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Shade as a Management Tool for the Invasive Submerged Macrophyte, *Cabomba caroliniana*

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ABSTRACT

Cabomba, or water fanwort (*Cabomba caroliniana*), is a submerged aquatic macrophyte that is currently spreading throughout the world and is considered a serious weed in many countries. It is difficult to manage because conventional chemical and physical methods are not sustainable or effective. Shading was investigated as a management technique. Floating pool covers were used to impose three shade treatments (0, 70, and 99%) at three depths (1, 2, 3 m) at a lake in subtropical Australia. The 99% shade treatment reduced biomass to zero within 120 days, and inspection found that no live material remained on or in the sediment. The 70% treatment reduced biomass at 2 and 3 m depth, but did not affect biomass at the 1-m depth. We conclude that shade can be used to create bare patches in dense cabomba infestations for subsequent revegetation, irrigation, or recreational activities. In addition, eradication of outlying populations is the most important means of reducing spread at a regional scale. There are many small farm dams and public ponds (<1 ha) in Australia with cabomba infestations (primarily brought in on eel traps). Because no viable seeds or energy storage mechanisms (i.e., tubers) are produced throughout much of cabomba's introduced range, shading can also be used to eradicate cabomba from these small outlying infestations.

Key words: alien aquatic plant, buoyant floating shading, control, eradication, fanwort, introduced weed, spread reduction.

INTRODUCTION

The primary resources limiting plant biomass are light, nutrients, and water. Because water is generally not a limiting resource for submerged aquatic plants, light and nutrients are expected to be the main variables driving plant productivity. At high light levels, nutrients limit growth, but as light is decreased it will inevitably become the limiting resource (Begon et al. 1996). Knowledge of shade tolerance will allow managers to weigh the potential for manipulating light levels to control populations of aquatic weeds. For example, riparian areas can be managed to provide greater shade (Bunn et al. 1998), and aquatic weed beds can be covered by shade fabric (benthic mats) to reduce biomass, prevent flowering and seed set, and potentially eradicate the target weed (Dawson and Hallows 1983, Carter et al. 1994). Floating aquatic species also provide shade and reduce the growth of submerged species (Janes et al. 1996), which may be a useful management method if floating native plants are available and considered desirable. However, all of these methods are expected to alter the physico-chemical environment under the mats, including reduction in dissolved oxygen concentrations, increase in carbon dioxide concentrations, and reduction of pH (Janes et al. 1996).

Cabomba (*Cabomba caroliniana* Gray, Cabombaceae), or water fanwort, is a fast-growing submerged aquatic plant that has the potential to infest permanent water bodies from tropical to cool temperate regions throughout the world (Wilson et al. 2007). It is considered a serious pest in the United States, Canada, the Netherlands, Japan, India, China, and Australia, and is present in Hungary, South Africa, New Zealand, and the United Kingdom. Cabomba grows well in slow-moving water bodies, preferring areas of permanent standing water <4 m deep; however, it can also grow at depths up to 6 m in Australia (Schooler and Julien 2006). Cabomba is recorded in the aquarium literature as having high light requirements (Scheurmann 1993, Hiscock 2003), and maximum depth is closely related to light penetration (turbidity) through the water column (Schooler et al. forthcoming 2009). Reproduction is almost entirely vegetative throughout most of the introduced localities, and viable seed production is very low even where seeds are found (Tarver and Sanders 1977). Most spread is through vegetative reproduction, and any fragment that includes nodes can grow into a new plant (Sanders 1979). The only location where viable seeds have been found in Australia is a population in the Darwin River, Northern Territory (S. Wingrave, pers. comm.).

Once cabomba becomes established there is little that can be done to manage the infestation (Mackey and Swarbrick 1997). Herbicides are largely ineffective and herbicide use is severely regulated in or around public water supplies (Anderson and Diatloff 1999). However, a population in Darwin (Marlow's Lagoon) was successfully eradicated using herbicides in 2003 (S. Wingrave, pers. comm.). Physical management using floating "harvesters" or suction dredging is expensive and must be frequently repeated to manage the infestation at desired levels (Schooler et al. forthcoming 2009). The only method that will likely be effective in sustained control of cabomba is biological control (Culliney 2005, Schooler et al. 2006, Schooler et al. forthcoming 2009).

