Australian Government
Department of Agriculture, Fisheries and Forestry

Weeds of National Significance

Sagittaria

National best practice management manual for sagittaria (*Sagittaria platyphylla*)

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We acknowledge the Traditional Custodians of Australia and their continuing connection to land and sea, waters, environment, and community. We pay our respects to the Traditional Custodians of the lands we live and work on, their culture, and their Elders past and present.

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Additional information sources

Three sagittaria best practice management workshops were held at Deniliquin, Griffith and Tatura in May 2018. Attended by approximately 40 people across 15 organisations, the workshops gathered a range of information on sagittaria and associated knowledge gaps, which has been drawn on to produce this manual.

The authors would like to acknowledge the role of the publication *Developing best practice management strategies for sagittaria in Australia. Phase 1: Current management practices – May 2018*. This was a seminal reference to build upon for this publication and was funded by Murray Local Land Services. A list of workshop attendees can also be found in this publication:

> *Clements, D., Dugdale, T. M., Kwong, R.M. 2018. Developing best practice management strategies for sagittaria in Australia. Phase 1: Current management practices – May 2018. Agriculture Victoria Research (Agriculture Victoria, Department of Economic Development, Jobs, Transport and Resources) Technical report for Murray Local Land Services. February 2018.*

Foreword

Sagittaria is a significant threat to waterways and irrigation systems in Australia. The weed has been present in Australia since the late 1950s, having been introduced as an ornamental pond plant. Since its introduction to Australia, sagittaria has infested hundreds of hectares of waterways and irrigation channels and is continuing to spread into areas where it was previously unknown. It has been recorded in every state and territory in Australia except Tasmania.

As an aquatic weed, sagittaria presents challenges to management that are not present in terrestrial weed management. Access to waterways and challenging management situations represent some of these difficulties.

This publication brings together the expertise of the authors and the most up-to-date information on best practice management options and contains detailed information about the plant itself. It has been reviewed by technical experts within Australia.

This manual will provide an important reference and should be recommended to all weed professionals and waterway managers whose waterways are affected by sagittaria or at risk of invasion.

I would like to thank those responsible for its production.

Charles Mifsud
State Priority Weeds Coordinator
Aquatic weeds, New South Wales Department of Primary Industries

Contents

Contents

Using this manual

Who should use this manual?

This manual has been written to guide anyone with an interest in managing sagittaria in Australia, including land and waterbody managers, community groups, contractors and government agencies. The manual's content is intended to help people make decisions about sagittaria management by providing a guide based on current knowledge and understanding of best practice.

Where does the information come from?

The information used in this manual has been obtained from a range of sources, including publications (scientific and grey literature), government websites and communications with experts who have direct experience managing sagittaria. A particularly important source was a recent literature review and industry survey developed to determine the effectiveness of current sagittaria management practices in Australia.

This survey consisted of 23 questions on current and past control methods and how these are utilised in a range of situations (i.e., irrigation channels, drains, rivers and creeks, natural wetlands and billabongs, and urban / constructed wetlands). The survey was distributed to approximately 45 organisations across Australia, with 13 responding from New South Wales, Queensland, South Australia and Victoria. Survey results were summarised and presented to industry workshops for discussion and agreement, before being collated into a report (Clements et al., 2018).

An important finding of the industry survey was that there are several key knowledge gaps identified as limiting our ability to effectively manage sagittaria. Most of these gaps align with, and build on, the research objectives described in the national strategic plan for sagittaria (Australian Weeds Committee, 2012).

How to use this manual

This manual is intended to help people implement best practice management of sagittaria using relevant and current knowledge about the weed. It provides this information in five chapters covering the biology and ecology of sagittaria, planning a management program, control methods for sagittaria, case studies of sagittaria management from around Australia and further information.

The information provided in this manual should be tailored to local environmental conditions and management situations.

Summary of the five chapters

1. Understanding sagittaria
- Identification
- Where it grows
- Life cycle
- Impacts

2. Planning a control program
- Identifying management objectives
- Developing a management plan
- Monitoring and surveillance
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Abbreviations

ACT	Australian Capital Territory
ALA	Atlas of Living Australia
AgVic	Agriculture Victoria
APVMA	Australian Pesticides and Veterinary Medicines Authority
FNQ	Far North Queensland
GMW	Goulburn Murray Water
GPS	global positioning system
MI	Murrumbidgee Irrigation
NCCMA	North Central Catchment Management Authority
NRM	Natural Resources Management
NSW	New South Wales
NSW DPI	NSW Department of Primary Industries
NT	Northern Territory
PPE	personal protective equipment
Qld	Queensland
SA	South Australia
SEQ	South East Queensland
Tas	Tasmania
Vic	Victoria
WA	Western Australia
WoNS	Weed of National Significance
YACTAC	Yanco Creek and Tributaries Advisory Council

See also References (Chapter 5) for other abbreviations not listed below.

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Hasan Rahmani	Agriculture Victoria
Russel Talbot	Goulburn Murray Water
B. Trounce	NSW DPI © State of New South Wales

Chapter 1

Understanding sagittaria

At a glance

- **Sagittaria, *Sagittaria platyphylla*, is an aquatic plant originating from the southern United States.**
- **Sagittaria is well established in southern parts of the Murray Darling Basin and the east coast of Australia, with great potential for future spread.**
- **Juvenile plants grow underwater as rosettes and adult plants have roots anchored in soil but their leaves emerge above the water surface.**
- **Sagittaria can reproduce by seeds and plant parts, spreading via water currents, animals and vehicles and machinery.**
- **Sagittaria invades irrigation and drainage networks and natural aquatic ecosystems, impacting water flow, aquatic biodiversity and recreational activities.**

In Australia, *Sagittaria platyphylla* (Engelm.) J.G. Sm. is commonly known as sagittaria or delta arrowhead. Sagittaria is a herbaceous aquatic plant that is rooted into the mud and has foliage and flowers that emerge above water. Native to the Mississippi Delta in the southern United States, it has become an invasive aquatic weed in several countries. In Australia, dense infestations displace native plants and obstruct water flows, slowing delivery of irrigation water and retarding drainage from the landscape. Impacts are magnified by being an emergent aquatic plant, having foliage both above and below the water surface.

Distribution

Plant origins

Sagittaria occurs naturally in southern North America, including Mexico and the states ringed by Kansas, Texas, Georgia and Florida, where it occurs in streams and lakes from sea level up to 900 m (Adair et al., 2012). These areas are primarily humid subtropical (Koppen-Geiger Climate Class: Cfa), characterised by a mild climate with hot summers and no dry season, but highly variable year round rainfall (Kottek et al., 2006). Sagittaria is naturalised in the former USSR, Indonesia, Panama, South Africa, Australia and New Zealand (Adair et al., 2012).

Growth in Australia

Sagittaria was most likely introduced into Australia as an ornamental plant, as it has been widely traded globally (Kwong et al., 2017b). It was first detected in Brisbane in 1959 and naturalised infestations were first detected in Victoria in 1962, New South Wales in 1973 and Western Australia in 1999 (Australian Government 2012; Clements et al., 2015). Sagittaria has been recorded in all states and territories except Tasmania.

In Australia, most infestations occur in the 'warm temperate fully humid' and 'warm temperate dry summer' parts of the east coast and Murray Darling Basin (Kottek et al., 2006). Sagittaria also occurs in the 'warm temperate dry summer' climate parts of Western Australia and 'equatorial savannah' areas of north Queensland and Northern Territory (Figure 1.1). The most substantial infestations occur in the Murray, Goulburn, Ovens and Edward Rivers and irrigation and drainage networks in northern Victoria and southern New South Wales. Smaller infestations

occur in South Australia on the Murray River from Mannum to the Younghusband and Bowhill areas; in Western Australia's south-west at Albany and the Canning River in Perth (Adair et al., 2012); in the Ross River at Townsville; in the Molonglo River in Canberra; and in a range of waterbodies along the east coast from southern New South Wales to south-east Queensland. Small infestations in Darwin have recently been eradicated (see Chapter 4, case study 4).

Frosts, which occur frequently within the Murray Darling Basin, destroy the parts of the plant above water, which may include adult foliage and juvenile rosettes, depending on water level. However, regrowth occurs rapidly from crowns, rosettes and subterranean tubers, protected from frost by soil and/or submersion in water.

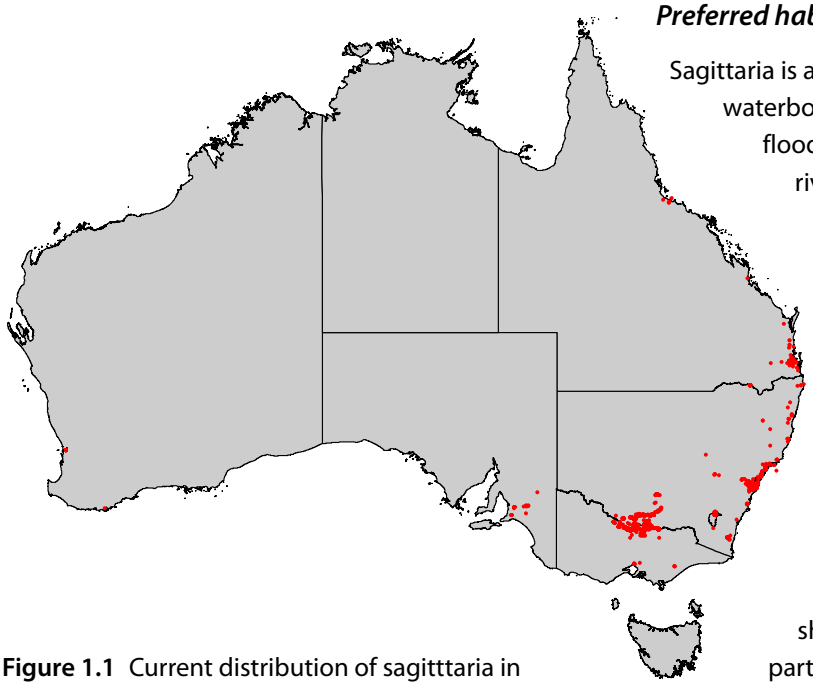


Figure 1.1 Current distribution of sagitttaria in Australia (Dr Farzin Shabani, Macquarie University; data from ALA (2022) and NSW Department of Primary Industries).

WoNS
WEEDS OF NATIONAL SIGNIFICANCE

Sagittaria is a Weed of National Significance

Sagittaria was one of 12 additional species or groups of species added to the existing list of 20 Weeds of National Significance (WoNS) in 2012 (AWC, 2012). Sagittaria was included on the WoNS list based on assessment of its invasiveness, impacts and potential for further national spread. A national sagittaria strategic plan was developed, which included actions aimed at preventing new incursions; developing and promoting best practice management for control of sagittaria; and further research into biological control. For more information visit: https://weeds.org.au/profiles/delta-arrowhead-arrowhead-slender-arrowhead/

Preferred habitats

Sagittaria is an invasive weed prevalent in shallow waterbodies and marshy areas, including floodplain wetlands. It grows rapidly in rivers, creeks, billabongs, wetlands and shallow water zones of permanent waterbodies, typically in water to a maximum depth of 1.5 m. It also occurs in channels, drainage ditches and swamps associated with irrigation and drainage systems. It is particularly widespread in earthen irrigation channels, either on the banks of larger channels or across the entire cross-section of smaller, shallower varieties. Sagittaria establishes particularly well on silt (in contrast to clay), and once established tends to trap sediment, thereby increasing sedimentation and increasing habitat availability (Adair et al., 2012).

Raelene Kwong

Sagittaria infestations along the margins of Nine Mile Creek, northern Victoria.

Raelene Kwong

Sagittaria is commonly found in earthen irrigation channels.

Potential distribution

The potential distribution of sagittaria includes waterways and wetlands throughout eastern and southern Australia (Adair et al., 2012). Recent northern invasions in Darwin and Townsville, along with habitat suitability modelling, suggest that waterbodies of northern Australia are also at risk of sagittaria invasion (Figure 1.2).

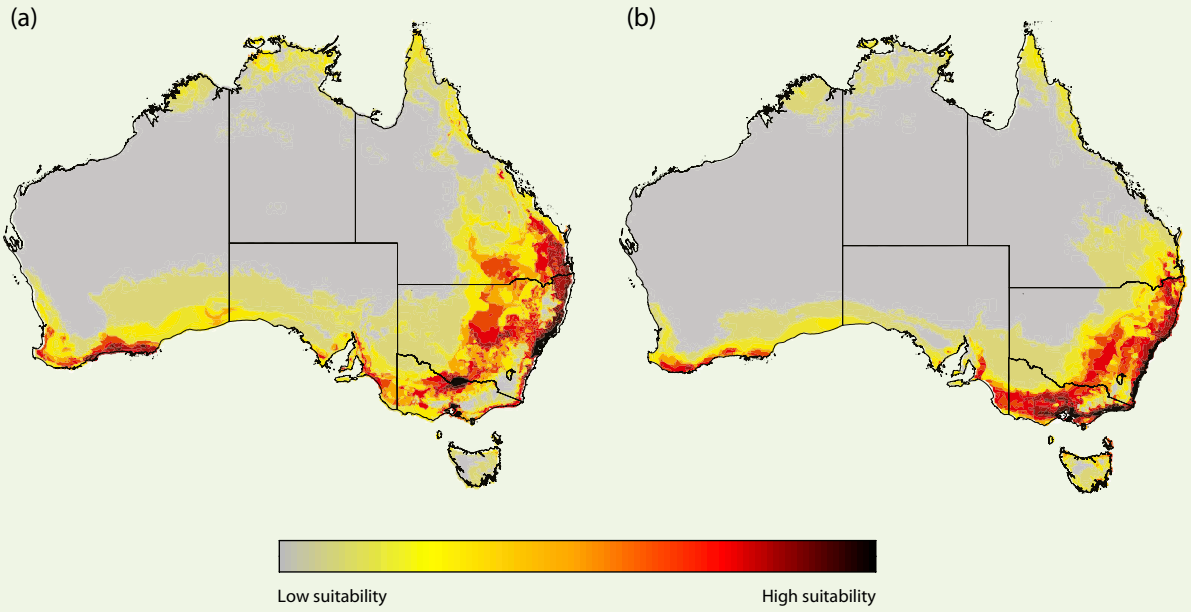


Figure 1.2 Areas of habitat suitability for sagittaria under (a) current climatic conditions and (b) predicted climatic conditions in 2050 (Duursma et al., 2013, www.weedfutures.net).

Identification

Sagittaria is a perennial monocot that belongs to the Alismataceae family (water plantains). Plants grow to a height of 150 cm (Table 1.1). The male flowers are about 3 centimetres across, with three white petals and a yellow centre. The female flowers lack petals and look like flattened green berries. Flowers appear during spring to autumn, clustered on flower stalks that are shorter than the height of the leaves. The flowers are borne in groups of three around the flowering stem, with the male flowers towards the top of the stem and female flowers below them.

Mature fruit produce one-seeded flattened and winged segments (called achenes), which are each 1.5–3 mm long. Each plant can produce up to 20,000 seeds.

Sagittaria has three distinct growth forms: narrow-leaved emergent, broad-leaved emergent and submerged rosette.

The **rosette growth form** is the juvenile stage of the plant, which has strappy leaves up to 50 cm long that are usually submerged (Australian Government, 2012).

Tobias Bickel

Sagittaria platyphylla *rosettes in situ.*

Raelene Kwong

Submerged rosette growth form with tuber and roots attached.

Adult plants grow as an emergent aquatic plant (i.e., anchored in submerged soil with foliage held above the water surface) up to 150 cm tall. Each stem (petiole) is topped by a single lance-shaped leaf with either a **broad-leaf or a narrow-leaf form**.

