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Note

Flowering rush control on drawn-down sediment: Mesocosm and field evaluations

JOHN D. MADSEN, THOMAS E. WOOLF, AND RYAN M. WERSAL*

Introduction

Flowering rush (*Butomus umbellatus* L.) is a nonnative, invasive aquatic plant that may grow as either a submersed or emergent plant, from the shoreline to depths of 4 m or more (Parkinson et al. 2010, Marko et al. 2015). A native of eastern Europe, it was introduced predominantly for the water garden trade, and is currently found in sporadic locations in the United States and southern Canada from the St. Lawrence River and Great Lakes, to the midcontinent, and western mountain region (Parkinson et al. 2010). Flowering rush can form dense growths that outcompete native aquatic plants, disrupt fish spawning habitat, favor predators of desirable fishes, disrupt water flow in rivers and irrigation canals, and interfere with recreation (Bellaud 2014).

Flowering rush was found north of the Clark Fork River's delta in both 2007 and 2008 and represents a unique population for Lake Pend Oreille (Cao et al. 2009). The majority of flowering rush in the Lake Pend Oreille system is located in the Clark Fork River delta area (Madsen et al. 2015). This area is owned and operated by the U.S. Army Corps of Engineers (USACE) and serves as a source of infestation to other parts of the lake and Columbia River system. Small populations have been found taking hold throughout the lake and downstream of Albeni Falls Dam on the Pend Oreille River in Washington. Flowering rush is an expanding problem in this region and currently there are no proven tools to effectively control it.

As part of the normal water management regime, Lake Pend Oreille undergoes a drawdown ($\geq$ 3.3 m) every fall and winter for flood control and to help protect infrastructure from ice damage. During this time, flowering rush plants are exposed and are easily accessible to implement management techniques. To date there is no published peer reviewed literature that can provide reliable control recommendations for flowering rush. Anecdotal and small-scale research studies suggest that foliar herbicide applications could control emergent plants though application timing and plant life stage will impact efficacy (Wersal et al. 2014). A few small-scale studies have investigated the efficacy of submersed herbicide applications on flowering rush (Poovey et al. 2012, Poovey et al. 2013). Endothall applied at concentrations approaching 3 mg L^{-1} reduced aboveground flowering rush if contact times were > 24 h (Poovey et al. 2012, Poovey et al. 2013). Auxin herbicides could offer short-term nuisance control when applied to the water column, but longer exposure times were needed to achieve biomass reductions (Poovey et al. 2012, Poovey et al. 2013, Wersal et al. 2014).

Given the resiliency of flowering rush to herbicide treatments in small-scale studies, there have been limited attempts to control this plant under field conditions in many of the areas where it grows in the Pacific Northwest such as in Lake Pend Oreille. Due to the water exchange characteristics and the overall water volume to treat, this plant may make in-season applications unfeasible in Lake Pend Oreille. Therefore, thorough evaluations of management techniques are needed to determine a viable approach to managing flowering rush in Lake Pend Oreille and other lakes in this region. Lake Pend Oreille, like many lakes and reservoirs with water-level control structures throughout the United States, is operated such that the water level is reduced during the winter to increase potential storage capacity for spring flooding. Reducing the water level in this manner leaves large expanses of sediment exposed during the fall and winter months. Lake managers commonly refer to this procedure as a "drawdown." Drawdown is commonly used for a variety of management objectives, including sediment compaction, organic sediment decomposition, native plant restoration, and fish population management (Cooke et al. 2005). For aquatic plants, it is often used directly as a technique to physically manage nuisance plant populations (Cooke 1980, Dugdale et al. 2013, Poovey and Kay 1998). Flowering rush, however, is not susceptible to desiccation or freezing during periods of drawdown. The management option presented is to apply herbicides to flowering rush without the overlying layer of water, reducing the amount of herbicide needed and ensuring that the herbicide contacts the plant. Treatment of flowering rush during times of lake drawdown represents a potential opportunity to effectively treat this plant. Our objectives were to 1) evaluate bare-ground herbicide

*First author: Research Biologist, U.S. Department of Agriculture Agricultural Research Service, Exotic and Invasive Weed Research Unit, University of California–Davis, Plant Sciences Department, Davis, CA 95616. Second author: Aquatic Program Manager, Idaho State Department of Agriculture, Coeur D'Alene, ID 83835. Third author: Aquatic Plant Biologist, Lonza, Alpharetta, GA 30004. Corresponding author's E-mail: jmadsen@ucdavis.edu. Received for publication September 8, 2015 and in revised form April 22, 2016.

applications under simulated drawdown conditions in a mesocosm facility and 2) compare benthic barrier, digging, hand pulling, and bare-ground herbicide application efficacy under field conditions in Lake Pend Oreille.

