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Simulated mechanical control of flowering rush (*Butomus umbellatus*) under mesocosm conditions

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Abstract

Flowering rush (*Butomus umbellatus* L.) is an invasive aquatic and wetland plant capable of developing monotypic stands in emergent and submersed sites. This plant can rapidly outcompete native vegetation and impede human practices by reducing recreation (boating, fishing, and skiing) and disrupting agricultural use of water resources (irrigation canals). Mechanical removal practices occurring biweekly, monthly, bimonthly, and once per growing season were compared with chemical control with diquat applied sequentially at 0.19 ppmv ai for two consecutive months over 2 yr (2016 and 2017). Biweekly removal gave the most consistent control of *B. umbellatus* biomass and propagules. Diquat application along with monthly and bimonthly clippings gave varying degrees of *B. umbellatus* control. Clipping once per growing season did not control *B. umbellatus* when compared with reference plants, while clipping *B. umbellatus* every 2 wk (biweekly) controlled rush propagules most effectively. However, it is unlikely this method will be sufficient as a stand-alone control option due to the slow speed of harvester boats, the potential these boats have to spread *B. umbellatus* propagules to more sites, and the expense of mechanical operations. However, clipping could be used as part of an integrated strategy for *B. umbellatus* control.

Introduction

Flowering rush (*Butomus umbellatus* L.) is an invasive plant in the northern United States and southern Canada (Anderson et al. 1974; Kliber and Eckert 2005) that impedes water flow, reduces human uses of water resources, and reduces biodiversity in aquatic and wetland habitats (Bellaud 2009). *Butomus umbellatus* is native to Europe and Asia and first entered the United States in 1928 (Muenscher 1930; Tutin et al. 1980). After introduction, *B. umbellatus* most likely expanded across North America via horticultural activities (Les and Mehrhoff 1999).

Butomus umbellatus has two biotypes (triploid and diploid) in its home and invaded ranges (Hroudova et al. 1996; Kliber and Eckert 2005), suggesting multiple introductions to North America. While the diploid biotype can reproduce sexually, vegetative propagation via rhizome fragments and buds appears to be the primary means of dispersal and colonization for both *B. umbellatus* biotypes (Hroudova et al. 1996). Carter et al. (2018) found that while initial *B. umbellatus* propagule size affected final plant biomass over a growing season, it did not affect propagule survivorship, suggesting the smallest rhizome fragments or individual rhizome buds are sufficient to establish new colonies. In fact, rhizome fragments and buds can sprout leaves and roots while free floating in water (GT, personal observation), which further prepares propagules for invasion of new sites while in transit. *Butomus umbellatus* has an adaptive growth form (Sarbu et al. 2009) and can grow as a wetland plant, a shallow-water emergent plant (0 to 1.2 m), or as a completely submersed plant (1.2 to 6 m; Rice et al. 2010), which facilitates survival in diverse environments with fluctuating water and light conditions (Carter et al. 2018; Madsen et al. 2017). Additionally, because most of the starch content of *B. umbellatus* is stored in the belowground structures (Marko et al. 2015) and because the species can produce hundreds of rhizome buds per square meter (Madsen et al. 2016c), it is also capable of survival and regrowth after many control activities targeting individual colonies.

Much has been learned about the biology and ecology of *B. umbellatus* in its invaded range over the past two decades (Carter et al. 2018; Eckert et al. 2000; Gunderson et al. 2016; Madsen et al. 2016c; Marko et al. 2015); however, few effective control measures have been found to reduce *B. umbellatus* colonies. Several small-scale mesocosm and laboratory studies have identified herbicide chemistries that are effective for controlling *B. umbellatus* (Madsen et al. 2016a, 2016b; Poovey et al. 2012, 2013; Wersal et al. 2014), but few of these have been further

