Appendix A

Investigating Alternatives for Control of *Phalaris arundinacea* (Reed Canarygrass) in Urban Wetlands

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Abstract

Management of invasive vegetation is one of the main challenges to natural resource managers whose goal is to preserve the biodiversity and functional values of wetlands. *Phalaris arundinacea* (reed canarygrass) is one invasive species that tends to dominate native vegetation, often resulting in a monoculture that is detrimental to many of the valuable functions provided by wetlands. Unfortunately, the common effective control techniques, such as herbicide application and removal of topsoil, often involve significant negative impact to wetlands. This study investigated the effectiveness of three alternative control techniques which may be able to reduce incidental impacts. Techniques were also chosen to be reasonably affordable and available for the management of smaller urban wetlands, not necessarily applicable to large tracts of land. Two commercial solutions of vinegar and other natural substances were applied as "natural herbicides." The effectiveness of solarization with sheets of black plastic and wood chip mulch was also investigated. Treatments were applied to mowed plots of homogenous *P. arundinacea* in two restored wetlands owned by The Wetlands Conservancy, in northwest Oregon. The results suggested that solarization with black plastic was the most effective technique, with a 100% reduction in the number of *P. arundinacea* stems at the conclusion of the study. Woodchip mulch successfully reduced the number of stems by about 85%, however it appeared that the grass would eventually grow through the mulch and reclaim the area. The vinegar solutions were not found to significantly reduce *P. arundinacea*, but further investigation into the effectiveness of such products seems warranted.

Introduction

Phalaris arundinacea (reed canarygrass) is an invasive species that has detrimental impact on the resource and functional values of wetlands. Its tenacity and rapid growth make it a serious threat to wetland systems because it can grow dense monotypic colonies that displace native plant species (Naglich 1994). Replacing native plant communities with a monoculture can cause a decrease in habitat quality and wildlife diversity (Pavegilo and Kilbride 2000). For example, native vegetation that provides a necessary food source for migratory birds can be lost, and increasingly anaerobic soil conditions caused by *P. arundinacea* monocultures can result in a decline in invertebrate species (Gaston 1998). Wetlands in urbanized areas that have been disturbed due to alteration of hydrology, water quality, vegetation or soil are particularly susceptible to invasion by *P. arundinacea* (Naglich 1994).

There is some uncertainty in the literature as to whether *P. arundinacea* is a native or introduced plant in North America. One of the dominant views is that it is native both to North America and Europe. It has been documented that European cultivars were planted in North America during the 1800s, and that they have coexisted with native *P. arundinacea* since then (Gifford 2002). It is also possible that the native strain has hybridized with the introduced one, and that agricultural varieties have been selectively bred over time to grow quickly and adapt to a wide range of habitats. The grass continues to be used in North America as a forage crop, as well as for wastewater treatment and erosion control. Whether it is a non-native, hybrid or native species is less relevant to environmental resource managers than the fact that it is highly invasive. Its success at dominating native vegetation in disturbed wetlands makes it a common management target for those who wish to preserve the environmental resources and functional values of urban wetlands.

Invasive characteristics of *P. arundinacea*

P. arundinacea possesses many characteristics typical of invasive plant species. As discussed in more detail below, it is highly competitive with wide genetic variability, phenotypic plasticity, tolerance for a variety of conditions, sexual and asexual reproduction, effective dispersal mechanisms, and small seed mass. It is also able to occupy the same ecological niche as many native plants.

It is a tall cool-season perennial found throughout the temperate regions with a strong presence in the Midwest and Pacific Northwest of America (Paveglio and Kilbride 2000). *P. arundinacea* grows as a perennial from scaly, creeping rhizomes and produces culms from 0.5 to 2 meters in height (Apfelbaum 1987). It produces seeds that germinate immediately after ripening with no known dormancy requirements (Apfelbaum 1987). Germination occurs in early spring and seedlings grow to maximum height within about five to seven weeks, after which tillering occurs (Comes et al. 1981). It reproduces sexually by seeds or vegetatively by rhizomes. The radial spread of the rhizome growth results in a dense, highly productive monoculture (Apfelbaum 1987). *P. arundinacea* is classified as a facultative wet (FACW) species that grows well in wetlands, wet prairies and riparian areas, but can also grow successfully in uplands (Naglich 1994). It favors seasonally saturated or moist soils, with open or partially shaded habitat, and most sources agree that it does not tolerate full shading (Naglich 1994). Constant inundation usually prevents establishment, but once it has become established, it can survive when submerged for extended periods of time (Gaston 1998). According to the 1994 paper on *P. arundinacea* by Naglich, it can survive inundation for up to 70 days.

Seeds of *P. arundinacea* are dispersed via flowing water, resulting in rapid colonization of unvegetated sediment deposits (Naglich 1994). Its rapid growth in streams and drainage ditches can trap sediment and form thick rhizome mats that clog channels and slow drainages (Naglich 1994). This is an example of how *P. arundinacea* can alter an ecosystem to enhance the ability of the invasive plant to spread while displacing the native species.

Miller and Zedler (2002) suggested that *P. arundinacea* will grow in balance with native wetland vegetation without becoming dominant until there is a nutrient input from anthropogenic sources (like stormwater runoff) that shifts the balance and allows *P. arundinacea* to dominate the natives. Plants that become dominant when there is a change in nutrient levels tend to behave invasively (Grime 1977). With nutrient pollution or other anthropogenic disturbances, *P. arundinacea* can dominate in wetlands and result in a monoculture that significantly reduces biodiversity and habitat value.

Controlling *P. arundinacea*

It has been well documented that monotypic stands of *P. arundinacea* can be detrimental to wetland resources and functional values (Apfelbaum and Sams 1987; Gaston 1998; Kilbride and Paveglio 1999; Miller and Zedler 2003; Naglich 1994). The complicating issue with *P. arundinacea* is that the control techniques known to reduce its presence are usually damaging to wetlands (Gaston 1998; Naglich 1994). In fact, many sources agree that the impact of common control techniques are so severe that removal of the species from wetlands with those techniques would not result in net benefit to the wetland (Gaston 1998; Naglich 1994). For example, in a 1999 study of *P. arundinacea* control techniques by Kilbride and Paveglio, suggested techniques involved herbicide application and disking or scraping of the soil, all of which would likely result in significant damage to the wetland. Furthermore, the equipment required for such mechanical removal may be too expensive for managers of small urban wetlands to use.

Glyphosate based herbicides such as Rodeo or Roundup are commonly used to control weeds, including *P. arundinacea*. Glyphosate has a relatively low impact on non-target organisms (Naglich 1994). However, commercial glyphosate-based herbicides are usually enhanced by surfactants to help the chemical cling to plant leaves. The surfactant components of glyphosate-based herbicides can be more persistent and potentially harmful than the glyphosate itself (Apfelbaum 1987; Naglich 1994). Because of the real or perceived negative impacts, urban resource managers who work closely with communities may not wish to use glyphosate products.

