Potential for lake restoration using the aquatic herbicide endothall

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Summary The aquatic herbicide endothall has been used to eradicate hornwort (at 5 mg L^{-1}) and lagarosiphon (at 0.1 mg L^{-1}) in New Zealand and has demonstrated a high selectivity for these species making it a very useful biosecurity and lake restoration tool. We trialled low dose endothall applications in Lake Otamatearoa, a 4 m deep, 10 ha lake dominated by hornwort (up to 3 m tall) in the North Island (near Auckland). A spring application (September 2009) resulted in 0.15 mg L^{-1} endothall (33 times less than maximum label rate) reducing the extensive beds of hornwort to scattered fragments within two months. Off-target impacts were minimal with the 35 other recorded macrophytes showing no signs of damage. Dissolved oxygen levels remained above 76% saturation in surface water column and above 61% close to the bottom of the lake. Water clarity and nutrient levels were not adversely affected. However, recovery of hornwort was rapid with weed beds returning after six months. Two years later the weed nuisance had returned and in winter (June 2011), three applications were applied over two weeks to maintain endothall levels above 1.5 mg L^{-1} for three weeks. Weed beds were reduced to decaying fragments within seven days and nine weeks later only the odd viable fragment was found buried within the bottom detritus. Six months later only a few scattered plants mostly less than 0.5 m tall were found. It took three years to return to pre-trial levels. It is likely repeated low dose applications or a higher rate would be required to eradicate hornwort in this lake.

Keywords Hornwort, lagarosiphon, aquatic herbicide, eradication, endothall, dissolved oxygen, nutrients, selectivity.

INTRODUCTION

Endothall has a long proven record as an effective aquatic plant management tool in the United States of America particularly for hydrilla (*Hydrilla verticillata* (L.f.) Royle) and Eurasian watermilfoil (*Myriophyllum spicatum* L.) (Parsons *et al.* 2004). Hornwort has an almost cosmopolitan indigenous range, but is not native to New Zealand or Tasmania where it is a declared weed. It ranks as one of New Zealand's worst aquatic weeds (Clayton and Champion 2006), causing large scale weed problems by forming weed beds up to 10 m tall, weed drift that blocks power station intakes and displacing native aquatic vegetation over the 1 to 14 m depth range (de Winton *et al.* 2009). There is a government funded program to exclude hornwort from the South Island by eradicating any sites found there. Endothall was evaluated in New Zealand (Wells and Clayton 1993, Hofstra *et al.* 2001), and was registered for use in 2005. Since then endothall has eradicated hornwort from 0.7 ha Centennial Lake, Timaru, the last known hornwort South Island field site in 2006–7. This was achieved with only one application of endothall at 5 mg L^{-1} total water body application (Wells and Champion 2010) with no hornwort found since, despite all other species remaining in good health. Similarly, lagarosiphon was eradicated (none present after five years) in five water bodies (up to 3.9 ha), with rates as low as 0.1 mg L^{-1}, under cool (~16°C) summer Southland temperatures (Wells and Champion 2010).

Lake Otamatearoa (Muir's Lake) (10 ha) is located about 60 km south of Auckland in coastal dunes with surrounding land use being dairy farming. The lake has no formed inlet or outlets. Hornwort was widespread in the lake and was surface reaching over about one third of the lake surface in early 2009, although the lake still supported small areas of diverse remnant native submerged vegetation (35 species) including charophytes and threatened species such as stout water milfoil (*Myriophyllum robustum* Hook.f.), swamp buttercup (*Ranunculus macropus* Hook.f.) and bladderwort (*Utricularia australis* R.Br.).

Removal or reduction of hornwort enhances the native vegetation by reducing abundance of outcompeting hornwort. The purpose of this study was to test the feasibility of eradicating hornwort from a 10 ha, 4 m deep lake at low cost by trialling low doses of endothall.

MATERIALS AND METHODS

Spring application September 2009 Endothall aqueous was applied to Lake Otamatearoa obtaining 0.15 mg L^{-1} endothall after dispersal throughout the main body of the lake.

Winter applications June 2011 Three applications of endothall were made over two weeks resulting in 1.5 mg L^{-1} in the main body of the lake for more than three weeks. Aqueous applications were made from a boat using a trailing hose in the open water and pellets were applied to shallow wetland areas to avoid contacting vegetation with undiluted aqueous product.

Monitoring Five equally spaced profiles (lake edge to centre) were surveyed using scuba divers to record plant species and their respective depth ranges, heights and covers. Herbicide damage to plants was also recorded at 7, 14, 28, 62 and 166 days after application (DAT).

