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Endothall Species Selectivity Evaluation: Southern Latitude Aquatic Plant Community

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ABSTRACT

Species selectivity of the aquatic herbicide endothall as the formulation Aquathol® K was evaluated on a variety of plant species commonly found in southern latitude United States aquatic plant communities. Submersed species included hydrilla [*Hydrilla verticillata* (L.f.) Royle.], wild celery (*Vallisneria americana* L.), American pondweed (*Potamogeton nodosus* Poiret), southern naiad [*Najas guadalupensis* (Sprengel) Magnus], watershield (*Brasenia schreberi* J. F. Gmelin), water stargrass [*Heteranthera dubia* (Jacq.) MacM.], and Illinois pondweed (*Potamogeton illinoensis* Morong.). Emergent species included soft-stem bulrush (*Scirpus validus* Vahl) and arrowhead (*Sagittaria latifolia* Willd.), and floating-leaf species included spatterdock [*Nuphar luteum* (L.) Sibth. & Sm.], and fragrant waterlily (*Nymphaea odorata* Aiton). The study was conducted in outdoor mesocosm systems (860 to 7000 L tanks) at the U.S. Army Engineer Research and Development Center, Waterways Experiment Station, Lewisville Aquatic Ecosystem Research Facility (LAERF) in Texas. The selectivity evaluations of submersed species were conducted in mesocosm tanks, and treatment rates included 0, 1, 2, and 5 mg/L active ingredient (ai) endothall with a 24 hour water flow-through half-life. Emergent species treatment rates included 0, 1, 2 and 5 mg/L ai endothall and a static water-flow exposure period of 120 hours. Floating-leaf treatment rates included 0, 1, 2, and 5 mg/L ai endothall and a static water-flow exposure period of 120 hours. Endothall was effective at controlling hydrilla at the 2 and 5 mg/L application rates, reducing the biomass by more than 90%, 6 weeks after treatment (WAT), with no regrowth observed. Wild celery and Illinois pondweed biomass were also significantly reduced following the endothall application at 1, 2 and 5 mg/L, but healthy regrowth was observed by 6 WAT. American pondweed and southern naiad biomass was significantly reduced by more than 90% by 6 WAT, and no regrowth was measured. Watershield and water stargrass showed no effects from endothall application at 1, 2, and 5 mg/L, and growth was actually enhanced by reduced competition from invading annual species. Soft-stemmed bulrush also showed no effects from treatment with endothall. Biomass of arrowhead, spatterdock, and fragrant waterlily was significantly reduced at the 2 mg/L application rate, and plants were controlled at the 5 mg/L application rate. Because the emergent and floating-leaf evaluations were conducted under static water-flow conditions, these evaluations represented a worst case scenario, which may not be indicative of endothall use patterns under field conditions. These evaluations demonstrate the potential of using endothall to selectively control hydrilla in mixed-plant communities.

Key words: Aquathol® K, endothall, *Hydrilla verticillata, Vallisneria Americana, Potamogeton nodosus, Najas guadalupensis, Brasenia schreberi, Heteranthera dubia, Potamogeton illinoensis, Scirpus validus, Sagittaria latifolia, Nuphar luteum, Nymphaea odorata.*

INTRODUCTION

The need to control excessive aquatic plant growth and invasion of exotic weeds is well documented, yet many resource and aquatic managers recognize the benefits provided by an appropriate amount of native aquatic vegetation. Some exotic weeds such as hydrilla and Eurasian watermilfoil, (*Myriophyllum spicatum* L.) form dense, surface canopies that can significantly reduce dissolve oxygen, increase water temperature, and limit light penetration for native plants (Bowes et al. 1979, Honnell et al. 1993). Removal of the canopy forming exotic plants can significantly increase native plant density and diversity (Getsinger et al. 1997) and improve navigation and recreation. The restoration of weed-dominated submersed plant communities to a more ecologically balanced native plant community has led to an interest in the species selective potential of several aquatic herbicides (Netherland et al. 1997, Sprecher et al. 1998). The dipotassium salt form of endothall (7-oxabicyclo(2.2.1)heptane-2,3-dicarboxylic acid), is generally recognized as a broad-spectrum compound and is listed as effective against a wide range of aquatic plants including both monocotyledons and dicotyledons (Madsen 1997, Westerdahl and Getsinger 1988). Anecdotal evidence from years of field use indicates that efficacy of endothall varies greatly with species and application rate and therefore has the potential to be used for selective aquatic plant control based on use rates and the tolerance/sensitivity of target and non-target species.