The broad-leaf form produces oval to lance-shaped leaves that are are much wider than the stems, but without lobes. The narrow-leaf form produces elongated, narrowly tapered leaves without an expanded blade that are not much wider than the stems. Regardless of leaf form, the adult leaves are borne on a three-sided stem and have a single main mid-vein.

Raelene Kwong

Broad-leaf sagittaria characteristic of young, unsprayed infestations.

B. Trounce

The narrow-leaf form of sagittaria, typical of old infestations and those previously sprayed with herbicide.

Leaf form is influenced by environmental conditions and management factors; for example, the narrow-leaf form often occurs where plants have regrown after herbicide application, or towards the centre of old infestations, possibly where nutrients have been exhausted, while the broad-leaf form is typical of young infestations that have not been sprayed.

All growth forms of the plant produce stolons (horizontal stem runners) connecting multiple plants, and tubers (swollen below-ground starch-storing organs, like small potatoes), the latter often referred to as bulbs or corms (Adair et al., 2012; Weiss and Dugdale, 2017).

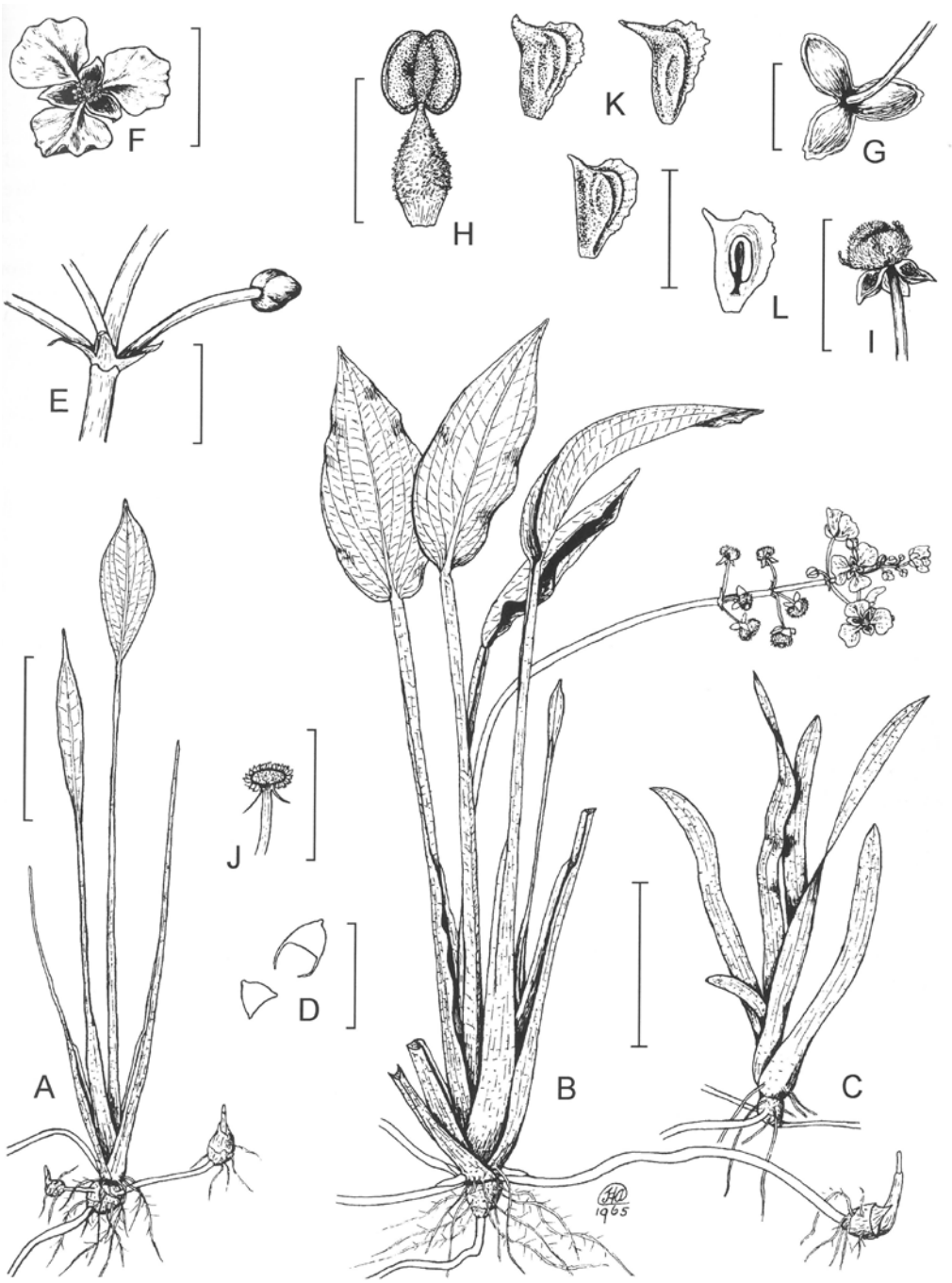


Figure 1.3 *Sagittaria platyphylla*. A, young plant; B, mature plants; C, submerged plant; D, petiole of emergent leaf, transverse sections; E, inflorescence whorl; F, male flower; G, sepals from beneath; H, stamen; I, semi-mature fruiting head; J, mature fruiting head, longitudinal section; K, fruits; L, fruit, longitudinal section. Scale bars: A–C = 10 cm; D, F, I, J = 2 cm; E, G = 10 mm; H = 2 mm, K, L = 3 mm (Jacobs and McColl, 2011, page 184; reproduced with permission).

Table 1.1 Identification features of sagittaria.

Distinguishing features

- Larger flowers 3 cm wide.
- Oval to lance-shaped leaves with only one main mid-vein.

Sonia Jordan

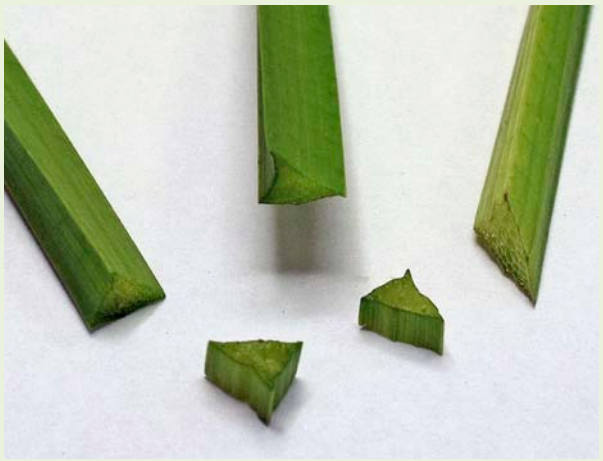
Broad-leaf form has lance-shaped leaves.

Raelene Kwong

Whole sagittaria plant.

Stems (leaf stalks/petioles)

- Triangular in cross-section.
- To 80 cm long.



Northern Territory Government

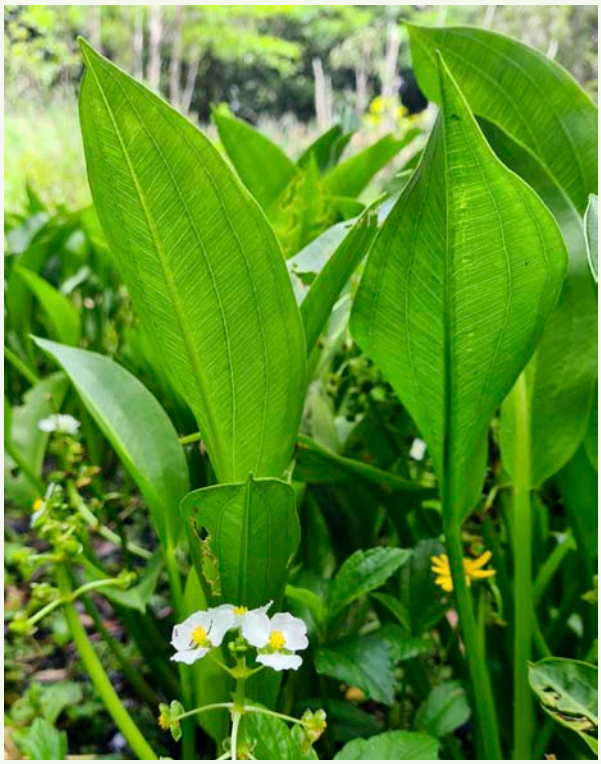
Strongly triangular cross-section of leaf stalks.

Leaves

- *Emergent leaves*: oval to lance-shaped with a pointed tip; to 25 cm long and 10 cm wide; only one main mid-vein.
- *Submerged leaves*: long, narrow strap-like without expanded blades; to 50 cm long.

Michelle Franklin

Emergent leaves cut from a single plant, showing the range in shapes (fully formed on the left, along with a range of developing leaves).



Melissa Green

Emergent leaves.

M. Kahler

Juvenile sagittaria plants.

Tobias Bickel

Submerged rosette with strap-like leaves.

Flowers

- Grow in whorls or coils.
- Appear below the height of the leaves during spring to autumn.
- *Male flowers*: three white petals with yellow centre; 3 cm wide.
- *Female flowers*: no petals; look like flattened green berries.

G. Prichard

Note flower height in relation to leaves.

Raelene Kwong

Sagittaria inflorescence with male flowers at the top of the stem and female flowers below.

Fruit/Seed

- Fruit clusters 0.5–1.0 cm across.
- 1 seeded segment (achene) flattened and winged 1.5–3 mm long.
- Each plant can produce up to 20,000 seeds.

Raelene Kwong

Seeds (achenes).

Raelene Kwong

Mature fruit.

Roots and tubers

- Septate roots (divided into segments).
- Tubers present.
- Stolons present.

Raelene Kwong

Close up of tuber.

Raelene Kwong

Close up of sagittaria roots. Septate partitioning of roots visible (indicated by ellipse).

Similar species

There are 40 described species in the *Sagittaria* genus, naturally distributed in North and South America, Europe, Africa and Asia. *Sagittaria platyphylla* (sagittaria) and *S. montevidensis* ssp. *calycina* (arrowhead) are naturalised in Australia. Three additional species are present, but may not be sufficiently well-established to be considered naturalised *(S. filiformis*, *S. macrophylla* and an unidentified species) (Adair et al., 2012).

Sagittaria can be distinguished from arrowhead as the latter has emergent leaf blades that are strongly arrow-shaped (sagittate), while the former has leaf blades that are oval to lance-shaped without lobes at the base.

Raelene Kwong

Arrowhead, Sagittaria montevidensis *ssp.* calycina*, has characteristic arrow-shaped leaves.*

Raelene Kwong

Arrowhead infestation in an irrigation drain in Griffith, NSW.

Sagittaria and arrowhead both have septate roots (divided into segments giving a striped appearance), which distinguish them from other common, similar species.

Emergent sagittaria can be confused with other members of the Alismataceae family (water plantains) and the submerged rosette can be confused with the native ribbon weed (*Vallisneria australis*). Ribbon weed and water plantains are widespread and abundant in Australia.

In addition to the septate roots, sagittaria can be distinguished from other similar-looking relatives such as alisma (*Alisma lanceolatum*), water plantain (*Alisma plantago-aquatica*) and star fruit (*Damasonium minus*) as, relative to sagittaria, these species have large inflorescences (groups of flowers) that are held above the height of the leaves.

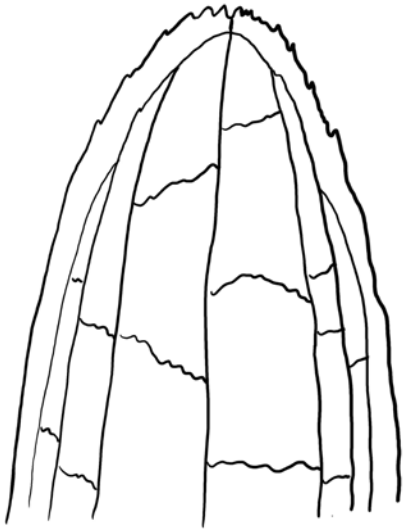
Water plantain and creeping burhead (*Echinodorus cordifolius*) can be distinguished from sagittaria as the former two have leaves with many veins, while sagittaria leaves have a single main mid-vein.

In shallow water, non-flowering ribbon weed plants produce short leaves, which can be confused with sagittaria rosettes. Ribbon weed can be distinguished by the presence of minute serrations along the leaf tips, which can be easily felt with a fingertip.

Refer to Table 1.2 for key distinguishing features of sagittaria and similar species.

Raelene Kwong

Sagittaria platyphylla *(centre) and two other very similar species present in Australia: Alisma (*Alisma lanceolatum*) on the left and water plantain (*Alisma plantago-aquatica*) on the right. Note both* Alisma *species have groups of flowers (inflorescences) held above the level of the leaves.*



Minute serrations along the leaf tip of ribbon weed (re-created from H. Aston, Aquatic Plants of Australia, page 239, Melbourne University Press, 1973).

Table 1.2 Distinguishing features of similar-looking species to sagittaria found in Australia (Adapted from NSW WeedWise, 2021).

	SAGITTARIA *S. platyphylla*	**ARROWHEAD** *S. montevidensis* ssp. *calycina*	**ALISMA** *Alisma lanceolatum*	**WATER PLANTAIN** *Alisma plantago-aquatica*	**STAR FRUIT** *Damasonium minus*	**CREEPING BURHEAD** *Echinodorus cordifolius*	**RIBBON WEED** *Vallisneria australis*
Origin	**North America**	North America	Europe, west Asia, north Africa	Native to Australia	Native to Australia	North and South America	Native to Australia
Height	**150 cm**	100 cm	100 cm	150 cm	100 cm	100 cm	Submerged only
Distinguishing features	**Larger flowers (3 cm wide), lance-shaped leaves with only one main mid-vein**	Large flowers (2.5 cm wide), strongly arrow-shaped adult leaves	Small flowers (10 mm wide), narrow leaves and large inflorescence held above the height of the leaves	Small flowers (10 mm wide) in inflorescence held above the height of the leaves, oval-shaped leaves with many veins	Small flowers (6 mm wide), large inflorescence held above leaves	Round stems (petioles); leaves with many veins	Minute serrations along leaf tips
Leaves	**Emergent leaves: oval to lance-shaped with a pointed tip; to 25 cm long and 10 cm wide. Submerged leaves: long, narrow strap-like without expanded blades; to 50 cm long**	Emergent leaves: arrow-shaped; prominently veined; to 25 cm long and 20 cm wide; lobes to 15 cm long and 10 cm wide. Submerged leaves: strap-like, linear	Spear-shaped; to 20 cm long and 4 cm wide; up to 7 prominent veins connected by several transverse veins. Submerged leaves: strap-like	Oval-shaped; 10–25 cm long and 7–10 cm wide; usually 7 prominent parallel veins connected by numerous transverse veins	Oval-shaped; 5–10 cm long and 1.5–4 cm wide; 3–5 parallel veins connected by numerous finer transverse veins	Emergent leaves: ovate to elliptic, 6.5–32 cm long by 2.5–19.1 cm wide, distinct veins. Submerged leaves mostly absent	Strap-like leaves to 3 m long
Stems (leaf stalks / petioles)	**Triangular in cross-section; to 80 cm long.**	Round in cross-section	To 80 cm long; flattened on one side with small wings at the base	To 80 cm long, flattened on one side with small wings at the base	To 30 cm long	To 45 cm long, round in cross-section	N/A

…/Table 1.2 continued from previous page.

