NSW DPI

WEEDS OF NATIONAL SIGNIFICANCE

Salvinia control manual

Management and control options for salvinia (Salvinia molesta) in Australia

Australian Government

national aquatic weeds management group

NSW DEPARTMENT OF PRIMARY INDUSTRIES

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Foreword

Salvinia is one of the world's worst aquatic weeds. Since its introduction to Australia in the 1950s salvinia has spread to many waterways on the east coast and in the Northern Territory. The potential for salvinia to invade waterways in all States and Territories in Australia is of great concern.

As an aquatic weed, salvinia poses a variety of challenges not often experienced in terrestrial weed management. Difficulty of access to waterways, as well as safety requirements and legislative restrictions on control methods, are just some of these.

The National Aquatic Weeds Management Group recognises the need to contain the spread of salvinia and to control existing infestations, as well as the need to provide best practice information to those attempting to carry out these often daunting tasks.

This manual is a platform for designing site-specific management strategies for salvinia. It brings together best practice information about existing control and management options and contains detailed information about the plant itself.

I recommend this manual to all weed control authorities, water boards and waterway managers whose waterways are affected by salvinia or at risk of invasion.

Finally, I would like to thank those responsible for its production.

Neale Tweedie

Chair
National Aquatic Weeds Management Group

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Rebecca Coventry

Salvinia has severe environmental, economic and social impacts.

Andrew Petroeschevsky

Attempting to kayak through a salvinia infestation.

Andrew Petroeschevsky

Thick floating salvinia prevents light from entering the water and can be mistaken for solid ground.

Introduction

Salvinia molesta is a free-floating, mat-forming aquatic fern native to Brazil. In Australia, salvinia is an invasive and widespread weed in freshwater systems.

About the manual

The information presented here provides a basis for the development of site-specific management strategies. It is based on a review of published information, a survey of field practices carried out by technical experts and weed managers, and a workshop on integrating control methods for salvinia. The quotes appearing in this document come from discussions and presentations by participants at the workshop (National Salvinia Workshop, Grafton, 2005—see list of participants in the Acknowledgments).

Case studies are presented in Part 4. These present specific management strategies, detail the control methods used and highlight successes and failures.

A Weed of National Significance

Salvinia is a Weed of National Significance because of its invasiveness and its severe environmental, economic and social impacts.

Impacts of salvinia

The presence of an infestation will affect most native plants, fish, birds or animals that use the infested water body. Thick floating mats of salvinia prevent light and oxygen from entering the water, shading out submerged native aquatic plants and creating unfavourable conditions for other aquatic organisms. The large amounts of decomposing plant material lower dissolved oxygen levels and affect water quality. Ultimately, the biodiversity of the system is reduced.

An infestation can cover the entire surface of a water body, reducing aesthetic values and preventing most recreational activities such as swimming, boating and water sports. Decaying plant material can produce foul odours, and recreational fishing is impeded.

Public health and safety are at risk, as infestations provide ideal habitat for mosquito larvae. The thick floating mats are easily mistaken for firm ground and can be dangerous for children and animals.

Fishing and agriculture are affected when commercial fishing nets are blocked and the passage of boats impeded. Water losses from evapotranspiration are markedly increased, and the decay of plant material affects water quality. Irrigation channels become blocked, and intakes, pumps and pipes can be blocked or damaged.

A national approach to management

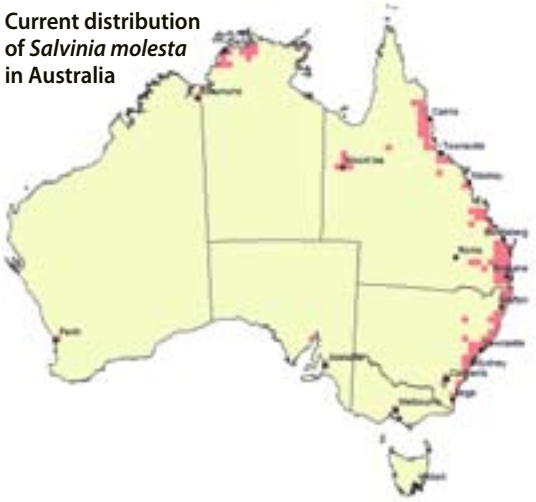
The National Salvinia Strategy was launched in 2003 to reduce the impacts of salvinia in Australia. The strategy is the basis of a nationally coordinated effort to:

- prevent and reduce spread
- decrease the rate of new infestations
- enforce a nationwide ban on trade
- minimise the impacts of existing infestations.

Andrew Petroeschevsky

Salvinia covering an irrigation channel.

Current distribution of *Salvinia molesta* in Australia



Map production by Bureau of Rural Sciences

The strategy is coordinated by the National Aquatic Weeds Management Group, which is representative of local and State government, industry bodies, research organisations and community groups.

History of spread

Salvinia was introduced to Australia in the 1950s as an ornamental aquatic plant. It was recorded in a natural water body in Luddenham in New South Wales in 1952 and in Brisbane in Queensland in 1953. By 1973 it was recorded in farm dams, ponds and streams in coastal catchments from Ulladulla on the NSW South Coast to Julatten in North Queensland, and small infestations in Western Australia were occurring in Bunbury and Albany. It was first recorded in the Northern Territory in a nursery in Darwin in 1976, and later that year in a water body at Nhulunbuy.

By 1980 serious infestations had developed in many coastal waterways in eastern Australia. By 1988 10 other infestations had been reported in the Northern Territory, one of these being in Kakadu National Park.

Inland infestations have also occurred: salvinia was found at Lake Moondarra near Mt Isa in 1975, and this had developed into a serious infestation by 1978. A small farm dam near Deniliquin in NSW was found to be infested in 1975.

Current distribution

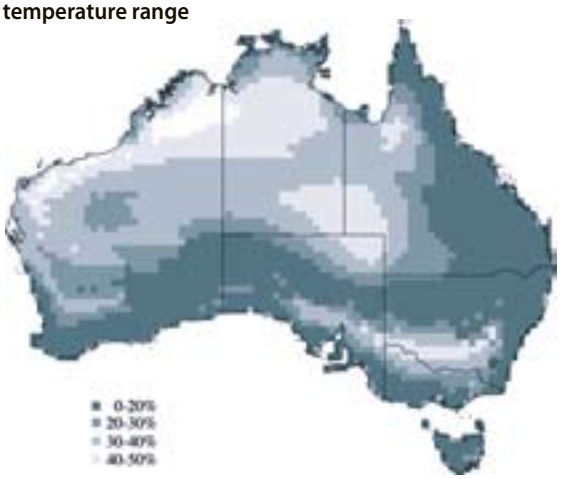
In its native range in Brazil, *Salvinia molesta* has a relatively small distribution occurring between latitudes equivalent to Bundaberg in Queensland and Taree in NSW, over an area the same size as Kakadu National Park (20 000 km^2). In countries where it has become an invasive weed (including Australia), salvinia is able to exist outside its native range latitudes.

Salvinia is highly invasive in Queensland, the Northern Territory, and NSW, generally occurring within 300 km of the coast. Some isolated infestations have occurred in water bodies west of the Great Dividing Range, south of Sydney, and in Victoria. There are scattered occurrences in Western Australia (around Perth and in Kununurra). Salvinia can be found in water bodies adjacent to all our mainland capital cities, and ornamental use of the plant occurs in all States and Territories. New infestations are continually identified.

Potential distribution

Predictive modelling based on temperature tolerances indicates that all States and Territories have favourable climatic conditions for salvinia, with excellent habitat conditions across southern and eastern Australia. Within the two highest-risk zones (conditions that are within 0% to 20% and 20% to 30% of ideal temperatures) salvinia can be expected to grow well and cause major problems in freshwater bodes. Outside these high-risk zones salvinia could grow in protected microclimates, with the potential to reinfest areas further down catchments.

Potential distribution of *Salvinia molesta* in Australia, based on conditions within a percentage of the ideal temperature range



Source: Thorp & Lynch 2000

Tom Anderson

The salvinia in this ornamental fish pond was the source of a large infestation in a nearby waterway.

Andrew Petroeschevsky

Salvinia is spread on boat trailers.

Andrew Petroeschevsky

Rebecca Coventry

Salvinia is spread on recreational watercraft.

Vectors of spread

The salvinia that is currently present in Australia does not produce viable spores and reproduces only vegetatively (see *Growth and reproduction* in *Part 1*). New infestations are usually linked to human activities, such as the continuing use of the plant as an ornamental; its deliberate release into water bodies to grow stocks for the nursery trade; the dumping of fishpond water into waterways; or the movement of salvinia on boats, trailers and other vehicles. Floods, winds and currents then distribute new infestations throughout catchments.

Waterbirds can spread small fragments of plants that stick to their feet and legs; however this is not thought to be a major cause of spread. Salvinia has been observed being spread short distances by water buffalo and cattle.

LEGAL STATUS OF SALVINIA IN AUSTRALIA	
State	**Declaration status of *Salvinia molesta***
ACT	Notifiable and prohibited pest plant under the *Pest Plants and Animals Act 2005*; presence of the plant must be notified to the chief executive; importation, supply and propagation are prohibited.
NSW	Class 2 and Class 3 noxious weed under the *Noxious Weeds Act 1993*; Class 2 plants must be eradicated and land must be kept free of plants. Class 3 plants are notifiable and must be fully and continuously suppressed and destroyed. Plants are banned from sale, trade or distribution throughout the whole of the State. Class 2 applies to the whole of NSW except for the areas listed as Class 3. Class 3 areas include the councils of Bellingen Shire, Camden, Campbelltown City, Cessnock City, Clarence Valley, Coffs Harbour City, Dungog Shire, Far North Coast County, Gloucester Shire, Gosford City, Great Lakes, Greater Taree City, Hawkesbury River County, Kempsey Shire, Lake Macquarie City, Maitland City, Nambucca Shire, Newcastle City, Port Macquarie-Hastings, Port Stephens, Wollondilly Shire and Wyong Shire.
NT	Class A, Class B and Class C noxious weed under the *Weeds Management Act 2001*; small infestations to be eradicated where feasible; growth and spread to be controlled; 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 1a declared plant under the *Natural Resources Management (NRM) Act 2004*; prohibited entry to the State; to be destroyed throughout the State; sale and transport prohibited; notifiable throughout the State.
TAS	Declared under the *Weed Management Act 1999*; importation, movement and sale prohibited; all plants/infestations are to be eradicated.
VIC	State Prohibited Weed under the *Catchment and Land Protection Act 1994*; all plants occurring in Victoria are to be eradicated by Victorian Government; entry to State, movement and sale prohibited.
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.
Commonwealth	All species of the genus *Salvinia* are prohibited entry to Australia under the *Quarantine Proclamation 1998*.

NSW DPI

A single floating plant showing the submerged root-like filaments.

An infestation is made up of individual plants floating together.

Elissa van Oosterhout

Part 1: The salvinia profile

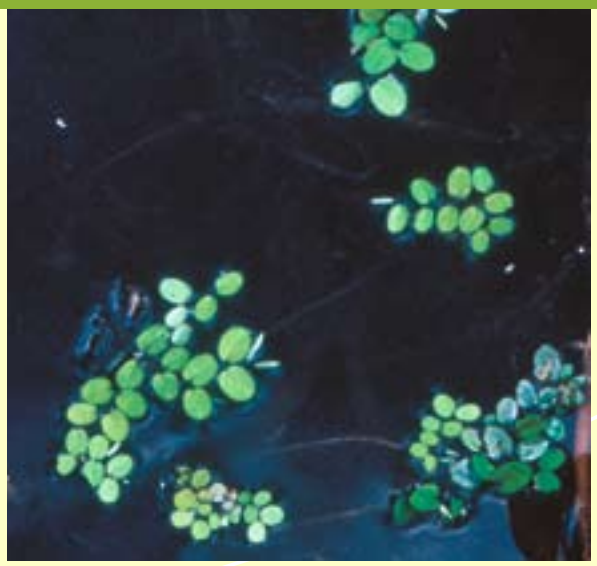
The genus *Salvinia* contains 11 or 12 species, seven or eight of which are native to South America, including *Salvinia molesta*. No salvinia is native to Australia, and all *Salvinia* species are prohibited entry. The only species currently present in Australia is *Salvinia molesta*. The Australian Quarantine Inspection Service (AQIS) identifies a number of other *Salvinia* species that could potentially enter Australia through northern borders. Any unrecognised or unusual plants with salvinia-like characteristics should be promptly identified and reported (contact the relevant State herbarium or weed agency).

Salvinia molesta: physical characteristics

Salvinia molesta is a free-floating, mat-forming aquatic fern. Plants have central stems (rhizomes) that lie beneath the water surface, pairs of hairy floating leaves along the stems, and submerged trailing root like filaments (modified leaves) below the water. The typically wedge-shaped plants rarely exceed 30 cm in length. Salvinia plants are ferns and therefore do not bear flowers.

A single plant, called a phenet, is made up of colonies of ramets (a ramet refers to each pair of leaves and associated bud on the rhizome). There are rarely more than 100 ramets in a phenet.

Plants float together, forming mats over the surface of the water. There are three distinct stages of growth that occur as floating plants become more crowded on the surface.



Mic Julien

Salvinia in the primary growth stage.
Water surface is visible between primary stage plants.

Anne Ferguson

Salvinia in the secondary growth stage.

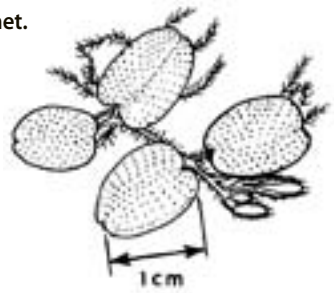
Primary stage

Primary growth occurs in the early stages of an infestation, when plants are not crowded. The small, flat, oval-shaped leaves lie in direct contact with the water surface and are less than 15 mm wide. The water surface is visible between plants. Salvinia recovering from damage also shows the primary growth form, and regrowth leaves can be as small as 2 mm in width.

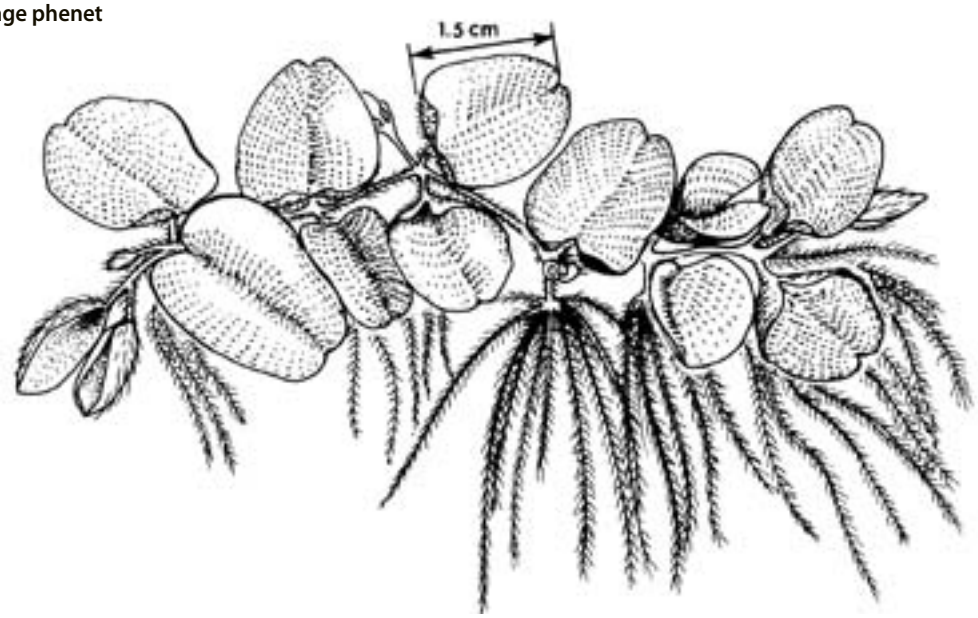
Secondary stage

Secondary growth occurs when the leaves become slightly cupped, with their lower surface in contact with the water. Leaves are between 20 and 50 mm in width.

Primary stage phenet.



Secondary stage phenet



Courtesy of the University of Florida

ndrew Petroeschevsky

Mic Julien

A single salvinia plant in the tertiary growth stage, showing typical wedge shape.

Ridge-like thickenings on multilayered tertiary salvinia. At this stage the water surface is not visible and light is prevented from entering the water.

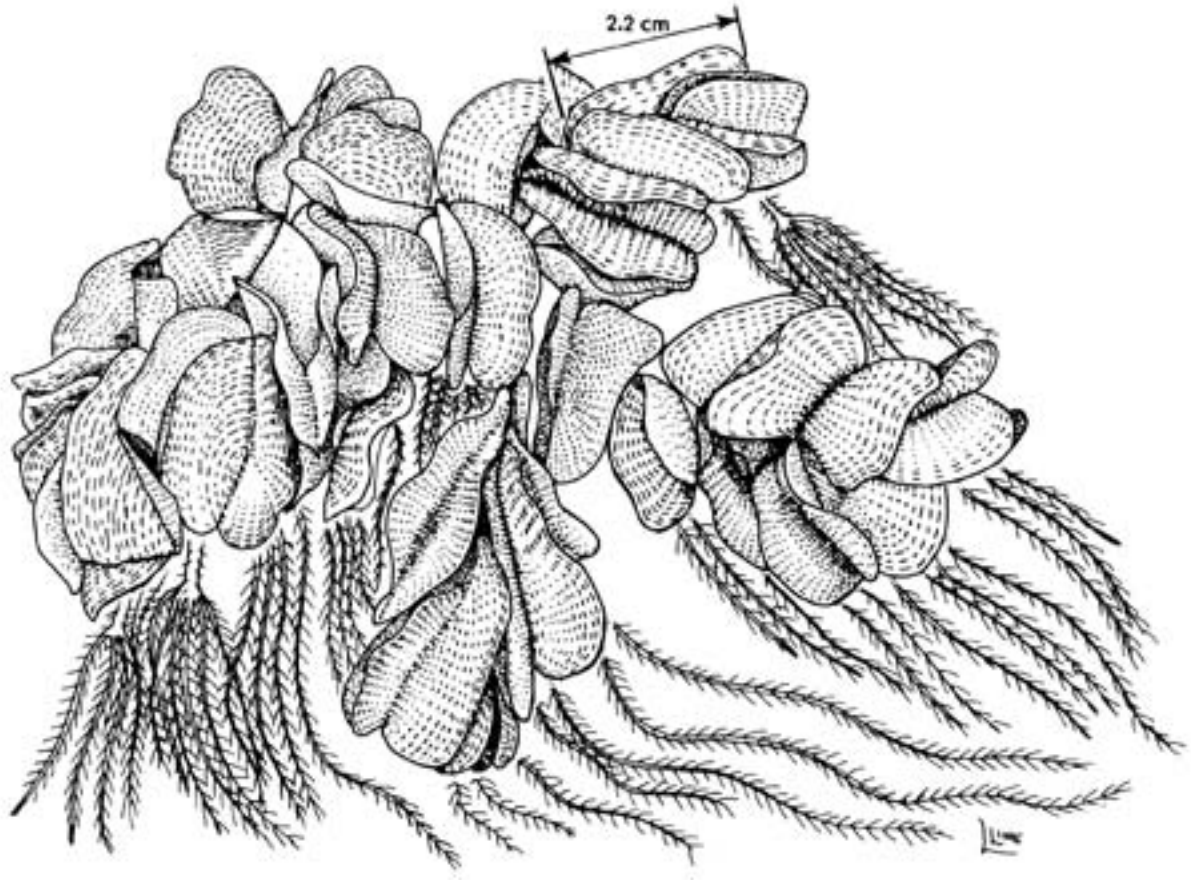
Tertiary stage

Tertiary growth occurs when plants become crowded in a mature infestation. Leaves become tightly folded and are up to 60 mm in width when forced open. Neighbouring leaves are pressed tightly against each other in an upright fashion, not in direct contact with the water. Leaves are kept wet through capillary action between their surfaces. The water surface is not visible, and light is prevented from entering the water.

Tertiary weed mats can become multilayered, displaying ridge-like thickenings as layers build up. Up to 30 000 ramets per square metre have been recorded in nutrient-rich water. Biomasses have been recorded at 400 tonnes of fresh wet weight per hectare.

Over time, other vegetation, including sedges, grasses, and small trees, is able to colonise thick multilayered mats, forming a floating island of vegetation referred to as a sudd.

Tertiary stage phenet



Courtesy of the University of Florida

Iain Jamieson

Salvinia will die in sea water.

Rebecca Coventry

Dead-looking frost affected salvinia.

Growth and reproduction

The salvinia that is currently present in Australia is incapable of sexual reproduction; therefore sporlings ('seedlings' of ferns) do not occur. The spore-bearing sacs (sporocarps) present among the root filaments have no viable spores and all reproduction is vegetative, via bud expansion and breaking of rhizomes.

The sporocarps present among the root-like filaments contain non-viable spores.

Courtesy of the University of Florida

Salvinia 'seedlings' do not occur

'Seedlings' are often mistakenly reported in field observations. New plants that form from a very small piece of stem with one set of small (2 mm) leaves can look like seedlings, particularly when they lodge on the surface of the mud at the edge of an infestation. Young duck weed plants are also mistaken for salvinia 'seedlings'.

Each ramet can exist independently, and therefore new plants form vegetatively whenever a rhizome breaks. Rhizomes break with age or damage.

Growth occurs at the ends of the rhizomes, where apical buds are present. New rhizome branches can develop from any ramet where axillary buds are present. Each bud can form a new branch of ramets, with the oldest branches eventually rotting and falling away. A growing salvinia plant displays this process in a zigzag pattern, giving rise to the wedge-shaped plants.