Endothall has been effectively used to control hydrilla and Eurasian watermilfoil throughout the United States. Endothall is described as a contact-type, membrane-active herbicide (Ashton and Crafts 1981), but other studies have shown slow initial uptake by submersed weeds (Haller and Sutton 1973, Reinert and Rogers 1986, Van and Conant 1988). Concentration/exposure time (CET) relationships developed for hydrilla and Eurasian watermilfoil (Netherland et al. 1991) indicate that both of these species can be effectively con-

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trolled at high concentrations and relatively short exposure periods (4 to 5 mg/L active ingredient (ai) endothall and 12 to 18 h exposure time for hydrilla, and 2 to 3 mg/L ai endothall and 8 h exposure time for Eurasian watermilfoil). Both species can also be controlled at low application rates (2 to 3 mg/L ai endothall for hydrilla and 1 mg/L ai endothall for Eurasian watermilfoil) and exposure periods of 48 to 72 h. Even though hydrilla and Eurasian watermilfoil are both controlled by endothall, their sensitivity to the herbicide is very different. The CET relationship showed that hydrilla may require as much as twice the application rate or twice the exposure time to achieve the same level of control as Eurasian watermilfoil. Anecdotal evidence indicates that sensitivity to endothall varies greatly between native plants. Since CET relationships have been quantified relative to target exotic species such as hydrilla and Eurasian watermilfoil, endothall application rates can be selected to achieve effective control of target species and minimize damage, or enhance growth of native submersed plants. Aquatic managers are also interested in potential impacts of herbicides, used to control target submersed plants, on non-target floating and emergent plant species.

The objective of this study was to evaluate the tolerance or sensitivity of selected aquatic plants to the herbicide endothall when applied over a range of concentrations generally recommended for field use. Plants evaluated represented a mixture of species that may occur in southern latitude aquatic ecosystems dominated by the submersed exotic plant hydrilla (Godfrey and Wooten 1979a, Godfrey and Wooten 1979b).

MATERIALS AND METHODS

This study was conducted in the outdoor mesocosm system at the U.S. Army Engineer Research and Development Center, Waterways Experiment Station, Lewisville Aquatic Ecosystem Research Facility (LAERF) near Dallas, TX. Plant species (Table 1) were assigned to independent experimental systems based upon morphological and physiological criteria: System A) submersed species grown without CO_2; System B) submersed and small floating-leaf species grown with the addition of CO_2; System C) emergent species; System D) large floating-leaf species.

Evaluations in System A and System B were conducted in 7000 L fiberglass, mesocosm tanks (water depth = 100 cm) with flow valves set to provide a constant flow-through that would provide a 24-h half-life dissipation for endothall. The stated half-life does not account for loses of endothall due to degradation. Sediment was collected from a dried pond located at the LAERF, and was characterized as a silty clay. Healthy tissues of the each species were planted between 23 and 27 June 1997 in 8 L plastic containers filled with sediment amended with 10 g ammonium sulfate (21-0-0) and 1 "Woodace" nutrient briquette (14-3-3) per container. Eleven containers per species were placed in each of 12 tanks, with plants grouped by species and separated into a quarter of each tank. Plants were allowed a 5-week pre-treatment growth period. In System A tanks, water pH values ranged from 8.0 to 9.0 during the day. Based on previous experience and unpublished research conducted at the LAERF, several species evaluated in this study were determined to require CO_2 for healthy growth and were included in System B. Each tank containing these species was injected with CO_2 gas for 4 h per day to maintain water pH of approximately 7.0 during the day. Maximum water temperature was 30C in all tanks.

Table 1. Aquatic plant species evaluated in this study were listed by each experimental system and include the type of planting material and number of plants added to each container.

Species	Planting material	Number of plants/container
System A:		
hydrilla	apical tips	3
wild celery	rooted plants	3
American pondweed	apical tips	3
southern naiad	apical tips	3
System B:		
watershield	rooted plants	3
water stargrass	apical tips	3
Illinois pondweed	apical tips	3
System C:		
soft-stem bulrush	rooted plants	1
arrowhead	rooted plants	3
System D:		
spatterdock	tuber	1
fragrant waterlily	tuber	2

On 4 and 5 August 1997, endothall was applied to provide treatment rates of 0, 1, 2, and 5 mg/L a.i. endothall, and each treatment was replicated in three tanks. In addition, three tanks received no endothall application and were used as untreated reference tanks. Plant biomass samples were collected at pretreatment, at 3 and 6 weeks after treatment (WAT). Immediately prior to treatment, one container per species per tank was harvested to determine biomass prior to endothall application. Four containers per species per tank were harvested 3 and 6 WAT. The two remaining containers provided backup for failed plantings. Failed plantings were identified and recorded prior to herbicide application. Shoot tissue samples were dried to a constant weight at 65C for 96 h prior to determining biomass.

