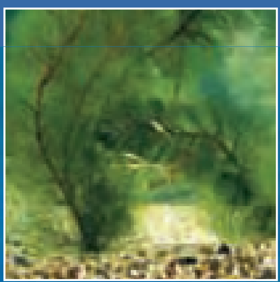

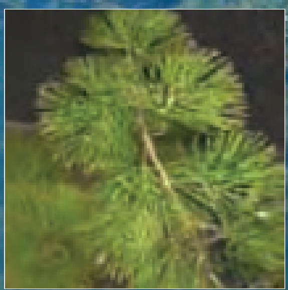

Cabomba control manual

Current management and control options for cabomba *(Cabomba caroliniana)* in Australia

WEEDS OF NATIONAL SIGNIFICANCE

Cabomba control manual

Current management and control options for cabomba *(Cabomba caroliniana)* in Australia

Australian Government

IMARY INDUSTRIES

ALWAYS READ THE LABEL

Users of agricultural or veterinary chemical products must always read the label and any permit, before using the product, and strictly comply with the directions on the label and the conditions of any permit. Users are not absolved from compliance with the directions on the label or the conditions of the permit by reason of any statement made or not made in this publication.

Parts of the chemical use pattern quoted in this publication are approved under permits issued by the Australian Pesticides and Veterinary Medicines Authority and in force at the time the publication was prepared. Persons wishing to use a chemical in the manner approved under permit should obtain a copy of the relevant permit from the APVMA and must read all the details, conditions and limitations relevant to that permit, and must comply with the details, conditions and limitations before using that chemical.

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Written by Elissa van Oosterhout
Design by N Parker
Orange, April 2009

For copies of this manual contact:

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Foreword

Although the current Australian distribution of cabomba is relatively small, cabomba is an insidious aquatic weed capable of rendering most Australian water bodies dangerous, lifeless and useless. Control of cabomba is currently limited by a lack of registered herbicides and biological control agents. The process of registering a safe and effective herbicide for use in water takes lengthy consideration, as does the process of finding and testing biological control agents. Both of these processes are currently under way and supported by State and Federal governments, with the hope of having a herbicide and a biological control agent available in the near future. In the meantime, managers of cabomba are restricted to physical control methods such as shading, drawdown, and manual and mechanical removal. There are also a number of situations where physical control methods are the only option, given public attitudes towards the use of herbicides.

Given these restrictions, over the past 10 years managers faced with cabomba infestations have pioneered and improved the available physical control methods. Advances have been made in the efficiencies of mechanical removal systems and the development of plant and machinery to support diver-operated suction dredging. Credit is due to the contractors and managers involved—particularly those associated with the Lake Macdonald and Ewen Maddock Dam infestations in south-east Queensland. Noosa & District Landcare, along with CSIRO and NSW DPI, has recently made great efforts to improve shading techniques, and the insights gathered over the course of these developments have been recorded and presented in this manual.

This publication brings together current experience and available information on the management and control of cabomba in Australia. The text has been reviewed by many of the people involved in the management of this weed.

I would like to particularly thank those managers and contractors who have put their time and experience forward for the sake of this manual. I believe it is the most comprehensive resource for cabomba control in Australia, and indeed a very useful reference for the control of submerged aquatic weeds in general, with nothing similar yet published in Australia.

Neale Tweedie

Chair
National Aquatic Weeds Management Group

Contents

Introduction

Cabomba caroliniana is a submerged aquatic weed that invades bodies of fresh water such as lakes, dams, slow-flowing rivers and billabongs.

Cabomba originated in South America (southern Brazil, Paraguay, Uruguay and north-east Argentina) and is widely naturalised in the south-east of the USA. It has become a weed worldwide, infesting bodies of water in climates ranging from tropical to cool-temperate. It is considered a serious weed in the USA, China, Canada, the Netherlands, Japan and India and is present in South Africa, Hungary and the United Kingdom.

Cabomba in Australia

Cabomba was introduced to most countries, including Australia, through the aquarium industry, as a popular ornamental, habitat and 'oxygenator' plant for fish tanks and aquariums. It was easily propagated and cultivated for trade. The trade and sale of cabomba is now banned in all States and Territories in Australia.

The first herbarium record of cabomba in Australia dates from 1967, but anecdotal evidence suggests that the weed was introduced in the 1930s. It was recorded in the flora of NSW in 1986 and soon after found naturalised in parts of eastern Australia. Cabomba has been unintentionally introduced into freshwater systems by people emptying aquarium water into creeks and streams, but experts believe the main means of introduction has been illegal planting in natural waterways for cultivation, collection and sale. It then spreads rapidly through catchments when stem fragments capable of reproduction move in water. Stem fragments can also be spread across catchments on watercraft, boat trailers, eel traps and fishing nets.

A Weed of National Significance

Cabomba has been present for over 70 years in Australia but has been identified as a significant aquatic weed only in the last 15 years. The National Weeds Strategy Executive Committee classified cabomba as a Weed of National Significance in Australia because of its impacts on the biodiversity and function of freshwater and riparian ecosystems, on water quality, water storage and distribution infrastructure, and on recreational and amenity values.

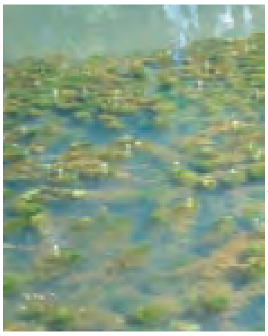
Impacts of cabomba

As an aquatic weed, cabomba has a range of environmental, social and economic impacts. Generally, aquatic plants are important parts of freshwater systems because they oxygenate water, provide shelter and habitat for fish and invertebrates, and stabilise banks and beds. However, dense stands of cabomba cause many problems, including:

- increased resistance to flows, resulting in stagnation of water
- increased siltation, affecting bottom-dwelling organisms
- degradation of water quality
- increased flooding
- blockage of pumps
- impeding of navigation
- restriction of recreation
- swimming hazards
- displacement of native aquatic vegetation.

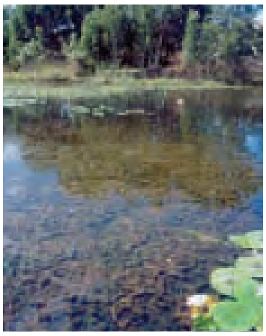
Northern Territory Government

Cabomba: a submerged aquatic weed



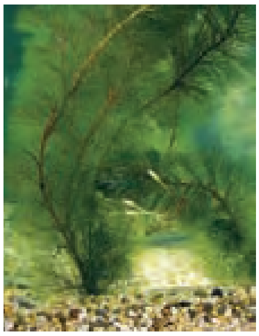
Andrew Petroeschevsky

Cabomba is a weed in many countries.



Andrew Petroeschevsky

Cabomba has been introduced to many freshwater systems by people.



Biosecurity Queensland, DPI&F

Cabomba was introduced as a popular fish tank plant.

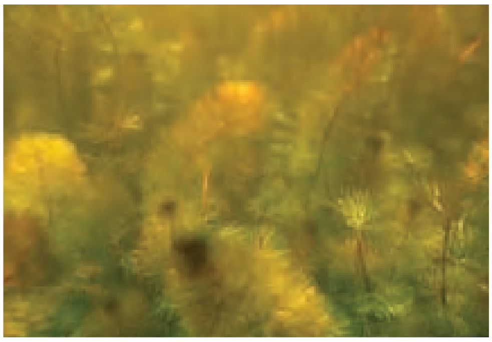
Andrew Petroeschevsky

Cabomba invades bodies of fresh water.

Shon Schooler

Cabomba is now a Weed of National Significance.

Cabomba alters the aquatic habitat for other organisms.



NSW DPI

Submerged growth restricts light penetration

Environmental impacts

The monoculture that results from fast-growing submerged cabomba infestations excludes native aquatic plants and alters the aquatic habitat for other organisms, ultimately reducing biodiversity. Light penetration is restricted, causing changes to food-chain structures and species composition. Cabomba will outcompete many aquatic plants, such as the native pondweeds (*Potamogeton* spp.), stoneworts (*Chara* spp.), hornwort (*Ceratophyllum demersum*) and water nymph (*Najas tenuifolia*). There are many examples of where such alteration of native aquatic flora has affected populations of native fauna, including platypus, water rats and Mary River cod.

Temperature-dependent seasonal dieback of cabomba infestations can leave large amounts of decomposing plant material and consequently reduce the amount of available oxygen in the water. This results in foul-smelling, oxygen-deficient water and an increase in the rates of release of some nutrients from bottom sediments.

Dense stands of cabomba cause many problems.

Lalith Gunasekera

Terry Stokes

Vanessa Moscato

▲ *OH&S issues are created for workers.*

◄ *Dense submerged stands create swimming hazards.*

Social impacts

Dense submerged stands of cabomba create public safety concerns and make swimming areas unsafe. Fishing lines become entangled in the weed, and water sports, including boating, sailing and canoeing, are also directly affected by the weed's dense growth. Occupational health and safety issues are created for a range of workers, including water supply engineers and managers, weed managers and protected-area staff.

Cabomba infestations also reduce the scenic amenity values associated with water bodies. Clear rippled water surfaces become darker, still and partly stagnant in the presence of a cabomba infestation.

Economic impacts

Cabomba will taint and discolour potable water, increasing the costs of water treatment processes. It blocks foot valves and pumps, increasing maintenance and running costs and reducing pumping efficiencies.

In those infestations in Australia that are subject to control measures, the costs are currently estimated to be in the range of $600,000 to $800,000 a year.

Phil Moran

Phil Moran

Clear water surfaces become darker, still and stagnant.

Cabomba affects irrigation systems.

M. Kean

Melissa Freeman

Cabomba increases the costs of water treatment.

Cabomba taints potable water.

Phil Moran

Current distribution

Infestations are currently distributed along the east coast of Australia in Queensland and New South Wales, with isolated populations occurring in the Northern Territory and Victoria.

Cabomba occurs in far north Queensland and south-east Queensland; Northern NSW, the NSW mid North Coast and the Blue Mountains; Lake Nagambie, Lake Benalla and Mildura in Victoria; and the Darwin River at Palmerston in the Northern Territory.

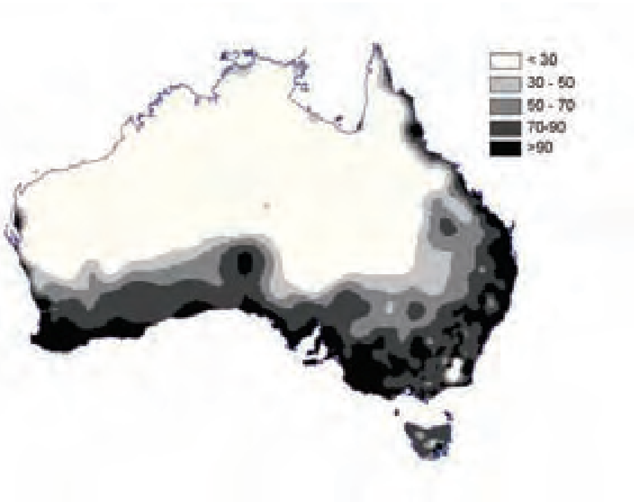
Cabomba infestations have not yet been found in Western Australia, South Australia, Tasmania or the Australian Capital Territory.

Potential distribution

Cabomba has a wide potential distribution. It currently exists in Australia in a distribution from monsoonal tropical climates to temperate zones. Worldwide it can persist in cold temperate conditions, even persisting under ice in Canada. Cabomba has demonstrated its potential to colonise most water bodies throughout the world and has the same ability in Australia. The potential distribution map shown here has been predicted using a CLIMEX model based on the temperature tolerance found in the native range of cabomba. Each prediction is shown as an EI or Ecoclimatic Index. An EI of less than 30 indicates a low potential for permanent populations and an EI greater than 70 indicates a very high potential for a permanent population. The ranges shown also assume the availability of water.

Current cabomba distribution in Australia
Andrew Petroeschevsky

Potential cabomba distribution in Australia
Weeds of National Significance Cabomba Strategic Plan 2000



Legal status of cabomba in Australia

The legal status of cabomba in some States is somewhat restricted by the lack of broad-scale control techniques and eradication strategies for large infestations. Cabomba is prohibited from trade or sale in all States and Territories in Australia. Declarations may change when more effective and sustainable control techniques become available.

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LEGAL STATUS OF CABOMBA

State	Declaration status of Cabomba caroliniana
ACT	Class 1 Notifiable Pest Plant and Class 4 Prohibited Pest Plant under the *Pest Plants and Animals Act 2005*; a pest plant whose presence must be notified to the Chief Executive; a pest plant whose importation, propagation and supply are prohibited.
NSW	Class 5 Restricted Weed throughout the State under the *Noxious Weeds Act 1993*; plants are notifiable throughout the State and are banned from sale, trade or distribution.
NT	Class A and Class C Noxious Weed under the *Weeds Management Act 2001*; small infestations to be eradicated where feasible; not to be introduced to the Northern Territory; restricted from sale in the Northern Territory.
QLD	Class 2 Pest Plant under the *Land Protection (Pest and Stock Route Management) Regulation 2003*; landowners must take reasonable steps to keep land free of Class 2 plants; it is an offence to introduce, keep, release, take or supply without a permit.
SA	Class 11+ under the *Weed Management Act 1999*, restricting sale only; control not required.
TAS	Category D – Declared plant under the *Weed Management Act 1999*; importation, sale, distribution, movement and storage are prohibited; plants/infestations are to be reduced, eradicated or restricted.
VIC	Restricted weed under the *Catchment and Land Protection Act 1994*; plants that do not occur in Victoria but pose an unacceptable risk of spread if they are sold or traded. (This classification is currently under review owing to the presence of cabomba in the State of Victoria).
WA	Category P1 and P2 Declared Plant under the *Agriculture and Related Resources Protection Act 1976*; cannot be introduced to the State; prohibited from sale, trade or movement throughout the State; plants are to be eradicated.
Federal	All species of the genus Cabomba are prohibited entry to Australia under the *Quarantine Proclamation 1998*.

Part 1:
The cabomba profile

Cabomba (*Cabomba caroliniana*) is a submerged freshwater plant with characteristic fan-shaped leaves and small, white flowers that emerge above the surface of the water. Populations of cabomba are usually very dense, with long branching stems that can fill the entire water column with plant material.

***Cabomba caroliniana*, showing (a) whole plant, (b) fruit, (c) flower, (d) floating upper leaves, and (e) dissected lower leaves**

Schooler, Cabrera-Walsh and Julien 2009

Physical characteristics

Cabomba is a completely submerged aquatic plant, except for its emergent flowers and occasional floating leaves.

Stems

The soft branching stems can be up to 10 metres long but usually range up to 5 metres. Stems can be olive green to reddish brown and are often coated with a mucus-like secretion. They are slightly oval-shaped in cross-section, and 2 to 4 millimetres in diameter. Stems can have scattered, short, white or reddish-brown hairs. Up to 40 stems can arise from a single root mass. Stems are fragile and break and decay quickly.

Thicker stems can lie prostrate and become partly buried in sediments. These are often referred to as rhizomes (underground stems bearing shoots and roots) but are not true rhizomes, and they sometimes have small, opposite leaves.

Under the water the stems and their leaves can have a tubular or columnar appearance.

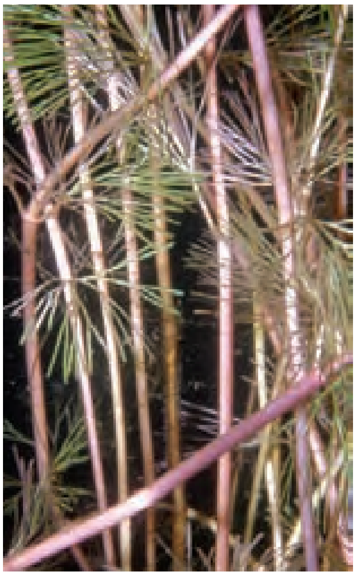
Leaves

The submerged fan-shaped leaves generally occur in opposite pairs along the stems on leaf stalks approximately 1 centimetre long. However, leaves can also occur in whorls of three.

Cabomba is completely submerged, except for its flowers and occasional small floating leaves. Biosecurity Queensland, DPI&F

Stems can be up to 10 metres long. Phil Moran

Phil Moran



Biosecurity Queensland

Stems can be olive-green to reddish brown.

NSW DPI

Up to 40 stems can arise from a single root mass.

Stems and leaves can look tubular under the water. Biosecurity Queensland, DPI&F

Fan-shaped leaves grow in opposite pairs along the stems.