During the spring trial endothall acid residues were monitored 1 h post-application and 7, 14, 28, and 62 DAT at mid-lake and a sample 7 DAT was taken at the lake edge, where healthy hornwort was found.

Lake pH, nutrients (nitrogen and phosphorus), suspended solids, turbidity and chlorophyll *a*, dissolved oxygen (DO) and temperature were measured in the middle of the lake at 0.5 m depth intervals to the bottom (3.6 m deep).

For the winter 2011 applications the same monitoring was undertaken except endothall water residue sampling was extended to include the dense rushes, the lake shore and the bottom detrital layer, and nutrients were not monitored.

RESULTS AND DISCUSSION

Spring application 2009 Before application, virtually the whole lake beyond the rush fringe (2 m water depth) had a 100% cover of hornwort with much up to 2.5 m tall. Following application, endothall concentrations measured in the centre of the lake remained close to 0.1 mg L^{-1} for one month although by two months was undetectable (Figure 1). However, at the lake edge a sole reading taken seven DAT was only 0.03 mg L^{-1} possibly due to groundwater inflows.

One month after application apical necrosis, chlorosis, and fragmentation resulted in the loss of the top *c.* 1 m of the hornwort weed bed. After two months there were only isolated plants of hornwort present beyond the rushes but some healthy plants were found floating in the shallows inside the rush fringe. All other hornwort was prostrate and decaying on the lake bed and overall there was an estimated 95% reduction in hornwort abundance. No damage was noted to the 35 other macrophyte species (mostly native). However, after six months the hornwort had mostly recovered and re-occupied the west end of the lake with a complete cover up to 2 m tall although in the east end of the lake there was only a 25% hornwort cover and the vegetation was now dominated by a mixture of native Characeae. Two years later the hornwort was similar to pre-trial nuisance levels.

Two weeks after application, when plant decay on the lake bed was most evident, DO levels dropped a little from 90% saturation pre-trial to no less than 71% in the upper 3 m of open water and to no less than 62% (6.4 mg L^{-1}) saturation at the bottom of the water column. After this DO increased towards pre-application levels (Figure 2). The flocculent layer of decaying weed on the bottom of the lake had little oxygen within it (~0.2 mg L^{-1}). However, a near-anoxic layer of flocculent organic sediment was also measured pre-application.

Water temperatures rose from 13.2°C to 16.9°C (Table 1) and no increase in nutrients or decline in clarity was recorded post herbicide application.

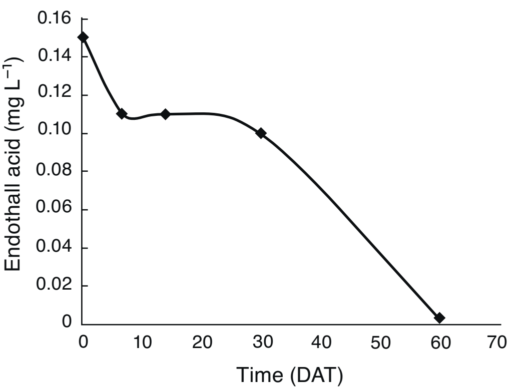

Figure 1. Endothall residues (mid-lake) post September 2009 application.

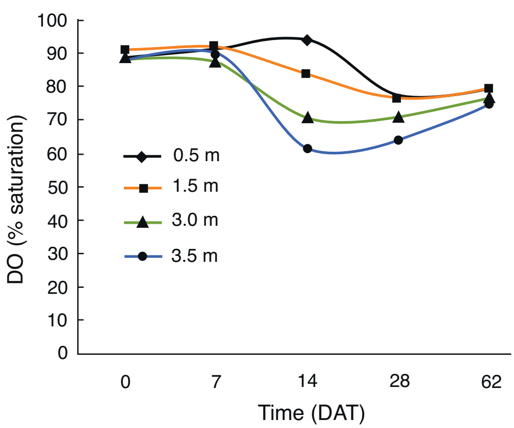

Figure 2. Dissolved oxygen mid-lake (3.6 m deep) midday, during lake-wide weed bed collapse and decomposition.

Table 1. Water quality after application with 0.15 mg L^{-1} endothall September 2009. No increase in nutrients or decrease in water clarity was recorded.

