Potential new herbicides for submerged aquatic weeds in Victoria

Tony M. Dugdale[1], Trevor D. Hunt[1], Daniel Clements[1] and Kym Butler[2]
[1] Department of Primary Industries, 40 Ballarto Rd, Frankston VIC 3199
[2] Department of Primary Industries, 600 Sneydes Rd, Werribee VIC 3030
(tony.dugdale@dpi.vic.gov.au)

Summary This paper describes a project to determine the key submerged aquatic vegetation (SAV) problems in Victoria and test herbicides with the potential to solve them. The main unresolved SAV control problems are cabomba (*Cabomba caroliniana* A. Gray) in weir pools; sagittaria (*Sagittaria platyphylla* (Englem.) J.G. Sm.) in natural waterways, irrigation channels and drains; elodea (*Elodea canadensis* Michx.), floating pondweed (*Potamogeton sulcatus* A. Benn) and ribbon weed (*Vallisneria australis* S.W.L Jacobs & Les) in irrigation channels; and egeria (*Egeria densa* Planch) in standing waterbodies. Control in irrigation channels is particularly critical because a single highly toxic herbicide (acrolein) is heavily relied upon. Endothal and diquat were short-listed for further testing. Results of a screening trial indicated that diquat was very effective on all species except cabomba. Endothal controlled all key aquatic weed species.

Keywords Endothal, diquat, *Cabomba caroliniana*, *Egeria densa*, *Elodea canadensis*, *Potamogeton sulcatus*, *Sagittaria platyphylla*, *Vallisneria australis*.

INTRODUCTION

This paper describes a project to determine the key submerged aquatic weed issues in Victoria and determine suitability of current controls and possible new herbicide options. It then describes a screening trial of the short listed herbicides.

MATERIALS AND METHODS

Extent To determine the extent of the problem that SAV present for Victorian agencies and communities, a telephone survey was conducted of the following: Corangamite, East Gippsland, Glenelg-Hopkins, North Central, North East, and West Gippsland Catchment Management Authorities (CMAs); Lower Murray Water, Goulburn-Murray Water (G-MW), Southern Rural Water (SRW), Parks Victoria and Grampians Wimmera Mallee Water staff. The survey was supplemented with meetings with Melbourne Water and Goulburn-Broken CMA (through current research collaborations). Based on this information, the properties of herbicides used around the world on SAV were consolidated to select those appropriate for use in Victoria.

Screening trial Endothal and diquat were identified as candidate herbicides for use on Victorian species. Twenty 1200 L round plastic troughs (189 cm x 53 cm high) were filled with municipal tap water, aerated and covered in 97.6% shadecloth. Plastic containers (700 mL capacity) were filled to 80% with topsoil (passed through a 5 mm mesh) amended with 5 kg m^{-3} Osmocote® (NPK 15:4.4:10) then topped with washed sand. Then [two 15 cm long sprigs (apical tips) of elodea, egeria and cabomba; one 15–30 cm long rhizome of floating pondweed; one rosette of ribbon weed and sagittaria] were planted into individual pots. Nine pots of each plant were placed in each of ten troughs. Plants were left to grow for 6 weeks.

A visual assessment of plant health was conducted on the day prior to treatment. Each of diquat, endothal dipotassium salt (E-DPS; liquid and granular) or endothal monoamine salt (E-MAS) was applied to two randomly assigned replicate troughs at target rates of 1 ppm a.i., 3.5 and 5.0 ppm a.e., respectively. Two further troughs did not receive any herbicide. At 6 and 24 hours after dosing, four pots of each species were transferred from each trough to a paired recovery trough that did not contain herbicide.

Above ground plant parts were harvested 6 weeks after treatment (WAT) and dried at 80°C. Water samples were taken from each treatment trough at 1, 6 and 24 hour intervals after dosing and analysed using an Enzyme-linked Immunosorbent Assay (ELISA), (RaPID Assay® Endothall Test Kit 7007000, Strategic Diagnostics Incorporated).

The biomass of plants from the same species and exposure time was averaged for each pair of troughs to form one experimental unit. These averages were $\log_{10}$(biomass + 0.01) transformed so that the residual variation did not increase as the means increased and then analysed using a multi-stratum factorial ANOVA (Table 1).

RESULTS

Extent Problematic SAV occurs in Victoria, primarily in two situations. The first situation is in irrigation channels, where SAV slows water flow and prevents efficient operation of automated water supply gates. Most problems for G-MW and SRW are caused by native members of the *Potamogeton* and *Vallisneria* genera and the exotic elodea and sagittaria. To give an indication of scale, G-MW has a network of 9800 km of open irrigation channels and drains.