Mowing is a common control technique which can effectively reduce *P. arundinacea* if it is repeated enough to exhaust the rhizomes (Naglich 1994). However, if it is not repeated enough, mowing could actually increase stem density because multiple shoots could grow from each mowed stem. Therefore, mowing in conjunction with secondary control methods would be more effective than simply mowing once during a season. Mowing reed canarygrass patches in small urban wetlands can be accomplished with little expense and effort using a hand held weed whip. The only likely impact to the wetland presented by mowing with a weed whip would be foot traffic. In cases where the area is dry enough, a field mower can be used with little impact to other vegetation or the soil.

Because *P. arundinacea* can have such a detrimental impact to wetlands and their associated resource functions, control and eradication where possible should be a management goal. However, continued research into control techniques that are not prohibitively destructive to wetlands is essential if we wish to protect wetland biodiversity and habitat quality. Research should also continue to improve management techniques available and acceptable for use by local communities and smaller scale management organizations focusing on wetlands in the urban setting.

Alternatives to the common control techniques

Research has begun to show that combinations of different techniques are more effective at controlling *P. arundinacea* than individual treatments (Kilbride 1999) (Paveglio 2000). This study investigates the effectiveness of some low cost alternative control techniques that can be applied after mowing *P. arundinacea* in smaller urban wetlands. The techniques chosen were two commercial solutions containing acetic acid (vinegar), solarization with black sheet plastic and woodchip mulch. The secondary techniques in this study were chosen because they were presumed to be less damaging to wetlands than conventional methods, as discussed above. They were also chosen for economy and availability to community land stewards and organizations with small budgets available for weed management. The study also focuses on techniques and conditions that are pertinent to smaller urban wetlands as opposed to larger tracts of land that are often managed by a single property owner or a government agency. Alternative techniques that were not investigated in this study, but that warrant additional future consideration include flooding, stomping, grazing (for example by goats), biological control, and competitive vegetation to shade or otherwise compete with *P. arundinacea*.

It has been documented that acetic acid can damage propagules and inhibit sprouting in the aquatic weed: *Hydrilla verticillata* (Spencer et al 1995). Supporting literature was not found to document that acetic acid would be effective against *P. arundinacea.* However, if it can inhibit *Hydrilla* growth, an investigation into the effectiveness of acetic acid for control of *P. arundinacea* is warranted. "Natural herbicides" containing vinegar were used to investigate whether acetic acid could be an effective alternative to glyphosate based herbicides for *P. arundinacea* control. The brand names of the two products were AllDown and BurnOut. A web site selling BurnOut provided the following description:

> "BurnOut is an all natural acid based non-selective herbicide made from vinegar and lemons. It is 100 per cent biodegradable and completely safe for the environment, man and animal. When you spray BurnOut on weeds and grass, it binds to the surface of the plant and begins to destroy the cell structure through a burn down process, killing the plant roots and all. Once BurnOut is applied, the plant begins to stress. Results can be seen in as little as six hours after application. Once in the soil, BurnOut becomes inert. There is no toxic residue left behind. It works best in non-shaded open areas when daytime temperatures are above 60 degrees (optimum is 73 degrees F). BurnOut is in a ready to use sprayer and contains 24 oz. of fast acting natural herbicide."
> (Gardenshoponline.com, 2004)

Ingredients of BurnOut:
Clove oil – 12%
Sodium Lauryl Sulfate – 8%
Vinegar, lecithin, water, citric acid, mineral oil - 80%

Similarly, a website selling AllDown advertised that:

> "AllDown is made of a special blend of synergistic components containing no harsh chemicals that will burn-down unwanted top growth foliage. Within less than an hour you will notice wilting of plants caused by desiccation. In some cases a repeat application may be required to perennial weeds."

(www.sumerset.com, 2004)

Ingredients of AllDown:
Citric acid – 5%
Garlic – 0.2%
Vinegar, water – 94.8 %

The technique of solarization was also investigated. This method involved placing a sheet of black or clear plastic over the area infested by *P. arundinacea* after mowing. The purpose of the plastic was to kill vegetation underneath by increasing the temperature. The final technique used for the study was a thick layer of woodchip mulch to cover the grass after mowing. The mulch was intended to prevent regrowth.

As stated previously, simply mowing reed canarygrass was expected to increase the density of stems. This study was designed to test the effectiveness of secondary treatments to prevent regrowth, assuming that mowing already occurred. We expected to see increasing stem numbers on the control plots because all plots were mowed, including the controls. The intent was to determine if and to what degree any of the study treatments, combined with mowing, would reduce stem numbers. It was hypothesized that despite the purported abilities of BurnOut and AllDown, they would not be able to significantly reduce *P. arundinacea* stem density. Since the solutions mostly cause damage to the above ground portions of the grass, the rhizomes could remain intact, allowing regrowth similar to when the grass is only mowed. Furthermore, it was hypothesized that solarization would be the most effective control technique investigated in this study, followed by wood chip mulching.

Methods

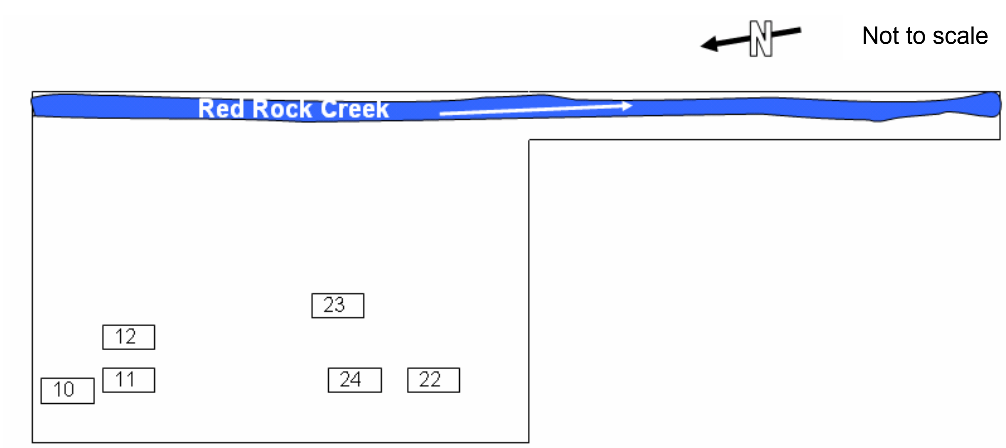
Test sites for the experiment were located at Cedar Mill wetland in Portland, Oregon and Knez wetland in Tigard, Oregon. Both are remnant wetlands surrounded by light industrial/commercial development and roads. Knez wetland is an approximately two-acre Willamette Valley wetland prairie with three main vegetative communities. The primary community is tufted hairgrass prairie, followed by a slough sedge assemblage and a reed canarygrass monoculture. Restoration work has been done on Red Rock Creek which flows through Knez wetland. Native plantings have also been installed in Knez over the past several years. Test plot sites may have been altered as part of a restoration or ditch excavation project. Cedar Mill wetland is an approximately sixteen-acre site with diverse vegetation including year-round ponds, forested upland, scrub-shrub areas, and wet meadow communities. Cedar Mill was a historical wetland that has been drained and used as a farm field and other uses for many years. It was restored as a wetland several years ago for mitigation. The area of Cedar Mill where test plots were established was likely altered as part of the restoration project. The study sites were located within areas of homogenous reed canarygrass stands throughout the two wetlands.