The continuing production of new plant material makes salvinia a self-perpetuating perennial under favourable conditions. A new plant can form from a piece of rhizome bearing a bud.

NRME Photo Library

New green leaves and buds can survive within the dead-looking weed mat.

Barry Powell

Yellowed nutrient poor salvinia.

Salvinia growth after 10 days at 30 °C.

Elissa van Oosterhout

Habitat and conditions for growth

Salvinia grows on still or slow-moving fresh water where nutrients are available, colonising open water or floating among other vegetation. Faster-flowing water is tolerated when other vegetation holds the salvinia in place.

Growth rates decrease by 25% in water that is 10% as salty as seawater. Growth is very slow in water that is 20% as salty as seawater, and plants die after 30 minutes in seawater.

Any depth of water can be colonised. A tertiary mat of salvinia can survive for up to 12 months on mud, as the plants beneath the top layer or next to the moist ground are sustained. In warmer climates very shallow water can reach temperatures above the preferred range for salvinia, making survival less likely.

Temperature

The ideal temperature for growth is 30 °C (air temperature), but growth can occur between 5 °C and 43 °C. Under laboratory conditions, the highest growth rates occur between 20 °C and 30 °C. Growth starts to increase above 10 °C and declines over 30 °C. Very little growth occurs below 20 °C. Plants die when the buds are exposed to temperatures below –3 °C or above 43 °C.

Regrowth after frost, drought or heat stress

Salvinia can regenerate after being drought stressed, heat stressed or frosted, with new green leaves appearing on a dead-looking brown weed mat. Frost kills exposed leaves and buds, but leaves and buds within the weed mat can survive provided that they do not freeze. Buds will also remain viable in dry or extremely hot conditions if they are protected inside the weed mat.

Nutrients

Nutrient levels can affect the appearance of the plant at any growth stage, but they are often difficult to measure. Nutrients are generally optimal when the salvinia is a healthy deep green (not yellowed, brownish or light green) and is growing vigorously as typical wedge-shaped plants. Long, thin, yellowish plants with very long roots and larger leaves are an indicator of low nutrient levels.

Plant health and nutrient levels can affect the success of biological control and some herbicides.

Temperatures and nutrients

There may be a relationship between temperature and nutrient levels. At low temperatures high nutrient levels can have an anti-freeze effect, allowing plants to survive conditions that are colder than normal; at high temperatures lower nutrient levels may lead to better survival.

Rates of growth

Growth rates are governed by temperature and nutrients. Nitrogen levels determine how many buds a plant will produce, and also how many buds will break their dormancy to grow into new rhizome branches. Higher levels of nitrogen increase the growth rates of existing branches and the production of new branches.

Under ideal conditions (30 °C with optimal nutrient levels) an infestation can double in size in **less than 3 days**.

Rates of growth vary according to climate zones, starting to increase as temperatures warm up, peaking in late summer, and slowing over the cooler months. Growth rates are therefore seasonal in southern Australia and relatively uniform throughout the year in northern Australia. There are no distinct seasonal periods for stages of plant development.

Salvinia washed onto a floodplain in the Northern Territory.

Anne Ferguson

Part 2: Managing salvinia

Salvinia management requires site-specific consideration. Priorities depend on the climate; the nature and use of the water body; the extent of the infestation; and the availability of resources. Control methods for salvinia include a biological control agent, a number of registered herbicides, and mechanical and manual removal methods. Management strategies should consider the use of these control methods according to the site-specific variables.

Climate

The distribution of salvinia across tropical, subtropical and temperate climates in Australia has implications for biological control. Management considerations for biological control in different climates are summarised in the Biocontrol Management Table (see *Biological control* in Part 3).

Seasonal growth rates associated with different climates also affect other control methods. Under ideal conditions salvinia growth can exceed the capabilities of mechanical removal or herbicide application (see *Herbicides* and *Mechanical removal* in Part 3).

Tropical climates

Tropical climates provide ideal conditions for salvinia growth. During the dry season, permanent water bodies, billabongs and waterholes provide perfect conditions for salvinia growth, as temperatures remain ideal. Flushing associated with the wet season usually moves infestations downstream to estuarine waters where the plant does not survive; however, salvinia can be washed out onto floodplains where fresh water can sit for months, allowing large infestations to build up. These usually dry out and die off when the water recedes, but some salvinia is likely to remain in these systems.

Problems arise when one or more poor wet seasons are experienced and flushing does not occur to the usual extent allowing salvinia levels to build up.

Subtropical climates

Subtropical climates provide ideal conditions for salvinia for most of the year. Growth will slow in the cooler months. Subtropical areas can be subject to prolific salvinia infestations, often without the benefit of a cyclical wet season to flush fresh water systems out.

Temperate climates

In temperate climates growth is more seasonal, with a definite slowing over winter. There is still enough time over the year when temperatures are high enough to allow prolific growth to occur.

Nature and use of the water body

The nature and use of a water body will often determine which control methods are appropriate. Infestations can occur in any still bodies of fresh water (such as dams, lakes and wetlands), as well as in rivers, creeks, drains, and channels when flows are slow or still. Water bodies have a range of uses and values, such as conservation, primary production, recreation and consumption.

Manipulating water levels

In some situations it may be possible to drain a small enclosed body of water, stranding an infestation and

George Wisemental

Salvinia on a farm dam.

Mel Schroder

Use of waterways may need to be restricted for salvinia control.

causing it to dry out and die. This requires follow-up treatment of any remaining sections where regrowth occurs (a multilayered mat stranded on mud can contain viable buds for up to 12 months).

Conservation areas

In conservation areas it is usually critical to keep salvinia at low levels to prevent impacts on other aquatic wildlife. Minimal use of herbicides, manual removal and biocontrol are relied on in areas of high conservation value. Some of the best examples of ongoing salvinia management occur in conservation areas, as the importance of follow-up is recognised (see *Myall Lakes National Park case study*).

Fish stocks

Some control methods can affect fish stocks by lowering the levels of dissolved oxygen that fish and other aquatic organisms use to survive. Decreases in dissolved oxygen (deoxygenation) occur when decomposing organic matter and bacterial activity consume oxygen. The reduction in available dissolved oxygen in the water causes fish to die.

Massive deoxygenation can occur if large amounts of salvinia die and sink at once, such as after broadscale treatment with herbicides (see *Herbicides* section). Deoxygenation can also occur as a result of successful biocontrol, but the effects are lessened as the process occurs over a longer period of time.

Stock watering, domestic use and potable water

If herbicides are to be used, check the product label for stock withholding or potable water withholding periods (see *Herbicides* in Part 3). Booms can be used to keep potable water offtake areas free of salvinia.

Irrigation

Salvinia can clog pump intakes and cause water losses from storage areas by increasing levels of evapotranspiration. Booms or meshed containment fences can be used to keep intake areas free of salvinia. If herbicides are used, check the product label for irrigation water withholding periods.

Recreation

Groups and individuals who use recreation areas where salvinia is present should be aware of salvinia and able to identify it. Aquatic weed hygiene practices should be observed (see *Aquatic weed hygiene* under *Planning a management strategy* below) so as not to spread salvinia to other areas on boats, trailers or watercraft. Recreational use of a water body should be restricted while salvinia control is being carried out. Signage and public awareness campaigns may be required, particularly when herbicides are used.

Extent of the infestation and availability of resources

The extent of an infestation depends on the length of time salvinia has been present in a system, the conditions (e.g. temperatures, nutrients) over that time, and other external factors such as the degree of flushing a system has been subject to. Primary salvinia growth will occur for as long as it takes for plants to become crowded on the water surface. The rate of growth will depend on the seasonal climatic conditions and the availability of nutrients. For example, salvinia may be introduced to a system at the end of autumn and remain scattered in primary form over the cooler months, only starting to build up into the secondary and tertiary forms the following spring and summer. Alternatively, salvinia may be introduced to a system in late spring and then rapidly build up to form an extensive infestation in a matter of weeks.

Early detection

If detected early, salvinia can be kept at low levels while plants are scattered and in the primary stage of growth. Containment, herbicide application and small-scale mechanical or manual removal will be required regularly (possibly weekly) over the warmer months to prevent the infestation progressing, and then each year thereafter (before and during each growth season). In some cases, small new infestations may be eradicated (see *Eradication* below).

Multilayered mats

Multilayered infestations require thinning to promote new regrowth so that herbicides and biocontrol are effective. Strip treatments with herbicides have been used to break up multilayered mats and promote new regrowth. Alternatively, some degree of mechanical removal will be necessary once a mat has become multilayered.

Reducing resource inputs over time

Cases have occurred where large stretches of river (up to 80 km) have become covered with multilayered salvinia over a single summer. Such extensive infestations on rivers often require very high levels of resources to bring them to a manageable level.

The initial high costs associated with controlling extensive infestations can be reduced over time with biological control, strategic use of herbicides and ongoing small-scale mechanical removal (see *Hawkesbury River case study* and *Ewen Maddock Dam case study*). Resource allocation should allow for monitoring and follow-up each year on an ongoing basis.

Eradication

There are very few situations where eradication is possible. These are usually restricted to new infestations (small amounts of salvinia found early) or small infestations on enclosed bodies of water (surface areas up to 1 ha) such as farm dams, where every plant can be treated or removed. Ongoing monitoring and follow-up treatments are required whenever regrowth occurs, until every plant has been removed from the system.

For eradication to be successful the source of the infestation needs to be found and contained, and time and resources need to be compatible with the extent of the infestation. Eradication will not be possible without dedicated follow-up effort and monitoring on an ongoing basis (for numbers of years). Bodies of water with emergent vegetation have less likelihood of eradication, as it is physically more difficult to retrieve or treat salvinia in amongst other vegetation.

Substantial infestations in conservation areas have been eradicated by extensive follow-up programs of manual removal and herbicide application (see *Myall Lakes National Park case study*).

Even if eradication is possible, there will usually be a threat of reinfestation. Most salvinia infestations require ongoing management and monitoring.

Planning a management strategy

Undertake planning and assessment as early as possible. As well as accommodating the site-specific variables mentioned above, it is important that you consider a number of factors that apply to all salvinia management strategies.

- **Contain the infestation where possible.** Containment is important for new or small infestations, or where an extensive infestation has the ability to invade new areas (see *Booms and containment* in Part 3).
- **Identify the source of the infestation.** Find, contain and manage upstream or off-stream sources. Check nearby garden ponds as these are often the source of an infestation.
- **Consider seasonal implications for the timing of control methods.** All the control methods are affected by either seasonal changes or corresponding salvinia growth rates. Take advantage of slow growth periods over cooler months (particularly after frosts) to carry out physical removal, and plan to carry out herbicide treatments as early as possible in the growth season (usually early spring). Starting herbicide treatments during peak growth periods may have little impact on an infestation. Some herbicides require active growth and some have minimum temperature requirements. Release biocontrol agents as early as possible in the growth season (see Biocontrol Management Table). Carry out monitoring and follow-up as early as possible each growth season (usually early spring).
- **Check for permit requirements.** Permits may be required if control treatments are likely to cause disturbance to an aquatic environment (including stream banks, stream beds, other vegetation, or water quality). Check with local and State government before undertaking any form of control.
- **Map the infestation and record changes.** If maps aren't available, draw a simple outline of the water body on an A4 piece of paper and make 24 copies (one per month for a 2-year period). This allows the areas that correspond to salvinia coverage to be sketched and recorded each month. Keep the series of drawings to show changes over time.

> *You've got to try and map it—make some guestimates so that you don't waste money.*
>
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- **Assess priority and available resources.** Small or new infestations in catchments that are relatively free of salvinia should be given higher priority for a complete eradication effort.
- **Allocate resources for ongoing control and follow-up.** In all cases ongoing control and follow up will be required. Even if the infestation is eradicated there is a chance of reinfestation, and monitoring will be required.

You'll never get rid of it completely on a river system—maybe on a farm dam where you can get to it all, but not on a river. From the second year onwards you have to keep monitoring weevils, re-releasing if necessary, checking for regrowth, and mopping up the hotspots with herbicide … and keep doing all that forever.

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- **Monitor the efficacy of control treatments.** Record where and when control treatments are carried out, and use photo reference points to record progress. Photographs can be taken from the same point of reference each time treatment or monitoring is carried out.
- **Identify and minimise sources of nutrients entering the water body.** Increases in nutrient levels can occur from a number of sources:
  - septic systems and grey water runoff
  - stormwater drains
  - intensive livestock handling or feeding areas
  - garden runoff
  - golf course runoff and leachate
  - cropping and agriculture
  - erosion of cultivated land
  - urban sewage outflows
  - industrial wastewater.
- **Carry out regular early detection surveys.** Identify areas at high risk of infestation by salvinia (or other aquatic weeds), and carry out early detection surveys in spring and summer, and after seasonal rain. Risk of infestation is higher in ponded or slow-moving permanent water bodies. Check areas known to receive artificially high nutrient loads from surrounding land uses (i.e. agriculture, horticulture, industrial land); and areas close to human activities or urban development (e.g. waterways near residential estates; bridge crossings; waterways beside parks; boat ramps).
- **Aquatic weed hygiene.** Ensure that good hygiene practices accompany any control operations to prevent spreading salvinia on boats, machinery and equipment. Boat hulls and propellers, scoops, trailers, harvesters and any other vehicles or equipment should be thoroughly washed down before they leave a control site. Small fragments of plants can reinfest a water body, and any parts of plants that do not dry out completely can remain viable for long periods of time (i.e. while equipment is stored between uses).
- **Act early.** Don't miss opportunities for early releases of biocontrol agents and containment that can occur during the planning stage.

Collecting samples for biocontrol monitoring by airboat.

Shon Schooler

Part 3: Control methods

Integrating control methods

Successful management is achieved when control methods are combined in order to put greater pressure on the weed, or to treat the weed according to the conditions in different sections of an infestation.

The variables associated with any infestation make it difficult to prescribe integrated control strategies. (These variables are discussed in Part 2: Managing salvinia.) The case studies in this manual provide examples of integrated control, and the following combinations[1] are useful in most situations:

- Herbicide spot spraying and manual removal methods are good follow-up techniques, once the bulk of an infestation has been removed through either mechanical removal or broadscale herbicide treatments.
- Herbicide strip treatments or small-scale mechanical removal can assist biocontrol by maintaining ideal weevil habitat (keeping the salvinia in a single, actively growing layer).
- Small-scale mechanical removal can be used to thin out multilayered salvinia, allowing herbicide applications to be more effective.
- Floating booms and containment can be used in combination with all of the control methods and generally increase the effectiveness of any control strategy.

In most cases managers will have to consider each control method and make decisions about how to combine them in site-specific management strategies.

Booms and containment fences

Containing floating salvinia allows for more effective use of control methods. Floating booms and containment fences can be used to:

- contain sections of salvinia in one area to minimise costs and the time required to carry out herbicide treatments or physical removal
- separate areas that have had different control treatments (i.e. different herbicides, herbicide and biocontrol, mechanical removal and biocontrol)
- keep certain areas salvinia free
- separate and protect biocontrol release sites from disturbances and other control treatments
- allow for monitoring of treatment efficacy
- collect regrowth and leftover salvinia for further treatment or removal
- prevent downstream spread
- allow for early detection of new infestations.

We've got one hotspot where we've got a permanent boom in, and every now and then we go in for one day and harvest out what's built up against the boom.

Booms allow for closer management, checking for herbicide efficacy, controlling movement, or separating sprayed or unsprayed weed.

We have booms in place across the river to keep track of how much weed there is, to gather it into one place for either spraying or harvesting, and to delineate the biocontrol areas.

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Rebecca Coventry

Using an industrial floating boom to contain salvinia.

Containing salvinia for biocontrol.

Tom Anderson

A small ag-pipe boom used to monitor downstream movement of salvinia.

Global Spill Pty Ltd

Heavy duty industrial boom with buoyancy chambers.

Global Spill Pty Ltd

Industrial boom with buoyancy chambers.

Types of booms

Small areas of salvinia can be temporarily contained by using a rope floating on the water surface, but for ongoing containment or for larger infestations a floating boom needs to sit approximately 10 cm above and below the water surface.

Floating booms range in size and capacity. Commercially available booms can be hired or purchased, or possibly borrowed from a marine or waterways authority. Smaller-scale booms can be made up in-house.

Booms need to be durable and strong enough to hold the considerable amount of force created by the weight and movement of the floating salvinia, the wind, tidal influences and currents. They can be designed to accommodate rises and falls in water levels (i.e. leaving some slack will accommodate small rises), and should also be designed to let go when floodwaters occur, so as not to lose the boom completely. Debris can damage or displace a boom.

Under ideal conditions salvinia growth can be so rapid that the build-up of biomass can tear out a boom embedded in concrete. At peak growth, booms should be used only to contain or separate relatively small sections of a weed mat while control is carried out.

Commercial booms

Industrial-strength booms are available commercially for oil spill control. Commercial booms are generally more durable than in-house designs, are able to cover larger spans, and can be used on a permanent basis.

> *Initially we had trouble finding suitable booms, oil booms were borrowed from the Maritime authority — new booms can be $55–$65 dollars per metre or more.*
>
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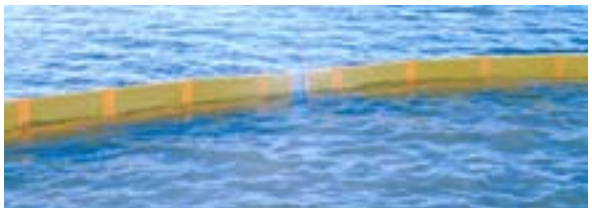


Global Spill Pty Ltd

Fence booms float upright in the water.

Rebecca Coventry

A fence boom containing salvinia.

Global Spill Pty Ltd

A curtain boom awaiting inflation of the air chamber

Rod Ensbey

This 60 metre long ag-pipe boom effectively retained tertiary salvinia until water levels rose after heavy rains.

Tom Anderson

A containment fence constructed at a causeway, used for monitoring downstream movement of salvinia.

Industrial booms are available in a range of sizes and capacities. They are usually constructed from high-tensile reinforced fabric with a polyurethane coating, with built-in buoyancy chambers.

Fence booms have a foam construction and float upright in the water (40% above, 60% below), creating a vertical barrier.

Curtain booms have a hanging curtain that prevents movement of material under the boom. This can prevent salvinia from pushing underneath the floating boom.

Ag-pipe booms

Floating booms can be made from unslotted agricultural pipe and can be effectively used to contain small areas of salvinia, with regular checking and maintenance. Experiences with floating ag-pipe booms up to 100 m long have been successful.

Elissa van Oosterhout

Use 100 mm diameter unslotted Polydrain® to make the boom.

Elissa van Oosterhout

Thread 5 mm diameter wire cable through the pipe.

Take 100 mm diameter unslotted black poly pipe (unslotted Polydrain®), thread 5 mm diameter wire cable through it, and attach it to star pickets to create a floating boom. Expanding foam can be used to seal the ends to prevent water entering the pipe and sinking the boom. Treeguard mesh or similar plastic mesh tubing can be used as a sleeve and fastened around the ag pipe with plastic ties. This creates a hanging curtain, which effectively retains the salvinia and prevents it from pushing under the boom.

Additional flotation may be required every 10 to 15 metres. Expanding foam can be injected into the pipe, or polystyrene floats attached to it.

Containment fences

Containment fences are used on smaller creeks, or across drains, channels, spillways, causeways or culverts where water is flowing and salvinia can be trapped. Fences help to prevent downstream spread, and can be used for monitoring.

You can use 10 × 10 mm mesh to construct a fence across a channel or culvert, and even hay bales and shadecloth can be used to contain infestations at dam spillways.

Containment fences can be permanent, but they need to be checked regularly (sometimes daily) and cleared of weed and debris.

A higher-gauge trash fence (10 × 10 cm mesh) placed above the containment fences will trap larger debris and prevent damage to the finer fences. However, containment fences are not usually designed to withstand floodwaters.

Treeguard mesh added to an ag-pipe boom retained tertiary salvinia over a period of heavy rains and water level rises.

Andrew Petroeschevsky

Elissa van Oosterhout

Placing booms and containment fences

Depending on its purpose, a boom may need to be placed across the main channel of water flow, or across inlets or still sections of water. Floating booms are affected by winds, strong currents and the rise and fall of water levels. If livestock have access to a water body they can destroy booms and fences.

Containment fences can be constructed at an angle to the flow (i.e. across only three-quarters of the channel on a bend in the creek) in a herringbone fashion, making use of a steady flow of water to deposit salvinia, and still allowing for movement of watercraft.

Shrinking boom technique

This method of using a floating boom to assist control is useful for enclosed water bodies because it allows work to be carried out over a number of days and with fewer resources. It also allows herbicides to be used in a way that is less likely to cause the massive deoxygenation of the water that can lead to fish kills.

Gradually constrict the boom around the infestation once a section has been sprayed and killed or physically removed. Repeat this until the main body of the infestation has been treated. Follow-up treatments for regrowth and around edges will be required.

Maintenance

Booms and fences usually need to stay in place for the duration of the management effort (i.e. a number of years, possibly permanently). All booms and containment fences should be checked regularly and routinely after rainfall, and cleared of debris. When possible, booms and fences should be removed or opened before flooding occurs.

*The adult salvinia weevil, **Cyrtobagous salviniae**.*

Mic Julien

Mic Julien

(TOP) The weevil causes the salvinia to turn brown.

The brown salvinia dies and sinks, leaving the water surface clear, with only low levels of salvinia remaining.