The evaluation in System C (emergent plants) was conducted in twelve, 860 L mesocosm tanks (water depth = 50 cm). The experimental design was similar to the submersed test, except only two plant species were included in each tank, and the endothall exposure period was static for 120 h (i.e. no water exchange). At the end of the 120-h exposure time, the tanks were flushed with clean, untreated water. Plant materials were planted between 23 and 27 June 1997, and endothall was applied (0, 1, 2, 5 mg/L a.i.) on 19 August 1997. Water temperature at time of treatment was 29C. Initial survival of newly planted arrowhead was less than 100% immediately following planting; therefore only 3 containers of this species per tank could be harvested at each of the 3 and 6 WAT evaluations. All remaining plants were large, healthy, and growing vigorously at the time of endothall application.

The evaluation in System D (large floating-leaf plants) was conducted in twelve, 1600 L mesocosm tanks (water depth = 50 cm). The experimental design was identical to System C.

Endothall was applied on 12 September 1997, and water temperature at time of treatment was 28C. Initial survival of newly planted spatterdock was less than 100% immediately following planting; therefore only 3 containers per tank could be harvested at each of the 3 and 6 WAT evaluations. Much of the spatterdock remained in a submerged state during the study period with few emergent or floating leaves, therefore this system was treated at a later date in order to give spatterdock more time to form floating leaves. This effort was only marginally successful, and many of the spatterdock plants remained completely submerged or retained submersed leaves during the course of the study.

Biomass data for all evaluations were subjected to analysis of variance (ANOVA) and the least significant differences (LSD) intervals ($p < 0.05$). The experimental design included 4 harvested pots each for 3 and 6 WAT nested within 3 replicated tanks per treatment. Biomass for each species was compared between treatments (0, 1, 2, and 5 mg/L) for the 3 and 6 WAT harvests. In addition, biomass for each species was compared between time intervals (3 and 6 WAT) for each treatment. Data was transformed using the square root of biomass value in order to meet the assumptions of normality and equal variance.

RESULTS AND DISCUSSION

All plants were healthy growing plants prior to herbicide application. Mean pretreatment biomass and standard error for each species are presented in Figure 1 for reference. Some invasion of other plant species occurred in most pots, primarily southern naiad and *Chara* sp. Presence of these species probably occurred as a result of seed or spores in the sediment which was collected from nearby ponds at the LAERF. After herbicide application, southern naiad was the primary invasive species in untreated reference tanks, and *Chara* sp. tended to be primary invasive species in treated tanks. The effects of species competition on planted species biomass could not be addressed in this study, but should not have affected efficacy of endothall on study species.

System A

Hydrilla significantly declined in biomass following application of endothall (Figure 2). Biomass harvested from treatment rates of 2, and 5 mg/L were less than the untreated reference at 3 WAT, and from treatment rates of 1, 2, and 5 mg/L at 6 WAT. Hydrilla biomass was reduced by more than 93% at an application rate of 2 mg/L compared to the untreated reference. Biomass from the 2 mg/L application rate was less than biomass from the 1 mg/L rate, and biomass from the 5 mg/L rate was less than from the 2 mg/L rate at 3 WAT. By the 6 WAT biomass evaluation, differences among treatments were no longer significant.

Wild celery biomass was reduced at all endothall application rates compared to the untreated reference at 3 and 6 WAT (Figure 2). Wild celery did not, however, show a rate response to endothall among treatments. Biomass was not different between application rates of 1, 2, and 5 mg/L. By the 6 WAT evaluation, wild celery showed good recovery from the initial herbicide injury noted 3 WAT. Biomass was greater