Finely dissected leaves have a feathery appearance.

The leaves are finely dissected, giving the characteristic feathery, fan-like appearance. Individual leaves can have up to 200 divisions each, with a combined diameter of approximately 5 centimetres per leaf.

The leaves secrete gelatinous mucus that covers the entire plant.

Narrow floating diamond-shaped leaves (5 to 20 millimetres long and 1 to 3 millimetres wide) may be produced during the flowering period. They occur alternately along the flowering stems and have a firmer texture than the fan-shaped leaves. These usually occur in groups at the tips of flowering stems and are attached to the stems by a leaf stalk from their undersides.

Flowers

Single flowers are raised 1 to 4 centimetres above the surface of the water on stalks. They are approximately 2 centimetres in diameter and can be milk-white, pale yellow or purplish (usually white petals with yellow centres). The flowers have three petals and three sepals, giving the appearance of six alternating petals.

Flowers are short-lived, emerging from the water only for 2 days and only during the day, receding back into the water and closing overnight. Flowers open by mid-morning and begin to close and recede by late afternoon.

The raised flowers are often the main visible signs of a cabomba infestation; infestations are most commonly found during periods of flowering in the warmer months.

In a well established infestation, plants can produce up to 50 flowers per square metre each day.

Seeds

Cabomba in Australia is not known to produce viable seed, with the exception of the infestation in the Darwin River in the Northern Territory. Although flowering occurs throughout Australia, viable seed production has not yet been observed outside this infestation. Seeds have been produced in some other infestations but have not yet been observed to germinate. It is thought that most of the cabomba

Cabomba secretes a gelatinous mucus.

Narrow floating diamond-shaped leaves occur in groups on the flowering stems.

Phil Moran

The raised flowers are the main visible signs of an infestation.

Andrew Petroeschevsky

Flowers appear to have six petals.

Flowers recede back into the water by late afternoon.

Steve Wingrave

in Australia is a hybrid between an American and an Argentinean variety and is therefore infertile.

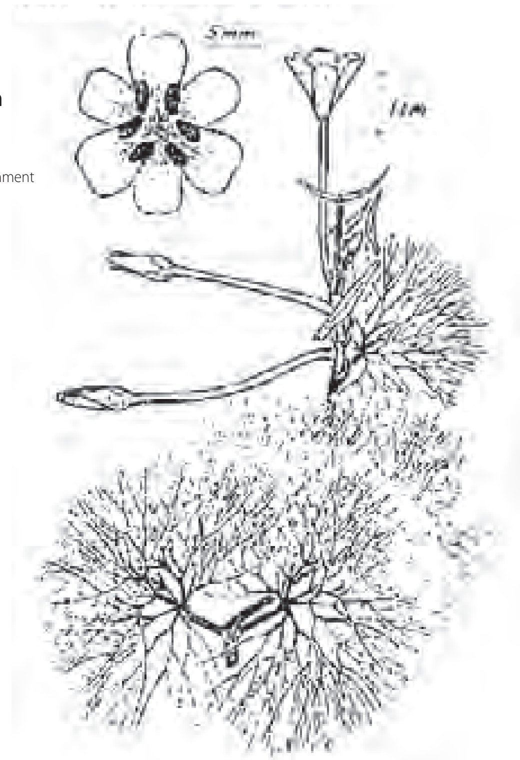
Where seeds are produced, they are oblong and up to 3 millimetres long and 1 millimetre wide. They are slightly wider at one end, with a small cap at the other end. Seeds are dark when mature and have four longitudinal rows of tubercles. Seeds are coated in the gelatinous mucus.

Toby Grant

Seeds are up to 3 millimetres long and dark when mature.

Single raised flowers are approximately 2 centimetres in diameter when open.

Northern Territory Government



Roots

Cabomba plants have shallow fibrous root systems made up of numerous long, slender, branched roots. Roots are initially smooth, white and unbranched, becoming branched and dark brown or black with age. When the roots are young their colour can be closer to purple.

Roots can form at any node on attached and free-floating stems, without the need for contact with a substrate. Nodal roots are thin, white and unbranched, and they can be up to 24 centimetres long.

Cabomba does not take root very deeply, and its lack of strong roots limits its distribution to slow-moving waters.

Russell Rainbird

The fibrous roots are white or purplish, turning dark brown or black with age.

Variation within the species

Cabomba can exhibit a high degree of physiological variation. Research has indicated that shoot colour, leaf size and leaf shape are strongly influenced by environmental variables such as water quality, nutrients and light availability. Plants in shade tend to be green to olive green. Plants growing in nutrient-rich water may have larger leaves. Plants exposed to full sun can have smaller leaves and be reddish.

Reproduction and spread

In Australia, reproduction of cabomba is mostly vegetative (i.e. the plants reproduce when stem fragments break away and take root in a substrate).

Vegetative reproduction

Cabomba can reproduce vegetatively by fragmentation or through the production of daughter plants (i.e. by clonal reproduction).

A stem fragment capable of reproduction is called a propagule (any part of a plant capable of producing new plants). Any stem fragment that includes a node (pieces as small as 1 centimetre) can grow into a new plant. Stems break up easily when disturbed, and fragmentation also occurs naturally at the end of the growing season. Disturbance (e.g. by outboard motors) can break the stems into thousands of individual propagules, all capable of spread and reproduction. Anything that moves through an infestation (fishing gear, traps, humans, animals) can create large numbers of propagules.

Clonal reproduction occurs when plants lose buoyancy in autumn and winter, causing the stems to sink to the bottom. At this point stems can break down into small pieces, some of which remain viable and regrow the following spring. Alternatively, the growing tips can take root in the substrate, producing new daughter plants. The connecting stem then breaks down.

The many stems present in an infestation make vegetative reproduction prolific and allow cabomba to be a highly invasive species that can rapidly colonise an entire water body.

Andrew Petroeschevsky

Any stem fragment that includes a node can grow into a new plant.

a) In summer, the buoyant stems keep the tips in a vertical position. b) Stem tips lose buoyancy during the winter and drop to the sediment. In the spring, nodes near the tip form roots and a new growing tip. Eventually the connecting stem disintegrates, separating the mother from the daughter plants. Schooler, Cabrera-Walsh and Julien 2009

Reproduction by seed

There is much uncertainty surrounding cabomba seed production, seed viability and germination. The reasons for the current situation in Australia whereby cabomba is producing viable seed only in the Darwin River are also unclear. Genetic analyses may help to explain the differences in seed viability in Australian cabomba infestations.

In studies in the USA, seeds were produced only in flowers that were visited by flying insects; caged plants did not set seed. However, other studies have suggested that plants can set seed in the absence of pollinators. If a flower has been pollinated, the stem forms a coil and the carpels begin to swell. After a few weeks the carpels detach from the flower stalk, sink and decompose, leaving a mature seed. Large numbers of flowers are produced by mature infestations, and each flower is capable of producing up to nine seeds.

It is likely that the cabomba in the Darwin River is able to produce viable seed for 7 to 12 months of the year, restricted only by wet-season water-level rises. At 1 month of age 100% of seeds produced are capable of germinating. This drops to 76% after 4 months. Other studies suggest that small numbers of seeds can remain viable for at least 2 years.

Viable seeds in south-east USA are thought to germinate 5 to 10 weeks after fertilisation occurs.

Seeds are thought to be capable of dormancy but conditions for germination are not yet known, although early studies have suggested that seeds dried and stored have a much higher germination rate (75%) than those kept moist (25%). This suggests that drying is a germination stimulant and could indicate that seeds are a means of overcoming fluctuating water levels or seasonal lack of water (e.g. in ephemeral water bodies), which would not support vegetative reproduction. Other studies have shown that desiccation over a 9-hour period kills seeds.

Checking for seed viability
It is important to observe whether an infestation is producing viable seeds. To check for seeds, place some flowering cabomba into a container of water and leave it for 4 or 5 weeks in a place where flying insects have access. Any seeds produced will sink to the bottom of the container, and most of the water can be poured off, leaving the seeds behind.

Even viable seeds can be difficult to germinate, and any seeds produced may need to be sent to a laboratory or propagation nursery to establish their viability. In cabomba seedlings the first few pairs of leaves are narrow and not divided. These are followed by transitional leaves until the typical submerged adult leaf form appears.

Spread

Stem propagules are easily spread, as they float on the water surface. Seeds do not float and are not moved as easily away from the parent plants. Propagules can be transported on fishing equipment, watercraft or animals. Individual stem fragments dry out very quickly (plant material rarely remains viable for more than 24 hours in dry conditions), but large bunches of stems that remain attached to boat trailers, fish or eel traps, nets or propellers are more likely to remain moist and therefore carry a viable propagule from one waterway to another. Stems in contact with moist soil can remain viable for weeks, even in hot or dry conditions (see *Part 4: Drawdown*).

Seeds are less easily transported but do not dry out as easily; therefore, they are more likely to survive transportation for considerable distances. Seeds could plausibly be carried in mud on shoes, boots or tyres but do not have specialised methods of attachment (i.e. bristles). Seeds are thought to die when ingested by animals or birds.

The third method of spread through a waterway is the clonal production of daughter plants. Plants are able to colonise deeper water this way. The mother plant continues to deliver nutrients to the daughter plant through the attached stem until the daughter plant has grown into the photic zone (i.e. the zone where enough light is penetrating the water for plant growth to occur).

Cabomba's primary means of dispersal is by fragments
In Kasshabog Lake in Canada, stem fragments 30 to 40 centimetres long have been found floating on the water surface up to 3 kilometres from the nearest cabomba infestations and only 3 days after the break-up of the winter surface ice sheets.

Growth habits

Cabomba grows rooted in the substrate, with erect stems and floating leaves growing up through the water column to the surface. Plants can produce multiple stems from their bases, so that single plants can occupy a large proportion of the water column.

Cabomba stems can also survive free-floating for some time (possibly around 6 weeks).

Seasonal variations

In tropical climates cabomba grows and flowers continuously throughout the year and plants remain upright in the water column.

In subtropical climates plants stop flowering during the winter months, lose buoyancy, and sink down below the surface, although plant mass and abundance do not decrease. Growth can continue during mild winters.

In temperate climates cabomba sinks back to the substrate and completely fragments during winter, leaving stem fragments and root masses with only a few centimetres of stem attached. It can then grow rapidly back to the surface (from buds on fragments or root masses) with the beginning of the warmer weather.

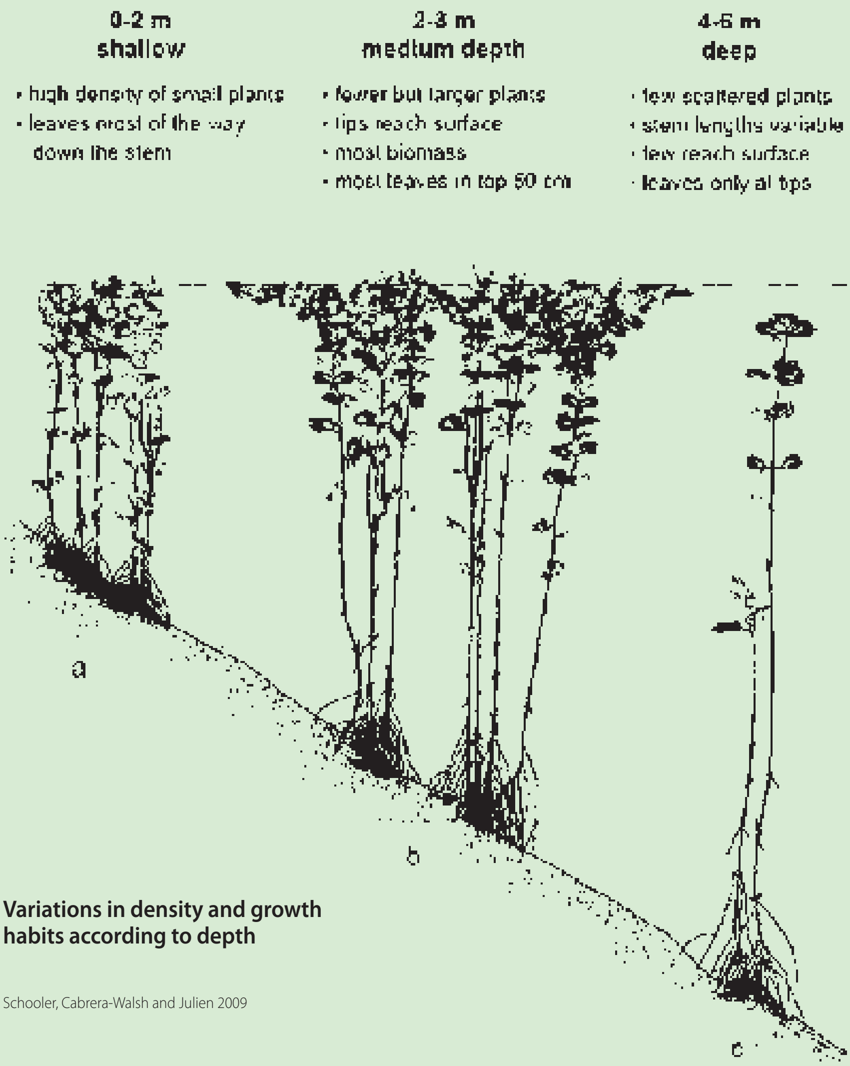
Growth rates

Cabomba is considered to be fast-growing in ideal conditions. Growth rates of 5 centimetres a day have been recorded in Queensland.

Growth rates increase with increasing light, temperature, nutrients and dissolved inorganic carbon. Growth rates can decline over 27 °C because of increasing respiration levels at these temperatures.

Depth variations

Cabomba plants assume different habits at different depths. Occurrence of leaves along the stems, plant size, and plant population density are all affected by the depth of the water. The greatest biomass is found in water 2 to 3 metres deep. Plant size has been found to increase with water depth to 3 metres and then decline. Plant population density decreases with water depth.



Variations in density and growth habits according to depth

Schooler, Cabrera-Walsh and Julien 2009

In simulation trials to establish the effects of drawdown (the lowering or draining of a water body), cabomba has survived in water depths of 5 centimetres for periods of 3 months, and in glasshouse trials cabomba has survived on damp soil for 30 days (see *Part 4: Drawdown*). A maximum length of time has not been established for cabomba survival in extremely shallow water.

Cabomba will grow in low levels of light. Andrew Petroeschevsky

Habitat and conditions for growth

In its introduced range cabomba has the ability to tolerate much more extreme conditions than it is adapted to in its native range. In Australia the environmental factors that appear to have most effect on the abundance of cabomba include substrate type, water flow, water turbidity, dissolved carbon dioxide and pH. Cabomba can tolerate low light intensities.

Water depth, flow, turbidity and light availability

Cabomba grows well in slow-moving water, but it prefers bodies of permanent standing water of less than 4 metres depth. Rooted plants have, however, been observed at depths of up to 6 metres in Australia. It is often found along the margins of deeper water. Recent studies show that depth is the main environmental variable affecting cabomba growth, the limiting factor being light availability.

Cabomba grows well in slow-moving water. Andrew Petroeschevsky

Sue Hayward

Cabomba will grow in turbid (muddy) water.

Cabomba is often found along the edges of deeper water. Terry Stokes

Andrew Petroeschevsky

Cabomba prefers soft, silty sediments.

In glasshouse experiments cabomba responded well in turbid conditions, even though turbidity reduces light availability. Growth was highest at medium turbidity levels, followed by high turbidity levels. Stem length growth was greater and adventitious root development was enhanced. Turbid water may contain nutrients available at high levels to the stem and shoot zones of the plants.

Climate

Cabomba prefers a warm-temperate, humid climate with rain throughout the year. Its optimal temperature range is reported as 13 to 27 °C, although it can survive under ice in frozen lakes in temperate climates (Ontario, Canada). Air temperatures in these conditions drop below 0 °C, but water temperatures under the ice remain above 4 °C. The preferred mean annual temperature is described as 15 to 18 °C (although infestations in Canada survive a mean annual temperature of 6 °C).

The physiological means by which this tropical plant has been able to adapt to sub-zero conditions is unknown. It is not known how fragments remain viable at the bottom of ice-covered lakes at 4 °C with reduced light penetration.

pH

Cabomba occurs in both acid and alkaline waters, but the optimum pH for growth is 4 to 6, with growth inhibited when pH reaches 7 to 8. Above pH 8 the stems lose their leaves and growth is inhibited. The better growth in acidic waters is possibly caused by greater availability of nutrients in acidic conditions. Most freshwater bodies in Australia are considered to be slightly acidic, with average pH levels in the vicinity of 6.0 to 7.0.

