

Chapter 3

Controlling sagittaria

Overview

There are five methods available to control sagittaria:

- the herbicides glyphosate and flumioxazin
- mechanical excavation
- manual control
- recontouring
- biological control.

At a glance

- Limiting the spread, establishment and subsequent seeding of sagittaria is critical for its effective control.
- The most suitable control option will depend on the size, density and accessibility of the sagittaria infestation.
- Mechanical removal is a costly, but effective, way to remove sagittaria and significantly reduces the likelihood of re-establishment.
- Manual removal is also very effective for small infestations, but requires the removal of plants, stolons and tubers.
- There are limited herbicide options, and many weed managers use herbicides under permit arrangements.
- Herbicide effectiveness can depend on the situation they are used in.
- The first biological control agent, a fruit-eating weevil, was released in 2022. The weevil feeds on the plant's fruiting structures, resulting in reduced seed production.

Multiple applications per year of the herbicide glyphosate, under minor use permits, is the most widely used and effective control method for core infestations of sagittaria. These high-rate applications are necessary to achieve satisfactory control but require a permit from the Australian Pesticides and Veterinary Medicines Authority (APVMA). This method is unlikely to achieve site-based eradication, so ongoing costs to continue an annual glyphosate control program will be high.

Flumioxazin is a herbicide recently (2020) registered in Australia for sagittaria control. It is expected that flumioxazin will provide a suitable alternative to glyphosate for managing core infestations of sagittaria, but information on its use and effectiveness is currently limited to lab and small field trials in Queensland and Victoria. Further operational use of flumioxazin is required before understanding how effective it is in different situations, and if it is a tool suitable for site-based eradication of sagittaria.

Smaller infestations, or outlier infestations that represent range expansions of sagittaria, can be manually or mechanically excavated. Mechanical excavation also removes the sediment that contains crowns, seeds and tubers. This is an effective site-based eradication tool but requires site hygiene and careful management of excavated material. It is costly, but if successful, ongoing annual costs of control are eliminated.

The sagittaria fruit-feeding weevil is a biological control agent that has recently been released in Australia (March 2022). Managers of sagittaria should determine whether this weevil is present, and if absent, attempts to establish it locally should be made. The best strategies to integrate herbicide or mechanical control methods with the fruit-feeding weevil are not yet known but are the subject of ongoing research.

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The management challenges of sagittaria

Control of sagittaria is hampered by the difficulties associated with managing weeds in aquatic environments. Caution must be applied to the use of herbicides in water and decision-making must consider the risk of off-target impacts (e.g. to flora, fauna and water quality). Further, only a small number of herbicides are considered to have low enough impact on the aquatic environment to be used on aquatic weeds. Of these, only a few have been registered in Australia for control of aquatic weeds, and as at 2023 only one herbicide has sagittaria listed on its label.

As well as these broader issues, a number of practical issues make it difficult to manage sagittaria. Chief among them is difficulty with access because sites are underwater and surrounded by muddy substrates, often within valuable wetland communities. This limits selection of vehicles and ability to traverse on foot, which both then limit the surveillance and control activities that can be carried out. Water

can also completely obscure the rosette lifeform of sagittaria and protects it from foliar herbicide application.

Several control measures are currently used by weed managers in Australia. Generally, these managers recognise that sagittaria is difficult to control. A 2018 national survey commissioned to develop best practice guidelines for sagittaria revealed that weed manager ability to control sagittaria is poor, with nine of 16 respondents reporting they are 'somewhat satisfied' with their ability to manage sagittaria ('somewhat satisfied' was defined as 'there are techniques that can be used but the desired level of management is not always achieved' for the purposes of the survey). Five were 'not satisfied' (i.e. control is almost a waste of time or there are no suitable methods) and two were 'extremely satisfied' (i.e. the technique used gives a desired outcome). Respondents were from NSW, Qld, SA and Vic. Refer to Box 3.1 for more information.



Sonia Jordan

Choosing a control method

A critical part of developing a control program is to decide which control method to use. Figure 3.1 lists the main options available for sagittaria arranged according to the size and accessibility of the infestation. A summary of these methods is provided in Table 3.1.

Deciding whether an infestation is small or large can be somewhat subjective and requires thinking about what is realistically achievable. For example, manual removal will require the successful removal of all plants and reproductive material (see Chapter 4, case study 3). The likelihood of achieving this reduces as the size and complexity of an infestation increases. Consideration also needs to be given to personnel safety because of the manual work required by this method.

Proximity to other sagittaria infestations is important when selecting control methods. A new infestation that is distant from any other infestation, often referred to as an outlier infestation, is important because it will represent a range expansion. Eradication of such outlier infestations will reduce the sagittaria range and slow its spread. In such situations, it is worthwhile using the most effective control tools available, such as mechanical and manual removal, which are initially much more expensive than using control methods such as herbicide or biocontrol.

In contrast, control of core infestations (i.e. those that are within areas that have many other well-established sagittaria infestations) should be guided by considerations of efficiency, which usually means the cheapest control measure is appropriate (i.e. herbicide application and biological control).

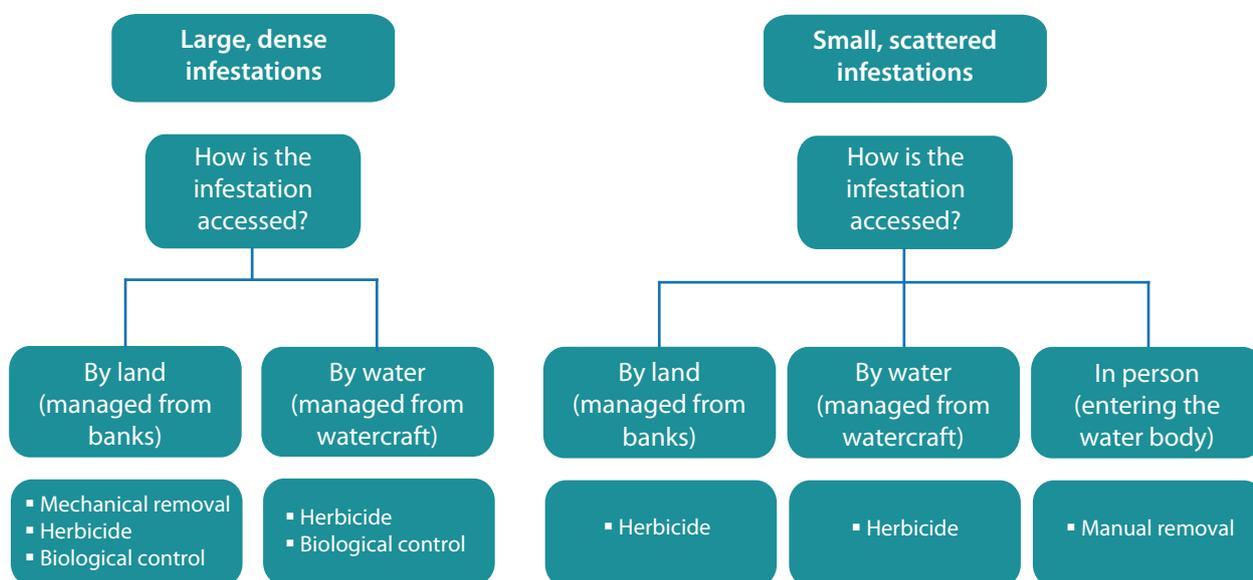


Figure 3.1 Suitable sagittaria control methods depend on the size and accessibility of the infestations.

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Table 3.1 Summary of sagittaria control methods.