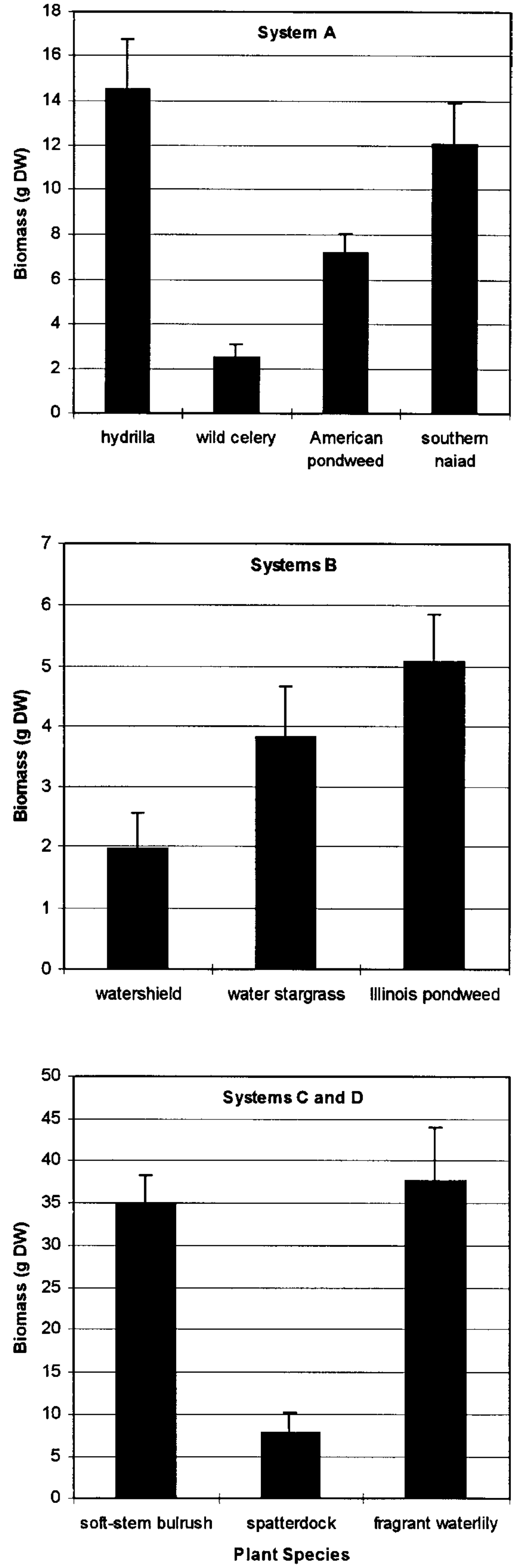

Figure 1. Mean Pretreatment shoot biomass for all tanks (g dry weight). Error bar represents the standard error. No data was available for arrowhead.

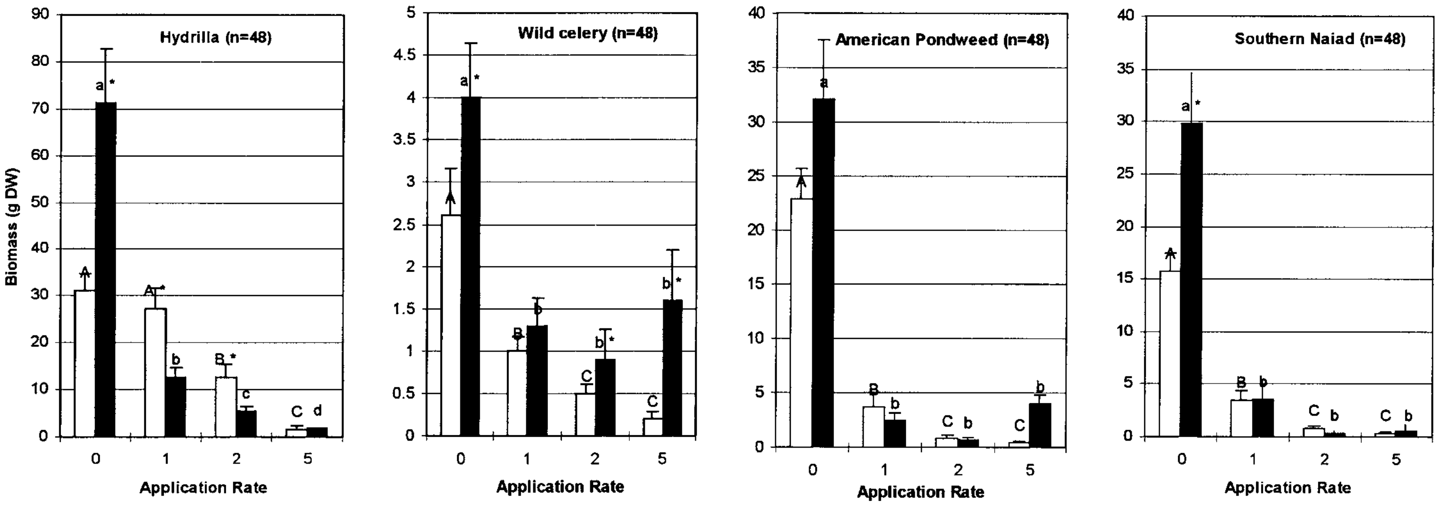

Figure 2. System A shoot biomass (g dry weight) at 3 (white bars) and 6 (black bars) weeks after treatment with varying concentrations of endothall (mg/L a.i.). Capital letters indicate significant differences ($P < 0.05$) between treatments at 3 WAT samples, and lower case letters indicate differences between treatments at 6 WAT. Letters with asterisks (*) indicate significant differences between 3 and 6 WAT within an endothall application rate. Note differing biomass scales. Error bar represents the standard error.

at the 6 WAT evaluation than at the 3 WAT evaluation at all application rates, but the difference was only significant at 5 mg/L. Based on visual observation, plants at the 6 WAT evaluation had healthy vigorous new shoots that showed signs of a strong recovery.