Management Implications

Butomus umbellatus (flowering rush) is an invasive plant species with an adaptive growth form capable of growing in aquatic and wetland habitats. This requires resource managers to control *B. umbellatus* in a variety of environments, and resource managers therefore need multiple control strategies. In most aquatic environments, *B. umbellatus* is controlled with the use of herbicides labeled for use in aquatic sites; however, in some locations herbicides may be prohibited or may not be a feasible control option due to high rates of water exchange. In areas such as these, mechanical control in the form of clipping and harvesting may be a suitable control option. However, mechanical removal requires frequent repetition at 2-wk intervals, if control is the ultimate objective. Monthly or bimonthly clipping had varying degrees of success for control of *B. umbellatus* tissues and propagules. Two potential negative effects of mechanical control are spawn disturbance of fish or other desirable aquatic fauna and spreading *B. umbellatus* propagules in hydrosoil; areas targeted for clipping would need to have floating booms placed around them to capture floating propagules for containment and later disposal.

substantiated with field trials. In fact, the contact herbicide diquat is the only chemical control strategy with documented operational use for the control of *B. umbellatus* (Madsen et al. 2016a; Turnage et al. 2018). While control is evident with large-plot submersed treatments of diquat, repeated treatments may be required (Madsen et al. 2016a; Turnage et al. 2018), and in locations where threatened or endangered species are present, herbicide applications may be prohibited.

Resource managers need alternatives to chemical control methods for *B. umbellatus* management in areas that restrict chemical options and for management of herbicide resistance in treated populations. At this time, no biological control options have been identified for *B. umbellatus*. Madsen et al. (2017) investigated the use of annual drawdown as an alternative to chemical control of *B. umbellatus* and found that physical (benthic barriers) and mechanical (hand pulling and excavation) control methods were ineffective. The fact that *B. umbellatus* was already present at the test sites suggests that drawdown is an ineffective control measure (Madsen et al. 2017).

Using mechanical harvesting to manage aquatic nuisance plants has not been investigated for *B. umbellatus*. Clipping, done often enough, should reduce nutrient stores in the rhizome complex of *B. umbellatus* comparable to repeated contact herbicide applications. Therefore, the purpose of this study was to evaluate short- (over a growing season) and long-term (across years) efficacy of mechanical harvesting on *B. umbellatus*.

Materials and Methods

Experiments were conducted twice (2016 and 2017) at the R.R. Foil Plant Research Center's Aquatic Plant Research Facility at Mississippi State University in 378-L (100-gal) mesocosms. Six treatments were used over a 4-mo period: a nontreated reference, plants that received two submersed diquat (Harvester® Aquatic Herbicide, Applied Biochemists, 1200 Bluegrass Lakes Parkway, Alpharetta, GA 30004) applications (0.19 ppmv ai) 1 mo apart, plants clipped twice per month (biweekly, eight clippings), plants clipped every month (four clippings), plants clipped every other month (bimonthly, two clippings), and plants clipped once per growing season (Table 1). Mesocosm water treated with diquat was in contact with plants for 12 h, then mesocosms were drained and refilled. Pots (3.78 L) filled with sand amended with fertilizer (Osmocote® 19-6-12 fertilizer, Scotts-Sierra Horticultural Products, 14111 Scottslawn Road Marysville, OH 43041) at a rate of 2 g L^{-1} of sand were planted with two 8-cm-long (3-inch-long) *B. umbellatus* rhizome segments. Ten pots of *B. umbellatus* were placed in each mesocosm. Mesocosms were filled with water to a volume of 216 L (16-inch depth), and plants were given 1.5 mo to become established. Each treatment was replicated in three mesocosms. Two extra mesocosms were planted for harvesting pretreatment data for a total of 20 mesocosms and 200 pots. Pretreatment plants (20 pots) were harvested the day before the first treatments were administered. Harvested plant tissues were separated into above- and belowground biomass, placed in labeled paper bags, and dried in a forced-air oven at 70 C for 5 d. Rhizome bud number was recorded before drying. Biomass weights were recorded after drying.

Mechanically treated plants were clipped approximately 5 cm (2 inches) above the sediment surface. Clipped biomass was removed from the mesocosms to simulate mechanical control from harvesting-boat operations in field settings. At 16 wk after initial treatment (WAT), half the pots in each mesocosm were harvested in the same manner as pretreatment samples. The remaining pots were harvested at 52 WAT.

