were monitored for two years post-treatment. Relative importance values (RIV) were determined to assess the efficacy of herbicide treatments. Each treatment was replicated three times within the 1-ha site. A control area was established beyond the drift potential of the treatment plots. Three experimental blocks were used to yield three replicates per treatment. Each treatment was uniformly applied within a 10 × 10–m macroplot using a portable backpack sprayer. To ensure consistent application between macroplots, a ladder was used to reach above the *Phragmites* canopy to mimic aerial application. Post-treatment data were collected yearly in September 2005 and 2006.

Within each quadrat, the following response variables were measured yearly: (1) number of living *Phragmites* stems, (2) mean height of living *Phragmites* stems, (3) percent cover of living *Phragmites* foliage, and (4) percent cover of living non-*Phragmites* vegetation. To provide a quantitative measure of herbicide effects on *Phragmites*, the first three attributes were combined to reflect a RIV index to determine statistical differences between application treatments using the equation:

$$\mathrm{RIV} = \left[\left(\frac{d}{D} \times 100\right) + \left(\frac{h}{H} \times 100\right) + \left(\frac{c}{C} \times 100\right)\right]$$

where d = the stem density within an individual quadrat, D = maximum stem density of all quadrats, h = mean height within an individual quadrat, H = maximum height among all quadrats, c = percent cover *Phragmites* within an individual quadrat, and C = maximum percent cover *Phragmites* among all quadrats. RIV and percent non-*Phragmites* data were analyzed in SAS (version 9.1) using PROC MIXED, taking into account that this was a repeated measures design. Post hoc tests were determined by contrasts. Replicate plots within macroplots were averaged prior to statistical analysis.

Results

We report that imazapyr foliar application is significantly superior to glyphosate in reducing *Phragmites* RIV ($df = 1$, $F = 6.88$, $p = 0.0121$) (Fig. 1), with no significant differences observed between the 2 and 5% imazapyr formulation ($df = 1$, $F = 0.05$, $p = 0.8321$) (Fig. 1). Over the course of two years, RIV of imazapyr-treated plants was reduced by over 95% compared to glyphosate, which reduced RIV by 79%. Additionally, all herbicide treatments are significantly more effective in reducing *Phragmites* RIV if applied early in the growing season (Fig. 1) ($df = 1$, $F = 4.62$, $p = 0.0374$). The application time effect was greatest in the glyphosate application, resulting in 20% greater reduction of *Phragmites* RIV, compared to 3% with imazapyr. No significant differences were observed between either herbicide treatments in regard to plant recolonization over the two-year time course ($df = 2$, $F = 0.26$, $p = 0.7749$) (Fig. 2). However, there is a significant

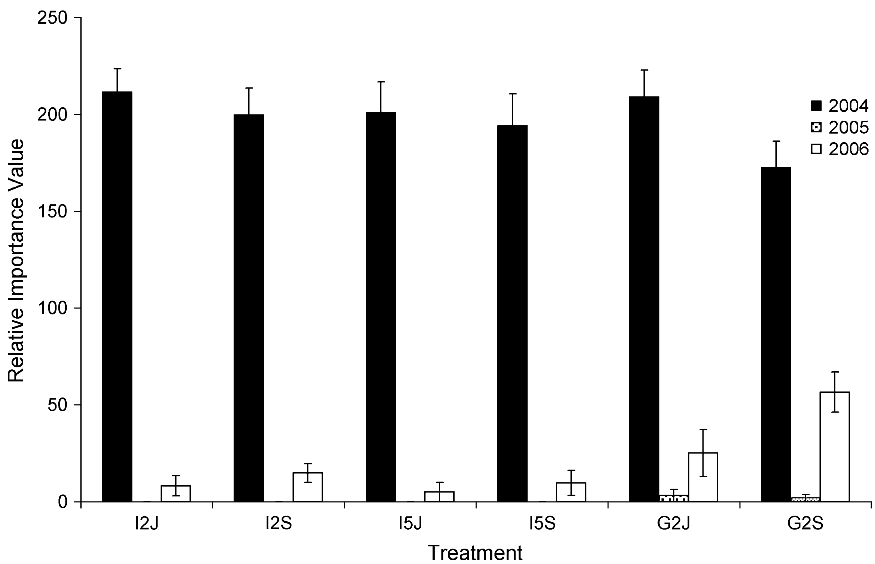

Figure 1. Effects of herbicide treatment on RIV. n = three replicate plots per year. Error bars indicate 95% confidence intervals.

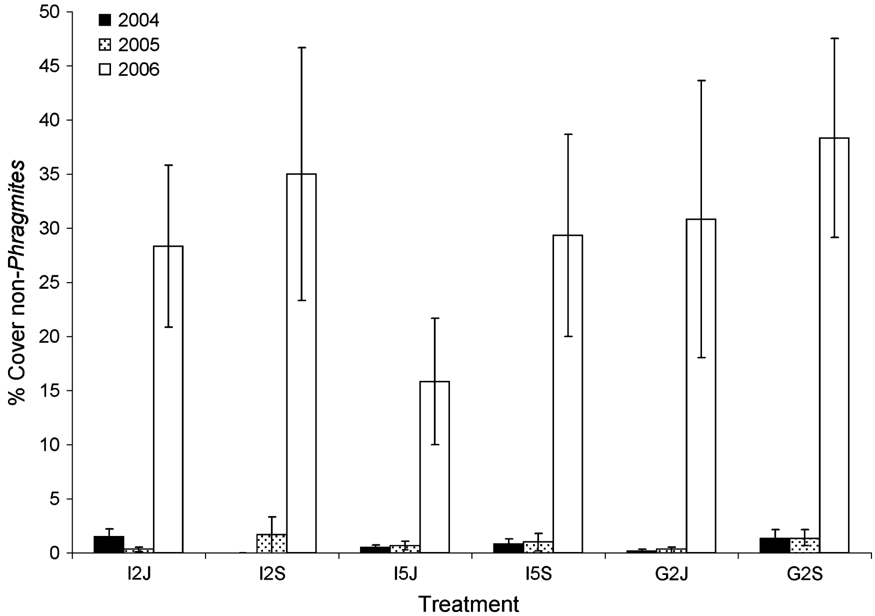

Figure 2. Effects of herbicide treatment on non-*Phragmites* percent cover. n = three replicate plots per year. Error bars indicate SE.

