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Drawdown herbicide applications for control of flowering rush on dewatered littoral sites

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ABSTRACT

Flowering rush (*Butomus umbellatus* L.) is an invasive weed in shallow water and moist soil environments. It thrives in reservoirs and rivers, and is able to tolerate significant water level fluctuations. In the western United States, it is spreading along the Flathead, Clark Fork, Pend Oreille, and Columbia river systems in Washington, Idaho, and Montana. In this study, we evaluated the efficacy during several herbicides applied to moist soil sites of a scheduled drawdown in Lake Pend Oreille, Idaho. Fifteen plots (0.1 ha) were established in the Clark Fork River delta, Lake Pend Oreille, with three replicates each of four treatments, including an nontreated reference. Herbicide treatments included imazapyr (1.68 kg ae ha^{-1}) and imazamox (0.56 kg ae ha^{-1}), with and without the addition of 2,4-D (1.06 kg ae ha^{-1}). All applications included a nonionic surfactant at 2.8 L ha^{-1}. Herbicides were made by all-terrain vehicle prior to predicted rain event, and immediately following emergence of new flowering rush growth in the spring (late April). Plots were evaluated using estimated percentage of cover and biomass samples ($n = 10$) within each plot using a 0.18-m^2 core sampler before treatment and 1 and 2 yr after treatment (YAT). Only imazapyr-treated plots had a significant reduction in rhizome bud density, but not until 2 YAT. Rhizome and root biomass were significantly reduced in plots treated with imazamox and imazapyr by years, but not by other treatments. Midsummer cover was significantly lower in imazamox- and imazapyr-treated plots at 1 YAT, but not by 2 YAT. Both imazapyr and imazamox drawdown treatments are promising approaches to control flowering rush, but treatments will likely have to be done in two or three consecutive years.

Key words: 2,4-D, *Butomus umbellatus*, drawdown, imazamox, imazapyr.

INTRODUCTION

Flowering rush (*Butomus umbellatus* L.) is a noxious plant that grows as an emergent on saturated soils or in shallow water, but can also grow in a submersed stage forming persistent stands in depths up to 4.6 m (15 ft). Dense infestations destroy native plant communities and degrade fish and wildlife habitat. Both diploid and triploid flowering rush are present in the United States. The diploid can reproduce both asexually and sexually, but triploids reproduce clonally through rhizome lateral branching, inflorescent bulbils, and rhizome buds (Lui et al. 2005).

It has been estimated that ~ 27% (~ 10,000 ha [25,000 ac]) of Lake Pend Oreille, Idaho (38,324 ha), is littoral zone habitat supporting aquatic macrophytes, and that the lake has a rich vegetative community of more than 50 species of plants (Madsen and Wersal 2008). By the mid 2000s, Eurasian watermilfoil (*Myriophyllum spicatum* L.) invaded large areas of this littoral zone habitat, reaching a peak infestation of some 2,000 ha by 2007; however, Eurasian watermilfoil populations were reduced to ~ 200 ha after 7 yr of intensive management with herbicides (Madsen et al. 2015). While the selective removal of Eurasian watermilfoil resulted in an increase in native submersed plant species, flowering rush began to invade the lake in 2008 (B. Hull, pers. comm.). By 2012, over 140 ha of the lake were infested with scattered small patches of flowering rush that were consolidating into much larger stands. Based on its growth habit, it is estimated that the plant could infest an additional 2,400 ha of the lake's littoral zone.

Since 1996, the water level of Lake Pend Oreille has been manipulated to higher winter levels in an effort to improve kokanee salmon [*Oncorhynchus nerka* (Walbaum)] spawning (Wahl et al. 2015). Operation of Albeni Falls Dam on the Pend Oreille River keeps the lake level stable during summer (June to September), but lowers the level by ~ 3.5 m during fall and winter (B. Hull, pers. comm.). While many of the flowering rush populations in the lake occur as submersed stands, the plant responds well to fluctuating water levels and can quickly colonize newly exposed areas (Hroudova et al.1996, Delisle et al. 2003). Drawdowns to unvegetated sediments provide ideal sites for flowering rush establishment from rhizomes. However, stable water levels do not cause a decrease in abundance of established stands (Hroudova 1989). The ability to tolerate fluctuating water levels, the capability of dispersal by rhizomes, and the lack of natural predators make this noxious weed a serious threat to native vegetation and a risk for widespread colonization within the Pend Oreille Basin and neighboring systems.

