Response of fanwort (Cabomba caroliniana) to selected aquatic herbicides in New Zealand

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ABSTRACT

Fanwort (Cabomba caroliniana A. Gray, also known as cabomba) is an obligate submersed macrophyte native to the southern United States and Central and South America that has naturalized in the eastern United States, Canada, and various countries in Europe, Asia, and Oceania. It has been cultivated in New Zealand as an aquarium plant for at least 30 yr, but until recently (2009) had not naturalized. Fanwort is now declared an Unwanted Organism in New Zealand and as part of incursion response planning, effective management responses are required to achieve eradication. In this study we conducted herbicide trials on fanwort in containment using the herbicides carfentrazone, endothall, flumioxazin, and triclopyr. All four herbicides reduced fanwort biomass; however, with all herbicides viable plant material remained, indicating the potential for rapid regrowth after treatment, and a high degree of uncertainty of outcome where the herbicides are to be used for the management of field populations. None of the herbicides are recommended for use in eradication programs on fanwort without a clear understanding that multiple applications will likely be required, and there is a degree of uncertainty regarding the level of efficacy that can be achieved.

Key words: aquatic weed control, cabomba, carfentrazone, endothall, flumioxazin, triclopyr.

INTRODUCTION

Cabomba caroliniana A. Gray (fanwort, also known as cabomba) is an obligate submersed macrophyte native to Central America, South America, and the southern United States (Bultemeier et al. 2009). It has naturalized in the eastern United States (Bultemeier 2014), Canada, Malaysia, New Guinea, China, Japan, southern Europe, India, and Australia (Wilson et al. 2007). In the Northeast and Midwest of the United States fanwort behaves more like an invasive species (Bultemeier 2008) and less like a native that has found an expanded range. In New Zealand, it has been cultivated as an aquarium plant for at least 30 yr (Champion and Clayton 2001), but until more recently (2009) had not naturalized.

Fanwort is a perennial and primarily reproduces via vegetative fragmentation. Fanwort is not known to reproduce sexually in New Zealand, although reproduction by seed has been recorded in northern Australia (Schooler et al. 2006). Shoot fragments have a high regeneration potential (Dugdale et al. 2013a), a single-node fragment had 50% establishment success when planted in substrate and this increased to 100% for fragments with two or more nodes. Establishment success was lower for free-floating propagules, which had a 1 to 30% chance of colonization, depending on fragment size (Bickel 2017). As with other similar submersed invasive weeds, dispersal between water bodies is largely human mediated (Bickel 2015). Potentially, human-mediated spread by contaminated machinery, boats, and trailers or nets could disperse plants from the naturalized site in New Zealand.

Importantly, variation has been recognized amongst fanwort from different locations that is reportedly influenced by temperature and light (Bultemeier et al. 2009). In the United States, plants differ in color (green to red and intermediate) and respond differently to pH and temperature, both of which are parameters that influence photosynthesis and plant growth. “Green” fanwort had peak photosynthesis at pH 6.2, and was tolerant of a wide temperature range, including cool conditions expected for overwintering in the northeastern United States (Bultemeier 2008). By comparison the “red” and the “intermediate” (“aquarium”) fanwort had peak photosynthesis at pH values of 5.9 and 6.5 respectively. Red fanwort had higher photosynthetic rates than both the intermediate and green fanwort phenotypes as temperature increased to 32°C (Bultemeier 2008).

Climate modelling suggests that fanwort could potentially grow in most lowland New Zealand water bodies (Champion and Clayton 2001). Fanwort can grow rooted in sediment, or free-floating in stagnant to slow flowing water, including streams, small rivers, lakes, ponds, and ditches, although it does prefer slightly acidic waters (DiTomaso et al. 2013). Fanwort was assigned an Aquatic Weed Risk Assessment score of 58 in New Zealand in 2001, but at that time it was considered premature to ban the species from sale and distribution based on its long cultivation history and lack of naturalization (Champion and Clayton 2001, Champion et al. 2007). However, it was recognized that locally, native species will be displaced where fanwort occurs and that uncontrolled populations of fanwort pose a threat if the continued spread of the plant occurs.

