Silt, snags and snapping handbags – managing *Cabomba caroliniana* in the tropics of the Northern Territory

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Summary Cabomba (*Cabomba caroliniana* Gray), a submerged aquatic plant from the southern United States, is one of the world's most serious aquatic weed species and recognised in Australia as a Weed of National Significance (WoNS). In 2004 cabomba was located in the Darwin River, posing a significant threat to the quality of the Darwin region's drinking water, tourism, recreation and the aquatic ecology of the iconic rivers and billabongs of the Northern Territory. In response, an eradication program was initiated in 2004. This program has reduced the size of the infestation from over 11 km of river down to an area less than 1 km using methods such as drawdown, shading and chemical control with 2,4-D n-butyl ester. The program remains ongoing and continues to challenge with the unique environmental conditions of the Northern Territory. A change of herbicide has been necessitated and interim results of carfentrazone-ethyl treatment indicate that after stagnation of the program eradication is back on track.

Keywords Cabomba, aquatic weeds, WoNS carfentrazone.

INTRODUCTION

Eradication of the WoNS species *Cabomba caroliniana* continues to pose a challenge to the Northern Territory (NT). An infestation in the Darwin River has been subject to an eradication program since 2004. Significant investment since this time has resulted in the reduction of infestation size from 11 km of river to less than 1 km. However this small infestation continues to pose a significant social and economic threat to water quality of the Darwin Region potentially impacting tourism and the ecology of the NT's iconic wetlands. This paper outlines the history of management practices to date, the subsequent challenges faced and the future direction of the program including the use of carfentrazone-ethyl.

HISTORY OF CABOMBA IN DARWIN

Cabomba was first found in Marlow Lagoon, a man made recreational lake near Darwin in 1996. The Marlow Lagoon infestation was successfully eradicated by the Northern Territory Government though combinations of shading, drawdown and eventually in 2002 though the successful application of 2,4-D n-butyl ester (2,4-D) (NRETA 2006). The success at the Marlow Lagoon site supported a multi-stakeholder decision to commence a cabomba eradication program in the Darwin River following the discovery in 2004 (Van Oosterhout 2009).

A large publicity campaign initiated wide community response exposing multiple instances of cabomba as an ornamental plant including an infestation in Pine Creek, 200 km south of Darwin. The Pine Creek infestation resisted control and was found to be producing viable seed (NRETA 2006). Experiments determined fragments of cabomba from Darwin River were also able to produce viable seed. Subsequent trials with sediment from cabomba infested areas revealed two instances of plants germinating from seed (Anon. 2006). Longevity of viability was never established as supplies of seed were depleted before this was concluded (Wingrave 2011).

The upper reaches of Darwin River form the Darwin River Dam, the main water source to Darwin City. The dam regulates flow throughout the year but flooding events and runoff from tributaries ensures variable but sustained flow during the wet season (summer) discharging into Darwin Harbour. During the dry season (winter) the river forms a series of billabongs with minimal flow. The system is intercepted sporadically with subterranean springs which are able to inject substantial amounts of water into the larger billabongs. This prohibits the use of drawdown and effective containment as discussed by Dugdale *et al.* (2013). The Darwin River site remains the only current infestation in the NT and a significant priority for eradication.

2,4-D application Subsurface injection of 2,4-D has been the most successful tool used in the elimination of cabomba in Darwin River (APVMA permit PER11145).

In late 2004 following the discovery of cabomba, 2,4-D in a diatomaceous earth suspension was applied directly into plants though hand-wands and calibrated, dinghy mounted booms.

Initial treatments produced an estimated knockdown of 99.99% of the living cabomba with the

stringent environmental protocols at that time revealing no significant effect on the flora or fauna in the Darwin River system. However, by mid wet season 2005 the cabomba was estimated to have returned to 60% of pre-treatment levels (NRETA 2006).

Small contained billabong infestations of cabomba were successfully controlled with combinations of drawdown, shading and application of 2,4-D. Shading was utilized in the larger billabongs but constrained by the uneven depth, snags and the impending but unpredictable arrival of the wet season and associated flow.

Between 2004 and 2007 cabomba was eliminated from the top 8 km of the known area, leaving only the largest, at 2.4 km long, and most downstream billabong, Lok Landji, containing the weed.

Cyclone Carlos, in February 2011, produced a once in 100 year flooding event. The huge initial volume of water and the corresponding sustained flow contributed to a natural flushing of sediment from Lok Landji into Darwin Harbour effectively killing cabomba which has minimal tolerance to salinity. Since 2011, there has been no emergence in once recurrent infestation sites toward the upstream regions of Lok Landji leaving only the downstream half of the billabong with cabomba remaining.

In mid-2011 the Darwin River Dam wall was raised 1.3 metres ensuring future flood mitigation and allowing the dam an additional 20% capacity. There has only been one minor flooding event since the wall was raised.

Between 2011 and 2013 cabomba appeared sporadically throughout the downstream end of Lok Landji billabong with weekly visual 'seek and destroy' patrols aiming to eliminate small isolated plants with spot treatments. The program stagnated with no real mechanism seemingly available to nail the decisive eradication blow.

CHALLENGES FACED

A number of confounding factors contributed to the apparent regression in the cabomba program including herbicide efficacy, physical and environmental factors.

Herbicide constraints In October 2006 the APVMA undertook a review of 2,4-D high-volatile esters and the active constituent was consequently deregistered. All products containing 2,4-D esters were removed from sale across Australia on the grounds they posed an 'unacceptable risk for off target damage' (APVMA 2006).

