NSW DEPARTMENT OF
PRIMARY INDUSTRIES

Salvinia control manual - Readers' Note

This document is part of a larger publication. The remaining parts and full version of the publication can be found at:

http://www.dpi.nsw.gov.au/aboutus/resources/majorpubs/guides/salvinia-control-manual

Updated versions of this document can also be found at the above web address.

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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.

National Salvinia Workshop

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.

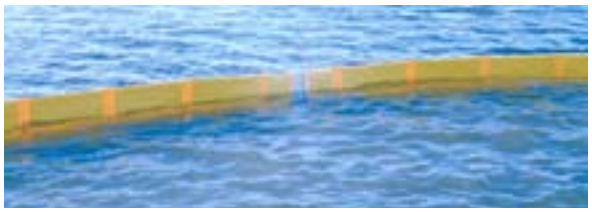
Booms need to be durable and strong enough to hold the considerable amount of force created by the weight and movement of the floating salvinia, the wind, tidal influences and currents. They can be designed to accommodate rises and falls in water levels (i.e. leaving some slack will accommodate small 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.*
>
> **National Salvinia Workshop**



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.*

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.

Karen Kranney

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.

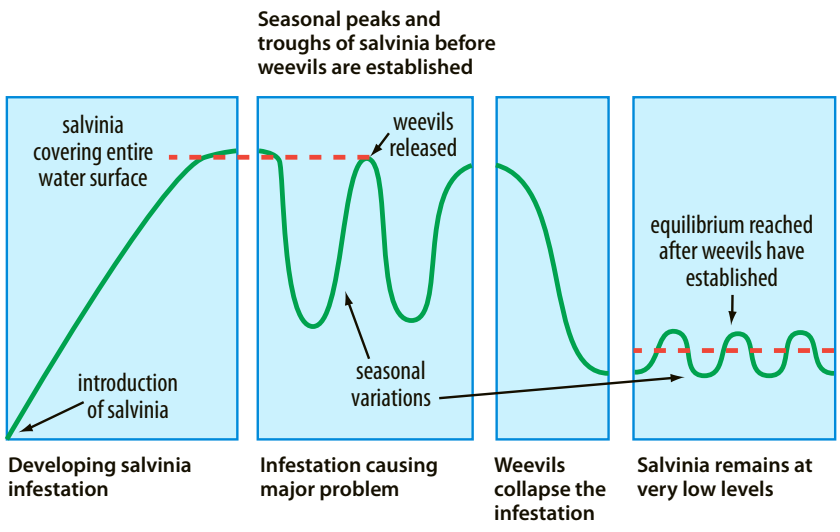
Peaks and troughs

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.

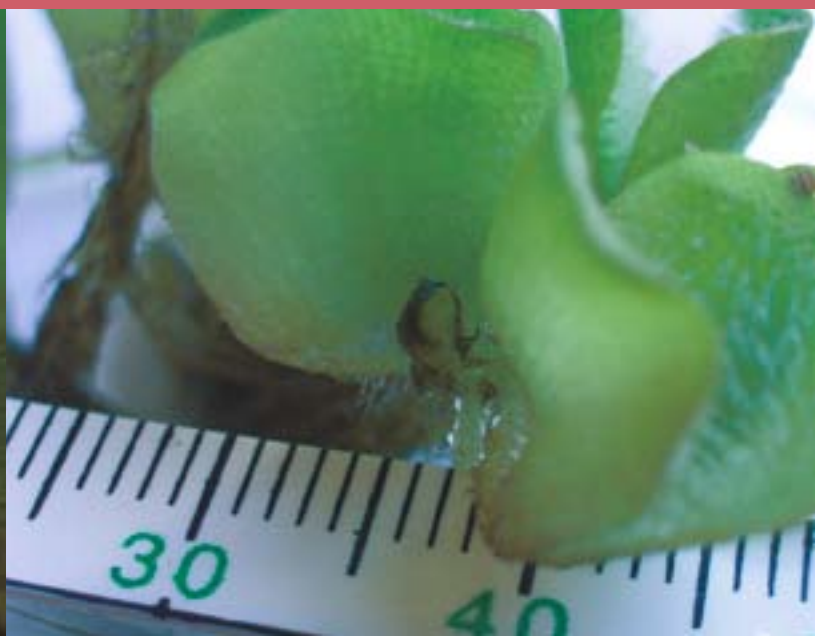
Andrew Petroeschevsky

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.