Biological control

Cyrtobagous salviniae (commonly referred to as the salvinia weevil) is the only successful biological control agent for salvinia in Australia. The weevils were brought to Australia from Brazil in 1980 by CSIRO. The first field release was at Lake Moondarra near Mount Isa. Within 11 months the weevils had destroyed an estimated 50 000 tonnes of salvinia on the lake, reducing the infestation to very low levels (see *Lake Moondarra case study*).

Subsequent releases in tropical and subtropical Australia have resulted in similarly successful levels of control. In temperate climates weevils may be effective when conditions are suitable (see *Temperature* below).

The salvinia weevil *Cyrtobagous salviniae*

The salvinia weevil is a small, dark, sub-aquatic weevil 2 to 3 mm long, with the characteristic elongated 'snout' of the weevil family.

Iain Jamieson

Adult weevil with five cent piece as scale reference.

Life cycle

Cyrtobagous salviniae has the typical weevil life cycle of egg, larvae, pupae and adult, with every stage occurring in, or on, salvinia plants. Development of all four stages is affected by temperature, and development of adults and larvae is affected by nutrient levels in the plants. In good conditions the life cycle can be completed in around 7 weeks (between 42 and 68 days). The complete life cycle is required for the weevil to reduce salvinia levels.

Eggs. Females deposit eggs singularly in cavities chewed in the stems, bases of leaves, and root stalks, or amongst the root filaments. Each female lays 2 to 5 eggs a day over 60 days, and only on plants in contact with water. In laboratory tests eggs hatch after 10 days at 25.5 °C.

Larvae. Newly hatched larvae feed externally on young leaf buds. After 3 to 14 days the larvae tunnel into the stems, where they complete their development in between 14 and 28 days, depending on the temperature.

Pupae. Pupation occurs under water amongst roots or at the bases of leaves in cocoons spun by the larvae, and pupal development takes between 9 and 15 days.

Adults. Newly emerged adults are light brown, darkening to black within 5 days. Adults can live for several months and can be found on, or under, leaves, within leaf buds or amongst the roots. They are able to stay underwater by breathing from a film of air held between their legs and abdomen. Adults feed on new

1 *Weevils starting to take effect in December 2003, Tweed Heads.*

2 *Biocontrol progress by mid January 2004 showing gradual browning.*

3 *Biocontrol progress by late January 2004 showing complete browning.*

4 *Biocontrol progress by early February 2004 showing salvinia starting to sink.*

5 *Clear water – successful biocontrol by mid February 2004.*

Karen Kranney

buds, preventing growth, and also on very young developing leaves and roots. Adults mate more than once, between 5 and 26 days after emerging from the pupal chamber.

Management considerations

Biological control will not eradicate salvinia. Weevils are able to reduce an infestation to very low levels, with small amounts of salvinia left growing along edges or in shaded areas, and open water mostly salvinia free.

Successful use of biocontrol allows a reduction in total control inputs over time. Other methods may still be required to maintain critical areas of open water or to keep the salvinia in a state that allows weevils to be effective. The use of biocontrol depends on the time frame and the climate.

Time frame

Biocontrol does not produce instant effects. Weevils need time and favourable conditions to build up a population that will reduce an infestation, and it is difficult to generalise about the time required. In tropical and subtropical climates weevils usually reduce an infestation in 2 years, sometimes less. In temperate climates it can take 3 or more years for weevil populations to increase enough to reduce an infestation (see Biocontrol Management Table). However, under ideal conditions weevils have reduced infestations in less than 12 months in tropical, subtropical and temperate areas.

If the presence of an infestation is unacceptable for any amount of time (i.e. if it occurs in a high-use recreation area or a high-value conservation zone), the bulk of the infestation can be removed with herbicides or physical removal. Biocontrol can then be used as part of the ongoing management.

Climate

Biocontrol is effective in tropical and subtropical climates where conditions are ideal for most of the year. In tropical climates weevil populations can be wiped out in water bodies that completely dry up during the dry season or by floods associated with monsoonal flushing. A combination of biocontrol and seasonal flushing provides good ongoing control of salvinia, but re-releases can be necessary if whole infestations (and therefore populations of weevils) are dried or flushed.

In temperate climates weevils take longer to build up populations and require more careful management and monitoring during release and establishment. In very cold temperatures weevils are able to seek refuge within the weed mat, particularly in areas that are sheltered by other vegetation, and can often survive well enough to build up populations when temperatures increase. Current research is looking at how well the weevil can survive and function in colder climates and how to best manage the weevil over a number of cold seasons.

The management considerations for different climate zones are summarised in the Biocontrol Management Table below. Refer to the *Temperature* section below for more information.

Biocontrol and eradication

In the few situations where eradication is considered possible, methods other than biocontrol should be used. However, most infestations cannot be eradicated and therefore biocontrol is an important management tool that should be used early in the management strategy.

BIOCONTROL MANAGEMENT TABLE: EFFECTS OF CLIMATE				
Climate	**When to release**	**Average time until effective**	**Effect of biocontrol**	**Biocontrol follow-up**
Tropical monsoon	End of wet season.	Generally 12–24 months	Will reduce salvinia to a low level.	Usually not required. Re-release if monitoring indicates weevils are not present, possibly after monsoonal flushing.
Subtropical	All year round. Avoid releasing in cooler months in southern areas.	Generally 18–36 months	Will reduce salvinia to a low level.	Usually not required. Re-release if monitoring indicates there is no presence of weevils.
Temperate	Early spring. Avoid releasing after Christmas.	3–4 years	Will reduce salvinia to a low level, but in some areas biocontrol may not achieve the level of control required and other methods will also be required.	Re-release if monitoring after winter indicates there are no weevils present.

Brown weevil-affected salvinia starting to sink.

Reece Luxton

NRM&E Photo Library

The biocontrol process

Both the adults and the larvae contribute damage to plants. Adults feed on new buds, preventing growth. This can stimulate the plant to produce more buds, which are subsequently eaten. This compensatory bud production eventually depletes the plant's reserves. Larvae tunnel through the stems and destroy the structure of the plant. Plants cannot tolerate this combined level of damage and eventually deteriorate, become waterlogged and sink. Weevil damage is apparent in the form of a gradually expanding brown area in the infestation. The brown salvinia eventually sinks, creating a widening area of open water in the infestation.

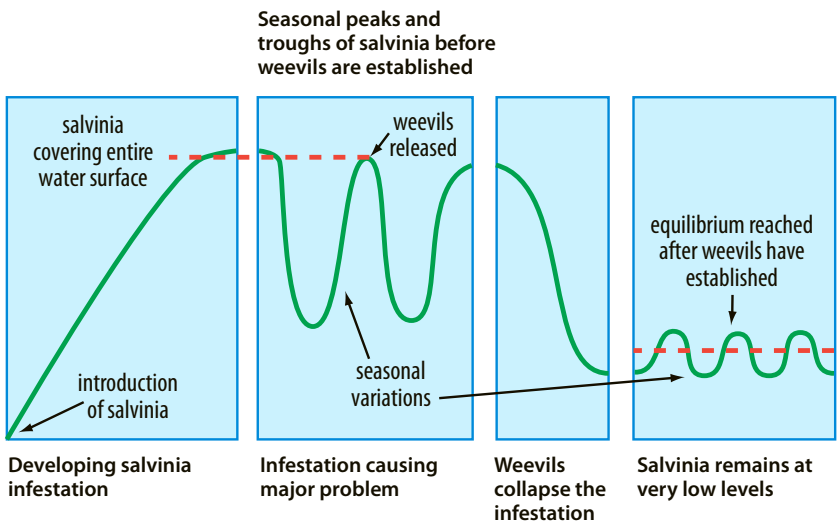
Peaks and troughs

In favourable conditions weevil populations increase rapidly, reducing their food supply (the salvinia) to such low levels that they starve and their populations crash. At population peaks adults and larvae can destroy buds faster than plants can produce new ones. Larvae and new adults die of starvation or, along with eggs and pupae, on waterlogged plants. The weevil population plummets, along with the salvinia level.

In response to weevil decline, the remaining salvinia may re-grow. After a time lag the weevil population responds to an increased food supply, and the whole cycle happens again. The salvinia and the weevils

Peaks and troughs in a salvinia infestation before and after release of salvinia weevils. Red dashed lines indicate levels of infestation.

(Adapted from Harley & Forno 1992).



Andrew Petroeschevsky

Herbicide strip treatments (brown sections) applied to weed mat to assist biocontrol.

go through this series of peaks and troughs until equilibrium or 'biocontrol balance' is reached, where the weevils maintain the salvinia at greatly reduced levels.

The cyclic process can occur on a seasonal or sub-seasonal basis, depending on conditions. It can take a number of years to reach the point where open water is largely salvinia free. Once established, the process is self-perpetuating. As long as weevils have not been removed from the system through flushing, drying out or extreme seasons, their numbers can increase again if salvinia levels increase. Monitoring and re-releases may be required after droughts, floods or extreme seasons.

Population density

The weevils can build up to levels of around 1000 adults per square metre before food declines to a level that reduces reproduction and causes the insects to starve or migrate. These figures will vary with location and climate. Modelling based on field observations indicates that a density of 300 adults per square metre will control salvinia in most situations.

Other biocontrol agents

The salvinia biocontrol moth Samea multiplicalis was also released in Australia and has become widely established. Although it causes localised damage to salvinia leaves, it will not control an infestation. Native moths are known to cause periodic damage to salvinia in the Northern Territory. Fish take refuge amongst the roots but are not thought to feed on salvinia. Aquatic snails may feed on the undersides of the leaves, causing minor damage to plants. Cattle may occasionally graze small amounts of weed. No organism other than the salvinia weevil will cause enough damage or remove enough weed to reduce an infestation.

Requirements for weevil survival

Habitat, temperature and nutrients are the most important factors affecting the survival, development and success of the weevil.

Habitat

Salvinia weevils are host-specific to the *Salvinia* species that occur in South America. In Australia, the weevil will not complete its life cycle on any other plant.

Weevils develop quickly in salvinia that is actively growing as a single layered infestation, in open areas where there is no over-storey vegetation. They will live in salvinia that is growing as an understorey, but for unknown reasons they are unable to control infestations under these conditions.

Providing ideal weevil habitat. Multi-layered infestations provide poor habitat for weevils. Weevils can survive in these conditions but will not build up to the numbers required to achieve control. Multilayered mats need to be thinned to encourage new regrowth, providing a better food source for the weevils. This can be done by either physical removal or herbicide strip treatments. Thinning should aim to maintain an actively growing single layer of salvinia. (Refer to *Releasing in multilayered salvinia* below and *Strip treatments* in the *Herbicides* section for more information).

Temperature

Weevils do not generate their own body heat. Their activity and survival are governed by the external temperature. The temperature chart on the next page shows the temperatures that are known to affect salvinia weevil activity under laboratory conditions, compared with the temperatures known to affect salvinia growth.

The optimum temperature range for weevil development is between 25 °C and 30 °C, and development can occur rapidly when ideal temperatures remain constant. Weevil activity declines above and below these temperatures.

High temperatures. Little is known about the effects of higher temperatures on weevils. In laboratory tests adults continue to feed at 33 °C, but most eggs fail to hatch when held at 37 °C. If temperatures reach the high 30s and low 40s, weevils move to parts of the plant just beneath the water, where temperatures are lower.

Low temperatures. Laboratory tests indicate that weevils cease feeding below 13 °C, eggs fail to hatch at 17 °C, and females stop laying eggs at 21 °C. The lowest temperatures at which adults cease activity and die are currently under investigation, with preliminary findings that females will start laying eggs at 19 °C.

As a field guide, air temperatures that are reaching only the low 20s for the warmest part of the day will cause weevil activity to slow down, with feeding and reproduction occurring only when temperatures exceed the thresholds for those activities.

Specific temperatures affect activity

Weevils respond to specific, rather then average, temperatures. Weevil activity will occur only during the hours of the day during which specific temperatures are maintained. For example, adults will only feed during the hours of the day when temperatures are above 13 °C. Then, as temperatures increase towards the optimum (between 25 °C and 30 °C), the rate of feeding will increase. Adults would be able to feed day and night, year round, if temperatures were to remain above 13 °C.

Weevil development will take longer if temperature-dependent activity fluctuates daily or seasonally, whereas weevils in continually optimum temperatures can achieve successful control in a much shorter time and can maintain year-round activity.

TEMPERATURES AFFECTING *SALVINIA MOLESTA* AND *CYRTOBAGOUS SALVINIAE* WEEVILS				
Salvinia	Temp. (°C)	Weevil		
Buds die when exposed to 43 °C temperatures for 2 hours	43			
	42			
	41			
No salvinia growth occurs above 40 °C	40			
	39			
	38			
	37	Most eggs fail to hatch at, and above, 37 °C		
	36	Optimum range for weevil development is between 25 and 36 °C		
	35			
	34			
	33		Adults feed normally	Percentage of eggs hatching is similar between 21 and 33 °C
	32			
Salvinia growth rates start to decline at 31 °C	31			
	30			
	29			
	28			
	27			
	26			
	25			
Highest growth rates occur at temperatures between 20 and 30 °C	24			
	23			
	22			
	21	Females fail to lay eggs at or below 21 °C (although current research is suggesting that they will begin to lay at temperatures as low as 19 °C)		
Salvinia growth slows below 20 °C	20			
	19	Most eggs fail to hatch at, or below, 19 °C		
	18			
	17	Larvae fail to develop at 17 °C		
	16			
	15			
	14			
	13	Adults do not feed below 13 °C		
	12			
	11			
Growth stops below 10 °C	10			
	5			
	4			
	3			
	2			
	1			
Exposed parts of plants die at 0 °C	0			
	–1			
	–2			
Buds die if exposed to –3 °C temperatures for 2 hours	–3			

Salvinia weevil breeding facility at the Grafton Agricultural Research and Advisory Station. Andrew Petroeschevsky

Other noxious aquatic weeds (small parrot's feather plants) in among salvinia plants taken from the field. Andrew Petroeschevsky

Nutrients

When nutrient levels are optimal, adults and larvae are able to maximise their nutrient intake by feeding on buds and new growth where nitrogen is concentrated. Adults are then able to lay more eggs, and the development of the eggs and larvae is faster, resulting in higher rates of weevil population growth and therefore higher and faster rates of damage to the salvinia.

Note: When nutrient levels are low salvinia growth will be poor and weevil development will be slow.

Measurements of percentage nitrogen in dry matter have been used to determine nutrient levels. These indicate that levels above 1.8% nitrogen are optimal for the weevil. Weevils have been able to establish populations on salvinia containing 0.8% nitrogen but growth is slow, yet other populations have failed to establish on salvinia containing 1.2% nitrogen. There may be critical densities at which weevils can achieve control when nitrogen levels are low (i.e. the population must have achieved a certain density before the nitrogen levels decrease).

Control will be fastest when temperature and nutrient levels are optimum

When both nutrients and temperatures are in the optimum range for weevils, weevil populations are able to increase at their fastest possible rate. Under such conditions mats of salvinia have been reduced by over 95% in less than 12 months.

Releasing weevils

Populations can be established either by releasing adult weevils or by introducing 'host' salvinia containing adults, larvae, eggs and pupae.

Obtaining weevils

Weevils are currently reared in breeding facilities in Brisbane (managed by Brisbane City Council), Bundaberg (managed by Bundaberg City Council) and Yeppoon (managed by Livingstone Shire Council); Grafton (managed by the NSW Department of Primary Industries Grafton Agricultural Research and Advisory Station); and Darwin (managed by the Department of Natural Resources, Environment and the Arts). Other facilities are planned for North Queensland. Local government authorities and councils have arrangements to obtain weevils from these facilities.

Note: Weevils should be obtained from breeding facilities. Transferring salvinia containing weevils from one infestation to another can spread other noxious weeds.

Storage and transportation

Weevils can be sent by courier or picked up from the breeding facility. Transportation is best in an air-conditioned vehicle. Overheating can sterilise or kill weevils.

Adults can be sent in concentrated numbers on small amounts of salvinia in takeaway food containers with air holes in the lids. Up to about 200 adults can be held in a takeaway container that is 10 cm high and 10 cm in diameter. To prevent overheating, containers of weevils must be placed inside an insulated polystyrene box or esky, kept moist and out of direct sunlight.

Alternatively, weevils can be transported on host salvinia in 40 litre tubs or bins or in hessian bags. There are usually about 200 adult weevils per tub or bag. Weevils in tubs of salvinia will be insulated as long as they are kept moist and out of direct sunlight.

Ensure that infestations have been positively identified as salvinia before you introduce host salvinia containing weevils.

Andrew Petroeschevsky

Weevil-infested host salvinia in 40-litre tubs.

Rod Ensbey

Releasing weevils at a site contained by a boom.

Do not keep weevils in containers for over 48 hours. Release weevils as soon as possible to maximise the chance that they will lay their eggs in the infestation rather than in the containers.

Selecting release sites

It is difficult for weevils to move upstream; therefore, releases should be made on the upstream side of an infestation and on infestations higher in the catchment. Additional releases can be made lower down the catchment.

Release sites should be protected from treatment with other control methods. Weevil establishment is more likely if the salvinia is not moved around by wind or currents, and releases are more successful in protected areas such as coves or inlets. Areas can be cordoned off with booms to allow weevil numbers to build up. When the population has established itself, the boom can be removed to allow the weevils to move into the surrounding infestation.

Weevils must be released in:

- actively growing salvinia
- open areas that receive direct sunlight for a major part of the day
- free-floating salvinia in at least 10 cm of water.

Do not release weevils in:

- old, brown or multilayered salvinia
- shaded areas where there is an over-storey of other vegetation
- shallow water that may dry up seasonally.

Releasing weevils in multilayered salvinia

If the salvinia is old and multilayered, weevils can be released into a small, contained area where most of the salvinia can be removed to encourage new regrowth (at least one-third of the contained area should be salvinia-free). Alternatively, an area can be sprayed with herbicide to promote new growth. Await regrowth before you make a release. Don't release onto herbicide-treated areas, as the salvinia is likely to die and sink or become unhealthy and not sustain the insects. Thin other sections of the multilayered mat to promote better conditions for the weevils, either by physical removal or by using herbicide strip treatments.

Rebecca Coventry

Releasing into new regrowth in a contained area.

Release numbers

Between 200 and 600 adult weevils should be released together into one small area (i.e. 1 square metre or less) of the weed mat. This allows the weevils to find mates quickly.

The number of releases needed depends on the size of the infestation and the available weevils. Populations can establish from a single release, but the more insects released, the greater the chance of survival,

Ideal release site conditions.

Elissa van Oosterhout

Introducing host salvinia containing weevils into one small area 4 metres from the water's edge.

Elissa van Oosterhout

establishment and rapid spread. As a rough guide, one release site every 500 to 1000 m (if the infestation is linear) or three releases over an area of 1 hectare will allow relatively fast dispersal of weevils.

Note: Do not spread weevils over the infestation or separate them into smaller numbers in an attempt to make multiple releases (at least 200 adults are recommended for a single release into one small area).

Release technique

Releases should be made 3 or 4 metres from the water's edge if possible. This will decrease the chance of the host salvinia being stranded if water levels recede.

Keep records of the release sites: GPS co-ordinates if possible; date of release; numbers of weevils released; approximate water depths; and health and growth stage of the salvinia. These factors can affect success.

A photo reference point (i.e. a landmark in the distance or a point on the bank) can be identified and used to record visual changes at the release site over time.

Introducing salvinia containing weevils. A rake can be used to make a small space (1 m diameter) in the weed mat where the salvinia containing the weevils can be placed in direct contact with the infestation. Choose an area where the salvinia looks healthy and is in direct sunlight. Make sure that the host salvinia is in contact with the water surface.

Releasing adult weevils. Adult weevils can be tipped from the small containers directly onto the infestation. Place 200 or more adults into the one small area (1 m in diameter).

When to release weevils

Release weevils as early as possible once an infestation has been discovered. In warm climates releases can generally be made at any time of year. In cooler climates it is best to make releases as temperatures begin to increase after winter. Early spring releases provide optimum time for the populations to build up over summer. In cooler areas releases should not be made after Christmas, as the weevils may not achieve the population densities they need to survive in viable numbers over winter.

Weevil dispersal

Weevils crawl across plants (a few hundred metres a month), or travel on salvinia plants that are moved by wind or currents. Weevils rarely take flight. There is some evidence that unfavourable conditions can stimulate their underdeveloped flight muscles, but this is not common. Weevil dispersal can be rapid within catchments but slow between catchments. It can be beneficial to help dispersal by manually distributing the weevils through an infestation once their numbers have built up around the original release sites.

Biocontrol monitoring

Monitoring aims to detect the presence of weevils and any increases in the damage they cause to plants over time. Damaged buds are the best indicator of weevil activity, as adults can be difficult to find on a plant. Because one adult is able to eat and damage a number of buds, there is a direct relationship between the amount of bud damage and the number of adult weevils present in an infestation.

Monitoring is most important at release sites to determine whether weevil populations have established and are increasing.

Monitoring regimes

Because of climatic effects it is necessary to carry out different monitoring regimes in different climates.

Elissa van Oosterhout

Counting and recording damaged buds on plants may be easier at a desk until you are confident with the task.

Andrew Petroeschevsky

Select the newest, greenest set of paired leaves on each plant.

Monitoring in tropical and subtropical climates. Monitor release sites monthly, looking for the presence of, and an increase in, bud damage over a 4- to 6-month period in optimal conditions.

If there is no presence or increase, check that conditions at the release site are optimal, and check for external influences such as physical disturbance, treatments with herbicides, or spray drift from insecticides.

Monitoring in temperate climates. Monitor release sites monthly over late spring, summer and autumn, looking for the presence of, and an increase in, bud damage by the end of autumn.