Samples were analyzed statistically using a mixed model to determine whether significant differences existed in mean biomass and bud density. Treatment was considered a fixed variable, while year of experiment (2016 and 2017) was considered a random variable. Differences in means were further separated using a Tukey's post hoc test. All statistical tests were conducted at the $P \leq 0.05$ significance level in the statistical software R using the 'lmerTest' and 'emmeans' packages (R Core Team 2017).

Results and Discussion

At 16 WAT, aboveground biomass of *B. umbellatus* was only reduced by diquat treatments (80%) and biweekly clippings (95%) when compared with reference plants (Figure 1). However, control of aboveground biomass at 16 WAT was not significantly different between all clipping and diquat treatments. At 52 WAT, only biweekly clippings had reduced *B. umbellatus* aboveground biomass (95%) compared with reference plants, but monthly clippings had the same level of control as biweekly clippings.

Butomus umbellatus belowground biomass was reduced 71% by diquat, 76% with monthly clippings, and 91% with biweekly clippings when compared with reference plants at 16 WAT. Clipping every other month (bimonthly) had the same level of control on *B. umbellatus* belowground biomass as biweekly clippings at 16 WAT. At 52 WAT, only monthly (84%) and biweekly (99%) clipping reduced belowground tissues compared with reference plants; however, the two sequential diquat applications caused the same level of control as both monthly and biweekly clippings, while bimonthly clippings had the same level of control as diquat and monthly clippings (Figure 1).

Reduction of *B. umbellatus* rhizome bud density was only achieved by diquat (66%), monthly (70%), and biweekly (81%) clippings compared with reference plants at 16 WAT. Rhizome bud density was still controlled by diquat (54%), monthly

Table 1. Diquat and clipping treatments.

Treatment no.	Treatment	No. of applications	Timing
1	Reference	NA	NA
2	Diquat 0.19 ppmv ai	2	June, July
3	Clipped once per season	1	June
4	Clipped every other month (bimonthly)	2	June, August
5	Clipped once per month (monthly)	4	June, July, August, September
6	Clipped twice per month (biweekly)	8	June (2×), July (2×), August (2×), September (2×)

(78%), and biweekly (89%) clippings compared with reference plants at 52 WAT. Bimonthly clippings had the same level of control over *B. umbellatus* rhizome buds as diquat at 52 WAT (Figure 1).

These data are the first to provide evidence that mechanical control of *B. umbellatus* is possible. In locations where herbicide use is restricted, mechanical harvesting may be the only option to control *B. umbellatus*. However, there are concerns that should be considered before initiating a mechanical harvesting program. For example, the timing of clipping/harvesting would need to be such that it did not coincide with spawning of desirable fish species, as the cutter head would likely kill or injure any fish or other desirable aquatic fauna it contacts, or kill these same organisms by trapping them in harvested vegetation (Booms 1999; Mikol 1985; Wile 1978). Also, the cutter head could disturb spawning sites, as vegetation below the cutter head would move in such a way as to disturb the habitat around it. Additionally, if *B. umbellatus* is growing in a heterogeneous plant stand with desirable native species, clipping/harvesting activities may need to be avoided or timed when *B. umbellatus* would be controlled and desirable plant species avoided (e.g., *B. umbellatus* is the only sprouted species present or the tallest species).

Similar studies examining mechanical control of other invasive aquatic and wetland plant species have also shown that control was enhanced with higher-frequency clipping events (Derr 2008; Wile 1978). While effective at high intensity (every 2 wk), mechanical control via clipping/harvesting may be too time-consuming and expensive (Bryant 1970, 1974; Charudattan 2001; Haller 2009) to see wide use among resource managers dealing with *B. umbellatus* infestations. Culpepper and Decell (1978) found that less than 9,072 kg (10 tons) of waterhyacinth [*Eichhornia crassipes* (Mart.) Solms] and less than 4,536 kg (5 tons) of hydrilla [*Hydrilla verticillata* (L. f.) Royle] could be removed per hour from a body of water via clipping/harvesting; which was lower than their minimum stated management goal of 72,575 kg (80 tons) h^{-1}. Culpepper and Decell (1978) also found that the pace for clipping/harvesting operations is usually set by the time needed to transport clipped vegetation to shore and/or disposal sites rather than the rate at which the harvester operates.