METHODS AND MATERIALS

Mesocosm evaluation

The study was conducted as a completely randomized design in 68 380-L tanks. Flowering rush was obtained from field locations in Lake Pend Oreille, ID, or Detroit Lakes, MN, (both populations are triploid, see Poovey et al. 2012) and propagated in a mesocosm facility at Mississippi State University. In August and September 2010, after a sufficient stock population was established, two rhizome sections (approximately 10 cm in length) were planted into 3.8-L containers filled with a mixture of sand and topsoil, and amended with granular (19–6–12) fertilizer[1] at rate of 2 g L^{-1}. Six pots of planted flowering rush were placed into each tank. An additional 20 pots were planted at the same time to assess pretreatment above- and belowground biomass. Pretreatment biomass is used only as an indication of plant condition at the time of treatment; it is not used in a statistical comparison. Plants were allowed to grow through the remainder of 2010. The water in each tank was slowly drained to coincide with the drawdown in Lake Pend Oreille beginning in November 2010. In March 2011, any remaining aboveground biomass was clipped at the sediment surface and pretreatment belowground biomass harvested by removing the rhizomes from the additional 20 pots prior to herbicide applications. Plants were clipped to ensure that new growth from buds would be treated, rather than old growth, to better simulate spring regrowth as encountered in Idaho, and to remove dead leaf material.

Herbicides were applied in March 2011 to coincide with applications made during the field study in Lake Pend Oreille. Two rates each of seven herbicides were applied: acetic acid[2] (45 and 90 kg ae ha^{-1}), aminopyralid[3] (0.06 and 0.12 kg ae ha^{-1}), flumioxazin[4] (1.31 and 2.63 kg ai ha^{-1}), fluridone[5] (1.12 and 2.24 kg ai ha^{-1}), imazamox[6] (0.28 and 0.56 kg ae ha^{-1}), imazapyr[7] (0.84 and 1.68 kg ae ha^{-1}), penoxsulam[8] (0.05 and 0.10 kg ai ha^{-1}), and triclopyr[9] (3.36 and 6.73 kg ae ha^{-1}). Herbicides were applied to the bare soil of the pots in respective tanks using a CO_2-pressurized single-nozzle spray system[10] using a spray volume of 136 L ha^{-1}. A 1% v/v nonionic surfactant[11] was added to all treatments. Each treatment, including an untreated reference, was replicated in four tanks. Two weeks after treatment, water was incrementally (approximately 20 cm wk^{-1}) added to each tank to coincide with water returning to Lake Pend Oreille. The final water level in each tank was 40 cm or approximately 20 cm from the top of the containers.

At 12 wk after treatment (12 WAT), three pots selected randomly from each tank were harvested, and processed by separating plants to above- and belowground tissues. At 24 WAT, the remaining three pots in each tank were harvested in a similar manner. Once harvested, plant samples were dried at 50 C, and weighed to assess treatment effects on both above- and belowground plant material. Biomass data were analyzed using a general linear model in SAS[12] to determine herbicide treatment effects. If a treatment effect was observed, a Dunnett's test was used to compare herbicide treatments to the untreated reference plants. Biomass data were analyzed within time period at a $P < 0.05$ significance level.

Field evaluation

Due to concerns regarding endangered species in the Lake Pend Oreille system, only a small number of herbicides were applied to the drawdown area *in situ*. The field evaluation was conducted in 3- by 3-m plots that were established in March 2011 in Lake Pend Oreille during the winter drawdown period. Plots were delineated using a frame constructed from polyvinyl chloride (PVC) pipe and held down with sandbags. Additionally, the coordinates of each corner of every frame were recorded using a global positioning system (GPS) device.[13] Once the plots had been established, management techniques were randomly assigned to each plot and pretreatment belowground biomass was collected using a 0.018-m^2 PVC coring device (Madsen et al. 2007).