The second situation where SAV causes problems is within water bodies with artificially stable water levels, such as weir pools (lakes Mulwala, Nagambie and Benalla, cabomba) and stormwater retarding basins (around Melbourne, egeria).

With the partial exception of Lake Benalla, control work is carried out primarily when the weeds disrupt human activities, rather than for environmental gain. The current asset-based approach to managing submerged aquatic weeds in non-irrigation water bodies is hampered because control techniques suitable for Victorian conditions are under-developed, particularly with respect to the use of herbicides.

Ballarat City Council (milfoil in Lake Wendouree) and Parks Victoria (*Potamogeton* spp. and egeria in Albert Park Lake) have both had harvesting programs in place to remove submerged aquatic weeds that interfere with boating and recreation.

Aside from harvesting, the only tool regularly used for control of aquatic weeds in impoundments is water drawdown. Lake Benalla has been subject to at least three drawdowns since 1999 to control cabomba. Lake Mulwala has been subjected to six drawdowns to control submerged aquatic weeds since 1989, including three since 2008. Initially these were to control the native floating pondweed, but they are now aimed at egeria which is much more abundant.

Water supply authorities who administer and supply irrigation water, vary in how they respond to the presence of weeds in supply channels and drains. SRW currently drawdown channels during the irrigation off-season. However, in the past they have relied heavily on treatment of the channels with acrolein while they are carrying water. In December 2009, SRW returned to using acrolein in some channels and drains as excessive vegetation severely restricted water delivery during that irrigation season. In contrast, G-MW do not drain their channels through winter (to save water) but rely on acrolein. An acute issue facing irrigation companies is the mooted withdrawal of acrolein from sale.

Diquat is currently registered for SAV control and is known to be effective against a wide range of species. However, it is ineffective in turbid water, which is common in Victoria. Therefore, an alternative herbicide is required. Based on its use in USA (Sisneros *et al*. 1998, Gettys *et al*. 2009) and New Zealand (Wells and Champion 2010), endothal was identified as a candidate herbicide that has the potential to control the combination of problematic SAV species and situations in Victoria. Endothal efficacy is not reduced in turbid water and is used in both static water and flowing irrigation channels (Sisneros *et al*. 1998, Hunt and Dugdale 2010).

Screening trial Endothal DPS liquid and MAS concentrations in troughs were 4.3 ± 0.4 and 5.0 ± 0.2 ppm a.e., respectively. E-DPS granules did not release endothal so are not discussed further. Herbicide had a large effect on biomass ($P = 0.0016$, Table 1). The biomass of each species was different after treatment ($P = 1.33 \times 10^{-10}$) and this effect differed with each species per herbicide combination ($P < 0.001$), indicating that the effect of herbicide differed with species (Table 1). There was no effect of exposure period ($P = 0.29$, Table 1).

Diquat, E-MAS and E-DPS reduced biomass of most species, although their effectiveness differed between species (Table 2). Generally E-DPS was less effective in reducing growth than E-MAS and diquat, with diquat having little effect on cabomba.

Cabomba, floating pondweed, sagittaria and ribbon weed which were not treated with herbicide, were healthy throughout the trial, with all reaching the water surface, except sagittaria which remained in its submerged rosette growth form. Although egeria grew well in culture, one E-DPS and one diquat trough contained egeria plants of moderate to poor health. The same occurred for elodea, in one each of the E-DPS and E-MAS troughs.

DISCUSSION

There are two important problems facing SAV managers in Victoria.

The first is the need to use drawdowns to control SAV. Drawdown is the removal of all or most of the water from a water body. However, it provides no capacity to treat restricted areas. For example, a useful strategy is to treat localised areas of weed around high use areas of a lake such as boat ramps and jetties. This serves two purposes:

(i) it reduces the impact of the weed on users,
(ii) it lessens the risk of the weed entangling equipment (such as boat trailers) and then being spread to new sites.

In addition, there are no herbicide control options suitable for cabomba (although carfentrazone was registered in 2011, its use is restricted where water is used for irrigation). Therefore control in Lake Benalla requires frequent drawdowns, and control in Goulburn Weir is not possible.

Secondly, control of SAV in irrigation channels is reliant on a single herbicide, acrolein. Based on its use elsewhere, endothal is an aquatic herbicide that has the

Table 1. ANOVA of aquatic plant biomass (log_{10}(Biomass +0.01)) 6 weeks after treatment with herbicide.