If there is no presence or increase, check that conditions at the release site are optimal, and check for external influences such as physical disturbance, treatments with herbicides, or spray drift from insecticides.

In the following late spring, summer and autumn, monitor release sites to see if weevils have survived over winter; once again, look for the presence of, and an increase in, bud damage over this period.

If there is no presence or increase they may not have survived the winter. Check all release sites, as some may have provided better over-wintering conditions.

Simple monitoring techniques

In the field it is easier to record damaged bud counts if one person checks the buds and another person records the counts. The counter can wade out to the release site or pick up plants from the bank with a long-handled rake. Alternatively, plants can be collected from an infestation and taken back to a desk for counting, within 24 hours of collection. Ensure that appropriate permits have been obtained under State Government legislation to transport and dispose of the salvinia for this purpose.

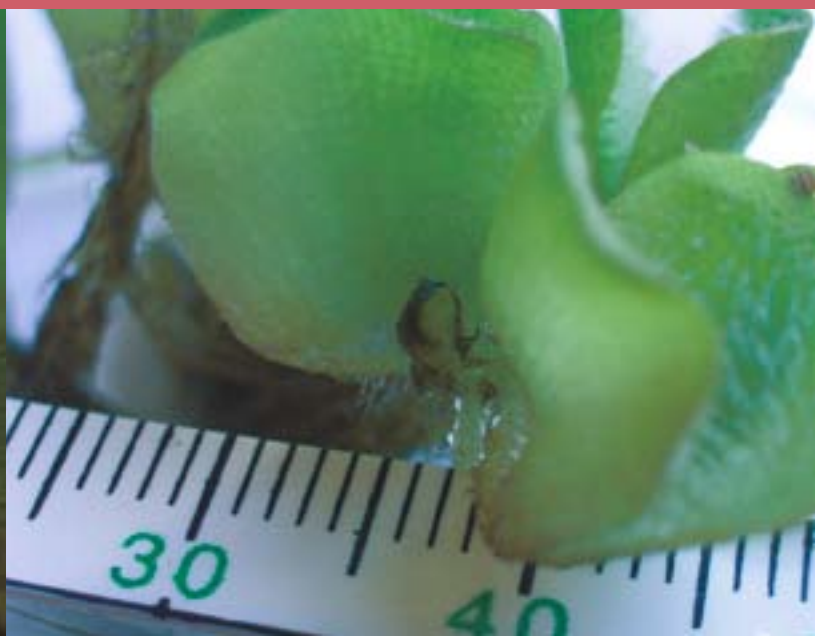
Andrew Petroeschevsky

Separate the leaves to expose the stem and bud.

Elissa van Oosterhout

A probe may help to locate the bud.

Healthy, firm, light green bud.



Healthy bud with dark plant hairs.

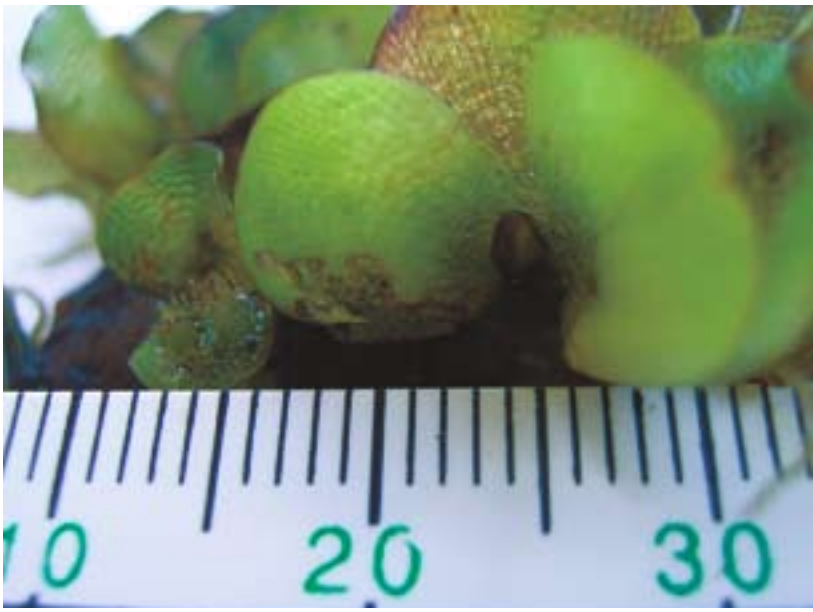
Count damaged buds. Take a sample of at least 50 plants from each release site, over an area of between 1 and 4 square metres. Check one bud on each plant for damage and record counts. Only the bud between the newest set of paired leaves is checked for damage (one bud per plant). Plants should be taken from the same general area each time monitoring is carried out.

Pick up a plant and select the newest, greenest set of paired leaves (usually the last set of leaves growing from the pointy end of a wedge-shaped plant, also known as the end ramet).

Using fingers or a probe, separate the young leaves to expose the stem and new bud (also known as the apical bud on the end ramet). A bud can be at various stages of development. Select another plant if the bud has begun to separate into a set of new leaves, or if a very new bud is difficult to assess (i.e. if it is difficult to tell the bud from the stem), or if the bud is gone completely. For this reason you will need to collect a sample of more than 50 plants.

Assess the bud for damage. Damaged buds look black or brown **and** feel soft and mushy. Some new buds look brown or black because of their coverings of dark plant hairs. Healthy buds are always firm, and usually light green. Use a probe or roll the bud between your fingers: soft, mushy buds are quite obvious to the touch. Always check for firmness to determine whether they are damaged. Keep counting until 50 buds have been checked for weevil damage. Checking a sample of 50 plants for damaged buds should take no longer than 15 minutes once you have practised.

Discount moth damage. Larvae of *Samea multiplicalis*, the salvinia biocontrol moth, also cause visible damage to plants, making irregularly-shaped chewing holes in the leaves. Moth larvae may also chew buds, but only buds that are blackened and mushy to touch are indicators of weevil damage. Moth larvae damage makes plants look untidy and tattered. Windows or holes in mature leaves are also very likely to be moth



Brown, soft, damaged bud.

Blackened, rotten damaged bud.

Andrew Petroeschevsky

Andrew Petroeschevsky

Moth larvae causing damage to leaves.

Elissa van Oosterhout

Use wire mesh to submerge salvinia in a tub of water.

damage. Plants will recover from moth damage and continue to grow. The damage caused by weevils will eventually kill a plant.

Record numbers of adult weevils. Numbers of adult weevils that can be seen on plants are not a good indicator of their presence or activity (there may be hundreds of adults present and none will be seen). It is, however, useful to record the numbers of adult weevils that you see while you are checking each plant for bud damage. The numbers of adults seen will be much lower than the number of damaged buds present (see sample graph below). You are also less likely to see adult weevils if plants have been collected from the infestation and taken elsewhere for counting.

The presence of brown weevils (new generation adults) is an indication that the population is not only present, but reproducing. It can be useful to record the numbers of brown adults seen, particularly after winter and in temperate areas. The numbers of brown adults seen will also be very low in comparison with the number of damaged buds.

Adult weevils can be counted relatively accurately by the **submerged extraction method**. Submerge a sample of between 0.5 and 1 square metre of salvinia in a large tub of water and place a wire mesh (fine chicken wire) over the top. The mesh needs to be weighted down to hold the salvinia under the water.

Scott Bauer

A presence of brown weevils indicates the population is reproducing.

Leave one or two salvinia plants floating on the surface. After 24 to 48 hours, most of the adult weevils present in the salvinia will have come to the surface and taken refuge on the floating plants.

Note: The **submerged extraction method** is necessary only if it is vital to know that adults are present. Counts of damaged buds are an excellent indication of weevil presence and activity for biocontrol monitoring purposes.

Graphing the results

Counts of damaged buds and adults can be converted to a percentage and graphed to show an increase or decrease over time. Weevil populations are complex, and it is difficult to generalise about the densities required to cause fatal damage to plants. In rearing facilities weevils have been known to collapse an infestation shortly after 80% of buds have shown damage. Counts of 10 adults per 100 plants also indicate that a weevil population is increasing to the point of causing major damage to an infestation. However, the most important result is the **presence of, and increase in numbers of, damaged buds** over time.

If release sites are showing good presence of, and increase in, weevils and damage, or if the release site starts to brown off and sink, take a sample from an area a short distance away from the release site where the salvinia is still green and healthy. It is not necessary to routinely monitor beyond release sites, except to reassure yourself that the weevils are moving through the infestation.

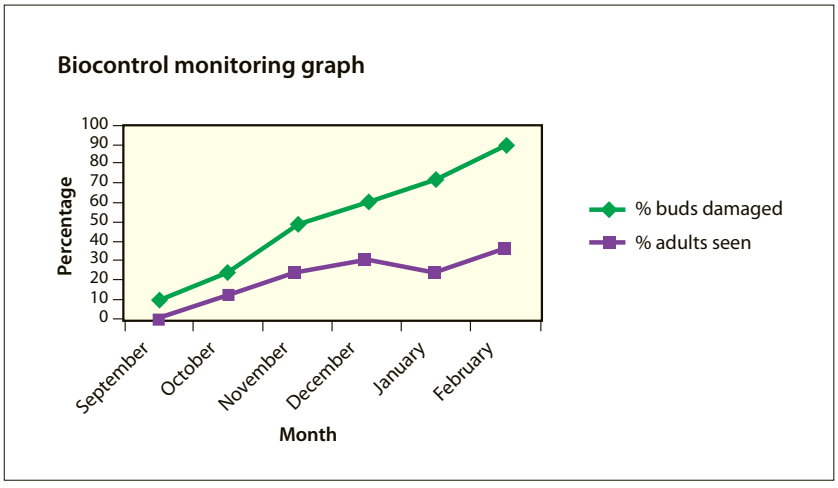
The following table and graph are hypothetical counts that could occur at a release site. Actual field counts can be much lower than this over a similar time period, but they would still indicate that weevils are present and increasing.

Andrew Petroeschevsky

Collect the weevils on the refuge plants 24-48 hours later.

Biocontrol monitoring data example		
Month	**% of damaged buds in 50 plants**	**% of adults seen on 50 plants**
September	10 (i.e. 5 buds out of 50 were damaged)	0 (i.e. 0 adults were seen on 50 plants)
October	24 (i.e. 12 buds out of 50 were damaged)	6 (i.e. 3 adults were seen on 50 plants)
November	48	12
December	60	15
January	72	14
February	90	18

Results of biocontrol monitoring example



Get to know the biocontrol process

Knowing the cycles that occur during the biocontrol process takes a number of years of observation and monitoring. To begin with, it is difficult to predict when interventions (i.e. re-releases or use of other control methods) will be required. Over time, patterns become more apparent.

Elissa van Oosterhout

New regrowth in herbicide-treated salvinia.

Herbicides

Herbicides are used to their best advantage as part of an integrated management strategy. Extreme care must be taken in order to apply herbicides legally, effectively and safely in and around water.

Management considerations

There are no situations where a single application of herbicide will provide ongoing control of salvinia.

Initial treatments will always need to be followed up with further treatments. This is supported by research trials showing that a good initial knockdown after herbicide application can be misleading, and that regrowth is likely to occur after treatment with any of the registered herbicides. The decaying biomass of sunken herbicide-treated salvinia will also return nutrients to the water, creating ideal conditions for regrowth of surviving plants and making the need for ongoing follow-up and monitoring more critical.

Correct application

Some of the registered herbicides receive negative reports after field applications, probably because of incorrect application and failure to monitor treatment efficacy for a sufficient time period after the initial treatment. Each registered herbicide has a different mode of action and specific requirements to be effective (see *Herbicide Table*). All of the registered herbicides require follow-up.

Timing of applications

There is generally a greater window of opportunity for herbicide applications over the warmer months; however, there is also the possibility that salvinia growth rates during the warmer months can exceed herbicide kill rates (see quotes in the boxes on this page).

> *I've had situations in the subtropics where we've been out spraying all day and you come back the next day and you can see the browning, but the mat has grown out beyond where you started from.*
>
> **National Salvinia Workshop**

> *Near Mt Isa in Queensland they were using helicopters to boom spray it in summer, but they gave that up because the salvinia was growing faster than they could spray it.*
>
> **National Salvinia Workshop**

Using herbicides in and around water

Herbicide use in and around water may require a licence. Each State and Territory has regulations for the use of herbicides in and near waterways, and a licence to use herbicides in aquatic situations may be required. Check with your relevant government department for details.

When using herbicides in and near waterways:

- always consider alternative control methods and use herbicides only when other options are not available
- use herbicide products that are registered for use in aquatic situations (or allowed to be used under an off-label or minor use permit issued by the Australian Pesticides and Veterinary Medicines Authority (APVMA)

- use all herbicides strictly in accordance with the directions specified on the registered label (or in accordance with the conditions specified in an off-label or minor use permit issued by the APVMA)
- keep detailed records of all herbicide applications (this is a legal requirement in most States and Territories).

Effects of herbicides on aquatic organisms

Herbicides can affect fish and other aquatic organisms through deoxygenation of water caused by decay of the biomass of the treated weed, or through contamination of the water with high concentrations of the herbicide itself. Both effects can kill fish.

Deoxygenation

Deoxygenation can be minimised by treating sections of an infestation in strips no larger than 25% of the infestation at one time, with up to a week between treatments. Some herbicide labels specify the proportion of the infestation to treat and the time to leave between treatments (see *Herbicide Table*). Starting strip treatments close to the shore or bank and moving out towards the middle of the water body allows fish to move towards the untreated areas. Use booms to contain unsprayed areas between strip applications (see *Shrinking boom technique* in *Booms and containment* section).

Edge treatments or follow-up treatments on smaller amounts of regrowth are less likely to cause enough deoxygenation of the water to affect fish. Warmer water temperatures and prolonged cloudy weather can exacerbate the effects of deoxygenation, and the potential for fish kills is higher in situations where fish movement is restricted (i.e. in small dams).

Contamination

Contamination of the water can occur if herbicide is applied at higher than registered rates. It is important to calibrate all spray equipment to ensure that you are using only the registered rates. Most aquatic herbicides have very low toxicity to fish, and the concentrations that occur after application at registered rates are far lower than those that are toxic to fish. Some permits require a certain concentration of the herbicide not to be exceeded in a water body; this is stated in parts per million (ppm).

Calculating parts per million (ppm)

If the volume of the water body is known, the amount of herbicide needed to create a certain concentration in ppm can be calculated. Be careful in noting whether it is the concentration of the active chemical constituent or that of the herbicide solution (i.e. the product mixed with water) that is specified.

In metric measures, ppm can be calculated on the basis of the fact that 1 litre in 1 million litres (1 megalitre or 'ML') equals 1 part per million. Therefore:

1 L in 1 ML = 1 ppm
1000 mL in 1 ML = 1 ppm
1 mL in 1000 L = 1 ppm
1 g in 1000 L = 1 ppm

In comparison with the possible effects of herbicides, the effects of complete coverage of a water body by salvinia can be equally detrimental to fish and aquatic organisms in terms of lowering dissolved oxygen levels, changing the temperature profiles in the water, changing water chemistry and reducing light penetration.

Herbicides registered for salvinia

Herbicides registered for the control of salvinia are listed in the Herbicide Table, and their use is discussed below.

Diquat

Diquat is a contact herbicide that causes rapid desiccation of broadleaf weeds. Diquat can be used as an initial knockdown agent on dense mats of salvinia, but plants must be displaying active growth. Diquat is known to be ineffective on low-density salvinia infestations; this reinforces its best use as a knockdown treatment for dense, actively growing mats. Use of the recommended wetting agent will increase effectiveness.

Lower-concentration products are available (20 g/L diquat), and these are specified for use as chemical edgers or spot spray.

Use clean water for mixing solutions, as suspended soil particles will interfere with herbicidal action. Diquat becomes inactivated on contact with clay particles.

Note: Misting machines and controlled droplet applicators must not be used to apply diquat.

Diquat for knockdown, calcium dodecyl benzene sulfonate for follow-up

Diquat can be used effectively in tandem with calcium dodecyl benzene sulfonate, where the diquat herbicide is used as an initial knockdown agent on dense mats and the calcium dodecyl benzene sulfonate is used as a follow-up treatment once some water surface is visible between plants.

Diquat breakdown in water

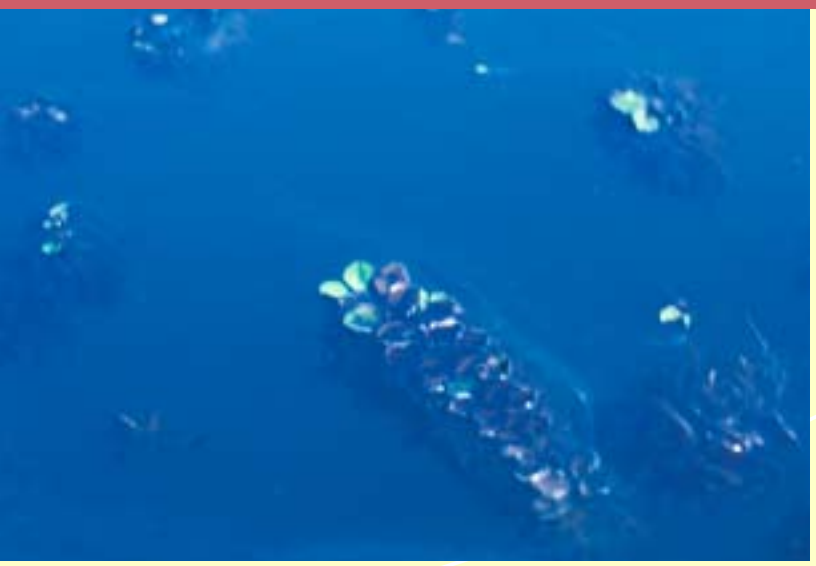
Diquat is rarely found longer than 10 days after application and is often at levels below detection 3 days after application. Diquat is taken up by aquatic vegetation and bound tightly to clay particles in the water and the bottom sediments, where it becomes biologically unavailable. When bound to organic matter it can be slowly broken down by micro-organisms. In foliar application, it breaks down to some extent on leaf surfaces exposed to light, and a small proportion is held within the plant tissues and eventually broken down when the plant decays.

Calcium dodecyl benzene sulfonate 300 g/L (Immerse®, previously available as AF100®)

Calcium dodecyl benzene sulfonate is an oil-soluble surfactant in a hydrocarbon liquid which, when mixed with kerosene, spreads out over the water surface in a very thin layer. Because of its lower surface tension, the layer is able to penetrate among the surface hairs of salvinia, reducing its buoyancy and sinking the plant. Because of its mode of action, this chemical specifically targets free-floating aquatic ferns, leaving plants other than aquatic ferns undamaged.

This herbicide must be applied in large droplets to the surface of the water between the plants. This allows the mixture to move over the plants. It will not work on solid mats where no water surface is visible. Therefore, it should be used only on primary or early secondary stage infestations or for follow-up applications on regrowth or around edges once the bulk of an infestation has been removed.

HERBICIDE TABLE: HERBICIDES REGISTERED FOR THE CONTROL OF SALVINIA			
Herbicide	**Registered use**	**Application and rate**	**Comments**
Active constituent: **diquat 200 g/L** Registered products: **Reglone®** **Sanction 200 Non-residual Herbicide®** Poison schedule 6	Salvinia in aquatic areas. Registered for use in all States. Withhold treated water for human consumption, livestock watering or irrigation for 10 days after application. Usage must not exceed 1 part per million of active constituent in a body of water.	5 or 10 L/ha 400 mL plus 150 mL Agral 600® (surfactant) per 100 L water Boom spray, high-volume spot spray or aerial application. Do not apply with misting machines or Controlled Droplet Applicators.	Apply as an overall spray, wetting foliage thoroughly. Clear water is necessary for best results, as suspended particles interfere with herbicidal action. Use higher rate for deep or dirty water. A repeat application 7 to 14 days later may be necessary to control dense infestations. Oxygen depletion from decaying weeds may occur; therefore, to ensure adequate oxygen supply for fish, not more than a quarter of an area should be treated at any one time. Observe withholding period.
Active constituent: **diquat 20 g/L** Registered products: **Vegetrol®** **Watrol®** Poison schedule 6	Salvinia in aquatic areas. Registered for use in all States. Use as a spot spray. Do not use treated water for human consumption, livestock watering or irrigation purposes for 10 days after application.	50–100 L/ha at 4 L per 100 L water Do not apply with misting machines or Controlled Droplet Applicators.	Apply as an overall spray. Thoroughly wet foliage. Best results will occur if water is clear. Use higher rate for heavy weed infestations or for deep or dirty water. Treatment of dense water-weed area can result in oxygen loss from the decomposition of dead weeds. This can cause fish suffocation. Treat only one-third to one-half of the dense weeds at a time and wait 10 days between treatments. Observe withholding period.
Active constituent: **calcium dodecyl benzene sulfonate 300 g/L** Registered product: **Agricrop Immerse® Floating Herbicide** (previously available as AF100®) Poison schedule 5	Salvinia in aquatic areas (drains, channels, margins of streams, lakes and dams). Do not use in potable water. Registered for use in Qld and NSW only.	1 part in 19 parts kerosene Apply 1 L of mixture per 100 m^2 Light sprinkle spray (large droplets) onto free-floating plants and visible water surface—enough to change their normal colour (plants will darken to greenish brown).	Do not use in potable water. Salvinia plants must be floating in water with a visible water surface between plants. Do not spray onto solid mats of salvinia. Sprayed areas are instantly visible.
Active constituent: **glyphosate 360 g/L** **products specifically registered for use in aquatic situations, and with off-label registration for use on salvinia** Currently registered products are listed in the Glyphosate Permit Table. Poison schedule 5	A small number of specific minor-use and off-label permits have been issued by the APVMA for the use of glyphosate for salvinia control in certain areas. See the Glyphosate Permit Table for details. Must be used only in accordance with the conditions set out in each permit.	Rates and application are specified in each permit. Use a low-volume, low-pressure boom sprayer, Controlled Droplet Applicator or sprinkler sprayer to avoid submerging floating weeds at the time of treatment.	Do not treat weeds under poor growing or dormant conditions. Apply when actively growing. Rainfall occurring up to 6 hours after application may reduce effectiveness. Heavy rainfall within 2 hours of application may wash the chemical off the foliage and a repeat treatment may be necessary. Do not submerge treated plants, as this may result in the spray being washed from the plant surface, reducing effectiveness. Treating the area in strips may avoid sudden impact on habitat. Reduced effectiveness may occur if water contaminated with soil particles is used for mixing.
Active constituent: **orange oil 55.2 g/kg and 195 g/kg surfactants** Registered product: **Water Clear®** Aquatic Weed Control	Salvinia in artificial impoundments and enclosed bodies of water (golf course dams and lakes, minor water impoundments, ornamental lakes) in NSW and Qld only. Not for use in natural water bodies, or in streams where it will reach natural water bodies. Do not use in dams holding water for human use. For the control of salvinia in non-potable water exclusively by operators under supervision of Polo Citrus Australia Pty Ltd.	Mix 1 part product with 100 parts water. Spray onto free-floating plants lightly—enough to change their normal colour (plants darken and show an oily sheen) Apply with hand-held spray equipment as close to the infestation as possible, using coarse droplets.	Avoid a single heavy application; instead, apply several light applications over a 1–3 week period. Apply when weed infestation is small, rather than advanced. Do not spray dense solid mats with no visible water surface. Water bodies with an average depth of less than 1 metre should not be treated.