Alternative control methods, such as the manipulation of light, may assist in locally managing the spread and abundance of cabomba, however. First, eradicating cabomba from source populations where possible will reduce potential for

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spread. Second, spread downstream from infested areas may be reduced by creating and maintaining a dense riparian canopy (Bunn et al. 1998). Light manipulation may also be used to reduce the abundance of cabomba in key locations, such as around public swimming areas and irrigation intake pumps, or used to reduce flowering and seed-set, as is currently in progress in the cabomba eradication effort in the Darwin River (S. Wingrave, pers. comm.). Prior research on the control of aquatic weeds using shading has focused on nonbuoyant fabric or benthic mats (Dawson and Hallows 1983, Carter et al. 1994, Bailey and Calhoun in press). However, this technique allows sediment to accumulate on top of the mats (Carter et al. 1994), floating plant fragments can survive in the water column above the mats and root through woven mats, and gases produced in the sediment lift the mats (Bailey and Calhoun 2008).

In this study we used floating shade fabric to examine the effect of surface shading on cabomba abundance at a site in subtropical Australia. Prior work on the effect of shade in aquaria on two submerged species (*Elodea canadensis* Michx. and *Myriophyllum spicatum* L.) found that 23% and 40% shade treatments had no effect on biomass after 77 days (Abernethy et al. 1996). Here we used higher shade treatments to represent moderate riparian shading (70%) and complete shade (99%), as would likely be used in management situations. Biomass surveys have found that most of the cabomba biomass occurs <4 m depth (Schooler and Julien 2006) so we focused or treatments within that depth range.

MATERIALS AND METHODS

This study was conducted near Eumundi in a lake (-26.493, 152.972) in southeast Queensland, Australia. The experiment was set up in a randomized block design consisting of three shade treatments (0, 70, and 99% shade). Each block was replicated three times at each of three water depths (1, 2, and 3 m). Transparent and opaque floating plastic mats (5 by 5 m pool covers, ABGAL Pty Ltd, QLD, Australia) were used to create shade treatments (medium = 70% shade [Oasis solar blanket®] and high = 99% shade [Oasis thermal blanket®]). The buoyant plastic mats were anchored by metal stakes (star pickets, MetalCorp, Brisbane, Australia) driven into the substrate (one at each corner), and a styrofoam buoy was attached to each corner to provide greater buoyancy. An opaque black plastic strip (1 m wide by 21 m long) was attached to the edges of each plastic mat with cable ties (50-cm intervals) to provide a hanging skirt that prevented sunlight from angling under the material. Treatments were spaced 5 m apart to reduce additional shading from nearby mats. Control treatments consisted of a buoy attached to a stake driven into the centre of the plot. Treatments began on 19 October 2004.

Light intensity (PAR) and temperature were measured under the plastic mats and in unshaded controls using submersible data loggers (Odyssey photosynthetyic irradiance recording sensor, Odyssey submersible temperature recording sensor, Dataflow Systems Pty Ltd, Christchurch, NZ) on a cloud free day, 29 January 2005. Using SCUBA, we drove poles into the substrate in the centre of each plot, and a second pole was added so that the sensor array (light and temp) was 10 cm under the water surface. Sensors were supported from underneath so to eliminate additional effects of shade from the support system. Sensors recorded light incidence and temperature at 5-min intervals. They were set in the morning and then retrieved in the afternoon, giving 2 hr of readings during peak daylight. Light sensors were calibrated using a hand-held light sensor (LI-250A, Li-Cor, Lincoln, Nebraska, USA) and temperature sensors were calibrated using a thermometer (Taylor, Las Cruces, USA) prior to taking measurements.

We sampled the plots four times over the eight month duration of the experiment (approximately every two months). Surface cover of cabomba and other plant species was visually assessed in each plot at the beginning of the experiment and recorded as percent cover to nearest 5%. We assessed the effect of shade on cabomba biomass, stem length, and plant density. At each sampling event, all cabomba plants were removed from a randomly selected sub-plot (0.25 m^2) using SCUBA and a plot frame. The plot frame had three sides to allow it to be inserted among the stems at the substrate level. Plots were marked to prevent re-sampling at that location. Samples were then taken back to the lab and the number of plants and stem length was recorded. Dry biomass was obtained by drying to constant weight at 60 C. The difference between treatments at each depth was examined using ANOVA. All statistical analyses were conducted on the data from the final harvest. Where differences were found, the ANOVA was followed with pair-wise t-tests to determine differences among treatments. Data were analyzed using Excel (version 2000, Microsoft). Biomass data were natural log transformed ($\ln(x + 1)$) to equalize variances before conducting statistical tests.

