Managing a priority outlier infestation of *Cabomba caroliniana* in a natural wetland in the Blue Mountains, NSW, Australia: could this be eradication?

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Summary In December 2012 an eight hectare priority outlier infestation of cabomba (*Cabomba caroliniana* Gray) at Glenbrook Lagoon, New South Wales was treated with Shark™ Aquatic Herbicide (active ingredient (a.i.) carfentrazone-ethyl 240 g L^{-1}) (hereafter Shark or carfentrazone).

The herbicide was applied to 50% of the total water body volume of Glenbrook Lagoon as per label rates and directions (2 ppm a.i.). Despite the treatment targeting only 50% of the infestation, it was effective in controlling cabomba across the entire water body resulting in complete weed bed collapse. As of March 2014 the post treatment monitoring program has found no sign of viable cabomba, an encouraging result for the potential eradication of cabomba from Glenbrook Lagoon. However, significant off-target damage was done to aquatic flora and fauna.

Several factors are believed to have contributed to the higher than expected extent of cabomba control at this site, including the water column stratification observed at the time of treatment.

Keywords *Cabomba caroliniana*, aquatic weed control, Glenbrook Lagoon, Shark™ Aquatic Herbicide, carfentrazone-ethyl, herbicide drift.

INTRODUCTION

Cabomba is a submerged aquatic plant originating from South America. It is declared as a class 5 noxious weed across New South Wales and in 1999 was listed as a Weed of National Significance (WoNS) because of its impacts on the biodiversity and function of freshwater ecosystems, water quality, water storage and distribution infrastructure, and on recreational and amenity values (NSW DPI 2009 and AWC 2012).

An infestation of cabomba was recorded in Glenbrook Lagoon in the City of Blue Mountains, near Sydney, New South Wales prior to 1992 (Keogh 1996). This is one of only two infestations known from the Sydney Region, and the only one known in the Hawkesbury-Nepean Catchment area. This infestation was ranked by the National Aquatic Weeds Management Group in the top 10 strategic priority sites nationally for control due to its outlier status, threat of spread to other important aquatic assets and the contained nature of the infestation making it feasible to control.

Prior to 2011 on-ground control options for cabomba were restricted to physical methods due to a lack of biological control agents or registered herbicides (AWC 2012). In August 2011 Shark (a.i. carfentrazone-ethyl 240 g L^{-1}) was registered in Australia for the control of cabomba in non-flowing aquatic situations (FMC 2011).

This paper outlines the application of Shark herbicide to control cabomba at Glenbrook Lagoon; the weed control outcomes achieved; some of the off-target impacts observed; and explores the factors thought to have contributed to the efficacy of Shark in controlling cabomba across the entire water body.

FIELD SITES AND METHODS

Site Glenbrook Lagoon is an eight hectare 'shallow lake' or 'pond' (Wetzl 2001), surrounded by an urban catchment in the Blue Mountains, New South Wales. It is one of three natural escarpment wetlands of this type in the Hawkesbury-Nepean Catchment area (Coordinates in decimal Lat/Long: −33.7574; 150.6152). The lagoon is managed by Blue Mountains City Council (council or BMCC).

Glenbrook Lagoon is highly valued by local residents and provides habitat to a range of aquatic and terrestrial plants and animals. It is a flat bottomed basin bordered by wide shallow margins, with a total estimated maximum water volume of 225,147 m^3, mean depth of 2.7 m and maximum water depth of 4.05 m (Keogh 1996). Water levels, and thus volumes, fluctuate seasonally.

Herbicide treatment In consultation with the National Aquatic Weeds Coordinator, Blue Mountains City Council initiated a cabomba control program at Glenbrook Lagoon in 2012. On 3 and 4 of December 2012, Shark was applied to 50% of the lagoons total water body volume (Figure 1) at the label rate of 2 ppm a.i. (FMC 2011) using subsurface injection from