Tom Anderson

Regrowth of leaf pairs after initial treatment with calcium dodecyl benzene sulfonate indicates another application is required.

For salvinia control, calcium dodecyl benzene sulfonate can be applied:

- at any temperature
- at any time, but just after rain or dew while the salvinia is still wet can be extremely successful
- only to salvinia where there is a visible water surface between plants
- only to salvinia that is floating in some depth of water, not lying in, or on, mud.

Applications usually need follow up, as indicated by regrowth from leaf pairs (see quote).

Calcium dodecyl benzene sulfonate treatment

A few days after the first treatment the plants will have sunk to just beneath the water level, and then the next pair of leaves will come up from underneath and start to grow, and that's when you need another treatment … it depends on the temperature and how healthy the salvinia is, but whenever a pair of new leaves come up you need to reapply it—you usually need at least three applications and anything from a week to three weeks between applications.

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Environmental considerations

Calcium dodecyl benzene sulfonate mixed with kerosene was considered for use in national parks by the Australian Nature Conservation Agency. This agency found that it causes relatively little disruption to the environment because of its low persistence in soil and water, its low hazard to the user, and its low hazard to mammals, fish and other plants from residue in water. The application of large droplets prevents spray drift from occurring, and the chemical is not water soluble (only floating on top of the water). Although kerosene has a toxic effect on plants, the kerosene component volatilises quickly (within hours in direct sunlight) and the calcium dodecyl benzene sulfonate takes between 24 hours and 7 days to vaporise, depending on weather conditions (it takes longer on overcast days). The mixture does not bioaccumulate.

Some impact is to be expected on native free-floating aquatic ferns if they are present, and there is little information on how frogs are affected. Despite some negative impacts, the Australian Nature Conservation Agency considered it to be an appropriate herbicide to use in environmentally sensitive areas that are threatened by salvinia, with careful site-specific consideration of whether endangered species or habitat would be harmed.

Note: Immerse® is registered for use in Queensland and NSW only. For use in other States, an off-label permit should be obtained from the APVMA.

Elissa van Oosterhout

Small patches of bright green reqrowth occurring one week after initial treatment with glyphosate herbicide.

Tom Anderson

Glyphosate herbicide used to expose the shoreline of a farm dam.

Glyphosate

Glyphosate is a systemic, non-selective herbicide that can kill many annual and perennial broadleaf plants and grasses. It is absorbed by foliage and green stems, and moves through a plant from the point of contact into the root system. Visible effects of glyphosate on salvinia can take between 3 days and 3 weeks, when complete browning occurs and plants eventually die and sink. Repeat applications are necessary, as regrowth will occur.

Glyphosate is inactivated upon contact with soil with sufficiently high clay content. In water it binds to dissolved and suspended clay particles and bottom sediments and becomes inactive. It is broken down into carbon dioxide, water, nitrogen and phosphorus over several months.

Apply glyphosate:

- under a current off-label permit from the APVMA (only small numbers of permits are currently held, see Glyphosate Permit Table below. Apply to the APVMA to obtain a permit for glyphosate use on salvinia in other areas).
- at water temperatures above 18 °C (water temperatures below 18 °C may give poor results)
- when the salvinia is actively growing
- to single-layered infestations (it will not kill multilayered infestations).

Note: Misting machines must not be used to apply glyphosate.

Using glyphosate to expose the shoreline

When salvinia is present among bank and edge vegetation, it may be possible to completely remove the vegetation in order to get access to the salvinia. This will depend on the type of vegetation and whether it is protected under State or local legislation. A permit to remove or interfere with native vegetation may be required under State vegetation protection laws. Glyphosate can be used to kill the edge vegetation, exposing the shoreline and allowing better access to salvinia around the edges of the water body. This may not be appropriate for infestations in natural waterways but will help if eradication is a feasible objective.

Orange oil

Orange oil herbicide has a relatively restricted registered use for the control of salvinia, but it can be used in specific situations under the supervision of the manufacturer. It appears to be used mainly by operators that have a preference for herbicides with lower poison scheduling, in situations such as ornamental ponds in urban areas and golf courses. Orange oil herbicide has been used in Brisbane to give successful control of primary form salvinia.

Note: Water Clear® is registered for use in Queensland and NSW only. For use in other states, an off-label permit should be obtained from the APVMA.

GLYPHOSATE PERMIT TABLE SHOWING CURRENT APVMA PERMITS FOR THE MINOR AND OFF LABEL USE OF GLYPHOSATE FOR SALVINIA CONTROL.			
APVMA permit type and number	**Products listed in permit**	**Situation and jurisdiction of permit**	**Permit holder**
Minor use permit PER7784	Roundup Biactive Herbicide by Monsanto 360 g/L glyphosate Nufarm Weedmaster Duo 360 g/L glyphosate Nufarm Credit Broadhectare Herbicide 540 g/L glyphosate Nufarm Bonus Adjuvant/Surfactant Or other registered products with the same level of active constituents as their only active constituents and that are registered for use in aquatic situations.	Hawkesbury-Nepean river system only. Permitted use with rates and applications by nominated persons only, as specified in the permit.	NSW Department of Primary Industries
Off-label permit PER5283	Roundup Biactive Herbicide by Monsanto 360 g/L glyphosate Nufarm Weedmaster 360 Herbicide Nufarm Weedmaster 360 Weedkiller Plus any other registered glyphosate products approved for use in aquatic situations and containing only 360 g/L glyphosate present as iospropylamine salt as their only active constituent. Nufarm Credit Broadhectare Herbicide 540 g/L glyphosate Nufarm Bonus Adjuvant/Surfactant	Salvinia in flowing creeks and stationary canals and dams in Wollongong and Shellharbour City council areas and Kiama Municipal Council area. Permitted use with rates and applications by nominated persons only, as specified in the permit.	Illawarra District Noxious Weeds Authority, NSW.
Minor off-label use permit PER4278	Roundup Biactive Herbicide by Monsanto 360 g/L glyphosate Plus any other registered products approved for use in aquatic situations and containing 360 g/L glyphosate as their only active constituent.	Salvinia in swamp at Lot 1 DP 832946, North Moruya. Permitted use with rates and applications by nominated persons only, as specified in the permit.	Eurobodalla Shire Council, NSW.
Minor use permit PER7000	Roundup Biactive Herbicide by Monsanto 360 g/L glyphosate Plus any other registered products approved for use in aquatic situations and containing 360 g/L glyphosate as their only active constituent.	Salvinia on farms and in dams and watercourses in the North Coast Weed Control District (Far North Coast Weeds, Clarence Valley, Coffs Harbour, Bellingen and Nambucca). Permitted use with rates and applications by nominated persons only, as specified in the permit.	Coffs Harbour City Council, NSW.

Note: These permits are held by various local and State government departments. Other local or State government authorities or organisations wishing to use glyphosate for salvinia control need to obtain off-label permission from the APVMA. These permits are listed here to provide examples of the current off-label permits that exist for the use of glyphosate on salvinia.

Applying herbicide by boat. Elissa van Oosterhout

Spraying edge salvinia from the shore. Elissa van Oosterhout

Using salt as a herbicide

Field applications of salt water sprayed directly onto salvinia have shown promising results for small-scale control. However, further research into both the use of salt as a herbicidal agent for salvinia and its impacts on freshwater ecology and water quality must be carried out before this method can be registered by the APVMA and recommended for use.

Herbicide application methods

The application methods associated with the registered herbicides for salvinia (see *Herbicide Table*) are well established in terrestrial and agricultural weed control and can be adapted to aquatic situations. In most cases, herbicides are applied to salvinia infestations by boat or other watercraft. Edge treatments or applications to small or narrow water bodies can be carried out from the banks using hand-held equipment.

Strip treatments

Herbicide can be sprayed in strips across a tertiary stage or multilayered mat of salvinia for the purpose of promoting the new regrowth necessary for successful biocontrol. This can be done either by spraying sections from the bank, or by spraying whole strips across the width of an infestation by boat. Applying a number of strip treatments across the infestation will give a better result. Thinning should be aimed at maintaining an actively growing single layer of salvinia.

Boom spraying

Most watercraft equipped with booms are adapted in-house by councils or other water management authorities. Spray booms have been fitted to runabouts and hovercraft for the purposes of treating salvinia. Boom spraying is probably the most difficult to adapt to aquatic situations, but if it can be done it is an accurate and cost-effective way to apply herbicide to large areas of salvinia, in comparison to hose and hand-gun applications.

Herbicide summary table

The following table summarises the above-described usefulness of the registered herbicides for the various stages of salvinia growth.

HERBICIDE SUMMARY TABLE

Herbicide	Primary stage salvinia	Secondary stage salvinia	Tertiary stage salvinia	Multilayered salvinia
Diquat	√	√	√√	√
Immerse®	√√	√	x	x
Glyphosate	√	√√	√	x
Orange oil	√	√	x	x

Note: Always refer to the product labels and the information provided in this section before choosing a herbicide.

Applying herbicide with a hose and hand gun from a boat.

Roy Durre

Hose and hand-gun

Hose and hand-gun spray rigs can be easily set up to operate from boats, canoes, amphibious vehicles or hovercraft. Such mobile spray rigs can be used to treat relatively large areas of infestation. Hose and hand-gun rigs on vehicles or tractors can be used for edge spraying and mop-ups.

A venturi injection system can be fitted on the output side of a positive displacement pump, allowing direct use of the water from the water body to create the herbicide mixture and avoiding the need to carry a spray tank. This is appropriate for glyphosate or diquat herbicides. Water quality must be high enough so as not to interfere with the herbicidal action, as both diquat and glyphosate are inactivated by clay and soil particles.

Air intake nozzles improve herbicide effectiveness

Air intake nozzles can be fitted to a standard spray gun to create a heavy foam spray. This has been done for applications of diquat and glyphosate to salvinia at their normal registered rates, and it has been found to reduce the number of repeat applications required to achieve the same level of kill.

We've put an air intake into the nozzle of the gun, which allows you to see where you have sprayed as it creates a foam—without any addition to the chemical—and the foam remains on the weed for up to an hour, allowing the chemical to be in intimate contact with the plant surface for longer, meaning more uptake by the plant, and we've cut our chemical usage down by two-thirds simply by adding that air intake—we don't need to do as many treatments.

National Salvinia Workshop, Grafton.

High pressure will 'wash' herbicide off floating plants

Although good penetration of the spray into the target foliage is usually necessary, sprays should not be applied with so much pressure that the floating plants are pushed under the water by the force of the spray, as this will effectively wash the herbicide off the salvinia, leading to poor success.

Operators always want to use maximum pressure, which hits the plants, sinks them under and washes the chemical off almost immediately. You're better off using a much lower pressure if you're spraying a floating weed with a contact herbicide.

National Salvinia Workshop, Grafton.

Knapsack spraying

Knapsack spraying is applicable to areas where access is difficult for watercraft, and where water depth allows a person to wade, carrying the knapsack sprayer. Knapsacks are readily available and are very effective for follow-up spraying around edges and amongst other vegetation.

Knapsack sprinkler sprayer

A simple sprinkler spray unit can be constructed by attaching an irrigation micro sprinkler nozzle to a 3 m telescopic fishing rod and knapsack compression spray tank. This equipment was originally developed to apply AF100® to salvinia in large droplets with a longer wand reach and bigger spray bandwidth at low pressure.

The telescopic fishing rod becomes watertight when extended, creating a long, lightweight wand that can

A 200-L spray tank in a flat-bottomed tinny. Elissa van Oosterhout

12-volt battery-operated pump for spray tank. Elissa van Oosterhout

be rinsed out and collapsed for transporting. A micro sprinkler is connected to the end of the telescopic fishing rod so as to operate in an inverted position. The micro sprinkler needs to discharge approximately 60 L/hour at a discharge pressure of 1 bar (100 kPa pressure) and a swathe width of about 3 m.

A pressure regulator valve and detachable gauge can be installed on the spray tank to regulate pressure. The calibration of a sprinkler sprayer is based on walk speed, discharge rate and swathe width (spray width). The required walk speed can be calculated if the herbicide application rate, discharge rate and swathe width are known. Discharge rate can be determined by measuring the amount of mixture discharged into a bucket in 1 minute (measure the volume and convert to litres per hour).

For example:

To apply Immerse® herbicide at a rate of 1 litre of mixture per 100 square metres with a micro sprinkler nozzle that discharges 60 litres per hour at a swathe width of 3.0 metres at 1 bar pressure, the operator would need to walk at approximately 33 metres per minute.

Aerial spraying

Only diquat has registration for aerial application to salvinia in aquatic situations. Glyphosate is registered for aerial application but needs off-label permission to be applied to salvinia in aquatic situations. Aerial application of herbicides in aquatic situations must be carefully considered and may require permission from the relevant environmental protection agency.

Watercraft for chemical control

The various watercraft that are used for chemical control of salvinia include boats with outboard motors (usually flat-bottomed runabout-type dinghies or punts), hovercraft, amphibious all-terrain vehicles and canoes.

Hovercraft

Hovercraft have been used extensively in the past to apply herbicides to aquatic weeds, but they are not as commonly available as they once were. The pressure created by the bow wave provides an ideal opportunity to apply Immerse® herbicide to the exposed water surface via a front-mounted boom sprayer, as the herbicide is discharged onto the water rather than onto the plants: this is critical for its effectiveness. Boom sprays or controlled droplet applicators can be mounted at the sides.

Tom Anderson

Using a hovercraft to apply herbicide to salvinia.

Scattered plants remain close to edges after harvesting.

Rebecca Coventry

Other methods are required for the salvinia that is left after mechanical removal.

Elissa van Oosterhout

Other methods are required in shallow, difficult access areas.

Rebecca Coventry

Amphibious vehicles

Amphibious vehicles can effectively carry a spray unit and move across areas where water depth varies and access is difficult.

Canoes

Canoes are widely available and now have improved manufacturing technologies (stronger, lighter more stable canoes are now available). Canoes can be used where access or water depth is not suitable for larger watercraft, and small electric or outboard motors can be fitted to them. Bigger models have carrying capacities of up to 500 kg, allowing for spray rigs (tank, pump, hose reel) to be fitted.

Ensure that all watercraft and equipment are thoroughly washed down after use to prevent spreading salvinia.

Elissa van Oosterhout

Clean all salvinia fragments from boats and equipment.

Mechanical removal

Mechanical removal uses purpose-built machinery to remove or 'harvest' salvinia from the surface of the water. Machinery can remove the bulk of an infestation in accessible areas, and other control methods are then required for the remnant salvinia left close to edges, or in shallow or inaccessible areas. Mechanical removal can be broadscale or small scale.

Management considerations

Broadscale mechanical removal is expensive because of the high operating costs and the ancillary plant and machinery required to process the weed once removed. Broadscale harvesting may be appropriate when:

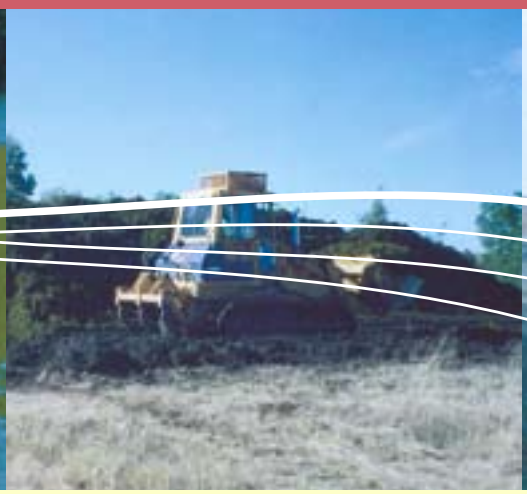
- an infestation occurs in a priority area, such as an area where there is high recreational use, high value conservation or potable water uptake
- the salvinia can be contained during the harvesting operation
- the rate of removal can exceed the rate of weed growth
- the harvested salvinia can be adequately disposed of.

Broadscale harvesting of very large infestations is often resorted to once an infestation has become too extensive for other methods to be feasible (i.e. complete coverage of water surface with a multilayered weed mat), or when urgent action is required. At this stage the extremely high costs and the ability to remove and dispose of weed faster than it can regrow must be considered against the priority of the situation (see *Hawkesbury River case study*).

For smaller infestations mechanical removal in conjunction with other control methods is an effective ongoing management strategy. Smaller-scale methods

Broadscale salvinia harvesting.

Andrew Petroeschevsky



Substantial areas may be required to stockpile, turn and spread large amounts of composting salvinia.

Andrew Docking

Compacting garbage truck unloading harvested salvinia.

Rebecca Coventry

can be used on a regular basis at lower costs, rather than deployed once an infestation has become extensive (see *Ewen Maddock Dam case study*).

Mechanical removal can also be used to facilitate other control methods. For example, sections of a weed mat can be removed to promote single layer regrowth that is more susceptible to herbicide treatments and biocontrol.

Estimating capability of mechanical removal

In cases where infestations have become extensive (usually over the summer growth period) it is important to know whether the rate of mechanical removal will exceed salvinia growth rates; where and how the removed weed will be disposed of; the associated costs of the whole operation; and whether adequate follow up can be carried out to ensure the operation is worthwhile.

> *It's rare that you can throw a lot of money at harvesting and get the biggest machine possible; most of the time you need to work out how much weed is in there, how fast it's growing, what size machine can move what amount of weed, turnaround times, and how to cart it away, and whether you can afford it.*
>
> **National Salvinia Workshop**

To do this, weed mass and growth rates need to be estimated. Quadrats can be used to weigh salvinia covering an area of 1 square metre. The area of the infestation needs to be estimated. Multilayered sections need to be considered separately. Booms can be used to contain sections, and weight per area changes can be measured over time.

> *You should harvest in the coldest time of year, and make sure you can do it all and do follow-up before it heats up again, or else you might get to the end of 3 months of harvesting, and if you haven't followed up, the salvinia starts to grow like fury as soon as it warms up.*
>
> **National Salvinia Workshop**

Disposal of harvested salvinia

Harvested salvinia must to be stockpiled away from the shoreline and above flood level. Stockpiled salvinia can be spread and dried out if space permits, or left in piles to break down. Piles will leak water for some time, and it may be necessary to bund the piles to stop the water flowing back into a water body and taking other contaminants with it. The composting of large amounts of organic matter (i.e. 5000 tonnes a year) may require various licences or permits, and in some States an Environmental Impact Statement is needed. Check with State Government authorities for requirements. Problems can arise if the salvinia is contaminated with other noxious weeds, such as alligator weed. Any salvinia contaminated with other noxious weeds should be processed at a sanitised and quarantined area. Stockpiles can be treated with herbicide to minimise the chances of contamination by other noxious weeds.

Large amounts of weed may need to be transported to a waste disposal facility and actively managed throughout the composting process. There can be considerable fees associated with this, and a permit to transport a noxious weed may be required from the relevant State Government department.

Rebecca Coventry

The Aquamarine H-7–400 (12 cubic metre load, 500 mm minimum water depth, 1.5 m depth cut) cost $1030/day plus relocation in 2004.

Rebecca Coventry

Salvinia being collected onto a harvester's conveyor.

The HV2600 (11 cubic metre load, 600 mm minimum water depth, 2.7 m depth cut), cost $1680/day plus set-up, including compacting garbage truck in 2004.

Boat ramps provide access for heavy machinery.

Roy Durre

Andrew Petroeschevsky

Broadscale harvesting machines

A number of broadscale harvesters have been purpose-built for commercial aquatic weed control. Harvesters range in size, capacity, manoeuvrability and cost.

Paddlewheel-driven harvesters collect weed onto a conveyor that moves it to an onboard storage area. As salvinia is free-floating, harvesters generally don't need to cut as well as collect. If the salvinia is held by other aquatic weeds, cutting action may also be required. Paddlewheeled machines create surface turbulence, which can cause turbidity in shallow water.

