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# Selective Effects of Aquatic Herbicides on Sago Pondweed

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## ABSTRACT

Three aquatic herbicides effective on the exotic weed Eurasian watermilfoil (*Myriophyllum spicatum* L.)—2,4-D ((2,4-dichlorophenoxy)acetic acid), endothall (7-oxabicyclo[2.2.1]heptane-2,3-dicarboxylic acid) and triclopyr ([(3,5,6-trichloro-2-pyridinyl)oxy]acetic acid)—were evaluated in the laboratory for selective effect or efficacy on the native submersed species, sago pondweed (*Potamogeton pectinatus* L.). For each herbicide, three concentrations in ranges associated with Eurasian watermilfoil or sago pondweed control were applied in static exposures of 24 hr, and plants were monitored for 35 d. Endothall at 0.5, 1 and 2 mg $L^{-1}$ significantly reduced final biomass, by ≥ 72%, confirming that this herbicide will not maintain populations of sago pondweed where it is used to manage Eurasian watermilfoil. Application of the growth regulator-type systemic herbicides at 1, 1.5 and 2 mg $L^{-1}$ resulted in no significant reduction in biomass from 2,4-D, but up to 24% reduction with triclopyr. The more selective activity of these compounds towards sago pondweed supports their use for controlling Eurasian watermilfoil in plant communities where it is desirable to maintain the native species. However, in areas where sago pondweed is itself a nuisance plant, endothall gives effective chemical control.

*Key words:* aquatic habitat restoration, aquatic weed control, *Myriophyllum spicatum, Potamogeton pectinatus.*

## INTRODUCTION

One of the strengths of herbicide use for vegetation management resides in its potential to provide selective plant control. Some herbicides can eliminate all vegetation while others target only specific groups of plants, and both broad-spectrum and selective herbicides can be manipulated to provide wide flexibility in control by varying application rates and timing. The capacity for selectively eliminating nuisance vegetation without lethal damage to desirable species means that chemical control often provides a precise technique for nuisance and exotic species management in natural ecosystems. In aquatic habitats the effects of available herbicides on exotic or native nuisance weeds are known, and techniques for control of many target species are well described (Van and Conant 1988, Green and Westerdahl 1990, Netherland et al. 1991, Netherland and Getsinger 1992, Netherland et al. 1993). However, the need remains for more information on herbicide effects on native species that enhance the macrophyte communities of aquatic systems.

Documentation of herbicide effects on non-target plants makes it possible to define use rates that result in minimal harm to native plants and allows them to regain their natural balance in the community following weed eradication. The influence of herbicide concentration and exposure time, as well as the timing of application and the physiological condition of plants at treatment (phenology), have been studied in the target plants Eurasian watermilfoil and hydrilla (*Hydrilla verticillata* (L.f.) Royle) (Van and Conant 1988, Green and Westerdahl 1990, Netherland and Getsinger 1992, Netherland and Getsinger 1995, Madsen 1994, Madsen 1997). While herbicide concentrations and exposure requirements are well-described for exotic plants there is much less infor-

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mation available on desirable non-target species such as sago pondweed.

The pondweeds, genus *Potamogeton*, comprise an important monocotyledonous plant family with numerous submersed species of major importance in North American aquatic environments. Sago pondweed is a submersed perennial macrophyte, native to a range of fresh, alkaline, and brackish waters in marshes, lakes, and streams of the United States (Fassett 1957, Godfrey and Wooten 1979). Throughout its natural range the entire plant, particularly its fleshy rhizome and starchy tubers and fruits, provides one of the best food sources for waterfowl[3], as well as good fish habitat (Godfrey and Wooten 1979). It is frequently recommended for inclusion in plantings to enhance wildlife habitat and to restore lake and reservoir vegetation (Spencer 1987, Smart et al. 1996). The submersed morphology of sago pondweed subjects it to displacement by thick surface canopies produced by non-native weed species such as Eurasian watermilfoil (hereafter "milfoil") or hydrilla (Madsen et al. 1991, Smart et al. 1995). Once these target exotics are eliminated, however, sago pondweed is one of the species that can prevent or slow reinvasion of weeds by colonizing re-opened habitat, having potential to regrow from crowns or rhizomes, or to emerge from seeds or tubers.