RESULTS

Cabomba was abundant in all plots before treatments were applied. The plant community at the 2- and 3-m depths consisted of monospecific stands of cabomba with >90% cover of cabomba. The plant community at 1-m depth included cabomba (>70% cover) along with low densities of two emergent plant species, water snowflake (*Nymphoides indica* (L.) Kuntze) and spikerush (*Eleocharis equisetina* Presl.).

The mean light intensity (PAR) above the water surface was 1722.6 µmol/s/m^2 (SD = 85.3). In 10 cm of open water the amount of light was reduced by 45% to mean 931.3 µmol/s/m^2 (SD = 50.7). The medium shade treatment (transparent fabric) reduced light by an additional 70% to mean 280.2 µmol/s/m^2 (SD = 26.9) at 10-cm depth. The high shade treatment (opaque fabric) reduced light to mean 8.6 µmol/s/m^2 (SD = 2.6) at 10-cm depth, a reduction of 99% compared with that of unshaded open water at that depth. Temperature above the water surface averaged 32.6 C (SD = 0.88), at 10-cm depth was mean 26.5 C (SD = 0.14), under 70% shade fabric at 10-cm depth averaged 25.5 C (SD = 0.14), and under 99% shade fabric at 10-cm depth averaged 26.2 C (SD = 0.10).

Shade treatments negatively affected biomass (dry weight) of cabomba at each of the three depths; 1 m ($F_{2,6} = 194.7$, $P < 0.001$), 2 m ($F_{2,6} = 59.8$, $P < 0.001$), 3 m ($F_{2,6} = 13.5$, $P = 0.006$) (Figure 1). Biomass under the high shade treatment (99%)