Most large harvesters have weed load capacities of 11 or 12 cubic metres. Once full, the harvester has to off-load to shore or to a shuttle barge.

Ancillary plant and machinery

The amount of ancillary plant and machinery required will depend on the scale and location of the operation.

Ramps

Boat ramps provide access for launching harvesters and unloading the weed. On-shore site hardening may be required where heavy machinery and trucks are moving around, as large volumes of water are involved and vehicles may easily get bogged.

Shore conveyors

A shore conveyor may be needed to move salvinia from the harvester to the shore, or to dump trucks or compacting garbage trucks.

Shuttle barges

Small barges used to convey salvinia from the harvester to the shore allow the harvester to maximise removal time. Some shuttle barges can unload directly into a dump truck, negating the need for a shore conveyor. Some barges can also harvest independently and are able to access shallower areas than harvesters. Their load capacity is less than that of a harvester, but their outboard motor-driven speed and shallow draft make them more suitable for some situations.

Dump trucks or compacting garbage trucks

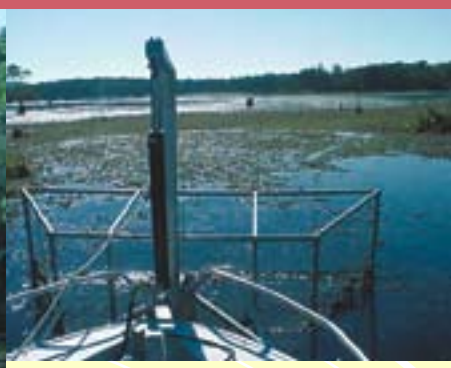
Removed weed needs to be transported away from the shore to a site above the flood level. Wet salvinia can be compacted to remove water before transportation to reduce costs. Compacting is generally able to reduce weed mass at a rate of 5 to 1, i.e. 50 cubic metres of

A shore conveyor may be required to get the weed from the harvester to the shore.

Unloading from shore conveyor into a dump truck.

Rebecca Coventry

Shuttle barge (10 cubic metre load) cost $1030/day in 2004.



Roy Durre

Russell Rainbird

Mechanical scoop attached to the bow of a 5.25 m aluminium boat.

Harvester unloading salvinia into a compacting garbage truck.

salvinia will be compacted down to 10 cubic metres, and most trucks have a load capacity of between 10 and 20 cubic metres.

Dump trucks can be used if the material only has to be moved a short distance to the stockpile. Dump trucks drain water and may not be allowed on public roads.

Support vehicles

Backhoes or bobcats may be needed to transfer the weed to dump trucks or garbage trucks, or to move piles of weed around on shore.

Smaller watercraft or amphibious vehicles may be needed to rake, push or move salvinia around in the water, out of inaccessible areas into the path of the harvester (see *Small-scale mechanical removal*).

Booms

By containing salvinia in one area, booms improve the efficiency of a harvesting operation and keep fuel and operating costs to a minimum. Booms can be used in conjunction with currents, tides and wind to hold salvinia in a convenient place for removal. It may be necessary to open and close booms to allow access to the weed. Booms will also provide delineation for follow-up control with herbicides or biocontrol (see *Booms and containment* section).

Small-scale mechanical removal

Small-scale mechanical removal that can be carried out on an ongoing basis is an effective, relatively low-cost approach that can be integrated with other control methods for good ongoing management of salvinia (See *Ewen Maddock Dam case study*).

Councils and weed control authorities often develop their own in-house equipment for carrying out small-scale mechanical removal, such as scoops that operate like front-end loaders and are attached to boats.

Some commercial operators have developed smaller harvesters that can suck, rake, scoop or push aquatic weeds. In most cases these machines are prototypes or under continual improvement.

Mechanical scoops

Scoops attached to the fronts of small boats have been used very successfully for ongoing salvinia control. An example of an in-house design is the Caloundra City Council's hydraulic mesh scoop attached to the bow of a 5.25 m aluminium boat. This scoop is able to remove around 4.5 tonnes of salvinia per day, depending on the distance the load needs to be taken to shore. The load capacity is 150 kg. (See *Ewen Maddock Dam case study* for more details, including construction and running costs).

Suction-based harvester

An example of a suction-based harvester is the Freshwater Environmental Management machine developed commercially at Penrith in Sydney. Using a vacuum hose connected to a cutter bar on a scoop, it can suck floating weed, or cut and suck anchored weed, into an on-board bag with a capacity of 1.5 cubic metres. The water compresses the salvinia as it fills the bag (approximately 3 cubic metres of wet salvinia

Rebecca Coventry

Suction-based harvester.

Rebecca Coventry

The amphibious Truxor® used to rake, push, cut and harvest in difficult access areas.

Using a canoe to assist with manual removal.

Roy Durre

will compact down into one bag). This machine can fill 32 bags in 12 hours. Cost examples are provided in the *Hawkesbury River case study*. It requires 300 mm water depth and is powered by outboards, creating less disturbance than a paddle-wheeled harvester and exhibiting better manoeuvrability.

Amphibious vehicles

Amphibious vehicles provide support for mechanical removal of salvinia, as they are able to access very shallow areas where debris or snags make boat access difficult. They can help free-up sections of weed mat, moving sections out of shallow water and getting logs and branches out of the way. An example of an amphibious vehicle that has been modified for aquatic weed control is the Truxor®, which has attachments for raking, pushing, cutting and harvesting, as well as a 250 kg capacity bucket.

Ensure all watercraft and equipment are thoroughly washed down after use to prevent spreading salvinia.

Andrew Petroeschevsky

Harvesters and equipment can easily spread aquatic weeds.

Manual removal

This method involves manually removing salvinia from the water.

Management considerations

Although labour intensive, manual removal is effective in the early stages of an infestation when:

- plants are in primary form, scattered, or lining the edges of a water body
- salvinia is growing amongst other vegetation, such as in wetlands or swampy areas, particularly if the vegetation has high conservation status
- follow-up is required, after the bulk of an infestation has been removed using other forms of control.

It can also be applied to smaller infestations in open water, where nets can be hauled across the surface to remove the bulk of a more established infestation.

There are cases where extensive and careful ongoing manual removal has effectively eradicated salvinia, reducing infestations to undetectable levels (see *Myall Lakes National Park case study*).

Removal techniques

The salvinia can be accessed by wading or paddling (using a canoe is easier when thick mud makes walking in waders difficult). Scoops, nets, shovel rakes, bins, bags, waders and wetsuits and adequate numbers of personnel are required. Wetsuits are often easier to move in than waders. Where possible, use booms to contain areas while manual removal is being carried out. Manual removal should start at the most upstream point and work downstream.

Collecting salvinia in bags.

Collecting scattered plants from among edge vegetation.

Roy Durre

Scoops and bins

Groups of people using pool scoops can cover stretches of creekline, scooping salvinia from the edges and from amongst reeds and other vegetation, moving out into the water body as far as depth will allow (waders or wetsuits can be worn). Canoes can be used in deeper sections. Carry 20 L garbage bins or heavy-duty plastic bags to collect plants in.

With follow-up over a 2-year period, this approach was successful in Myall Lakes National Park, and no salvinia has been detected in the water body to date (see *Myall Lakes National Park case study*).

Nets and shovel rakes

Two people can drag a fishing net across the surface to collect salvinia, using shovel rakes to pull as much as possible out from amongst other vegetation and into the net. This method requires personnel to be chest-deep in water, and wetsuits rather than waders should be used.

Manual removal as follow-up

If done regularly and continuously, manual removal is a very effective follow-up measure to use after the bulk of an infestation has been removed by other methods. Checking and removal can be carried out weekly, reducing to monthly after the active growth season. Manual removal also provides a good opportunity to carry out monitoring of coverage or for the presence of other aquatic weeds.

There are also cases where manual removal has been used initially to remove the bulk of the salvinia from amongst other vegetation, and the remainder treated with herbicide. This has been done successfully in paperbark wetlands with high conservation value in South East Queensland. Personnel with nets and shovel rakes removed as much salvinia by hand as possible, working in chest-deep water to retrieve the salvinia from amongst the other vegetation. The remaining salvinia was treated with Immerse® herbicide. Follow-up spot spraying was carried out, and monitoring is ongoing.

Dragging a fishing net around floating plants.

Tom Anderson

Manual removal was used to removed the bulk of this infestation and the remainder was treated with Immerse® herbicide.

Tom Anderson

Part 4: Case studies

Ewen Maddock Dam: Salvinia management through continuous small-scale mechanical removal

Contents

Introduction

The information in this case study was provided by Russell Rainbird, Technical Officer with Cal Aqua, Caloundra City Council.

Ewen Maddock Dam

Ewen Maddock Dam is a 371 ha water reserve in Caloundra Shire in South East Queensland. Constructed in 1976, it is now managed by Cal Aqua, a commercial branch of Caloundra City Council. The dam was originally used as a water supply but was taken offline in the late 1980s when other storages were activated. It is currently used for recreation and has significant environmental value, providing habitat for native flora and fauna. It is destined to go back online as a water supply in the next decade.

The dam has a volume of approximately 17 000 megalitres and an average depth of 4.08 metres. The deepest parts of the dam are around 12 metres. Most of the aquatic weeds occur in the lower half of the dam, where the average depth is 2–4 metres. The spillway is 25.3 metres across.

The salvinia problem

Salvinia was first reported on the dam in 1995. Salvinia present on small farm dams in the catchment would wash into Ewen Maddock Dam after heavy rain. Managers had some awareness of the damage potential of the weed, but no budget or strategy to manage a salvinia infestation. Few of the surrounding landholders had the information they needed to control their infestations.

Courtesy Cal Aqua

Aerial photograph of Ewen Maddock Dam showing the main areas of salvinia infestation in red.

Current salvinia levels

The main areas of the dam where salvinia is present are marked in red on the aerial photograph below. Natural barriers created by vegetation (sedges, reeds and lilies) and booms help contain the salvinia to these areas and prevent movement into other parts of the dam. The areas are numbered, and the extents of the infestations in each section are as follows:

- section 1: very light infestation, no thick mats present, salvinia is scattered throughout the reeds, inspections are done weekly
- sections 2 and 3: light to medium infestations, small mats are present but confined mainly to reeds, inspections are done weekly
- section 4: medium infestation, some large mats close to shoreline, some salvinia lightly scattered throughout reeds and lilies
- section 5: very light infestation, no thick mats present, inspections are done weekly
- section 6: very light infestation, no thick mats present
- section 7: only scattered salvinia found after heavy rains or wind.

Management issues

The use of herbicides on the water was a sensitive issue for local residents, and broadscale use of herbicides on the dam had been unpopular in the past.

> *We are limited in what we can do, because the public are very sensitive to the use of herbicides. We can use them but we have to really limit what we use them for and how we use them.*
>
> **National Salvinia Workshop, Grafton***

*Comments from a presentation by Russell Rainbird to the National Salvinia Workshop in Grafton in September 2005 have been used throughout this section.

A commercial harvester was engaged to remove salvinia, but it caused large amounts of damage to other native aquatic vegetation. The action of the harvester was also aiding the spread of cabomba (another serious invasive aquatic weed) throughout the dam. Enough complaints were received from conservation groups and birdwatchers to have the harvesting stopped.

An alternative strategy was needed that would have less impact on the environment. A technical officer was made responsible for managing aquatic weeds as well as other aspects of the water reserve, including water quality sampling and fire management; however, a lack of available staff and resources was accepted as part of the problem.

The management strategy

The successful management strategy is based on small-scale mechanical removal combined with strategic use of herbicides, biocontrol, manual removal and a public awareness campaign. The in-house development of

Russell Rainbird

The salvinia on the dam is maintained at physically and financially manageable levels.

a mechanical scoop proved to be a more selective method of physical removal, causing less damage to native vegetation; operating at much lower cost than a broadscale harvester; and allowing management to be adaptive and ongoing.

Aim and objectives

The aim is to maintain the salvinia at the current levels, which are considered to be physically and financially manageable.

> *Our main goal is to keep it at a level where we can control it—that's the key thing—not letting it get past that point.*
>
> **National Salvinia Workshop, Grafton**

Work is rarely required in the main body of open water (section 7 on the aerial photograph), as the salvinia is contained and kept within the other areas.

> *We've only got salvinia in certain areas, and that's where we try to keep it. If it gets out into the open, there's no way the scoop would get on top of it. We have natural barriers created by sedges and water lilies, and we use those barriers as containment lines, making sure it never gets past them.*
>
> **National Salvinia Workshop, Grafton**

Integrated management is carried out over the year on an ongoing basis, as shown in the table on the next page.

Containment

Floating booms are used in key areas such as across inflows, swimming areas or small bays and inlets to help with control. There are four sites where booms are used on a regular basis (1 × 100 m StormFlex® pipe; the others ranging between 20 m and 50 m StormFlex pipe).

Floating booms are also used to contain salvinia to the areas that dry out when water levels recede.

Small-scale mechanical removal

Small-scale mechanical removal is done with a removable mechanical scoop attached to the bow of a 5.25 m aluminium boat and worked like a front-end-loader bucket. An aluminium bar at the front of the scoop pushes native vegetation under the water, at the same time releasing any trapped salvinia and causing it to be caught in the scoop. This allows for selective removal of salvinia, minimising damage to native aquatic plants. The scoop can be raised and tilted to dump loads of salvinia on shore.

Russell Rainbird

Small-scale mechanical scoop in operation.

INTEGRATED STRATEGY FOR MANAGEMENT OF SALVINIA AT EWEN MADDOCK DAM		
Method/technique	**Application**	**Timing/season**
Containment	Floating booms are installed before physical removal and herbicide treatments; to contain salvinia that will be stranded; and to separate biocontrol areas. One permanent boom prevents spread into the main area of open water.	Year-round
Small-scale mechanical removal	The mechanical scoop used in all accessible areas to remove salvinia and push it into areas that dry out when water levels recede.	Year-round, particularly after rain when water levels are high
Herbicides	Glyphosate is sprayed over piles of harvested salvinia as a precaution to prevent reinfestation. Glyphosate is used to treat stranded salvinia around the shoreline. Glyphosate strip treatments are applied to thicker mats to assist biocontrol. Immerse® herbicide is used to treat scattered salvinia amongst other vegetation close to the shore.	Year-round
Biocontrol	Biocontrol releases are made in areas inaccessible to the scoop. Biocontrol prevents salvinia establishment beyond vegetated areas. Established biocontrol populations are considered as safeguards should salvinia levels increase dramatically.	Releases early spring
Manual removal	Small amounts of salvinia that occur in areas used for swimming and recreation are manually removed.	On an as-needed basis, mainly after heavy rains or winds
Monitoring	Both the dam itself and the surrounding catchment are monitored regularly.	Weekly (dam), late winter (surrounding catchment)
Public awareness	A Catchment Care Information Kit is distributed to surrounding landholders.	Ongoing

The scoop is constructed from aluminium tubing fitted with wire mesh that acts as a strainer, allowing water to flow through and trapping the salvinia. A prototype was constructed out of PVC pipe to see if the concept would work. The scoop is capable of removing 4.5 tonnes of salvinia a day, depending on the distance the boat has to travel between loads. A single load averages 150 kg, and an operator can do between 25 and 30 loads per day. In 2005, the scoop removed approximately 75 tonnes of salvinia in over 74 hours of operation.

Making this scoop was a lot of trial and error. We originally tried the same shape with PVC pipe and chicken wire. Then we used a hand winch, which got the operators very fit … and it was very slow.

National Salvinia Workshop, Grafton

A stainless-steel bracket fixed permanently to the bow allows the scoop to be attached with minimum effort, taking two people a few minutes to lift and attach the scoop to the boat. The detachable scoop allows the boat to be used for other purposes. The boat is fitted with additional foam beneath the deck to increase buoyancy and comply with standards.

Russell Rainbird

The removable mechanical scoop.

Russell Rainbird

The scoop has a load capacity of 150 kg.

Russell Rainbird

Russell Rainbird

Two people can lift and attach the scoop.

The scoop is attached to a stainless steel bracket fixed permanently to the bow.

The scoop is raised, tilted and lowered on a hydraulic ram fitted to the centre of the bow, powered by a 12-volt hydraulic power pack. It is capable of lifting over 300 kg but has been limited to 150 kg per load for buoyancy and safe manoeuvrability. The power pack is stowed at the rear of the boat beside the engine transom, helping to balance the boat and conserve deck space. Initially a hand winch was tried, but the loads were too heavy.

The scoop is also used to push large mats of salvinia into areas that dry out when water levels are low, or up onto the bank to about 3 metres above the shoreline.

Herbicides

The salvinia that is removed with the scoop is dumped at designated areas on shore, spread out, and sprayed with glyphosate 360 g/L (Weedmaster Duo® or Envirospray 360®) to prevent any possible recontamination during the time it takes to dry out.

> *The boat is fitted with a 100-litre spray tank and a 5-hp Honda diaphragm pump at the rear behind the driver's seat, which also helps with balance. So when the operator has finished scooping, he just goes all around the shoreline wherever there are piles of salvinia and sprays them.*
>
> **National Salvinia Workshop, Grafton**

The salvinia that becomes stranded when water levels recede is also treated with glyphosate herbicide, either from the boat or from a 4WD or ATV (all-terrain vehicle) from the banks. This is imperative, as stranded salvinia can stay alive and reinfest open water when water levels rise.

In biocontrol areas, glyphosate strip treatments are used to prevent salvinia mats from becoming too thick; these treatments allow the biocontrol to be more effective.

Immerse® herbicide is used to treat scattered salvinia that is trapped among aquatic vegetation close to the shore (too close to access with the scoop).

Biocontrol

Biocontrol alone is not considered acceptable because of the time frames involved and the use regimes of the dam, but it is seen as providing a safeguard for the dam should the salvinia ever reach unmanageable levels. A number of releases are made each year to ensure that weevils are always present.

Weevils are released in areas that are inaccessible for the boat and scoop—usually in small coves or inlets where edge vegetation and water depth make it difficult to use the scoop.

Weevils are obtained from Brisbane City Council and released two or three times a year (about three batches of 200 adults each time). Weevils can be lost when sections of salvinia are stranded after water levels drop, adding to the rationale to carry out a number of releases each year.

Weevils successfully prevent the salvinia from moving out beyond the vegetated areas into open water.

> *Anywhere we can't get the scoop into we use biocontrol. There are some large areas where the other vegetation restricts the success of the weevil, but we know the weevils take refuge there.*
>
> **National Salvinia Workshop, Grafton**

Russell Rainbird

The scoop is raised and tilted on a hydraulic ram to dump loads on shore.

Manual removal

If water levels rise quickly after rain, containment booms can give way, allowing the salvinia to escape. Any salvinia that gets into areas used for swimming and recreation is manually removed.

Seasons and timing

Salvinia growth is greatest over the warmer months (November to February), and slow to dormant when water temperatures drop below 15 °C (March to July). Salvinia starts to build up from about August onwards.

The scoop is used year-round, but particularly when water levels are high after inflows of stormwater following rain. This allows better access, and takes advantage of areas that will dry out when water levels recede.

> *After rain we get large mats washed down into the dam, so we push them to an area that will be high and dry when the water level goes down.*
>
> **National Salvinia Workshop, Grafton**

Weevil activity increases when temperatures consistently above 15 °C are recorded. Herbicide treatments are carried out year-round.

Monitoring

Regular monitoring is incorporated into the ongoing management routine, with most of the infested areas inspected weekly.

Inspections of the surrounding catchment are started in winter to allow time to enforce compliance regulations, if required. Reinfestation from surrounding dams is likely as soon as the wet season starts (peak rainfall occurs from December to March/April).

> *We keep a good eye on the dam; if it gets out into the rest of the dam we scoop it. There is a manager there all the time, so it's early detection and it works.*
>
> **National Salvinia Workshop, Grafton**

Public awareness

A public awareness campaign in the form of a Catchment Management Info Kit was developed to inform and help landholders, making aquatic weed management less reactive and more proactive. This has received positive feedback from landholders, but further help for landholders in the catchment to eradicate small infestations is required before salvinia management costs on the dam will decrease any further.

Costs and resources

Two permanent full-time staff (a technical officer and a leading hand) are responsible for the day-to-day management of salvinia and other aquatic weeds, as part of the overall management of the dam. Salaries for the two permanent staff take up the major portion of the weed control budget for the dam.

The leading hand carries out most of the operational work of scooping, spraying, maintaining booms, and inspection, with help from the technical officer, who is responsible for aquatic weed administration and management (including water hyacinth and cabomba),

as well as other aspects of the dam's management (including water sampling and fire management). Casual operational staff are employed on an as-needed basis, as the control work is adapted to the conditions and extent of the infestation at any one time. In 2003, over 300 operational hours were spent on salvinia control (scooping, spraying, booms, inspections), whereas in 2004 operational hours were 180.

Capital costs

Capital costs for the boat and scoop range between $5000 and $7000, depending on the size of the boat, outboard motor, power pack, etc. (This does not reflect costs associated with the scoop's in-house development.)

Operational costs

Approximate operational costs (fuel, herbicides and operators) in 2005 were $8902 (see table below).

The scoop operator is very good, he uses two to three tanks of fuel a week, he's very careful … so the costs per week are only in the hundreds not in the thousands compared to other big harvesters.

National Salvinia Workshop, Grafton

Key points

Small-scale mechanical removal allows the infestation to be maintained at a manageable level, with minimum resource inputs; however, it must be carried out continuously and must be integrated with other methods to be successful.

There is a constant process of adaptive management and decision-making to ensure that control efforts are able to maintain salvinia levels in response to rainfall and water levels, salvinia growth, recreational use patterns and environmental values.