	 Situation	 Advantages	 Disadvantages	 Caution!	 Timing	 Integrate with
Herbicide control	<ul style="list-style-type: none"> All situations where the herbicide label can be complied with or a minor use permit exists 	<ul style="list-style-type: none"> Low-moderate cost Enables targeted control of sagittaria Quick to apply to multiple plants Can control large areas Low access requirements (can be used in most situations) 	<ul style="list-style-type: none"> Results can be unpredictable with potential poor control and regrowth Can be difficult to comply with herbicide label Risk of off-target effects on desirable plants and other environmental impacts Limited herbicide options 	<ul style="list-style-type: none"> There is a legal requirement to follow all label or permit instructions Follow safety directions Long-term use may lead to herbicide resistance Permits may be required 	<ul style="list-style-type: none"> Boom or spot spraying multiple times per year while sagittaria is actively growing 	<ul style="list-style-type: none"> Manual removal Mechanical removal It is unclear whether herbicide can be integrated with sagittaria biocontrol
Mechanical removal	<ul style="list-style-type: none"> Portions of rivers, drains, channels and wetlands that are accessible by an excavator, typically restricted to areas near banks 	<ul style="list-style-type: none"> Can be very effective Removes upper sediment layer, which contains entire plants, seeds and tubers, reducing regrowth 	<ul style="list-style-type: none"> High cost, major equipment needs Time-consuming and labour intensive Limited by access High environmental impact, so mainly suitable for drains, irrigation channels and constructed wetlands 	<ul style="list-style-type: none"> Care needed to remove tubers Creates large volumes of soil and plant material that needs to be disposed of Care required to prevent spread Care to avoid damaging banks Permits may be required 	<ul style="list-style-type: none"> Year-round 	<ul style="list-style-type: none"> Manual removal Herbicides Recontouring
Manual removal	<ul style="list-style-type: none"> Shallow portions of rivers, drains, channels and wetlands 	<ul style="list-style-type: none"> Can be very effective Suitable for small infestations No specialised equipment required Minimal impacts on environment (soil, fauna, etc.) 	<ul style="list-style-type: none"> High cost (labour) Time-consuming and labour intensive Not practical for large infestations Limited by access Regrowth may occur Restricted to shallow water (~30 cm) 	<ul style="list-style-type: none"> Drowning risk Care needed to remove tubers Care required to prevent spread 	<ul style="list-style-type: none"> Year-round 	<ul style="list-style-type: none"> Mechanical removal Herbicides

	 Situation	 Advantages	 Disadvantages	 Caution!	 Timing	 Integrate with
Recontouring	<ul style="list-style-type: none"> Very limited application (irrigation channels) 	<ul style="list-style-type: none"> Reduces habitat suitability of irrigation channels for sagittaria (water depth too great for establishment/persistence) 	<ul style="list-style-type: none"> High cost Not suitable for drains since water depth fluctuates Unsuitable for natural waterbodies Potential for high environmental impact 	<ul style="list-style-type: none"> Requires specialist planning to maintain channel integrity and flow Creates large volumes of soil and plant material that needs to be disposed of Care required to prevent spread Permits may be required 	<ul style="list-style-type: none"> Year-round 	<ul style="list-style-type: none"> Mechanical removal
Biological control	<ul style="list-style-type: none"> Dense and extensive infestations Difficult to access infestations or where other control methods may harm sensitive aquatic habitats 	<ul style="list-style-type: none"> Low cost Limits spread Can be self-sustaining Suitable for both sagittaria and arrowhead No off-target impacts on other plants or the environment No permits required 	<ul style="list-style-type: none"> Not an eradication tool – unlikely to give sufficient control on its own Does not control mature plants Long time required for efficient control Uncertainty of control efficacy 	<ul style="list-style-type: none"> Other control methods should be withheld from release sites to enable biocontrol establishment 	<ul style="list-style-type: none"> Release agents October through April 	<ul style="list-style-type: none"> It is unclear whether biocontrol of sagittaria can be integrated with other methods

The five methods available for sagittaria control have a variety of advantages and disadvantages, which are considered in Table 3.1. The effectiveness of these (excepting recontouring), according to a practitioner survey and associated workshops, are considered in Box 3.1.

Box 3.1 Rating the effectiveness of sagittaria control methods – a practitioner survey.

Control methods that waterway managers in Australia have reported using are shown in the table below, which contains information collected from a national survey of sagittaria managers, along with follow-up workshops (Clements et al., 2018). Information on flumioxazin and the fruit-feeding weevil has been added because they were not available at the time of survey. Detailed information on each of these control methods is provided in the following sections.

Methods used to control sagittaria in NSW, Qld, SA and Vic, along with self-reported effectiveness.

Control method	Effectiveness ¹	Relative control cost or difficulty of implementation	Situation ²
Herbicides			
Glyphosate applied at aquatic label rate (3.24 kg/ha) up to 3 times per year	Poor to moderate	Low cost / easy	All
Glyphosate applied at 3 to 10 × label rate (9.72 to 32.4 kg/ha) up to 3 times per year ³	Moderate to great	Low cost / easy / permit required	All
Flumioxazin application direct to waterbody, with or without foliar spray ⁴	Moderate to great. Lack of operational use by weed managers means effectiveness relative to other control measures cannot be estimated ⁵	No data. Likely to be low cost/ easy	Non-flowing bodies of freshwater and the margins of streams, lakes, dams and channels that are slow moving or quiescent
Biological control			
Sagittaria fruit-feeding weevil ⁴	The weevil eats sagittaria seed and fruit but data from populations established in Australia has not yet been collected, so effectiveness relative to other control measures cannot be estimated	Expected to be easy if the weevil readily establishes in Australia	All
Other methods			
Mechanical excavation	Great	Expensive / difficult	All, where access allows
Manual removal 2–3 times per year	Moderate	Expensive / difficult	All, where access allows, outlier infestations
Steam	Poor	Expensive / difficult	All, where access allows
Floating weed control booms	Moderate (at reducing dispersal, not controlling plants)	Moderate	Rivers and creeks, natural wetlands, billabongs, lakes and dams

¹ Effectiveness: Poor = level of desired control requires >3 applications per year; moderate = effective but short-term control, 2–3 applications per year required; great = effective for longer term control, i.e. 1 application per year required.

² Situation: irrigation channels, drains, rivers and creeks, natural wetlands and billabongs, and urban / constructed wetlands.

³ Permits required. More information on permits can be found in the Factsheet: Using herbicides legally, safely and effectively.

⁴ Flumioxazin and the sagittaria fruit-feeding weevil became available in 2020 and 2022 respectively; thus, there is no reliable information from weed managers on their effectiveness, cost or ease of application.

⁵ Personal communication, Tobias Bickel.

Herbicide control

Herbicides are applied by mixing a herbicide concentrate with water and spot spraying or boom spraying the solution over the weeds (see images of spot spraying and boom spraying of sagittaria in Chapter 4, case study 1).

Spot spraying is usually undertaken from the bank with long-hosed spray rigs that are mounted on a vehicle (ute, ATV, boat, tractor, truck). Spot spraying is used where sagittaria density is relatively low or infestations are small. Backpack spray units are not typically used to spray sagittaria because carrying the heavy unit through water is not safe.

Boom spraying covers all parts of the infested area with the herbicide solution. Boom spraying is rarely used for sagittaria control because the blanket approach results in greater amounts of herbicide entering the water.

Flumioxazin is a specialty herbicide used to control aquatic weeds, including sagittaria. It can only be applied by people accredited by the flumioxazin manufacturer. Application includes spot spraying, boom spraying and direct application to the water.

Refer to Tables 3.2 and 3.3 for information on herbicides available for use on sagittaria.

Before commencing any weed control ensure you:

- read the **factsheet on using herbicides safely and effectively (page 36)**
- are aware of legislation in your state/territory regarding herbicide use – refer to your state/territory weed control contacts (Chapter 5) for advice and assistance
- visit the APVMA website for up-to-date herbicide registration details and current permits: www.apvma.gov.au.

By law, you must read the label (or have it read to you) before using any herbicide product. The same applies for minor use permits.

Take care to minimise off-target herbicide damage to desired plants and animals, the environment, yourself and other workers.

FACTSHEET: Using herbicides legally, safely and effectively

Herbicide labels and legislation

The Australian Pesticides and Veterinary Medicines Authority (APVMA) regulates the availability of all pesticides, which includes herbicides. Herbicides are registered with the APVMA for specific applications as stated on the label, and state/territory governments regulate the use of herbicides after sale. A herbicide label is a legal document that defines where, when and how a herbicide can be used, on which weed species and at what rate. This is referred to as its 'on-label' use.

Not all registered herbicides are commercially available. Often companies will improve herbicide formulations and only market the new formulation. For example, many herbicides are being marketed in higher concentrations. This reduces transport, storage costs and container disposal costs.

Off-label use

'Off-label' use is the use of a registered chemical to address a specific issue that is not covered by the APVMA approved label, such as:

- to control a different weed (or pest)
- to apply at a different (lesser) rate
- to apply in a different manner (not allowed in ACT, NSW and Tasmania).

Off-label use is permitted in all states and territories; however, conditions vary in each jurisdiction.