As shown in Table1 below, three test plots were used at Cedar Mill for AllDown application and three were used for BurnOut application. Three control plots were at the same site location in Cedar Mill. At Knez there was one AllDown Plot, one BurnOut plot and one control plot. Four plots at Cedar Mill were used for solarization. Two control plots accompanied those solarization plots at Cedar Mill. At Knez there were two solarized plots and one control plot. There were two plots covered with wood chip mulch at Cedar Mill with one control plot at the same site. Ideally, 12 test plots would have been used for each of the treatment types, however, there were not enough areas of homogenous reed canarygrass to create 12 for each treatment type. The plots for each treatment type were accompanied by a control plot in the same area in order to reduce the confounding factors of differing environmental conditions between sites.

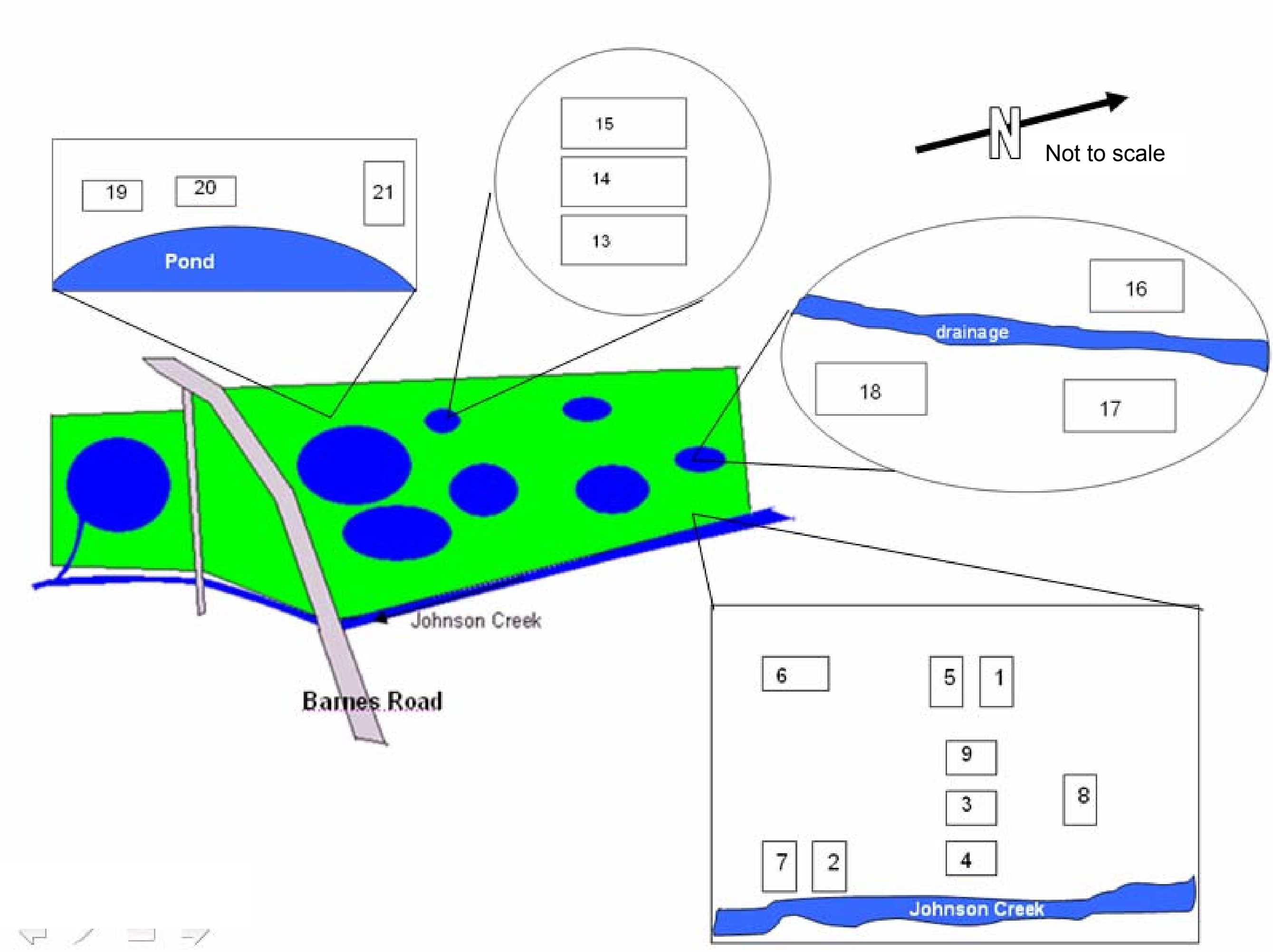
In 2004, beaver activity on the creek adjacent to some of the test plots caused complete flooding of Plot 4 and greatly increased the wetness on Plots 2, 3, 7 and 9. Plot 4 was the closest to the creek, and at the time of the final stem count it had been cleared of grass by the beavers for use in their dam. Plot 4 was almost entirely devoid of grass at the final count. The other plots listed received much more moisture than the previous year, boosting reed canarygrass growth later in the dry fall months. Plot 6 was a control plot which was not mowed as it should have been. Since it was not mowed, it was not comparable to the other plots. Also, beaver activity completely inundated the area where solarization Plots 13, 14 and 15 were located. In the past, this area remained dry in the late spring through the fall. In order to eliminate these confounding factors, Plots 2, 3, 4, 6, 7, 9, 13, 14 and 15 were removed from the data set. Although it is regrettable that the data from these plots could not be used, the data from two AllDown plots, two BurnOut plots and two control plots were still available with Plots 1, 5, 8, 10, 11 and 12. Solarization plots and adjacent controls: 16, 17, 18 , 22, 23 and 24, were still available for data collection. Each plot contained three sample blocks, resulting in six stem count blocks for each treatment type and the control.

Map 1. Location of Cedar Mill and Knez Wetlands

Map 2. Test Plots at Knez Wetland



Map 3. Sites and Test Plots at Cedar Mill Wetland



Test plots were 200 square feet each, with dimensions of 10 feet by 20 feet. Each test plot contained a grid of 50, two-foot by two-foot, sample blocks. Three sample blocks in each plot were chosen for sampling. The sample blocks were numbered from one to 50, and three sample blocks were chosen using a random number table generated by statistical software. Plots were mowed with a weed whip so that reed canarygrass stems were approximately three inches tall. After mowing, stems in the selected sample plots were counted and the number of stems in each sample block was recorded.