APPROXIMATE COSTS OF SALVINIA CONTROL AT EWEN MADDOCK DAM IN 2005

2005 operational cost item	Usage over year	Cost	Cost over year
Scoop operator	74 hours	$30.00/h	$2220
Fuel	40 L/week	$1/L	$2080
Herbicide	4.7 L on dumped piles 102 L on stranded weed	$120 per 20 L	$642
Spray operator	132 hours	$30.00/h	$3960
Total			$8902

The small-scale removal is not a method for if it gets out of control—if that happens you'd really have to reassess the whole situation. But we've maintained it at a manageable level for over 10 years now.

National Salvinia Workshop, Grafton

Successes

The current integrated management strategy is maintaining a manageable level of salvinia in Ewen Maddock Dam at any given time and is supporting the dam's recreational and environmental values and uses.

The development of the scoop allows the management strategy to be based around continuous small-scale mechanical removal, with good integration of other forms of control.

The realisation that ongoing management is required has allowed resource inputs to be reduced over time, once considerable time and effort was dedicated to developmental approaches.

For something like salvinia it has to be a permanent thing, like a tug of war. You have to apply permanent pressure to the weed, you can't just come in and do things now and then—luckily our management have accepted that.

National Salvinia Workshop, Grafton

Failures

The initial broadscale harvesting caused an unacceptable level of damage to the native aquatic vegetation, and also spread cabomba. Broadscale use of herbicides was considered unacceptable by the surrounding landholders and the general public.

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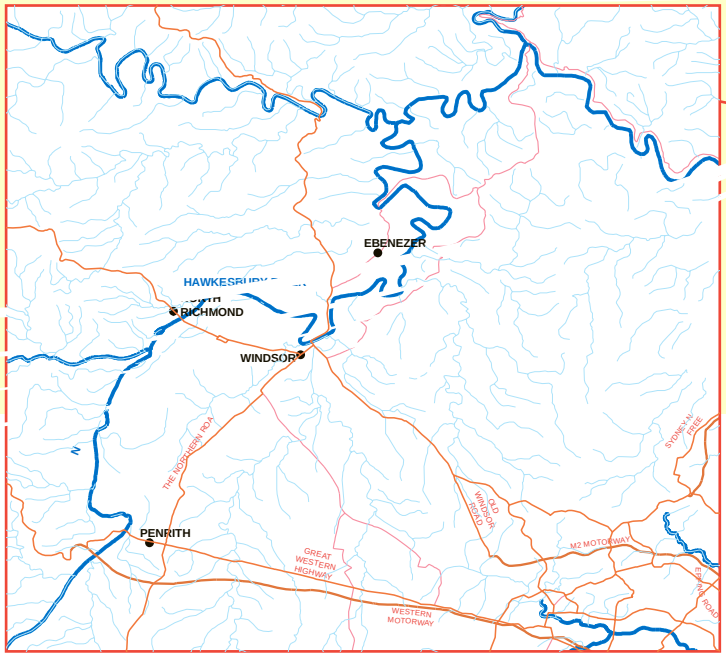

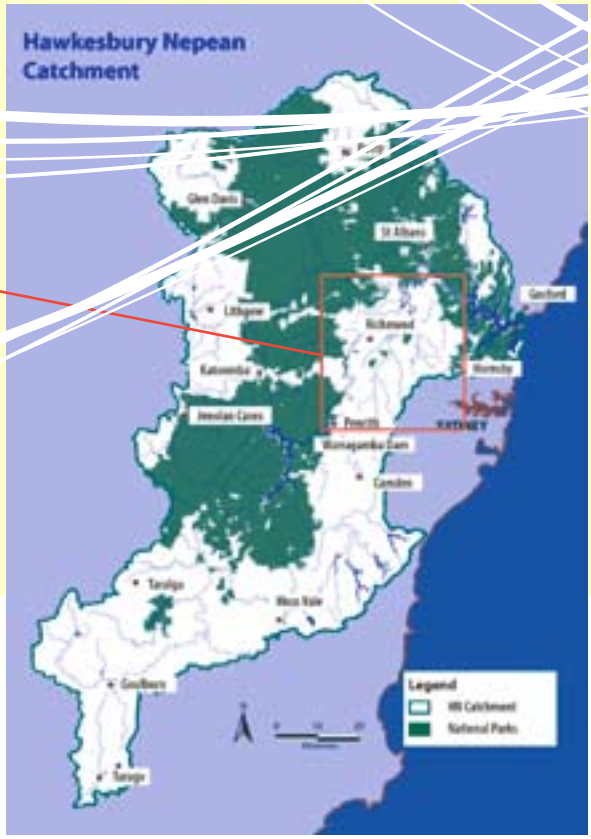

Cartoscope Pty Ltd

Hawkesbury River: Managing salvinia on the Hawkesbury—a $1.8 million cooperative effort

Contributing author: Rebecca Coventry

Contents

Introduction

This case study highlights the extensive costs and effort associated with the successful mechanical removal of a salvinia infestation from a major coastal river.

The Hawkesbury River

The Hawkesbury River drains the Hawkesbury Nepean catchment, an area of 22 000 km^2 with a population of approximately 1 million. The river is located north-west of Sydney, and the catchment provides most of Sydney's water supply from the Warragamba Dam. Agriculture in the catchment generates $1 billion annually, and the river is a popular recreation and fishing destination with a high public profile.

The salvinia problem

Small amounts of salvinia had been present in the Hawkesbury Nepean River system for some time before an alarming increase in levels in late 2003. Over summer 2003, ongoing drought and high temperatures led to low flows and increased water temperatures in the river. Combined with high nutrient levels, this allowed large stretches of river to become covered with salvinia. The infestation was concentrated mostly between the townships of Penrith and Windsor, including North Richmond, Ebenezer and Yarramundi. By May 2004 approximately 347 ha of multilayered salvinia infested 88 km of the river and

Over 88 km of the river was covered with salvinia.

Thick, multilayered mats covered large sections of the river

Rebecca Coventry

its tributaries. This is now recognised as possibly the largest temperate infestation of salvinia to ever occur in Australia.

Current salvinia levels

An ongoing salvinia monitoring program, including biocontrol, ensures that salvinia is now maintained at a manageable level in the river system and is not interfering with river usage or environmental values. The main channel is largely clear of salvinia, with only small amounts remaining caught against snags or rocks or among other vegetation. Some of the creeks and tributaries, backwaters and farm dams within the catchment still contain salvinia, and these are carefully monitored and treated. Managers are now facing other aquatic weed problems because of continued drought and high nutrient levels.

Management issues

Complete coverage of parts of the water surface by thick mats of salvinia had extremely high impacts on the river's commercial, recreational and environmental values.

Contingency funding was not on hand, and emergency funding applications had to be made to the Federal Government by the Hawkesbury Nepean Catchment Management Authority.

Collaboration and coordination were required between the many levels of authority relating to the management of the river and the salvinia. The river was officially closed to boating from South Windsor to Sackville for 12 weeks in April 2004 to allow control efforts to proceed safely and unhindered.

The management strategy

Management efforts began on 27 April 2004, with an expected duration of 6 months. The initial aims were to mechanically remove the salvinia biomass from the main navigable stretch of the infestation (from the Windsor bridge to the saltwater confluence at the junction of the Colo River) and to dispose of the harvested material on land. This task proved to be larger and more complex than originally anticipated, and after 4 months it was apparent that further funding would be required. A second injection of funding in August 2004 allowed more effort to be dedicated to the removal efforts, as well as providing

Rebecca Coventry

The main channels are largely clear of salvinia.

Rebecca Coventry

Small amounts remain caught against snags.

Rebecca Coventry

An industrial boom was placed across the river to prevent downstream movement.

for biocontrol releases and herbicide follow-up treatments.

The secondary aim was to develop a strategy for the ongoing management of the remaining salvinia in the system, in order to prevent any future recurrence.

Cooperative project management

The control effort was overseen by a project officer from NSW DPI, through an executive committee made up of various state and local government authorities, catchment managers and community representatives. An Operations Committee was made up of officers from the Waterways Authority and Hawkesbury River County Council, and other involved parties such as officers from the EPA, Sydney Water and NSW Fisheries. The Operations Committee met weekly. An on-river management team was on call 24 hourly to ensure efficient weed removal through boom management, making use of flow, tides and winds, and to carry out support activities such as additional boom placement, movement and maintenance, and removal of debris.

Some of the issues encountered with the mechanical removal effort included organising RTA clearances for the movement of oversized machinery; finding weighbridges to weigh weed loads; obtaining council and private landowners' permission to stockpile weed; getting regulatory approvals from government departments (EPA for stockpiling; the Department of Planning and Natural Resources [DIPNR] for constructing ramps, DPI to transport noxious weeds, and the National Parks and Wildlife Service for access through national parks).

In July 2004, an expert panel of salvinia specialists was convened to assess progress and advise on the management of options and on future actions. They concluded that the harvesting effort was exemplary and needed to be followed up with herbicide applications, and that trial biocontrol releases needed to be made. A scientific trial program was then designed to establish and monitor the viability of salvinia weevils as an ongoing control option.

Mapping

An aerial survey was carried out by helicopter in May 2004 to determine the exact extent and density of the infestation. Most of the salvinia was between Penrith and Sackville on the main stretch, and in numerous creeks, tributaries and farm dams.

Containment

The logistics of containing an 88-km stretch of salvinia on a major river system were complicated. An appeal was made for more oil retention booms, and several kilometres of booms were provided on loan by the Waterways Authority and the Sydney Ports Authority.

The booms were used to delineate collection zones, allowing salvinia to accumulate in strategic areas where the harvesters could then remove it. The placement of the booms made use of the river flows, tides and wind, and the booms were opened and closed as needed 24 hours a day to maximise the accumulation of salvinia.

Booms are still used to contain salvinia to strategic areas where it can be mechanically removed, subjected to weevils, or treated with herbicide.

Broadscale mechanical removal

A team of broadscale harvesting machines operated non-stop over an 8-month period between April and December 2004. Initially, two harvesters with 13 m^3 load capacities were used. These were supplemented for a 12-week period over June, July and August by a 26 m^3 load capacity harvester. Without the addition of the third harvester, it is doubtful whether the bulk of

Two 13 m³ load capacity harvesters were operating on the river for an 8-month period.

The 26 m³ load capacity harvester allowed the operation to be successful.

Rebecca Coventry

the infestation could have been removed before the next growth season.

An amphibious Truxor® craft was used to cut, push and collect weed from difficult-to-access areas and move it to areas where the larger harvesters could remove it.

A barge was adapted to collect weed, and it was able to move faster than the harvesters over longer distances. This was useful in the shallower creeks where small amounts of weed were spread out over some distance, and also in the final clean-up operations along the river.

Shore conveyor ramps were used in some places to move the weed from the harvesters to the shore, unloading either into dump trucks or compacting garbage trucks, or dumped in piles and moved by backhoe or bobcat. In other places the harvesters unloaded directly to the garbage trucks.

Each compacting garbage truck took about 11 t of compacted weight (equivalent to up to 10 harvester loads, or 19 m^3). Each truck or harvester team offloaded between three and five truckloads a day (averaging 133 m^3 per day).

The large harvester unloaded onto a shore conveyor into a giant dump truck, and the salvinia was then stockpiled on site. Over 12 weeks the harvester removed 72 500 m^3 of salvinia from an 8 km stretch of river.

In total, an estimated 140 000 t of salvinia was removed by the harvesters over a 14-month period.

Occasional harvesting of weed mats is carried out against the booms that are still in place in certain parts of the river.

Disposal of harvested weed

The removal of these amounts of salvinia from the river created a significant disposal issue. Removed salvinia had to be stockpiled, and a number of associated problems arose, including the presence and growth of another notifiable noxious weed, alligator weed, (*Alternanthera philoxeroides*) in the stockpiles. The disposal sites therefore had to be set up to manage alligator weed outbreaks, including quarantining and bunding the stockpiles and ensuring appropriate hygiene practices were carried out (e.g. machinery washdown). Alligator weed outbreaks had to be treated with herbicides and monitored.

An agreement was reached with the Hawkesbury City Council to dispose of the salvinia to their waste management facility, and to temporarily stockpile the weed until composting could be organised.

Most of the stockpiles are now undergoing recycling for commercial compost production.

Herbicides

Follow-up treatment with herbicides was necessary where salvinia remained lodged in areas that were inaccessible to the mechanical removal effort, or where salvinia was left along the edges of channels after the bulk had been removed by harvesters.

Community concern towards the use of diquat herbicides led to an application to the APVMA for a permit to use dual salt glyphosate herbicide.

Herbicide treatments commenced in September 2004 and continued for 11 weeks. Two teams treated 88 km of river (remnant salvinia) using 645 litres of the dual salt glyphosate herbicide Weedmaster Duo® applied under permit.

Follow-up spraying consisted of three teams spending 2 days per month treating any remaining salvinia with herbicide. A total of 203 L of glyphosate herbicides

Rebecca Coventry

Stockpiles of harvested salvinia.

Andrew Docking

One of the stockpiles of composting salvinia covering approximately 1 ha.

was used for initial follow-up over a 4-month period between December 2004 and March 2005.

Ongoing follow-up spot spraying of regrowth salvinia was then done, particularly after rain. Less than 30 L of glyphosate was used for follow-up spot spraying over the 6 months after March 2004.

Biocontrol

There was a commonly held perception that the salvinia weevils (*Cyrtobagous salviniae*) would not be successful in a temperate climate. It was not known how well weevils would survive over winter, or if they did, how long they would take to build up viable populations to a level where they could successfully control salvinia over the warmer months.

However, the obvious need to have an ongoing management strategy supported trial releases of weevils, and a decision was made that biocontrol releases should be attempted and monitored. Two sites within the Hawkesbury catchment were known to have had effective weevil populations established, and this supported the possibility of broader effective use of biocontrol.

Weevils were released on a monthly basis from August to December 2004. Massive releases were made in strategic locations (over the whole extent of the infestation, and in different environments (four sites on the main channel of the river, four on creeks and billabongs, and four on farm dams). The total number of weevils released is thought to be approximately 124 000. A number of the mass release sites were protected with booms to provide nursery areas.

An extensive research project was designed to further understand the success of the biocontrol agent in cooler climates. A project officer was appointed to carry out biocontrol monitoring on a weekly basis. The twelve weevil release sites were intensively monitored. Quadrats (2 × 2 m) were anchored in the release sites, and data loggers were attached to collect water temperatures and air temperatures.

Initial findings are that the weevils are surviving, with over 90% of the salvinia in the quadrats showing some degree of damage, and the weevils have moved beyond the release sites. However, final determination of the future reliability of weevils in the Hawkesbury system will require populations to be monitored for at least three, and possibly five, consecutive winters.

Weevil activity is still occurring and is very encouraging.

Seasons and timing

It was essential to remove as much of the weed biomass as possible over the cooler months before the following summer growth season. Harvesting continued into summer, but by this time enough weed had been removed to allow progress to exceed weed growth.

Monitoring

The follow-up treatment program called for weekly reporting on the state of the river and its tributaries for the period from December 2004 to May 2005. This was done by mapping and photographing any weed presence.

All remaining presences of salvinia are carefully monitored. The biocontrol trials also provide an opportunity for ongoing monitoring.

Ongoing management

There may be a need to release large numbers of weevils every year in early spring to assist the winter-surviving populations to reach a point where they can exert control over each season's salvinia growth.

Ongoing surveillance of the river system and the catchment should continue on a regular basis to

prevent such an extensive outbreak from occurring again. The off-river source infestations have been located and are under inspection and treatment regimes in cooperation with the relevant local government authorities.

The works program was finalised in June 2005, with the realisation that salvinia management will need to be ongoing on the river system until significant and long-term changes in flow and nutrient levels are achieved, reducing the risks of repeated outbreaks. Efforts to reduce nutrient loads in the system have been recommended.

Costs and resources

The mechanical removal effort cost around $8000 per day, including machines and ancillary plant, staff input and all incidentals such as fuel.

The NSW Government contributed a total of $954,000, with additional in-kind costs of over $200,000. The Australian Government contributed $650,000 through the Natural Heritage Trust (NHT).

Key points

The extensive effort to remove the bulk of the infestation relatively quickly was justified. The only other way of removing the bulk of the infestation would have been to use broadscale herbicide treatments, which were not publicly acceptable in this situation and would also have created a secondary problem of decomposing weed biomass in an already nutrient-overloaded waterway.

The realisation of the extreme effort and cost of managing such an extensive infestation has ensured that ongoing salvinia management is now part of the River Health Strategy for the Hawkesbury Nepean catchment.

Successes

The effective use of booms increased the efficiency of the harvesting effort to the point that the salvinia biomass could be removed before the following growth season.

Early results are indicating that, with careful release strategies and monitoring, the salvinia weevils can provide effective biocontrol in temperate areas. This has also allowed reduced dependence on herbicides and harvesting for ongoing control.

Failures

Daily problems and logistical issues were encountered throughout the project, and many unforseen circumstances needed to be dealt with. Initially there was no clear delineation of responsibilities between the parties and organisations involved, hindering any quick responses to the salvinia problem. There is now a clear salvinia management plan in place for the Hawkesbury Nepean catchment.

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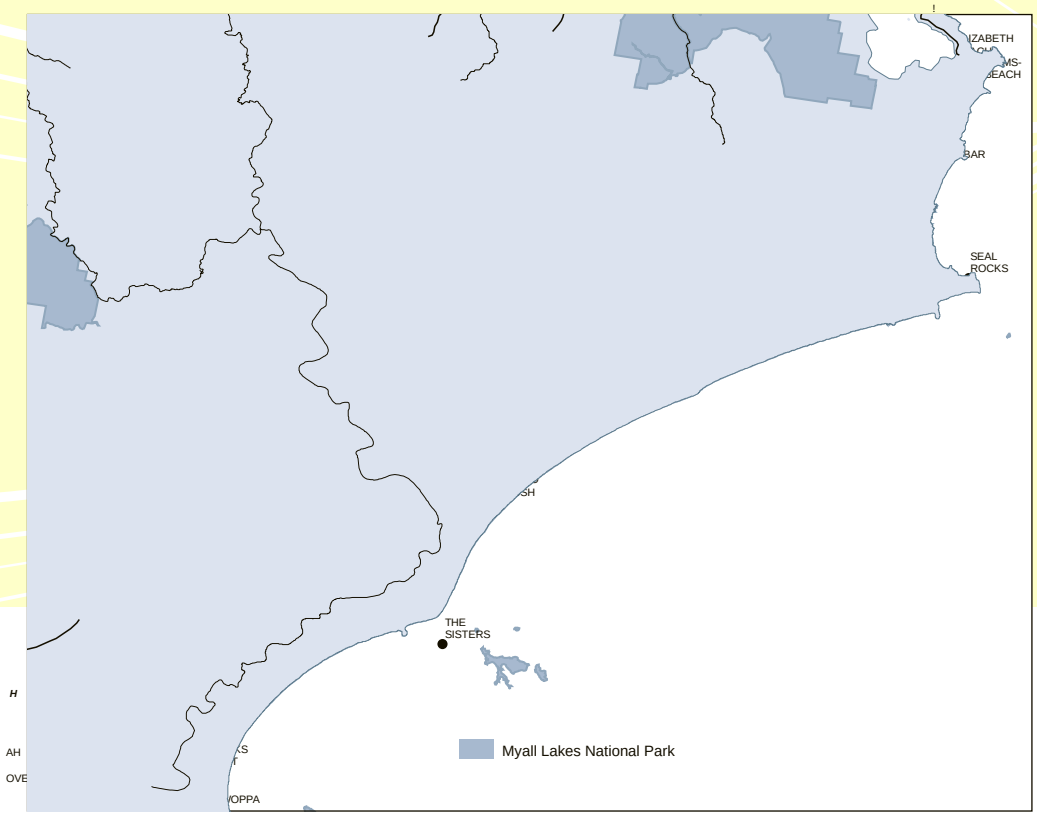


Myall Lakes National Park: Successful eradication of salvinia through extensive manual removal

Contents

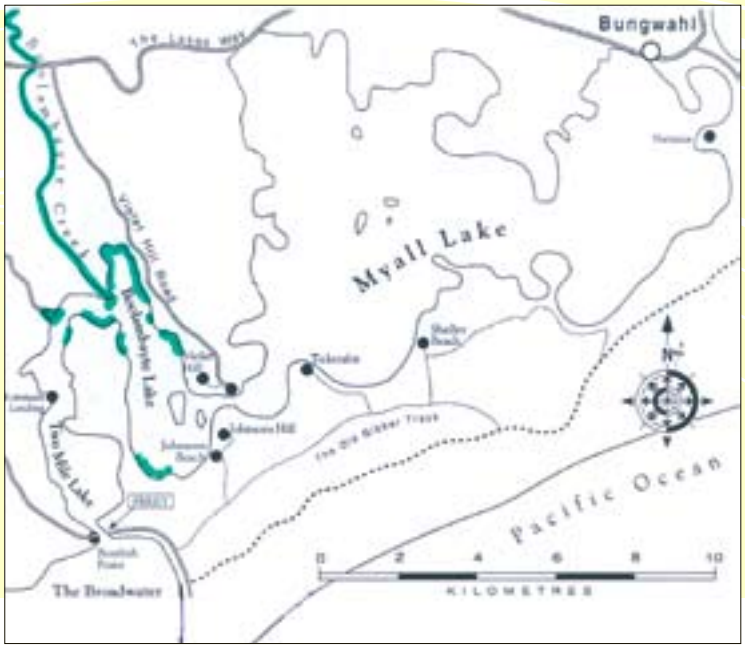
Introduction

Myall Lakes National Park

Myall Lakes National Park is in the warm temperate region of the Mid North Coast of NSW, approximately 100 km north of Newcastle. The park covers an area of 44 000 hectares and contains the largest natural coastal lake system in NSW. The 10 000 ha system of interconnected lakes, creeks and rivers is known as the Myall Lakes system and contains three main lakes: Boolambayte Lake, Myall Lake and the Bombah Broadwater. The lakes are fed by Nerong Creek, Two Mile Lake, the Myall River and Boolambayte Creek (see map below).