American pondweed was very sensitive to endothall (Figure 2) as biomass was reduced at all application rates; and it was reduced by 92% at the lowest application rate of 1 mg/L by the 6 WAT evaluation. American pondweed did not show a rate response to endothall between treatments, as biomass was not different between endothall application rates of 1, 2, and 5 mg/L. Based on visual observations American pondweed showed more recovery by the 6 WAT evaluation at the 5 mg/L application rate than at the 1 mg/L or 2 mg/L application rates. It has been suggested that endothall may have the ability to translocate when used at lower concentrations, and perhaps movement of the herbicide into the root crown at the 1 and 2 mg/L treatments caused greater mortality of the plants. In contrast, at 5 mg/L, leaf and stem tissue may have been killed too quickly for translocation to occur, thus preserving the root crown with subsequent regrowth occurring.

Southern naiad response to endothall was similar to American pondweed (Figure 2). Biomass at all application rates was reduced by 88% to 93% compared to the untreated reference. Southern naiad showed a small but significant rate response between the 1 and 2 mg/L application rates but no difference at 6 WAT. No recovery was apparent by 6 WAT.

System B

Watershield did not decline in biomass following application of endothall (Figure 3). Biomass at all evaluation dates and endothall application rates was not different than the untreated reference.

Water stargrass was not affected by application of endothall (Figure 3). Biomass was greater in treatment rates of 1 mg/L and 2 mg/L compared to the untreated reference at both the 3 WAT and 6 WAT evaluations. Biomass increased between the 3 WAT and 6 WAT at application rates of 0, 1, and 2 mg/L a.i., and actually doubled at the 1 and 2 mg/L a.i. application rates. Visual observations conducted during the first week post treatment, showed that water stargrass was the first species to exhibit visual symptoms of herbicide effects. Many of the leaves and stems began to turn black less than 24 h after treatment (HAT) at all treatment rates, and remained black for several days. At 5 to 7 days after treatment the leaves and stems began to return to a green color, and new growth was evident.

Illinois pondweed declined in biomass (~90% at the 3 WAT evaluation) due to endothall treatments (Figure 3), with biomass at all application rates less than the untreated reference; however. Biomass was not different among application rates. Biomass at the 6 WAT evaluation was greater than at the 3 WAT evaluation indicating that plants were recovering. Visual observations at the 6 WAT evaluation indicated much of the plant material was new growth, characteristic of recovering plants.

System C

Since these plants were exposed to endothall-treated water in a static system (no flow through), this evaluation represented the worst case scenario for endothall exposure. Maximum static application rates in this study (5 mg/L) were equal to 3 to 4 times the maximum rate required to control hydrilla with a 72-h exposure time (Netherland et al. 1991).

Soft-stem bulrush did not decline in biomass at 3 WAT (Figure 4). Biomass from the 6 WAT evaluation and 5 mg/L application rate was statistically less than the untreated reference, but the actual difference was only about 25% and plants were healthy and vigorous.

Arrowhead significantly declined in biomass following application of endothall (Figure 4). Arrowhead also showed a decline in biomass due to increased endothall application rates. While biomass was reduced at the 1 and 2 mg/L application rates, and death occurred at 5 mg/L, the remaining vegetation treated with 1 and 2 mg/L was strong and viable.