Table 1: Plots and Applications

Plot #	Wetland	Application	Note
1	Cedar Mill	BurnOut	Data used
2	Cedar Mill	AllDown	Flooded (Data not used)
3	Cedar Mill	AllDown	Flooded (Data not used)
4	Cedar Mill	Control	Flooded (Data not used)
5	Cedar Mill	AllDown	Data used
6	Cedar Mill	Control	Not mowed (Data not used)
7	Cedar Mill	BurnOut	Flooded (Data not used)
8	Cedar Mill	Control	Data used
9	Cedar Mill	BurnOut	Flooded (Data not used)
10	Knez	Control	Data used
11	Knez	BurnOut	Data used
12	Knez	AllDown	Data used
13	Cedar Mill	Solarization	Flooded (Data not used)
14	Cedar Mill	Solarization	Flooded (Data not used)
15	Cedar Mill	Control	Flooded (Data not used)
16	Cedar Mill	Solarization	Data used
17	Cedar Mill	Solarization	Data used
18	Cedar Mill	Control	Data used
19	Cedar Mill	Wood chip mulch	Data used
20	Cedar Mill	Wood chip mulch	Data used
21	Cedar Mill	Control	Data used
22	Knez	Solarization	Data used
23	Knez	Solarization	Data used
24	Knez	Control	Data used

Dates and Actions:

Spring 2003:

All plots were established, mowed and stems were counted

Fall 2003:

All plots were mowed

AllDown and BurnOut were applied

Black plastic was put in place for solarization

Woodchip mulch was put in place

Spring 2004:

AllDown plots, BurnOut plots and all control plots were mowed

(There was no *P. arundinacea* growing on solarization or woodchip plots at this time)

Stems were counted on all plots with *P. arundinacea*

AllDown and BurnOut were reapplied

Fall 2004:

AllDown plots, BurnOut plots, woodchip plots and all control plots were mowed

(Some *P. arundinacea* was growing on woodchip plots at this time, but not on solarization plots)

Stems were counted on all plots with *P. arundinacea*

AllDown and BurnOut were broadcast sprayed with backpack sprayers as instructed on the containers. The brand of plastic sheet used for the solarization was TRM Manufacturing 62050B - 0.006 mm thickness. The plastic was extended approximately three feet beyond the edges of the plots to help prevent rhizomes from grass beyond the plastic from supporting the growth under the plastic. Wood chip mulch was placed approximately 10 inches thick over the test plots. The mulch was placed about three feet beyond the edges of the plots. Chips were acquired from local tree chipping companies, and consisted of various tree and shrub species.

Results

Stems were counted before treatments were applied. The Spring 2003 pre-treatment counts are shown in the column labeled "Initial / Combined Stem Count" in Tables 2, 3, 4 and 5 below. These stem count numbers are the combined number of stems of the sample blocks counted in each treatment plot. The separate sample block counts are shown in the column preceding each combined stem count column. The second stem count is in the column labeled "Spring 2004 / Combined Stem Count." Black plastic and wood chip mulch were installed in the

Fall of 2003 and remained unchanged throughout the duration of the experiment. AllDown and BurnOut treatments were reapplied in the Spring of 2004. Final stem counts from Fall 2004 are shown in the column labeled "Final / Combined Stem Count." The percent increase or decrease in number of stems is provided for each stem count. In the "% Change from Initial" columns, the "+" indicates an increase from the initial number of stems and the "–" indicates a decrease.

The most pertinent data in Tables 2, 3, 4 and 5 are the percent changes between the initial stem count and the final stem count (see the "Final / % Change from initial" column). Based on the initial stem count, the natural herbicide control plots at Knez wetland increased 123.8 percent by the end of the study period, and the control at Cedar Mill increased 255.7 percent. The stem counts at Knez in the AllDown and BurnOut plots increased by 76.3 and 128 percent, respectively. The stem counts at Cedar Mill for AllDown decreased 23.4 percent from the initial amount, while BurnOut counts at Cedar Mill showed an increase in stems of 3.4 percent from the initial count.

The stem counts for the control of the solarization plots increased by 21 percent, whereas the plots covered by the solarizing plastic were reduced to zero stems (100 percent decrease). Finally, the stem counts for the control of the wood chip mulch treatment only slightly increased with a 0.2 percent rise in the number of stems. The stem counts in plots covered with wood chip mulch were reduced to zero for the first stem count, and then in the final count, were showing a 85.6 percent reduction from the initial count.

Table 2. Results of AllDown and BurnOut experiment at Knez Wetland

Knez Wetland	Initial		Spring 2004			Final		
Treatments/ plot #	Stem count of individual Sample Blocks	Combined Stem Count	Stem count of individual Sample Blocks	Combined Stem Count	% change from Initial	Stem count of individual Sample Blocks	Combined Stem Count	% change from Initial
Knez AllDown/ Plot 12	61 134 130	325	112 105 147	364	12 +	177 224 172	573	76.3 +
Knez Burnout/ Plot 11	103 120 109	332	121 117 119	357	7.5 +	281 288 188	757	128 +
Knez Control/ Plot 10	138 159 93	390	227 209 120	556	42.6 +	304 279 290	873	123.8 +

Table 3. Results of AllDown and BurnOut experiment at Cedar Mill Wetland

Cedar Mill Wetland Treatments/ Plot #	Initial: Stem count of individual Sample Blocks	Initial: Combined Stem Count	Spring 2004: Stem count of individual Sample Blocks	Spring 2004: Combined Stem Count	Spring 2004: % change from Initial	Final: Stem count of individual Sample Blocks	Final: Combined Stem Count	Final: % change from Initial
Cedar Mill AllDown/ Plot 5	141 35 55	231	127 34 57	218	5.6 -	90 25 62	177	23.4 -
Cedar Mill Burnout/ Plot 1	105 68 215	388	102 88 179	369	4.9 -	125 80 196	401	3.4 +
Cedar Mill Control/ Plot 8	41 37 53	131	94 67 47	208	58.8 +	164 150 152	466	255.7 +

Table 4. Results of Stem Counts for Woodchips

Treatments/ Location/ Plot #	Initial: Stem count of individual Sample Blocks	Initial: Combined Stem Count	Spring 2004: Stem count of individual Sample Blocks	Spring 2004: Combined Stem Count	Spring 2004: % change from Initial	Final: Stem count of individual Sample Blocks	Final: Combined Stem Count	Final: % change from Initial
Woodchip Mulch/ Cedar Mill/ Plot 19	274 314 289	1474	0 0 0	0	100 -	51 6 85	212	85.6 -
Woodchip Mulch/ Cedar Mill/ Plot 20	192 183 222		0 0 0			51 3 16		
Woodchip Mulch Control/ Cedar Mill/ Plot 21	143 146 303	592	194 167 279	640	8.1 +	214 145 234	593	0.2 +

