Herbicide control of submerged bog moss (*Mayaca fluviatilis* Aubl.)

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Summary Bog moss, *Mayaca fluviatilis* Aubl., is an invasive perennial aquatic plant native to Central and South America, the Caribbean and the United States. Sold as an aquarium plant for many years, bog moss is now naturalised in Sri Lanka, Singapore and three locations in Australia. It can grow either fully submerged as semi-floating mats in water up to 2 m in depth or as a semi-terrestrial plant on the margins of wetlands. The mats can block drains and irrigation channels, contribute to water-logging in adjacent cropland, impede recreational activities, endanger swimmers and threaten biodiversity. Bog moss mats which break free during flooding can damage bridges and moored boats. Despite a variety of management techniques, effective control remains elusive. Our objective was to examine the efficacy of subsurface application of ten herbicides, registered in Australia or the USA for aquatic weed control, which could also be applied to emergent foliage. A replicated microcosm study was conducted in 2-L aquaria beginning in January 2011. The maximum and one-fifth labelled rates of bispyribac, dichlobenil, diquat + guar gum, endothal, flumioxazin, glyphosate, imazapyr, metsulfuron, triclopyr and carfentrazone were applied to the water column of each designated microcosm. One hundred and twenty days after treatment (DAT), bispyribac, dichlobenil and glyphosate proved ineffective with biomass reductions of less than 40%. The higher application rates of triclopyr, flumioxazin, endothal and diquat gave >90% biomass reductions of bog moss at 120 DAT. Regrowth occurred in at least one replicate regardless of herbicide, indicating multiple applications may be necessary to provide longer term plant control. Future research should identify effective rates for triclopyr, endothal, imazapyr, metsulfuron, flumioxazin, carfentrazone, diquat + guar gum and possible timing of applications to maximise treatment efficacy.

Keywords *Mayaca fluviatilis*, bog moss, aquatic herbicides.

INTRODUCTION

Mayaca fluviatilis (family Mayacaceae), bog moss, is extensively promoted and sold throughout the aquarium industry and through the internet (eBay 2012). Invasive in parts of its native range, in the field bog moss can grow either in water, submersed or floating, forming at times dense floating mats, or solid mats on the edges of waterbodies. Its soft, thin, simple leaves are arranged in spirals on white, pale green or translucent stems which often grow up to a metre. Emergent stems are thinner and tend to have shorter, thicker and more densely arranged leaves (Thieret 1975). Bog moss flowers grow on single 2–5 cm long stalks; flowers up to 1 cm in diameter have three petals varying in colour from white to light pink/purple (CAIP 2009, de Carvalho *et al*. 2009). Seeds produced by bog moss are dispersed by water (Thieret 1975), however aquarium plants are thought to be sterile (Csurhes and Hankamer 2010). Bog moss stem fragments as small as 2 cm are reported to re-establish as new plants (Yakandawala and Dissanayake 2010).

Bog moss has to date only been found at three sites in Australia (Innisfail and Mossman in north Queensland and Taree in northern New South Wales). Given its history as an aquarium plant and rapid proliferation at the Queensland sites, bog moss is likely to be found elsewhere in Australia. At the Innisfail site, bog moss became the dominant species, blocking drains and causing localised flooding. The Cassowary Coast Regional Council raised concerns in 2010 that the infestation could spread downstream into National Park wetland areas (Csurhes and Hankamer 2010).

Herbicide screening trials undertaken in New South Wales on bog moss were inconclusive (Csurhes and Hankamer 2010). Mechanical control has been dismissed due to concerns of stem fragmentation, potentially leading to further spread downstream (Yakandawala and Dissanayake 2010). Grass carp (*Ctenopharyngodon idella* Val.) have been used in Florida to control bog moss and other aquatic macrophytes (Hanlon *et al*. 2000), but are not a feasible option in north Queensland. So far, no effective control of bog moss in Queensland has been found.

In recent years there has been an emphasis on using herbicides that are selective for aquatic weed species and where possible evaluating selectivity of both older and newer aquatic herbicide chemistries (Getsinger *et al*. 2008). Typically, a series of small-scale trials have screened aquatic herbicides for appropriate application rate and exposure time. These have been followed by larger-scale field evaluations (Poovey and Getsinger 2007). This paper reports on phase one, the initial small-scale trial used to determine the efficacy of bog moss control with subsurface application of ten herbicides registered either in Australia or the USA. It is hoped that herbicides found to control submerged bog moss will also control emergent bog moss, as submerged plants are more difficult to control than emergent plants (Getsinger *et al*. 2008).