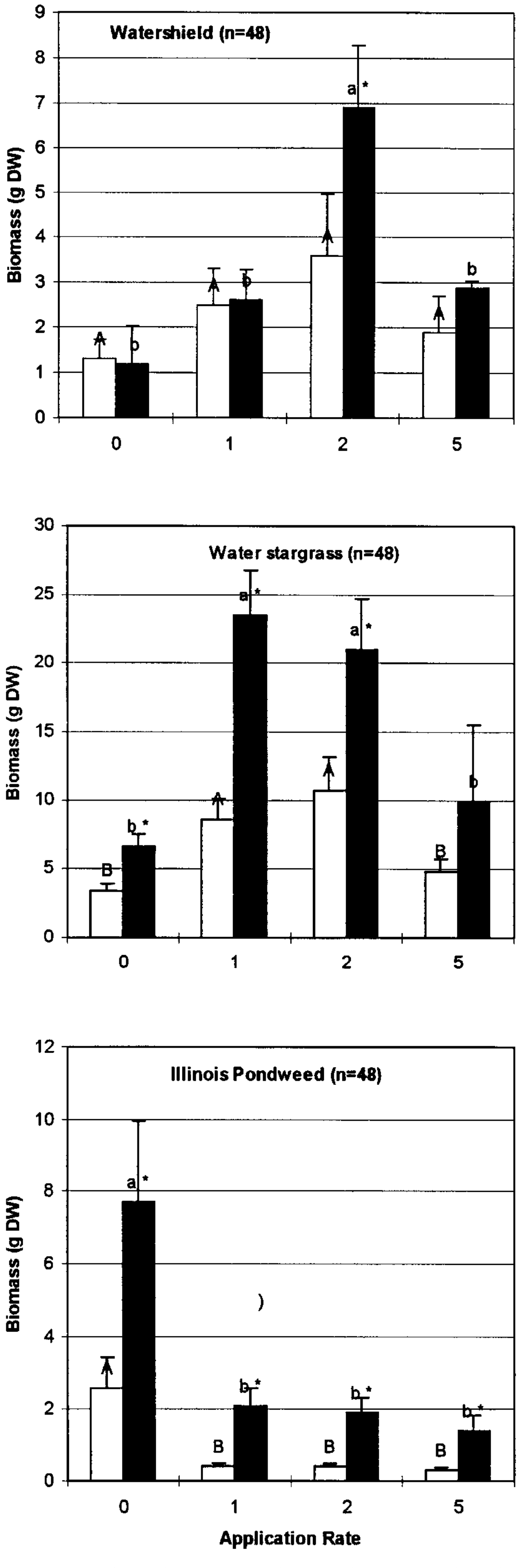

Figure 3. System B shoot biomass (g dry weight) at 3 (white bars) and 6 (black bars) weeks after treatment with varying concentrations of endothall (mg/L a.i.). Capital letters indicate significant differences (P < 0.05) between treatments at 3 WAT, and lower case letters indicate differences between treatments at 6 WAT. An asterisk (*) indicates significant differences between 3 and 6 WAT within an endothall application rate. Note differing biomass scales. Error bar represents the standard error.