The dense growth of sago pondweed often produces problems in the western U.S. where it can choke irrigation canals and significantly impede water flow. The effectiveness of selected herbicides for sago pondweed control has been demonstrated in these high-flow environments (Corbus 1982, Westerdahl and Hall 1983), and there is continued interest in finding minimum rates and effective application techniques for control in irrigation canals (Netherland et al. 1994, Sisneros and Turner 1995). However, there is not much information available on herbicides and use rates that will maintain sago pondweed in those aquatic systems where exotic weeds need to be targeted but where sago pondweed is considered a valuable resource.

Information on herbicide selectivity for sago pondweed under conditions of milfoil control is available from preliminary evaluations of triclopyr and fluridone (1-methyl-3-phenyl-5-[3-(trifluoromethyl)phenyl]-4(1*H*)-pyridinone). In outdoor mesocosms with mixed communities of milfoil and four species of native, non-target plants that included sago pondweed, triclopyr applied at 0.5 mg $L^{-1}$ for a 12-hr half-life exposure selectively slowed the growth of milfoil and allowed the other species to increase in biomass compared to similar untreated units (Smart et al. 1995). Other treatment combinations of 0.5 or 1.0 mg triclopyr $L^{-1}$ with 12- or 24-hr half-life exposures significantly reduced milfoil and increased these native species (Smart et al. 1995). Growth chamber studies with two herbicides indicated their potential selectivity on sago pondweed based on variation in concentration and exposure time (CET). A 24-hr exposure to 2.5 mg triclopyr $L^{-1}$ reduced sago pondweed biomass by two-thirds in the month following treatment, while 12 hr at 1 mg $L^{-1}$ did not affect biomass (Sprecher 1995). Selective concentrations of fluridone were bracketed by 2 and 10 μg $L^{-1}$, as exposure to 10 and 25 μg $L^{-1}$ for 60 d decreased sago pondweed biomass to < 2% of untreated controls, while plants at 2 μg $L^{-1}$ grew well and underwent normal flowering and seed set in spite of a 24% reduction in biomass (Sprecher 1995). Mesocosm data on individual species showed similar sago pondweed response to differences in fluridone application rates, with recovery from early season 90-d exposures to 5 μg $L^{-1}$, but not to 10 or 20 μg $L^{-1}$ (Netherland et al. 1997).

The dipotassium salt of endothall is labeled[4] for control of sago pondweed at a lower rate (1 to 2 mg $L^{-1}$ for entire pond or large area treatment, 2 to 3 mg $L^{-1}$ for spot or lake margin treatments) than milfoil (1 to 2 and 2 to 3 mg $L^{-1}$, respectively), and selectivity is not expected when using endothall to eradicate milfoil without altering timing or some other application factor to favor the native species. However, there is interest in determining the most efficient CETs for efficacy where sago pondweed is a nuisance plant. To characterize further the selective or control effect on sago pondweed of chemicals used to control milfoil, this study evaluated the response of the pondweed species to less than maximal field application rates of the systemic herbicides 2,4-D and triclopyr, and the contact herbicide endothall.

## MATERIALS AND METHODS

Sago pondweed tubers were acquired from a commercial source (Wildlife Nurseries, Inc., WI) at the end of October 1996, immediately after being harvested from outdoor plantings. They were held refrigerated at 5 ± 2 (standard error: s.e.) C. After 33 days, tubers were removed from refrigeration and placed in shallow water in light. In three days, shoots had emerged up to 5 cm. Four sprouted tubers were then planted per each glass beaker holding 250 ml of lake sediment previously amended with nitrogen at 12.5 mg $NH_4Cl$ $L^{-1}$. Ten planted beakers were placed in each of 52 aquaria holding 49 L of simulated hard water (Smart and Barko 1984). Aquaria were held in a controlled environment chamber maintained at 24 ± 2 C under illumination at 412.7 ± 11.7 μE $m^{-2}$ $sec^{-1}$ for 14L:10D cycles, with constant aeration. Simulated hard water was refreshed via flow-through exchange three times a week. After 25 days plant shoots had reached the top of the water column (66 cm) and were healthy, flowering and setting seed. At 28 days of growth, immediately prior to herbicide treatment, all plant material from three randomly-selected aquaria was harvested and dried for 48 hr at 70 C to determine initial average dry weight (DW) biomass per treatment unit.