Substrate type

Cabomba prefers areas with fine and soft silt sediments, and it tends to be less vigorous on sand or stony bases. On clay or sand substrates the thin roots struggle to hold the plants in place. In Australia cabomba is less aggressive where it is growing on hard or stony substrates. In lakes or impoundments with hard clay substrates, cabomba will occur in depressions where layers of sediment have accumulated.

Nutrients

Cabomba grows well in nutrient-rich waters. It can also grow very well in water with very low calcium ion concentrations (more than 4 ppm of calcium inhibits growth).

Early experiments have shown that shoot sections of cabomba take up much more phosphorus than root sections, suggesting that nutrient uptake occurs directly from the water through the shoots.

Taxonomy

Cabomba caroliniana occurs within the Cabombaceae family, which consists of two genera, *Cabomba* and *Brasenia*.

The genus *Cabomba* consists of five species:

C. caroliniana

C. furcata

C. aquatica

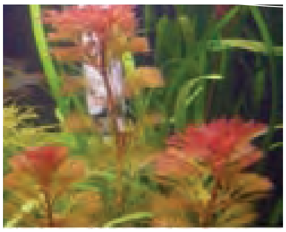
C. palaeformis

C. haynesii.

Cabomba caroliniana is the only one of the five recognized *Cabomba* species known to have become naturalised in Australia.

Cabomba aquatica has been traded in the past in the aquarium industry in Australia, and the weed risk it poses is currently under assessment.

Cabomba furcata is known as pink cabomba and is legally sold in some States of Australia as an aquarium plant. It is not known to be occurring naturally in any waterways in Australia and is not considered to pose a significant weed risk. Pink cabomba has distinctive pink leaves and stems, although large parts of the stems and leaves can be green, with bright pink or



Pink cabomba is sold as an aquarium plant.
Copyright Aqua Botanic

Phil Moran

Brasenia schreberi is native to Australia.

reddish-pink growing tips. Flowers are purple with yellow centres.

Cabomba palaeformis and *Cabomba haynesii* are both cultivated for the aquarium trade overseas. They are not known to be currently traded or naturalised in Australia.

The current definition of *Cabomba caroliniana* includes the previously separate species *Cabomba australis* (creamy white flowers) and *Cabomba pulcherrima* (purplish or purple-tinged flowers with darker veins), and a number of natural and horticultural varieties.

Differentiation between cabomba species is best done on the basis of seed characteristics.

The genus *Brasenia* consists of one species, *Brasenia schreberi,* which is native to Australia and is found worldwide, except in South America.

Other names for cabomba

The word 'cabomba' is thought to be an indigenous American word meaning 'aquatic plant'. Cabomba is also referred to as water fanwort, fanwort, Carolina water-shield, purple fanwort, fish grass, Washington grass, and cabomba de Caroline.

Similar-looking plants

A number of other submerged aquatic plants in Australia (both native and introduced) can be mistaken for cabomba, particularly when viewed looking down into the water from above. However, on close inspection cabomba can be easily distinguished.

Ambulia *(Limnophila spp.)*

There are a number of native and introduced ambulias (various *Limnophila* species) that can look very similar to cabomba. However, ambulia leaves are always arranged in whorls around the stem. Some leaves are emergent, and these are darker green and broader. The submerged leaves are finely divided and feathery. Ambulias have solitary, small, blue, pink or violet flowers in the leaf axils.

Hornwort *(Ceratophyllum demersum)*

Hornwort is usually free-floating, but it sometimes takes root loosely in the substrate. Its submerged leaves look similar to those of cabomba as they are dissected and appear feathery, but are always arranged in whorls around the stem. Each leaf is dissected or

Sue Hayward

Other plants can be mistaken for cabomba when viewed from above: cabomba is on the left and ambulia is on the right.

Andrew Petroeschevsky

▲ *Ambulia can look very similar to cabomba.*

► *Ambulias have a larger blue or violet flower.*

Andrew Petroeschevsky

Rohan Wells

Hornwort has dissected leaves arranged in whorls around the stem.

Graham Prichard

Hornwort leaves are forked rather than finely dissected and feathery.

NSW DPI

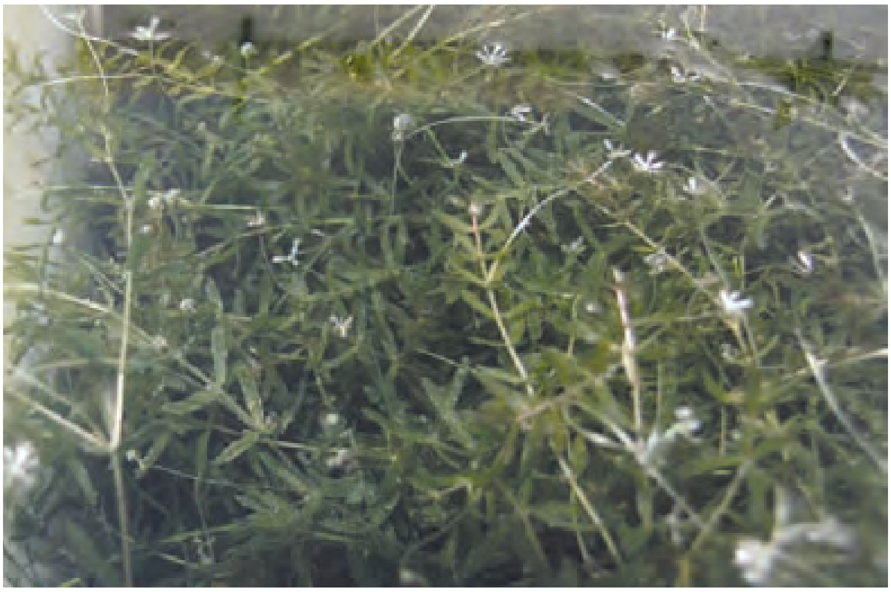
Egeria leaves are not dissected and feathery.

Sue Hayward

◄ *An egeria infestation can look like cabomba from a distance.*

► *Elodea leaves are not dissected and feathery.*

NSW DPI



Hydrilla leaves are not dissected and feathery.

'forked' only two to four times, whereas cabomba has many more dissections per leaf. Fine forward-pointing teeth are also visible with the naked eye along the sides of each leaf division. Hornwort does not produce the masses of emergent flowers that cabomba does, nor does it have any form of floating leaves. Hornwort is native to mainland Australia.

Egeria, leafy elodea or dense waterweed *(Egeria densa)*

Egeria is common and often confused with cabomba when looking at an infestation from a distance. Like cabomba it has white flowers that are held above the surface of the water. However, on close inspection it is easily distinguished from cabomba as the leaves are not dissected and feathery but are entire and up to 4 centimetres long, occurring in whorls of four or five along the stem, and the flowers have only three petals.

Elodea *(Elodea canadensis)*

Elodea can also look similar from a distance, but on close inspection it has leaves that are not dissected and feathery, occurring in whorls of three along the stems. The flowers are very small (5 millimetres in diameter) and inconspicuous. They float in or on the water surface attached to long, white, thread-like stems.

Hydrilla *(Hydrilla verticillata)*

Hydrilla is a submerged aquatic plant that can look similar to a cabomba infestation under the water. The leaves are not feathery (dissected), but they have slightly toothed margins and occur in whorls of three to eight on the stems. Hydrilla is native to mainland Australia.

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M. Kean

▲ *Control options are limited for large infestations.*

▼ *Shading, drawdown and manual removal are feasible in small infestations.*

Phil Moran

Part 2: Managing cabomba

Introduction

The current management of cabomba in Australia is restricted by the lack of effective registered herbicides and biological control agents. Many infestations that would be appropriate for management and possible eradication with herbicides and/or biological control have to be managed by other methods such as mechanical removal, manual removal, shading and drawdown (see the relevant sections following). Limited herbicide use is carried out under minor-use permits (see the *Herbicides* section on page 34).

Unless infestations are small and control is possible through methods such as shading or drawdown, the aim of management is generally to reduce the cabomba biomass; keep particular areas free of the weed; and prevent spread to other water bodies.

It is hoped that effective registered herbicides and active biological control agents will soon be available for cabomba control in Australia.

The major cabomba infestations in Australia are currently managed according to local considerations and available control methods. The following five pages contain examples of current cabomba management strategies in Australia. Further information is presented later in case studies.

Current and future management issues

The main restrictions to the current management of cabomba are the lack of an effective registered herbicide and biological control agent. Also, the practice of aquatic revegetation (see below) as an important follow-up measure is relatively new and is still being pioneered by those currently involved in cabomba management.

MANAGEMENT STRATEGY:

Ewen Maddock Dam, Southeast Queensland

Management of the extensive infestation in the Ewen Maddock Dam in south-east Queensland is restricted by negative public attitudes towards both herbicides and mechanical removal with harvesters. The cabomba management program aims to:

- perform intensive, selective manual removal in a number of high-priority exclusion zones (including swimming areas) by using diver-operated suction dredging
- follow up in exclusion zones with monitoring and revegetation using native aquatic plants, with trials of the best methods of aquatic revegetation (i.e. using jute matting impregnated with aquatic species)
- use drawdowns wherever possible to strand cabomba above the high water mark
- prevent spread by using earth bunding planted with thick reed beds at overflow and outflow points
- maintain public signage at all access points
- provide washdown facilities for canoes and trailers at boat ramps and launching sites.

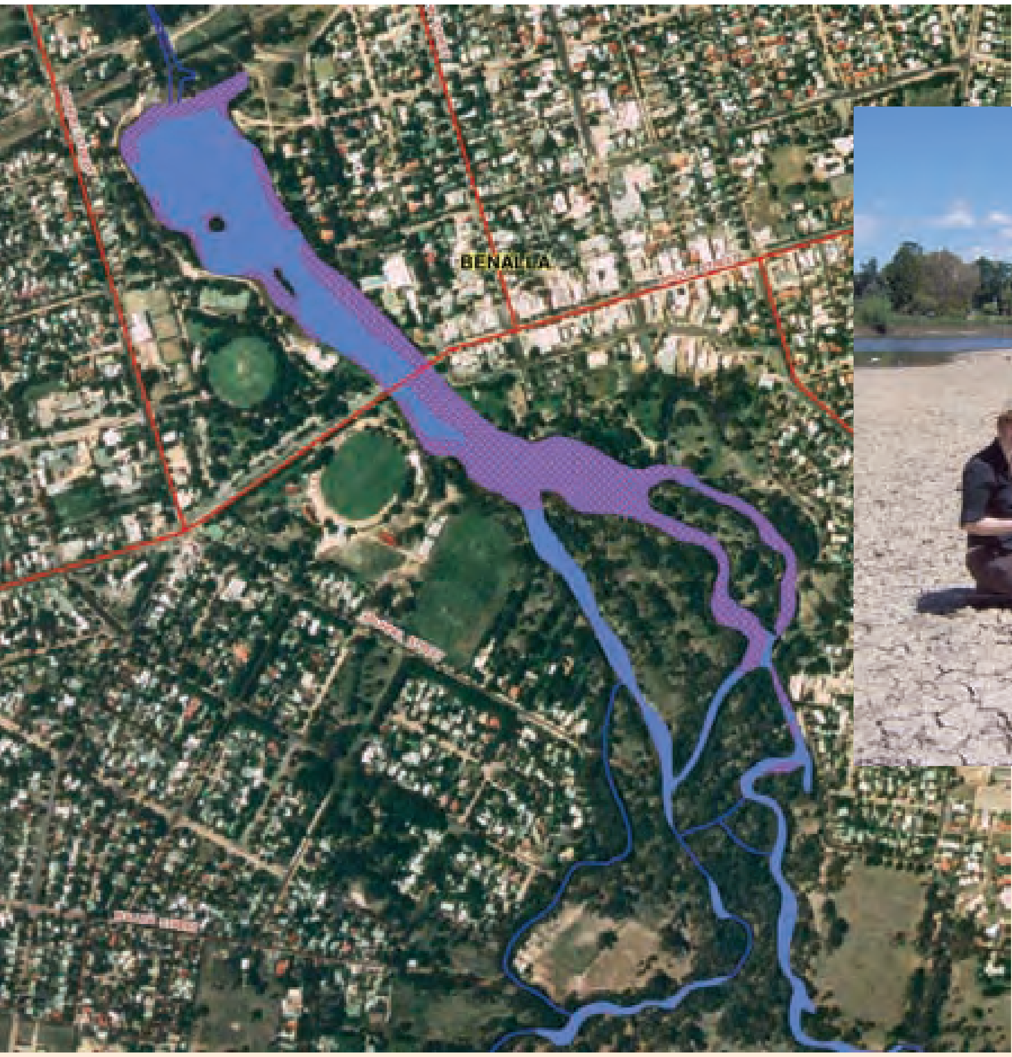
(See Case Study: Diver-operated manual removal in Ewen Maddock Dam, south-east Queensland for further information.)

Russell Rainbird

Selective mechanical removal of cabomba

Purpose-built plant for selective manual and mechanical removal of cabomba in Ewen Maddock Dam

Russell Rainbird



Benalla Rural City Council

Drawdown in the hottest part of summer is integral to the cabomba management strategy.

Comprehensive mapping and monitoring are carried out each year.

MANAGEMENT STRATEGY:

Lake Benalla, Victoria

After a full risk assessment of all the available control methods, and after a history of repeated drawdowns to control cabomba for periods of 2 to 3 years, a more integrated management strategy has been devised for the cabomba infestation in Lake Benalla. It includes:

- drawdown of the lake in the hottest part of summer, with repeat drawdowns every 2 to 3 years, taking into account irrigation needs and fauna-breeding seasons
- isolation and drawdown of channel sections of the waterway using earthworks and pumps
- spraying of exposed cabomba with aquatic glyphosate under an APVMA (Australian Pesticides and Veterinary Medicines Authority) permit (during a drawdown)
- use of suction dredging to remove cabomba that remains in shallow pools of water during drawdowns
- hand-pulling in new, small areas of cabomba growth
- revegetation with native aquatic plants
- a hygiene and education campaign
- comprehensive mapping and monitoring of the distribution of cabomba each year
- restriction of use of the lake to permitted uses only.

(See Case study: Drawdown in Lake Benalla, Victoria for further information.)

MANAGEMENT STRATEGY:

Lake Macdonald, Southeast Queensland

Management of the extensive cabomba infestation in Lake Macdonald has been restricted over time by the decision to avoid the broadscale use of herbicides in the lake, which is a local water supply storage and a highly valued environmental asset. Cabomba management aims to:

- carry out ongoing suppression of cabomba in the lake by using a mechanical harvester in two priority areas (only 1/20th of the lake's area)
- prevent spread to other water bodies through harvesting close to the spillway and offtake areas; through education and awareness campaigns; and through the provision of washdown facilities for recreational water users
- use mechanical removal to allow an area of the lake to be used for aesthetic and recreational purposes, without the public safety concerns of entanglement and drowning created by cabomba
- eradicate all small outlying infestations in the catchment (*see Small outlying infestations, Lake Macdonald Catchment, southeast Queensland*)
- improve riparian vegetation in all parts of catchment to create higher levels of shade
- reduce nutrient levels in the lake through restriction of livestock access.

(See Case study: Mechanical removal in Lake Macdonald, south-east Queensland for further information.)

Queensland DPI&F

Mechanical harvesting is done in two priority areas.

Public safety concerns of entanglement and drowning are posed by the cabomba biomass.

Andrew Petroeschevsky

Phil Moran

Noosa & District Landcare have undertaken shading trials on small outlying infestations.

Phil Moran

Revegetation is a follow-up measure after shading.

MANAGEMENT STRATEGY:

Small outlying infestations, Lake Macdonald Catchment, south-east Queensland

The management strategy for the 8 to 10 outlying cabomba infestations in the Lake Macdonald Catchment is:

- eradicate all small and isolated infestations (currently under way using shading , manual removal and revegetation)
- undertake early detection surveys across the catchment every 6 months to detect new outlying infestations
- consider the appropriate use of herbicides in future for infestations that are not in potable water supplies
- install containment measures where possible
- implement public awareness programs, including aquatic weed identification training
- use signage and fencing to restrict public access to isolated infestations where possible.

(See Case study: Floating blankets on a small dam at Kin Kin, south-east Queensland for further information.)