Minor use and emergency use permits

The APVMA may issue minor use and emergency use permits for herbicide applications that are not otherwise registered for that particular use. Minor use permits can also be referred to as off-label permits. Minor use and emergency permits are valid ('in force') for a limited time. See the APVMA website to find current permits.

Some states/territories also have permits for declared weed control but may not specifically list the weed species to be controlled. These permits will often list a range of herbicides that can be used for declared or environmental weed control. To find current permits for your state/territory go to:

- the APVMA permits search
- enter 'declared weeds' or 'environmental weeds' in the 'key words' box
- click the search term 'Pest/purpose'
- click 'Search'.

Permits for sagittaria

A range of current permits are listed on the APVMA website and detailed in Table 3.3. Current permits are for use of high rates of glyphosate, with one including 2,4-D. Use of the current APVMA permits is subject to the conditions listed on each individual permit.

Note sagittaria is listed under multiple names on the APVMA permits because of past confusion on the naming conventions of the species. All of the following refer to *Sagittaria platyphylla*: Arrowhead, *Sagittaria graminea*, *Sagittaria platyphylla* and *Sagittaria* spp.

Chemical use training and certification

Chemical use training is required for people using herbicides as part of their job or business. Training is also recommended for community groups and may be required if working on public land. Commercial weed control operators need to be licensed in most states/territories.

Safe use of herbicides

Operator safety

Herbicide labels will indicate the personal protective equipment (PPE) required for operator safety. This may include:

- chemical-impervious gloves
- eye protection
- respirator (with a filter appropriate to the level of herbicide toxicity)
- clothes, hat and boots that cover the whole body.

For herbicides with a higher risk to operator safety, additional PPE and precautions may apply, including wearing a full-face respirator and chemical-resistant overalls.

Always follow the herbicide label requirements and consult the Safety Data Sheet (SDS) on the health risks of exposure and PPE recommendations.

Environmental protection

Herbicide labels provide the mandatory measures an operator needs to adopt to protect the environment and non-target plants during the product use. This may include instructions for preventing spray drift.

Herbicide users have a legal obligation to avoid spray drift damage and to ensure that the applied chemical stays within the target area.



Tobias Bickel

This is to avoid 'off-target' impacts to crops, native vegetation and other plants, and 'chemical trespass' onto neighbouring properties.

Measures to reduce the risk of spray drift include:

- spraying when the wind is 3–15 km per hour or when there are no surface temperature inversion conditions
- using a coarse to very coarse spray quality nozzle type
- avoiding the use of high pump/sprayer pressures that create small droplets that float in the air
- having buffer zones.

Using herbicides near water

Riparian zones are sensitive habitats, and a licence may be required to conduct weed control works. Only use herbicides that are registered or permitted for use in and around aquatic areas; some are formulated to be lower risk when used near water, e.g. Roundup Biactive®.

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Never add adjuvants to herbicides to be used near water unless they are registered for aquatic use.

Detailed information about the risk of herbicide use around water can be found in the section 'Herbicide use around water'.

Effective use of herbicides

Successful herbicide control is dependent on:

- selecting the right herbicide for the target species
- the growth stage of the target species
- the weather conditions during and after spraying
- how thoroughly the herbicide is applied
- the herbicide mix and application rate.

For spraying, wind speeds should be low (3–15 km/h) with no rain expected in the following six hours.

Do not apply herbicide to plants that are under any sort of stress because herbicide will not be absorbed and translocated effectively, resulting in a reduced level of control. Plants may be stressed because of:

- low humidity
- air temperatures above 30°C
- frost.

Herbicide effectiveness can be maximised by:

- ensuring spray equipment is correctly calibrated and maintained, including being thoroughly cleaned between uses.

Where to get help

State contacts for weed control and herbicide use are listed in Chapter 5 – Further information.

Herbicides for use on sagittaria

Flumioxazin is the only herbicide registered in Australia that lists sagittaria on the label as a target in 'Weeds Controlled'; thus, its use to control sagittaria is considered on-label. Glyphosate, imazapyr and dichlobenil are also used to varying degrees and in varying situations, but none of these list sagittaria on their labels as a target in 'Weeds Controlled'; thus, their use to control sagittaria is considered off-label.

Glyphosate

The most commonly used sagittaria control option is chemical control with glyphosate. This is in use across all situations where sagittaria occurs (irrigation channels, drains, rivers and creeks, natural wetlands and billabongs, and urban/constructed wetlands). Since sagittaria is not listed on the label of any glyphosate products, this use has been conducted as off-label use.

Regrowth is rapid after glyphosate application at legal off-label rates (probably from tubers, rosettes and damaged crowns beneath the water). The APVMA issues permits (see herbicide factsheet) to legalise the use of chemicals at rates at least three times higher than the aquatic label rate (see Table 3.3). These higher rates provide more effective control, albeit with regrowth and variable results.

Regardless of rate, repeat applications in a single year are usually required to reduce sagittaria abundance. Applications in November, February and April are a common strategy in south-east Australia. Efficacy is greater when water levels are low because a greater proportion of the foliage is exposed to herbicide spray.

In natural areas (rivers, creeks, wetlands) foliar application of glyphosate to emergent plant parts, repeated in November, February and April, is known to prevent seed set, although one application per year, in autumn, has been successful at slowly reducing population size for the Goulburn Broken Catchment Management Authority. The aim of

programs in natural areas is usually to prevent further spread and reduce sagittaria density levels to protect biodiversity.

In irrigation channels and drains, glyphosate is applied to the emergent parts to restore or maintain irrigation channel function and reduce seed load. As per natural areas, three applications per year are generally required to prevent seed set, although two applications per year can be used to prevent population expansion. Glyphosate application with a handgun from a vehicle-mounted spray rig typically costs \$1600 to \$3200 per kilometre per application.

See Chapter 4 (case study 1) for an example of management of sagittaria using glyphosate.

Results of glyphosate application can be variable. The factors thought to affect success include seasonality, plant morphology (generally excellent control is associated with broad-leafed young emergent plants), detritus on leaves reducing effectiveness, and water level at the time of herbicide application (plants submerged at the time of herbicide application cannot be treated, while plants with greater portions of their foliage emerging above the water receive a large herbicide dose and are controlled better).

Specific details to improve the effectiveness of regimes using glyphosate are not available (e.g. timing, water level, herbicide and surfactant formulation, detritus). Refer to Box 3.2 for general advice.

Adjuvants are often added to herbicides to improve their effectiveness. When controlling aquatic weeds, the glyphosate formulations commonly used by water authorities, such as Roundup Biactive® and Weed Master Duo®, do not require addition of adjuvants.

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The reliance on glyphosate to manage sagittaria increases the likelihood that herbicide resistance may occur, particularly because in some locations sagittaria has been controlled with glyphosate for over 30 years. In fact, some weed managers suspect that resistance has already evolved, although there is no data to demonstrate this.

Box 3.2 Maximising the effectiveness of glyphosate on sagittaria

- Where possible, spray when water levels are low, exposing more of the plant to herbicide contact.
- Obtain an APVMA permit to allow application at high rate (at least 3 × standard rate).
- If possible spray 3 × per year, in November, February and April, to prevent seed set and suppress abundance.
- If you can't spray 3 × per year, spraying once in autumn can reduce seed set and slowly reduce population size.

Flumioxazin

A new herbicide option is flumioxazin, which was registered for sagittaria control in Australia in 2020, under the trade name Clipper®. It provides an alternative mode of action for sagittaria managers as an alternative to glyphosate. Use of Clipper® requires accreditation from the supplier. It can be used to control sagittaria in a range of situations, but data on its effectiveness is not currently available due to its limited operational use.

An advantage of flumioxazin is that it can be applied via a foliar spray (like glyphosate) or via in-water application (where it is mixed directly with the water in the waterbody); therefore, efficacy is not affected

by the proportion of leaves that are above the water surface as it is for glyphosate. When used via in-water application, flumioxazin also controls the rosettes that are underwater, which glyphosate does not. An aquatic adjuvant is recommended to improve efficacy.

See Chapter 4 (case study 2) for more information on the use of flumioxazin to control sagittaria.

Other herbicides

Although effective against sagittaria, off-label use of imazapyr and dichlobenil is not widely used because of restrictions on their labels, which are difficult to comply with, and risks associated with movement of herbicide-treated water (which can cause crop and environmental toxicity). Further, sagittaria is not listed on their labels, so their use is considered off-label.

Herbicide use around water

Use of herbicides to control sagittaria requires special consideration of the potential off-target impacts.

