This draft field guide was produced in December 2019 in preparation for the anticipated release of candidate biological control agents for the aquatic weeds, *Sagittaria platyphylla* (sagittaria) and *S. calycina* (arrowhead). The information presented here provides a framework for the development of biological control (biocontrol) implementation plans at the local, regional and national scale. It considers the role of biocontrol within integrated weed management strategies and provides guidelines for selecting suitable sites for the release of biocontrol agents.

**The problem**

*Sagittaria platyphylla* (sagittaria, delta arrowhead), and *S. calycina* (arrowhead) are serious aquatic weeds and declared Weeds of National Significance. They are capable of aggressive growth and rapid spread. In irrigation systems, dense infestations reduce water holding capacity and increase siltation, thereby reducing flow and effectiveness of water delivery. In natural systems, these weeds can form thick monocultures that threaten native aquatic flora and fauna. Dense infestations can substantially alter the flow regime of waterways affecting biodiversity and stream health. Infestations also have detrimental impacts on recreational activities such as fishing, boating, swimming and reduce the visual amenity of waterways.
The Victorian Government initiated a biocontrol program against *S. platyphylla* (sagittaria) and *S. calycina* (arrowhead) in 2009/10 to identify natural enemies from the weeds’ native range in the southern USA. Both species were formerly declared Targets for Biological Control in Australia in November 2015, after an in-depth biogeographical study on the genetic, demographic and herbivory differences between native USA and invasive Australian populations concluded that the prospects for successful biocontrol were high. Three weevil species were prioritised as prospective biocontrol agents due to their impact on seed and tuber viability and plant survival. The sagittaria fruit-feeding, crown-boring and tuber-feeding weevils were imported from the USA into the insect quarantine facility at AgriBio, Centre for AgriBioscience in Bundoora, Melbourne, where they have undergone host specificity testing. Approval for the release of the sagittaria biocontrol agents may be granted by the Australian government pending the outcome of a thorough Import Risk Analysis.

**The sagittaria fruit-feeding weevil - *Listronotus appendiculatus***

Eggs are laid among flower buds, underneath the nodal bracts or deposited underneath the sepal's on fruiting heads in small clusters of up to four eggs. Eggs take around four days to hatch at 25 deg C. Each female can lay several hundred eggs during her lifetime.

Adults are small and slender, approximately 5 mm long. Adults appear in spring when plants come into bloom. Unlike many other *Listronotus* species, the adults of the fruit-feeding weevil are diurnal and are often seen during the day congregating and feeding on male flowers. At night, and during the heat of the day, adults shelter between the petioles towards the base of the plant.

Larvae pupate in the base of inflorescence stalks or leaf petioles and after eclosion, adults chew a small exit hole from which to emerge.

Upon hatching, larvae tunnel into the fruit where they feed on the receptacle tissue and the seeds. After destroying one fruit, the larvae will move onto the next one.
The crown-boring weevil - *Listronotus sordidus*

**Adults** of the crown-boring weevil are large (7.5 to 8 mm long) and brown to tan in colour. They are nocturnal, but adults can be observed in the early morning, resting on flowering stalks. During the day they hide amongst leaf litter or between the sagittaria stems.

**Larvae** develop within the plant crowns, stolons and tubers where they destroy the vascular tissue causing the plant to rot and die. Pupation occurs in the soil near the roots.

**Eggs.** Females prefer to lay their eggs inside dead plant material such as spent flowering stalks, rather than live tissue. They make a small incision and deposit one to two cigar-shaped eggs. Each female can lay several hundred eggs during the summer-autumn period.

The tuber-feeding weevil - *Listronotus frontalis*

**Adults** of the tuber-feeding weevil are the largest of the three weevils (6 to 9 mm long) and are dark brown in colour. Females lay between 150 to 450 eggs over a four-month period.

**Eggs.** Young adults form mating pairs that appear to stay together for most of their adult life. This "mate-guarding" behaviour is a male adaptation to avoid sperm competition, thereby ensuring that he will fertilize most of the female’s eggs. Females lay eggs at the base of plants by inserting their eggs singly or in pairs into the plant tissue.

**Larvae** hatch within one week and tunnel through the crown, roots or soil in search of tubers. As larvae develop, they completely consume the inside of the tuber. Larvae take around six weeks to develop and pupate within the tuber or surrounding soil.