MANAGEMENT STRATEGY:

Darwin River, Northern Territory

The infestation in the Darwin River in the Northern Territory is subject to the Cabomba Eradication Program, devised by a multi-agency/stakeholder Taskforce in 2004 and aiming to:

- eradicate the existing cabomba infestation (given the previous successful eradication of cabomba in Marlow Lagoon and the relatively limited extent (less than 1 hectare) of the infestation
- quarantine the area of the Darwin River under management
- conduct a public awareness program
- conduct regular surveillance for new infestations
- apply herbicide under APVMA permit and with careful planning to avoid contamination of river water, estuary water and ground water and negative impacts on surrounding fauna (see *Suspension of use of 2,4-D herbicides* section below)
- carry out shading to hinder flower and seed production
- carry out drawdown in small billabongs and follow up with shading.

Extensive water-quality testing is carried out to ensure that herbicide residues are within acceptable limits. Herbicide applications are made only in the dry season when flow is minimal. In areas close to estuaries bund walls have been built to contain treated water until residue levels are undetectable. Where the river provides residential water supplies, alternative water supplies are arranged with residents before the herbicide applications.

Steve Wingrave

Herbicide applications are essential to the cabomba eradication program in the Darwin River.

Markers are placed at sites where regrowth cabomba has been spot sprayed to allow for monitoring.

Steve Wingrave

Containment and prevention of spread

Cabomba fragments spread easily in the water and are also commonly spread from one water body to another by human activities. Stems and fragments are easily caught on boats, trailers, propellers, fishing nets and tackle, canoes and other watercraft and equipment. Introduction to a waterway through the dumping of aquarium water is another major issue. These vectors are managed through the use of containment measures such as booms and reed beds; restrictions on the use of a water body through quarantines; and public awareness campaigns.

QDPI&F

Stems are easily caught on trailers and moved to other waterways.

Virginia Seymour

Dumping of aquarium water is a major issue.

Containment measures

Efforts can be made to restrict the movement of cabomba fragments in water. However, containment measures will be subject to damage or will not work in high flows, and they will generally require high levels of monitoring and maintenance.

Booms

Floating booms can be used to prevent the movement of floating fragments. Booms with hanging curtains are useful where flows are minimal.

Steve Wingrave

Floating booms prevent movement of cabomba fragments.

Curtain booms are effective where flows are minimal.
Far North Coast Weeds

John Spearpoint

Reeds such as Phragmites species can provide a barrier to the movement of fragments.

Steve Wingrave

Quarantine is an integral part of the Cabomba Eradication Program in the Northern Territory.

Phil Moran

Canoe washdown facilities can be installed where cabomba is present.

Reed beds

Reed beds (using thick plantings of reeds, rushes or banks of similar vegetation such as *Lomandra*) have proven successful as a barrier to the downstream movement of cabomba fragments. A series of three reed beds with retention ponds in between has allowed for constant monitoring and containment of cabomba fragments moving downstream of the Ewen Maddock Dam spillway.

Reed beds or other types of containment barriers (mesh screens; shadecloth fencing) are best installed across outflows, overflows, drains, channels, spillways, causeways or culverts.

Prevention of spread

A number of measures can be taken to reduce the spread of cabomba by humans or animals.

Quarantine

Quarantine can be a critical component of a management strategy, particularly when eradication is the objective.

In order to support eradication and minimise the chance of spread, the infested section of the Darwin River was placed under quarantine in November 2004. The quarantine order prohibits the movement of people or any object (including boats, vehicles and fishing equipment) into or out of the quarantined section of river and the 5 metres of land adjacent to the water's edge, unless under permit from the Department of Natural Resources, Environment and the Arts. Vehicles are not to pass over causeways in the quarantine area if the river is flowing over the causeways. Non-compliance is an offence with a maximum penalty of $50,000 for individuals and $250,000 for a body corporate.

Hygiene

Information about cabomba and washdown facilities should be available at all public access points to waters with cabomba infestations. Boat and canoe hulls, propellers, scoops, trailers, harvesters, diving gear and any other equipment used for recreation, water management or cabomba control should be washed down and checked thoroughly before leaving an infested area.

Animal movement

In some situations preventing animals (such as feral pigs and cattle) from entering infested waters will also help to minimise spread of fragments.

Public awareness

It is important that as many people as possible are aware of cabomba. High levels of awareness will help

Public awareness helps prevent the spread of cabomba.

Daniel Stock Phil Moran

Phil Moran

Signage can help to raise public awareness.

Jessica Grantley

▲ *Aquatic weed identification training is the first step towards early detection of infestations.*

▼ *Aquatic weed identification and early detection training materials are available from NSW DPI.*

Jessica Grantley

prevent spread caused by the dumping of aquarium water and the movement of fragments on watercraft and trailers. It will also help in early detection of new infestations.

Awareness can be raised through information days; quarantine or warning signs; notices posted in public places (shops, service stations); advertisements in local newspapers; mailouts in relevant areas; brochures and information for distribution to industry outlets (bait and tackle shops, pet shops, nurseries); water managers (protected-area staff, council staff, researchers, Landcare groups, Waterwatch groups); and water users (nature-based clubs, fishing clubs, canoeing clubs or businesses).

Early detection

Regular monitoring of uninfested areas and water bodies close to known infestations will help in the early detection and possible eradication of small, new infestations. Good public awareness campaigns and aquatic weed identification training will lead to early detection of infestations.

Herbicides

There are currently no effective registered herbicides for use on cabomba in Australia. Diquat herbicides are registered but are not considered highly effective (see Diquat 200 g/L section below). 2,4-D n-butyl ester was registered and effective against cabomba, but its use is currently suspended (see Suspension of use of 2,4-D herbicides below). Research is currently under way to support new herbicide registrations for use against cabomba in non-flowing water, and future research hopes to support the development of a herbicide for use in flowing water.

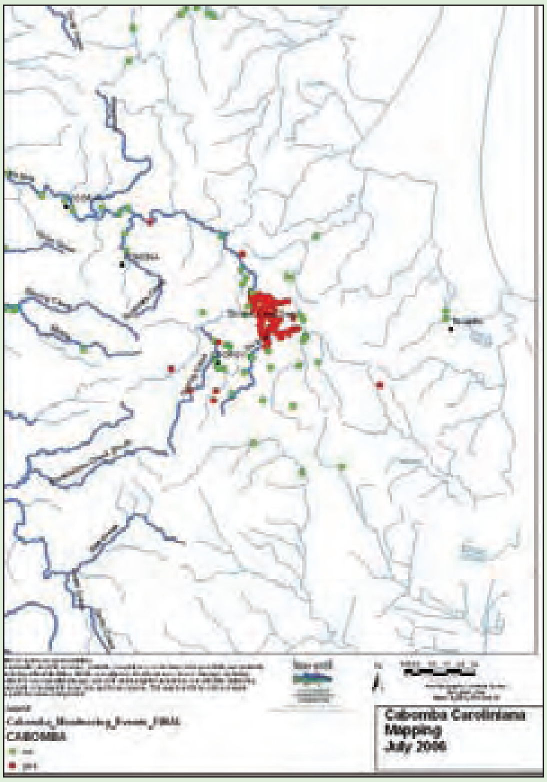
Andrew Petroeschevsky

This cabomba infestation was reported by a person who had attended an Aquatic Weeds Identification Workshop in Grafton.

Cabomba early-detection surveying

Noosa & District Landcare in conjunction with Sunshine Coast Regional Council and the Mary River Catchment Coordinating Committee devised a method of using concentric circles radiating out from each cabomba infestation in the Lake Macdonald catchment to identify bridge crossings, picnic parks, and boat- and canoe-launching areas. This process took half a day to map out and half a day of ground checking to ensure all the potential sites of cabomba introduction and spread had been highlighted. These priority areas are checked at least every 6 months. One new cabomba infestation has been detected at Maryborough as a result of the community aquatic weed identification training and early detection program.

Red dots show the presence of cabomba.
Mary River Catchment Coordinating Committee



Green dots show sites at high risk of cabomba introduction. These are regularly checked and have no cabomba.
Mary River Catchment Coordinating Committee

Elissa van Oosterhout

Research is currently under way to support new herbicide registrations for cabomba.

Suspension of use of 2,4-D herbicides

Control with 2,4-D n-butyl ester has been the only method that has achieved successful eradication of a large cabomba infestation in Australia (Marlow Lagoon in the Northern Territory). A 2,4-D-n-butyl ester herbicide product (Agricrop Rubbervine Spray®) was registered for use on cabomba in Australia, but it is no longer generally available owing to the ongoing suspension and review of 2,4-D high-volatile esters by the Australian Pesticide and Veterinary Medicines Authority (APVMA) in October 2006.

2,4-D-n-butyl ester is an important component of the Cabomba Eradication Program in the Darwin River in the Northern Territory. Since the suspension, the Northern Territory Government has been able to continue the use of this herbicide under APVMA permit PER11145, Expiry 30.11.11.

The APVMA advises that it may consider issuing minor use permits for the use of 2,4-D-n-butyl ester to control cabomba. Permit applicants need to provide appropriate data (e.g. area to be sprayed, amount of chemical to be used, presence of potable water or irrigation intakes, physical details of the water body) and include risk-mitigation strategies to address identified risks to a) protect crops and off-target plants and b) protect water quality by managing the environmental contaminants (see '2,4-D High Volatile Ester Permits – Background and Criteria' on the APVMA website at www.apvma.gov.au for details). Risks to crops and off-target plants would be mitigated through the application of this herbicide by subsurface injection with diatomaceous earth (see *2,4-D-n-butyl ethyl* section below).

2,4-D-n-butyl ester

2,4-D n-butyl ester herbicide is used in a suspension of diatomaceous earth in water and is applied to underwater stems through submerged nozzles on hand-held or boat-mounted booms. Diatomaceous

Steve Wingrave

Herbicide control in the Northern Territory has achieved a high level of cabomba suppression. With continued use the aim is to eradicate cabomba altogether.

Steve Wingrave

Steve Wingrave

Herbicide is applied via submerged nozzles in a suspension of diatomaceous earth in water.

Tom Anderson pioneered much of the aquatic herbicide screening for cabomba in Australia.

Andrew Petroeschevsky

earth is a light silica soil that absorbs the chemical and makes it less mobile, increasing contact with the target plants and minimising off-target effects.

Note: This herbicide is currently under suspension and may be used only for cabomba control under a minor-use permit issued by the APVMA (see *Suspension of use of 2,4-D herbicides* above).

Diquat 200g/L

Diquat is a non-selective contact herbicide that causes rapid desiccation of broadleaf weeds. Because of their general registration for use against pond weeds, diquat herbicides may be used on cabomba. However, diquat has a minimal effect on cabomba; anecdotal reports and field trials of diquat in Hydrogel® (see below) show that diquat reduces cabomba infestations by about 50%. This reduction is likened to 'giving the cabomba a haircut', because the lower halves of most stems are left viable and regrowth therefore occurs rapidly, usually after a number of weeks. Diquat has, however, been rated good (out of good and excellent) for the ongoing treatment of cabomba infestations in Texas, USA.

Hydrogel®

Hydrogel® is a relatively new product in Australia. It is a guar-gum carrier product that is mixed with diquat 200 g/L. It is specifically designed to control submerged aquatic weeds, under APVMA Permit PER11030 (Expiry 07.09. 10).

When applied as a steady stream the gel and diquat mixture sinks and attaches to submerged weeds and the diquat is released into the surrounding water. The heavy nature of the gel prevents the diquat from being dispersed as it sinks in the water column and lands on target foliage. The guar gum is a non-toxic polysaccharide starch, which can be mixed on site to any viscosity and retains a constant viscosity at constant temperatures. The starch polymer is non-toxic and is dispersed in water. Hydrogel® can be applied into water by knapsack, hand gun and hose, boat-mounted boom, or helicopter-mounted boom.

The Hydrogel®–diquat mixture is less effective on cabomba than on other submerged aquatic weeds; this is thought to be related to a lower rate of retention of the gel on the fan-like cabomba leaves. Replicated trials carried out by NSW DPI have shown that treatments with the Hydrogel®–diquat mixture reduced the cabomba biomass by 47% twelve weeks after treatment. It is not known whether repeat treatments would achieve better levels of control (Officer D. NSW DPI Personal communication, March 2009).

Other herbicides trialled for use against cabomba

Many other herbicides have been screened or trialled for use against cabomba in Australia.

Research is still ongoing into safe and effective herbicides for cabomba and the best ways of delivering them to submerged aquatic plants (using delivery mechanisms such as gels and diatomaceous earths), and into ways of minimising any impacts caused by the use of herbicides in water.

Biological control

CSIRO

CSIRO is currently reviewing the weevil Hydrotimetes natans for use against cabomba in Australia.

CSIRO researchers are currently reviewing the weevil *Hydrotimetes natans* as a promising biological control agent for cabomba. The larvae of this weevil feed in the stems of cabomba and cause the plants to break down. Preliminary testing has shown the insect to be host specific, and it is now in quarantine and subject to the strict review process that assesses its potential impacts on Australian off-target species. It is hoped that if the insect passes the testing process it may be available for broadscale releases by 2010.

Regardless of the success of the current proposed biocontrol agent, further research continues in the home range of cabomba to find other agents that may be viable for use in Australia.

Aquatic revegetation

Revegetation with native aquatic plants has been performed after shading, diver-operated suction dredging and manual removal. Techniques for more successful aquatic revegetation have been tried, but the ability of revegetation to prevent further cabomba establishment has not been fully determined.

Various methods have been tried, including the use of jute matting impregnated with native plant seedlings.

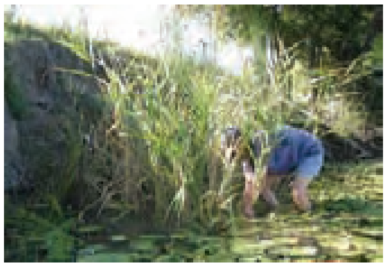
> *We found that water birds were eating the new seedlings, so we used a cage to cover newly planted areas. Then it worked and the plants got established.*
>
> **Russel Rainbird, National Cabomba Workshop, 2007**

Plants are generally propagated from locally collected seed in a nursery and then planted out in shallow water. Plants need protection from birds and other disturbances, including even very low levels of wash from boats.

Shon Schooler

Further biocontrol research continues in the home range of cabomba in South America.

Techniques for successful aquatic revegetation are under development.



John Spearpoint

Species should be restricted to endemic (locally occurring) native water plants. Landcare or Catchment Management groups may have local species lists. Species that have been tried in various regions for aquatic revegetation include:

Lepironia (and other rushes that are members of the Cyperaceae family)

Phragmites australis (common reeds)

Brasenia schreberi (watershield)

Ceretophyllum demersum (hornwort)

Isolepis fluitans (floating clubrush)

Myriophyllum species (milfoils)

Nymphoides crenata (wavy marshwort)

Potamogeton crispus (curly pondweed)

Triglochin procerum (water ribbons)

Charophyta (stoneworts)

Philydrum lanuginosum (frog's mouth)

Nymphoides indica (snowflake)

Baumea rubiginosa (soft twigrush)

Vallisneria (ribbonweed).

John Spearpoint

Aquatic plants ready for planting out

The Noosa & District Landcare Nursery aquatic revegetation propagation area

Phil Moran

Growing frog's mouth (Philydrum lanuginosum) from seed

Phil Moran

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Noosa & District Landcare

Shading can be used over small areas (less than 1 hectare in surface area).

Steve Wingrave

Edge shading is used to reduce flowering in the Darwin River.

Part 3: Shading

High levels of shade are known to kill cabomba. Restriction of sunlight over a period of 3 or 4 months causes cabomba to die, with higher levels of cabomba mortality achieved in less time with higher levels of shade.

Recent shading research (Schooler 2008)

Shade created with a 99% light-blocking floating blanket (blocks out 99% of light) reduce cabomba biomass at depths of 1 to 3 metres to 10% within 60 days and to 0% within 120 days. No live cabomba material remained in the sediment.*

Shade created with a 70% light-blocking floating blanket reduced cabomba biomass at depths of 2 to 3 metres. It did not reduce cabomba biomass at a depth of 1 metre. A shade level of 70% was created to represent that provided by a moderate amount of riparian vegetation containing trees and shrubs.*

**(Data were not collected at depths of less than 1metre.)*

Simulated shading trials (NSW DPI)

In simulated shading trials carried out by NSW DPI, black plastic was used to create shade over cabomba growing in 100-litre plastic tubs. Wherever 100% shade was maintained, 100% kill rates resulted 1 month after treatment. Where minute amounts of light were able to enter, very small amounts of cabomba remained viable and capable of regrowth. These trials have shown that shading is able to achieve 100% kill rates if all light can be excluded for at least 1 month. Where it cannot be guaranteed that all light is excluded, shading should be used as part of an integrated control program and kept in place for at least 2 months.