Table 5. Results of Stem Counts for Solarization

Treatments/ Location/Plot #	Initial: Stem count of individual Sample Blocks	Initial: Combined Stem Count	Spring 2004: Stem count of individual Sample Blocks	Spring 2004: Combined Stem Count	Spring 2004: % change from Initial	Final: Stem count of individual Sample Blocks	Final: Combined Stem Count	Final: % change from Initial
Solarization/ Cedar Mill/ Plot 16	109 114 72		0 0 0			0 0 0		
Solarization/ Cedar Mill/ Plot 17	156 125 115		0 0 0			0 0 0		
Solarization/ Knez/ Plot 22	185 183 157		0 0 0			0 0 0		
Solarization/ Knez/ Plot 23	158 210 118	1702	0 0 0	0	100 -	0 0 0	0	100 -
Solarization Control/ Cedar Mill/ Plot 18	83 86 52		89 58 44			122 151 45		
Solarization Control/ Knez/ Plot 24	193 117 189	720	236 180 270	877	21.8 +	227 223 103	871	21 +

For Figures 1, 2 and 3 Spring 2003 is the pre-treatment count. Therefore, stem counts at Spring 2003 are 100% of the stems on plots before treatments were applied. Percentages were calculated by combining the stem counts for all plots of each treatment and comparing them to the initial 100%.

Figure 1.

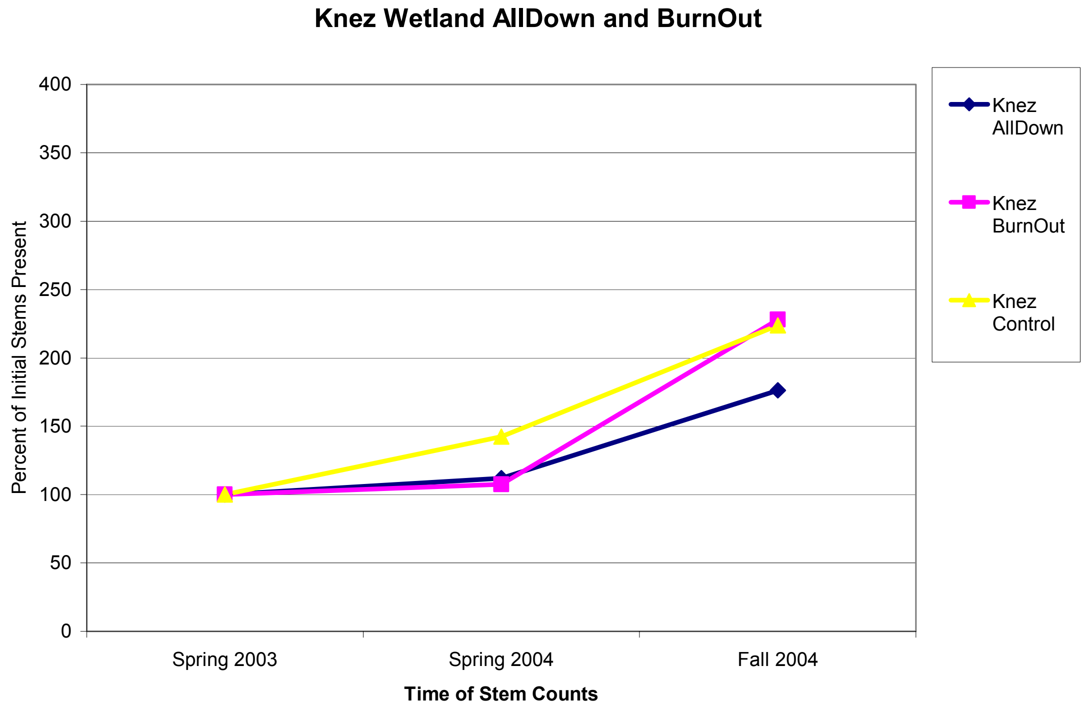


Figure 2.

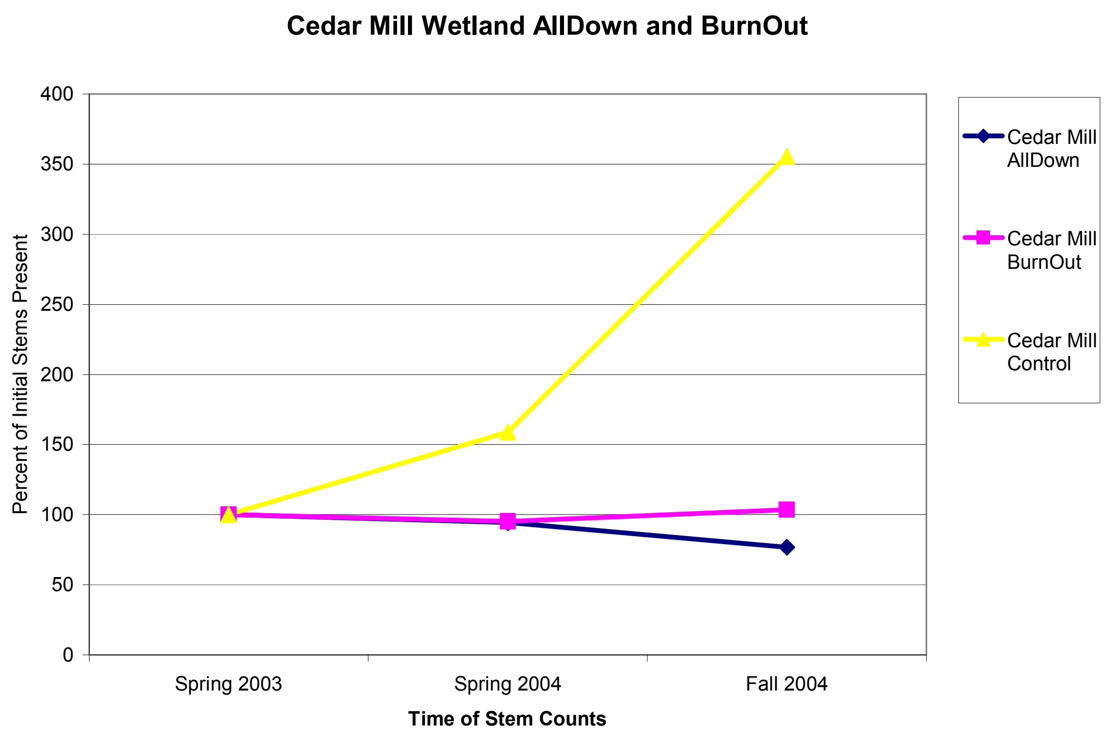
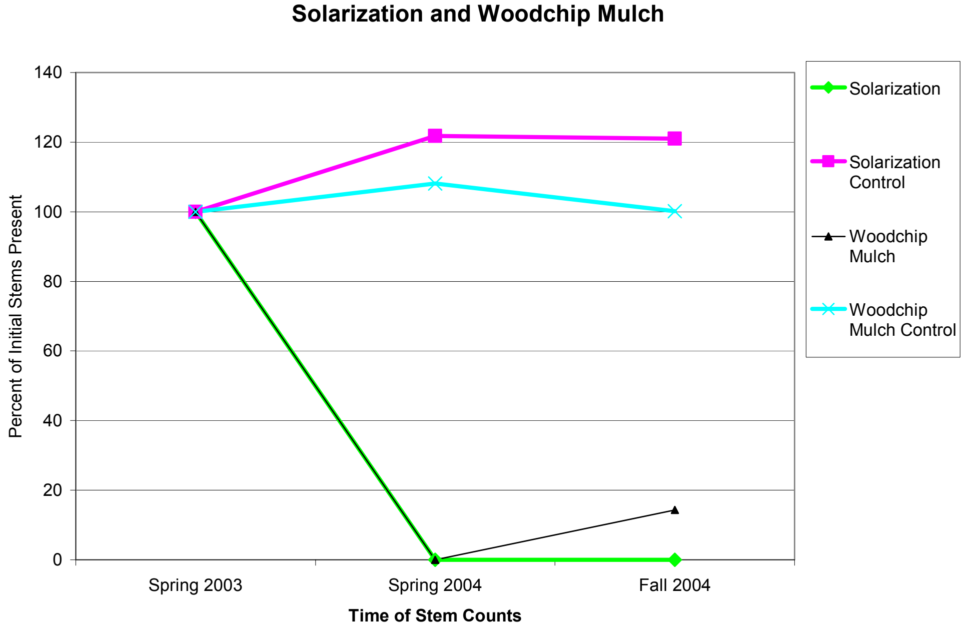