In addition, the U.S. Fish and Wildlife Service (USFWS) is concerned about flowering rush populations disrupting critical habitat for the threatened bull trout (*Salvelinus confluentus* Suckley), a landlocked salmonid species in the basin (USFWS 1998, 2010). Thick plant stands can alter bull trout foraging sites and provide ambush cover for fish that prey on juvenile bull trout (Muhlfeld et al. 2008), and

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potentially impede migration routes in upstream arms of the lake and tributaries. The plant also modifies diurnal and seasonal water temperature regimes by reducing littoral zone water exchange and increasing sedimentation rate in the littoral zone, contributing to warmer waters (Rice and Dupuis 2009), a potential issue for bull trout life cycles (Fraley and Shepard 1989, Rieman and McIntyre 1995)

Currently, there are no reliable, cost-effective, long-term strategies for managing flowering rush—submersed or emergent forms—including the use of biocontrol agents or chemicals. However, results from growth-chamber and field studies have shown various levels of control against submersed flowering rush using quick-acting aquatic herbicides such as diquat, flumioxazin, and endothall (Poovey et al. 2012, 2013; Madsen et al. 2013; Wersal et al. 2014; Getsinger et al. 2018). Foliar applications to emergent flowering rush shoots with 2,4-D, triclopyr, aminopyralid, imazapyr, glyphosate, and some combinations resulted in reduction of rhizomes in mesocosms (Wersal et al. 2014), and foliar treatments with imazamox reduced flowering rush biomass in Montana field demonstrations (Rice et al. 2009). In addition, soil applications of triclopyr, fluridone, imazamox, and imazapyr to dewatered sediments in mesocosms reduced biomass of flowering rush, but results of a small-scale field evaluation were inconclusive (Madsen et al. 2017).

The dewatering of the littoral zone provided an opportunity to evaluate bare ground management techniques as a means of controlling flowering rush in Lake Pend Oreille. Bare ground herbicide applications on bottoms of dewatered irrigation canals in the western United States have provided seasonal control of some nuisance aquatic plants (Madsen 2016). The objective of the study was to document efficacy of selected aquatic herbicides when plants were treated under early-season bare ground conditions. Results of this study will contribute to the understanding of short- and long-term strategies for managing flowering rush populations in public water bodies of the Pacific Northwest region.

MATERIALS AND METHODS

Site description

The evaluation site was located in a 2.4-ha littoral zone area of the drift yard in the Clark Fork Delta in the upper reaches of Lake Pend Oreille, Idaho. When lake levels were elevated (May to October 2014), the site supported a well-established and moderately dense stand of flowering rush exhibiting emergent growth in shallow areas ($<$ 1 m) and submersed growth in deeper areas (1 to 2.5 m). Intermingled with the flowering rush stand, small patches of other submersed macrophytes, predominated by sago pondweed [*Stukenia pectinatus* (L.) Böerner] and Eurasian watermilfoil, were present. The site had been dewatered since fall of the previous year (2014), when the annual drawdown of the lake occurred, creating bare ground conditions which slowly dried at the surface during the winter. Prior to study initiation in late April (2015), vegetative shoots of flowering rush (2.5 to 2.8 cm [1 to 1.1 in] long), were sprouting from overwintering storage structures (rhizomes) buried just below the sediment. Other submersed macrophytes were still dormant.

Herbicide treatments

Fifteen rectangular treatment plots (18 m by 55 m or 0.1 ha in size) were established in the evaluation site in a random design. Plots were permanently marked using global positioning system (GPS) technology, creating a digital spatial record of the plots. Liquid herbicide treatments included imazapyr[1] (1.68 kg ae ha^{-1} [1.5 lb ae ac^{-1}]) and imazamox[2] (0.56 kg ae ha^{-1}), with and without the addition of 2,4-D[3] (1.06 kg ae ha^{-1}). All herbicide treatments included a nonionic surfactant[4] at 1% v/v (2.8 L ha^{-1} [0.3 gal. ac^{-1}]). Treatments (herbicides and references) were randomly assigned to plots and replicated three times. These products and rates were selected based on acceptable performance in previous bare ground treatments of flowering rush in Oden Bay, 2014 (B. Bluemer, pers. comm.).