These may include:

- direct impacts on non-target organisms including native aquatic plants, frogs and fish.
- indirect impacts on bank stability, water quality and water temperature as sagittaria decomposes.

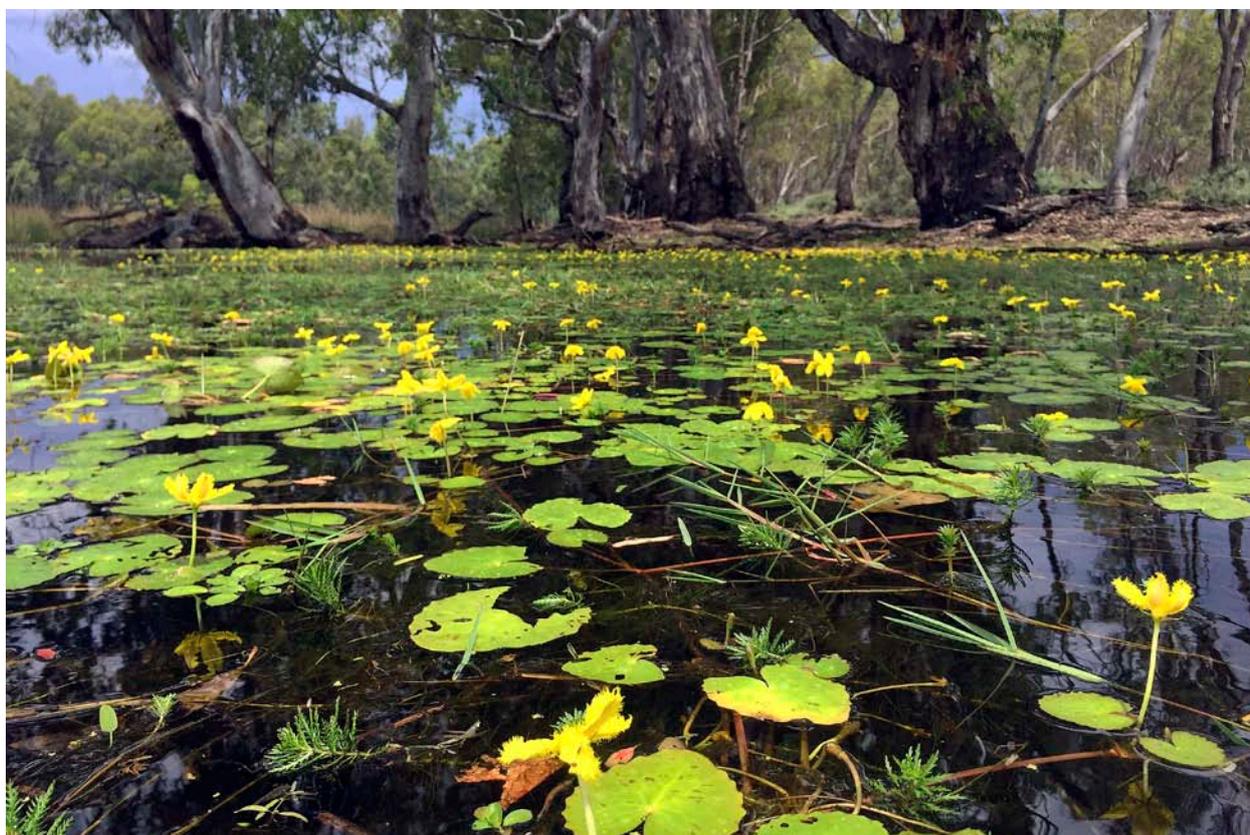
Guidelines are available to help weed managers in planning for using herbicides in and around water, which can be found in the following factsheet: Herbicides: guidelines for use in and around water. Cooperative Research Centre for Australian Weed Management (Ainsworth and Bowcher, 2005) <https://www.dbca.wa.gov.au/media/941/download>

The guidelines can be consulted when developing a weed management plan utilising herbicides. Refer to Chapter 5 for more details.

Table 3.2 Herbicides registered for use on sagittaria.

Application method	Active ingredient	Commercial product examples	State or territory	Rate	Situation in which the herbicide is registered	Comments
Water bodies deeper than 0.5 m with estimated water volume greater than 37.5 m ³ , with no physical barriers to restrict water circulation:						
Direct tablet application	Flumioxazin 15 g/tablet	Clipper®	All	Apply 1 tablet for every 37.5 cubic metres of water to achieve 400 parts per billion (ppb)	Control of submerged and emergent weeds in enclosed water bodies and margins of larger open aquatic systems, including natural water bodies	Refer to label for critical comments
Water bodies less than 0.5m deep, or with estimated water volume less than 37.5 m ³ , or with barriers to water circulation where direct tablet application is not practical:						
Injection of spray solution*	Flumioxazin 15 g/tablet	Clipper®	All	200–400 ppb plus approved aquatic adjuvant/surfactant @ 0.5–1% v/v	Control of floating, emergent and submerged weeds where Direct tablet application is not practical	Refer to label for critical comments

* Refers to application with conventional spraying equipment, either as a spot spray or injected into the water column. Refer to product label for more information.



Damien Cook, NCCMA

Reedy Lagoon, on the Gunbower Forest floodplain, is a high value wetland that can be protected by preventing the spread of sagittaria.

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Table 3.3 Herbicides permitted for use on sagittaria under minor use permits.

<p>Permit: PER89861 – expires 30 November 2027. Permit holder: Murrumbidgee Irrigation Limited (MIL)</p> <p>Persons who can use the product under this permit: Persons generally who are suitably trained in the application of agricultural chemicals in aquatic situations.</p> <p>Refer to permit critical use comments.</p>					
Application method	Active ingredient	Commercial product examples	Rate	State or territory	Situation
Spot spray	glyphosate (360 g/L) products registered for use in aquatic situations	Roundup Biactive®	10 L product/100 L water. DO NOT exceed a maximum of 40 L product/ha	NSW only, specifically the Murrumbidgee Irrigation Area.	Aquatic areas (Irrigation and drainage channels) within the MIL areas of responsibility
<p>Permit: PER80934 – expires 31 May 2026. Permit holder: Biosecurity Queensland</p> <p>Persons who can use the product under this permit: Persons who are experienced, suitably trained and accredited in the application of agricultural chemicals in aquatic situations.</p> <p>Refer to permit critical use comments.</p>					
Spot spray	glyphosate (360 g/L) products registered for use in aquatic situations	Roundup Biactive®, weedmaster Duo	10 L/100 L	Qld only	Artificial Ponds, Irrigation and Natural Waterways
<p>Permit: PER13448 – expires 30 April 2025. Permit holder: Goulburn Murray Water Authority</p> <p>Persons who can use the product under this permit: Staff employed or contracted and supervised by Goulburn Murray Water Authority, who are suitably trained, hold a current Agricultural Chemical Usage Permit, are experienced in the application of agricultural chemicals in aquatic situations and are directed by qualified and experienced Goulburn-Murray Water Officers.</p> <p>Refer to permit critical use comments.</p>					
Spot spray, wiper or boom spray	glyphosate (360 g/L) products	weedmaster Duo	Up to 40 L/ha	Vic and NSW (specifically Murray River) only	Irrigation and natural waterways within Victoria (including the Murray river)
Spot spray or boom spray	2,4-D 625 g/L	Zephyr 625	Up to 10 L/ha	Vic and NSW (specifically Murray River) only	Channels and drains within the Goulburn Murray water irrigation system. The Nine Mile and Broken Creeks in the Murray valley and Shepparton irrigation areas
	2,4-D 800 g/kg	Baton® Low	Up to 7.8 kg/ha		
<p>Permit: PER14933 – expires 30 April 2024. Permit holder: Murray Irrigation Limited</p> <p>Persons who can use the product under this permit: Operators employed or contracted by the permit holder who are suitably trained in the application of agricultural chemicals in aquatic situations.</p> <p>Refer to permit critical use comments.</p>					
Not specified. Contact the permit holder for further information.	glyphosate (360 g/L) products registered for use in aquatic situations	Apparent Glyphosate Green 360	Up to 40 L/ha	NSW only	Aquatic areas within the Murray Irrigation Limited (MIL) area of responsibility

Mechanical removal

Mechanical removal is widely used for sagittaria control. In particular, mechanical removal is used where the aim is to eradicate sagittaria from a site, or where rapid restoration of flow capacity is required in irrigation channels and drains.