Figure 3.



Figures 4, 5 and 6 are based on actual numbers of stems counted on plots. All plots for each treatment are combined for the total number. Only the initial pre-treatment and final stem count numbers are shown in these graphs. Note that initial numbers of stems were different for all of the groups.

Figure 4.

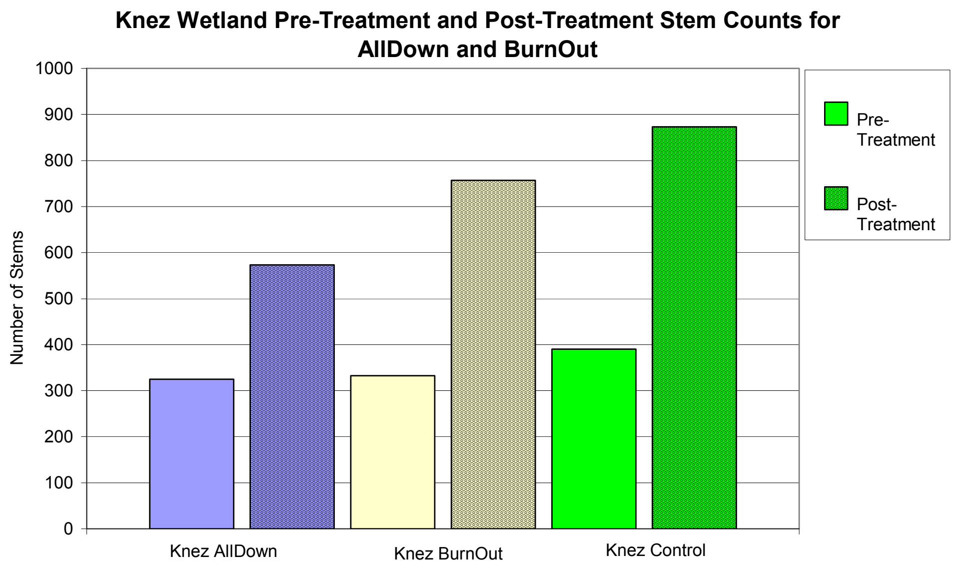


Figure 5.

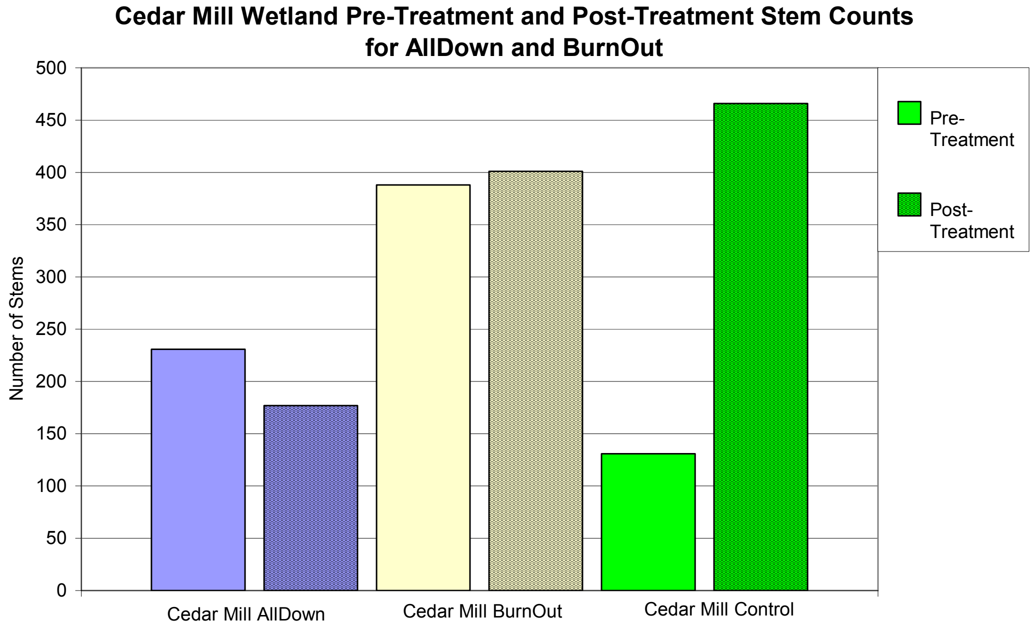
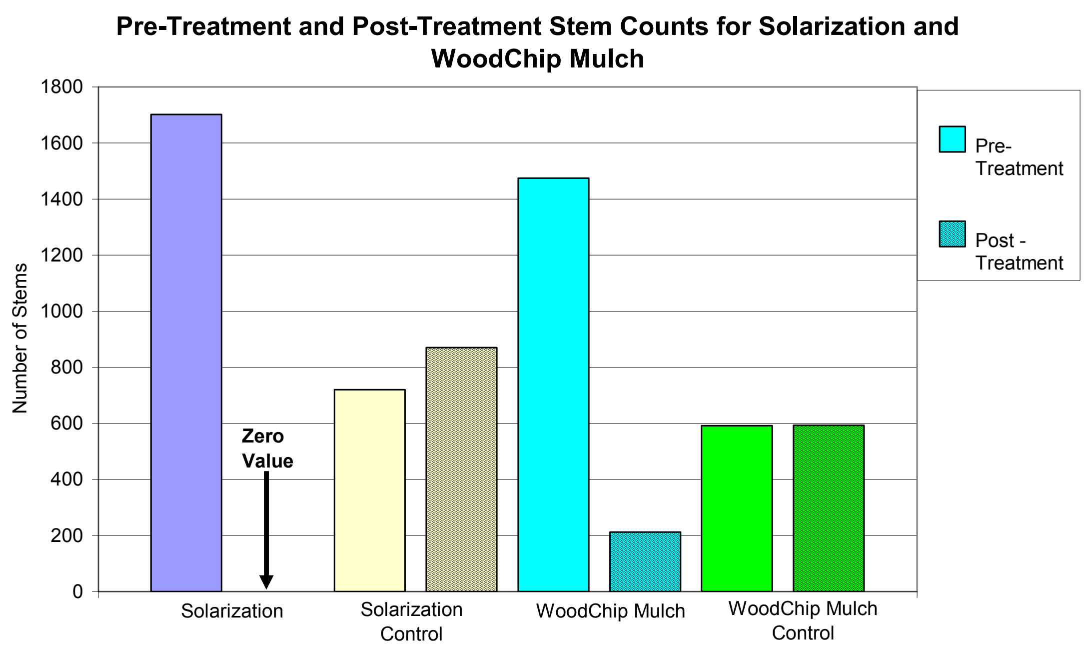