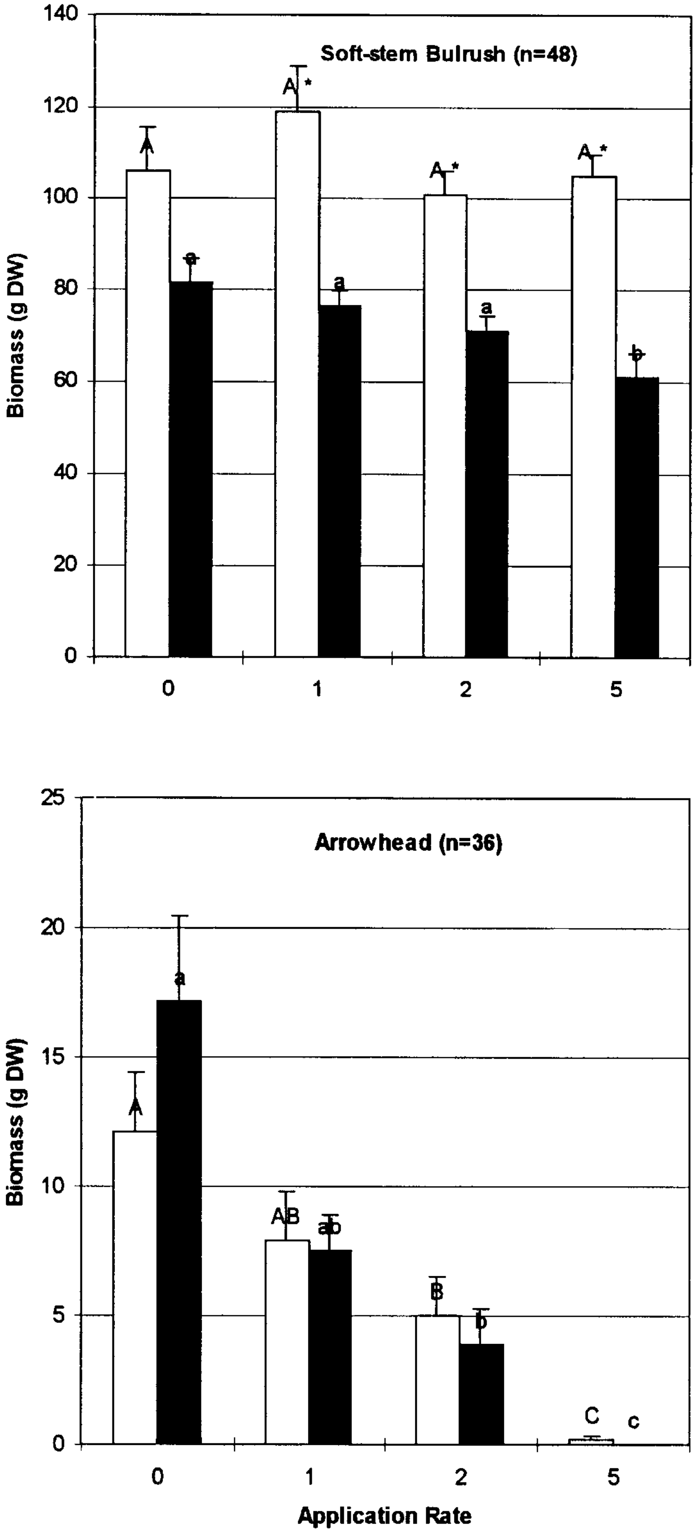

Figure 4. System C shoot biomass (g dry weight) at 3 (white bars) and 6 (black bars) weeks after treatment with varying concentrations of endothall (mg/L a.i.). Capital letters indicate significant differences (P < 0.05) between treatments at 3 WAT, and while lower case letters indicate differences between treatments at 6 WAT. An asterisk (*) indicates significant differences between 3 and 6 WAT within an endothall application rate. Note differing biomass scales. Error bar represents the standard error.

System D

The floating-leaf plant evaluation was conducted in a static system (no flow through) and also represented the worst case scenario for endothall exposure. Because the leaves of spatterdock remained submersed, effects of endothall were more severe than previously observed under field conditions. Spatterdock declined in biomass following application of endothall, particularly at the treatment rate of 5 mg/L (Figure 5). At the 6 WAT evaluation, spatterdock appeared to show a rate response, and biomass declined as application rates increased. These results contradict observations of field applications, where mature spatterdock plants are usually unaffected by endothall applications. As previously mentioned, leaves of spatterdock were predominantly submersed forms, and these data would suggest that newly emergent spatterdock may be sensitive to endothall. In addition, unlike the System A and B evaluations, the System C and D evaluations were conducted using static water conditions and therefore represent a worst case scenario with respect to exposure time.

Fragrant waterlily declined in biomass following application of endothall (Figure 5). Fragrant waterlily also showed rate response to endothall concentrations. Biomass from the 2 mg/L application rate was less than biomass from the 1 mg/L application rate, and biomass from the 1 mg/L application rate was less than biomass from the untreated reference. While biomass was reduced at 1 and 2 mg/L, and death occurred at 5 mg/L, the remaining vegetation was strong, viable, and recovering from the lower application rates.

The herbicide endothall applied as Aquathol®K, effectively controlled hydrilla at application rates ranging from 2 to 5 mg/L ai under a 24-h half-life dissipation regime. While endothall is generally recognized as a broad-spectrum product, plant response to endothall and ultimately selectivity, varied in several ways (Table 2). Some plants such as watershield, water stargrass, and soft-stem bulrush were not injured or killed by endothall at any application rate evaluated. In fact, plant growth was enhanced at medium application rates possibly due to reduced competition from invading plants such as southern naiad. Other plants such as wild celery and Illinois pondweed, which showed initial injury, were recovering by 6 WAT. Rapid, strong recovery of natives such as these could inhibit the regrowth of target species such as hydrilla thus enhancing the overall effectiveness of the herbicide treatment. Some native plant species were, however, reduced by endothall application, and recovery was slow or did not occur, most notably American pondweed and southern naiad.

Based on field observations, results of the arrowhead, spatterdock, and fragrant waterlily evaluations were unexpected. These results do, however, emphasize the importance of exposure time when using broad spectrum herbicides to selectively control a target species. Based on previous concentration exposure time studies (Netherland et al. 1991) approximately 1.6 mg/L a.i. endothall would be required to control hydrilla given a static exposure time of 72 h and 5 mg/L a.i. given an exposure time of 18 h. Given the 120-h static exposure time used in the System C and D evaluations, 1 to 2 mg/L ai endothall would be expected to control hydrilla but probably would not significantly damage the emergent and floating-leaf species. The use of broad spectrum herbicides to selectively control one species re-