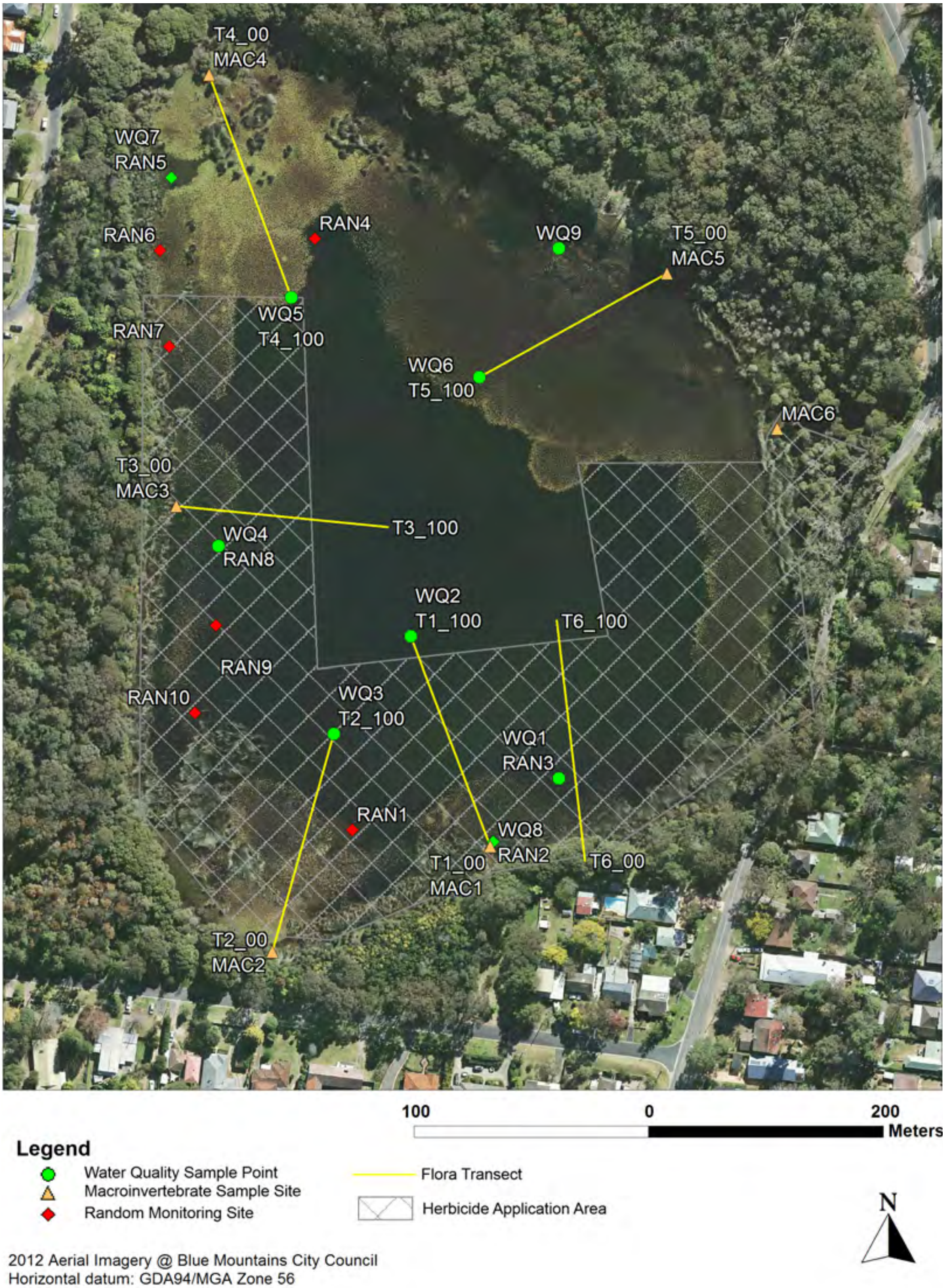

Figure 1. Glenbrook Lagoon showing indicative location of flora survey transects (yellow lines e.g. T1_00 to T1_100), 10 permanent cabomba assessment sites (red/green diamonds: RAN 1–10), macroinvertebrate (orange triangles: MAC 1–6) and water quality monitoring sites (green circle/diamonds: WQ 1–9), and herbicide application area (hatched area).

a boat mounted boom with trailing hoses. At the time of treatment total water body volume was estimated at *c*. 209,000 m^3. This equated to 864 litres of Shark being applied.