	0 DAT	7 DAT	14 DAT	28 DAT
Temp. °C (top/bottom)	15.3/15.2	15.8/15.9	13.6/13.2	16.9/16.3
Secchi disc (m)	2.47	2.95	3.0	3.07
Turbidity NTU	2.2	1.7	1.2	1.4
Total SS g m^{-3}	4.0	2.2	<2.0	<2.0
Chlorophyll *a* g m^{-3}	0.0043	0.0078	0.0055	<0.0030
pH	7.9	7.9	7.5	7.6
Total P g m^{-3}	0.110	0.008	0.021	0.005
DRP g m^{-3}	<0.004	<0.004	<0.004	<0.004
N nitrate + nitrite g m^{-3}	<0.002	<0.002	<0.002	<0.002
Tot. Kjeldahl N g m^{-3}	0.49	0.37	0.33	0.33

Winter Application June 2011 Endothall concentrations were in the order of ten times greater than the spring application with levels around 1.5 mg L^{-1} for about three weeks (Figure 3). Similar endothall concentrations were measured in the flocculent bottom layer, the band of emergent rushes and lake margins. Levels fell most quickly along the lake margins but still had about two weeks minimum concentrations of nearly 1 mg L^{-1} (Figure 3). Samples 72 DAT had no endothall residues.

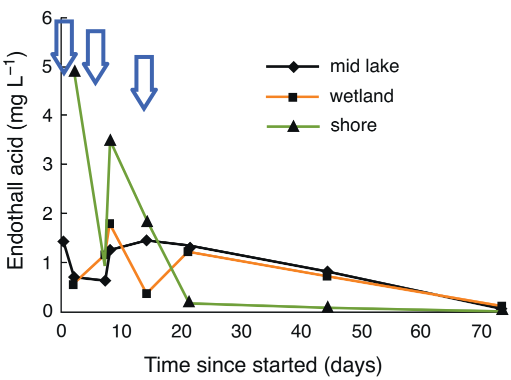

Figure 3. Endothall concentrations post June 2011 applications for mid-lake, wetland and shore locations. The first two arrows represent endothall applications with aqueous to open water and pellets to the wetland margins; the third application was pellets to the wetland margins.

The onset of herbicide symptoms was much faster at this higher endothall rate with hornwort weed beds fragmented and collapsed by the first inspection seven days after the first application. All that remained was a flocculent layer of plant detritus 0.8 m thick on the bottom of the lake. After one month this layer had compressed to 0.4 m with few fragments identifiable as hornwort. After two months a few hornwort fragments were found and some were viable. Overall hornwort abundance from this application was estimated to be reduced by more than 99%.

After six months, effects on other macrophytes were still not apparent and native submerged macrophytes had apparently become more abundant. Only occasional scattered shoots of hornwort were present mostly ranging from 0.1 to 0.5 m in height but with a few shoots up to 1.3 m tall. Much of the lake bed below 2.5 m water depth was bare, except in the east end of the lake where characean meadows were present to 3.5 m deep and were very abundant.

Water temperatures were *c.* 4°C cooler than the spring trial ranging from 10 to 14°C during the first two months (mid-winter) and were nearly isothermal throughout the lake. DO concentrations were similar to the spring trial with a 20% drop in saturation after one month and with recovery evident by two months post application. No observable impact was noted on fish populations, with common bully (*Gobiomorphus cotidianus* McDowall) still abundant post-application and no recorded fish mortalities. Rotifer composition and abundance was not impacted as identified in surveys pre- and post-application conducted by the Waikato Regional Council (Dr Bruno David, scientist Waikato Regional Council, pers. comm.) Black swan

(*Cygnus atratus* Latham) continued to nest and raise young.

Eradicating hornwort from this lake with endothall could be feasible but would take more herbicide possibly requiring higher rates or more treatments timed when biomass was minimal. Possibly a gel carrier or pellets in the main body would enhance subsequent applications better targeting the bottom layers of the lake. If total water body application at maximum label rate (5 mg L^{-1}) was permitted (NZ label restricts use to <25% of a water body) then one application might be sufficient for eradication.

Endothall provides an opportunity to manage hornwort and potentially eradicate it from water bodies with minimal adverse impact on other biota. Removal of hornwort reduced competition and provided increased habitat for some species, particularly charophytes. Charophyte meadows are considered a highly desirable attribute for lake management and restoration and their return has the added benefit of restoring their seed banks (de Winton *et al.* 2000).

Despite large volumes of hornwort being killed in a short space of time, monitoring indicated the effects of this whole-of-lake weed bed collapse on water quality were minimal. Low DO levels resulting from weed control are a potential impact of concern to water body managers. The New Zealand endothall label restricts applications to 25% of the area of a water body with the intent of avoiding lake-wide weed kill and anoxia. These results show endothall disperses post-application and remains active for long enough and at very low concentrations to have lake-wide effects, but this does enhance its utility.

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