Management techniques included the maximum labeled rates for bare ground applications of acetic acid[2] (45 kg ae ha^{-1}), fluridone[5] (2.24 kg ai ha^{-1}), imazamox[6] (0.56 kg ai ha^{-1}), imazapyr[7] (1.68 kg ai ha^{-1}), and triclopyr[9] (6.73 kg ae ha^{-1}); other techniques included hand pulling, digging, and benthic barrier (deployed for 4 mo). Each treatment, including an untreated reference, was replicated in four plots. Herbicides were applied using a CO_2-pressurized backpack spray system[10] with a five-nozzle boom and 8002 flat fan spray tips. Applications were made using a spray volume of 136 L ha^{-1}. Hand pulling consisted of pulling only visible plants within the designated plots; no attempt was made to excavate underground plant structures. Manual digging was completed using a shovel to physically remove all soil in the plot, to a depth of 15 cm below grade. Benthic barriers were affixed to a PVC frame and placed on the sediment in respective plots. Sand bags were used to hold the benthic barrier in place. In addition to biomass data, the total time of utilizing each management technique was recorded in each plot to assess labor for each technique.

At 16 WAT, the 4-mo benthic barriers were removed and two biomass samples collected in all plots for each management technique using a 15-cm-diam PVC coring device (0.018 m^2, Madsen et al. 2007). All biomass samples were separated into above- and belowground tissues, dried at 50 C, and weighed to determine biomass. Percentage of control, stem density, and biomass were determined pretreatment and 16 WAT. Field data were subjected to a Kruskal-Wallis nonparametric ANOVA to determine treatment effects using SAS.[12] Time data for each management technique were averaged and reported.

RESULTS AND DISCUSSION

Mesocosm evaluation

Pretreatment belowground biomass was 13.2 g dry weight (DW). At 12 and 24 WAT, belowground biomass in the

Table 1. Aboveground and belowground biomass (g dry weight [gDW] m^{-2}) of flowering rush 12 and 24 wk after treatment (WAT) for 16 herbicide treatments and an untreated reference.

	12 WAT		24 WAT	
	Belowground Biomass (gDW tank^{-1})	Aboveground Biomass (gDW tank^{-1})	Belowground Biomass (gDW tank^{-1})	Aboveground Biomass (gDW tank^{-1})
Treatment	Mean ± SEM	Mean ± SEM	Mean ± SEM	Mean ± SEM
Untreated reference	19.7 ± 1.1	7.77 ± 0.59	81.4 ± 38.0	5.9 ± 0.94
Acetic acid (45 kg ha^{-1})	19.5 ± 3.43	5.46 ± 0.98	70.3 ± 16.2	7.89 ± 2.03
Acetic acid (90 kg ha^{-1})	24.6 ± 6.51	3.74 ± 1.39	57.5 ± 13.5	9.88 ± 3.74
Aminopyralid (0.06 kg ha^{-1})	15.8 ± 4.37	3.37 ± 1.02	53.8 ± 25.4	10.3 ± 2.23
Aminopyralid (0.12 kg ha^{-1})	20.9 ± 14.5	3.21 ± 0.71	48.8 ± 24.0	9.12 ± 3.23
Flumioxazin (1.31 kg ha^{-1})	25.9 ± 5.66	12.5 ± 2.69	53.9 ± 14.6	11.5 ± 4.05
Flumioxazin (2.63 kg ha^{-1})	11.8 ± 2.94	4.17 ± 1.79	44.7 ± 7.87	8.63 ± 1.01
Fluridone (1.12 kg ha^{-1})	15.9 ± 6.35	1.27 ± 0.84*	9.06 ± 6.08*	4.48 ± 2.66
Fluridone (2.24 kg ha^{-1})	10.4 ± 3.43	0.14 ± 0.07*	0.23 ± 0.2*	3.88 ± 3.86
Imazamox (0.28 kg ha^{-1})	5.67 ± 0.96	2.48 ± 1.13*	17.4 ± 4.61	4.71 ± 1.65
Imazamox (0.56 kg ha^{-1})	13.9 ± 1.21	1.85 ± 0.35*	15.6 ± 3.99	3.61 ± 0.78
Imazapyr (0.84 kg ha^{-1})	20.1 ± 5.34	2.29 ± 1.03*	35.5 ± 16.2	4.97 ± 1.47
Imazapyr (1.68 kg ha^{-1})	7.81 ± 1.83	1.3 ± 0.71*	31.7 ± 14.3	2.43 ± 1.0
Penoxsulam (0.05 kg ha^{-1})	15.1 ± 6.9	3.76 ± 1.7*	42.0 ± 12.7	13.4 ± 4.52
Penoxsulam (0.10 kg ha^{-1})	23.0 ± 15.0	1.89 ± 0.66*	43.9 ± 8.88	9.94 ± 0.72
Triclopyr (3.36 kg ha^{-1})	20.3 ± 9.61	2.75 ± 1.64*	28.0 ± 8.74	4.09 ± 0.55
Triclopyr (6.73 kg ha^{-1})	3.57 ± 1.36	0.81 ± 0.81*	3.5 ± 2.02*	3.03 ± 1.97