A specialized application technique was developed by the county noxious weed management section (Bonner County, Sandpoint, ID). The system consisted of an all-terrain vehicle (ATV; four-wheeler) equipped with snow tracks to allow for consistent and reliable propulsion across bare ground plots. A volume of 95 L (25-gal ac^{-1}) tank spray unit was mounted on the rear rack of the ATV and outfitted with a pressurized boom-less system using two Boominator© 1870 spray nozzles.[5] The large droplet nozzles were set at a 0.9-m height above the ground to minimize spray drift and deliver a 6-m-wide spray (pattern) swath. Products were tank-mixed with water and the spray system was calibrated to deliver 237 L ha^{-1} of solution. Designated tank mix solutions were sprayed evenly across each plot (three swaths per plot) from 9:00 A.M. to 2:00 P.M. on 28 April 2015. Nontreated buffer strips (6 m wide) were established between treatment plots to minimize cross-contamination during the application process. At the time of treatments, skies were partly cloudy, wind was SSW at 0 to 3.2 km h^{-1}, air temperature was 12 to 16 C (54 to 61 F), soil temperature at 10-cm depth was 11 C, and lake elevation level was 626 m. Measurable rainfall in the area was light following treatment, with 0.03 cm on 29 April (1 day after treatment [DAT]) and 0.64 cm on 13 May (15 DAT). The rainfall did not adversely affect the treatment, as indicated by the results below.

Vegetation assessment techniques

Treatment effects were assessed using two techniques: biomass sampling and visual percentage of cover estimates. Each spring (2015, pretreatment; 2016: 1 yr after treatment [YAT]; and 2017, 2 YAT), biomass samples were collected from all plots before the reservoir water level was raised to summer pool levels. Ten samples were taken from each plot using a 0.018-m^2 core sampler (diameter 15 cm), to a sediment depth of at least 8 cm (Madsen et al. 2007). A stratified-random pattern was used to determine sample location within the plot. Samples were washed to remove sediment, transported on ice to the U.S. Department of

Figure 1. Aerial photograph of flowering rush plots in the drift yard, Lake Pend Oreille, Idaho, at 20 wk posttreatment. Herbicide-treated plots show good reduction of flowering rush, while nontreated reference plots and buffer strips show dense stands of the plant. Photo by Terry McNabb, Aquatechnix.

Figure 2. Ground-view photograph of flowering rush plots in the drift yard, Lake Pend Oreille, Idaho, at 20 wk posttreatment. Herbicide-treated plots show good reduction of flowering rush, while nontreated reference plots and buffer strips show dense stands of the plant. Photo by Terry McNabb, Aquatechnix.

Agriculture–Agricultural Research Service Aquatic Weed Research Facility (Davis, CA), where the plants were separated into shoots and rhizomes plus roots, and the number of rhizome buds per sample were counted. Samples were dried at 70 C for at least 48 h, then weighed to determine grams of dry weight. One-way analysis of variance (ANOVA) was used to compare bud density, shoot biomass, and rhizome plus root biomass between treatments within a given year for all treatments and the nontreated reference. Means were compared using a least significant difference (LSD) comparison at the $P = 0.05$ level (Anonymous 2013).

Visual estimates of percentage of cover in the plot were taken in the summer (August) of 2015 and 2016, 12 and 64 wk after treatment (WAT), respectively. Visual estimates were taken from a boat, when water depths were from 1 to 2 m. Estimated visual percentage of cover was used as the best representation of perceived nuisance growth in midsummer. The boat was allowed to drift lengthwise through each plot, which was determined by use of GPS and visual observation of corner posts underwater. Four experienced observers independently estimated percentage of cover. All four observers were in the same boat as the plot was traversed. Statistical analysis was performed on all observational data for each treatment within a given year using a one-way ANOVA, with estimated percentage of cover means compared using a LSD at the $P = 0.05$ level. Statistical analyses were performed using Statistix 10.0.[6]

RESULTS AND DISCUSSION

Photographs of the plots at 20 WAT (Figures 1 and 2) shows substantial reductions in flowering rush standing mass in the herbicide-treated plots. In addition, dense stands of flowering rush are visible in nontreated reference plots and buffer strips that separated plots. Anecdotal evidence from 2014 trials indicated that lateral soil movement of the herbicides was minimal when applied to bare ground in early spring (B. Bluemer, pers. comm.), and the condition of these plots and buffer strips supported that observation. Pretreatment samples showed the rhizome bud density was higher in the imazamox plus 2,4-D and imazapyr plots in comparison to the other three plots, which is due to the variability in the spatial growth of this plant (Figure 3A). At 1 YAT (2016), no treatments were significantly different from the nontreated reference regarding rhizome buds, but by 2 YAT (2017), rhizome bud levels in imazapyr-treated plots were significantly lower than the reference.

