

## Ecology of the submersed aquatic weed *Cabomba caroliniana* in Australia

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**Summary** *Cabomba caroliniana* Gray (hereafter cabomba) is considered worldwide to be a serious aquatic invader that displaces native vegetation. There are limited effective control options available. Currently we know little about the ecology of cabomba, particularly regarding its habitat requirements.

We conducted a range of experiments to identify habitat requirements, focusing particularly on nutrient availability in the water column and the substrate.

Cabomba prefers high nutrient concentrations in the substrate. Nutrients in solution appear to be of less importance, indicating that cabomba will be able to establish well even in oligotrophic (nutrient poor) systems as long as there are sufficient nutrients available in the substrate.

Above all, the pH of the culture solution is a strongly limiting factor for healthy cabomba growth. Cabomba can grow at a pH above 7, but growth is greatly reduced. These experimental findings corroborate what has been observed in field populations, i.e. cabomba infestations are predominantly found in soft water lakes (low in dissolved calcium and magnesium cations) that are slightly acidic to neutral in pH. Cabomba regenerates readily from single node stem fragments, with around 50% of fragments developing a healthy new shoot within 5 weeks.

Cabomba poses a high risk of spread due to the viability of even small stem fragments that contain only a single node. However, it also has specific habitat requirements which might limit the development of troublesome infestations, at least to some degree.

**Keywords** *Cabomba caroliniana*, ecology, submersed aquatic macrophyte, substrate, nutrients, regeneration.

### INTRODUCTION

Cabomba is a submersed aquatic macrophyte originating from freshwaters of South America. Cabomba is a popular aquarium species and was introduced to the wild worldwide through unintentional disposal of surplus aquarium material and escape from culture for the trade. Today, it is a serious aquatic weed in many countries including Australia, United States of America, and China (Ørgaard 1991, Wilson *et al.* 2007).

Cabomba was first recorded in Australia in 1967 and is today naturalised in several states (Victoria,

New South Wales, Queensland and the Northern Territory) (Mackey 1996, Schooler *et al.* 2006). Cabomba is a declared species in QLD and NSW and a Weed of National Significance (WoNS) in all of Australia. Although cultivation and sale of cabomba is now prohibited, the plant is increasing its naturalised range and could potentially establish in large parts of Australia with suitable habitat.

Cabomba predominantly reproduces through vegetative propagules (stem fragments); viable seeds have so far only been observed in NT populations (Anonymous 2008). Cabomba readily spreads within catchments through the movement of fragments in water currents, particularly floodwaters. However, humans are the main vector for the dispersal of stem fragments between water bodies, mainly through boating and fishing activities where equipment is fouled by fragments (Jacobs and Macisaac 2009, Wilson *et al.* 2007).

Once established, cabomba has serious environmental and economic impacts and is difficult to control due to limited availability of effective control options (Anderson and Diatloff 1999, Hogsden *et al.* 2007, Schooler *et al.* 2006). While there is general knowledge about suitable culturing conditions for cabomba in the aquarium literature, there are few scientific data available about the ecology of cabomba, both from its native and introduced range.

Detailed knowledge about the ecology of cabomba is necessary to predict likely habitats where it could establish. A predictive capacity will allow concentration of monitoring efforts to areas deemed as high risk, and therefore improve the likelihood of detecting cabomba infestations in an early stage of invasion when successful removal from a site is still viable. There is also limited understanding of the ecology of cabomba in its naturalised range and how it is impacting on the environment (Schooler and Julien 2006). This knowledge is crucial to assist in mitigating the ecological and economic impacts of this serious pest.

### MATERIALS AND METHODS

For each experiment, fresh cabomba material was collected in Ewen Maddock Dam, Sunshine Coast (26°46'34"S, 153°0'11"E) and immediately transported to the Ecosciences Precinct, Brisbane. The

experiment investigating the effect of dissolved nutrients, was carried out in 15 L plastic tubs in a temperature-controlled glass house. The remaining experiments were conducted in 110 L indoor aquariums that were pH-regulated through CO<sub>2</sub> injection. The water temperature was kept constant at 25°C with aquarium heaters. 14 h of daily light was supplied with fluorescent lights at ~80 mmol m<sup>-2</sup> s<sup>-1</sup>.