The NT permit PER11145 remained valid as it was understood risk to crops and off-target plants would be mitigated by subsurface injection in diatomaceous earth suspension (Van Oosterhout 2009). In response all remaining Australian product was purchased for use under the permit (Wingrave 2011).

By late 2013 cabomba was appearing in high concentrations throughout the downstream end of Lok Landji. Cabomba was noted to resist 2,4-D treatment, consequently repeat treatments became commonplace. Successive low rainfall wet seasons and no flooding meant that seasonal flushing did not occur. Likewise water clarity remained higher for longer allowing light to penetrate deeper and treatment periods were extended throughout the year.

During 2014 new areas of infestation began to appear midstream in water >3 m. The reserves of herbicide had diminished and questions regarding the efficacy of the product were raised. Samples of 2,4-D were sent for testing however results indicated minimal deterioration of the active ingredient. Irrespective there remained doubt as to the uniformity of deterioration between drums. Correspondence with manufacturers estimated the product to have a shelf life of five to six years. In October 2015 the program used the last remaining 2,4-D ester in supply.

Subsurface flowering Weekly surveillance and control was deemed necessary to prevent the plants from producing flowers, negating the essential step to them forming seed. Whilst surface flowers were preventable occasionally, cabomba was observed producing subsurface flowers. Irregularly, dislodged floating strands were also witnessed to produce flowers. This posed questions regarding the possibility that flowers could be pollinating under water. Again, samples of silt from regular infestation sites were sent, in 2015, to an aquatic plant specialist to grow out in a carefully controlled quarantine environment. To date no cabomba has been found to germinate.

Crocodiles Surveying the depths of the billabong for cabomba also presents a challenge. *Crocodylus porosus* pose a real threat. Four estuarine crocodiles in the vicinity of 3.8 to 4.4 metres long have been trapped within freshwater Darwin River between 2010 and 2014 (Nichols 2015). Although measures are taken to mitigate encounters the hazard restricts entry into the water and hampers the ability of personnel to use aquatic weed control methods such as diving and manual removal.

A device cast into the water consisting of opposing rake heads on an anchor rope revealed substantial infestations prospering beyond the field of vision at between four to six metres. This suggested the spotting and spraying method from the dinghy was ineffective for complete control. The downside of benthic sampling 'rake' was that it caused substantial

cabomba fragmentation with the potential to make the distribution of cabomba propagules significantly worse.

FUTURE DIRECTION

The stagnation of the eradication program necessitated a review of methodology. Suitable herbicides were researched as well as alternative methods such as dredging, raising the salinity or pH (Bickel 2012).

Dr Tony Dugdale was engaged to review the program in October 2015. Recommendations were that Shark™ (240 g L^{-1} carfentrazone-ethyl) be used as either spot spray application or as a half billabong treatment. Shark was registered in Australia for treatment of cabomba in 2011 and had shown great promise reducing cabomba in ponded waterbodies such as those to protect the Ramsar listed Myall Lakes (Inkson *et al*. 2014) and Glenbrook Lagoon in the Blue Mountains (Day *et al*. 2014). Being a contact herbicide rather than systemic the most reliable results occur with sustained exposure concentrations of 2 ppm (Day *et al*. 2014). The spring fed Lok Landji maintains a small amount of flow posing an issue with exposure time and off-target movement. Additionally it meant the label specifications of Shark, restricted to contained, non-flowing waterbodies, would not apply. The APVMA granted an off-label permit for spot application of cabomba in Lok Landji in November 2015- PER81710 (DLRM 2016).

In late 2015 flumioxazin also gained registration for use on cabomba in Australia. Similarly a permit to use flumioxazin was granted in December 2015, PER81721.

LOK LANDJI CARFENTRAZONE TREATMENT

Spot treatment of Shark began in December 2015 and has shown promise reducing and degrading cabomba. Shark has shown a long lag between application and degradation, taking over three weeks before significant weakening of stems, loss of colour and vigour became apparent.

Fragmentation of weakening stems has been prolific. Attempts are being made to collect the pieces however the ability of these fragments to effectively form new plants remains unknown.

Environmental monitoring A new regime of environmental monitoring protocols were required with the use of new herbicides in flowing waterbody. Collaboration between NT Government departments developed a regime to assess exposure against concentration over time, and to measure water quality pre- and post-treatment to ascertain any changes in chemistry resulting from herbicide application. At this early stage, there has been no trace of carfentrazone when sampled after 48 hours post- treatment (DLRM 2016).

Pre- and post-treatment sampling of pH, conductivity and dissolved oxygen revealed no change after Shark spot treatment. Differing from the 2004 2,4-D treatments where a significant drop in the dissolved oxygen had to be rectified with the use of aerators (Wingrave 2010).

The future A permit for half billabong treatment with Shark is currently being considered in conjunction with development of associated monitoring protocols (DLRM 2016). The aim is to raise the concentration across the bottom half of the billabong to 2 ppm as done in the Glenbrook Lakes (Day *et al.* 2014). By treating half the waterbody the need to determine the exact location of the cabomba will also become redundant. To maximise exposure time, treatments are to commence when the flow of water into and from the billabong is minimal. It is anticipated, as with ponded waterbodies, there will be a required three month interval between carfentrazone treatments. Flumioxazin will be used as a knockdown spot treatment should cabomba emerge between applications of Shark.

While program successes have been substantial, the prospect of eradication has at times seemed distant. Positive results with carfentrazone reinvigorate the expectation that eradication of cabomba from the NT may again become a reality in the near future.

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