Shoot biomass was not significantly different in 1 and 2 YAT (Figure 3B). These samples were taken in the early spring, and differences in the progression of spring warming would have affected the amount of sprouting and growth that had occurred at the time of sampling.

Flowering rush rhizome and root biomass is less sensitive to time of the year than shoot biomass (Marko et al. 2015). Before treatment (2015), plots to be treated with imazamox plus 2,4-D and imazapyr had significantly higher rhizome biomass than plots receiving the other three treatments (Figure 3C). At 1 YAT (2016), no significant difference in rhizome biomass was noted between the treatments. By 2 YAT, plots treated with imazamox and imazapyr had significantly lower rhizome biomass than the nontreated reference plots.

Phenological studies have indicated that the rhizome bud is the key stage of the life history of triploid flowering rush, as it is the propagule that regenerates from management, spread, and overwintering (Marko et al. 2015, Madsen et al. 2016b). It is difficult to reduce rhizome biomass of mature flowering rush with a single herbicide treatment in a growing season. A study of five herbicides (endothall, flumioxazin, 2,4-D amine and ester formulations, and triclopyr) applied once as a submersed injection found that none were able to reduce rhizome biomass (Poovey et al. 2013). In contrast, operational treatments with submersed injection of two diquat treatments per growing season reduced rhizome biomass by 80% (Madsen et al. 2016a). Foliar applications with 2,4-D, triclopyr, aminopyralid,