Figure 6.



Statistical Analysis

Because large amounts of data were lost due to beaver activity and flooding of several test plots, only two plots each were available for analysis of AllDown and BurnOut. Each plot contained three randomly chosen sample blocks. One set of plots was located at Knez wetland, and the other set was located at Cedar Mill Wetland.

Pre- and post-treatment stem counts were compared using a paired two sample t-test. Pre- and post-treatment counts were compared instead of post-treatment and control in part to avoid confounding factors associated with the differences between control plots and treatment plots. Determination of significance was based on $\alpha = 0.05$.

The original intent of the study was to statistically compare the treatments to controls. However, with the data lost due to uncontrollable conditions (flooding of plots), the planned statistical analysis was reconsidered. Ideally, there would have been randomly assigned treatments to plots with at least three replications of each treatment and the controls. Instead, with the reduced amount of data, it was necessary to use sample blocks as sub-samples. The t-test was used to compare the pre-treatment to post treatment stem counts within test plots, using the three sample blocks as pseudo-replicates. In this case, the pre-treatment stem counts functioned as the controls. Since sample blocks were compared only within test plots, not between test plots, there was not a violation of the requirement for independent samples (Pan 2004). The results of the study would have been more applicable and meaningful if data had not been lost.

For AllDown and BurnOut, significance was measured separately for each wetland using the counts from three sample blocks of each plot. The null hypothesis was that the number of stems before and after treatment was the same. This test indicates whether there was a significant difference in pre- and post-treatment stem density. After considering whether the stem densities on the test plots either increased or decreased, the statistical results can be used to comment on the significance of the increase or decrease. In other words, the statistical analysis measured the significance of the difference between the initial stem count and the final stem count.

Table 6. t-test results

Treatment	% Change from initial stem density	t-test result (P-value)	Interpretation (α = 0.05)
AllDown – Cedar Mill	23.4 -	0.405	Non-significant decrease
AllDown – Knez	76.3 +	0.062	Non-significant increase
BurnOut – Cedar Mill	3.4 +	0.751	Non-significant increase
BurnOut – Knez	128 +	0.046	Significant increase
Solarization – Knez & Cedar Mill	100 -	0.00003	Significant decrease
Woodchip Mulch – Cedar Mill	85.6 -	0.0002	Significant decrease

AllDown at Cedar Mill reduced the number of stems by 23.4%, whereas AllDown at Knez had a 76.3% increase. The t-test indicated that the reduction in stems on the Cedar Mill AllDown plot was not a significant change. Accordingly, the null hypothesis was not rejected (P = 0.405). This indicates that AllDown did not significantly reduce the number of *P. arundinacea* stems at Cedar Mill. Stem density on the Knez AllDown plot increased. The increase was not statistically significant (P = 0.062), although at the 95% confidence level the AllDown plot at Knez was much closer to having a significant difference in stem density than the Cedar Mill plot. We can infer that AllDown at Knez was associated with a nearly significant increase in stem density.

BurnOut plots had an increase in stem density at both sites. BurnOut failed to show a statistically significant increase in stem density at Cedar Mill (P = 0.751), but did show a significant difference at Knez (P = 0.046). Thus, BurnOut at Cedar Mill was not associated with a significant increase in stem density, whereas at Knez, stem density increased significantly despite the application of BurnOut.

It should be noted that because of the disparity between the plots at Knez and Cedar Mill, the conclusions that can be drawn about the applicability of the findings are not strongly supported. The difference implies that extraneous conditions somehow impacted stem density changes. Since there is not enough evidence to determine whether this is the case, the BurnOut and AllDown results of Cedar Mill should be separated from those of Knez.

Solarization plots at Knez and Cedar Mill both reduced stem density and had statistically significant differences pre- and post-treatment ($P = 0.00005$ and $P = 0.001$ respectively). Therefore, the data from the two sites were combined for a t-test on a single data set. The change in stem density on combined solarized plots was also significant ($P = 0.00003$).

Woodchip mulch plots were only located at Cedar Mill. All woodchip mulch plots resulted in reduced stem density. The t-test indicated that the woodchip mulch had a statistically significant different number of stems post-treatment ($P > 0.0002$).

Discussion

With the growing concern about the detrimental effect of invasive species such as *P. arundinacea* on resource and functional values in wetlands, researchers have been seeking effective control techniques that do not cause more damage to the wetland than the grass itself. The use of glyphosate based herbicides and heavy machinery for mechanical removal are both known to be effective, but often involve a significant incidental impact to the wetland. Many recent studies have been seeking a combination of low impact techniques that can effectively control this invasive species (Kilbride 1999; Paveglio 2000).

P. arundinacea has the biological characteristics that make it an excellent invader. Those characteristics also make it difficult to control and remove once established. Mowing alone tends to increase stem density, although repeated mowing may be an effective control technique if repeated until resources stored in the rhizomes are exhausted from re-growing stems. The context of this study was that of small urban wetlands managed, for example, by community volunteer organizations or conservation agencies. Assuming that management resources are minimal in such cases, this study investigated a combination of mowing once or twice a year, combined with a secondary technique. The techniques chosen for investigation were relatively inexpensive and required minimal equipment.

Acetic acid and other organic extracts can be used to control weeds. There is evidence that such “natural herbicides” are effective against some weeds, however during literature review for this study, no evidence was found as to whether *P. arundinacea* could be effectively controlled with acetic acid.

This study investigated the possibility of using herbicides made with acetic acid, in combination with spring and fall mowing, to control established *P. arundinacea* in wetlands. The use of thick mulching with wood chips and solarization with sheets of black plastic were also investigated as secondary treatments to mowing twice a year. The effectiveness of each technique was measured by statistically comparing pre- and post-treatment stem density. Percentage change in stem density was calculated for comparison with control plots that were also mowed, but not treated with a secondary technique.