Herbicides, formulations, and treatment CETs used in the study are shown in Table 1, along with labeled rates and treatment guidelines for milfoil established in previous laboratory CET studies. These soluble concentrate formulations were applied to aquaria as stock solutions diluted with distilled water. Treatment concentrations were calculated based on active ingredient (ai), or acid equivalent (ae) of herbicide compound. Each treatment was replicated in three randomly-assigned aquaria, and three aquaria were left

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[3] Eggers, S. D. and D. M. Reed. 1997. Wetland Plants and Plant Communities of Minnesota and Wisconsin. 2nd edition. U.S. Army Corps of Engineers, St. Paul District, St. Paul, MN, 263 pp.

[4] Elf Atochem. 1995. Aquathol® K aquatic herbicide label. Elf Atochem North America, Inc. Philadelphia, PA, 4 pp.

TABLE 1. FORMULATIONS AND CONCENTRATIONS/EXPOSURE TIMES (CETS) OF THREE HERBICIDE TREATMENTS APPLIED TO ASSESS SELECTIVITY ON SAGO PONDWEED (SPW). RECOMMENDED RATES FROM FORMULATION LABELS (MG L$^{-1}$ WHERE GIVEN), AND RESULTS FROM PREVIOUS CET STUDIES FOR CONTROL OF EURASIAN WATERMILFOIL (EWM), INCLUDED FOR COMPARISON.

| Herbicide/Formulation | Concentrations/Exposure Times | Recommended Rates from Labels and Results from Previous CET Studies[1] |
|---|---|---|
| 2,4-D | 1.0 mg L$^{-1}$ 24 hr | EWM: 10.6 to 42.6 kg ae ha$^{-1}$ |
| WEEDAR 64 | 1.5 mg L$^{-1}$ 24 hr | |
| 38.9% ae[2] | 2.0 mg L$^{-1}$ 24 hr | Green and Westerdahl 1990 |
| | | 2 mg ae L$^{-1}$ for 24 hr → control |
| | | Netherland et al. 1991 |
| | | 1 mg ae L$^{-1}$ /24 hr → 75% control 6 WAT |
| | | 2 mg ae L$^{-1}$ /24 hr → $\geq$ 75% control 6 WAT |
| Endothall | 0.5 mg L$^{-1}$ 24 hr | EWM: 2 to 3 mg L$^{-1}$ |
| AQUATHOL K | 1.0 mg L$^{-1}$ 24 hr | SPW: 1 to 2 mg L$^{-1}$ |
| 40.3% ai | 2.0 mg L$^{-1}$ 24 hr | |
| | | Netherland et al. 1991 |
| | | EWM: 2 mg ai L$^{-1}$ /24 hr → $\geq$ 85% control 6 WAT |
| Triclopyr | 1.0 mg L$^{-1}$ 24 hr | EWM: 1 to 2.5 mg L$^{-1}$ (proposed label) |
| GARLON 3A | 1.5 mg L$^{-1}$ 24 hr | |
| 31.8% ae | 2.0 mg L$^{-1}$ 24 hr | Netherland and Getsinger 1992 |
| | | 1.5 to 2.5 mg ae L$^{-1}$ for 24 hr → 85% control |

[1] See current herbicide label for complete application recommendations; see Literature Cited for full references.

[2] Abbreviations: ae, acid equivalent; ai, active ingredient; WAT, weeks after treatment.

untreated as reference units. Immediately following treatment exposures, aquaria were drained and re-filled three times with untreated culture medium, in order to remove all herbicide residues. Plants were then maintained for an additional four and a half weeks under the same growing conditions provided pretreatment, and were monitored via visual observations of physical condition on a weekly basis. At 35 days after treatment (DAT), viable plant tissue remaining in treated aquaria and the untreated reference units was harvested and dried to determine final DW biomass.

Statistical comparisons of final DW biomass data were made using SigmaStat (Jandel 1992). Within each herbicide, ANOVA were carried out on the three treatment levels and the untreated reference, and the Student-Newman-Keuls pairwise multiple comparison method was used to show significant differences among concentrations ($p < 0.05$).