Variable	Degrees of freedom#	Mean square	F ratio	P value
Pair of troughs stratum				
Herbicide	4	4.559	25.2	**0.0016**
Residual	5	0.181		
Exposure grouping with trough pair stratum				
Exposure time	1	0.013	1.38	0.29
Herbicide by exposure time interaction	4	0.038	3.95	0.082
Residual	5	0.010		
Position in troughs within trough pair stratum				
Species	5	1.911	37.6	**<0.0001**
Herbicide by species interaction	20	0.314	6.19	**<0.0001**
Residual	24 (1)	0.051		
Exposure grouping by position within trough pairs stratum				
Exposure time by species interaction	5	0.045	1.34	0.28
Herbicide by exposure time by species interaction	20	0.038	1.11	0.40
Residual	24 (1)	0.034		

Values in parentheses are reductions in degrees of freedom due to missing values.

Table 2. The effect of herbicide for each aquatic plant species on plant biomass (log_{10}(Biomass + 0.01)), with back-transformed values (g dry weight per pot) and the % reduction relative to controls in parentheses. SED between herbicides for the same species = 0.190; statistically significant differences indicated by *.

Species	Control	E-DPS	E-MAS	Diquat
Cabomba	-0.44 (0.36)	-0.42 (0.37; -2)	-1.95 (0.00; 100)	-0.70 (0.19; 47)
Elodea	-0.82 (0.14)	-1.33 (0.04; 71)	-1.80(0.01; 93)	-2.00 (0.00; 100)
Egeria	-0.58 (0.25)	-0.92 (0.11; 56)	-1.85 (0.00; 100)	-2.00 (0.00; 100)
Floating pondweed	-0.73 (0.18)	-0.99 (0.09; 50)	-1.24 (0.05; 72)	-1.73 (0.01; 94)
Sagittaria	-1.00 (0.09)	-1.37 (0.03; 66)	-1.34 (0.04; 66)	-1.94 (0.00; 100)
Ribbon weed	-0.23 (0.58)	-0.42 (0.37; 36)	-0.99 (0.09; 84)	-1.16 (0.06; 90)

potential to be used in both of these situations, because:

(i) it is used for localised applications within larger water bodies,

(ii) it is used in flowing irrigation channels.

Based on our screening trial, herbicide effectiveness across the range of species follows the order diquat = E-MAS >E-DPS (Table 2). E-MAS reduced biomass in the six species tested, suggesting that it will be a useful herbicide in Australia.

There was a notable difference in biomass reduction between the two formulations of endothal on all species except sagittaria, where they were both equally effective (although not statistically significant). In all other cases E-DPS was less effective or often not effective at all.

Our results for cabomba agree with Bultemeier *et al*. (2009) who found E-MAS to be useful against cabomba, and with the USA endothal label-description (where cabomba is listed for E-MAS but not E-DPS).

We are unaware of any other reports of endothal being tested on sagittaria, ribbon weed or floating pondweed, so we cannot compare the susceptibility found here with other studies.

Bowmer and Smith (1984) and Skogerboe and Getsinger (2002) report that E-DPS is ineffective against elodea, and it is not listed on the USA label, so it is concerning that statistically significant control was achieved (Table 2). The poor health of the elodea in our trial may have contributed to the greater than expected level of elodea control by E-DPS. E-MAS is reportedly effective on elodea (Bowmer and Smith 1984, USA E-MAS label).

Egeria was controlled by E-MAS only (Table 2) and it is listed on the USA E-MAS label but Gettys *et al*. (2009) do not recommend it. Like us, Hofstra and Clayton (2001) report that E-DPS is ineffective on egeria.

There was no statistical difference in biomass between 6- and 24-hour exposure times (Table 1). However, in some cases more injury was visible on plants that received longer contact time indicating a longer exposure may improve biomass reduction.

Current herbicide control of sagittaria focuses on the treatment of emergent stems, rather than the submerged rosette stage. Regrowth after herbicide application (glyphosate or 2,4-D amine) is rapid (M. Finlay, G-MW, pers. comm.). If it can be demonstrated that diquat or endothal are as effective in the field as in laboratory trials in controlling sagittaria rosettes, the use of these herbicides may provide a better control option, allowing plants to be treated before they become problematic (i.e. large enough to affect hydraulic capacity of irrigation channels and drains). Although already registered in Victoria, a major drawback to using diquat is its rapid adsorption to particles suspended in the water or attached to plant surfaces, rendering it inactive. In contrast to diquat, endothal is not affected by high turbidity (Hofstra *et al*. 2001), so is likely a better choice for controlling sagittaria.

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