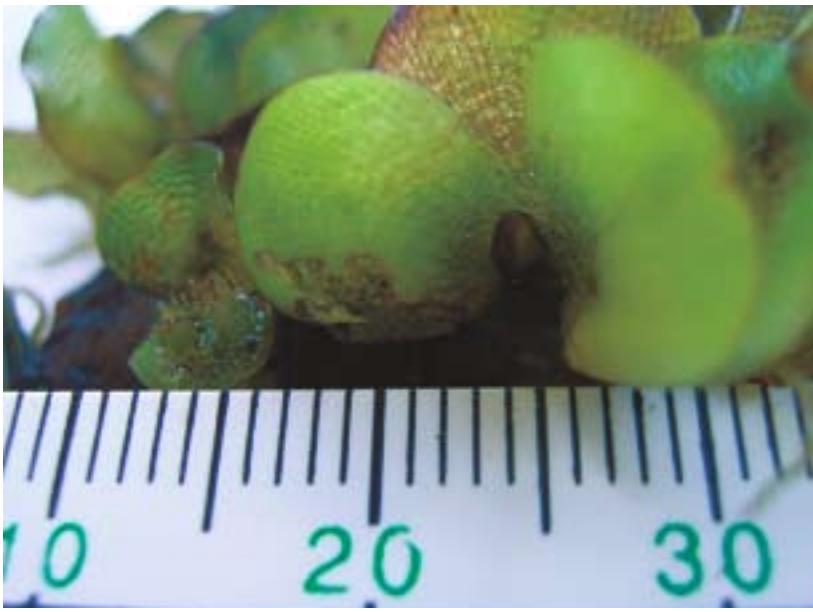
Count damaged buds. Take a sample of at least 50 plants from each release site, over an area of between 1 and 4 square metres. Check one bud on each plant for damage and record counts. Only the bud between the newest set of paired leaves is checked for damage (one bud per plant). Plants should be taken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

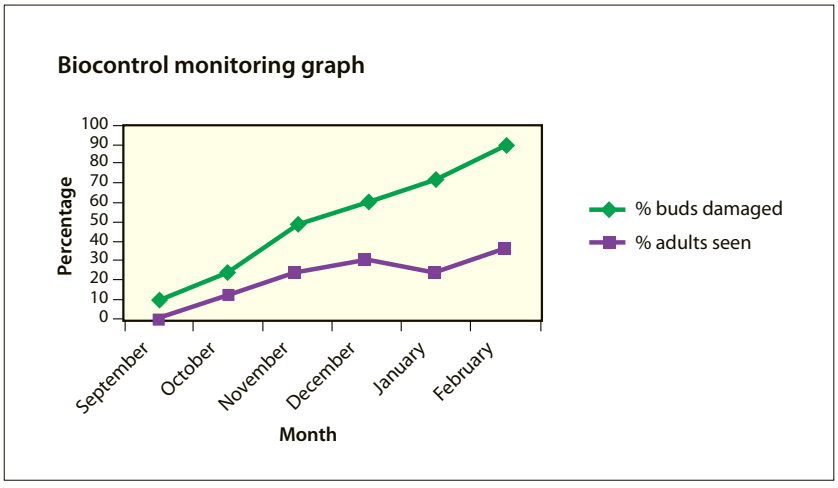
The following table and graph are hypothetical counts that could occur at a release site. Actual field counts can be much lower than this over a similar time period, but they would still indicate that weevils are present and increasing.