In irrigation channels and drains, excavators are used to remove sagittaria to restore channel function as an alternative to herbicide application. The main benefit of mechanical removal over herbicide application is it results in immediate improvements to water flow, whereas with herbicides it takes several weeks for the sagittaria to die and decompose. Another important advantage is that there is less regrowth because crowns, tubers and seeds are removed by the excavator with the sediment, and thus control is more enduring. It can also be used on demand whenever required, unlike herbicides, for which issues associated with seasons, water contamination and label restrictions limit use to certain windows.

The main drawback with mechanical removal is the high cost. Mechanical de-weeding of sagittaria from irrigation channels, which involves the excavator removing the weeds and leaving the sediment in place, typically costs \$6500 per km. Full desilting of irrigation channels, where a deep layer of accumulated sediment is removed, is often prioritised in areas that contain dense sagittaria infestations. This more intensive exercise typically costs approximately \$13,000 per kilometre of channel.

For new, isolated infestations where site-based eradication is desired, mechanical removal with an excavator is effective because crowns, tubers and seeds are removed. If performed thoroughly, regrowth can be minimised or prevented completely; however, follow-up monitoring for any regrowth is essential. Mechanical excavation targeting site-based eradication has occurred in greater Melbourne, where sagittaria was discovered in a constructed wetland. Sagittaria appeared to be eradicated from this site after initial excavation, but reappeared seven



Russel Talbot

Mechanical removal of sagittaria from an irrigation channel.

years later, at which time (2021) it was excavated a second time. At another location in Gippsland, a similar operation occurred in a private pond in 2019, with no known reappearance. For success, at least the top 30 cm of sediment should be excavated, to capture all seeds and tubers, although investigation at the site is best to decide how deeply to excavate. Sagittaria tubers are known to form as deep as 40 cm below the sediment in irrigation channels with a deep silt layer, while in sandy or hard substrates they are shallower (approximately 20 cm). Management of sagittaria in this way is costly and difficult but the required investment is warranted, because removal will eliminate a new infestation and thus prevent the expansion of sagittaria's range.

Improving the effectiveness of mechanical removal of sagittaria

- Where possible, determine how deep the sagittaria tubers are buried and then excavate to at least that depth; otherwise, excavate at least the top 30 cm of sediment.
- When eradicating an outlier infestation, consider carefully where to dispose of the plant material and sediment to ensure no further spread.
- Ensure excavators and other equipment are clean before leaving the site to prevent spread.
- Consider access for the excavator and how much damage to the waterbody and bank is likely to be caused by its operation.

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Manual removal

Manual removal is the removal by hand of sagittaria plants, including stolons and tubers. It can provide effective control of sagittaria at a site scale but is very labour intensive. It is used for low-density populations and new outbreaks, with the aim of achieving site eradication.

The efficacy and cost of manual removal has been assessed by officers working to eradicate sagittaria near Townsville, North Queensland. Done carefully in this example, it was very effective at removing new infestations of sagittaria but was very time-consuming. The trial involved gently removing stolons and tubers from a 10 square metre plot of soft, muddy substrate in the Ross River. It took two people 16 hours, spread over three visits. The technique involves gently tracing the stolons with fingers to ensure that the individual networks and associated tubers are removed completely. After a short time, the water becomes muddy, dictating that most of the removal is done by touch, rather than sight. Follow-up inspections indicate that the method was successful, with regrowth only occurring from plants outside of the plot. Townsville City Council estimate that this procedure cost approximately \$200 per square metre (Calvert, 2015). Repeated manual removal in these plots has substantially depleted the number of tubers and stolons, and reduced the size of the stolons.

A feature of sagittaria is that tubers remain attached to the stolons for a reasonable, but unknown, period after they are formed. This allows them to be detected and removed as part of the careful manual removal method described above, thus improving the chance of successful eradication for new, small infestations.

Follow-up monitoring is critical to ensure all plants have been removed and to enable removal of any new plants arising from seeds and tubers. Ideally, this would happen three times per year, so that removal



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When manually removing sagittaria, care must be taken to ensure the extensive underground system of stolons and tubers are removed. Examples of sagittaria plants after manual removal from mud: (a) a long stolon connecting daughter plants with a mother plant after removal from mud, (b) multiple stolons with tubers emanating from a mother plant, (c) multiple stolons, each with daughter plants emanating radially from a central mother plant – note a secondary daughter plant of one of the daughter plants already producing a stolon (top).

can occur before the plant is large enough to begin producing seeds, stolons or tubers. Seeds and tubers will generally germinate or sprout within several weeks during the warmer months but can remain dormant for several months over winter, especially if buried in mud, where cooler temperatures and darkness delay development. A study showed that the viability of seeds buried up to 10 cm deep in an irrigation channel bank were still viable up to 18 months after burial (Kwong unpublished data), so monitoring should occur for at least this long.

See Chapter 4 (case study 3) for more information on manual removal for eradication.



Tony Dugdale

Excavating sediment from an irrigation channel.

Recontouring

Recontouring of irrigation channels has been used by rural water authorities to reduce the habitat suitability for sagittaria. While this is similar to desilting, the specific aim of recontouring is to deepen the profile of the irrigation channel to reduce its suitability for sagittaria. Emergent sagittaria plants grow in permanent water that is generally less than 50 cm deep (Adair et al., 2012), although it can occasionally persist in deeper water (refer to Chapter 1). Excavation to a depth greater than 50 cm can result in the central portions of irrigation channels being sagittaria free.

Recontouring works well in channels because water levels remain constant. However, it is less suitable for drains, where water is ephemeral, resulting in fluctuating water levels. In these situations, sagittaria migrates in response to water levels, growing across the bottom of the drains whenever levels are low (or standing water is absent).

Recontouring is unsuitable for use in natural waterbodies, where the shape and slope of the bottom of the waterbody is governed by natural processes.

Recontouring is a major undertaking that requires careful consideration of the hydrology to ensure flow and structural integrity of the channel is maintained. It will be subject to planning permits and require the engagement of engineers and other specialists. Consult your water authority to discuss the feasibility of recontouring for your situation.

Disposal and site hygiene associated with mechanical and manual removal of sagittaria

Mechanical and manual removal is an effective way of controlling sagittaria. However, it comes with a risk of spreading sagittaria via propagules that remain attached to equipment, which is then transported to a different location. Also, material that is removed needs to be carefully disposed of so that it does not start a new infestation at the disposal site. These problems can be managed with extreme care.

Disposal

For outlier infestations, where mechanical or manual removal is used to eradicate sagittaria, it is imperative to carefully dispose of all soil and plant material that is removed from the waterbody.

Deep burial on land near the infested waterway is best because this minimises the requirements for transport (and thus potential for contamination of vehicles) and minimises the distance that sagittaria may disperse should an incident occur (such as spillage or incomplete burial).

Waste should be buried in a pit at least two metres deep and be covered by compacted earth. The location of the disposal site should be recorded and arrangements made to prevent future disturbance of the site. Care needs to be taken to prevent animals from accessing the pit prior to it being closed to prevent them from dispersing the removed material (e.g. seeds and tubers).

Detailed guidance on burial of biosecurity waste is provided by the Australian Government (2021):

Australian Government. 2021. *Approved Arrangement Requirements 8.2 – burial of biosecurity waste. Version 4.0.* www.agriculture.gov.au/biosecurity-trade/import/arrival/arrangements/requirements#class-8

In core infestation zones, that is, where sagittaria is widespread and abundant, no special considerations are required for disposal because the area will already be heavily populated by sagittaria. In this case, excavated material can be left on the bank of the waterbody adjacent to where it has been removed.

Machinery hygiene

Hygiene procedures must be in place to ensure viable sagittaria material (crowns, seeds and tubers) are not present on machinery and equipment used at the site. There are a range of resources available that describe procedures for this:

- https://www.daf.qld.gov.au/__data/assets/pdf_file/0011/58178/cleandown-procedures.pdf
- https://www.mirrigation.com.au/ArticleDocuments/303/Weed%20Hygiene%20Procedure_update%20Sept%202022.pdf.aspx
- <https://nt.gov.au/environment/weeds/how-to-manage-weeds/prevent-weed-spread-industry-and-recreation/keep-your-vehicles-and-equipment-clean>

Floating booms

Floating weed and debris booms can also be used to reduce sagittaria dispersal, particularly to contain dislodged plants associated with manual or mechanical excavation. They come in lengths that can be connected to form a flexible floating barrier, usually with a skirt that sinks into the water, to encircle the area where removal works are occurring. Dislodged plants tend to float on the water surface because they are positively buoyant and are retained by the curtains.