	SAGITTARIA *S. platyphylla*	**ARROWHEAD** *S. montevidensis* ssp. *calycina*	**ALISMA** *Alisma lanceolatum*	**WATER PLANTAIN** *Alisma plantago-aquatica*	**STAR FRUIT** *Damasonium minus*	**CREEPING BURHEAD** *Echinodorus cordifolius*	**RIBBON WEED** *Vallisneria australis*
Flowers	**Appear in whorls or coils. Male flowers: 3 white petals with yellow centre; 3 cm wide. Female: no petals; look like flattened green berries. Flowers appear below the height of the leaves during spring to autumn**	Female flowers carried in groups of 3 ringing the stem, with male flowers in groups above them; all borne on a leafless stem. Petals are white. Flowers are 2.5 cm wide	Inflorescence to 60 cm long and 40 cm wide. Flowers 10 mm diameter. Sepals to 2 mm long. Petals 4 mm long, white or pink. Flowers in summer	Wiry inflorescence, to 60 cm long and 40 cm wide. Flowers 10 mm diameter. Sepals to 2 mm long. Petals 4 mm long, pale pink or almost white. Flowers on long stems above height of leaves	Inflorescence to 50 cm long. Flowers 6 mm in diameter. Sepals 1 mm long, green. Petals ovate 6 mm long, white or pink. Flowers early summer	Inflorescence arching and then prostrate at maturity. Flowers bisexual, white	Submerged
Fruit/Seed	**Fruit clusters 0.5–1.0 cm across; 1 seeded segment flattened and winged 1.5–3 mm long**	Clustered; laterally flattened, 1.5–3 mm long, beaked at the apex with dorsal wings	Triangular; 2–2.5 mm long. Each fruit contains 1 seed	2–2.5 mm long, falling singly	Star-shaped	2.5–3 mm long in clusters	On long stems arising from the rosette, below water
Roots and tubers	**Septate roots, tubers present, stolons present**	Septate roots, no tubers, stolons absent	Roots not septate, no tubers, stolons absent	Roots not septate, no tubers, stolons absent	Roots not septate, no tubers, stolons absent	Roots not septate, no tubers, stolons absent	Roots not septate, no tubers, stolons present

Reproduction and spread

Seeds and germination

Sagittaria reproduces by both seeds (achenes) and vegetative organs (stolons and tubers). Sagittaria is a prolific seed producer, with one fruiting head bearing around 700 seeds (Kwong et al., 2017b). A healthy emergent plant is capable of producing more than 20,000 seeds over the flowering season.

Seed germination occurs on the surface of moist mud or sediment, which provides favourable light and moisture conditions (Australian Government, 2012). Germination is inhibited in the dark (Adair et al., 2012). Beyond this basic information, there is a lack of knowledge about seed bank dynamics, time to germination, germination requirements and seed viability. This has been identified as a knowledge gap (refer to Chapter 3).

Vegetative reproduction

Both the emergent and rosette forms reproduce vegetatively through stolons and tubers. These vegetative parts can survive over winter and allow infestations to rapidly regenerate in spring or following periods of stress. Tubers can remain viable in moist soil for several years and can be detached and dispersed downstream by strong water currents.

Dispersal

The small and buoyant seeds of sagittaria are reported to float for 7 days to 3 weeks and can be easily dispersed by relatively light water currents (Adair et al., 2012; Australian Government, 2012), rendering long-distance dispersal likely. Sagittaria infestations have been recorded where propagules from infested irrigation channels 'escape' into local rivers (Maureen Zeschke, MLLS, personal communication).

Another major source of seed spread appears to be ducks and other waterbirds, which likely transport seed internally through feeding and externally via mud attached to their bodies. It is likely that carp ingest seeds as they suck in and filter mud from the bottom of waterbodies, which may remain viable when excreted.

Raelene Kwong

Swans and other waterbirds feeding on sagittaria in the Nine Mile Creek, Numurkah, Victoria.

Seeds can also be spread by mud attached to boats, vehicles or other equipment, such as excavators used to maintain drains and channels.

Sagittaria can also be spread as an ornamental plant via trade among plant enthusiasts. Once established in outdoor ponds and water features, it may easily escape, either via natural dispersal of seed or dumping of garden waste. These dispersal mechanisms have allowed sagittaria to spread rapidly in Australia (Australian Government, 2012).

Life cycle

Sagittaria is capable of rapid growth. Seedlings in glasshouse situations have been observed to reach the adult stage within several weeks. Regrowth after herbicide application in northern Victorian irrigation channels occurs within the same growing season as the herbicide was applied. In Townsville, regular sagittaria surveys occur in Ross River at 2–4 week intervals to allow the control program to keep pace with sagittaria's rapid growth and development. This

rapid growth, combined with prolific reproduction, make sagittaria a highly invasive plant.

In south-eastern Australia, emergent and rosette plants cease active growth and overwinter vegetatively. Frosts kill off emergent leaves and flowering ceases, but submerged crowns and rosettes remain alive due to the protection of the overlying water. In spring, a flush of regrowth occurs from tubers (Table 1.3).

Active growth occurs throughout the year in Queensland (Table 1.4).

Table 1.3 Sagittaria seasonal growth table for south-east Australia (modified from Adair et al., 2012).

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Flowering	✓✓	✓✓	✓	✓	✓			✓	✓	✓	✓✓	✓✓
Fruit production	✓	✓	✓	✓	✓					✓	✓	✓
Active growth	✓	✓	✓						✓	✓	✓	✓
Emergent	✓	✓	✓	✓	*	*	*	*	✓	✓	✓	✓
Rosette	✓	✓	✓	✓	✓	✓	✓	✓✓#	✓✓#	✓✓#	✓	✓

✓✓ more pronounced growth at this time than other times of active growth.
* emergent growth dies back, unless protected from frost.
\# flush of rosettes as tubers start to sprout.

Table 1.4 Sagittaria seasonal growth table for south-east Queensland and north Queensland (Townsville). Where they differ, north Queensland is shown in parenthesis. (Tobias Bickel and Melissa Green pers com).

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Flowering	✓	✓	✓	✓	✓ (×)				✓	✓	✓	✓
Fruit production	✓	✓	✓	✓	✓ (×)				(✓)	(✓)	✓	✓
Active growth	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Emergent	✓✓ (✓)	✓✓ (✓)	✓✓ (✓)	✓✓ (✓)	✓✓ (✓)	✓	✓	✓	✓✓ (✓)	✓✓ (✓)	✓✓ (✓)	✓✓ (✓)
Rosette	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓

✓✓ more pronounced growth at this time than other times of active growth.
(×) no flowering or fruit production in north Queensland at this time of year.

Impacts

Sagittaria is particularly problematic in permanent and semi-permanent water bodies of south-east Australia, where it has invaded irrigation and drainage networks and natural aquatic ecosystems (Australian Government, 2012). Sagittaria has four main impacts:

- displaces native aquatic plants
- retards water flow
- increases sedimentation
- reduces human access.

The impacts are most acute in south-eastern Australia owing to its long history of establishment in drainage and irrigation networks. Sagittaria grows well in many other parts of Australia, and impacts may become similarly severe in these areas if it becomes more widespread and established.

Environmental impact

Sagittaria forms monocultures in shallow, fresh waterbodies that displace native aquatic plants, retard water flow and increase sedimentation. This alters the ecological character and reduces the habitat value of these waterbodies (Australian Government, 2012).

Sagittaria has a very dense growth habit in Australia, restricting water flow in shallow wetlands and creeks. This capacity occurs at a larger magnitude compared

Raelene Kwong

An extensive infestation of sagittaria in the billabongs along the Lower Ovens River in the Warby-Ovens National Park near Bundalong, Victoria.

to many (but not all) native species (Weiss and Dugdale, 2017 and citations within).

Dense monocultures of sagittaria outcompete and displace native aquatic plants, reducing their abundance. The degree to which displacement of native aquatic plants occurs is not known, but is likely to be high as sagittaria monocultures are common in shallow areas of wetlands, creeks and rivers, where native aquatic plants would otherwise be present.

In the absence of proactive management, reaches of the Murray River from Albury to below Mildura could be occupied by sagittaria (Adair et al., 2012). Environmental water allocations to Murray River wetlands could benefit invasive species, including sagittaria, by increasing their abundance and rate of spread (Adair et al., 2012).

The lower Murray River endangered ecological community, iconic wetland areas of Barmah and Gunbower Forests, and RAMSAR sites such as the Kerang wetlands and Chowilla floodplain are at risk from invasions by sagittaria (Adair et al., 2012). In Victoria, sagittaria poses a high threat to six ecological vegetation classes: red gum swamp, aquatic herbland, rushy riverine swamp, floodplain grassy wetland, spike-sedge wetland, and floodway pond herbland/riverine swamp forest complex. In NSW, it threatens the ecological character of wetland vegetation communities, such as the Yanco Creek system in the southern Riverina and the Gywdir River at Bingara (Weiss and Dugdale, 2017). Sagittaria infestations have resulted in loss of understory species in *Melaleuca linariifolia* forests in Porters Creek wetlands, coastal New South Wales (Adair et al., 2012).

The suitability of sagittaria infestations for supporting native fauna has not been studied, but extensive monocultures are considered less desirable for native fauna than a mosaic of multiple species of native aquatic plants.

Agricultural impacts

Sagittaria forms dense infestations in irrigation channels and drainage ditches, obstructing water flow. Delayed water delivery to irrigators and delayed drainage from agricultural land leads to decreased crop heath and productivity, rising water tables and exacerbated flooding (Clements et al., 2018). The foliage of sagittaria directly retards water flow and hydraulic capacity. In addition, increased sedimentation associated with the slowed water velocities results in greater sedimentation, thus infilling irrigation channels, further reducing their capacity to deliver irrigation water and increasing the frequency of mechanical desilting needed to maintain channel function (Australian Government, 2012).

Extensive infestations occur in the earthen irrigation channels and drainage systems of northern Victoria and the Riverina area of NSW. Precision operation of irrigation networks is critical in modernised irrigation schemes, where farmers require delivery of greater volumes of water over shorter irrigation events. Obstruction of channels by sagittaria prevents irrigation companies from meeting farmer demands, resulting in reduced crop productivity (Clements et al., 2018).

These impacts threaten Australia's $15 billion irrigated agriculture industry. In the Murray-Darling Basin, irrigated agricultural productivity is valued at $6.9 billion (ABS, 2016), with up to 4,300 gigalitres of water supplied annually by irrigation schemes therein (ABARES, 2015). Annual losses to production have not been quantified but costs to minimise impacts are high (Clements et al., 2018). For example, in the mid-2000s, Goulburn-Murray Water spent more than $2 million annually on sagittaria control, which was estimated to infest 85% of the 14,000 km of creeks, drains and irrigation channels within the Goulburn-Murray system (Adair et al., 2012).

In Queensland, sagittaria is recognised as a problematic weed. An extensive sagittaria infestation in the Ross River in Townsville is currently managed with the aim of preventing spread into the nearby Burdekin River irrigation system.

Arrowhead (*Sagittaria montevidensis* ssp. *calycina*) has major impacts on rice production. As a crop competitor, infestations of arrowhead and other native Alismataceae species can reduce yields by up to 75% (Adair et al., 2012), but these impacts are not known for sagittaria (*S. platyphylla*).

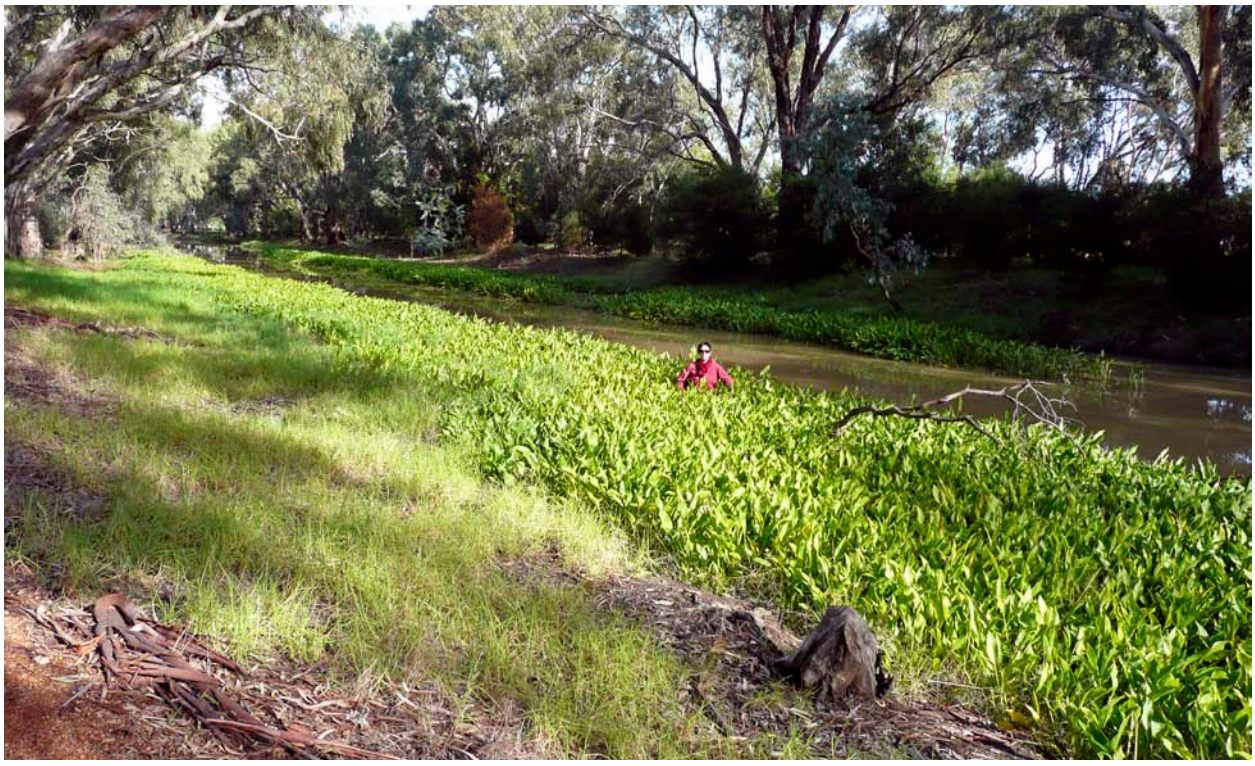
Members of the sagittaria genus are alternate hosts in North America to the aster leaf hopper, *Macrosteles fascifrons* Stål (Hemiptera: Cicadellidae), a vector of aster yellows phytoplasma, oat blue dwarf virus and clover phyllody virus. Although the leaf hopper is not present in Australia, infestations of sagittaria are a potential biosecurity risk to agricultural and floricultural industries (Adair et al., 2012).

Social impacts

Unmanaged infestations in drains can retard drainage of floodwaters from the landscape and result in increased flooding. This occurs via the same mechanism described for irrigation channels above, whereby water velocity is slowed and sedimentation is increased, which together result in more rapid infilling of the drains and more frequent need for mechanical desilting.

Infestations form dense monocultures that choke out shallow margins of waterbodies and restrict access, which has detrimental impacts on recreational activities, such as boating, swimming and fishing, and reduces visual amenity of waterways (Adair et al., 2012; CHAH, 2011).

Sagittaria has invaded south-east Queensland's water grid around Brisbane, such that it interferes with drinking water production.