To investigate the effects of dissolved nutrient concentrations on fragment regeneration, single node cabomba fragments with one pair of leaves were incubated in plastic containers filled with a solution differing in nutrient concentrations to simulate trophic conditions encountered in south-east Queensland freshwater systems: no added nutrients (nil ~ ultra-oligotroph); 0.5 mg TN L<sup>-1</sup> (TN = total Nitrogen, low ~ oligotroph); 1 mg TN L<sup>-1</sup> (medium ~ mesotroph); and 5 mg TN L<sup>-1</sup> (high ~ eutroph). Fragments were monitored for 10 weeks for the regeneration of new shoots.

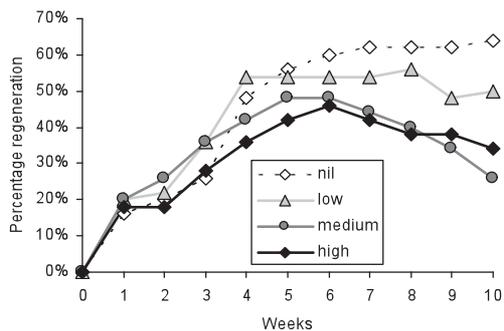
For the remaining experiments, cabomba shoots (~10 cm long, 3 nodes) were planted in 150 mL plastic containers that were placed in the aquariums. Pots were filled with a mixture of fine sand and alluvial topsoil ranging from 0–20% organic content by mass to suit the respective experiment; nutrients were added in the form of slow release fertiliser (Osmocote®). Fertiliser addition was 0 g kg<sup>-1</sup> (zero), 1 g kg<sup>-1</sup> (medium) and 2 g kg<sup>-1</sup> substrate (high).

At the end of each experiment, cabomba material was dried at 55°C for at least 48 hours to assess final dry biomass to the nearest 0.01 g. Final biomasses were compared among treatments using one and two-way ANOVAs carried out in R ver. 2.13.1 (R Development Core Team 2011).

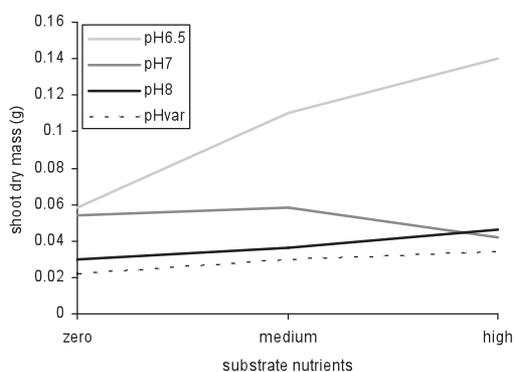
## RESULTS

Cabomba readily regenerated new shoots from single node fragments. Independent of nutrient availability in the culture solution, averaged across all culture solutions 52% (±5% SD, Standard deviation of the mean) of the fragments regenerated by week 6 (Figure 1; one-way ANOVA:  $F = 0.69$ ,  $p = 0.61$ ). Excessive algae growth in the high and medium nutrient culture solution actually impacted on regeneration by the end of the experiment.

While dissolved nutrients had no measureable effect on regeneration, substrate nutrient concentration did have an effect on cabomba biomass (Figure 2). However, the pH of the aquarium water was an overriding factor (two-way ANOVA, pH × nutrient interaction:  $F = 2.63$ ,  $p = 0.03$ ). Only at pH 6.5 did cabomba react positively to an increase in nutrients in the substrate. At higher pH cabomba growth was unaffected by nutrients in the substrate.



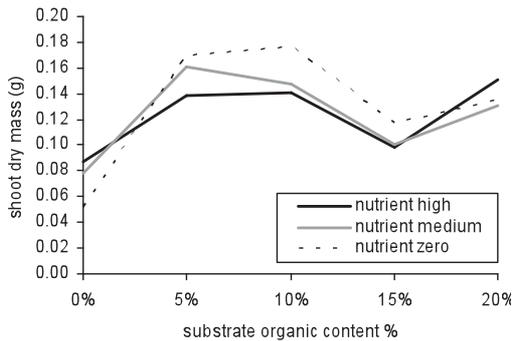
**Figure 1.** Effects of nutrients in culture solution on regeneration of single node stem fragments of cabomba.