MATERIALS AND METHODS

The aquaria experiments were conducted in a glasshouse at the Tropical Weeds Research Centre (TWRC, 20°5'43"S, 146°16'5"E), Charters Towers, Queensland. Glasshouse temperatures were set at 30° day/20° night. In November, 2010, 300 g of a 4:1 topsoil/sand mixture was added to 2 L wide mouthed glass jars (20 cm high, 12 cm outside diameter). Field collected (17°43'11"S, 146°3'0"E) bog moss from the Innisfail infestation was planted in the substrate and jars filled with 1.6 L of rain water. To help keep temperatures constant, the jars were put into four plastic troughs filled with water to a height of 15 cm. Within each trough a temperature and light logger (Hobo®logger by Onset - #UA-002-64) was placed in the water (data not reported here). Rain water was added to each jar as needed to maintain the 1.6 L volume. Twice weekly, ~ 0.1 g each of a 10% gluteraldehyde solution (Dinosaur Spit – Aquagreen) and a soluble fertiliser (Dinosaur Pee – Aquagreen) were added to the water in each jar.

Three months post-planting, bog moss was actively growing and well established. Prior to the commencement of the herbicide trial, jars were separated into four replicates based, visually, on bog moss density and the extent of algae/particulate matter in the water. At the start of the trial the average dry weight of bog moss was 0.569 g.

The experimental design was a randomised complete block, with each trough (21 jars) representing one of four blocks. The 21 treatments were a control and two rates each of ten herbicides/herbicide mixtures (Table 1). Each herbicide treatment was added directly to the water which was immediately agitated slightly to ensure even chemical distribution. For each herbicide, except the diquat/guar gum mixture, the higher rate was five times the lower rate. In the diquat/guar gum mixture, the higher rate had diquat at five times the lower rate but both rates used guar gum at 750 g ha^{-1} as required by the Australian Pesticides and Veterinary Medicine Authority (APVMA) minor use permit PER11030 (APVMA 2010a).

The pH of the water in each jar was measured twice a week (pHScan 1 meter–Eutech Instruments–data not reported here). Both visual and dry weight assessments of bog moss were made (Wersal and Madsen 2007). Visual assessments on a rating scale of 1 (no effect) to 6 (all dead, no regrowth) were made at 3, 7, 28, 60, 90 and 120 DAT. At 120 DAT, all remaining bog moss was removed from each jar, dried and weighed. Efficacy was calculated as treatment dry weight relative to control, where % control = (control dry weight - treatment dry weight)/control dry weight * 100. An ANOVA was performed on dry weights. Where the F-test was significant ($P < 0.05$), treatment means were compared using Fisher's Protected Least Significant Difference test (GenStat® Release 14.2 - VSN International Ltd).

RESULTS

Both the visual scores and final dry weights differed significantly ($p < 0.001$) among herbicide treatments (Table 1). Of the treatments trialled, only triclopyr and endothal at 2.5 ppm gave total mortality with no regrowth by 120 DAT. No significant differences were observed in either assessment method between the two rates of endothal, triclopyr and diquat, and the higher rates of metsulfuron and flumioxazin. Fragmentation was also prevalent in both flumioxazin treatments, although fragments generated from the higher flumioxazin treatment were found to be non-viable.

DISCUSSION

Contact herbicides normally affect only the plant parts directly in contact with the herbicide, and plants with roots in the sediment tend to regrow following treatment. In this trial, the higher rates of the contact herbicides diquat and endothal were effective (>93% control) at controlling bog moss, whilst the third contact herbicide, carfentrazone, performed poorly (65%).

Diquat is reported to control a wide range of aquatic weeds, giving varied results when controlling submersed weeds in flowing water in canals with exposure times of less than 12 hours (Skogerboe *et al*. 2006). In this experiment, diquat was mixed with guar gum, allowing the herbicide mixture to sink and attach itself to the plant. This method of application and the constant exposure time of the herbicide for 120 DAT may have contributed to the high efficacy levels. Diquat, however, generally performs best in clear, non-muddy water as it will cling to suspended sediments in the water body and to epiphytes on plant surfaces rendering it inactive (Wells and Clayton 1993). Thus

Table 1. Treatments and results at 120 DAT of a submerged bog moss (*Mayaca fluviatilis*) herbicide trial in 2-L aquaria in 2012. Means followed by a common letter within each assessment method do not differ significantly according to Fisher's protected l.s.d. test (P = 0.05).