Biological control

Biological control (or biocontrol) is the use of a weed's natural enemies – usually an insect, herbivore, parasite or pathogen – to reduce a weed's population density to levels that reduce its impacts in its invasive range (Figure 3.2). These host-specific natural enemies, referred to as biological control agents, are introduced from the native range of the host plant, into areas where the plant has become a weed.

Biological control:

- should not be regarded as an eradication tool
- should only be used where the weed is widespread
- is most effective at sites with a high density of healthy, active-growing weed individuals that allow the agent population to build, spread and reach numbers that cause significant damage to the target weed population.

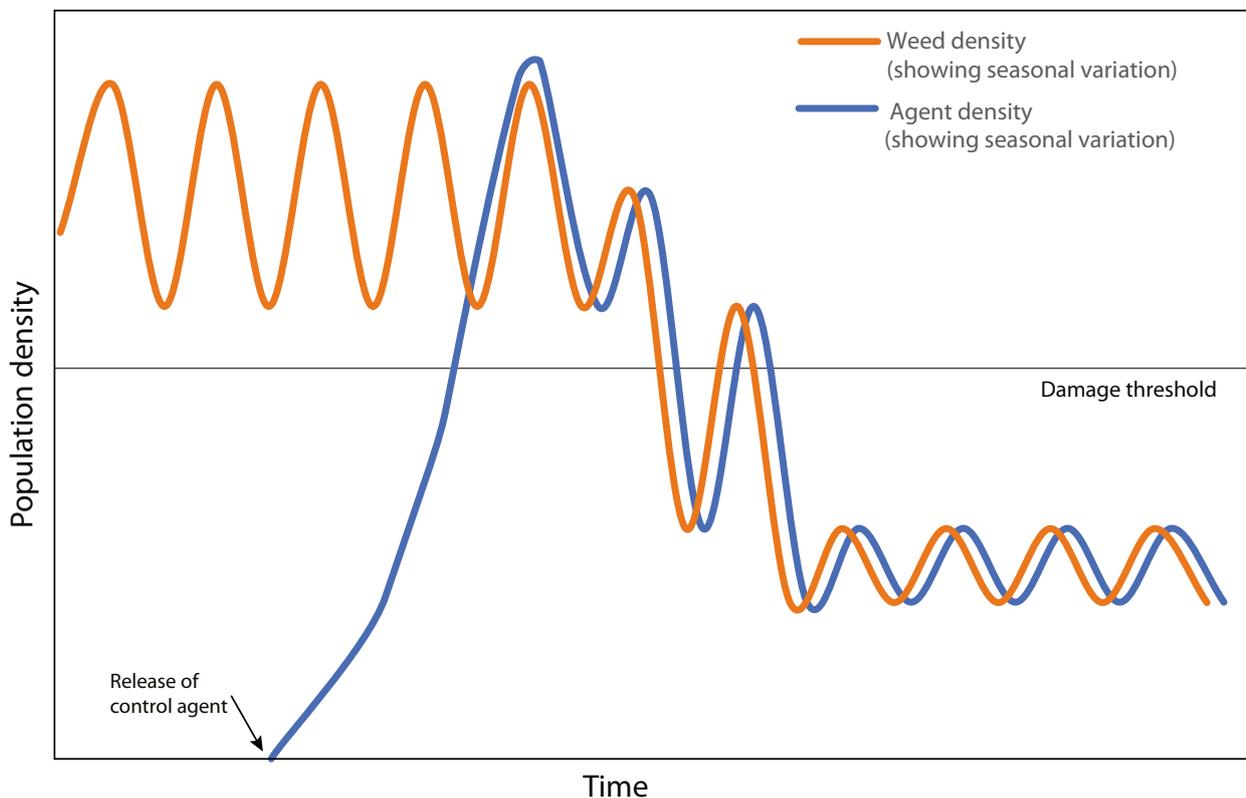


Figure 3.2 The relationship between a weed and its biocontrol agent, illustrating the critical point at which successful control is achieved (Source: Sheehan and Potter, 2017).

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History of biocontrol of sagittaria

The first systematic survey for natural enemies of sagittaria in its native range of the southern US commenced in August 2010, through Mississippi, Tennessee and Alabama, with follow-up surveys conducted across Georgia, South Carolina, Arkansas, Texas and Louisiana in September 2011 and 2012. A total of 32 arthropod and 29 fungal taxa were collected (Kwong et al., 2014). Of the insect species, 19 were confirmed to be associated with *S. platyphylla*. Leaf spot symptoms were present at 53% of sites but none of the isolated organisms were considered promising candidates because they were either generalist pathogens or secondary invaders. The most common and abundant insect species encountered was the fruit-feeding weevil, *Listronotus appendiculatus*, which was collected at 74% of sites. Two further weevils, *Listronotus sordidus* and *Listronotus frontalis*, were also promising candidates because of the damage they cause to plant crowns, roots and tubers, while *Listronotus lutulentus* adults

feed on foliage and their larvae mine inside the leaf and flowering stems.

Sagittaria platyphylla and *S. montevidensis* ssp. *calycina* were declared targets for biological control in Australia in November 2015. An in-depth biogeographical study on the genetic, demographic and herbivory differences between native US and invasive Australian populations concluded that the prospects for successful biological control were high (Kwong et al., 2014; Kwong, 2016; Kwong et al., 2017a, 2017b).

Three of the weevil species have since undergone host specificity testing, but only the fruit-feeding weevil demonstrated sufficient specificity and was approved for release in Australia in December 2020. More information on the approval process for this agent can be found at: <https://www.agriculture.gov.au/biosecurity-trade/policy/risk-analysis/biological-control-agents/risk-analyses/completed-risk-analyses/ra-release-listronotus-appendiculatus>

Sagittaria fruit-feeding weevil

The adult weevils are small and slender, about the size of a grain of rice. They are a mottled brown colour with a lighter diamond-shaped band at the base of their wings.

Life cycle

The fruit-feeding weevils have several generations per year. Adults appear in spring, when sagittaria plants come into bloom, and congregate on male flowers where they feed and mate (Figure 3.3). At night and during the heat of the day, adult weevils shelter in dead leaves or at the base of the stems. Eggs are laid among flower buds or deposited between the seeds on the fruit. After four days, eggs hatch and the larvae burrow into the fruit and feed on the tissue and seed embryos.



Raelene Kwong

Adult sagittaria fruit-feeding weevil, Listronotus appendiculatus.

After two to three weeks, the mature larvae burrow down the flowering stems and pupate inside the stalk. After about five days, the new adult chews a small exit hole and emerges from the stem. In the southern US, the weevils complete two to three generations over the spring-summer-autumn period. Adults spend the winter hibernating in leaf litter.