Flora and fauna monitoring A pre- and post-treatment monitoring program was implemented to monitor the potential impacts of Shark herbicide treatment on the cabomba itself, aquatic flora and fauna, macroinvertebrates and water quality in the lagoon (AMBS 2013 and BMCC 2013).

Pre-treatment aquatic flora surveys were undertaken by Australian Museum Business Services (AMBS). Six transects were established and surveyed at intervals of 10 to 20 metres (m) using 1 × 1 m plots (Figure 1: T 1–6). Ten 1 × 1 m plots were also established at random locations within dense cabomba infestations (Figure 1: RAN 1–10). The six transects and ten random plots were re-surveyed at 2, 4, 12, 52 and 64 weeks after treatment (WAT) (AMBS 2012 and 2013, AMC 2014).

Herbicide symptoms were monitored in the aquatic vegetation by council at *c.* daily intervals for three weeks, then during water quality monitoring.

A benthic diver and underwater video survey was undertaken in March 2014 by ABCO commercial diving.

Aquatic fauna monitoring involved a pre-treatment survey by Australian Museum Business Services (AMBS) in 2012. Post-treatment monitoring was undertaken by council using a fauna condition checklist. A fish population study was conducted by BIOSIS in summer and autumn 2014.

Water quality monitoring In-situ water quality measurements were taken regularly at nine sampling locations and at macroinvertebrate sites (Figure 1: WQ 1–9, MAC 1–6). Parameters were measured at 0.5 m deep at 10 am (± 1 hour) and included dissolved oxygen (DO mg L^{-1} and %), temperature (°C), turbidity (NTU), pH, electrical conductivity (EC mS cm^{-1}) and salinity (mg L^{-1}) (Day *et al*. 2014). Water samples were collected at six sites (WQ 1–6) and tested for aromatic hydrocarbons by a NATA accredited laboratory pre, during, and post: 1, 3, 7 days after treatment (DAT); then 2, 3, 4, 8, 52 and 60 weeks after treatment (WAT).

RESULTS

Pre-treatment flora and fauna survey Surveys found close to 100% of the benthic habitat and water column of Glenbrook Lagoon was covered by cabomba, whilst the surface area was 37% covered by exotic water lilies (*Nymphaea mexicana* Zucc. and *Nymphaea alba* L.). The shallower margins of the lagoon support dense native rush beds dominated by *Lepironia articulata* (Retz.) Domin (grey rush) and in deeper water, *Eleocharis sphacelata* R.Br (spike rush). Native bladderwort (*Utricularia australis* R.Br and *U. gibba* L.) were found floating in open waters and backwaters (AMBS 2012 and BMCC 2010 and 2013).

Pre-treatment fauna surveys found three species of fish (two native and one introduced) with the introduced gambusia (*Gambusia holbrooki* Girard) abundant and the dominant fish species in the lagoon. Native flathead gudgeon (*Philypnodon grandiceps* Krefft) was uncommon in the survey (three recorded) and a single eel (probably *Anguilla reinhardtii* Steindachner) was recorded (AMBS 2012).

Extent and rate of cabomba weed control Changes to the cover and condition of cabomba were observed in all plots surveyed across the lagoon confirming that the effect of the herbicide was not limited to vegetation within the targeted area (AMBS 2013).

Within the application area weed decline was observed within three days of treatment with tip wilting and fragmentation occurring rapidly. Monitoring sites well outside the treatment area (e.g. RAN5) remained green, dense and healthy for *c.* 7 days post treatment before showing signs of declining health; dieback was quick once it commenced.

Cabomba was visibly reduced to below observable levels (1.5 m visibility depth) 4 WAT at all RAN sites and at a range of water depths. In most plots dead, decaying cabomba was still present 4 WAT. 12 WAT cabomba was only recorded in two plots and one year post treatment no cabomba was recorded in any plots (AMBS 2013 and AMC 2014) or anywhere in the lagoon by scuba diver and underwater video inspections (ABCO 2014).

Non-target flora species Changes in the number, frequency (Figure 2) and health of non-target flora species were recorded, both native and introduced.