*Significant difference from untreated reference plants as determined by a Dunnett's test at $P < 0.05$ significance level.

untreated reference tanks was 19.7 and 81.4 g DW, respectively, indicating plants were actively growing throughout the study (Table 1). At 12 WAT, fluridone at both rates, imazamox at both rates, imazapyr at both rates, penoxsulam at the maximum rate, and triclopyr at the maximum rate resulted in a decrease ($P < 0.01$) in aboveground biomass as compared to untreated reference plants (Table 1). There was no difference ($P = 0.53$) in belowground biomass with respect to herbicide treatments and untreated reference plants at 12 WAT. It is unclear as to why belowground biomass was unaffected by herbicides at 12 WAT. Plausible explanations include high variability in belowground samples thereby reducing the ability of detecting a difference or that a longer time period is necessary for herbicides to be taken up by rhizome tissue and begin to inhibit plant growth.

By 24 WAT, fluridone at both rates and triclopyr applied at the maximum rate reduced ($P = 0.02$) belowground biomass of flowering rush when compared to untreated reference plants (Table 1). There were no reductions ($P = 0.05$) in aboveground biomass at 24 WAT, which is likely due the life stage of the plants. At 12 WAT, plants were still producing new leaves from rhizomes and emerging from the water surface and thus were susceptible to herbicides. However, by 24 WAT plants had flowered, which likely stopped growth as plants began reallocating resources to belowground tissues as senescence began, though a thorough evaluation of life history characteristics is needed to confirm this hypothesis.

Based on this mesocosm evaluation, fluridone applied at both rates and triclopyr applied at the maximum rate were efficacious at reducing plant foliage at 12 WAT and belowground rhizomes by 24 WAT, which corroborates triclopyr data from small-scale studies of shorter duration (Poovey et al. 2013). These results suggest that these herbicides could be effective under field conditions if sprayed on the sediment surface. Acetic acid, aminopyralid, and flumioxazin were not effective at reducing flowering rush mass during any harvest time. Imazamox and imazapyr reduced aboveground mass by 12 WAT.

Field evaluation

Flowering rush biomass was not reduced by any management technique with respect to untreated reference plots in the field treatment plots (aboveground $P = 0.46$, belowground $P = 0.12$) (Table 2). Belowground biomass of all management techniques was lower than pretreatment belowground biomass (635 g DW m^{-2}), although biomass in reference plots was also lower. High variability in the results is likely due to the clumped growth pattern of the flowering rush population in the Clark Fork Delta area of Lake Pend Oreille and the sampling intensity utilized in the study (i.e., two samples per plot). In addition, pretreatment samples were collected during the winter drawdown

Table 2. Average effort (person-minutes) of implementation and aboveground (g dry weight [gDW] m^{-2}), and belowground biomass (gDW m^{-2}) at 16 wk after treatment (WAT) for management activity in field plots in Lake Pend Oreille, ID. No statistical difference was found between treatments for either aboveground or belowground biomass.