The acetic acid experiment took place at two different wetlands. The difference between pre- and post-treatment stem densities at Knez wetland was more significant than at Cedar Mill. Because of the between wetland variation evident in the statistical analysis, the findings are presented separately for Knez and Cedar Mill. The conclusions that can be drawn from these results are less certain because of the unexplained difference between wetlands. We must conclude that there was either an inconsistency in conditions between Knez and Cedar Mill, or human error during the experiment skewed the results.

The line graphs (Figures 1 and 2) and percentage tables (Tables 2 and 3) comparing acetic acid treatments to adjacent control plots at Cedar Mill and Knez provide some additional insight into the effectiveness of treatments under different conditions. Figure 2 and Table 3 show that the control plot at Cedar Mill had about a 250 percent increase in stem density, while the treated plots either increased very slightly or decreased from the pre-treatment stem density. It is important to notice, therefore, that although there was not a significant net decrease in stem density, the treatments appear to have resulted in much less increase than the control plot. Figure 1 and Table 2 show that the treated plots at Knez increased either slightly more than or about half as much as the control plot. In simple terms, the acetic acid treatments appear to have been more effective at Cedar Mill than at Knez.

This study did not gather comprehensive information about the differences between the two wetland sites. Cedar Mill was graded during construction of the mitigation project about 10 years ago. A soil study preformed by Portland State University students found evidence that the study site at Knez had disturbed soil, possibly due to excavation several years ago for a drainage ditch near the site (Garland 2003). Hydrology at the sites would have been roughly the same, except that flooding occurred at Cedar Mill from a beaver dam in Johnson Creek. The Cedar Mill site is somewhat more sheltered from wind and shaded than the Knez site. If more was known about the different conditions at the sites, it might have been possible to make some assumptions about the effectiveness of these treatments under different conditions. The only inference we can make with the information available is that the flooding at Cedar Mill probably boosted stem density on the control, while the acetic acid treated plots did not show such an increase.

Neither of the acetic acid based applications resulted in greatly reduced *P. arundinacea* stem density. Only the AllDown test plot at Cedar Mill actually resulted in fewer stems than the pre-treatment amount. All other acetic acid plots did result in a smaller increase than the mowed control plots. However, as discussed in the introduction, mowing alone once or twice a year seems to increase density. Even though the acetic acid treatments were able to reduce some stem density, the net result of mowing plus acetic acid treatment was an increase in stems. For the purpose of weed control, the application of acetic acid combined with mowing twice a year would provide little benefit. However, since the applications both resulted in less increase in stem density than the control plots, it is possible that repeated applications of the "natural herbicides" could increase effectiveness of this treatment. Furthermore, the concentrations of acetic acid in AllDown and Burnout were not known for this study. When used at a five percent concentration acetic acid can successfully kill weeds such as the aquatic plant: sago pondweed (Sytsma 2005). It is possible that formulas made with different concentrations of acetic acid would more successfully control *P. arundinacea*. Future research of varying concentrations of acetic acid might be able to determine which concentration of acetic acid is most useful for control of *P.* arundinacea. Further study of acetic acid based weed control is certainly warranted based on the findings of this study.

One concern with repeated applications of acetic acid is that eventually the soil pH could be altered to the extent that native organisms would not be able to return once *P. arundinacea* was eliminated. An additional issue associated with the products used in this study was the cost relative to the area needing application. Approximately $150 was spent on AllDown and BurnOut for this project, in order to apply twice to a 1600 square foot area. The cost of this treatment is greater than glyphosate based commercial herbicide treatment. However, in small wetlands the use of products like BurnOut and AllDown may still be cost effective. Certainly these costs are minor compared to the use of heavy machinery and labor associated with standard mechanical control methods.

Wood chip mulch resulted in an approximately 85% reduction in stem density, which was much more effective than the acetic acid applications. Wood chips are biodegradable and native plantings can be inserted through the mulch, making it a favorable technique where managers are intending to re-vegetate immediately. It should be noted that, even with mulch applied approximately 10 inches deep on mowed grass, after a year *P. arundinacea* stems were protruding through the mulch with increasing density. In order to prevent eventual growth through the mulch, one option would be to continually re-apply mulch once or twice a year, in spots where stems were protruding.

There are some concerns associated with wood chip mulch. The mulch is typically delivered with a large truck and must be transported into the wetland by hand (with wheelbarrows or buckets). If the target area is not close to a road or area accessible to a vehicle, transporting the woodchips may require a prohibitive amount of labor. Also, wood-chipping companies who can provide free loads of wood chip mulch usually will not verify the species of trees and plants in the wood chips. This presents the possibility that seeds from invasive species or even vegetative propagules could be in the mulch, which would then be introduced into the wetland.

Solarization with black plastic sheets was the most successful technique investigated in this study. Stem density was effectively reduced to zero on all plots to which this treatment was applied. Any other plants growing in the solarization test plots with the *P. arundinacea* were also killed by this process. The plastic has been removed on some plots for over a month between the final stem count and the time that this paper was written. In that time, no *P. arundinacea* has re-grown in those plots. Even in August – September *P. arundinacea* would be expected to produce some new shoots from living rhizomes if enough moisture is available. It can be assumed, therefore that the above and below ground portions of the grass have been killed. Those areas are now ready for revegetation with native grasses, sedges and rushes that were growing there prior to invasion by *P. arundinacea*, which is the ultimate goal of such management practices.

One concern associated with solarization is the cost of the plastic sheeting relative to the area that must be covered. For this study, 100 by 20 foot rolls were purchased for approximately $40 each. Although, in smaller wetlands infestations are often small enough to make this technique cost effective. Furthermore, the plastic can usually be re-used after one area of *P. arundinacea* has been eliminated.

Another potential complication with solarization is the impact of the solarization on the soil and soil organisms. From a strictly vegetation enhancement perspective, there may be a loss of organisms and interruption of organic processes that are critical to plant growth, making revegetation difficult without soil enhancement of some kind. Also, seeds of desirable plants existing in the seed bank may be destroyed by the solarization process. For these reasons, and also from an ecological impact perspective, further research should be undertaken to investigate the effect of solarization on soil and the associated organisms.

In conclusion, all of the techniques investigated in this study were effective to varying degrees. More importantly, all of them posses strengths and weaknesses that should be considered when planning a *P. arundinacea* control strategy. Strategies should use multiple techniques in a combination designed to minimize use of resources and impacts to the wetland, while maximizing control of *P. arundinacea.* Factors to consider include the location and size of the infestation, proximity to flowing water, potential for water level manipulation, wildlife use of the area and surrounding vegetation. An experienced land manager can certainly benefit from adding the methods investigated in this study to the palette of available techniques for control of *P. arundinacea*.

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