As a control method, shading can be used to suppress and possibly eradicate small cabomba infestations less than 1 hectare in surface area (i.e. small farm dams or public ponds). Costs and logistics generally prohibit the use of constructed shade on a large scale.

Shading can be used to create clear areas in dense cabomba; allowing better management of irrigation, recreation, or revegetation in infested areas. Shade can also benefit by reducing flowering and seed set where cabomba is known to produce viable seed.

Two types of shading can be constructed over a cabomba infestation: floating blankets and benthic blankets. Riparian vegetation will also provide some degree of shade, and water dyes have also been used to restrict light penetration, but with less effect for cabomba control. Floating blankets have been tried a number of times with success in Australia (see *Case Study: Floating blankets on a small dam at Kin Kin, south-east Queensland* below).

Floating edge blankets are used in the Darwin River in the Northern Territory.

Steve Wingrave

Benthic blankets are not used commonly in Australia. They are used more routinely for aquatic weed control in the USA to create access for swimming in lakes and dams and along residential canal estates. In the USA they have been used to successfully eradicate small infestations of other submerged attached aquatic weeds (elodea and milfoil) over areas that were too extensive for manual removal.

Floating blankets

The most commonly used floating blankets for cabomba control in Australia have been constructed in-house from builders' black plastic. Builders' black plastic completely excludes light, giving 100% shade. Successful small-scale trials have used pool covers, but these are expensive (see below).

A floating blanket must prevent light from entering the water. Lengths of rope or cable need to be attached along the edges to allow it to be secured and to keep the edges afloat on the water surface.

If a floating blanket is being installed over a section of water (i.e. along edges of an infestation or when treating sections of a larger water body), hanging side-curtains must also be installed. Side-curtains must block all light that can enter through the water column from adjacent unshaded areas. Side-curtains have been made out of black plastic and attached to the rope-reinforced edges of the blankets with cable ties at 50-centimetre intervals.

Floating blanket in use near Cooroy in south-east Queensland

Phil Moran

A floating blanket constructed from builders' black plastic

Phil Moran

Lengths of rope or cable are stitched along the edges.

Side curtains need to be attached if using shading to control edge infestations.

Steve Wingrave

Pool covers

Pool covers (solar blankets) have been used in trials to shade small patches of cabomba (5 × 5 metres). These were anchored with star pickets and had polystyrene foam buoys added to the corners. Black plastic side-curtains (1 metre) were attached to the edges of the pool blanket with cable ties every 50 centimetres. This method achieved complete kill of cabomba (including fragments in the sediment) after 120 days. The pool blanket was opaque and gave 99% shading (Schooler 2008).

Because of their effectiveness, pool blankets have been considered for larger trial areas (100 × 50 metres). However, the cost of $58,500 for a blanket of this size (price obtained in 2007) or $11,700 for a 100 × 10 metre blanket was prohibitive. Black plastic was used instead.

Floating blankets can be secured with star pickets or steel rods driven into the substrate in the corners and along the edges of the plastic.

Advantages

On a small scale and with ongoing follow-up, shading with floating blankets can drastically reduce biomass. It may be able to eradicate cabomba if complete shade can be achieved, or if follow-up control is able to remove all regrowth.

Disadvantages

Shading will alter the physical and chemical environment by reducing dissolved oxygen levels, increasing carbon dioxide levels and reducing pH (Schooler 2008). In trials in south-east Queensland, the presence of two dead fish and one dead eel raised enough public concern to cause a shading trial to be abandoned.

Steve Wingrave

Floating edge blankets successfully reduce flowering in the Darwin River, contributing to the Cabomba Eradication Program.

Floating blankets present a drowning hazard and public access must be restricted.

Phil Moran

Constructing and maintaining shade requires effort and dedication. Steve Wingrave Phil Moran

Floating blankets present a drowning hazard. In any site it is important to restrict public access.

Constructing and maintaining shade over small areas is physically difficult and requires effort and dedication.

Constructing shade over larger areas (i.e. greater than 1 hectare) is generally cost prohibitive and physically difficult.

Floating blankets need to be in place for a length of time (usually 3 or 4 months) to achieve high mortality rates and little or no regrowth. Floating blankets need to be checked regularly and repairs are often needed.

Repairs are often needed. Steve Wingrave

Benthic blankets

Benthic blankets (also known as bottom screens, bottom covers, pond liners, benthic barriers) sit over the substrate at the bottom of a water body, both compressing aquatic plants and blocking out sunlight.

Bottom blankets need to be durable and light blocking. Materials such as burlap (hessian), PVC plastics, felt-like polyesters and woven synthetics have been used as bottom blankets (plants can grow through woven fabrics or easily take root from above). Commercially made benthic blankets are produced in the USA and Canada for the purpose of aquatic weed control. Products such as fibreglass 'stabilising paper' used in road construction have also been tried successfully.

Benthic blankets will accumulate layers of sediment on top where fragments of aquatic plants, including cabomba, can take root. Depending on the water turbidity and flow rates, sediment can build up quickly (i.e. in 2 or 3 weeks) and has been known to accumulate to a depth of over 40 centimetres within a single growing season. In sites where benthic blankets are installed, resources are usually made available for regular removal of sediments or recolonising plants (usually by SCUBA divers), particularly when the blankets are used to treat only a section of a cabomba infestation.

Underwater view of the edge of a benthic blanket installed over a submerged aquatic weed infestation in the USA © AquaTechnex

A geo-textile benthic blanket ready for installation in a Pacific Northwest Lake in the United States © AquaTechnex

Layers of sediment will build up on top of benthic blankets. © AquaTechnex

Blanket secured to bottom with sandbags © AquaTechnex

Blankets must be strongly secured to the bottom. Rocks, sandbags and concrete blocks can be used to anchor the blankets. Poorly maintained anchors and unsecured blankets can create safety hazards for swimmers and navigation.

Gases can build up underneath blankets, causing them to lift. Very small longitudinal slits can be cut to allow gases to escape, but this may allow small amounts of light to reach the bottom. Even very porous materials will billow because of gas build-up underneath. Some specifically made semi-permeable American products allow gases to permeate, but they eventually become clogged by debris and micro-organisms. This has been addressed by using PVC or timber frames to allow the blanket to sit a small distance above the substrate, still effectively blocking light but allowing gases to escape.

Install blankets in winter, when aquatic plants are more prostrate. If growth is tall, the cabomba canopy needs to be reduced before the blanket is installed. More gas is produced under blankets that are laid over the top of large amounts of plant material.

Advantages

Benthic blankets can kill plants within 1 or 2 months.

Benthic blankets are most appropriate for small dams or ponds where the entire bottom can be covered, thereby reducing re-colonisation on top of the blanket by floating cabomba fragments.

Benthic blankets may be useful as a follow-up measure after treatments with herbicide, floating blankets, riparian shade or physical removal have been used to suppress an infestation, particularly in areas where cabomba is thought to be producing viable seed.

Disadvantages

Benthic blankets require ongoing maintenance to prevent sediment build-up; recolonisation by cabomba fragments; gas build-up and billowing; breakdown of the blanket itself; and dangers to swimmers and boaters created by poorly anchored blankets or the anchoring structures themselves.

Benthic blankets can have impacts on invertebrate populations and fish spawning.

The need to reduce the height of the canopy before installing a blanket limits the economy of this control method.

Experience in Australia with benthic blankets for cabomba control is limited.

Benthic barriers for cabomba control in Canada

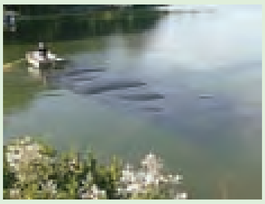
Benthic barriers were successfully tested on cabomba infestations in Kasshabog Lake in Ontario. Sheets (4m x 4m) of landscape fabric held down with bricks at the corners, with slits every 0.5 metres to allow release of gases, were positioned over stands of cabomba from September 2002 to May 2003. The benthic barriers blocked out almost all light and the result was the elimination of between 95% and 100% of the cabomba. Two months after removal of the blankets, cabomba had not recolonised the areas. The researchers concluded that the use of benthic blankets was a low-cost option for small, newly established cabomba infestations in the lake, or in sites subject to high-intensity use.

Lake Bottom Blankets in the USA

The Lake Bottom Blanket® is a commercially produced benthic blanket used to control submerged aquatic weeds, including Eurasian water milfoil, in Lake Luzerne in New York's Adirondack State Park. These benthic barriers block out light and do not rest entirely on the substrate, except where the blankets are held down by weight bars. Between the weight bars the blankets float above the substrate, shading out the aquatic weeds and allowing gases to escape and fauna to move underneath the blankets. The blankets are 3 metres wide and 12 metres long and are made of several layers of polyethylene. Tubes are built in to the sheets to hold the weight bars, and the tubes are placed in such a way that the decomposition gases are directed to patented release ports in the plastic. The blankets are intended to be used over a growing season, then removed and stored until the following season's use.

Information provided by Warren Grosjean, Lake Bottom Blankets, www.lakebottomblanket.com

Unfolded Lake Bottom Blanket®
© Lake Bottom Blanket



Installing a Lake Bottom Blanket®
© Lake Bottom Blanket

Light area shows where Lake Bottom Blanket® is installed
© Lake Bottom Blanket

Steve Wingrave

When riparian vegetation is substantial, artificial shade is needed only along the shallower edges of the river.

Water dyes

Water dyes aim to reduce penetration of the kind of light that is necessary for plant growth. This method is effective only in ponded water bodies at depths over 1 metre. While waterdyes are relatively standard practice in the USA, there are no products registered for use in Australia.

Riparian vegetation

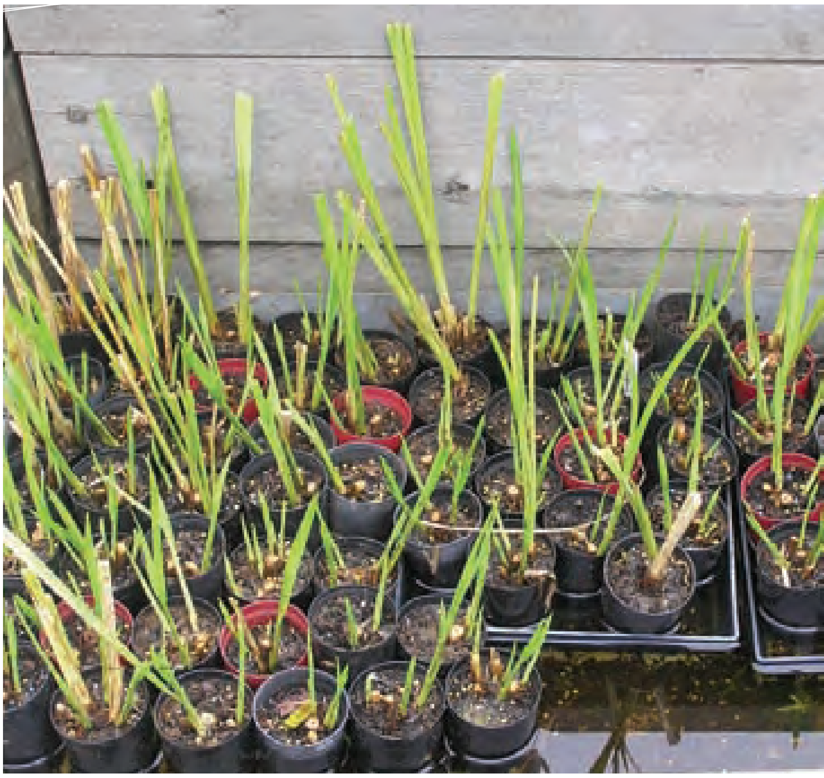
Riparian vegetation offers some degree of suppression, particularly along stream edges, where the water is generally slower flowing. However, cabomba is known to grow well at low light intensities.

In the Northern Territory cabomba is present along the edges of the Darwin River, even in areas with relatively substantial riparian vegetation. However, the shade cast by the riparian vegetation may be enough to prevent cabomba from becoming established in the deeper parts of the river, supporting research that showed that 70% shade (equivalent to that cast by healthy riparian vegetation) restricted cabomba at depths of 2 to 3 metres, not at depths of 1 metre.

Aquatic revegetation after shading

Areas should be revegetated with appropriate aquatic plants after any successful shading treatments and associated follow-up control have taken place. In areas cleared using benthic blankets, extensive populations of milfoil had become established within two growing seasons following the removal of the blankets.

In the USA, biodegradable blankets such as hessian have been used and left in place to allow sediments to build up in readiness for revegetation or recolonisation with native aquatic plants.



Local native aquatic plants propagated for revegetation after shading

Phil Moran

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Vanessa Moscato

Planting-out edge species

CASE STUDY:

Floating blankets on a small dam at Kin Kin, south-east Queensland

A successful shading trial was carried out on a private dam near Kin Kin in south-east Queensland by Noosa & District Landcare with funding assistance from the Australian Government and in cooperation with CSIRO. The dam is approximately 35 × 40 metres and was heavily infested with cabomba, with some small patches of waterlilies.

Making the black plastic blanket

Rolls of builders' black plastic were used to create the floating blanket. Rolls were 4 × 50 metres and therefore needed to be overlapped to create a complete light barrier. Nylon rope was stitched into the edge of each piece of plastic by using a 'bag stitcher' (a Portable Bag Sewing Machine from Ezypack® in Western Australia). The ropes were then used to secure each piece of plastic on the water surface, with some overlap. The sewing of the plastic was time consuming and tedious, but techniques improved with practice.

Installing the plastic on the dam

The plastic was positioned on the dam on 18 December 2007. This process took four staff and the landholder most of the day to complete.

Repairs needed

Heavy rains 2 months after installation caused the overlapped plastic to open. Some sections sank and light entered between the sheets. Repairs were made by using plastic zip ties to join the roped edges of the sheets back together.

A good result

The plastic was removed 3 months after the repairs were made by towing it off with 4WD vehicles. The results were very encouraging. Only three small patches of cabomba could be seen from the edge of the dam. These were manually removed and an underwater inspection showed that no other cabomba was visibly present in the dam.

The water was extremely clear when the plastic was removed, and water quality was acceptable with higher than expected levels of dissolved oxygen. pH levels also remained relatively steady during the trial.

The small dam is 35 × 40 metres

Phil Moran

Heavily infested with cabomba

Phil Moran

The sewing was time-consuming and tedious.

Phil Moran

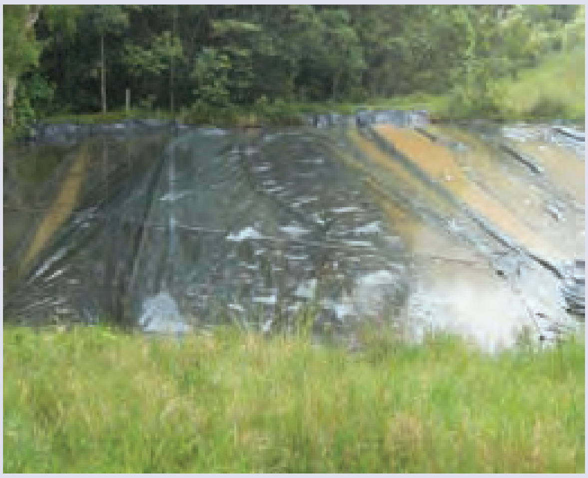
A bag stitcher was used to sew rope into the edges of the plastic.

Phil Moran

Sheets were overlapped to create a complete light barrier.

Phil Moran

Plastic was positioned on the dam in December 2007.



Phil Moran

Heavy rain caused the overlaps to open.

Plastic zip ties were used to join the roped edges back together.

Vanessa Moscato

Phil Moran

Only three small patches of cabomba were found after the plastic was removed.

Phil Moran

Revegetation with native aquatic plants was carried out after the plastic was removed.

Plants for revegetation were grown by Noosa & District Landcare.

Revegetation

Revegetation with native aquatic and edge species was carried out in the weeks after removal of the plastic. The plants had been grown by Noosa & District Landcare specifically for this purpose. They included the following species:

- *Philydrum lanuginosum* (frog's mouth)
- *Nymphoides indica* (snowflake)
- *Lepironia articulata* (lepironia)
- *Baumea rubiginosa* (soft twigrush).

Surveys 8 months after the plastic was removed showed that all the plants were growing very well and water quality was excellent.