## RESULTS AND DISCUSSION

At time of herbicide application, plant biomass had reached an average of 11.8 ± 0.76 g DW per treatment unit (aquarium), or 188.8 g DW m$^{-2}$, comparable to mid-season field production of sago pondweed in natural systems and irrigation flumes (Davis and Carey 1981, Madsen and Adams 1989, Sand-Jensen et al. 1989, Sisneros and Turner 1995). With 25 d growth, the original tubers had produced roots and healthy rhizome systems, although these tissues were not included in top growth biomass measurement. Treatment of actively growing plants at the flowering stage also represents response in sago pondweed populations that have reached nuisance proportions.

By 4 DAT, there were marked differences among treatments. Plant canopies in aquaria treated with endothall already had a brownish appearance; those treated with triclopyr and 2,4-D remained bright green. Most damage was seen at the highest endothall rate, 2 mg L$^{-1}$ for 24 hr, where the pondweed had already lost tissue integrity and was being colonized by algae, suggesting cell rupture and leakage of nutrients. Distinct epinastic curling of leaf, tips, shoot apices, and flower stalks had occurred in treatments with the auxin-type herbicides 2,4-D and triclopyr at this time.

At 11 DAT, triclopyr treatments showed the least damage and effects, with epinastic curling evident only in scattered leaf tips; otherwise stems and tissue were firm and green. 2,4-D had produced slight chlorosis and leaf-tip curling. Plants treated with 1 or 2 mg endothall L$^{-1}$ showed symptoms that included softening of leaf and stem tissue, initial collapse of the plant canopy, stem chlorosis, dark green “water-soaked” areas in leaves suggesting disintegration of tissue, and epiphytic algal colonization. Plants in untreated reference aquaria remained healthy and bright green, with resilient stems.

A week later (18 DAT), differences among herbicides had become more pronounced. The higher rates of endothall had produced water-soaked, decomposing tissue that was heavily colonized by algae. Plants subject to the other herbicide treatments, as well as the untreated references, remained in good condition, although some apical curvature was still present in upper shoots of triclopyr-treated plants.

At 31 DAT, most plants in the endothall-treated units consisted of leafless stems, but in several cases a few short new shoots had emerged from crowns. Full canopies and active growth, with flowering and seed set, had been maintained in all triclopyr and 2,4-D-treated units. Harvest data at 35 DAT indicated that DW biomass had doubled in untreated aquaria during the month following herbicide application, increasing to 23.6 ± 1.91 g. Effects of treatment levels within individual herbicides varied significantly for endothall and triclopyr in comparison to this untreated material (Figure 1).