Raelene Kwong

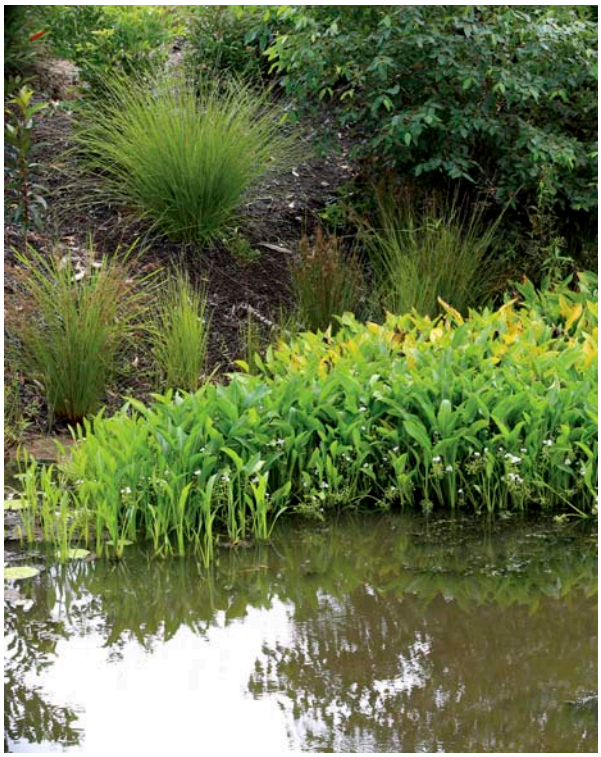
Sagittaria can restrict recreational access to waterways. Broken Creek, Numurkah, Victoria.

Chapter 2

Planning a control program

At a glance

- **Planning helps to prioritise the actions needed to manage sagittaria infestations.**
- **Consideration of an infestation's size, location, density and proximity to other sagittaria infestations will help identify the most appropriate management objective.**
- **This chapter outlines considerations for planning a sagittaria control program and how to choose a control method that complies with these considerations.**



Sonia Jordan

Accessing infestations in waterbodies presents management challenges

A sagittaria control program requires a planned approach to ensure the best possible results are achieved with minimal cost and effort. This is particularly important given that sagittaria:

- can spread by seed and plant parts
- produces large numbers of seed and
- grows in aquatic environments, which presents a range of management challenges.

Aquatic weeds spread across boundaries and to ensure that control efforts are effective, they must be long term, planned, coordinated and adequately resourced across regions (Osmond and Petroeschevsky, 2013). The most appropriate management strategy for sagittaria will depend on the situation. Factors such as the nature and use of the waterway; climate; size and age of the infestation; presence or absence of an upstream infestation; and current and ongoing resources available need to be considered in the control and management of sagittaria (Osmond and Petroeschevsky, 2013).

A good understanding of the situation, management options, available resources and management objectives will support a systematic and responsive approach to sagittaria management.

Setting management objectives

Identifying a management strategy based on the level of weed invasion is a common practice in weed control programs. This involves identifying whether the objective is one of prevention, eradication, containment or asset protection (Table 2.1). Determining the objective provides a good framework for planning and designing sagittaria control programs.

Table 2.1 Weed management objectives and actions based on stage of weed invasion.

Management objective	Description
Prevention	This aims to prevent a weed from arriving and/or establishing in a new area. Actions taken for prevention may include surveillance, movement controls at borders, machinery and equipment hygiene, awareness and education. Return on investment is much greater for a prevention strategy than for managing weeds after they establish in a new area.
Eradication	This aims to eradicate a weed from a geographic area, requiring elimination of all plants and propagules (seeds, tubers, stolons) where there is limited or no potential for reinvasion. Actions taken for eradication may be similar to those adopted for prevention, but also include determining the extent of infestation and eliminating all plants and reproductive plant parts (e.g. through herbicide control or other methods). Eradication programs have a high upfront cost because surveillance and control activities are more intensive and frequent than they are for weed control programs for other objectives, such as asset protection. Return on investment is much greater for an eradication strategy than for ongoing management of weeds because recurring costs of control and ongoing weed impacts are avoided in the long term.
Containment	This aims to prevent an infestation expanding beyond a defined area, effectively using the approaches of 'asset protection' inside the containment area and 'eradication' outside of it. Actions taken may include those used for eradication and asset protection objectives. This is used where an infestation has become too established to attempt eradication, but nearby areas remain free of the weed.
Asset protection (suppression)	This aims to reduce the abundance of a weed such that its impacts are reduced. Actions taken may include surveillance, identification of priority assets for protection and weed control at priority assets (e.g. through herbicide, mechanical or biological methods). This is the most commonly applied weed control strategy and has a high recurring cost in the long term.

The identification of management objectives can occur on multiple scales. Figure 2.1 identifies sagittaria management objectives at the national scale, based on its national distribution. In this scenario, areas of potential habitat are targeted for prevention activities; outlier infestations are targeted for eradication; and core infestations (e.g. those in the Murray and Goulburn rivers) are managed to reduce the impact on key assets (asset protection) by reducing infestation densities and their potential to spread.

Objectives may change at the local or regional scale. For example, a weed manager may wish to contain sagittaria to certain waterways even though the infestation falls within a national asset protection zone.

When setting a management objective, weed managers should also consider the assets and communities affected by sagittaria. For example, an irrigation authority is responsible for maintaining unobstructed channels and will therefore prioritise sagittaria management to protect this asset. In contrast, conservation managers may target sagittaria to maintain and protect the diversity of natural aquatic environments.

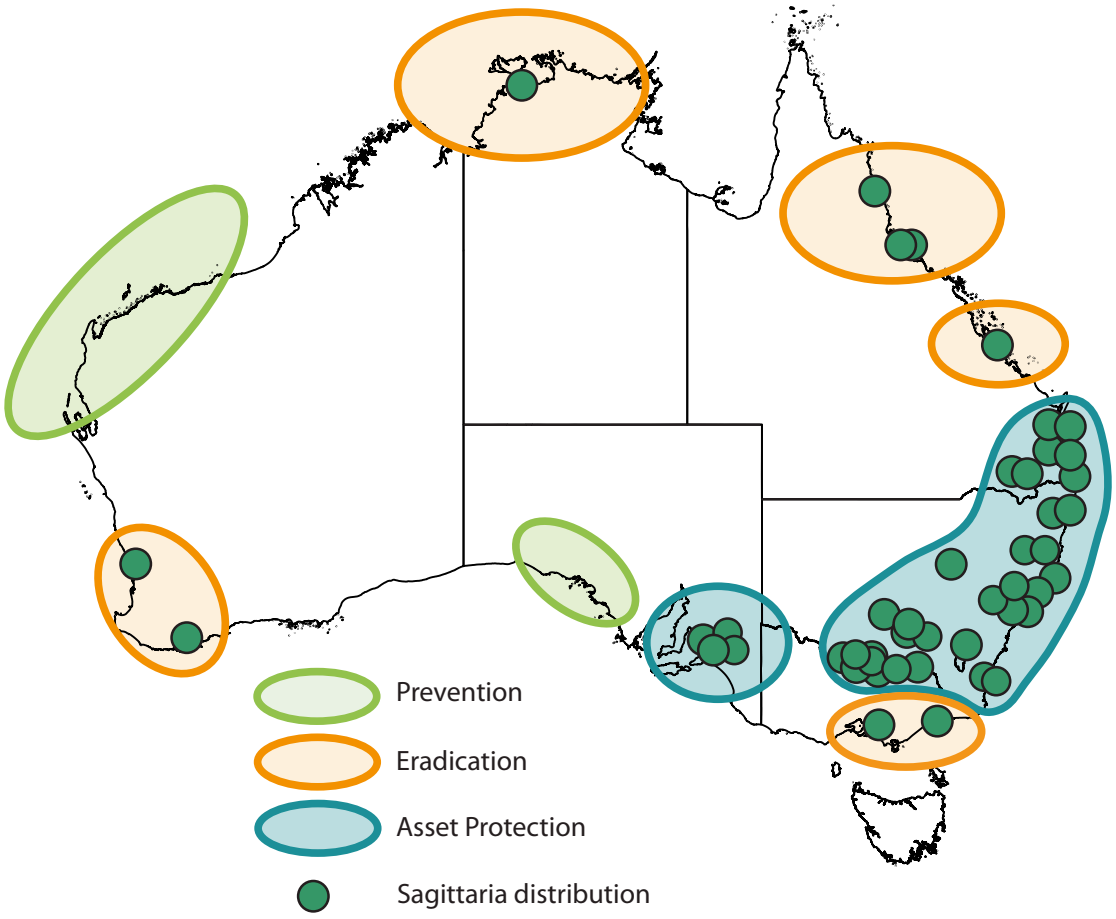


Figure 2.1 Distribution of sagittaria in Australia with idealised management objectives to consider for each infestation depending on their proximity to other known infestations.

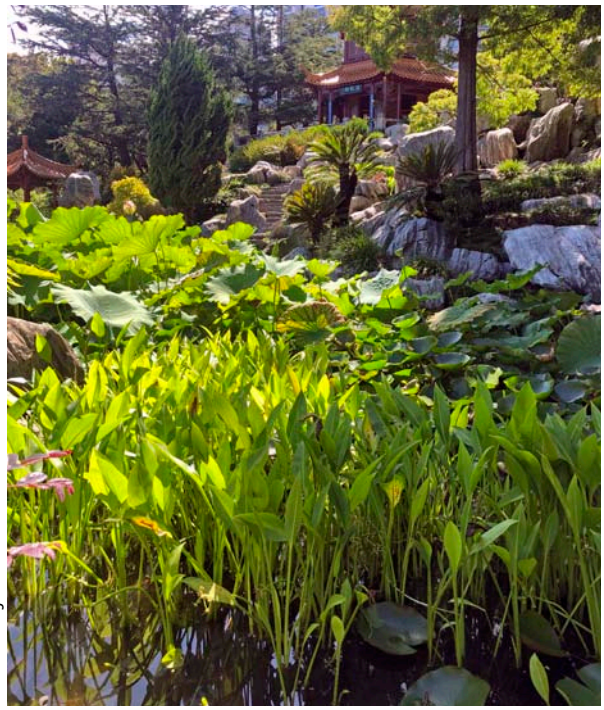
Prevention

Although sagittaria is widespread in Australia, there are still many areas where it is not present. Thus, it is critical to implement measures to prevent it establishing in areas where it is currently absent. The most cost-effective way of dealing with any weed is to prevent its introduction, particularly through the sale and trade of plants among enthusiasts. Other likely sources of new infestations are the escape of cultured plants from ornamental ponds; natural downstream dispersal of upstream infestations via drift of seed and tubers; and dispersal of weed propagules (seed, tubers, plants) by waterfowl.

For sagittaria, the most obvious prevention measure is to ensure earth-moving machinery that is moved between waterbodies to excavate and maintain drains and irrigation channels is cleaned to remove soil and vegetation that might contain seeds and tubers or better still, to ensure that only local machinery is used.

Upstream infestations of sagittaria may pose a risk to clean areas downstream, particularly after flood events. Thus, it is important to consider the need for additional surveillance post-flood to increase the likelihood of detecting new infestations.

For more information on weed hygiene, see Chapter 3 page 46 – *Disposal and site hygiene associated with mechanical and manual removal of sagittaria*.



Raelene Kwong

Ornamental plantings of sagittaria in public places pose a risk of escape. Chinese Friendship Garden, Darling Harbour, Sydney.

Raelene Kwong

Sagittaria seeds (achenes) are buoyant for several days and can float long distances downstream.

Eradication

Eradication means to eliminate all plants and propagules (includes seeds, stolons and tubers) in the infestation until sagittaria is locally extinct. To be successful there should be limited or no potential for sagittaria reinvasion from surrounding areas.

Eradication of weeds is often a desired outcome of weed control programs; however, in reality eradication is difficult to achieve. The best chance of success occurs when the control is conducted in the very early stages of invasion, when there are few plants and a limited seedbank. There is considerable expense associated with establishing an eradication program. The expenses are for delimitation surveys to determine the infestation's extent as well as equipment and chemical costs for initial and follow-up control. However, the payoff of a successful eradication program is that these costs do not continue into the future, and the area is free of the impacts of sagittaria.

Raelene Kwong

Sagittaria growing in a lake at Waring Gardens, Deniliquin New South Wales presents an opportunity for eradication. Eliminating this small infestation will prevent its expansion and the spread of propagules into the surrounding waterways.

The importance of early detection

Education and awareness raising among waterbody and land managers, contractors and the public is an important way to improve the chances of early detection of sagittaria. Early detection allows eradication programs to commence while infestations are small, thereby improving the chance of management success.

Outlier infestations of sagittaria were found in this wetland and targeted for eradication. Plants were carefully removed, reducing the likelihood of spread of sagittaria into the western half of Goulburn–Murray Water's irrigation districts.

Early detection was achieved, with plants found before flowering and seeding had occurred, thus limiting the potential for re-establishment of sagittaria.

Russel Talbot

Russel Talbot

Eradication is usually only worth considering in the case of new infestations that represent significant range expansions. Formal responses to attempt sagittaria eradication have been initiated in Western Australia, South Australia, Queensland and the Northern Territory.

Case studies describing early detection and eradication programs in the Northern Territory and in North Queensland are provided in Chapter 4.

Reduced sagittaria dispersal associated with the Ross River eradication program

The sagittaria infestation in the Ross River, North Queensland, is part of an ongoing eradication program. As described, eradication programs are difficult to achieve and require time and perseverance. While eradication may take a long time, the benefits of control efforts may be realised sooner.

In 2019, the Ross River experienced a severe flood event that affected the site of the sagittaria infestation that was subject to eradication. In the four years prior to the flood, land managers had successfully reduced the sagittaria infestation from 560 square metres to 50 square metres. Frequent spraying and plant removal further reduced seed and tuber production. This management led to a reduction in the number of propagules in the environment and a depleted propagule bank in the river sediments, limiting the potential for dispersal and establishment of new infestations.

The flood caused major scouring and changes to the watercourse in the section where sagittaria had previously been located. Without the control efforts in the four years prior to the flood, this would have resulted in significant downstream dispersal of sagittaria plants, seeds and tubers and an associated increase is sagittaria infestations. Instead, post-flood surveying downstream of the original infestation has shown limited spread, which has been attributed to the successful management in the four years prior to the flood event.

Containment

Containment refers to situations where sagittaria is too well established in a particular area for eradication to be feasibly achieved but other nearby areas are free of sagittaria. In such a situation, establishing a containment zone could reduce further spread of sagittaria into clean areas. In these situations, sagittaria would be managed within the containment zone to reduce its local impact (i.e. managing to achieve the objective of asset protection); while outside of the containment zone, sagittaria would be managed to achieve eradication. Management of containment zones is costly because of the need for ongoing control works and coordination of management activities undertaken by multiple landholders and agencies.

Containment programs are worth considering at catchment or sub-catchment scales, for example, where there are heavy infestations of sagittaria in one catchment, but it is absent or sparse in a nearby catchment. This situation exists in the western part of Goulburn–Murray Water's irrigation districts, where sagittaria is managed to kill every plant, compared with the suppression approach (asset protection) used in the east, where sagittaria is widespread.

Asset protection

Asset protection, or suppression, refers to management activities to reduce the impact of sagittaria and is the most common weed management strategy. For sagittaria, asset protection may include controlling infestations to reduce obstruction of drains and irrigation channels or to allow greater growth of native aquatic plants in wetlands. The latter approach was undertaken by Parks Victoria in Barmah National Park. Asset protection also has the benefit of reducing propagule load, and thus the potential for spread of sagittaria.

Chapter 4 (case study 1) has an example of sagittaria management for asset protection.

Raelene Kwong

Controlling sagittaria infesting this drain leading into Reedy Swamp will protect a significant wetland asset near Shepparton, Victoria.

Hasan Rahmani

Biological control is often utilised in asset protection control programs because other control methods may not be cost effective for these widespread infestations.

Full details of where and how to make releases of the sagittaria fruit feeding weevil can be found in Chapter 3.