Monitoring finds regrowth

Monitoring was performed by the landholder and by Noosa & District Landcare and CSIRO to establish whether the shading trial had successfully eradicated cabomba from this site. Eight months after the removal of the plastic (January 2009) a small but solid patch (1.5 metres in diameter) of regrowth cabomba was found in the middle of the dam. Underwater survey using SCUBA and torches revealed that between 5% and 10% of the dam had become reinfested. Areas with dense leaf litter appeared to be free of cabomba regrowth.

Water quality analysis during cabomba shading trial – Kin Kin

	Start of trial 17.10.07	Mid-trial 24.01.08	End of trial 23.04.08
Dissolved oxygen (mg/L)	0.17	0.77	3.14
pH	5.76	5.69	6.29
Conductivity (mS/cm)	0.169	0.139	0.144
Turbidity (NTU*)	133	240	10
Temperature	18.34 (12.50 pm)	23.03 (8.20 am)	18.87 (9.30 am)
Nitrogen (mg/L)	0.1	0.2	0.2
Phosphorus (mg/L)	0.02	0.05	0.02

*NTU, nephalometric turbidity units

Phil Moran

A small patch (1.5 metres) of cabomba regrowth was found 8 months later.

Underwater monitoring will be ongoing.

Costs

Materials:

Star pickets	$ 315
Orange barrier webbing	$ 450
Floats	$ 450
Plastic	$1,400
Bag stitcher	$ 462
Ropes	$ 315
Miscellaneous (zip ties, wire etc.)	$ 120
Scuba boots	$ 108

Labour:

Volunteers (200 hours)	$0
Paid labour (40 hours)	$1,000
Supervisor (1 day/week × 6 months)	$8,000
Travel, communications and vehicles	$3,000
Admin support	$1,000
Total	**$16,620**

There are not many things that I would do differently ... however

- *the labour required to stitch the plastic together was more than we expected. Ideally you would have a large shed to spread the plastic out before sewing. We were able to press some of our regular volunteers into service. However, it was a difficult and time consuming task.*
- *the cost of rope that was robust enough to be tensioned was higher than anticipated.*
- *the problem of the plastic separating is a tough one. Maybe we should have used a canoe and paddled out as each width of plastic was moved into place, and zip-tied them together. We tried to overlap each width of plastic to minimise this need and also to make sure that light did not enter through the joins.*
- *one of the problems with the zip-tying was that it made removal very difficult … hence the 4WD vehicles. The plastic had a large amount of algae growing on it, which increased the weight.*

It has been logistically difficult, and at times frustrating, but ultimately proved the hypothesis that exclusion of all light will kill cabomba.

Phil Moran, Natural Resource Manager, Noosa & District Landcare, 14 August 2008

Conclusion

Although this was a difficult exercise and regrowth did occur after 8 months, this technique did reduce the biomass by at least 95% and is a viable approach to biomass reduction, particularly in combination with low-volume herbicide treatments (when herbicides become available).

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CASE STUDY:

Benthic blankets in Lake George, USA

Water milfoil in a protected lake

In 1998, Lake George, an 11 330-hectare lake in the Adirondack Park protected area in the State of New York, contained 127 dense but isolated infestations of Eurasian water milfoil (*Myriophyllum spicatum*), a submerged, attached aquatic weed with growth habits similar to those of cabomba. Herbicide use is not authorised in the Lake, and various other physical control strategies had been tried, including suction harvesting, but by 2004 the number of infestations had increased to 148 despite control efforts.

Benthic blankets trialled in 2004

Benthic blankets were introduced to the integrated management program for Lake George and in 2004 approximately 3855 square metres of Palco® pond-liner panels were installed. The panels are negatively-buoyant polyvinyl chloride (PVC) material 20 millimetres thick and cut to 2.1 × 15.2 metre panels. Panels are overlapped with adjacent panels and weighted down with steel bars. Routine inspections allowed panels to be checked, cleaned where possible and repaired as needed, including repositioning panels to close gaps, venting trapped gases, and moving and installing additional weight bars where necessary.

Of the 148 sites under treatment, 64 were completely clear of milfoil after use of the benthic barriers, and 56 more were clear after small amounts of recolonisation had been removed by hand after removal of the barriers.

The Lake George Park Commission concluded that benthic barriers were an effective management strategy, particularly when infestations are scattered. When integrated with hand harvesting the control effort cleared significant portions of the lake bottom. It was realised that active annual maintenance was necessary to prevent regrowth and recolonisation of cleared areas, but the use of benthic barriers had been pivotal to the management of the milfoil in the lake.

Benthic blankets as an ongoing management tool

By 2007 the Lake George management program had increased the number of person-hours spent on milfoil control with benthic barriers from 560 in 2004 to 1514, yet the average number of person-hours spent installing and maintaining each panel had decreased from 4 to 3 over that time. In 2007 a total of 1.58 hectares (487.25 panels) of benthic barrier was installed across 15 new sites, giving a total of 160 known sites under management with a combination of

© AquaTechnex

Many other lakes in the Pacific Northwest of the United States have used benthic barriers against water milfoil infestations.

A section of benthic blanket installed over water milfoil

© AquaTechnex

Over time water milfoil sites are reduced through the use of benthic barriers.

benthic barriers and hand removal. By the end of 2007 there were only 22 sites requiring future management efforts.

The Commission has found that the use of hand harvesting in conjunction with the benthic barriers is more cost effective than the use of suction harvesters alone. Suction harvesters have not been used on the lake since 2003. Management of water milfoil with benthic barriers and hand removal will be ongoing, because some infested areas are not suitable for physical control. It is expected that there will always be milfoil in this vast lake.

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Part 4: Drawdown

Introduction

Drawdown is a method of managing aquatic weeds by draining or lowering a water body for a period of time. Drawdown is possible only where water levels can be controlled through pumping or outflow—usually only in water storages, reservoirs and dams. Natural lakes, ponds and billabongs are less appropriate sites for drawdown; they could suffer significant ecological impacts and are less practical for achieving drawdown.

To control cabomba it is necessary to completely drain a water body and allow the substrate to dry out, in order to destroy (though drying) all the vegetative parts of the cabomba plants, including the roots. If the soil remains damp there is a greater than 50% chance of cabomba surviving and re-establishing. Even if the soil is completely dried, there is a chance that some cabomba will survive. This risk is reduced if drawdown is done when temperatures are at their extremes, in summer and winter.

High risk of spread

Drawdown for cabomba management should be considered only where the risks of spreading cabomba fragments in the pumping out or outflow of water can be minimised. In catchments where cabomba is not present downstream of the proposed drawdown site, the risks of spreading the infestation are high. In these

Benalla Rural City Council

Drawdown is used to suppress cabomba in Lake Benalla.

Benalla Rural City Council

Substrates must become completely dry to destroy cabomba.

Benalla Rural City Council

Water-filled depressions that remain after drawdown provide refuge for cabomba.

cases any water that is pumped or drained must be either:

- moving downstream to areas where salinity levels are high enough to prevent further establishment of cabomba, or
- pumped onto dry land, where there is no risk of backflow into uninfested water bodies.

Earthworks to enable drawdown

In some situations, sections of a water body can be isolated from the main water body through earthworks to enable a drawdown to be performed in a particular section of an infestation.

Regrowth can still occur after 1 month of drawdown

In aquarium experiments 7% of cabomba seedlings survived a 30-day drawdown with the substrate also drained and allowed to dry over that time. Regrowth of the surviving seedlings started within 14 days after the tanks were refilled. In tanks where the substrate was not drained, but remained saturated, 53% of the seedlings survived and regrowth was evident after 7 days (Sanders 1979).

Simulated drawdown trials carried out by NSW DPI have shown that drawdown that achieves completely dry conditions can effectively kill 100% of cabomba within 1 month. These were open-air trials carried out in hot summer conditions.

Refuges/depressions

Any depressions in the bed that hold water will provide refuge for cabomba fragments. Trials have shown that regrowth can occur from cabomba remaining in 5 centimetres of water for a period of 3 months. The effectiveness of the drawdown is increased by the use of shading or excavation to treat the cabomba remaining in these refuge areas. All refuges should be identified and treated wherever possible. The choice of follow-up treatment will depend on the size and number of the remaining wet areas.

Shading-out refuge areas

Where cabomba remains in small refuges, shading with black plastic can be an effective treatment. Builders' black plastic can be used to cover small areas (see Case study: Floating blankets on a small dam at Kin Kin, south-east Queensland) during a drawdown, and left in place for as long as possible (at least 1 month). The use of this shading technique over shallow water and when temperatures are warmer will create very high temperatures beneath the plastic, contributing to a faster kill of the remaining cabomba. This technique is the most appropriate when the cabomba remains in sludge, mud or putrefied water.

Successful trial of shading over shallow-water drawdown

In drawdown simulation trials performed by NSW DPI, black plastic was used to shade cabomba that remained in 5 and 20 centimetres of water. When 100% shade was achieved, 100% kill resulted after 1 month at both depths.

Excavation of refuge areas

Excavation of refuge areas may be feasible over small areas if stable access for machinery is available. Excavated cabomba material needs to be placed where it can be completely dried out, without risk of re-introduction to the water body (particularly after reflooding/refilling). Cabomba will dry out quickly if the material can be spread out.

Does drawdown work?

Cabomba control using drawdown will be most effective in dams where the entire substrate can be exposed and inspected, and where further treatments can be carried out to increase the likelihood that all cabomba material is killed.

In larger lakes or dams drawdown can be expected only to suppress cabomba levels for periods of time, as complete control will be achieved only if no live cabomba material remains in the water body. Drawdowns have been used to successfully reduce and manage cabomba levels in large water storages in Queensland and Victoria. For example, in Lake Benalla in Victoria, drawdowns reduce cabomba levels for periods of up to 3 years (see Case Study: Drawdown in Lake Benalla, Victoria), and it is hoped that drawdown has eradicated cabomba from a small ornamental lake in Mildura Victoria (see below).

Steve Wingrave

Drawdown and shading have controlled this cabomba infestation.

Steve Wingrave

▲ *The billabong was drained in 2005.*

◄ *Black plastic was installed to shade out any remaining cabomba.*

Drawdown + shading success in the Northern Territory

A small cabomba-infested backwash billabong (20 × 8 metres), isolated from the main Darwin River during the dry season, was drained and hand weeded in July 2005. However, because of the presence of a spring under the billabong, cabomba had become re-established in shallow water by October 2005. Black plastic shades were then installed and during 2006 a combination of draining, hand weeding and shading successfully controlled the cabomba.

There may be situations in Australia where

- drawdown is possible
- drawdown can occur for long enough during dry weather for the substrate to completely dry out
- drawdown can be integrated with other control methods to treat any remaining cabomba refuges, and
- cabomba is not producing seed.

In these situations there is a good chance that drawdown will effectively control cabomba. Chances of success are increased by consecutive drawdowns during very hot or very cold weather, or by integration with other treatments as described above.

Advantages

- Option for potable water.
- Chance of cabomba eradication in small dams, particularly if integrated with other treatments.

Disadvantages

- Ecological implications of drawdowns for other aquatic organisms.
- Losses of large amounts of storage water.
- Alternative water supplies or storages may need to be provided during drawdown.
- Cabomba fragments may be moved downstream, resulting in further spread.

Follow-up after drawdowns

Monitoring for any re-established cabomba is very important once the waterbody is refilled. High levels of suppression can be maintained if areas of regrowth are found early. Hand-pulling has been the most effective follow-up treatment for small patches of regrowth after drawdowns.


Alan Roberts

Cabomba-infested ornamental lake close to the Murray River


Alan Roberts

Spillway connecting the lake to the river

Successful drawdown in Mildura

Drawdown has been performed in a cabomba-infested ornamental lake in Mildura, Victoria. The lake is situated in public parkland on the banks of the Murray River, and a spillway connects the lake to the river. The threat of cabomba entering the river was high, and this infestation needed to be removed. In November 2008 a 75-millimetre pump was used to pump the water onto the surrounding parkland, with no risk of the water re-entering the river. The lake was completely dry by December, received rainfall, and then dried completely again by February 2009. The plan is to refill the lake in winter 2009 and monitor it closely for any regrowth. Regrowth is not expected, thanks to the extremely dry conditions achieved during this drawdown.


Robert Metcalf

Drawdown occurred in November 2008.


Robert Metcalf

The cabomba was completely dried by December 2008.

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CASE STUDY:

Drawdown in Lake Benalla, Victoria

Introduction

Lake Benalla is an ornamental and recreational lake created by a weir on the Broken River at Benalla in Victoria. Cabomba was identified in Lake Benalla in 1990 and has become well established in the lake since that time. Various control trials (herbicides and drawdowns) have been carried out on the cabomba in the lake.

Management of cabomba by drawdown was considered because of the extreme concern created by the presence of cabomba in the lake, which is integral to the irrigation infrastructure of the region. The potential for further spread into the Goulburn and Broken Rivers and then into the Murray River and the irrigation areas between is high and is enhanced by the connectivity of the waterways in the area. Recently some minor infestations have been identified downstream in the Broken River.

There have often been local concerns over decisions to carry out drawdown in the lake. Issues include the need to service adjoining landholders with an alternative water supply; loss of recreational opportunities; and the reduced aesthetics of the lake during drawdown. These concerns were considered minor in comparison with the potential environmental and economic impacts of allowing the cabomba to become further established.

A number of drawdowns have occurred and have successfully reduced the population of cabomba in the lake, but some areas of the lake are unable to be fully drained and the cabomba in these sections remains viable. Two drawdowns of the lake for 2 months in 1999 and 2000 left one small area undrained, and by 2005 that area of surviving cabomba had re-established to cover one-third of the lake.

Effects of drawdown

The following maps show the distribution of cabomba in the lake before and after the drawdowns in 1999 and 2000. The area that fails to dry out providing refuge for cabomba is the narrow channel between Jaycee Island and the mainland.

Benalla Rural City Council

▲ *Lake Benalla in Victoria*

▼ *Cabomba was found in 1990.*
The negative impacts of cabomba outweighed local concerns towards drawdown.

Benalla Rural City Council

Issues associated with drawdown

There are a number of issues associated with carrying out drawdown in Lake Benalla. They include:

- The timing of drawdowns to minimise impacts on flora and fauna, taking into account the breeding and migration patterns of fish and platypus.
- The modification of infrastructure for water users (stock and domestic supplies). Previously users have been connected to the reticulated water supply during drawdowns at considerable expense. In future drawdowns it is proposed to extend existing pipes into deeper water to allow continued access to river water during drawdown. Excavation of a storage depression within Lake Benalla to allow water users to have continued access to river water during drawdown has also been considered.
- Timing drawdowns to maintain the functions of the lake and river in the area's irrigation scheme.

Cabomba management strategy

The underlying approach for management of cabomba relates to mapping the surveyed cabomba in the lake and in its adjoining waterways; monitoring to know whether infestations are growing, shrinking or moving; and the response to control activities such as drawdowns.

Although drawdown is currently the integral method of suppressing cabomba in the lake, a broader management strategy for cabomba has been developed to ensure the benefits of drawdown are maximised. The management approach for the lake and the adjoining weirs and channels is as follows:

- isolation of Casey's Weir and Jaycee Island Channel, to allow for separate control methods, including drawdown, to be applied
- complete drawdown of Lake Benalla
- spraying of exposed cabomba with glyphosate herbicide under permit
- hand-pulling of new populations when they are still small
- replacement of cabomba with native species to provide some competition
- hygiene and education
- regular monitoring.