Until recently, fanwort was not managed in New Zealand (Champion et al. 2013). However, following the discovery of
an infestation (ca. 2.5 ha) in the Paremuka stormwater retention ponds, West Auckland, an incursion response has been enacted and fanwort declared an Unwanted Organism in 2016. Under this designation, it is an offense to propagate, sell, or distribute the species as the plant poses a major weed risk to New Zealand (New Zealand Government 2019).

Neither of the two herbicides currently registered for control of submerged aquatic weeds in New Zealand (diquat dibromide, endothall dipotassium salt) are particularly efficacious on fanwort. The effective chemical control treatments against fanwort to guide subsequent eradication efforts in New Zealand.

**MATERIALS AND METHODS**

The effectiveness of four herbicides was tested on fanwort in a mesocosm study during summer (January to April 2017), at the National Institute of Water and Atmospheric Research experimental research facility, Hamilton, New Zealand (37°46′30.6″S; 175°18′45.12″E). Fanwort plant material collected from West Auckland (36°52′9.966″S; 174°18′45.119″E) was cultured in a greenhouse with 30% shade, in plastic tanks filled with municipal dechlorinated water and continuously aerated. One shoot (250 mm long) of fanwort was planted into each pot (375 ml) containing topsoil (1.3 g phosphorus: 3.6 g nitrogen per kilogram dry weight of soil), augmented with fertilizer1 (N-P-K, 15.3–1.96–12.6; at label rate of 5 g L⁻¹ soil) and topped with a layer of washed sand (10 mm). A total of 15 pots containing fanwort were placed in each of 25 experimental tanks (180 L). An additional 20 shoots of fanwort were prepared and oven dried to determine initial plant weight (0.218 ± 0.08 g SD). Water temperature and light was

### Table 1. Summary of effective herbicide treatments on fanwort. For each herbicide, target concentration rate, comments on efficacy and the cited literature is listed. Information is summarized and expanded on from Hackett et al. (2014) and DiTomaso et al. (2013).

<table>
<thead>
<tr>
<th>Herbicide</th>
<th>Concentration</th>
<th>Efficacy Comments</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carfentrazone</td>
<td>100 µg ai L⁻¹ to 2 mg ai L⁻¹</td>
<td>Not registered for use in water in New Zealand 60 to 90% biomass reduction in mesocosms Likely eradication of a field site</td>
<td>Bultemeier et al. 2009, Day et al. 2014, Hunt et al. 2015, Gettys et al. 2018</td>
</tr>
<tr>
<td>Diquat</td>
<td>0.3 to 2 mg ai L⁻¹</td>
<td>Approved for aquatic use in New Zealand</td>
<td>Bultemeier 2008, Bultemeier et al. 2009, Dugdale et al. 2012</td>
</tr>
<tr>
<td>Endothall amine salt</td>
<td>1 to 5 mg ai L⁻¹</td>
<td>Not registered for use in water in New Zealand Ca. 86% biomass reduction Biomass reduction of 83, 100, and 100% at 0.5, 1.5, and 3 mg ai L⁻¹; 50% biomass reduction at 6.9, 2.8, and 0.3 h exposure period were obtained at 0.5, 1.5, and 3 mg ai L⁻¹</td>
<td>Bultemeier et al. 2009, Dugdale et al. 2012, Hunt et al. 2015</td>
</tr>
<tr>
<td>Endothall dipotassium</td>
<td>1 to 3 mg ai L⁻¹</td>
<td>Approved for aquatic use in New Zealand Symptoms within 3 to 7 d</td>
<td>Bultemeier et al. 2009, Dugdale et al. 2012</td>
</tr>
<tr>
<td>Florpyrauxifen-benzyl</td>
<td>10 to 20 µg ai L⁻¹</td>
<td>Not registered for use in water in New Zealand Ca. 90% reduction of biomass in mesocosms Not effective with static 4-wk exposure at 81 µg ai L⁻¹ in mesocosm experiment</td>
<td>Gettys et al. 2018, Richardson et al. 2016</td>
</tr>
<tr>
<td>Flumioxazin</td>
<td>0.1 to 0.4 mg ai L⁻¹</td>
<td>Reduced photosynthesis in laboratory study, ca. 96% reduction of biomass of whole plant and field success</td>
<td>Bultemeier 2008, Bultemeier et al. 2009, Valent 2009</td>
</tr>
<tr>
<td>Fluridone</td>
<td>5 to 20 µg ai L⁻¹</td>
<td>Not registered for use in New Zealand Reduces biomass by &gt; 80% after 84 d at 0.02 mg ai L⁻¹ Exposure period – weeks</td>
<td>Mackey 1996, Nelson et al. 2001, 2002</td>
</tr>
<tr>
<td>Penoxsulam</td>
<td>0.1 to 0.2 mg ai L⁻¹</td>
<td>Not registered for use in water in New Zealand Exposure period – weeks Penoxsulam with diquat, ca. 90% reduction of biomass in mesocosms</td>
<td>DiTomaso et al. 2013, Gettys et al. 2018</td>
</tr>
<tr>
<td>Triclopyr</td>
<td>0.5 to 2.5 mg ai L⁻¹</td>
<td>Permitted for use in water in New Zealand, under Environmental Protection Agency controls and permissions Ca. 90% biomass reduction in mesocosms</td>
<td>DiTomaso et al. 2013, Gettys et al. 2018</td>
</tr>
</tbody>
</table>
Data were analyzed using ANOVA with Student’s test for the dry weight biomass per tank for each treatment. A constant dry weight was achieved. Data are reported as harvested from each tank, washed, and dried at 80 °C until growth was initiating on some plants. Plant material was time, damaged plant material had largely decayed, and new harvest of viable plant biomass was undertaken. At that posttreatment. Four weeks after treatment a destructive sampling was undertaken to rapidly as pH increases (Netherland 2014). Those herbicides (e.g., flumioxazin) that degrade more rapidly at midday, to provide an estimate of likely contact time for pH was recorded prior to treatment, 1 h after treatment and applied at dawn, when the water pH was lowest. The water pH3 of the water in each tank (8-wk culture period), the selected herbicides were applied directly to the water column to maximize dispersal and contact with plant surfaces. The treatments were flumioxazin4 (400 μg ai L−1), carfentrazone5 (2 mg ai L−1), endothall dipotassium salt6 (5 mg ai L−1), and triclopyr7 (2.5 mg ai L−1). The treatments reflect maximum label rates of the active ingredients. It is noted that the maximum label rate for carfentrazone, as sourced, exceeds the maximum on the label rate in the United States (0.2 mg ai L−1). Treatments were replicated five times including untreated (no-herbicide) control tanks. Herbicides were applied at dawn, when the water pH was lowest. The water pH was recorded prior to treatment, 1 h after treatment and at midday, to provide an estimate of likely contact time for those herbicides (e.g., flumioxazin) that degrade more rapidly as pH increases (Netherland 2014).