Developing a management plan

This section describes considerations for preparing a management plan for sagittaria infestations. It is adapted from Osmond and Petroeschevsky (2013).

Management of sagittaria requires careful planning and coordinated activities over several years because of:

- the rapid growth of sagittaria
- the ability of sagittaria to quickly form seed and tuber banks within the sediments of waterbodies
- the interconnectedness of waterbodies, which allows sagittaria to spread and establish throughout suitable habitats within a region.

The factors to consider when preparing a management plan are discussed in Table 2.2.

Raelene Kwong

Sagittaria infestations occurring in remote and difficult to access locations can go unnoticed, hampering eradication and control programs. In the shallow 'everglades' section of the Murray River, upstream from Lake Mulwala, sagittaria surveys can be conducted only by boat, which hampers early detection and eradication.

Table 2.2 Factors to consider when preparing a management plan.

Early intervention	Commencing control activities as soon as possible after infestations establish (i.e. while they are small) increases the likelihood of success, reduces the cost of control programs, and reduces the likelihood of dispersal from the site. Early intervention requires regular formal monitoring of waterbodies. It can also be assisted by working with local communities such as citizen scientists and natural resource management organisations.
Map and record	Record the location and extent of the infestation. This can be achieved via a sketch or by recording geographic data with a GPS. The purpose of this step is to estimate extent of the infestation so that progress can be measured. Keeping such records also allows evaluation of how well the control methods are working and if changing the approach will result in improved control. Maps should be updated each time the site is monitored, and each map should have a date. It is also useful to record control methods used; presence of flowers, fruit and seed; and water levels (or flooding or drying events) and to keep photos of the site over time.
Identify the weed source	For new infestations, the source of the infestation is likely to be nearby. It is important to check upstream areas of the same waterbody first, along with nearby waterbodies such as billabongs, drains, garden ponds and farm dams. Accessing aerial imagery (where available) can be highly effective for this purpose. Implementing sagittaria management at the source infestations should be a high priority to prevent reinvasion.
Physically contain the infestation	For small new infestations, it may be possible to contain the infestation by installing floating booms, closing flow-regulating structures or constructing earthen bund walls. Such measures reduce the risk of spread and are particularly important if there are no nearby sagittaria infestations or where downstream locations have high environmental values.
Plan ongoing management and obtain resources	After control work has been conducted, sagittaria can repopulate a site from seeds and tubers buried in the sediment, damaged crowns of emergent plants, and submerged juvenile rosettes. Therefore, successful control requires repeated management over long periods, which in turn requires a long-term budget for monitoring and control. The high cost and difficulty of sustaining long-term management necessitates taking a strategic approach by determining whether eradication, containment or asset protection should be targeted for the infestation.
Check for permits	Permits may be required if sagittaria control tools are likely to cause disturbance to the aquatic environment, or where modifications to the banks of waterways are required to allow access for machinery. It is important to check with local and state governments before commencing control programs.
Decide which control method to use	Control methods are described in detail in Chapter 3. The characteristics of the waterway and access to it will influence which control method to use. See the section titled 'Choosing a control method' in Chapter 3 for more information.
Prevent seed and tuber set	To prevent seed and tuber formation, control should be applied early in spring before flowers have set seed, with follow-up control required at least once more during the growing season. Frequent monitoring (ideally monthly) will help determine when control tools should be applied before the next round of seed set. Control may need to be conducted throughout the year in some situations, such as where eradication is the target and in tropical and sub-tropical areas where vegetative growth and seed set can occur throughout the year.
Have hygiene measures in place	Weed control programs should include hygiene practices to prevent further spread of sagittaria associated with movement of material attached to equipment and personnel. Boats, excavators, trailers and footwear should be washed down to remove plant material and mud that could harbour seeds and propagules.
Monitor and adapt	Utilise the information collected above in the 'Map and record' step to review the success of the control tools and management plan. Changes to the management plan should be made in an adaptive management context and the suitability of the following should be considered: control methods used; timing of application of control methods; frequency and timing of monitoring events; and future extent of management at the site compared with the available budget.

Monitoring and surveillance

Monitoring of areas where sagittaria control works have been undertaken is critical to determine success and guide further management.

Sagittaria is usually monitored via bankside surveys, on foot or in all-terrain or utility vehicles, with surveys sometimes undertaken in boats. The location of each patch should be recorded with a GPS device, along with an indication of its size and maturity.

The frequency of surveys should be varied according to the aim of the control program. Surveys at intervals of two to four weeks are required where local eradication is sought to ensure new plants are detected and controlled before they set seed or grow tubers. In this situation, surveys need to be highly intensive to detect all plants. Where the control program aims for asset protection or suppression, annual or biannual surveys may be sufficient to demarcate the extent of heavy and light infestations. This allows weed managers to evaluate past control measures and plan future ones.

Other planning considerations associated with aquatic environments

Control methods

A range of control options for sagittaria are outlined in Chapter 3. In addition to considering the type of control method to use, it is also important to consider herbicide requirements (e.g. what the herbicide label permits); potential off-target impacts; and whether a site requires regular control and site access (see Table 2.3).

Aquatic environment

Sagittaria grows in aquatic environments, which are sensitive to disturbance. Control programs can disturb the environment directly (e.g. entraining sediment in water associated with mechanical or manual removal of sagittaria) or indirectly by affecting fauna and flora through off-target effects of herbicides.

Table 2.3 Considerations when selecting a control option to manage sagittaria.

Herbicide label requirements	Consider whether the situation is compliant with the directions for use label. For example: restraints, do not statements, weed species, rate, critical comments and general instructions must all be appropriate for and compliant with the situation.
Potential for off-target impacts	This consideration will most often relate to the possible off-target impact of herbicides, but the impact of other control methods should also be considered. Examples of factors to consider include using excavators in high value areas such as national parks; co-existence of threatened species; impact of overspray; erosion when soil is exposed after control works; water quality during decomposition of dead plant material; and the disturbance of sediment and banks associated with excavation or manual removal.
Requirement for ongoing control	Sites where regular control activities are required to reduce sagittaria abundance are not suitable for releases of the fruit feeding weevil biocontrol agent because the use of herbicide will impede establishment of the biocontrol agent (see Chapter 3 'Implementing biocontrol as part of an integrated sagittaria management strategy' for more information).
Access	Herbicides require equipment to apply. Such equipment can range from small handheld devices to large machinery mounted devices. The method selected needs to be compatible with the water and mud associated with the aquatic habitats in which the sagittaria is found. Mechanical excavation and manual removal require disposal of material away from the excavation site, which means that a method of moving this heavy material is required. For manual removal, a boat can be used. For excavation, the reach of the excavator's arm is critical in efficiently accessing the sagittaria and accessing dry areas on the bank to dispose of it.

Excavation of plants and associated sediment affects mud-dwelling fauna, with sediment plumes reducing water quality in the area in the short term. Although this is undesirable, the long-term benefits associated with removal of sagittaria infestations outweighs these effects.

Much like sediment can form a plume of turbid water, herbicide application to the water surface can cause a plume of herbicide that moves away from the treated area, with associated potential off-target impacts on the aquatic environment. Guidelines for use of herbicides around water have been developed (Ainsworth and Bowcher, 2005) and are discussed in Chapter 3: 'Herbicide use around water'.

Raelene Kwong

An example of a large, dense infestation that is suitable for biological control. In this case, the sagittaria infestation occurs in a disused irrigation channel in northern Victoria.

Health and safety

Working in aquatic environments presents challenges for health and safety. The risk of drowning is real, particularly where the water depth changes quickly, such as along riverbanks or where weed management personnel can suffer trauma that renders them unconscious or unable to stand (e.g. heatstroke, hypothermia and head injury by falling branches).

Aquatic environments are often underlain by deep muddy sediment, which can be extremely difficult to wade through, making people excessively tired and exacerbating any other personnel conditions. Without proper caution it can be very difficult for people to wade back to the safety of land.

Direct contact with waterbodies also presents the risk of infection or poisoning. Waterbodies can contain toxins (e.g. avian botulism and blue-green algae), and bacterial and viral pathogens associated with stormwater, sewage or animal faeces are also common.

The risks outlined above can be minimised by performing a risk assessment before undertaking any weed management activities and enacting a range of controls to reduce or remove any identified risks. The risk of drowning can be minimised by not working in water that is too deep; not working around water alone; and carrying a stick to use for balance and support. Where possible, all activities should be undertaken from the bank, rather than by entering the water.

Where accessing the water is required, or use of a boat is required, lifejackets should be worn. Medical advice should also be sought in relation to appropriate vaccinations for bacterial pathogens and viruses.

Where herbicide is being used, personnel should undertake training on the proper use, application, and disposal of herbicides and ensure they read and comply with the label. Refer to Chapter 3 for more information.

Permits to manage weeds in water

Weed managers should check with state authorities, such as environmental protection authorities and agriculture and environment departments, for permit requirements for managing weeds in water and for using herbicides in water. More information on permits is provided in Chapter 3.

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.

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 difficultly 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).

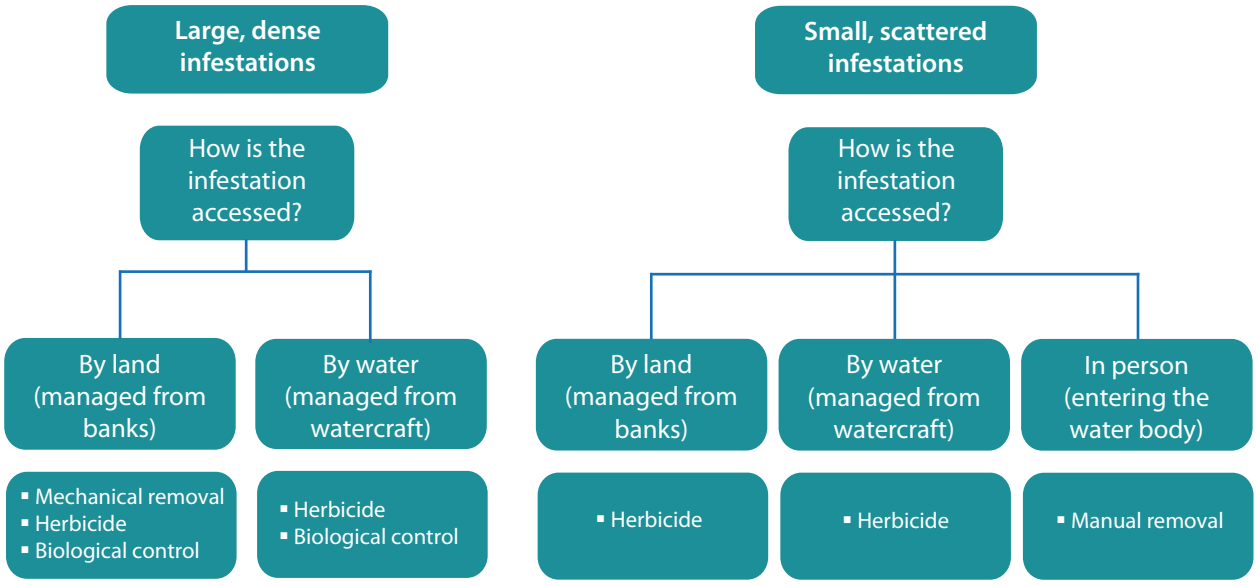


Figure 3.1 Suitable sagittaria control methods depend on the size and accessibility of the infestations.

Table 3.1 Summary of sagittaria control methods.

	Situation	Advantages	Disadvantages	Caution!	Timing	Integrate with
Herbicide control	▪ All situations where the herbicide label can be complied with or a minor use permit exists	▪ 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)	▪ 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	▪ 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	▪ Boom or spot spraying multiple times per year while sagittaria is actively growing	▪ Manual removal ▪ Mechanical removal ▪ It is unclear whether herbicide can be integrated with sagittaria biocontrol
Mechanical removal	▪ Portions of rivers, drains, channels and wetlands that are accessible by an excavator, typically restricted to areas near banks	▪ Can be very effective ▪ Removes upper sediment layer, which contains entire plants, seeds and tubers, reducing regrowth	▪ 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	▪ 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	▪ Year-round	▪ Manual removal ▪ Herbicides ▪ Recontouring
Manual removal	▪ Shallow portions of rivers, drains, channels and wetlands	▪ Can be very effective ▪ Suitable for small infestations ▪ No specialised equipment required ▪ Minimal impacts on environment (soil, fauna, etc.)	▪ 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)	▪ Drowning risk ▪ Care needed to remove tubers ▪ Care required to prevent spread	▪ Year-round	▪ Mechanical removal ▪ Herbicides

	Situation	Advantages	Disadvantages	Caution!	Timing	Integrate with
Recontouring	▪ Very limited application (irrigation channels)	▪ Reduces habitat suitability of irrigation channels for sagittaria (water depth too great for establishment/ persistence)	▪ High cost ▪ Not suitable for drains since water depth fluctuates ▪ Unsuitable for natural waterbodies ▪ Potential for high environmental impact	▪ 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	▪ Year-round	▪ Mechanical removal
Biological control	▪ Dense and extensive infestations ▪ Difficult to access infestations or where other control methods may harm sensitive aquatic habitats	▪ 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	▪ 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	▪ Other control methods should be withheld from release sites to enable biocontrol establishment	▪ Release agents October through April	▪ 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®.

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.

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.

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

Application method	Active ingredient	Commercial product examples	Rate	State or territory	Situation
Permit: PER89861 – expires 30 November 2027. **Permit holder:** Murrumbidgee Irrigation Limited (MIL) **Persons who can use the product under this permit:** Persons generally who are suitably trained in the application of agricultural chemicals in aquatic situations. Refer to permit critical use comments.					
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
Permit: PER80934 – expires 31 May 2026. **Permit holder:** Biosecurity Queensland **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. Refer to permit critical use comments.					
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
Permit: PER13448 – expires 30 April 2025. **Permit holder:** Goulburn Murray Water Authority **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. Refer to permit critical use comments.					
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		
Permit: PER14933 – expires 30 April 2024. **Permit holder:** Murray Irrigation Limited **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. Refer to permit critical use comments.					
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 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.

Russel Talbot

Mechanical removal of sagittaria from an irrigation channel.

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.

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

Russel Talbot

Russel Talbot

Russel Talbot

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.