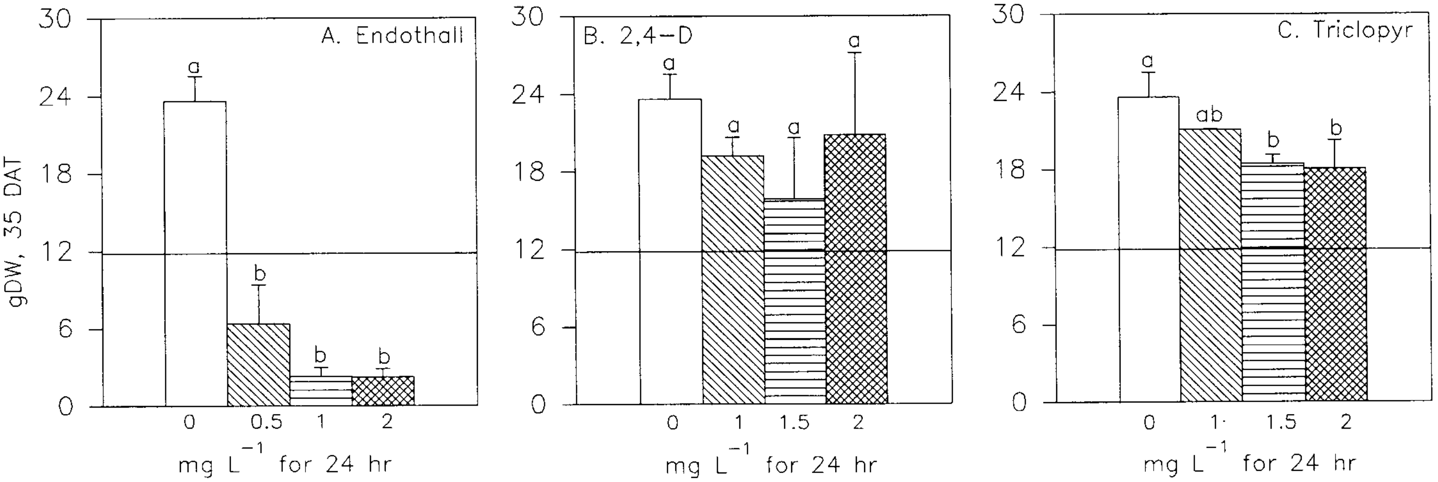

Figure 1. Biomass in grams dry weight (g DW) at 35 days after treatment (DAT) of sago pondweed with various CETs of the contact herbicide, A. endothall, or the systemics, B. 2,4-D, and C. triclopyr. Untreated reference shown with each treatment. Line indicates pretreatment biomass, 11.8 ± 0.76. Bars above histograms represent standard errors of the mean, N = 3. Letters indicate significant treatment differences, $p < 0.05$.

The systemic herbicides 2,4-D and triclopyr, both with growth regulator modes of action that generally target dicot and broadleaf monocot species, had significantly less effect on sago pondweed biomass than the contact herbicide endothall. Although the systemic compounds produced characteristic epinasty, related to overgrowth of meristematic cells, plants retained vigor, and significant biomass reduction was produced only by the higher rates of triclopyr (Figure 1). While Westerdahl and Hall (1983) showed that 2,4-D reduced sago pondweed biomass by half with 0.10 to 0.25 mg $L^{-1}$, this effect was produced following 11 weeks of constant exposure to these low concentrations. Since a more-readily achieved exposure time of 24 hr to concentrations of 1 and 2 mg 2,4-D $L^{-1}$ maintained ≥ 75% reduction in milfoil biomass through 6 weeks after treatment (WAT) (Green and Westerdahl 1990, Netherland et al. 1991), these CETs will effectively target milfoil while retaining sago pondweed in an infested environment.

The lowest triclopyr concentration did not reduce biomass significantly, and this result can be compared to the lack of effect following a 12-hr exposure to 1 mg triclopyr $L^{-1}$ previously seen in sago pondweed (Sprecher 1995). Although treatment with 1.5 or 2 mg $L^{-1}$ significantly decreased biomass production by ≥ 22%, plants maintained full canopies and underwent normal life-cycles, flowering and setting seed. Exposures of 24 hr at these concentrations effectively control milfoil, eliminating 85% of biomass (Table 1; Netherland and Getsinger 1992). However, since Sprecher (1995) showed that an exposure of 24 hr to 2.5 mg triclopyr $L^{-1}$ reduced sago pondweed biomass by two-thirds, CETs of 1.5 to 2 mg triclopyr $L^{-1}$ for 24 hr are indicated for targeting milfoil where subsequent rapid recovery of sago pondweed populations from plants is desired.

Results from both growth regulator herbicides indicate that they are able to eliminate or greatly reduce the presence of milfoil in the field at rates that allow for rapid recovery and recolonization by sago pondweed. With treatment early in the year, at a growth stage prior to that evaluated here, milfoil is expected to be readily controlled at lower rates with subsequent regrowth of this pondweed from tubers and rhizomes as well as plants.

The contact herbicide endothall reduced biomass below pretreatment levels, to ≤ 28% of final untreated biomass, and use of this compound to eliminate the target weed milfoil is not recommended where sago pondweed is to be maintained. This is consistent with label recommendations (Table 1) that indicate that this pondweed is more sensitive than the target weed. There were no significant differences among endothall treatments, indicating that where sago pondweed is to be controlled, concentration $\geq 0.5 < 1$ mg $L^{-1}$ may give adequate efficacy with a 24-hr exposure, particularly if early-season treatment of younger plants is possible.

These various responses in sago pondweed to herbicide application indicate the range of vegetation management options provided by chemicals. The selective effect of the growth regulator herbicides with their auxin-like activity make them suitable for operational application on milfoil in habitats where this native pondweed is to be maintained. As a narrow-leaf monocot, sago pondweed is more similar to hydrilla in not being seriously affected by 2,4-D or triclopyr. In this study, treatment of actively growing plants at the flowering stage represents response in sago pondweed populations that have reached nuisance proportions, or a "worse-case" scenario, where this species is the target weed. Control of sago pondweed by the contact herbicide endothall may be made more efficient by timing lower treatment rates to earlier stages of growth.

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