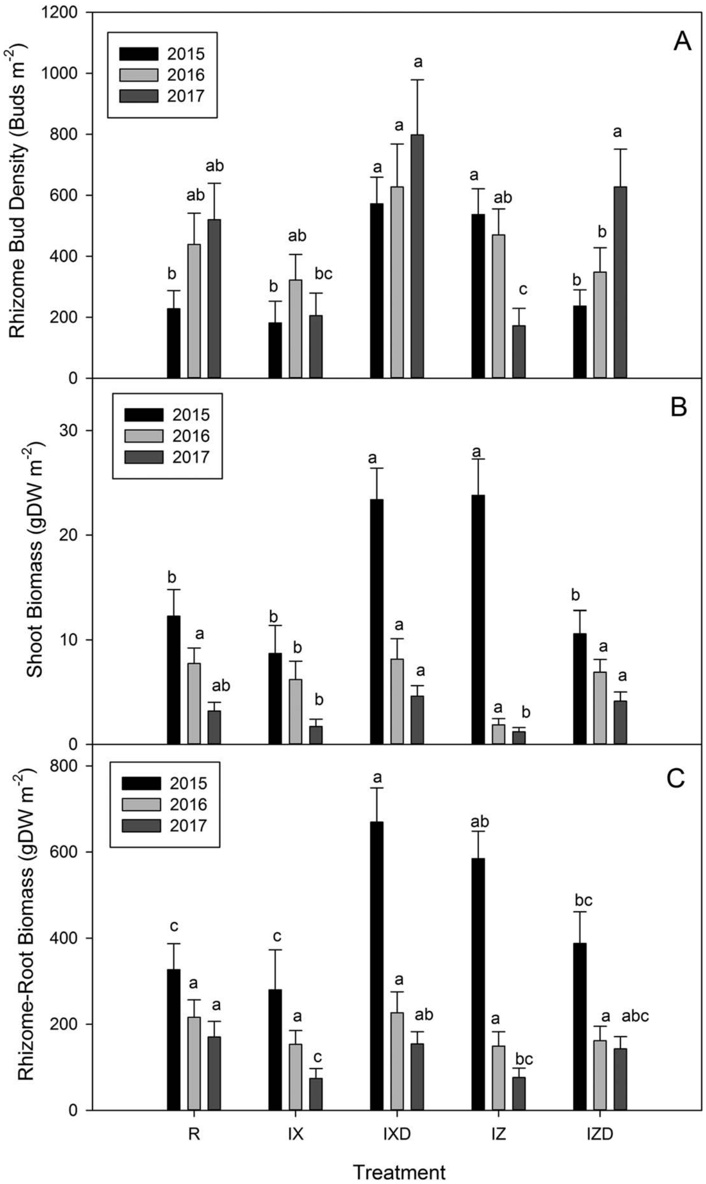

Figure 3. Flowering rush abundance in treated and nontreated plots at the Clark Fork River delta on Lake Pend Oreille, Idaho, sampled in spring of 2015 (pretreatment), 2016 (1 yr after treatment [YAT]), and 2017 (2 YAT). (A) Rhizome bud density (buds m^{-2}), (B) shoot biomass (g dry weight [DW] m^{-2}), and (C) rhizome and root biomass (g DW m^{-2}). Treatments are nontreated reference (R), imazamox plus surfactant (IX), imazamox and 2,4-D plus surfactant (IXD), imazapyr plus surfactant (IZ), and imazapyr and 2,4-D plus surfactant (IZD). Means with a different letter for the same year of treatment are significantly different at the $P = 0.05$ level of significance. Statistical comparisons are within a given year.

imazapyr, glyphosate, and some combinations resulted in reduction of rhizomes by 6 WAT (Wersal et al. 2014).

Percentage of cover is a good measure of nuisance impact by an invasive weed, and at 12 WAT, imazamox (15%), imazapyr (11%), and imazapyr plus 2,4-D (28%) treatments had significantly less estimated percentage of cover than the nontreated reference (62%, Figure 4). By 64 WAT, only the imazamox treatment (34%) had significantly less estimated

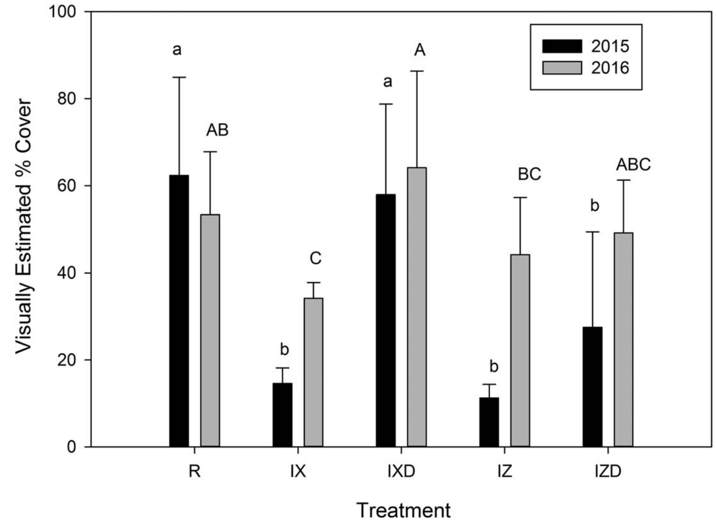

Figure 4. Flowering rush abundance by visually estimated percentage of cover in each plot at the Clark Fork River delta on Lake Pend Oreille, Idaho, in the summer of 2015 (12 wk after treatment) and 2016 (64 wk after treatment). Treatments are nontreated reference (R), imazamox plus surfactant (IX), imazamox and 2,4-D plus surfactant (IXD), imazapyr plus surfactant (IZ), and imazapyr and 2,4-D plus surfactant (IZD). Means with a different letter for the same year of treatment are significantly different at the $P = 0.05$ level of significance. Statistical comparisons are within a given year.

cover than the nontreated reference or other treatments. Substantial regrowth of flowering rush shoot biomass had occurred after treatment in late spring 2015. While imazamox provided the best control of flowering rush in this bare ground evaluation, successive, annual early spring applications will likely be required to achieve more than seasonal control of this invasive plant.

SOURCES OF MATERIALS

[1]Polaris©, Nufarm Americas Inc., 11901 S. Austin Ave., Alsip, IL 60803.

[2]Clearcast©, SePRO Corp., 11550 N. Meridian St., Carmel, IN 46032.

[3]Base Camp© Amine 4, Wilbur-Ellis Agribusiness, 3300 S. Parker Road, Aurora, CO 80014.

[4]Agrixdex©, Helena Chemical Co., 225 Schilling Blvd., Collierville, TN 38017.

[5]Boominator© 1870 spray nozzles, UDOR USA, Inc., 500 Apollo Dr., Lino Lakes, MN 55014.

[6]Statistix 10.0, Analytical Software, 2105 Miller Landing Road, Tallahassee, FL 32312.

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