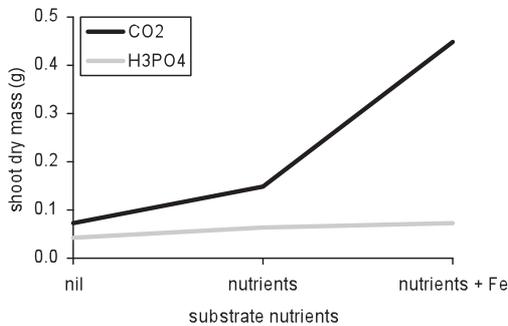
**Figure 2.** Effects of substrate nutrients availability and pH on cabomba biomass. Nutrient additions were 0, 1 and 2 g of Osmocote® kg<sup>-1</sup> substrate, respectively (zero, medium and high substrate nutrients).

There was an interaction between nutrient concentrations in the substrate and the organic content (Figure 3). When pure sand was used (0% organic matter), cabomba was growing poorly even with nutrients added. The best growth was observed at a low (5%) organic content independent of nutrient addition (two-way ANOVA, organic content:  $F = 6.62$ ,  $p < 0.0001$ ; nutrients: n.s.; not significant). The optimal organic content could not be determined within the tested range.

Apart from macronutrients, cabomba did respond positively to the addition of iron to the substrate (Figure 4). Again, growth did only improve with the addition of CO<sub>2</sub> to the aquarium water (two-way ANOVA, pH:  $F = 3.62$ ,  $p = 0.04$ ). In the aquariums where the pH was regulated through the addition of phosphoric acid, there was no discernable growth response to iron addition.



**Figure 3.** Effects of substrate organic content and nutrients on cabomba shoot dry mass. Percent organic content based on mass, substrate nutrients were 0, 1 and 2 g of Osmocote® kg<sup>-1</sup> substrate, respectively (zero, medium and high nutrient content).



**Figure 4.** Effects of iron (Fe) addition to the substrate and the regulation of the pH with CO<sub>2</sub> or phosphoric acid.

#### DISCUSSION

The findings in this project showed that cabomba has very specific habitat requirements. The pH of the water is a strongly limiting factor, with cabomba preferring slightly acidic to neutral water with (pH 6–7). The pH of water directly regulates the availability of dissolved CO<sub>2</sub>, with acidic waters (pH < 7) having large proportions of dissolved CO<sub>2</sub> compared to other forms of CO<sub>2</sub> (e.g. bicarbonate). The lack of growth of cabomba in water acidified with phosphoric acid shows that access to dissolved CO<sub>2</sub> regulates growth of cabomba. It appears that cabomba cannot take advantage of nutrient additions if the pH requirements are not met.

Cabomba seems to satisfy most of its nutrient requirements from the substrate. Nutrient concentrations in solution were of less importance, indicating that cabomba will be able to establish well even in

oligotrophic systems as long as there are sufficient nutrients available in the substrate. Cabomba growth was also influenced by substrate organic content, with best growth performance observed in substrates with low organic content. Substrate samples collected from lakes in south east Queensland with cabomba infestations, had on average ~1% organic content and therefore are consistent with experimental findings. However, further experiments need to be conducted to determine the ideal organic content. The experimental findings from this study corroborate field observations: cabomba infestations are predominantly found in soft water lakes with a slightly acidic to neutral pH, but there is no relationship between the occurrence of infestations and the trophic status (nutrient availability) of the water body.

Detailed knowledge of habitat requirements will allow prediction of the future expansion of cabomba in Australia. In particular, it will permit identification of sites that are at increased risk of cabomba invasion, and therefore increase the likelihood of timely detection and prevention of establishment. There is some scope for habitat manipulation to discourage cabomba establishment, for example through depositing unsuitable substrate in areas suitable for cabomba growth or altering the pH in the water column through chemical additives.

#### ACKNOWLEDGMENTS

This research project was funded through Rural Industries Research and Development Corporation (RIRDC), PRJ-006986, and the Queensland Government. Assistance with field and laboratory work by Cameron Clark and Christine Perret were invaluable for the successful completion of the project.

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