If *B. umbellatus* populations are large, mechanical clipping/harvesting may not provide control, as harvester boats may not be capable of clipping an entire infestation in 2 wk due to their slow speeds (Culpepper and Decell 1978) and need to periodically offload clipped vegetation (Culpepper and Decell 1978; Haller 2009; Newroth 1979; Unmuth et al. 1998). Additionally, harvesting operations can release vegetative propagules from clipped aquatic plants, which can drift away in water currents and infest new sites (Culpepper and Decell 1978; Haller 2009). Placing floating booms around *B. umbellatus* sites targeted for clipping may help to contain dislodged propagules for later collection and disposal.

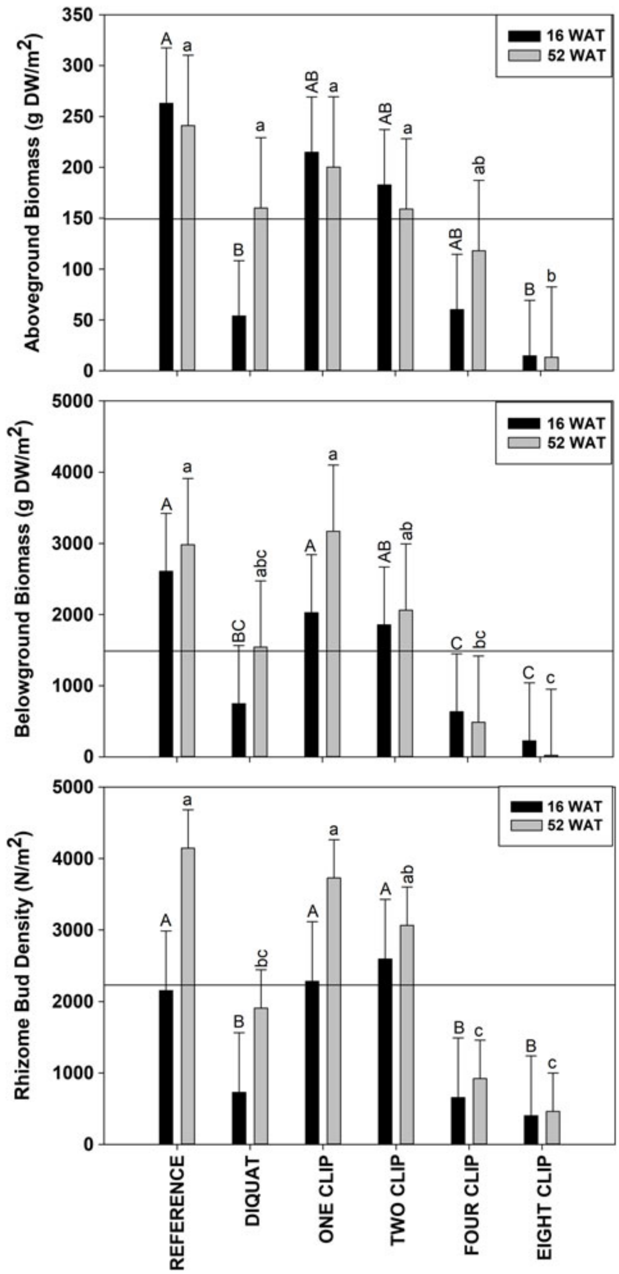

Figure 1. *Butomus umbellatus* aboveground biomass, belowground biomass, and rhizome bud density at 16 and 52 wk after initial treatment (WAT). Solid lines represent pretreatment levels of each plant metric. Error bars are 1 standard error of the mean. Bars sharing the same letter are not statistically different from one another at the P = 0.05 level of significance. Time periods (16 and 52 WAT) were analyzed separately.

Mechanical harvesting could be effectively used as part of an integrated management approach for *B. umbellatus* in areas where herbicide use may not reach an appropriate concentration exposure time. Similarly, clipping/harvesting could be useful as a short-term control option for small *B. umbellatus* colonies until

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resource managers can identify other more suitable control methodologies for their management areas. Regardless, these data indicate that both chemical and mechanical options can be effective alone, and possibly together, to manage this troublesome plant. Future studies should investigate the use and timing of clipping/harvesting as part of an integrated control strategy using chemical, physical, and mechanical control techniques on *B. umbellatus*.

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