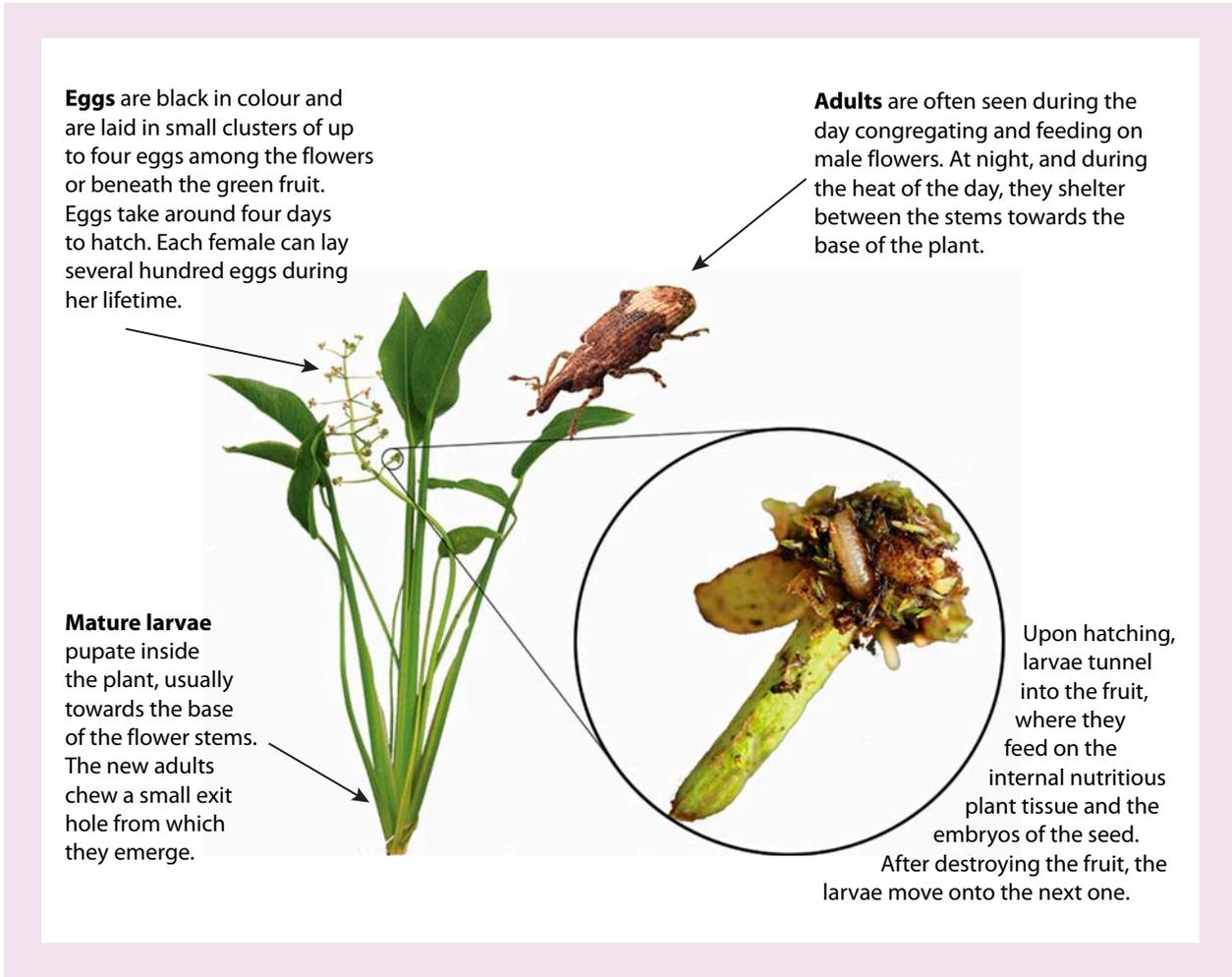


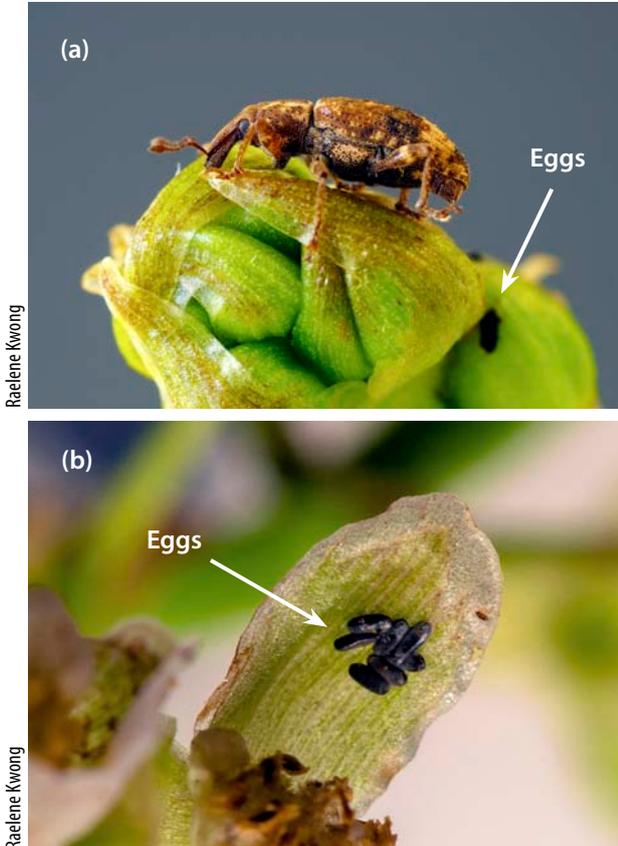
Figure 3.3 Life history of the sagittaria fruit-feeding weevil.



Raelene Kwong

A mating pair of fruit-feeding weevils resting on a male sagittaria flower.

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Listrionotus appendiculatus (a) adult laying eggs on *Sagittaria montevidensis* ssp. *calycina*; (b) a batch of eggs deposited onto a flower.

Impact

The sagittaria fruit-feeding weevil reduces the sexual reproductive capacity of plants by feeding on the fruiting structures, resulting in reduced seed production. In their native range of the southern US, the larvae of the weevil reduce seed production by an average of 60% (Kwong et al., 2017a).

Individual sagittaria fruit produce an average of 700 seeds in Australia and South Africa (where it is also a weed), and 500 seeds in the US where the fruit-feeding weevil is absent or sparse. However, in areas of the US where the fruit-feeding weevil is abundant, seed production is much lower, with as few as 20 seed produced per fruit. In Australia, where one sagittaria plant is estimated to produce 20,000 seeds



Sagittaria fruit-feeding weevils. Arrows show (a) damage to fruit caused by weevil larvae; (b) adult exit holes in sagittaria stems.

during its lifetime, the potential impact of the fruit-feeding weevil in reducing seed production is high.

Mass rearing and releases

Mass rearing of the weevils is being undertaken in both Victoria and New South Wales by Agriculture Victoria (at the Tatura SmartFarm) and NSW Department of Primary Industries (at the Grafton Biocontrol Facility). The first releases of the weevils occurred in March 2022 at two nursery sites in New South Wales (Deniliquin and Griffith) and one nursery site in Victoria (Cobram). Refer to Boxes 3.3 and 3.4 for information on how to implement biocontrol at national, regional and local scales, including how to collect and release weevils.

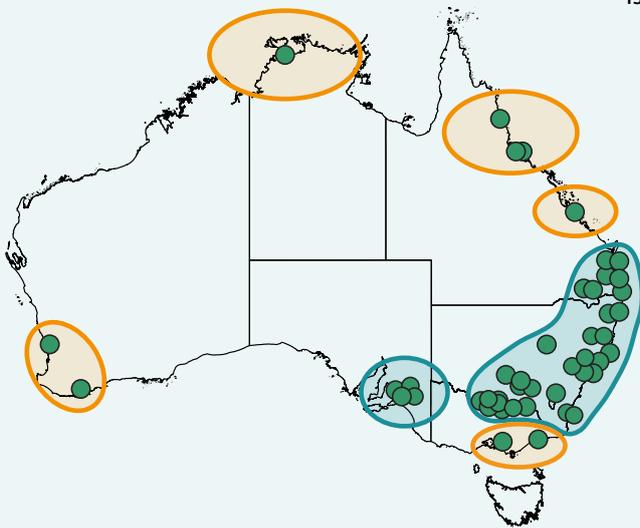
Box 3.3 Implementing biocontrol at the national scale

The Sagittaria Strategic Plan (AWC, 2012) contains three goals that aim to:

1. Prevent new infestations from establishing
2. Reduce the impacts of existing infestations
3. Build capacity and willingness to manage sagittaria.

Within the strategic plan, biocontrol fits within Goal 2 and is best suited to well-established infestations where the aim is to reduce weed impacts and spread.

Biocontrol should not be implemented in locations where eradication or immediate control is the priority (Goal 1).



Goal 1: prevent new infestations from establishing

Applies to restricted or new infestations, where immediate control is required

Not suitable for biocontrol



Goal 2: reduce weed impacts

Applies to well-established infestations where eradication is not feasible

Suitable for biocontrol

Biocontrol is particularly useful in situations where other weed control methods are difficult, or there are insufficient resources available to apply other methods.



Raelene Kwong

Irrigation channel east of Numurkah, Victoria, infested with sagittaria.

Chapter 3

Box 3.4 Implementing biocontrol at the local and regional scale

Map infestations and develop a long-term weed management plan that considers the following factors:

- Containment of new or small infestations, or where extensive infestations have the potential to invade new areas.
- Identification of infestation sources, giving high priority to up-stream or off-stream sources.
- Assessment of control priorities and available resources, ensuring resources are allocated for ongoing control and follow-up.
- Identification of infestations that can be set aside for three to five years as designated 'biocontrol agent nursery sites'. Once the agents have established in good numbers at these sites, they can be harvested for redistribution to other sagittaria infestations.