Plant condition was visually assessed at weekly intervals posttreatment. Four weeks after treatment a destructive harvest of viable plant biomass was undertaken. At that time, damaged plant material had largely decayed, and new growth was initiating on some plants. Plant material was harvested from each tank, washed, and dried at 80 °C until constant dry weight was achieved. Data are reported as fanwort dry weight biomass per tank for each treatment. Data were analyzed using ANOVA with Student’s t post hoc tests. All mention of statistical significance refers to P < 0.05.

RESULTS AND DISCUSSION

Over the trial period water temperature in tanks ranged from 14 to 27 °C with a daily average of 20.5 °C. Light levels varied greatly over the growth and experimental period with seasonal change and the increased shade cloth used to reduce light and minimize algal growth. The average daytime light in midsummer was 1,182 μmol photons m−2 s−1 (under 30% shade cloth) and ranged from 426 to 176 μmol photons m−2 s−1 (under 80% shade) toward the end of summer. However, light was sufficient to support fanwort growth, as indicated by the surface-reaching growth of plants after approximately 6 wk. The largest range in pH values was recorded in January with a minimum of 5 (at 9 a.m.) and a maximum of 8 (at midday), with values more typically recorded between 6 and 7 and within the range suitable for fanwort growth (Mudge 2018). Prior to herbicide applications water pH averaged 6.6 ± 0.2 SD.

During the posttreatment period, plants in the untreated control tanks remained healthy and continued to grow with new shoots and buds observed. Fanwort did not show herbicide symptoms within the first week following any treatment. In tanks treated with endothall dipotassium salt and flumioxazin, a distinct discoloration of some plants was observed, whilst others were relatively unaffected 1 wk after treatment (WAT) within those treatments. By harvest, at 4 WAT, individual plants within tanks ranged from discolored to collapsed and fragmented. Similarly, some, but not all, plants treated with carfentrazone and triclopyr were fragmented whilst others remained intact. In contrast, the triclopyr-treated plants appeared to be intact, yet when they were touched most plants collapsed, presenting little structural integrity.