**Eggs.** Females prefer to lay their eggs inside dead plant material such as spent flowering stalks, rather than live tissue. They make a small incision and deposit one to two cigar-shaped eggs. Each female can lay several hundred eggs during the summer-autumn period.
Implementing Biocontrol At The National Scale

The Sagittaria Weeds of National Significance strategic plan (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 the actions under **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.
Implementing Biocontrol as part of an Integrated Sagittaria Management Strategy

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.
- Identify sources of infestations, giving high priority to up-stream or off-stream sources.

- Assess priorities and available resources, ensuring resources are allocated for ongoing control and follow-up.
- Identify infestations that can be set aside for 3 to 5 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.

To address a key goal of the WONS Sagittaria Strategic Plan – prevention of further spread - sagittaria control zones (SCZ) are being developed for the Murray Darling Basin. These zones will allow control and management efforts to be strategically directed at containing the westward spread of sagittaria in the MDB and protecting priority MDB assets (http://www.riverinaweeds.org.au).

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.
- In sensitive aquatic habitats where other control methods may cause habitat destruction or damage to native plants and animals.
Implementing Biocontrol At The Local Scale

Follow the chart to determine if your site is suitable for a release of sagittaria biocontrol agents:

1. **Has the weed been correctly identified as *S. platyphylla* or *S. 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*, *A. lanceolata* or *Damasonium 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 removal. Refer to “Developing best practice management strategies for sagittaria in Australia, May 2018”.

3. **Is the site infested with *S. calycina* (arrowhead)?**
   - **Yes** Release fruit-feeding weevils
   - **No** Go to Question 4

4. **For sites infested with *S. platyphylla* (sagittaria):**
   - **Is the site in deep, permanent water such as an irrigation channel?**
     - Release fruit-feeding weevils
   - **Is the site in shallow water or does it experience periods of low water levels during summer/autumn such as drains, creeks, billabongs?**
     - Release fruit, crown-boring and tuber-feeding weevils

Irrigation channel, Shepparton, Victoria.  
Sagittaria growing in a billabong along the Murray River near Corowa, NSW.  
Sagittaria growing in a shallow drain, Reedy Swamp, Shepparton, VIC.
How to release weevils

Season
All of the sagittaria weevils are best released in spring to allow them maximum time over the warmer months for the populations to increase.

The fruit-feeding weevil lifecycle is shorter than the other two larger weevils, and therefore can complete multiple generations over the spring-autumn period.

In temperate regions of Australia, the crown and tuber-feeding weevils may complete only one generation per season and therefore these weevils may take longer for their populations to establish.

All three weevils go into a state of hibernation during winter, hiding amongst the leaf litter as adults.

What to release
The sagittaria weevils must be released as adults as these are the hardest of the insects’ life stages. Adults are mobile and can disperse by crawling and swimming. Although they have wings, they rarely seem to fly.

The optimum number of adults to release at a site has not yet been determined, however, it’s always better to release larger numbers of adults at fewer sites than fewer adults at more sites.

Release all adults together in a small area of 2-3 m² into a dense infestation. Mark the release site with a post and take a photograph of the release site including the post in the photo as a reference spot.

In the native range (southern USA), the crown boring weevil preferentially attack sagittaria plants growing along the margins of waterways or in shallow drains. Plants attacked by the crown boring weevil larvae appear yellow and wilted, before dying (above).

Larvae of the fruit-feeding weevil feed inside the developing fruiting heads of *S. platyphylla* and *S. calycina* causing extensive destruction of the seed (achenes).

Record the details of the release on the Sagittaria Weevil Release Form or on the Australian Biocontrol Hub.

www.biocollect.ala.org.au/biocontrolhub
Sagittaria Weevil Biocontrol Release Form

Landowner/Manager Details

Name: 
Postal Address: 
Phone/mobile: 
Email: 

Release Site Details

Target weed (circle): Sagittaria platyphylla (sagittaria)  S. calycina (arrowhead)
Infestation size (hectares or length x width (m)): 
Location address: 
GPS coordinates (Latitude and Longitude—decimal degrees):  
Latitude (South): Longitude (East): 
Waterbody type (i.e. irrigation channel, creek, drain): 
Approximate water depth (m): 

Biocontrol Agent Details

Agent released (tick):  
Fruit-feeding weevil
Crown-boring weevil
Tuber-feeding weevil

Please record your biocontrol agent release on the Australian Biocontrol Hub:  
www.biocollect.ala.org.au/biocontrolhub
Or download the Biocontrol Hub app to your smart phone

Or post/email your form to:  
Raelene Kwong, Senior Research Scientist  
Agriculture Victoria  
AgriBio, 5 Ring Road, Bundoora, VIC 3083  
Email: rae.kwong@agriculture.vic.gov.au