Product	Active ingredient	Herbicide group and action	Rate (ppm)	Assessment 120 DAT		
					Dry weight	
				Visual[A]	(g)	(% control)
Garlon® 3A	triclopyr (360 g/L)	I	0.5	5.75 [ab]	0.1339 [abc]	87.8
		systemic	2.5	6 [a]	0.1437 [abc]	86.9
Poachek®	endothal (175 g/L)	K	0.5	5.25 [abc]	0.2932 [abcd]	73.2
		contact	2.5	6 [a]	0.0673 [ab]	93.9
Roundup® Biactive	glyphosate (360 g/L)	M	1.0	3.25 [fg]	0.8323 [hi]	24.0
		systemic	5.0	4 [def]	0.846 [hi]	22.7
UniMaZ 250 SL	imazapyr (250 g/L)	B	0.2	3.5 [efg]	0.6848 [fgh]	37.4
		systemic	1.0	4.5 [cde]	0.4014 [bcdef]	63.3
Brush-Off®	metsulfuron (600 g/kg)	B	0.01	5.25 [abc]	0.3724 [bcdef]	66.0
		systemic	0.05	5.75 [ab]	0.2969 [abcde]	72.9
Casoron G	dichlobenil (67.5 g/kg)	K	3.0	4.25 [cdef]	0.7577 [ghi]	30.8
		systemic	15.0	4.75 [bcd]	0.4482 [cdefg]	59.0
Pledge® 500 WG	flumioxazin (500 g/kg)	G	.01	4.5 [cde]	0.1741 [abc]	84.1
		systemic	0.2	5.75 [ab]	0.0706 [ab]	93.5
Nominee®	bispyribac (100 g/L)	B	0.01	2.75 [gh]	0.8163 [hi]	25.4
		systemic	0.05	3.75 [defg]	0.5811 [defgh]	46.9
Shark™ Aquatic Herbicide	carfentrazone (240 g/L)	G	0.04	3.25 [fg]	0.6433 [efgf]	41.2
		contact	.02	4.5 [cde]	0.3742 [bcdef]	65.8
Reglone + Hydrogel	diquat (200 g/L) + guar gum	L	1.0	5.75 [ab]	0.0194 [a]	98.2
		contact	5.0	5.75 [ab]	0.1915 [abc]	82.5
Control	–			1.75 [h]	1.0945 [i]	0
LSD (P = 0.05)				1.095	0.3474	

[A] Rating of 1–6 where 1 is nil herbicide effect and 6 is mortality of all bog moss, no regrowth.

in field situations where water is turbid, diquat may prove to be ineffective at controlling bog moss.

Endothal has been in use in the USA since 1951 (CPC 2009), with the dipotassium and amine salt of endothal registered by the USEPA since 1959 for aquatic use (maximum application rate of 5 ppm) for the control of submerged aquatic vegetation and algae in lakes, ponds and irrigation canals (USEPA 2010). In New Zealand, endothal has been in use since 1993 for the control of the submerged species hornwort (*Ceratophyllum demersum* L.), curled pondweed (*Potamogeton crispus* L.), hydrilla (*Hydrilla verticillata* (L.f.) Royle) and lagarosiphon (*Lagarosiphon major* (Ridl.) Moss) (Hofstra and Clayton 2001). In Australia, however, endothal registration is confined to terrestrial use, with a minor use permit PER9835 issued for the control of submerged aquatic weeds including *Potamogeton* spp., *Myriophyllum* spp., *Hydrilla* spp., *Vallisneria* spp., *Elodea* spp. and *Cabomba* spp. growing in irrigation and drainage channels (APVMA 2010b). Based on our initial screening trials, endothal could prove to be an effective herbicide for the control of bog moss under field conditions as it is not affected by turbid water (Wells and Clayton 1993).

The poor carfentrazone result reported in this trial could possibly be attributed to the maximum rate used (0.02 ppm). In the USA, the maximum rate permissible for the control of submerged weeds using carfentrazone is 0.2 ppm (FMC 2004), whilst in Australia carfentrazone was recently registered at 2 ppm for the control of cabomba in non-flowing water bodies (FMC 2011). Increasing the rate to 2 ppm may prove to be effective.

The other herbicides trialled in our experiment were all systemic. Triclopyr at 2.5 ppm was the most effective systemic herbicide to control bog moss. Triclopyr has also been effective (91%) at controlling Eurasian milfoil (*Myriophyllum spicatum* L.) in a lake in Idaho, USA with no detrimental effect on native vegetation (Wersal *et al.* 2010) and parrot's feather (*Myriophyllum aquaticum* (Vell.) Verdc.) in New Zealand (Hofstra *et al.* 2006), but was ineffective in controlling hydrilla (Hofstra and Clayton 2001).

Further screening trials are planned to determine effective rates to control bog moss growing as a submerged or emergent plant and in still or flowing water. Consideration will be given to herbicide selectivity to minimise non-target damage and to resistance issues by ensuring alternative herbicides are found from groups with a different mode of action. In addition, exposure time trials for submerged bog moss are planned.

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