The highest biomass was recorded from untreated control tanks. All herbicides had a significant effect on fanwort biomass, reducing the amount of fanwort in the treated tanks compared with the untreated control tanks (Figure 1). However, biomass between herbicide treatments was similar, ranging from 47 to 67% reduction in biomass compared to the untreated control tanks.

Fanwort is sensitive to factors such as pH, water movement, and light levels in cultured conditions, as such the slow initial growth of fanwort in the experiment was not unusual. High pH levels (> pH 7) can strongly limit growth of fanwort (Mackey 1996, Nelson et al. 2002, Bickel 2015), with the optimum pH range being 5 to 6.5 (Bultemeier 2008, Schooler et al. 2009). In the experiment the addition of bubbling CO₂ and alternately bubbling air into the culture tanks with fanwort provided gentle water movement,
dissolved carbon, and aided in keeping the water slightly acidic for optimum plant growth.

There are relatively few studies that have treated rooted fanwort plants with herbicides against which the present study can be compared. Additionally, varied susceptibility to herbicides was noted between different fanwort phenotypes, with green fanwort being the most tolerant (Bultemeier et al. 2009). Furthermore, the green fanwort phenotype differs from the fanwort population that has established in Auckland, which is also green (as opposed to red) but often tinged with purple and the undersides of the leaves were paler (P. D. Champion, unpub. data), potentially similar to the intermediate phenotype known from the aquarium trade in the United States (Bultemeier 2008). In addition to phenotype, plant age (length of time in cultivation) and length of time between treatments and harvest all vary in the literature. All these factors complicate comparisons from which to draw a greater understanding of herbicide efficacy. For example, although the herbicides in the present study all reduced the biomass of fanwort, only the use of carfentrazone resulted in an apparently similar response to that reported in the literature, with ca. 60% reduction (Bultemeier 2008, Hunt et al. 2015). However, the similar level of biomass reduction was achieved with different rates, i.e., 0.2 mg ai L\(^{-1}\) (Bultemeier 2008) compared with 2 mg ai L\(^{-1}\) in the present study. Gettys et al. (2018) noted an even lower rate of carfentrazone (0.1 mg ai L\(^{-1}\)) also resulted in a higher level of biomass reduction (ca. 90%) when left for 16 WAT. Of note, carfentrazone was only a 40% biomass reduction of fanwort with 400 L\(^{-1}\) (the least susceptible phenotype). In the present study, there are likely required to fully explore herbicide efficacy and the levels of fanwort biomass reduction that can be achieved.

In summary, challenges in comparing studies, including the recognized variability in the tolerance of different fanwort to herbicides, highlights the importance of using plants from the local New Zealand infestation to assess herbicide efficacy relevant to a proposed eradication program. All four herbicides reduced fanwort biomass; however, in all treatments, the amount of viable plant material that remained indicates the potential for rapid fanwort regrowth after treatment. For a successful eradication program, multiple applications of the selected herbicides would likely be required, also noting a degree of uncertainty regarding the level of efficacy that could be achieved with the herbicides evaluated. Small-scale field trials are likely required to fully explore herbicide efficacy and the levels of fanwort biomass reduction that can be achieved.

**SOURCES OF MATERIALS**

1. Osmocote fertilizer, Scotts Miracle-Gro Company, 14111 Scottslawn Road, Marysville, OH 43041.
2. HOBO pendant lightlogger (UA-002-64), Onset, 470 MacArthur Blvd, Bourne, MA 02532.
3. EXO1 Multiparameter Sonde (SKU: 599501), 1700/1725 Brannum Lane, Yellow Springs, OH 45387.
4. Flumioxazin (Valor® 500 WG Herbicide), Sumitomo Chemical Co., Ltd., 27-1, Shinkawa 2-chome, Chuo-ku, Tokyo 104-8260, Japan.
5. Carfentrazone (Shark™) FMC Corporation, 2929 Walnut St, Philadelphia, PA 19104.
7. Triclopyr (Garlon™ 360), Dow Corporate, 2211 H. H. Dow Way, Midland, MI 48674.

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**LITERATURE CITED**