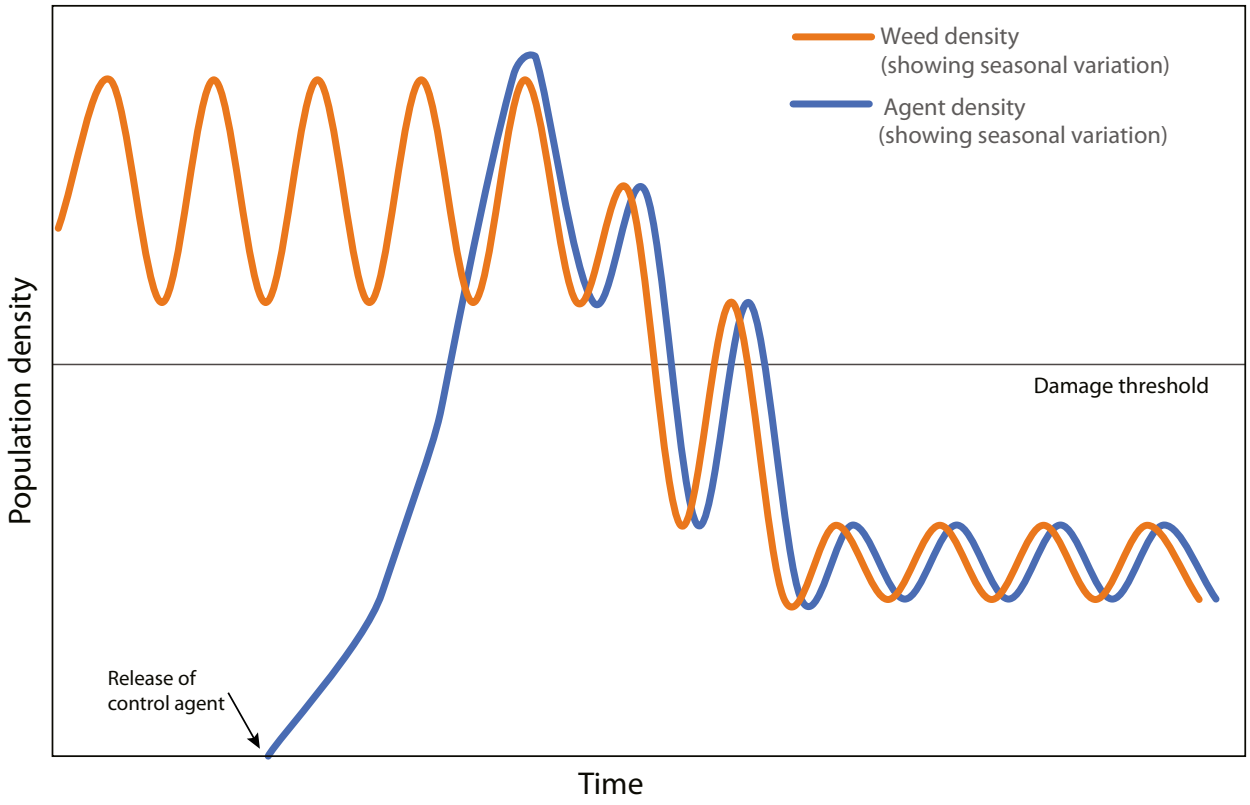


Figure 3.2 The relationship between a weed and its biocontrol agent, illustrating the critical point at which successful control is achieved (Source: Sheehan and Potter, 2017).

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).

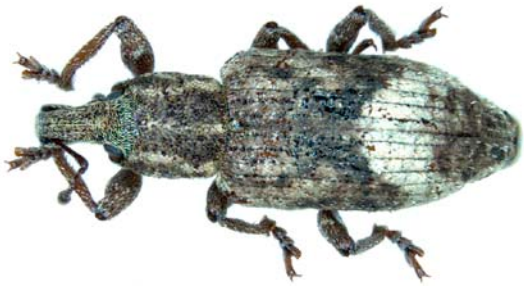
Three of the weevil species have since undergone host specificity testing, but only the fruit-feeding weevil demonstrated sufficient specificity and was approved for release in Australia in December 2020. More information on the approval process for this agent can be found at: https://www.agriculture.gov.au/biosecurity-trade/policy/risk-analysis/biological-contr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

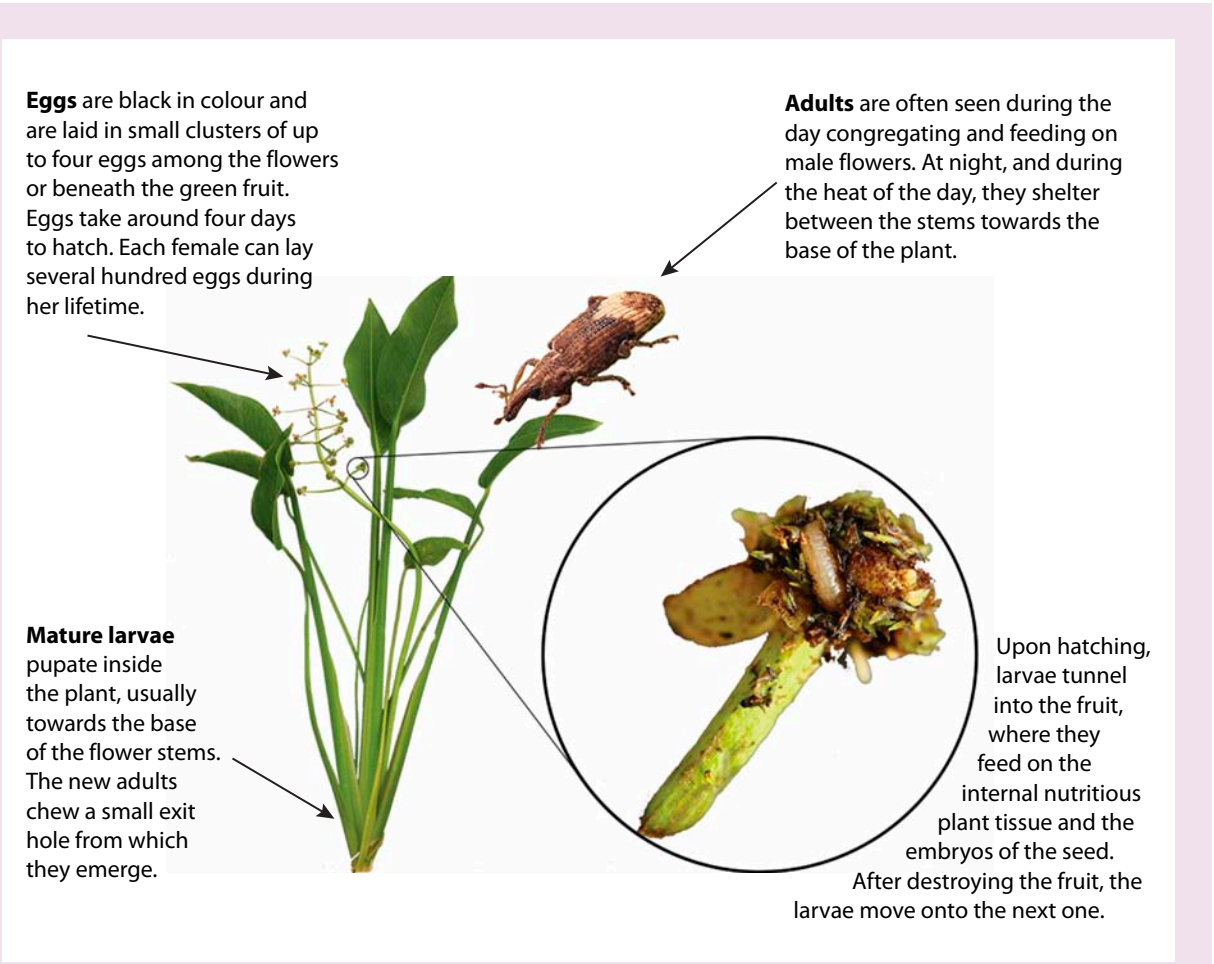


Figure 3.3 Life history of the sagittaria fruit-feeding weevil.

Raelene Kwong

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

Raelene Kwong

Raelene Kwong

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

Raelene Kwong

Raelene Kwong

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

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 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.

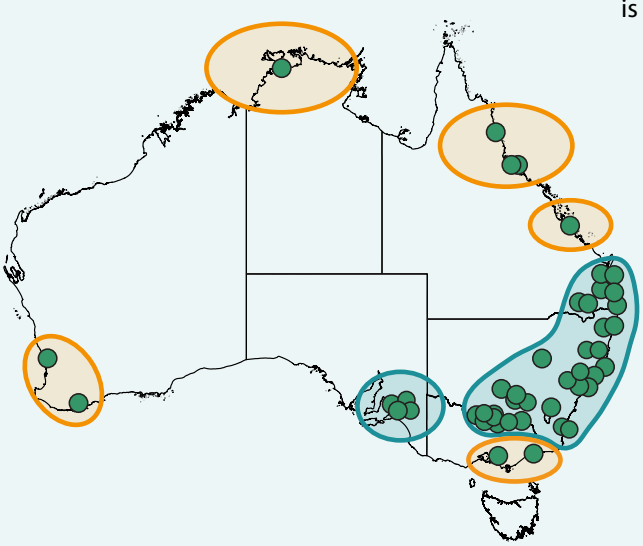
Box 3.3 Implementing biocontrol at the national scale

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

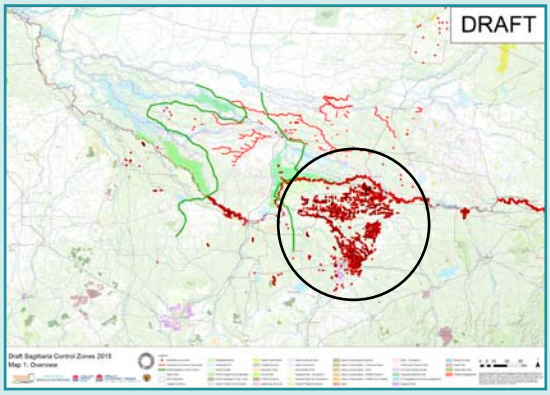
Irrigation channel east of Numurkah, Victoria, infested with sagittaria.

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.

Raelene Kwong



NSW Government

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).

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 Weevil 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.

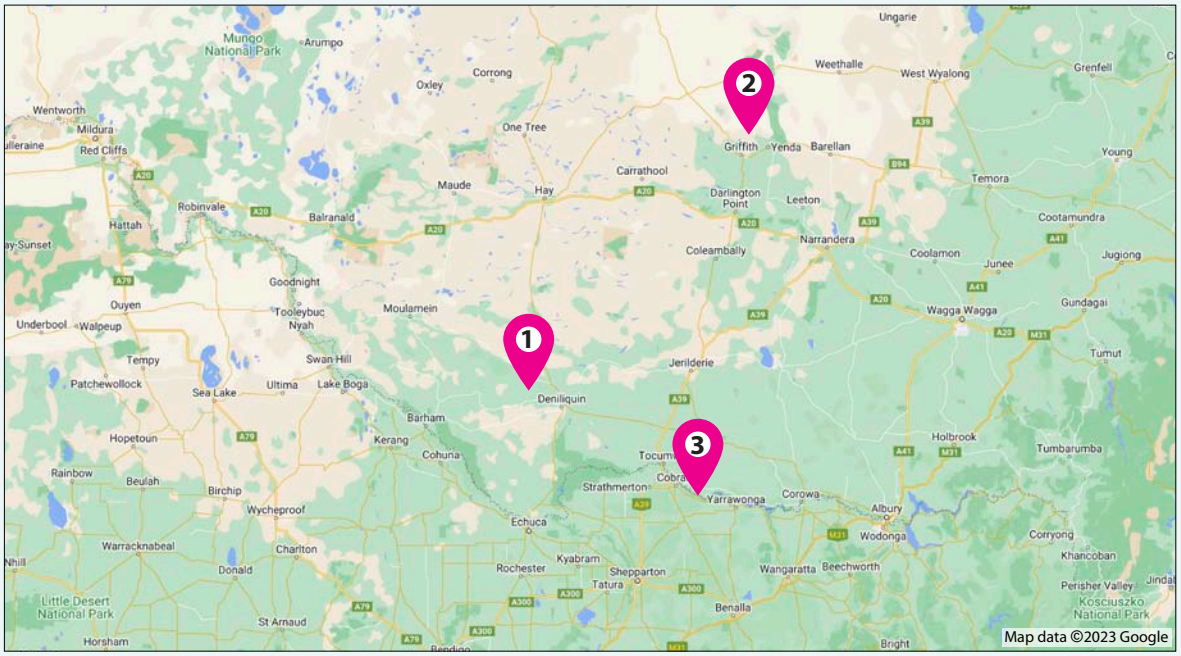
Murrumbidgee Irrigation

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.

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

Chapter 4

Case study 1

Goulburn-Murray Water glyphosate regime

Russel Talbot,* Dannielle McMillan* and Tony Dugdale

* Goulburn-Murray Water

Key points

- **Sagittaria is widespread and well established in waterbodies in northern Victoria.**
- **Drains and earthen irrigation channels provide a perfect environment for sagittaria to grow.**
- **Glyphosate applied at high rates (under permit) can reduce the size of infestations, thus restoring water flow.**
- **Treatments need to be repeated annually as regrowth is common.**

The problem

Sagittaria grows prolifically in waterbodies with shallow water and silty sediments – exactly the habitat provided by drains and earthen irrigation channels. Plant parts (including rosettes, and stems and leaves of mature plants) obstruct water flow, resulting in reduced capacity to deliver irrigation water and to discharge drainage water. If left unmanaged, sagittaria can occupy the entire cross-section of drains and irrigation channels, severely compromising water carrying capacity.

The situation – core infestation

Sagittaria is widespread and abundant in waterbodies throughout Northern Victoria, where it has been established since the 1960s. These waterbodies include 10,900 km of irrigation channels, drains and pipelines managed by Goulburn-Murray Water.

Raelene Kwong

An earthen irrigation channel infested with sagittaria.

Case study 1

The approach

To maintain open channels and drains, Goulburn-Murray Water undertake an extensive control program to combat sagittaria. Glyphosate has been the most widely used herbicide to control sagittaria for decades and remains so. Table 4.1 details the typical treatments of sagittaria in irrigation channels and drains by Goulburn-Murray Water.

The regime provides substantial suppression of sagittaria; however, regrowth from existing plants and germination of new plants occurs after glyphosate application for several reasons:

- Crowns of adult emergent plants are not always killed outright, so these can regrow.
- Juvenile plants still in the rosette growth stage at the time of application are not exposed to lethal doses of glyphosate because they do not have emergent foliage.
- Anecdotal evidence suggests that tubers are not damaged by glyphosate application, even when they are still attached to the adult plant.
- Seeds remain in the substrate and subsequently germinate.

Table 4.1 Typical treatments employed by Goulburn-Murray Water for sagittaria.

Product	Weedmaster Duo® Isopropylamine and mono-ammonium salts of glyphosate
Rate	* 27 L/ha (9.72 kg a.i./ha)
Mix & application	**Boom spray:** 200 L (173 L water + 27 L product)/ha **Handgun:** 600 L (573 L water + 27 L product)/ha No surfactant
Other information	Best applied when water levels are low to maximise the amount of foliage above the water, although this is often impractical because of limited control of water levels
Season	**Core infestations:** December (onset of substantial emergent foliage) to end of May for irrigation channels and rivers (senescence) Application in drains continues later in season
	New or priority infestations: November to end of May
Frequency	**Core infestations:** Once or twice per year. Ideally all infestations would be treated three times per year but more sagittaria exists than resources allow
	New or priority infestations: Three times per year

* Permit required.

Note: Goulburn-Murray Water currently apply glyphosate at these rates under APVMA permit 13448, which restricts use to persons employed or contracted and supervised by Goulburn-Murray Water. A number of conditions are associated with this permit. Permit 13448 applies only to Victoria and New South Wales and is current until 30 April 2025.

Sagittaria infestations that are old, or have previously been treated with herbicide, have a narrow-leaf form. This form is not as susceptible to herbicide as the broad-leaf form, most likely because less surface area is available for herbicide capture and uptake.

It is thought that sagittaria in core infestations of northern Victoria has evolved tolerance to glyphosate, although evidence of this is lacking. Anecdotal observations indicate that populations that have not previously been exposed to glyphosate can be controlled with lower rates than the 27 L/ha specified above in Goulburn-Murray Water's glyphosate-based regime.

Peter Cole

Foliar spray of sagittaria with handgun.

Peter Cole

Foliar spray of sagittaria with boom spray.

The outcome

When glyphosate is applied according to the approach described here, sagittaria abundance can be substantially reduced in irrigation channels and drains, thus restoring water movement. However, for well-established core infestations, this glyphosate-based regime needs to be continued annually in perpetuity.