Lake Benalla in the process of drawdown Benalla Rural City Council

Drawdown under way Benalla Rural City Council

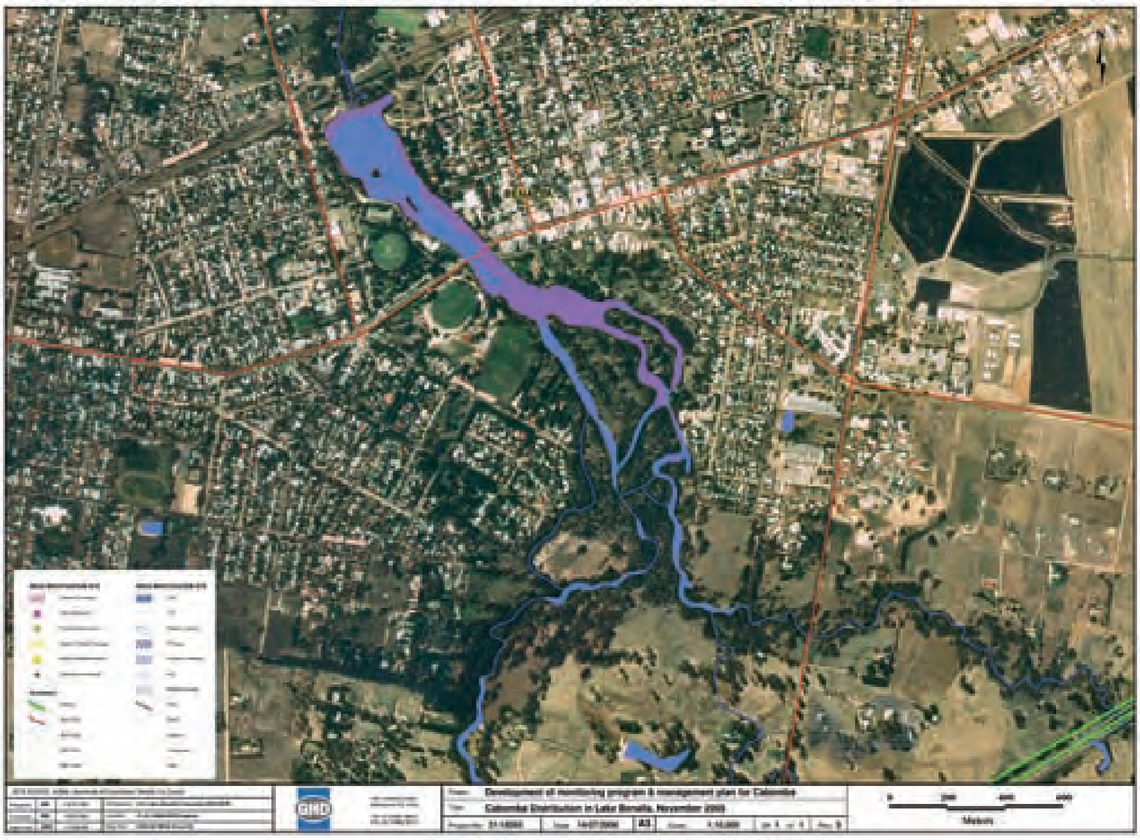
Very shallow areas dry out over the 2-month drawdown period. Benalla Rural City Council

Cabomba remains in the section of the lake that is unable to be fully drained.

Benalla Rural City Council

Purple hatching indicates cabomba distribution in Lake Benalla 1999, pre-drawdown. Benalla Rural City Council

Purple hatching showing greatly reduced cabomba distributions in Lake Benalla 2000, post-drawdown. Benalla Rural City Council



Purple hatching showing increased cabomba distribution in Lake Benalla 2005, 5 years post-drawdown. Benalla Rural City Council

Extreme temperatures during drawdowns give a high level of suppression. Benalla Rural City Council

Benalla Rural City Council

Refuge areas remain the challenge for future drawdowns.

Managing future drawdowns

Studies of management of cabomba in Lake Benalla have concluded that drawdowns should occur at least every 2 or 3 years during times of the year when extreme temperatures occur (summer or winter) and better drying of the lake bed can be achieved (preferably summer).

Management of the refuge areas that remain during a drawdown is the focus of current research, and any future drawdown will consider using integrated control methods such as shading, manual and mechanical removal (including suction-harvesting and diver-operated suction dredging), and herbicides to reduce the amount of viable cabomba that is able to remain in refuge areas.

These refuge areas are the focus of future management considerations and current research. Future drawdowns will include the pumping-out of some of the deeper depressions on the lake surface to the old Broken River bed to allow full drying of cabomba in those sections.

References

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Part 5: Manual removal

Manual removal is an important control method for cabomba infestations in specific contexts. It is usually done only in small infestations or in sections of larger infestations, or as a follow-up method in an eradication program. The method involves manually pulling cabomba plants out by the roots (hand-pulling), either while wading through shallow water or by diving with SCUBA. The method has been developed to include hand-held suction hoses to dredge the plants out, roots and all. The method is quite thorough and target-specific and minimises impacts on other aquatic vegetation.

Manual removal of regrowth in an eradication program

Phil Moran

Hand-pulling

Hand-pulling of cabomba can be viable over small areas. It is time and labour intensive and therefore generally not practical or economically viable for large areas.

Hand-pulling while wading

Hand-pulling can be done by operators standing or wading through shallow (knee-deep) water, depending on the water visibility. This is really only practical as a follow-up method while looking for regrowth of cabomba along edges of banks and shorelines.

Hand-pulling in conjunction with drawdown

Hand-pulling can be done in conjunction with drawdown, where operators can walk across the dry bed and remove exposed plants, as an alternative to treating the exposed plants with herbicide or waiting for them to dry out naturally.

Hand-pulling is appropriate over small areas.

Where water depths pose a risk, appropriate personal protective equipment should be used.

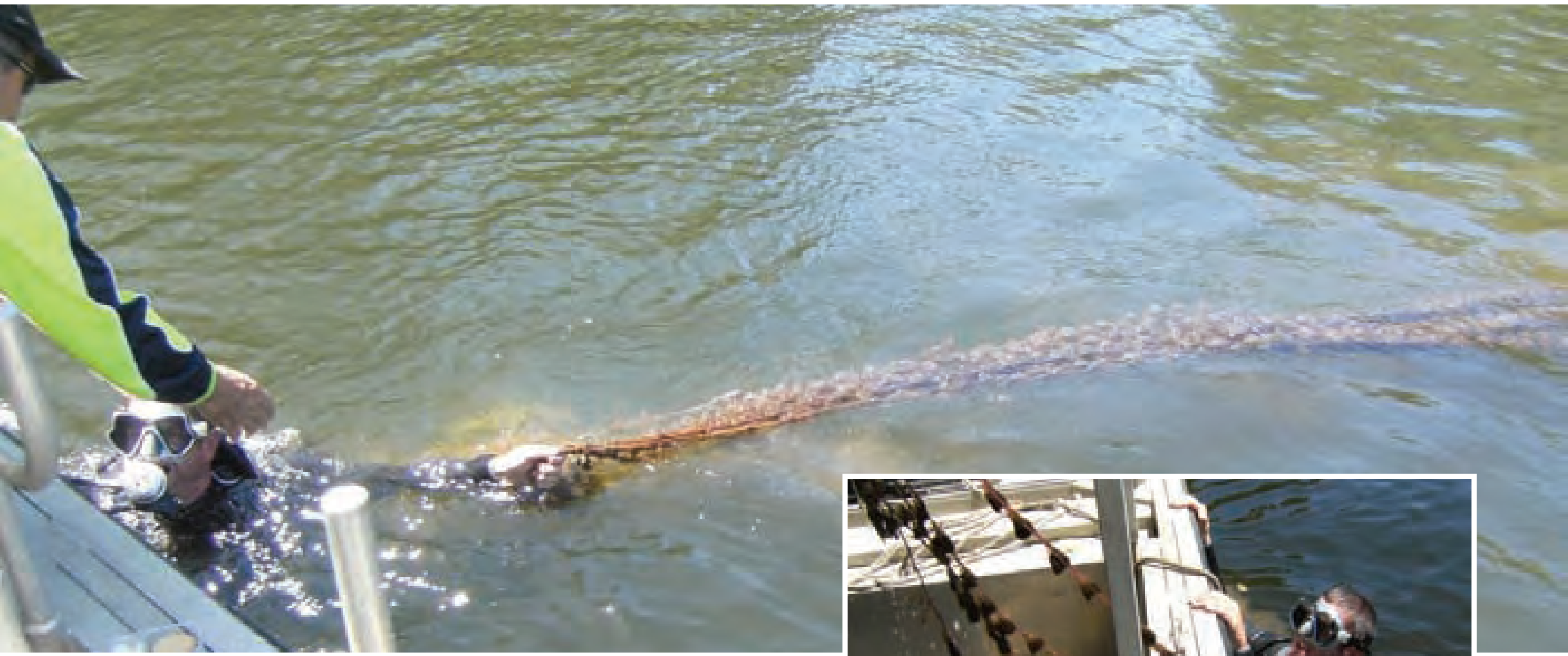
Sue Hayward

Hand-pulling using SCUBA divers

In many cases hand-pulling is viable only if SCUBA divers are used. This is usually done when small new infestations are discovered, as a follow-up method after shading, or to keep priority areas free of cabomba. Only qualified personnel may undertake this work.

Use of booms to avoid spreading fragments

Care is needed not to transport fragments on boots or clothing and not to create fragmentation through disturbance. Where possible, operators should stand



Phil Moran

Removal of plants by divers is very useful over small areas.

still and move very minimally through the water. Whenever hand-pulling is carried out in the water, floating curtain booms should be used to ensure fragments created by the disturbance are not able to float away.

Hand-pulling as an important follow-up technique

Where small infestations are under eradication programs (i.e. with shading or drawdown), hand-pulling is a critical follow-up technique for any regrowth that does occur.

Tips for hand-pulling

- Don't walk or swim out into or through the infestation; if possible, approach from the deeper side.
- Clear small areas completely before moving into a new area.
- Have extra people watching, ready to catch floating fragments.
- Pull out plants very carefully and slowly, taking time to feel your way down to the root ball and making sure you are removing the whole plant.
- Surround the area being pulled with a boom—either a rope with floats and netting or shadecloth attached to make a curtain, or a commercial curtain boom.
- Use divers where conditions are too difficult for wading (i.e. too deep, poor water clarity, thick infestations).

Phil Moran

This small area of regrowth was removed by hand after treatment with shading.

Phil Moran

Careful removal of the whole plant is necessary for successful follow-up.


Phil Moran

Have extra people watching for floating fragments.

Diver-operated suction dredging

Diver-operated suction dredging is a form of manual removal that involves the complete removal of submerged plants from the substrate by using a vacuum suction dredge. Divers use hand-held suction hoses to remove whole plants, including their root systems. Suction dredging systems range in size from smaller pumps to large boat- or barge-mounted systems.

The technique is skill and labour intensive, and only qualified personnel are able to undertake the work, making it relatively expensive. It is more difficult when water visibility is poor.

Although the technique can disturb benthic habitats through sediment disturbance, it is usually used only in small, target-specific areas.

The technique is used successfully for cabomba control in Australia (see *Case study: Diver-operated manual removal in Ewen Maddock Dam, south-east Queensland*) and has the advantage of being able to remove whole plants and roots without dislodging fragments.

References and further reading

Goulburn Broken Catchment Management Authority (2006), *Development of a Monitoring Program and Management Plan for Cabomba caroliniana in Lake Benalla and the Broken River.* Final Report. Goulburn Broken Catchment Management Authority, Shepparton, Victoria

CASE STUDY:

Diver-operated manual removal in Ewen Maddock Dam, south-east Queensland

The information in this case study was provided by Russell Rainbird, Caloundra City Council.

Introduction

Ewen Maddock Dam in south-east Queensland has a surface area of 370 hectares and holds 16 700 megalitres of water, with an average depth of 4.5 metres. The dam was built in 1973 across Addlington Creek (a tributary of the Mooloolah River) to supply the region with town water. Cabomba was identified in the dam in 1991, and despite control efforts over time cabomba now covers extensive areas in the shallower sections of the dam.

Cabomba management

Various control methods have been used in Ewen Maddock Dam. A number of techniques have been trialled, including drawdown, mechanical removal and various herbicides. Public outcries resulted after the trial use of herbicides in the dam (even though the dam was not used as a town water supply at the time), and after the use of harvesters (because of the non-selectivity of the technique and the damage caused to the native aquatic vegetation).

The main objectives of cabomba control in the dam are to keep certain high-priority areas free of cabomba and to perform selective control that has minimal impact on the surrounding aquatic vegetation and environment, as well as to prevent spread to other water bodies.

A range of cabomba management initiatives contribute to the overall management program, including revegetation with native aquatic plants such as *Lepironia* (reeds) and *Vallisneria* (ribbonweed); management of water levels; excavation of shallow areas to create deeper water with steeper banks; shading; riparian revegetation; and ongoing manual removal by divers.


Caloundra City Council

Ewen Maddock Dam has a surface area of 370 hectares.

Russell Rainbird

The diver-operated venturi suction dredge

This case study focuses on the techniques developed over time to improve the manual removal of cabomba in Ewen Maddock Dam, leading to the current use of a diver-operated venturi suction dredge.

Development of manual removal techniques over time

Manual removal techniques have been developed and refined to a large extent by the divers, both with and without the use of a venturi section-dredge. Manual removal is carried out in five specific areas of the dam that are important for recreation, currently covering a total cabomba-removal area of 26.8 hectares.

1998–2000 manual removal by divers using lug baskets

Before the use of the suction dredge all the removal was done manually by divers. To begin with, the operator diver carried a catch bag that could hold 10 kilograms of plant material and emptied the bag into lug baskets that were carried by the supervisor and the standby diver. The supervisor and the standby divers both collected fragments, but extra council staff used extended scoop nets to retrieve fragments by boat or canoe. The removed cabomba was spread on the shore above the high water mark to dry out. The areas to be worked were identified and marked out with floats and weights.

	Removal zone				
	Camp Koongamoon	North shore	Picnic swimming area	Dam wall	Spillway
Area in hectares	15.35	7.2	0.67	3.2	0.41

Equipment

- 3.8-metre aluminium punt with outboard engine, SCUBA gear and safety equipment (for divers)
- 4.3-metre aluminium runabout with outboard engine (for council staff)
- 1 two-person canoe
- 3 extended scoop nets
- 10 lug baskets
- catch bags (1 per diver with 10 kilograms capacity)
- marker floats and weights

Personnel

Three divers:

- 1 dive supervisor (collects floating fragments)
- 1 standby diver (collects floating fragments)
- 1 manual removal operator

Two council staff:

- 1 full time council employee
- 1 casual council employee as needed

Productivity

Budget restraints kept cabomba removal to 6.5 hours a day 3 days a week, over 40 weeks of the year. Contractors were paid an hourly rate of $130.00. The divers were able to remove about 800 kilograms of cabomba a day and worked over the same sites 3 or 4 times a year. Cabomba density was seen to be decreasing at the removal sites after some time.

1998–2000		
Labour	Cabomba removed	Costs
780 h/year	3200 kg/year	$101,400/year

2000–2004 manual removal by divers using metal crates

From 2000 cabomba was removed manually by divers and placed into metal crates, which were lowered into the water to reduce the underwater travel time for the divers. The crates were removed by a crane on a boat and the cabomba was dumped into a skip and taken to the council waste station by a waste collection contractor as necessary. From 2000 the areas to be worked were prioritised on the basis of the levels of recreational use.

Equipment

- 6-metre aluminium barge and outboard engine, fitted with crane and metal crates (metal crates carry about 150 kilograms each), also carrying SCUBA gear and safety equipment
- metal sling attached to a crane for lifting larger amounts of cabomba
- 8-metre skip for disposal of cabomba

Personnel

Three divers:

- 1 dive supervisor (collects floating fragments)
- 1 standby diver (collects floating fragments)
- 1 manual removal operator

Productivity

The hourly rate for the three divers in 2000–2003 was $144.70. Divers worked an average of 6.5 hours a day, 4 days a week, for 44 weeks of the year. The hourly rate for the three divers in 2003–2004 was $152.90. Divers worked an average of 6.5 hours a day, 4 days a week in winter and 5 days a week in summer, for 44 weeks of the year.

June 2002 – June 2003		
Labour	Cabomba removed	Costs
1398 h	258 650 kg	$ 202,291

June 2003 – June 2004		
Labour	Cabomba removed	Costs
1443 h	201,815 kg	$220,635

Divers use the suction hose to remove the cabomba including the root ball.

Second barge with diesel engine and pump

Russell Rainbird

Although the number of hours worked doubled, the efficiencies of the underwater crates and the boat-mounted crane allowed the amount of cabomba removed to increase from 3200 kilograms to over 200 000 kilograms a year.

2004–2008 removal by divers using a Venturi suction dredge

By 2004 the dive contractors had developed a system of using a diver-operated venturi suction dredge to remove the cabomba, including the whole root ball. The suction hose can work to a depth of 5 metres with a 7-metre reach and is capable of removing 1 tonne of plant material per hour. This method allows the root ball to be removed cleanly; therefore, the removed weight is plant material only. Previously, the material removed weighed 2.6 times this amount because of the attached mud and soil.

Equipment

- 6-metre aluminium barge and outboard engine, fitted with crane and metal crates (metal crates carry about 150 kilograms each), also carrying SCUBA gear and safety equipment
- metal sling attached to crane for lifting larger amounts of cabomba
- second barge with diesel engine powering a pump to run the venturi/suction dredge

The removed cabomba contains no mud and soil.