Treatment	Implement Effort (Person-Minutes)	Aboveground Biomass (gDW m^{-2}), Mean ± SEM	Belowground Biomass (gDW m^{-2}), Mean ± SEM
Untreated reference	0	171 ± 82.4	104 ± 27.4
Benthic barrier	30.0	63.8 ± 32.8	68.1 ± 26.3
Digging	12.6	56.7 ± 40.0	58.8 ± 24.5
Hand pulling	23.2	60.5 ± 41.7	121 ± 29.5
Acetic acid (45 kg ha^{-1})	0.6	98.4 ± 63.6	41.2 ± 21.8
Fluridone (2.2 kg ha^{-1})	0.6	121 ± 120	60.4 ± 23.5
Imazamox (0.56 kg ha^{-1})	0.6	109 ± 62.5	36.1 ± 20.4
Imazapyr (1.7 kg ha^{-1})	0.6	321 ± 131	77.2 ± 44.9
Triclopyr (6.7 kg ha^{-1})	0.6	401 ± 197	31.6 ± 22.0

whereas the 16-WAT samples were collected when there was 2 m of water on the plots. These factors likely increased the variability in biomass data. Marko et al. (2015) observed that flowering rush reproduces from rhizome buds, and the rhizome buds are produced on very short rhizomes, which leads to dense clumps of plants.

The lack of efficacy may be attributed to the environmental conditions in the area following treatment. Due to a high snowpack and high projected runoff for the spring of 2011 the water levels in Lake Pend Oreille were kept low for a longer period of time than was originally projected. As a result, plots were treated 3 wk prior to the lake level rising to the point of inundating the plots. This time lag between treatment and inundation accompanied by cold rainy conditions may have led to delayed plant growth and lack of observed efficacy in the field evaluation.

The time in implementing management techniques is depicted in Table 2. The application of herbicides took on average 38 s for each plot, whereas the other techniques required 12 to 30 min per plot. One compelling reason for the use of herbicides compared to other techniques is that the labor required ranges from 2 to 5% of that required for digging, hand pulling, or installation of benthic barrier. Given that labor costs are a significant source of expense for invasive plant management, the reasons for selection of techniques other than herbicides would be the small size of infestations, mitigating environmental restrictions or concerns, or stakeholder opinions on management techniques.

In summary, mesocosm research under controlled conditions indicated that flowering rush belowground biomass could be reduced by 24 WAT by soil applications of fluridone or triclopyr to dewatered sediment. A field experiment with a subset of the same herbicides as the mesocosm study did not find any significant difference between treatments, but statistical variability was high. The field study did demonstrate that the use of benthic barriers, hand removal, or manual excavation of sediment required 20 to 50 times more labor than application of herbicides.

SOURCES OF MATERIALS

[1]Osmocote® coated fertilizer, Everris, Israeli Chemicals Ltd., Millennium Tower, 23 Aranha Street, Tel Aviv 61070, Israel.

[2]Acetic acid (reagent-grade), Sigma-Aldrich Corporation, 3050 Spruce Street, St. Louis, MO 63103.

[3]Milestone specialty herbicide, DowAgrosciences LLC, 9330 Zionsville Road, Indianapolis, IN 46268.

[4]Clipper herbicide, Valent U.S.A. Corporation, 1600 Riviera Avenue, Suite 200, Walnut Creek, CA 94596.

[5]Sonar AS herbicide, SePRO Corporation, 11550 North Meridian Street, Suite 600, Carmel, IN 46032.

[6]Clearcast herbicide, SePRO Corporation, 11550 North Meridian Street, Suite 600, Carmel, IN 46032.

[7]Habitat herbicide, SePRO Corporation, 11550 North Meridian Street, Suite 600, Carmel, IN 46032.

[8]Galleon Herbicide, SePRO Corporation, 11550 North Meridian Street, Suite 600, Carmel, IN 46032.

[9]Renovate 3 herbicide, SePRO Corporation, 11550 North Meridian Street, Suite 600, Carmel, IN 46032.

[10]CO_2-pressurized single nozzle spray system, R&D Sprayers, 419 Highway 104, Opelousas, LA 70570.

[11]Dyne-Amic, Helena Holding Company, 225 Schilling Boulevard, Suite 300, Collierville, TN 38017.

[12]SAS statistical software, SAS Institute, Inc., 100 SAS Campus Drive, Cary, NC 27513.

[13]Yuma handheld GPS tablet, Trimble Navigation Limited, 935 Stewart Drive, Sunnyvale, CA 94085.

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