The free floating native species *Utricularia australis* was not observed again following herbicide treatment and *U. gibba* was significantly reduced 12 WAT. Neither species were observed one year post treatment.

Eleocharis sphacelata experienced extensive browning off to the water surface within 12 weeks of herbicide treatment and one year post-treatment was visibly reduced but the difference was not significant compared to pre-treatment surveys ($P = 0.07$).

There was a dramatic reduction in the cover of *Nymphaea* species pre- and post-treatment. Following Shark application all leaves in contact with the

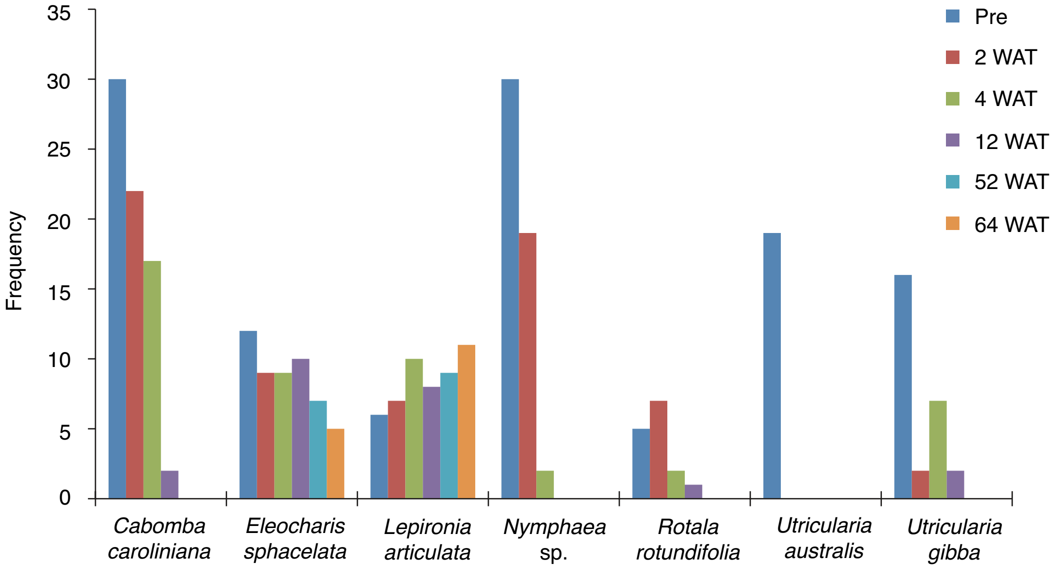

Figure 2. The frequency of occurrence (the number of plots in which each species was recorded) in transect plots for commonly observed flora species Pre; 2, 4, 12, 52 and 64 weeks after treatment.

water died and large *Nymphaea* rhizome masses were observed floating on the lagoon surface. One year post-treatment no *Nymphaea* species were recorded in the lagoon (AMBS 2013, AMC 2014).

Aquatic fauna Two days after herbicide was applied a fish kill of approximately 200 flathead gudgeon occurred in the vicinity of the boat ramp (site RAN2).

A second fish kill of approximately 50 stocked Australian bass (*Macquaria novemaculeata* Steindachner) occurred 11 days after treatment.

One year after treatment aquatic fauna surveys have found healthy populations of four native fish (eel-tailed catfish, *Tandanus tandanus* Mitchell; flathead gudgeon; long-finned eel; and southern smelt, *Retropinna semoni* Weber) and two introduced species (gambusia, and koi carp, *Cyprinus carpio* Linnaeus). Gudgeon, catfish and gambusia were all abundant throughout the lagoon with a range of size classes from juveniles through to adults. No Australian bass have been observed since the fish kill (BMCC 2013, BIOSIS 2014).

Water quality Following herbicide application a rapid decline in dissolved oxygen (DO) was observed in the first five days, followed by approximately 20 days of extremely low DO (mean: 10.31%, 0.88 mg L^{-1}; minimum 0.4%, 0.03 mg L^{-1}) before beginning to slowly recover. Significant changes in pH (range: 6.16−7.97), temperature (range: 20.0–27.7°C) and turbidity (range: 0−64 NTU) were recorded (Day *et al*. 2014).