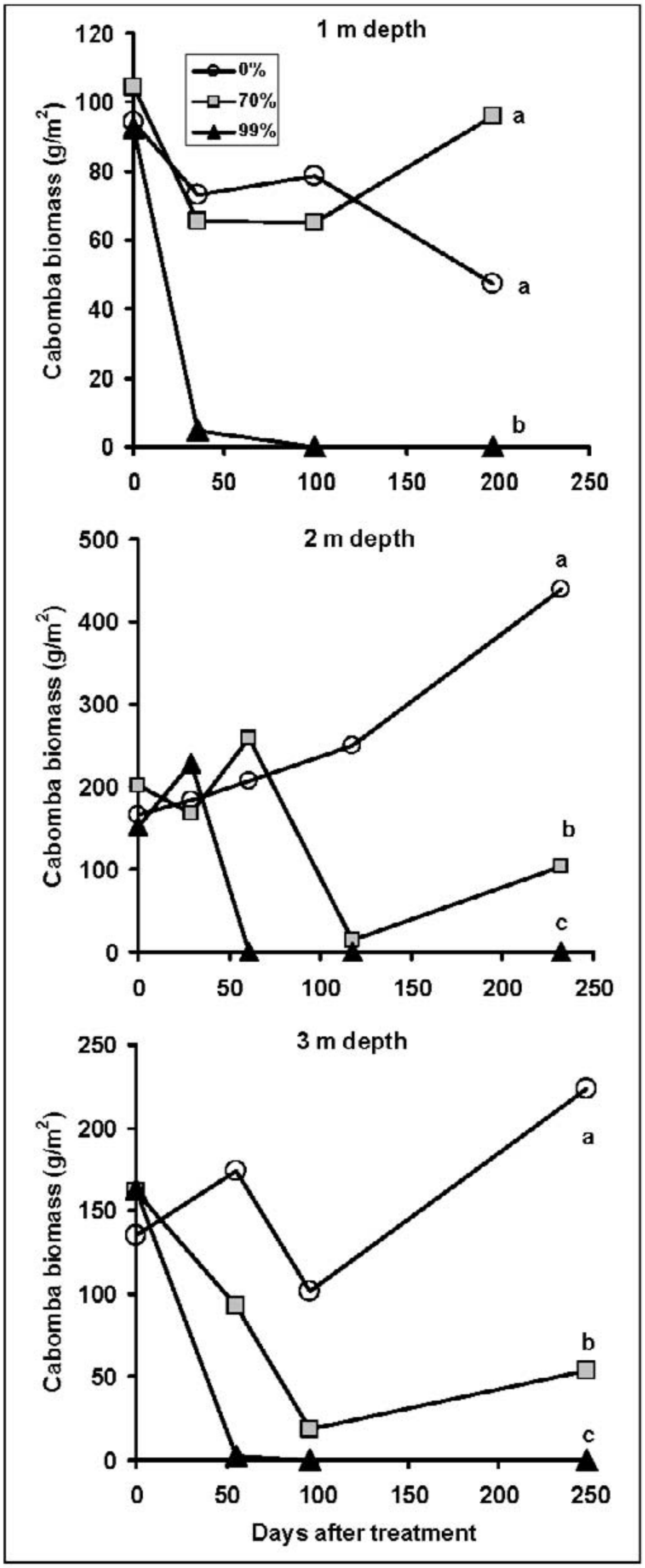

Figure 1. Effect of shade treatments on cabomba biomass at three depths (1, 2, and 3 m). Each point is the mean value of three replicates. Letters designate differences among means ($P < 0.05$) for the biomass (dry weight) at final harvest.

was always less than that of the controls (0%); 1 m ($t_4 = 15.5$, $P < 0.001$), 2 m ($t_4 = 61.2$, $P < 0.001$), 3 m ($t_4 = 152.4$, $P < 0.001$) and less than biomass of the medium shade treatment (70%); 1 m ($t_4 = 33.8$, $P < 0.001$), 2 m ($t_4 = 3.4$, $P = 0.009$), 3 m ($t_4 = 2.14$, $P = 0.049$). Although the medium shade treatment reduced cabomba biomass at the 2-m ($t_4 = 5.04$, $P < 0.003$) and arguably at the 3-m depth ($t_4 = 2.1$, $P < 0.052$), it did not affect cabomba biomass at 1-m depth ($t_4 = 0.4$, $P = 0.35$). Observations of the substrate confirmed that no rooted plants survived under the high shade treatments. Root remnants were brought to the surface and placed in aquaria to confirm that they were not viable.

DISCUSSION

High shade levels (99%) reduced cabomba biomass to <10% of former abundance within 60 days and eliminated cabomba within 120 days during summer at 1 to 3 m depth. Prior research has found that cabomba biomass is greatest at a depth of 2 to 3 m (Schooler and Julien 2006), and therefore the bulk of cabomba biomass at a given location is within this depth zone.

We propose that this management technique can be used to clear areas for irrigation (pumps and canals), revegetation efforts, recreation (fishing and swimming), and potentially eradicate cabomba from small ponds and farm dams. Since cabomba does not produce viable seeds throughout much of its introduced range (Schooler et al. in press) and does not have any appreciable energy storage mechanism (e.g., bulbs, turions, tubers), shade may be a useful method to clear areas for revegetation or possibly used for eradication of cabomba from small outlying infestations. Most other native aquatic competitor species produce seeds and/or have underground energy storage mechanisms (Stephens and Dowling 2002) and removal of cabomba is expected to stimulate the growth of these species. If propagules are not present (such as in human created reservoirs), desired vegetation can be planted in the cleared areas. Once established, emergent species are expected to reduce light and inhibit cabomba growth and biomass.

In addition, shade may be an effective eradication method with low environmental impact when compared with the other common eradication methods: draw-down and herbicide. However, entirely covering a pond or lake may also have significant negative effects, such as reducing dissolved oxygen (Janes et al. 1996), preventing amphibians from migrating to terrestrial habitats, and reducing water bird habitat. However, these problems can be ameliorated by sequentially covering parts of the water body while preventing propagules from moving to cleared areas.

Cabomba is primarily transported by humans, and there are many instances in Australia (and presumably throughout the world) where a small pond (>1 ha) is the only cabomba infestation in a catchment (Schooler, unpubl. observ.). Removing these nascent foci is the most effective means to reduce spread at a landscape scale (Moody and Mack 1988). We are currently investigating shading as a technique to eradicate cabomba from three ponds in Queensland.

Shading can also be integrated with other methods, such as herbicides, as is currently the case in the ongoing eradication effort in the Darwin River (Northern Territory, Australia). The bulk of the cabomba infestation has been removed using herbicides (reduced to <1% former levels). Floating shade fabric is being used to reduce flowering and seed-set in the remaining areas until conditions are conducive to herbicide use (S. Wingrave, pers. comm.). This strategy of using shade to prevent the accumulation of a seed-bank is a key toward the eventual eradication of the plant.