For new infestations given priority, sagittaria can be suppressed to extremely low levels of abundance with the intensive regime described, but breakouts can be rapid if scheduled monitoring and applications are missed.

Case study 2

Development of flumioxazin to control sagittaria

Tobias Bickel* and Tony Dugdale

*Invasive Plant Science, Department of Agriculture and Fisheries, Queensland Government

Key points

- **Sagittaria is widespread and well established in waterbodies in south-east Queensland.**
- **There are concerns sagittaria could impact on water supply, native aquatic plants and drain function.**
- **Management with glyphosate has limited effectiveness, however alternative herbicides are lacking.**
- **A new herbicide, Clipper®, has now been registered for use on sagittaria in a range of situations.**

The situation – core infestation

Sagittaria was first detected in Brisbane in 1959 and since then has spread, predominantly in coastal areas. Sagittaria has only become a management issue in the last 10 years and is well established in waterbodies of south-east Queensland. Queensland authorities are concerned about sagittaria's ability to interfere with drinking water and irrigation water supplies, obstruct drainage and displace native aquatic plants.

The problem

Glyphosate is the main management tool used for sagittaria, though it has limited effectiveness, for reasons similar to those described in Chapter 3 (page 39). This prompted the Queensland Department of Agriculture and Fisheries to initiate a program to develop other control options.

The solution

A research program was established to screen and test herbicides for potential use against sagittaria and other important aquatic weeds. Flumioxazin was selected for further investigation because it is capable of controlling a variety of key aquatic weeds. A series of laboratory and shade house trials were conducted to determine herbicide efficacy (i) at a range of rates, (ii) when sprayed on the emergent foliage or applied directly to the water, and (iii) under varying pH levels of the receiving waterbody.

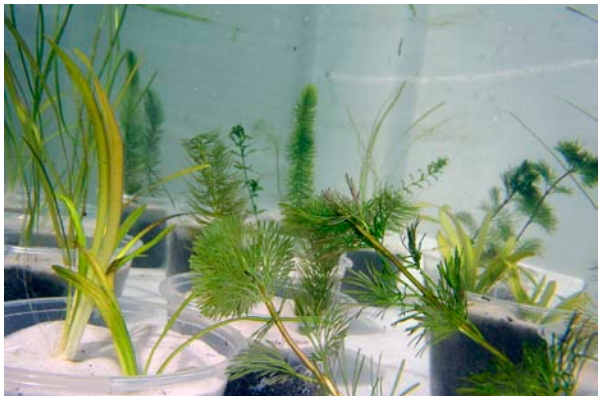
When applied directly to the water column, damage to sagittaria was noted within a week of flumioxazin application. The extent of plant damage continued to increase over the 12-week duration of the

Tobias Bickel

Experimental research facility with tanks under shade cloth for growing aquatic weeds, including sagittaria.

experiment, such that at the end of the experiment biomass was reduced by approximately 70–90% relative to untreated plants. Efficacy was best when applied to water between 6 and 8 pH, and reduced at 8.5 pH. Both foliar and water column application of flumioxazin provided similar levels of sagittaria control.

The information collected in the research program was used to undertake field trials to test the effectiveness of flumioxazin against sagittaria and other aquatic weeds in natural water bodies, with promising results. Flumioxazin was applied as a foliar spray (210 g a.i./ha) to a dense sagittaria patch in a small water body located in a suburban park. The herbicide removed the entire emergent foliage within 60 days and greatly reduced plant density. However, there was still a large amount of submersed growing rosettes remaining in the site, which will be controlled with a future subsurface application of flumioxazin. The rate of 210 g a.i./ha was between the upper and lower bounds of flumioxazin's subsequent label rate for application to foliage via surface spray.



Tobias Bickel

A range of submersed aquatic weed species in pots arranged on the bottom of one of the tanks prior to dosing with flumioxazin.

Tobias Bickel

Sagittaria infestation in a suburban park in south-east Queensland (prior to foliar herbicide application).

Tobias Bickel

Same infestation 60 days later after spraying with flumioxazin. Note emergent sagittaria has disappeared.

Case study 2

Flumioxazin was also applied as either a subsurface application (400 ppb) or combination of subsurface (200 ppb) and foliar (210 g a.i./ha) application to a slow-flowing drainage channel dominated by emergent sagittaria and Amazon frogbit. As performed at the other site, all the emergent sagittaria was removed within four weeks. The remaining subsurface rosettes were still present but showed considerable herbicide damage and potentially may die (results pending). There was no visual difference in control efficacy between the high subsurface or combination treatments. The subsurface applications of 200 and 400 ppb represent the upper and lower bounds of flumioxazin's subsequent label rate for subsurface application.

The outcome

Flumioxazin was granted APVMA registration for use in Australia in December 2020, under the trade name Clipper®. It can now be used to control sagittaria in a range of situations, including non-flowing freshwater bodies and the margins of slow-moving streams, lakes, dams and channels. This provides an additional tool to complement glyphosate and provide managers with different mode of action to use against sagittaria to limit potential development of herbicide resistance.

Further trials are underway to determine if its registration can be extended to irrigation channels.

Tobias Bickel

Foliar application of flumioxazin to sagittaria in a drainage channel (SEQ, September 2022).

Tobias Bickel

All emergent sagittaria removed about four weeks after treatment.

Tobias Bickel

Remaining submersed rosettes (four weeks after treatment) are brown and affected by herbicide.

Case study 3

Eradication from Ross River, Burdekin Dry Tropics Natural Resource Management region

Tony Dugdale and Melissa Green*

*Technical Biosecurity Officer, Townsville City Council

Key points

- **Discovery of sagittaria in the Ross River threatened the environmental, economic and recreational values of the area.**
- **A control program was instigated to supress reproduction and prevent spread.**
- **A combination of herbicide control and manual removal has been successful in preventing spread from the Ross River.**
- **Early intervention and rapid response are critical success factors.**

The situation – outlier infestations

Sagittaria was discovered in the Ross River at Townsville in December 2011. This discovery represented a major expansion of its range in Australia, approximately 1000 km north from known populations in south-east Queensland (Calvert, 2015).

Melissa Green

Melissa Green

Sagittaria growing in the Ross River, Townsville.

Case study 3

The problem

Sagittaria was immediately recognised as a threat to the ecology and recreational use of the Ross River and, more importantly, the other wetlands of the region and the nearby Burdekin irrigation areas, which are free of sagittaria. In particular, managers were concerned about sagittaria's potential to: reduce water flow in the region's extensive network of irrigation channels and drains; entrap silt, leading to increased flooding risk; and displace native aquatic species.

The solution

A control program in the Ross River was immediately enacted by Townsville City Council. The program employed herbicide application (glyphosate) and manual removal, guided by an intensive monitoring and survey program. The aim of the control works was to suppress flowering and seed production and thereby minimise the source of propagules that could spread to other parts of North Queensland.

Forming a regional working group

A regional sagittaria working group was formed around 2015 to formalise the management of sagittaria in the Burdekin Dry Tropics Natural Resource Management region. Since then, sagittaria in the Ross River has been subject to intensive treatment with glyphosate and regular surveys at two-to-four-week intervals. The short time between surveys is required so that the control program can keep pace with sagittaria's rapid growth in the Dry Tropics, allowing plants to be detected and treated before they flower and seed. In extreme situations, plants at this site have been recorded transitioning from juvenile to seeding in only one week.

Achieving control with glyphosate

Like elsewhere in Australia, glyphosate's effectiveness on sagittaria is limited. Glyphosate application in the Ross River kills the above-water foliage, but the plants survive via the network of stolons and tubers. Further, submersed rosettes are not damaged at all

Melissa Green

A patch of sagittaria invading a backwater after glyphosate application, Ross River, Townsville. Note narrow leaf blades, undamaged rosettes visible beneath the water, and presence of few flowers.

by the herbicide applications. The emergent foliage that regrows after glyphosate application has shorter and slimmer leaves than prior to application, such that after multiple applications the leaves are only marginally wider than the stems.

Repeated control in this way has resulted in significant reduction in infestation size, with the area of infestation reduced from 560 square metres in 2015 to just 50 square metres in 2019. As of 2023 the total area infested remains approximately 50 square metres. Tubers are now rare, and stolons have reduced from an average of 17 to 2 per plant. The typical size of the stolons has also reduced, from 6 mm diameter to 3 mm.

Manual control of small infestations

On occasions when new infestations are discovered early while they are small, manual removal of sagittaria occurs. Although time consuming and difficult to achieve, this method provides a way to eliminate new infestations. Newly formed tubers remain attached to stolons, so careful tracing and removing of these can eliminate these propagules, which herbicide application does not achieve.

Where intensive control with glyphosate has reduced the size of infestations, manual removal is also used in the Ross River. This final, intensive push allows sagittaria patches to be eradicated.

Manual removal of existing patches occurs on a weekly basis. The size and number of patches targeted is balanced between the growth of the sagittaria (several sites totalling less than 10 square metres in the cooler months compared to 40 square metres in the warmer months) and the time that the sagittaria removal crew has available.

The outcome

The outcome of the management program in the Ross River infestation is that 11 years after detection, sagittaria has not spread beyond the Ross River – a big win. This success would not have been achieved without the rapid response from Townsville weed officers, who recognised the threat posed by sagittaria and enacted and resourced an appropriate management program. Ongoing investment of resources is required to ensure this success is sustained.

Melissa Green

Crew returning from controlling sagittaria on Ross River. Note bags of manually removed sagittaria in the boat.

Case study 4

Rapid response to sale and propagation in the Northern Territory

Roni Opden,* Thomas Price,* Christopher Collins* and Tony Dugdale

*Weed Management Branch, Rangelands, Department of Environment, Parks and Water Security, Northern Territory Government

Key points

- **Mislabelled sagittaria plants were being sold at hardware stores.**
- **A rapid response by weed officers traced and recovered most of the plants sold.**
- **Two backyard infestations were found and treated.**
- **Media campaigns and cooperation from hardware stores, wholesalers and consumers contributed to the success of the response.**

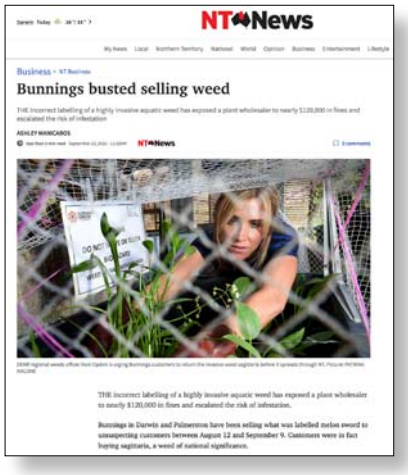
The situation – outlier infestation

Sagittaria was not known to be present in the Northern Territory until 2016, when it was found being sold at hardware stores in Darwin and Katherine. Establishment of sagittaria in the Northern Territory would represent a substantial expansion of its range in Australia.

The problem

The Northern Territory is renowned for its freshwater wetlands, which is just the habitat in which sagittaria thrives. In addition, parts of the Northern Territory also match sagittaria's climatic preference. Invasion of sagittaria into such habitats poses a serious threat, particularly to iconic wetlands such as Kakadu.

In 2016, sagittaria was detected for sale at a hardware store by an off-duty Northern Territory Government officer. The sagittaria was labelled Melon Sword (*Echinodorus osiris*).


NT News

Business

Bunnings busted selling weed

A news article was part of the media campaign and recall of sagittaria (Source: NT News).

The solution

A trace-back and trace-forward response was immediately initiated by the Northern Territory Government. This included an extensive media campaign for members of the public to report and return purchased sagittaria, and a rapid response to search the properties at which sagittaria had been reported. A compliance investigation was also launched as sagittaria is a declared weed under the Northern Territory's *Weed Management Act 2001*.

The media campaign successfully generated public interest and triggered the return of at least 24 of the 28 plants that had been sold. Additionally, 109 plants were seized from the wholesaler.

Extensive surveys of constructed and natural waterways were carried out throughout Darwin and surrounds, with no sagittaria detected. Detections were made however, in several urban backyard ponds. One of the respondents to the campaign had an urban pond where sagittaria had been growing for at least 10 years. Associated searches found an additional urban pond where sagittaria had been known to be present for at least 17 years.

Sagittaria plants were removed manually by Northern Territory Government officers. Soil and sediment that could potentially contain seeds and tubers was also removed and the material was buried onsite to limit potential spread.

The outcome

A compliance investigation found that the sagittaria plants had been misidentified and mislabelled, resulting the in plant wholesaler receiving a fine.

Backyard infestations of sagittaria were identified and plants and material removed. No further sagittaria plants were detected in the Northern Territory until 2022, when a single plant was found at one of the original urban ponds.

Northern Territory Weed Management Branch

Sagittaria growing in a backyard pond, Northern Territory.

Northern Territory Weed Management Branch

The pond after Northern Territory weeds officers removed the sagittaria.

Northern Territory Weed Management Branch

Burial of sagittaria plants and associated sediment from the pond.

Case study 4

Recovery of 24 of the 28 plants known to be sold by the hardware stores is considered a significant success story. The response from the Northern Territory Government, and the resultant cooperation for hardware stores, wholesalers and consumers, is a great example of the benefits of a coordinated and rapid response to eliminate the threat to the environment of a weed at a very early stage of invasion.

Rapid response to the inadvertent sale and propagation of sagittaria (*Sagittaria platyphylla*), an aquatic Weed of National Significance

Louis Elliott and Roni Opden, Weed Management Branch,
PO Box 496, Palmerston NT 081, Australia, email: roni.opden@nt.gov.au

Summary

Sagittaria (*Sagittaria platyphylla*) is an aquatic Weed of National Significance and a declared Class A weed in the Northern Territory.

In 2016 it was misidentified, mislabelled, propagated and sold by a commercial plant wholesale nursery which triggered a rapid response with the aim to eradicate it in the Top End.

During the highly successful response, 109 potted plants were seized and destroyed prior to sale. Of the 28 plants sold to the public prior to detection, 23 plants have been recovered. In addition, two historical pond plantings were discovered and controlled.

Surveys of surrounding land and native waterways failed to detect any wild populations.

The incident demonstrated the importance of correctly identifying and labelling plants prior to propagation and sale, and the vital role that government agencies play in reducing the risk of weedy garden and pond plants spreading into the natural environment.

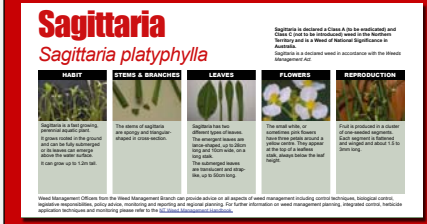
What is the problem?

- Sagittaria (*Sagittaria platyphylla*), also known as arrowhead, is an ornamental aquatic plant that can invade waterways and native vegetation.
- First reported naturalised in 1959 near Brisbane and spread rapidly in the 1970s in Victoria, New South Wales and Queensland.
- Chokes wetlands and waterways and restricts waterflow, adversely impacting biodiversity and recreational activities such as boating and fishing.
- Prolific seeder, producing up to 20,000 seeds per plant and can also spread through stolons and tubers.
- Spread by humans as an ornamental plant and can be accidentally spread from ponds into native waterways.
- Early detection is critical to successful control because sagittaria is difficult to control with herbicides.

Photo: Sagittaria infestation, Victoria (Raelene Kwong, DEDJTR).