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

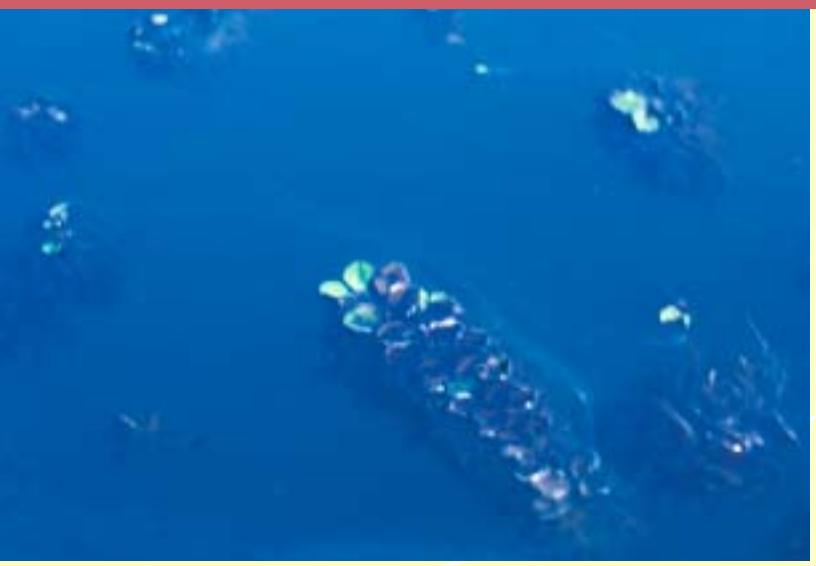
Diquat is rarely found longer than 10 days after application and is often at levels below detection 3 days after application. Diquat is taken up by aquatic vegetation and bound tightly to clay particles in the water and the bottom sediments, where it becomes biologically unavailable. When bound to organic 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:

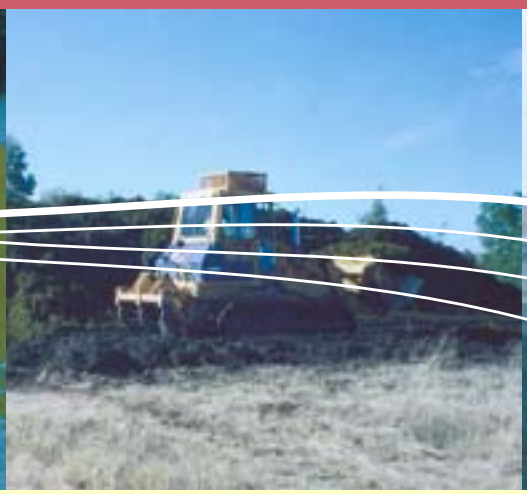
- an infestation occurs in a priority area, such as an area where there is high recreational use, high value conservation or potable water uptake
- the salvinia can be contained during the harvesting operation
- the rate of removal can exceed the rate of weed growth
- the harvested salvinia can be adequately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

Roy Durre

Salvinia being collected onto a harvester's conveyor.

Rebecca Coventry

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.

Andrew Petroeschevsky

Boat ramps provide access for heavy machinery.

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

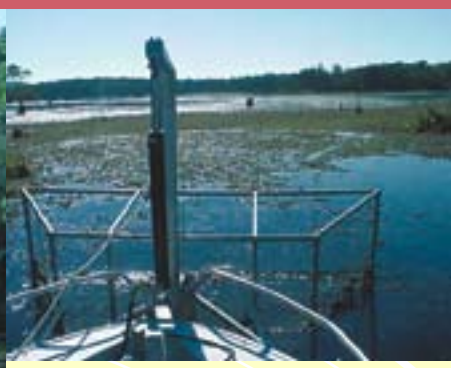
Removed weed needs to be transported away from the shore to a site above the flood level. Wet salvinia can be compacted to remove water before transportation to reduce costs. Compacting is generally able to reduce weed mass at a rate of 5 to 1, i.e. 50 cubic metres of

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