Cabomba is recorded in the aquarium literature as having high light requirements (Scheurmann 1993, Hiscock 2003); therefore, it was expected that our 70% shade treatment would have a large impact on biomass. Although it did reduce cabomba biomass at 2 to 3 m depth, it was not sufficient to eliminate the plants from the plots. In addition, it did not affect biomass at 1-m depth, and there was a trend for increased biomass over open controls. This may be due to the elimination of the two emergent species in the plots, water snowflake and spikerush, probably because the shade fabric submerged these emergent species and prevented the plants from respiring.

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LITERATURE CITED

Abernethy, V. J., M. R. Sabbatini and K. J. Murphy. 1996. Response of *Elodea canadensis* Michx. and *Myriophyllum spicatum* L. to shade, cutting, and competition in experimental culture. Hydrobiologia 340:219-224.

Anderson, T. and G. Diatloff. 1999. Cabomba management attempts in Queensland. pp. 42-45. *In:* S. D. Kay (ed.) Proceedings of the 10th Biennial Noxious Weeds Conference. Ballina, NSW, Australia.

Bailey J. E. and A. J. K. Calhoun. 2008. Comparison of three physical management techniques for controlling variable-leaf milfoil in Maine lakes. J. Aquat. Plant Manage. 46:163-167.

Begon, M., J. L. Harper and C. R. Townsend. 1996. Ecology: individuals, populations, and communities. Sinauer Associates, Sunderland, MA. 995 pp.

Bunn, S. F., P. M. Davies, D. M. Kellaway and I. P. Prosser. 1998. Influence of invasive macrophytes on channel morphology and hydrology in an open tropical lowland stream, and potential control by riparian shading. Freshw. Biol. 39:171-178.

Carter, D. R., S. Carter and J. L. Allen. 1994. Submerged macrophyte control using plastic blankets. Wat. Sci. Tech. 29:119-126.

Culliney, T. W. 2005. Benefits of classical biological control for managing invasive plants. Crit. Rev. Plant Sci. 24:131-150.

Dawson, F. H. and H. B. Hallows. 1983. Practical applications of a shading material for macrophyte control in watercourses. Aquat. Bot. 17:301-308.

Hiscock, P. 2003. *Encyclopedia of Aquarium Plants.* Barron's Educational Series, Inc., Hauppauge, USA. 205 pp.

Janes, R. A., J. W. Eaton, and K. Hardwick. 1996. The effects of floating mats of *Azolla filiculoides* Lam. and *Lemna minuta* Kunth on the growth of submerged macrophytes. Hydrobiologia 340:23-26.

Mackey, A. P. and J. T. Swarbrick. 1997. The biology of Australian weeds 32. *Cabomba caroliniana* Gray. Plant Prot. Q. 12:154-165.

Sanders, D. R. 1979. The ecology of *Cabomba caroliniana*. pp. 133-146. *In*: E. O. Gangstad (ed.). Weed Control Methods for Public Health Applications. CRC Press, Inc., Boca Raton.

Scheurmann, I. 1993. Aquarium Plants Manual. Barron's Educational Series, Inc., Hauppauge. 93 pp.

Schooler, S. S. and M. H. Julien. 2006. Effects of depth and season on the population dynamics of *Cabomba caroliniana* in SE Queensland. pp. 768-771. *In*: C. Preston, J. H. Watts and N. D. Crossman (eds.). Proceedings of the 15th Australian Weed Conference. Weed Management Society of South Australia, Adelaide, Australia.

Schooler, S. S., M. H. Julien and G. C. Walsh. 2006. Predicting the response of *Cabomba caroliniana* to biological control agent damage. Aust. J. Entomol. 45:326-329.

Schooler, S. S., G. C. Walsh, and M. H. Julien. Forthcoming 2009. The ecology and biological control of *Cabomba caroliniana. In:* R. Muniappan, G. V. P. Reddy, A. Raman, and V. P. Gandhi (eds.). Biological Control of Tropical Weeds. Cambridge University Press, Cambridge.

Stephens, K. M. and R. M. Dowling. 2002. Wetland Plants of Queensland. CSIRO Publishing, Collingwod, Australia. 145 pp.

Tarver, D. P. and D. R. Sanders. 1977. Selected life cycle features of fanwort. J. Aquat. Plant Manage. 15:18-22.

Wilson, C. E., S. J. Darbyshire and R. Jones. 2007. The biology of invasive alien plants in Canada. 7. *Cabomba caroliniana* A. Gray. Can. J. Plant Sci. 87:615-638.