How to distinguish sagittaria from other plants

- Aquatic herb.
- Flowers with 3 white petals and yellow stamens.
- Leaf form is variable with different submerged and emergent forms.
- Emergent leaves have stems that are triangular in cross section.
- Easily confused with sword plants (*Echinodorus* spp.) which are commonly cultivated in pots and ponds.
- Definitive method of distinguishing them requires flowers – sagittaria has separate male and female flowers, while sword plants have only one type of flower (with male and female parts).
- Sagittaria can also be confused with other sagittaria species. The most common is 'arrowhead' (*Sagittaria sagittifolia*) which is also cultivated and traded. Arrowhead (*Sagittaria sagittifolia*) can easily be distinguished from sagittaria (*Sagittaria platyphylla*) by the long lobes on the leaves which resemble the barbs of an arrowhead.



The Response

1. Detection

- An off-duty NT Government Officer detected sagittaria for sale in Bunnings in mid-2016, labelled Melon Sword (*Echinodorus osiris*).
- Bunnings immediately removed the plants from sale, but 27 had already been sold to the general public.
- Weed Management Officers seized 109 potted plants from the commercial plant wholesaler, and all remaining plants from Bunnings.
- Several plants were also found at Mitre 10 in Katherine, of which one had been sold.

Photo: Sagittaria for sale labelled Melon Sword.

2. Media campaign and recall

- An intense media campaign commenced, alerting the general public to report and return any sagittaria purchased.
- Many plants were reported and returned. One of these reports was a pond that was planted with sagittaria (more than 10 years old).
- The pond discovery triggered a rapid response.

Photo: Sagittaria flyer distributed to the public.

3. Rapid response

- Searching of residential blocks within 500 m of the historic pond detected a second pond cultivated for 17 years.
- Extensive surveys of surrounding wetlands and potential habitat within 2.5 km of pond failed to detect any wild populations.
- A compliance investigation was undertaken into the sale of a declared weed under the *Weeds Management Act*.

Photo: Media coverage in the *NT News*.

4. Outcomes

- The public recall raised community awareness, prompted the reporting of purchased plants and the discovery of two historic pond plantings, both of which have been controlled.
- To date, 23 sagittaria plants have been recovered, out of the 28 sold to the public.
- The plant wholesaler was fined for selling declared weeds to the retailers.
- The risk of spread to the natural environment of a new weed has been significantly reduced.

5. What went wrong?

- Potting up an unknown plant with weedy characteristics – not a good idea.
- Not getting accurate identification prior to sale.
- Plant labelled with a wrong name.
- Biosecurity checks were then conducted on the wrong name and did therefore not pick up the error.
- Nursery Industry Best Management Plant Labelling Guidelines are voluntary and not binding.

We still need your help

Although the recall and response from the general public has been successful, there may be up to five more mature sagittaria plants that were sold from Bunnings and Katherine Mitre 10 in 2016 still growing in gardens. We still need your help to locate them as well as any older plantings that may have gone undetected. If you see a plant that might be sagittaria, report it to the Weed Management Branch on 08 8999 4567.

Further information

weeds.ala.org.au/WoNS/sagittaria

www.nt.gov.au/sagittaria

NORTHERN TERRITORY GOVERNMENT

References

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Petroschensky, A. (2012). Weed Management Guide – Sagittaria, Australian Government. Canberra.

Acknowledgements

The Weed Management Branch would like to thank everyone who has reported suspected sagittaria plants during 2016–2017. The recall was extremely successful due to the high level of support from the general public. We would also like to particularly thank people that had sagittaria in their ponds for their support and help with its eradication.

Poster detailing the rapid response to the backyard incursion (Source: Northern Territory Weed Management Branch).

Chapter 5

Further information

Legal requirements to control sagittaria

The table below provides an overview of the declaration status and management requirements of sagittaria throughout Australia (as at July 2023).

State/Territory	Legislation	Declaration	Actions
ACT	*Pest Plants and Animals Act 2005*	Declared Schedule 1	Notifiable, must be suppressed, prohibited.
NSW	*Biosecurity Act 2015*	Declared	All of NSW: Must not be imported into the state, sold, bartered, exchanged or offered for sale. General biosecurity duty to ensure a biosecurity risk is prevented, eliminated or minimised, so far as is reasonably practicable. Regional strategic weed management priority varies throughout the state. Refer to Weed Wise for further detail on regional requirements: weeds.dpi.nsw.gov.au/Weeds/Sagittaria#biosecurity
NT	*Weeds Management Act 2001*	Declared Class A, Class C	Sagittaria is declared a Class A (to be eradicated) and Class C (not to be introduced) weed in the Northern Territory.
Qld	*Biosecurity Act 2014*	Declared Category 3 – restricted	Sagittaria must not be given away, sold or released into the environment. The Act requires everyone to take all reasonable and practical steps to minimise the risks associated with invasive plants under their control. Local government biosecurity plans detail requirements at the local level.
SA	*Landscape South Australia Act 2019*	Declared Category 1	Sagittaria's entry to the state, movement or transport on a public road by itself or as a contaminant, or sale by itself or as a contaminant are prohibited. Notification of the presence of plants is necessary to ensure any incursions are promptly destroyed. Landowners are required to destroy any sagittaria plants growing on their properties.
Tas	*Weed Management Act 1999*	Declared	The importation, sale and distribution of sagittaria are prohibited in Tasmania. The legal responsibilities of landholders and other stakeholders in dealing with sagittaria are laid out in the Sagittaria Weed Management Plan. Visit nre.tas.gov.au/invasive-species/weeds/weeds-index/declared-weeds-index/sagittaria for more information.
Vic	*Catchment and Land Protections Act 1994*	Declared Schedule 2	Depending on region: regionally prohibited; regionally controlled. Refer to agriculture.vic.gov.au/__data/assets/pdf_file/0003/538149/Victorian-noxious-weeds-list-by-scientific-name-20-July-2017.pdf for more information.
WA	*Biosecurity and Agricultural Management Act 2007*	Declared C3 – Management Whole of state	Introduction of the plant or its seeds into this area is prohibited. Supply or advertising supply of this pest into this area is prohibited. The infested area must be managed in a way that alleviates the impact, reduces the number or distribution and prevents or contains the spread of the declared pest in this area.

Weed control contacts

	Department	Phone	Email	Website
National	Department of Agriculture, Fisheries and Forestry	1800 900 090	agriculture.gov.au/about/contact/online-enquiry	weeds.org.au/
ACT	Environment, Planning and Sustainable Development Directorate – Environment	13 22 81	ACTBiosecurity@act.gov.au	environment.act.gov.au/parks-conservation/plants-and-animals/biosecurity/invasive-plants
NSW	Department of Primary Industries	1800 680 244	weeds@dpi.nsw.gov.au	dpi.nsw.gov.au/biosecurity/weeds
NT	Department of Environment, Parks and Water Security	08 8999 4567	weedinfo@nt.gov.au	nt.gov.au/environment/weeds
Qld	Department of Agriculture and Fisheries	13 25 23	info@daf.qld.gov.au	daf.qld.gov.au/business-priorities/biosecurity/invasive-plants-animals/plants-weeds
SA	Department of Primary Industries and Regions	08 8303 9620	invasivespecies@sa.gov.au	pir.sa.gov.au/biosecurity/weeds
Tas	Department of Natural Resources and Environment Tasmania	1300 368 550	Biosecurity.Tasmania@nre.tas.gov.au	nre.tas.gov.au/invasive-species/weeds
Vic	Agriculture Victoria	136 186	Refer to: agriculture.vic.gov.au/about/contact-us	agriculture.vic.gov.au/biosecurity/weeds/weeds-information
WA	Department of Primary Industries and Regional Development	1300 374 731	enquiries@dpird.wa.gov.au	agric.wa.gov.au/pests-weeds-diseases/weeds

Herbicides and the law

In addition to the regulatory role of the Australian Pesticides and Veterinary Medicines Authority, herbicide use is regulated by state and territory legislation; see below for contact details.

	Department	Phone	Email	Website
National	Australian Pesticides and Veterinary Medicines Authority (APVMA)	02 6770 2300	enquiries@apvma.gov.au	apvma.gov.au/
ACT	Environment, Planning and Sustainable Development Directorate – Environment	13 22 81	environment.protection@act.gov.au	ablis.business.gov.au
NSW	NSW Environment Protection Authority (EPA)	131 555	info@epa.nsw.gov.au	epa.nsw.gov.au/your-environment/pesticides/pesticides-nsw-overview/regulating-pesticides-nsw
NT	Department of Industry, Tourism and Trade	08 8999 2344	chemicals@nt.gov.au	nt.gov.au/industry/agriculture/farm-management/using-chemicals-responsibly
Qld	Business Queensland	13 74 68	qld.gov.au/contact-us	business.qld.gov.au/industries/farms-fishing-forestry/agriculture/sustainable/chemical
SA	Department of Primary Industries and Regions	1300 799 684	PIRSA.RuralChemicals@sa.gov.au	pir.sa.gov.au/biosecurity/rural_chemicals
Tas	Department of Natural Resources and Environment Tasmania	03 6777 2133	Stuart.Bowman@nre.tas.gov.au	nre.tas.gov.au/agriculture/agvet-chemicals
Vic	Department of Energy, Environment and Climate Action	136 186	agriculture.vic.gov.au/about/contact-us	agriculture.vic.gov.au/farm-management/chemicals
WA	Department of Primary Industries and Regional Development	1300 374 731	enquiries@dpird.wa.gov.au	agric.wa.gov.au/pests-weeds-diseases/control-methods/chemicals

Safety and welfare

Chemical training

A number of providers offer accredited training in the use of chemicals for weed control. To find a provider near you visit the following website and search for the code AHCPMG301 under the 'Nationally recognised training components' search function. Follow the link to find Registered Training Organisations (RTOs) approved to deliver this training package – training.gov.au/Search.

Further information on safety and welfare policy, standards, guidelines and legislation can be accessed by contacting the following government departments and volunteer organisations.

Agency	Website	Contact
National	safeworkaustralia.gov.au/	info@swa.gov.au
Volunteering Australia	volunteeringaustralia.org/wp-content/files_mf/1377053059VAManagersrunningtherisk.pdf	03 9820 4100 volaus@volunteeringaustralia.org
ACT	worksafe.act.gov.au/Home	13 22 81 worksafe@worksafe.act.gov.au
NSW	safework.nsw.gov.au/	13 10 50
NT	worksafe.nt.gov.au/home	1800 019 111 ntworksafe@nt.gov.au
Qld	worksafe.qld.gov.au/	1300 362 128 worksafe.qld.gov.au/contact/general-enquiries
SA	safework.sa.gov.au/	1300 365 255 help.safework@sa.gov.au
TAS	worksafe.tas.gov.au/	1300 366 322 wstinfo@justice.tas.gov.au
VIC	worksafe.vic.gov.au/	1800 136 089 myworksafe.vic.gov.au/s/customer-enquiry
WA	commerce.wa.gov.au/WorkSafe/	1300 307 877 wscallcentre@dmirs.wa.gov.au

Risk assessment of herbicide use around water

The table below details key messages and considerations for understanding and assessing the risk of herbicide use around water (adapted from Ainsworth and Bowcher, 2005).

Key message	Considerations	Check
It is the user's responsibility to read the herbicide label and comply with all of it	▪ The rate and application methods that are listed ▪ Most labels have prohibitions and restrictions (e.g. 'Do Not' statements)	Does the proposed use comply with the label?
Seek additional information before commencing use	▪ Is use restricted or prohibited by applicable regulations? ▪ Assess the risk of adverse herbicide effects on the local environment ▪ Obtain one or more expert opinions about the likely outcomes of use (e.g. weeds officer, agronomist, herbicide manufacturers, or Landcare, Bushcare or natural resource management staff)	Have you obtained advice on regulations, risk of adverse impacts and likely outcomes?
Understand the possible effects of the herbicide on waterways and how the herbicide may make its way into the specific waterway(s) associated with the proposed use	▪ Amount of herbicide applied ▪ Application method and equipment ▪ Mobility of the herbicide in soil and water ▪ Persistence of the herbicide ▪ Toxicity of the herbicide to flora and fauna	Have you worked through the procedure outlined in the guidelines?
Formally consider the risk of the herbicide to the non-target organisms at the site	▪ Undertake a risk assessment for each non-target organism at the site against each herbicide under consideration; OR ▪ Estimate the likely herbicide concentration in the water if it were to be used at the site and compare this to Toxicant Default Guideline Value (formerly Trigger Value) for the herbicide under consideration • In 2021 glyphosate's guideline value for use in freshwater was revised down from 0.37 mg/L to 0.18 mg/L • The latest values, along with guidance on using the guideline values for aquatic ecosystems, can be found here: www.waterquality.gov.au/anz-guidelines/guideline-values/default/water-quality-toxicants/search	Is there a low risk of non-target damage according to the procedures outlined in the guidelines?

Sagittaria Fruit-feeding Weevil Biocontrol Release Form

Landowner/Manager Details

Name: .....

Organisation: .....

Postal address: .....

Phone/mobile: .....

Email: .....

Release Site Details

Site Code (if applicable)**:** .....

Target weed (circle): *Sagittaria platyphylla* (sagittaria) *S. montevidensis* ssp. *calycina* (arrowhead)

Infestation size (hectares or length × width [m]): .....

Location address: .....

Waterbody type (i.e., irrigation channel, creek, drain): .....

Approximate water depth (m): .....

Latitude (South): ..... Longitude (East): .....

Biocontrol Agent Details

Stage released (tick): Adults ☐ Eggs ☐ Larvae ☐

Number released: .....

Date released: .....

Released by (if not landowner/manager): .....

Please record your biocontrol agent release on the Australian Biocontrol Hub:
https://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

Sagittaria Fruit-feeding Weevil Biocontrol Monitoring Form

Landowner/Manager Details

Name: ..... Organisation: .....

Contact: ..... Date/time: .....

Release Site Details

Site code (from Agent Release Form): .....

Target weed (circle): *Sagittaria platyphylla* (sagittaria) *S. montevidensis* ssp. *calycina* (arrowhead)

Infestation size (hectares or length × width [m]): .....

Approximate water depth (m): .....

Location address: .....

Waterbody type: .....

Latitude: ..... Longitude: .....

Weather conditions: .....

Monitoring methodology

1. Locate the original release site, which will be marked by a stake or 'release sign'.
2. Place a 0.5 × 0.5 m quadrat at the marked point. Within each quadrat, take the following measurements:
    a. Presence of adults on flowers (yes/no).
    b. Count the total number of emergent plants.
    c. Count the total number of flowering stems bearing fruit.
    d. For each fruiting stem, count the total number of fruits.
    e. For each stem, record the number of these fruits attacked by weevil larvae.
    f. Only do up to 10 stems per quadrat.
3. Repeat this process with the next quadrat thrown roughly 2 m away.
4. Repeat until you have assessed eight quadrats for the site. If possible, do four quadrats downstream and four upstream from the release point.

If you find evidence of weevils beyond the final quadrats, look further away and note the approximate distance from the release point that the weevils have been found.

Raelene Kwong

Sagittaria fruit damaged by weevil larvae.

Raelene Kwong

Monitoring sagittaria biocontrol release site using a PVC quadrat.

Example of how to fill out the monitoring data sheet

Quadrat number (1–8)	Total number of plants per quadrat	Total number of flowering stems per quadrat	Stem number (1–10)	Number of fruit per stem	Number of damaged fruit per stem	Adults present in quadrat Y/N
1	15	3	1	9	3	Y
1			2	6	5	
2	19	7	1	9	9	Y
2			2	6	6	

Sagittaria Fruit-feeding Weevil Biocontrol Monitoring Data Sheet

Date: .... **Site Code:** .... **Personnel:** ....

Quadrat number (1–8)	Total number of plants per quadrat	Total number of flowering stems per quadrat	Stem number (1–10)	Number of fruit per stem	Number of damaged fruit per stem	Adults present in quadrat Y/N

(Use extra rows if necessary)

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