The Myall Lakes National Park has very high conservation value, containing unusual freshwater ecosystems and Ramsar-protected wetlands, and providing habitat for 352 species of birds and animals (including 29 threatened species). The lakes system is an important breeding area for fish stocks and adds significant value to the NSW commercial fishing industry; the park provides for recreational activities such as camping, swimming, boating, fishing, canoeing and sailing.

The system drains an extensive catchment with only a narrow exit channel, and water levels rise significantly with rainfall runoff. The lakes contain both fresh and brackish water, and salinity fluctuates with runoff and the limited tidal inflows into the system. The Bombah Broadwater has the highest levels of salinity, whereas the Myall Lake itself remains mostly fresh.



Adapted from Clark & Gatenby 1998

Map of the Myall Lakes system showing the areas of salvinia infestation in green.

The salvinia problem

Salvinia was deliberately introduced as an ornamental plant to a dam in the upper catchment in 1995, and was then washed into the upper Boolambayte Creek during floods. A few small infestations developed into a 2 km length of infested creekline 4.5 km upstream from the national park.

Efforts were made to control this infestation. A floating boom (supplied by the Waterways Authority) was positioned at the lowest point of the infestation, and Great Lakes Council treated the weed with two applications of diquat herbicide. The diquat herbicide killed the bulk of the infestation but also killed native vegetation on and near the banks. Semi-exposed mud surfaces with large amounts of rotting vegetation made access for follow-up spraying too difficult, and consequently follow-up treatments were not carried out. Salvinia biocontrol weevils (*Cyrtobagous salviniae*) were released in summer but failed to establish, possibly because of shading by the overstorey vegetation.

The infestation was thought to be contained, but after heavy rainfall in May 1998 salvinia plants that had survived the diquat treatments escaped the boom and were washed into the lower reaches of the creek and into the national park. The ensuing mild winter and very low salinity levels during spring allowed the entire length of Boolambayte Creek to become infested with tertiary stage salvinia.

By 1999 a tertiary infestation was present in the park, along a 5 km length of lower Boolambayte Creek that reached 1 km from the mouth of the creek into Boolambayte Lake. The Waterways Authority installed a Marine Notice on the creek, closing it to all vessel movements.

Isolated plants were recorded in nearby sections of the lake system (Korsmans Landing and Violet Hill). Scattered infestations were also occurring in the surrounding wetlands and foreshores, to the point that 20 km of creek and lake foreshore had become infested (see map below). All three stages of growth were occurring within the park, and the salvinia was growing in open creek channels, amongst flooded swamp forest, and in the sedges lining the edges of the foreshores.

Current salvinia levels

By 2000 (3 years after the control efforts began), only scattered primary form plants were occurring in the national park. Two years later only a few single plants were being found. By 2002 no salvinia had occurred in Boolambayte Creek or Lake; however, a 'bucketful' of salvinia had been removed from a dam on an adjoining private property and salvinia had been reported on other dams in the catchment. Follow-up control and monitoring continued, and to date there has been no reoccurrence of salvinia in Myall Lakes National Park.

Management issues

The presence of salvinia in Myall Lakes was considered to be potentially the greatest ecological threat to the park's protected aquatic ecosystems. Extensive infestations could occur if a rise in water levels and prevailing winds were to carry the salvinia into Myall Lake, where salinity is low. The open waters of the main lakes received enough wind and wave action to prevent large mats from forming, but the fringing wetlands, foreshores and embayments were all under threat of being infested with tertiary stage salvinia.

It was difficult to predict how salinity levels in the system were affecting the distribution of the salvinia, as the salvinia was growing in brackish water with salinity levels higher than what was considered toxic in the scientific literature. Then, in 1998, a large inflow of freshwater runoff diluted salinity levels and provided ideal growth conditions for salvinia over much of the system. Historically both Boolambayte Lake and Myall

Fine mesh containment fence on the downstream side of the boom.

Mel Schroder

Lake provided ideal conditions for salvinia (salinity levels between 1.3 and 2.0 parts per thousand), whereas the salinity of the Bombah Broadwater fluctuated to levels possibly high enough to kill salvinia (between 1.0 and 10.0 ppt).

Before 1998, cooperation between adjoining landholders and management agencies had been difficult and had prevented proper follow-up from taking place. Once the infestation had entered the national park a Coordinated Control Strategy was developed, steered by the NPWS.

The management strategies

Control efforts were initiated in 1997 and a Salvinia Eradication Strategy and Works Program drafted by the NPWS. A Coordinated Control Strategy was developed in 1998 and implemented in 1999, and a 5-year Management Strategy was developed later in 1999.

Aims and objectives

The short-term aim was to control salvinia in the Boolambayte Creek and Boolambayte Lake and prevent spread to the Myall Lake.

The long-term aim was to completely eradicate salvinia from Myall Lakes National Park. Eradication was considered feasible through a combination of containment fencing, manual removal and herbicides, with extensive follow-up and monitoring over at least 3 years.

Prioritisation

The infestation was prioritised into management areas to ensure resources were allocated where the biggest threat of establishment of tertiary stage salvinia or further spread was occurring.

The highest-priority area was the tertiary infestation. This was to be contained and removed, with follow-up and monitoring on a weekly basis.

High-priority areas included wetlands and bays protected from wind and wave action and receiving freshwater runoff. The four known edge infestations in Boolambayte Lake were to be removed, with follow-up on a fortnightly basis.

Medium priority was given to areas where salvinia had been removed, but where wind and wave action was high and freshwater inflow was low. These areas were to be spot-checked monthly for at least 1 year.

Low priority was given to any sheltered bays and wetlands within Myall Lake, and to the remainder of the system. These were checked four times a year, and the priority level would be changed if salvinia were found. No salvinia was found in any of the low priority areas.

Surveying and controlling the source of the infestation

The areas outside the park were surveyed to establish the distribution of salvinia in the upper catchment, starting with the areas adjoining the property known to be the source of the infestation. Contractors undertook the survey work and treated any salvinia found, using manual removal and herbicides.

Containment

Containment of the existing infestation was a primary objective for the control and management of the infestation.

A series of four mesh containment fences were constructed on Boolambayte Creek with the aim of completely preventing downstream movement of salvinia. The fences consisted of one trash fence (10 × 10 cm mesh) installed above three finer mesh fences (10 × 10 mm mesh). The trash fence trapped larger debris and prevented damage to the finer fences.

Park staff undertaking manual removal with scoops and garbage bags.

Mel Schroder

The three fine fibreglass mesh fences were placed in a herringbone arrangement at strategic bends in the channel, anchored on the creek bank and reaching three-quarters of the way across at right angles to the flow. This allowed access for maintenance to the fences and prevented total loss of the fences in high flows. The fences required regular cleaning and maintenance and were monitored for trapped salvinia, either 1 day a month or as required, depending on the conditions.

The containment fences effectively prevented any further downstream movement of salvinia into the lakes system.

Manual removal

Manual removal was chosen as the lead approach for the control effort. Although it was labour intensive, its low environmental impact made it suitable for use in a sensitive system.

The initial phase involved 20 personnel (park staff and Conservation Volunteers Australia) for a 2-week period working in a 2 km section of dense salvinia in Boolambayte Creek. Staff and volunteers wore waders in shallower sections (between 10 cm and 50 cm water depth) and paddled canoes in deeper sections. They used pool scoops to retrieve the salvinia from amongst the reeds and other vegetation, and the salvinia was collected in 20-litre garbage bins and heavy-duty plastic garbage bags, composted, and then buried under landfill.

Two park staff and two contractors worked on the infestations in Boolambayte Lake for over 80 days.

The follow-up that was carried out over the next 2 years was undertaken by contractors (two people over 20 days) and park staff (two people over 10 days).

In total, approximately 15 km of salvinia along the shoreline in widths of between 10 m and 200 m was removed manually. More than half a tonne of salvinia was removed by hand during spring in 1998. A staff timetable was used to allocate human resources over the control effort.

Manual removal was also seen as an opportunity to provide accurate survey information about the rate of spread and the area of infestation. Anyone performing manual removal provided records of the location and extent of the salvinia, and efforts were made to map the known infestations on a 1:25 000 scale topographic map.

Herbicides

AF100®* was chosen as the most appropriate and effective herbicide for small-scale use. Diquat herbicide had been used outside the park but had caused difficulties for follow-up. The non-selective nature of diquat herbicide was also considered inappropriate for use within the national park.

In January 1999 the NSW Environment Protection Authority issued a licence to NSW NPWS to use AF100 herbicide on salvinia in the national park. AF100 had been reviewed for use in Kakadu National Park by the Australian Nature Conservation Agency and had been found to be appropriate for use in environmentally sensitive areas owing to its low persistence in the soil and water, low hazard to users, and low hazard to mammals, fish and other plants from residues in the water. AF100 has no spray drift, is not water soluble, and is applied in low volumes.

Some degree of damage was expected to occur to native free-floating aquatic ferns, such as *Azolla* species, but the threat of salvinia to their habitat justified any damage to native floating ferns at the time of application. A small amount of physical damage to a native sedge (*Baumea* sp.) was noted in one area but was not considered to be long-term or irreversible, and it was minimised through careful application.

* AF100® is now available as Agricrop Immerse® Floating Herbicide.

Mel Schroder

Applying AF100 herbicide to salvinia among sedges with a knapsack sprayer.

A number of 'eight-point tests' were carried out to determine whether the use of AF100 would be detrimental to the threatened frog species in the park (the Wallum Froglet and the Green and Golden Bell Frog), with the outcome that the use of AF100 would not have a significant impact on either species.

AF100 was effective on primary-form salvinia floating amongst reeds and sedges and in open water, and all follow-up control involved a combination of spot spraying with AF100 and manual removal.

AF100 was applied with hose and hand-gun by boat (two aluminium boats with 100-litre spray units), and by knapsack sprinkler sprayers on foot.

Biocontrol

The likelihood of achieving biological control of the salvinia was considered to be improbable in the short term, and unsuccessful attempts to release and establish the weevils had been made further up the catchment. This lack of success was thought to have been due to the presence of the overstorey vegetation that occurred in most areas where the salvinia was present.

Seasons and timing

The works program was conducted immediately after salvinia had been washed into the park in April–May, in order to maximise control efforts and remove as much salvinia as possible while it was in slow growth over the cooler months. Follow-up and monitoring then occurred over the following spring and summer.

The 5-year management strategy was reviewed in May each year to take advantage of the slow growth period over winter should major interventions be required.

Monitoring

Intensive monitoring was critical to the objective of eradication, as literally every plant had to be removed or treated as it was found. Staff were advised that monitoring should take place for at least 3 years after the initial eradication effort to be confident that the infestation had been eradicated.

In all infested areas, monitoring took place weekly, for up to 6 months, after the bulk of the salvinia had been removed. Monthly monitoring was then carried out for the rest of the 3-year period, with particular diligence during the peak salvinia growth periods. All other areas were monitored four times a year. This level of monitoring continued until 2005 to ensure that all salvinia plants had been removed from the system. Contractors were employed to help park staff with the extensive monitoring regime.

Monitoring efforts are now directed to high-risk areas (protected embayments and wetlands with low salinity levels) and times when large amounts of fresh water flow into the system after heavy rainfall. Other parts of the system are checked at least once a year.

Public awareness

A Community Involvement Strategy was prepared by NPWS in 1999 and helped with the control effort. Community involvement also made the closure of waterways to users more acceptable. The strategy involved:

- the distribution of information sheets and 6-monthly newsletters to all target user groups, including professional fishermen, recreational fishing groups, the yacht club, council, NSW Waterways, houseboat hire companies, neighbours, cruise operators and park visitors. A 'Wanted Dead or Alive' information sheet asked visitors to record sightings of salvinia on a map provided on the back of the sheet and report them to park staff.

COSTS OF SALVINIA CONTROL PROGRAM IN 2000	
Item	**Cost**
Staff and human resources	$40,613
Plant and equipment	$1,200
Vehicles	$374
Materials (herbicides, mesh, waders, scoops)	$1,030
Overheads/administration	$4,583
Contractors	$23,500
Total project costs	**$71,300**

- A community field day was held to increase awareness and encourage involvement in the control program (the manual removal component and the monitoring). Other agencies were also involved (Fisheries, Waterways, NSW Agriculture).
- Notices were placed throughout the park in information bays.
- Local media campaigns were used to promote community awareness and encourage reporting of salvinia infestations.

NHT funding helps to provide continued community education and awareness.

Costs and resources

The control program cost over $100,000 over the 4-year period before 2002. This was considered inexpensive in comparison with a fully established infestation throughout the system. As an example, the costs incurred in 2000 were as shown in the table above.

Key points

The integrated management strategy that aimed to eradicate salvinia from the park is considered to have been successful. No salvinia has been found to date. Monitoring is still an important part of the day-to-day management of the lakes system within the park and in the upper catchment.

Successes

The extensive manual-removal efforts and the use of the selective herbicide AF100 provided effective control. It was understood that a single plant would have the ability to reinfest the entire system and that intensive, long-term follow-up and monitoring efforts were imperative to the eradication effort.

The coordinated efforts to control the salvinia before it spread throughout the system or reached the tertiary mat-forming stage were critical. The work involved in manual removal was justified: tertiary infestations amongst protected vegetation (i.e. paperbark swamp) would be impossible to eradicate given the biomass involved, the sensitivity of the system to certain control methods, and the inability of the biocontrol weevil to control salvinia growing in shaded conditions.

Failures

The initial assumption that two diquat treatments and a floating boom would prevent the infestation from reaching the national park was proved incorrect. A lack of follow-up after the diquat treatments and flood rainfall allowed regrowth salvinia to escape the boom and move downstream into the national park.

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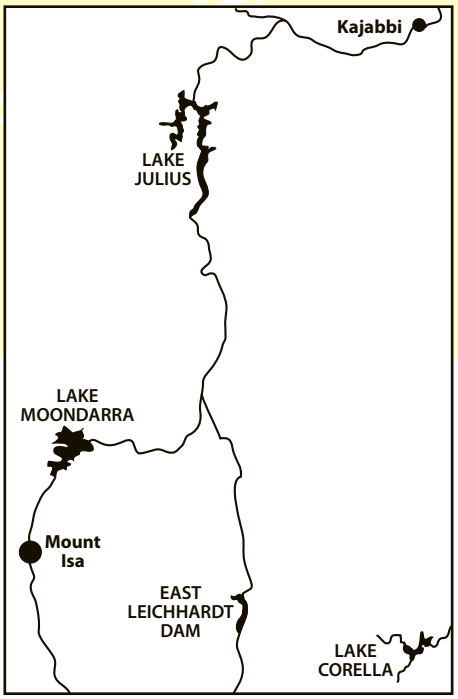


Lake Moondarra: Biological control of salvinia over three decades

Contents

Introduction

This case study highlights the successful, ongoing use of the salvinia biocontrol weevil *Cyrtobagous salviniae* on Lake Moondarra in Western Queensland. This use of the salvinia weevil was the first successful attempt at biological control of salvinia in Australia.

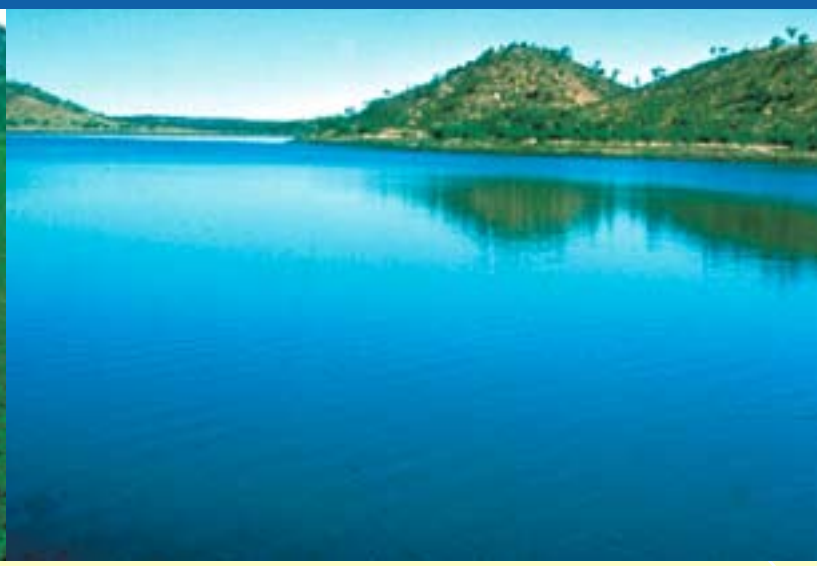
Lake Moondarra

Lake Moondarra is 20 km north of Mount Isa in the dry tropics of Western Queensland. The lake was constructed in 1957 by Mount Isa Mines on the western branch of the Leichhardt River, as both as an industrial water supply for the mines, and a domestic water supply storage.

The dam has a storage capacity of 106 000 ML, and a surface area of 2375 ha at capacity, with an average depth is of 6 metres.

The lake is used for recreational pursuits, including freshwater fishing, and is also the main water supply for the city of Mount Isa.

The salvinia infestation on Lake Moondarra in 1978.



Lake Moondarra in 1981, after successful biological control.

NRM&E Photo Library

The salvinia problem

In 1978, the most extensive salvinia infestation in Australia occurred on Lake Moondarra, covering some 400 hectares with an estimated at 50 000 tonnes of fresh weight of weed. Attempts had been made to control this infestation with aerial (helicopter) applications of herbicide, but these were abandoned in 1979 after costs reached $160 000, and the salvinia was growing faster than the herbicide could kill it.

Current salvinia levels

Salvinia remains on the lake at very low levels, with only scattered plants around the edges and in some of the creeks and inlets. The open water is salvinia free, and complete coverage of the open water has not occurred since the biocontrol was introduced.

The management strategy

The management of salvinia on Lake Moondarra took the form of the first successful trial releases of the salvinia weevil in Australia. Since then, salvinia management still centres around biocontrol, with re-releases of weevils made whenever salvinia levels appear to be increasing.

Aims and objectives

The aims of the biocontrol releases on the lake were to attempt to bring the infestation to an acceptable level; and to consider the potential for using the salvinia weevil to control salvinia elsewhere in Australia. The biocontrol releases were part of a closely monitored research program.

Biocontrol

In June 1980, approximately 1500 adult weevils were released into a salvinia-covered inlet on the lake. Two lots of 500 weevils were released into caged quadrats, and the remaining 500 were released near the cages.

By late December 1980, weevils had reduced the volume of salvinia in the cages by about 80%, and were causing visual damage to plants outside the cages. Fresh salvinia was added to the cages and the doors were left open. Weevils then began to move away from the heavily damaged salvinia, seeking out new undamaged plants further up the inlet.

In late January 1981 another 1500 adult weevils were released about 300 m from the inlet, and 10 large bags of weevil- infested salvinia were taken from the original release site to the opposite side of the lake.

In February, a storm swept the remaining weevil-infested salvinia out of the inlet into the main body of the lake.

By late March, the salvinia across the lake had started to turn brown and become waterlogged. By mid-April, the entire infestation was dark brown, and sampling showed that there were between 60 and 80 adult weevils per square metre, suggesting that the population had grown to over 100 million adult weevils. By this stage, 90% of buds showed damage.

By the end of May there was very little salvinia left on the lake, and samples were showing that the weevil population had decreased to about 6 million adults, with a 99% bud damage level. By August 1981, there was less than 1 tonne of salvinia remaining on the lake.

Time frame and expectations

The biocontrol process occurred in two phases over an 11-month period. The weevils were initially released in June and built up in numbers and distribution over an 8-month period, taking advantage of the mild winter conditions associated with the dry tropical climate.

Once the weevils had become well distributed in high enough numbers, control occurred very quickly over a 3-month period, in which the salvinia browned off, died and sank.

From that point onwards, it was expected that the salvinia and the weevils would be able to coexist on the lake in a dynamic equilibrium at low population densities, unless either the remaining weevils or the salvinia was destroyed due to stranding if water levels receded dramatically.

Ongoing management

The small amounts of remaining salvinia are monitored for any increases. Re-releases of weevils are made if the salvinia levels appear to be increasing, particularly after a good wet season (i.e. growing out from the edges of channels or starting to form small mats in the creeks and inlets). New weevil releases have been made only twice in the past 10 years.

Key points

Biocontrol has been used successfully over a 30-year period, to keep salvinia at low levels. Weevils are actively managed in accordance with fluctuations in the salvinia levels, and the lake is monitored on an ongoing basis.

It is important to note the time taken for the weevil populations to build up and disperse to the point they were able to provide control (8 months). Climatic conditions also remained ideal over the establishment period.

Successes

The releases of large numbers of weevils into protected areas of the lake allowed the release populations to become established within 6 months. Secondary releases were made 6 months later to assist with population growth.

Weevil distribution across the 400 hectare infestation was assisted manually and by wind action from a storm. However experience elsewhere has shown that weevils are able to disperse quite rapidly once localised populations increase. Once the weevils had become well distributed across the entire infestation (8 months after initial releases were made), control occurred relatively quickly and spectacularly (3 months).

Failures

Initial efforts to control the infestation with herbicides were abandoned due to the high costs, and the ability of the salvinia to outgrow the effects of the herbicides.

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