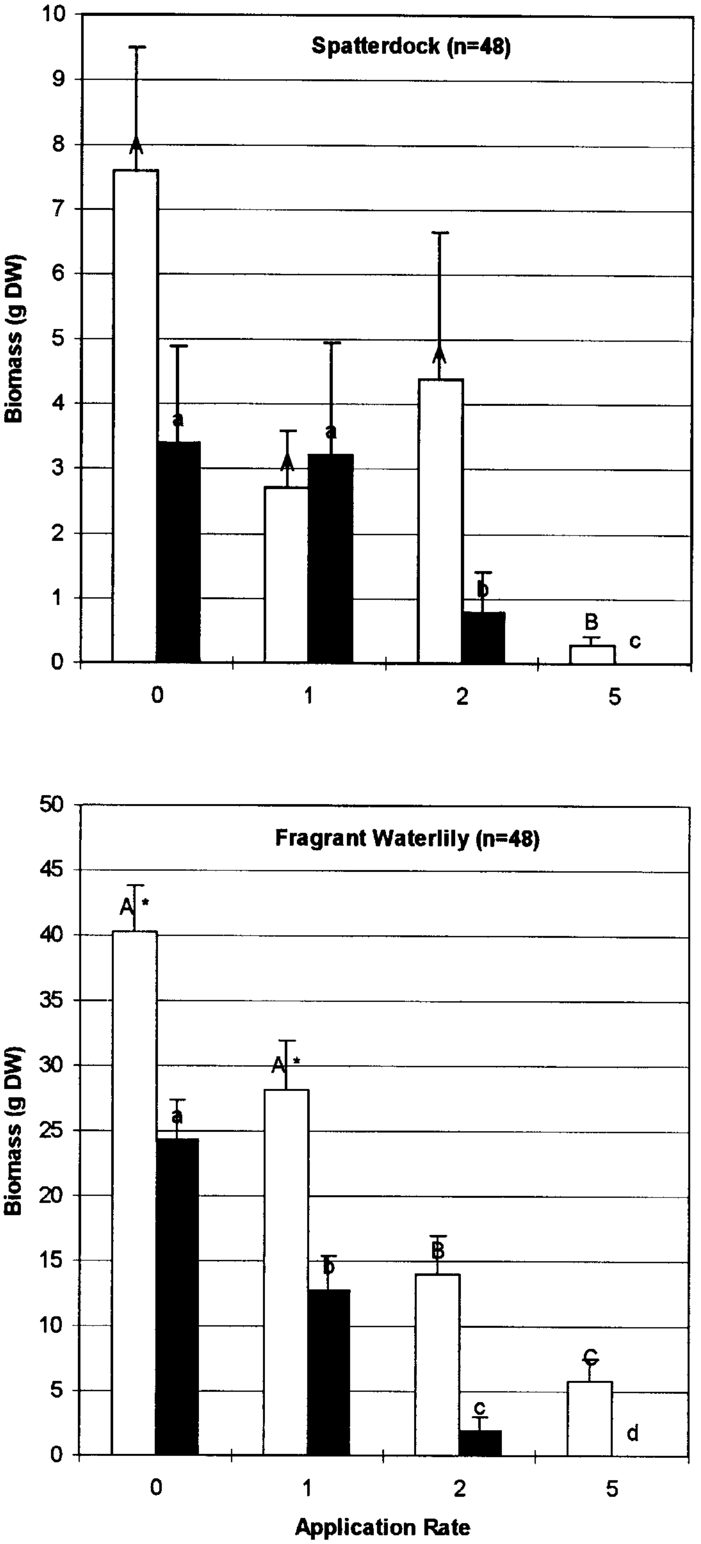

Figure 5. System D shoot biomass (g dry weight) at 3 (white bars) and 6 (black bars) weeks after treatment with varying concentrations of endothall (mg/L a.i.). Capital letters indicate significant differences ($P < 0.05$) between treatments at 3 WAT, and lower case letters indicate differences between treatments at 6 WAT. An asterisk (*) indicates significant differences between 3 and 6 WAT within an endothall application rate. Note differing biomass scales. Error bar represents the standard error.

TABLE 2. PLANT RESPONSE TO ENDOTHALL APPLICATIONS WERE SUMMARIZED ACCORDING TO INITIAL SENSITIVITY, RECOVERY FROM INITIAL INJURY, AND VISUAL CONDITION AT THE COMPLETION OF THIS STUDY.

Species	Sensitivity[1]	Significant recovery at 6 WAT[2]	Visual condition of existing plants 6 WAT
System A, 24-h half-life			
hydrilla	2 mg/L	not significant	poor
wild celery	1 mg/L	significant	excellent
American pondweed	1 mg/L	not significant	good
southern naiad	1 mg/L	not significant	poor
System B, 24-h half-life			
watershield	none	no initial injury	excellent
water stargrass	none	no initial injury	excellent
Illinois pondweed	1 mg/L	significant	good
System C, static			
soft-stem bulrush	none	no initial injury	excellent
arrowhead	2 mg/L	not significant	good
System D, static			
spatterdock	5 mg/L	not significant	good
fragrant waterlily	2 mg/L	not significant	good

[1] Endothall application rate that resulted in a statistically significant reduction in shoot biomass at 3 WAT.

[2] Recovery defined by shoot biomass harvested at 6 WAT being significantly greater than shoot biomass harvested at 3 WAT.

quires careful selection of application rates tailored to the specific hydrodynamic conditions in the target area. Incorrect assumptions with respect to contact times may lead to either poor control of target species or undesirable damage to non target species. Other factors, not addressed in this study, that may influence tolerance of these species to endothall treatment may include temperature and phenological growth stage of the plant.

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