Maps and ground truthing can be used to select sites suitable for biocontrol.

Biocontrol is most beneficial in the following situations:

- difficult to access infestations such as swamps and billabongs along rivers and creeks
- areas where sagittaria is unmanageable due to infestation size and density
- areas where other control methods are too costly to apply or are not effective
- sensitive aquatic habitats where other control methods may cause habitat destruction or damage to native plants and animals.

See Chapter 5 for templates on biocontrol agent releases and monitoring.

Implementing biocontrol at the local scale

Follow the chart to determine whether your site is suitable for a release of sagittaria fruit-feeding weevil.

1. Has the weed been correctly identified as *S. platyphylla* or *S. montevidensis* ssp. *calycina*?

- Yes** Go to Question 2 **No** Make sure that the 'weed' has not been mistaken for other closely related plants such as *Alisma plantago-aquatica* or *Damasonium minus*



S. platyphylla *S. montevidensis* *A. plantago-aquatica* *D. minus*

2. Is the site considered a low priority for immediate control and can be left undisturbed for at least three years to promote the establishment of the biocontrol agents?

- Yes** Go to Question 3 **No** Consider herbicide application or manual/mechanical removal

3. Can weevils be harvested from a known nursery site?

- Yes** Go to Question 4 **No** Contact:
Agriculture Victoria: 136 186
NSW DPI: 1800 680 244
NSW Biocontrol Taskforce: www.dpi.nsw.gov.au/biosecurity/weeds/weed-control/biological-control/nsw-weed-biocontrol-taskforce

4. How to field collect fruit-feeding weevils from nursery sites

- The best time to collect and release weevils is from December through to March.
- Look for adult weevils (often in mating pairs) on the flowers.
- Carefully catch the adults into a small plastic specimen jar.
- When up to 20 insects have been collected, empty into a larger plastic container that is lined with paper towel.
- Repeat until at least 100 adults have been collected, although the more weevils that can be released at a site, the better.
- Place several flowering sprigs into the container.
- Keep the insect container cool and out of direct sunlight. Containers can be stored in the fridge for several days before release.

5. How to release fruit-feeding weevils

- Remove the flowering sprigs from the weevil container and gently shake the adults off so that they land onto flowering sagittaria plants.
- Run your fingers through the sprigs, especially in dried flowers and leaves as the weevils are very good and hiding. Check the folds of the paper towel and under the lips of container lid.
- Do not leave the sprigs at the site, as you do not want to inadvertently introduce genetic material from another population.
- Record release information on a biocontrol release form (Chapter 5) and upload to the Australian Biocontrol Hub (<https://biocollect.ala.org.au/biocontrolhub>).

Chapter 3

Monitoring establishment and dispersal

Within one year of release of weevils at the nursery site, look for weevil presence by examining the plants for adults sitting on the flowers, and larval damage to the fruit. Simple annual monitoring done should ideally be done in autumn around March, when weevil densities will be at their highest. Refer to Chapter 5 (Sagittaria Fruit-feeding Weevils Biocontrol Monitoring Form) for detailed instructions.



Agriculture Victoria

A 0.5 × 0.5 m square quadrat made from PVC pipe is used to assess the density of sagittaria plants and the incidence of attacked fruit by the fruit-feeding weevil.

Case study: Releases of the fruit-feeding weevil in Australia

In preparation for the first releases of the fruit-feeding weevil in March–April 2022, Agriculture Victoria biocontrol scientists instructed waterway managers to select suitable sagittaria infestations that could be set aside for several years as designated ‘nursery sites’. The following sites were identified:

1. Deniliquin. The Yanco Creek and Tributaries Advisory Council (YACTAC) chose a protected shallow inlet along the Edward River. As a discrete infestation, it is hoped that the weevils will concentrate at the site, making it easier to harvest them for active redistribution in the future.

2. Griffith. Murrumbidgee Irrigation (MI) chose an irrigation drain that was infested with both *Sagittaria platyphylla* and *S. montevidensis* ssp. *calycina*. The fruit-feeding weevil can attack both species, making it an ideal biocontrol agent to use where these weeds co-occur.



Andrea Mitchell, YACTAC

First weevil release at Deniliquin, 8 March 2022.



Murrumbidgee Irrigation

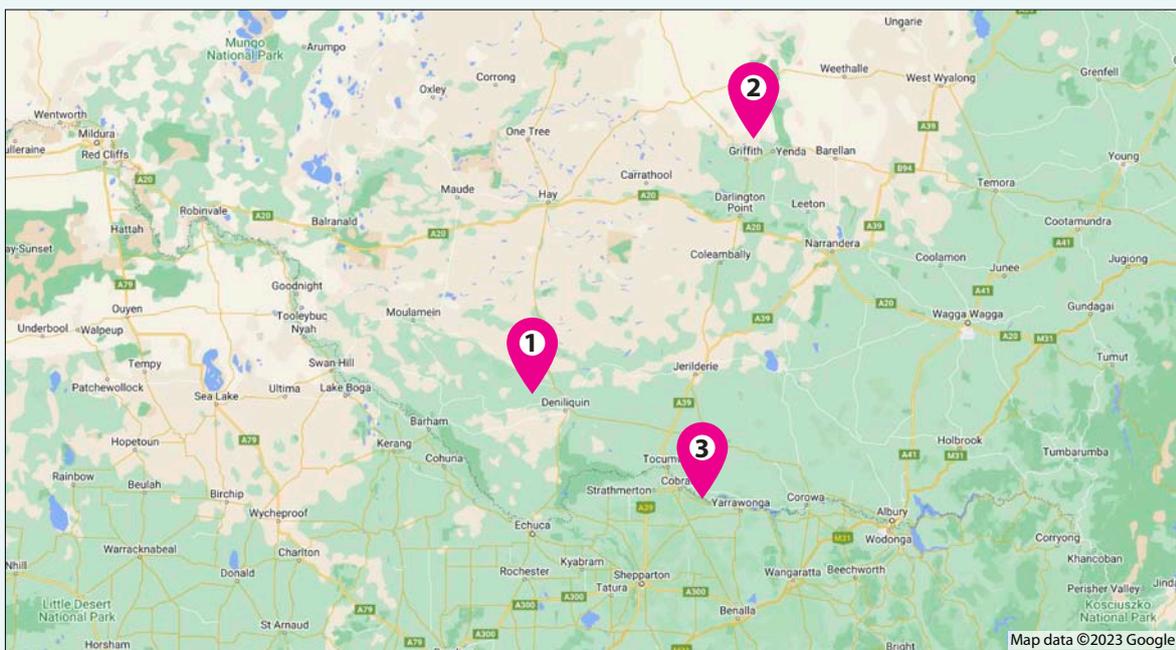
Raelene Kwong with MI staff releasing weevils at Griffith.

3. Cobram. Goulburn Murray Water (GMW) chose a spur drain that had a low demand for water supply. As such, the priority for control of *sagittaria* within this drain was low, making it a suitable nursery site. There was also some tree cover along the drain that may provide some protection against adverse weather conditions such as frost.



Goulburn Murray Water

Dannielle McMillan (GMW), Raelene Kwong and Hasan Rahmani (AgVic) at the Cobram nursery site.



Andrea Mitchell, YACTAC

Andrea Mitchell (YACTAC) and Raelene Kwong (AgVic) make the first weevil release.



Andrea Mitchell, YACTAC

*Fruit-feeding weevil feeding on the *sagittaria* pollen.*

Chapter 3

Knowledge gaps for sagittaria management

Despite its status as a Weed of National Significance, there are still several key knowledge gaps limiting the effective management of sagittaria, including knowledge gaps related to its biology, impacts and the development of accessible control options. The following gaps are derived from a study by Clements et al. (2018) and are summarised below:

- how herbicides can be best used to improve sagittaria control
- inability for multiple parties to work under shared off-label use permits, limiting utilisation of herbicides against sagittaria
- limited effective surveillance methods to detect new sagittaria infestations
- limited understanding of sagittaria demography and physiology (e.g. seed bank dynamics, germination requirements, seed viability, rosette and tuber production and growth), thus limiting development of effective control strategies
- uncertainty regarding the effective integration of biological control agents and herbicide techniques
- unquantified ecological and economic impacts of sagittaria limiting the political will to act
- limited knowledge on alternative management tools and integrated management strategies.



Sonia Jordan