Thermal stratification Weak thermal stratification was observed in the lagoon, with associated strong DO stratification. Thermocline depth occurred at *c.* 1.5 m below the surface (Day *et al*. 2014).

Dispersion and dissipation Fluorene (a component of carfentrazone-ethyl) and Naphthalene (in Shark formulation) were detected at all sites. Levels were highest on the day of treatment and were at similar levels at all sites (inside and outside the treatment area) after three days with a gradual decline to below detection limits after 23 days (BMCC 2013).

DISCUSSION

The extent of control of cabomba in Glenbrook Lagoon following a single 50% of water body volume treatment using Shark Aquatic Herbicide was more effective than expected, controlling cabomba and other aquatic weeds including *Nymphaea* species across the entire water body. While this is a great outcome for cabomba management it brought with it significant off-target impacts.

Efficacy Carfentrazone was found to be effective over a greater area and killed a wider range of non-target species than expected. The following factors may have contributed to this outcome:

- Carfentrazone may have been effective on cabomba, and toxic to certain native aquatic plants, at a concentration <2 ppm.
- Carfentrazone may not have mixed vertically in the water column (because of thermal stratification (Wetzel 2001, Jones *et al*. 2010)) and therefore its concentration in the surface water could have exceeded 2 ppm.
- The carfentrazone in this surface layer is likely to have dispersed horizontally and mixed with the adjacent areas (by water currents, convection etc.), eventually mixing with the entire surface layer across the lake.
- The effectiveness of carfentrazone may have been maximised by the neutral pH in the lagoon, in which carfentrazone decay is slower (*c.* eight days half life at pH 7 vs. <1 day in alkaline water (FMC 2012)).
- The effectiveness of carfentrazone may have been maximised by the relatively clear water (visibility to *c.* 1.5 m) and bright sunlight, as it requires light for activity (FMC 2012).
- Carfentrazone is likely to have eventually sunk below the thermocline (Jones *et al*. 2010) and with a longer half life (due to pH <7) may have remained active to also kill cabomba at depth.
- Low light availability at depth, loss of productivity from dieback of upper stems and leaves in the photic zone, shading of the sediment by a thick layer of dead plant matter and eventual penetration of herbicide through the thermocline may have acted together to provide the necessary conditions to effectively kill cabomba below the thermocline.

Non-target flora species Impacts to three native species, *Utricularia australis*, *U. gibba*, and *Eleocharis sphacelata* were observed and contrast to the listing of related species (*U. foliosa* and *E. acutus*) as being tolerant to Shark (Officer 2011, FMC 2012). It is possible that *Nymphaea* species and *Eleocharis* will re-shoot from rhizomes, as carfentrazone is a contact herbicide and may have killed the stems and leaves only.

Fauna and water quality Severe oxygen depletion was observed following the complete weed bed collapse and was the likely cause of a fish kill of approximately 50 stocked Australian bass (see Day *et al*. 2014 for further details).

An earlier fish kill of approximately 200 flathead gudgeon in a small area surrounding the boat ramp two days after treatment may have been caused by a pocket of higher herbicide concentration outside the tolerance limits of this species (LC_{50} for this species is not known but carfentrazone LC_{50} <2 ppm have been recorded for other fish species (FMC 2012)), other possible causes may include chemical changes due to disturbance of the organic sediments by frequent boat activity in this area (BMCC 2013) or a combination of factors.

Both fish kills were self-reported to the Environmental Protection Authority (EPA) who determined that Council had appropriately assessed the risks of the project and implemented appropriate mitigation actions. Post-treatment fauna surveys show no long term impacts to native fish in Glenbrook Lagoon with healthy, breeding populations of four native fish species recorded in 2014 (not including Australian bass which, being introduced stock, are not considered native to this water body and are not expected to breed in this type of aquatic system).

Ongoing management Monitoring of the lagoon will continue to determine any need for ongoing cabomba control and to determine whether native flora species are naturally recolonising or require reintroduction.

While it is too soon to claim eradication, the apparent efficacy of carfentrazone in controlling cabomba in Glenbrook Lagoon has been a significant achievement in reducing the threat of spread of this outlier infestation of cabomba, a WoNS, to surrounding waterways and reservoirs.

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