effect of application date for all treatments with September applications resulting in a slightly increased recolonization compared to those treated in June ($df = 25$, $F = 3.41$, $p = 0.076$). This effect was greatest in the glyphosate treatment.

Discussion

Our results suggest that imazapyr is significantly better at reducing *Phragmites* RIV compared to the traditionally applied herbicide, glyphosate. Although glyphosate reduced *Phragmites* RIV by 79%, imazapyr resulted in a greater than 95% reduction. Our results are consistent with long-term aerial applications (from 2003 to 2006) of imazapyr and glyphosate in Virginia wetlands that reported greater effectiveness of imazapyr over glyphosate at controlling *Phragmites* (Clarke 2006). Although the authors concede that a borrow pit may limit the degree to which these results can be generalized, this design does allow testing for the effects of herbicide treatment alone, limiting other environmental covariates.

Our study demonstrated that glyphosate was most effective at reducing *Phragmites* RIV when applied in June, which is contrary to label application instructions under the trademark name Rodeo. A level of uncertainty remains regarding the impact of imazapyr on native, nontarget species. Results from our study do not show a significant difference between imazapyr and glyphosate applications in regard to non-*Phragmites* plant recolonization. However, the highest application concentration of imazapyr, when applied in June, did coincide with the lowest recovery within all treatments. This result and those of Clarke (2006) suggest that recolonization by native species may be inhibited by imazapyr when applied earlier in the growing season. Although photodegredation of imazapyr occurs within two days in aquatic solutions, microbial degradation can take up to seven months (Tu et al. 2001), which can limit recolonization by desirable species if imazapyr enters the soil fraction. This area of uncertainty in *Phragmites* sites needs further research to determine long-term effects on native plant species recolonization. All tested herbicide treatments did effectively remove *Phragmites.* However, a likely candidate to recolonize these newly disturbed habitats is *Phragmites* if sufficient recolonization by native plants does not occur.

We recommend that land managers managing *Phragmites* remediation projects use imazapyr because it requires fewer applications and is more effective. In addition, herbicides applied early in the growing season may be up to 20% more effective. However, managers must note that this may negatively affect adjacent nontarget species.

Conclusions

Our study demonstrates that imazapyr reduces *Phragmites* RIV significantly more (about 15%) than does glyphosate. Therefore, the use of imazapyr may require fewer applications to reduce *Phragmites* RIV. Contrary to traditional practices, herbicides may be more effective if applied earlier in the growing season. However, managers must note that this may negatively affect adjacent non-target plant species and reduce non-*Phragmites* recolonization.

Implications for Practice

- The herbicide imazapyr, applied under the trade name Habitat, is more effective at reducing *Phragmites* than the herbicide glyphosate, applied under the trade name Rodeo over the course of two years.
- For improved control of *Phragmites*, herbicides may be more effective if applied earlier in the growing season. However, managers must note that this may negatively affect native nontarget species.

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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.

Bertness, M. D., P. J. Ewanchuk, and B. R. Silliman. 2002. Anthropogenic modification of New England salt marsh landscapes. Proceedings of the National Academy of Sciences of the United States of America **99:**1395–1398.

Chambers, R. M., L. A. Meyerson, and K. Saltonstall. 1999. Expansion of *Phragmites australis* into tidal wetlands of North America. Aquatic Botany **64:**261–273.

Clarke, P. A. 2006. Aquatic resources trust fund *Phragmites australis* control in Eastern Virginia; Year 3 final report. Natural Heritage Technical Report #06-12, Virginia Department of Conservation and Recreation, Richmond, Virginia.

Clevering, O. A., and J. Lissner. 1999. Taxonomy, chromosome numbers, clonal diversity and population dynamics of *Phragmites australis*. Aquatic Botany **64:**185–208.

Findlay, S. E. G., 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.

Holm, L. G., D. L. Plucknett, J. V. Pancho, and J. P. Herberger. 1977. The world's worst weeds. University Press of Hawaii, Honolulu.

Raichel, D. L., K. W. Able, and J. M. Hartman. 2003. The influence of Phragmites (common reed) on the distribution, abundance, and potential prey of a resident marsh fish in the Hackensack Meadowlands, New Jersey. Estuaries **26:**511–521.

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 United States of America **99:**2445–2449.

Tu, M., C. Hurd, and J. M. Randall. 2001. Weed control methods handbook: tools & techniques for use in natural areas (available from http://tncweeds.ucdavis.edu).

Windham, L., and R. G. Lathrop. 1999. Effects of *Phragmites australis* (common reed) invasion on aboveground biomass and soil properties in brackish tidal marsh of the Mullica River, New Jersey. Estuaries **22:**927–935.

Windham, L., and L. A. Meyerson. 2003. Effects of common reed (*Phragmites australis*) expansions on nitrogen dynamics of tidal marshes of the northeastern US. Estuaries **26:**452–464.