Russell Rainbird

Personnel

Three divers:

- 1 dive supervisor (collects floating fragments)
- 1 standby diver (collects floating fragments)
- 1 manual removal operator

Productivity

Although in 2004–2005 the weight of the cabomba removed was less than in the previous year, the weight is made up entirely of plant material, meaning that the proportion of plant material removed was more than double that of the previous year. This was therefore the most efficient method of cabomba removal tried to date. The contractors were paid a total hourly rate of $176.00.

June 2004 – June 2005		
Labour	Cabomba removed	Cost
1393 h	194 055 kg	$245,168

Advantages

- Use of the dredge enables divers to be selective and only target cabomba.
- Selectiveness encourages native plant regrowth and creates less space for further cabomba establishment.
- The method creates less fragmentation and spread of cabomba.
- The majority of root systems are removed slowing regrowth.
- Cabomba regrowth is made up of immature plants.
- Fragments are also collected.
- The dredge can work over submerged logs and snags.

Russell Rainbird

The suction-dredge enables divers to target cabomba in amongst other vegetation.

Results over time

The continued application of the suction-dredge technique has led to divers needing to spend relatively more time in the removal zones looking for progressively smaller amounts of cabomba. Native aquatic plants have increased their populations in some of the removal zones.

From 2003 to 2005 very large decreases in the weights of cabomba removed were recorded in three of the four removal zones where data were collected; a reasonable decrease of 16% was recorded in the other zone because of inconsistent seasonal work patterns in that zone. The relatively small decreases in the time spent searching for and removing the cabomba in these zones indicates that the cabomba was more scattered and harder to find.

Diver reports

The trends of decreasing cabomba density in the removal zones have continued. However, in some circumstances (i.e. between contract tendering times, or with seasonal changes to work patterns) areas can suffer heavier regrowth than usual. Divers are able to keep track of what is happening with regrowth and start to see patterns in the response of cabomba to removal. Divers provide weekly reports to management:

> *Worked in canoe area this week—this was an area we used to clean up in winter and we kept on top of it … not working it this winter has given the plant a head start on us and will require a lot more work*
>
> *… cleaned up patches of plants out wide of the north shore zone, then worked the camp—there were lots of small plants …*
>
> *Thursday's storm produced large rafts of floating fragments (largest was about 45 m × 15 m). The new machine was able to suck these up, but we will make modifications to allow the machine to handle floating rafts more efficiently…*
>
> **Aquatic Weed Technologies Commercial Diving Contractors 2008**

RESULTS OVER TIME

	Northern shoreline		Dam wall		Spill way		Camp Koongamoon	
Years	kg removed	hours worked	kg removed	hours worked	kg removed	hours worked	kg removed	hours worked
2003–2004	30 010	309	42 350	398	13 010	143	117 045	594
2005–2006	25 160	612	23 235	332	5650	118	70 890	443
Change over time	decreased by 16%	increased by 98%	decreased by 45%	decreased by 16%	decreased by 56%	decreased by 17%	decreased by 39%	decreased by 25%

Further development of head attachments allows for better removal in thick sections of cabomba.

Conclusion

Records show that use of the diver-operated suction dredge is the most efficient and effective method of manual removal of cabomba over an area of 28 hectares in Ewen Maddock Dam. It is, however, an expensive exercise:

> *Of the $1.1 million a year spent on weed control, $300,000 is spent on cabomba in Ewen Maddock Dam—only one weed in one place.*
>
> **Greg Brown, Caloundra City Council, Cabomba Best Practice Workshop.**

The system is constantly being refined by the operators, and there is now greater understanding of the response of cabomba in the removal zones. Underwater video transects are being recorded and are starting to show the positive effects of continual manual removal. The areas under revegetation are showing promising results on a small scale. Further development of a number of head attachments is also under way to allow better removal in thick, mature sections of cabomba or on harder substrates with large amounts of logs and debris.

Manual removal of cabomba in high-priority areas of an extensive infestation is the most effective and efficient technique, given the current restraints on the use of herbicides and the environmental impacts associated with mechanical removal by harvesters or cutters.

Russell Rainbird

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Rainbird R (various dates) Data records, CalAqua, Caloundra City Council.


Biosecurity Queensland, DPI&F

Mechanical removal is cost effective in some situations.


Phil Moran

Harvesters have load capacities of 11 or 12 cubic metres.


Phil Moran

Harvesters create a high degree of fragmentation.

Part 6: Mechanical removal

Cabomba is often mechanically cut and removed in large, established infestations, particularly where herbicides are considered inappropriate.

Mechanical removal needs to be done continually in order to suppress cabomba. Regrowth occurs so quickly that a clear body of water can only be maintained for a short time (several weeks). Mechanical removal is expensive, but it has been deemed cost effective in situations where priority areas within larger infestations need to be kept clear of cabomba (for either safety or recreational reasons, or to limit spread by keeping areas near spillways clear). It has also shown to improve water quality in areas where cabomba is removed.

Harvesting

Underwater cutting and removal of cabomba is referred to as harvesting. A harvester is effectively a barge mounted with a sickle-bar cutting blade and a conveyor belt to load the cut plant material onto the barge; the system operates like an underwater mower. Most harvesters are paddle-wheel driven, and commercially built harvesters are available in a range of sizes, capacities and manoeuvrabilities. Most large harvesters have weed load capacities of 11 or 12 cubic metres and have to off-load to shore or to a shuttle barge.

Regrowth occurs quickly, but cutting is still beneficial

During summer, harvesting in Lake Macdonald effectively halved the standing crop of cabomba, but within 3 weeks the cabomba had grown back to pre-cut levels. However, trials since have shown that two harvesting treatments over a month result in better water quality and some regrowth of other native aquatic species.

Paddle-wheeled harvesters create a lot of disturbance, causing a high degree of fragmentation of the cabomba. They are therefore not suitable for small or new infestations, as they will cause spread. Booms have been used to contain floating fragments in areas where cabomba is being harvested.

Disposal

Disposal of harvested cabomba needs to be considered. Cabomba dumped onshore will decompose within 3 or 4 weeks. This may be acceptable as long as there is no chance of it re-entering the water. Harvested cabomba is too wet to compost well on its own. Left in a heap it becomes an anaerobic, sludge-like material. Cabomba can also contain large amounts of heavy metals and should be tested before any further use as composting material.

Most harvesting operations use back-loading compacting garbage trucks to compress the cabomba and transport it to a refuse depot. The water that is squeezed out when the cabomba is compressed can contain large amounts of nutrients and heavy metals and may need to be collected and disposed of responsibly (proper facilities such as a hardstand with sump may need to be constructed onsite for collection and removal of runoff water).

Biosecurity Queensland, DPI&F

Phil Moran

Most operations unload into back-loading compacting garbage trucks.

Advantages

- Removal capacity is large enough to suppress substantial areas of cabomba for short periods of time.
- The process can remove a significant amount of nutrients and heavy metals from the system.
- The process contributes to oxygenation of the water profile.

Disadvantages

- Uneven bottom contours, snags, high flows and high wind speeds restrict harvesting.
- Harvesting is not species selective, and it does result in the capture of a wide range of organisms, including small fish. (Larger fish and tortoises are able to avoid capture or jump off the conveyor back into the water. The operator can also reverse the conveyor if necessary.)
- Harvesting causes a high degree of fragmentation, increasing chances of spread.
- Expense of maintaining an ongoing program is high. Contractors charge about $2000–2500 a day. In-house operations currently cost some organisations $120,000 a year.
- Clear water or GPS equipment is required to view or track cutting lines in order to operate economically.

Suction-based harvesters

Small suction-based harvesters have been commercially developed to cut and remove aquatic weeds at any depth up to 5 metres. Using a vacuum hose connected to a cutter-bar on a scoop they can cut and suck cabomba into an onboard bag.

The cabomba is drawn in through the collection funnel by a pump. The water compresses the cabomba as it fills the 1.5-cubic-metre-capacity bag (approximately 3 cubic metres of cabomba will compress down into one bag).

Suction-based harvesters cut and suck cabomba into an onboard bag.

Phil Moran

Phil Moran

Cabomba is drawn into the collection funnel by a pump.

Phil Moran

The boats can move into shallow areas.

Three cubic metres of cabomba is compressed into each bag.

When bags are full they are slid off on a conveyor belt into the water, where they float to await pickup. There is no need to return to shore to offload bags. The bags provide a high level of filtration of the water, straining in excess of 95% of the contained organic matter. The operation can fill 32 bags in 12 hours. Bags can be left onshore to drain overnight and then transported elsewhere for disposal.

The boats are powered by twin outboards at the stern. Because the cutter-bars cut a swath in front of the boat, the outboards are capable of moving through a cabomba infestation. If they do get caught up in cabomba while manoeuvring they can reverse to untangle the propellers. Having the outboards at the rear creates less disturbance and fragmentation of unharvested cabomba than are caused by the side-mounted paddles on larger harvesters. Fully loaded, the backs of the boats require a water depth of 300 millimetres, but the bows of the boats need only 100 millimetres, allowing them to move right in to shallow areas.

Advantages

- The harvesters have the benefits of suction as well as cutting, leaving substantially fewer fragments behind and creating less fragmentation while operating.
- The cutting depth can be adjusted while operating, following bottom contours and avoiding submerged snags and objects.
- Suction-based harvesters are a more transportable operation than the larger paddle-wheeled harvesters, as they are towed by a standard vehicle and launched from a trailer. (This gives utmost importance to the need to observe strict hygiene protocols when moving the operation between water bodies.)
- The process contributes to oxygenation of the water profile.
- Alteration of the cutting depths also allows for experimentation with optimum heights for minimising regrowth and maximising the length of time between operations.

Phil Moran

Bags can be floated or loaded for transporting.

Biosecurity Queensland, DPI&F

Harvesters can move fragments between waterways.

Disadvantages

- Suction-harvesting is not species selective, and it does result in the capture of a wide range of organisms, including small fish.
- Removal capacity is less than that of larger paddle-wheeled harvesters.
- Drainage water from compressed cabomba is returned into the system (but the compression is not as heavy as that created by a compacting garbage truck).
- The expense of maintaining an ongoing program is high.

Hygiene

Hygiene is of great importance in harvesting operations, particularly when external contractors move small harvesters from one water body to another. Harvesters need to be thoroughly cleaned and checked for cabomba fragments before they are launched in other water bodies. Ideally, harvesters should be operated in only one water body, i.e. they should not be moved from one water body to another.

References and further reading

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CASE STUDY:

Mechanical removal in Lake Macdonald, south-east Queensland

Introduction

Lake Macdonald in south-east Queensland is an 8000-megalitre constructed impoundment on Six Mile Creek at the headwaters of the Mary River System. The lake is a natural asset and potable water storage for the Noosa area. Cabomba was first discovered in the Lake in 1991 and by 1995 had invaded most of the shallower littoral zone. The lake now has approximately 75% of its surface area under infestation (180 hectares). The lake is used by recreational fishers and canoeists (power boats are restricted). Cabomba is seen to threaten potable water quality, natural area conservation and habitat, public health and safety, and operation of water treatment equipment.

Because of the scale and extent of the infestation, herbicides were considered an inappropriate form of management for an aquatic weed in the town water supply. Drawdown was also considered inappropriate for the water supply, which also provides habitat for the endangered Mary River Cod.

Cabomba was first discovered in Lake Macdonald in 1991.

Sunshine Coast Regional Council

Trial use of harvester

Although it was understood that some parts of the dam were not accessible for harvesting and that harvesting does cause fragmentation, Noosa Council* agreed to trial the use of a harvester, because the lake was completely infested and issues of spread within the lake itself were inconsequential.

The first model trialled was too large for the situation.

Biosecurity Queensland, DPI&F

In 1994 the Council trialled the HV3000 model of aquatic harvester manufactured by Aquatic Plant Harvesters Australia Pty Ltd. This model has a 3.0-metre cutting swath with a depth of cut to 3.0 metres. This machine was too large for the situation, and too much damage occurred from hitting submerged objects. However, the overall trial showed harvesting to be an effective form of suppression, and a smaller machine was commissioned (the HV2600).

In a 20-day trial with the HV2600 harvester 159 loads of cabomba were removed, equalling approximately 360 tonnes (18 garbage trucks-full or 342 cubic metres). Water quality was shown to have improved (clarity increased in cut areas). Dissolved oxygen levels improved after harvesting and wave height increased in cut areas; this increased oxygen levels and reduced the size of algal blooms. Over the course of the trial it became apparent that cabomba was sensitive to repeated cutting; the native plant *Hydrilla verticillata* reappeared after a 6-year absence in the lake. Moreover, 1500 kilograms of nitrogen, 380 kilograms of manganese and 216 grams of lead were removed in the 360 tonnes of cabomba that was cut in 20 days. The Council continued with the harvesting operation on a contractual basis.

Ongoing harvesting for suppression

In 2001 the harvester was purchased by Noosa Council and a harvester operator was employed by the Council. The aim of the ongoing cabomba harvesting in Lake Macdonald is to achieve ongoing suppression of cabomba in priority areas.

The harvesting operation

The harvester operates over an area of approximately 12 hectares and cuts down to 1.2 metres depth. Two priority areas are harvested—near the spillway and the offtake—making up approximately one-twentieth of the lake's surface area. Removal of cabomba in these areas helps to minimise outflow of fragments in water; maintain the highest water quality at the offtake; support aesthetic values of the lake; and increase public safety.

Harvesting is performed all year: in summer four cuts are made in the priority areas, but in winter fewer cuts are necessary over the same areas.

The harvester operator is employed on a permanent basis. Phil Moran

The cabomba is collected in a compacting garbage truck. Phil Moran

Biosecurity Queensland, DPI&F

Phil Moran

The smaller HV2600 harvester proved successful.

The harvester can cut to a depth of 1.2 metres.

From the operator's perspective …

Before it was all done visually; you'd have to wait until you could see the regrowth before you could re-harvest an area. Now we have a GPS on the harvester, which is very useful for tracking the harvesting rows and increasing accuracy of coverage. This maximises the assault on the plant's ability to regrow and allows you to find the weed regrowth after water inflows. Take note of wind direction and use booms to collect fragments drifting away from the areas being harvested. If wind speed exceeds 20 km/h, operation ceases.

Ross Paulger, Noosa Council*, Second National Cabomba Workshop, Caloundra, 2008

Disposal

The cut cabomba is compacted in garbage trucks to remove the water content and then taken to the council refuse tip. A permit from Queensland Primary Industries and Fisheries is required to transport the weed. The leachate water (the water that is squeezed out of the compacted cabomba) is collected in a purpose-built onboard tank and is discharged to the sewer each time the truck is unloaded at the local landfill refuse tip.

Costs

The harvesting operation costs $120,000 a year; this covers wages, running costs and maintenance but does not include capital expenditure on the harvester and the rear-loading garbage compactor truck.

The results

A trial has since been run over 3 years to look at the efficacy of the venture. Over this time there has been a successful reduction of cabomba biomass in the areas harvested. Plants that originally had up to 60 stems emanating from their root bases had only 10 to 12 stems after continual harvesting. Harvesting to a depth of 1.2 metres also restricts the light received by the remainder of the plant, making regrowth slower.

Where the harvester has 'mown' the cabomba, the regrowth tends to look thicker. In the trial, plant abundance did increase by 1.5 times, but although there were more plants they were much smaller and less overall biomass was recorded.

The harvester can remove 10 tonnes a day in any areas that have never been harvested. In the areas that are repeatedly harvested the removal weight is reduced to 5 tonnes per day, indicating that repeat harvesting does suppress an infestation.

Determination of the optimum timing, depth and frequency of harvesting for ongoing suppression requires more research and trial work; observations are constantly being carried out.

Ongoing harvesting is considered cost effective in combination with the broader Cabomba Management Strategy of the Lake Macdonald Catchment care Group, which aims to eradicate outlying infestations in the lake's catchment area and prevent spread from the lake to other waterways. Other activities include the provision of sealed boat ramps to prevent snagging of cabomba on trailers; education campaigns to promote decontamination of vehicles and equipment; restoration of riparian vegetation (nutrient traps, exclusion of stock, shading); and limitation of generation of nutrients and their flow into the system.

**Lake Macdonald is now managed by Seqwater, and Noosa Council is now part of the amalgamated Sunshine Coast Regional Council.*

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Phil Moran

The harvester can remove 10 tonnes of cabomba a day.

Australian Government

national aquatic weeds management group

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