

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

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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/>

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.

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).

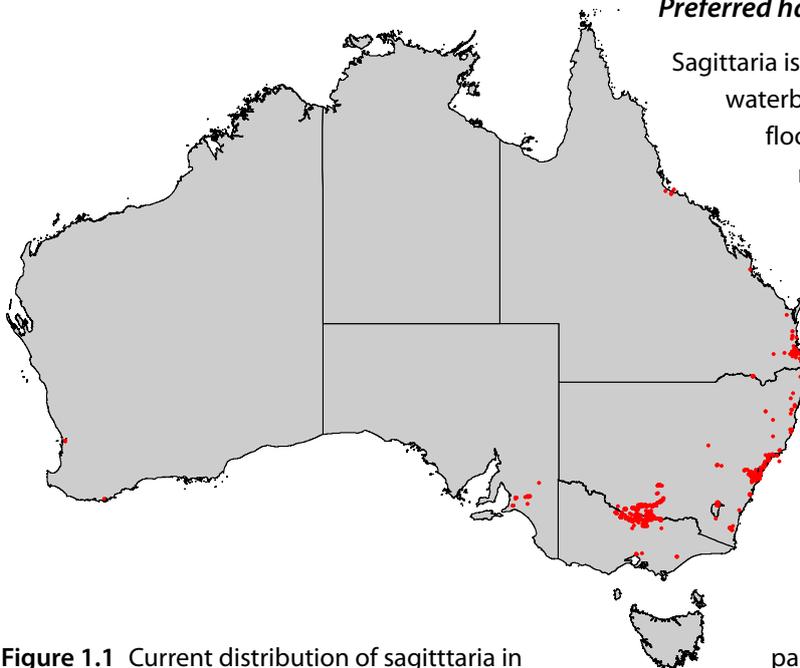


Figure 1.1 Current distribution of sagittaria in Australia (Dr Farzin Shabani, Macquarie University; data from ALA (2022) and NSW Department of Primary Industries).



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).

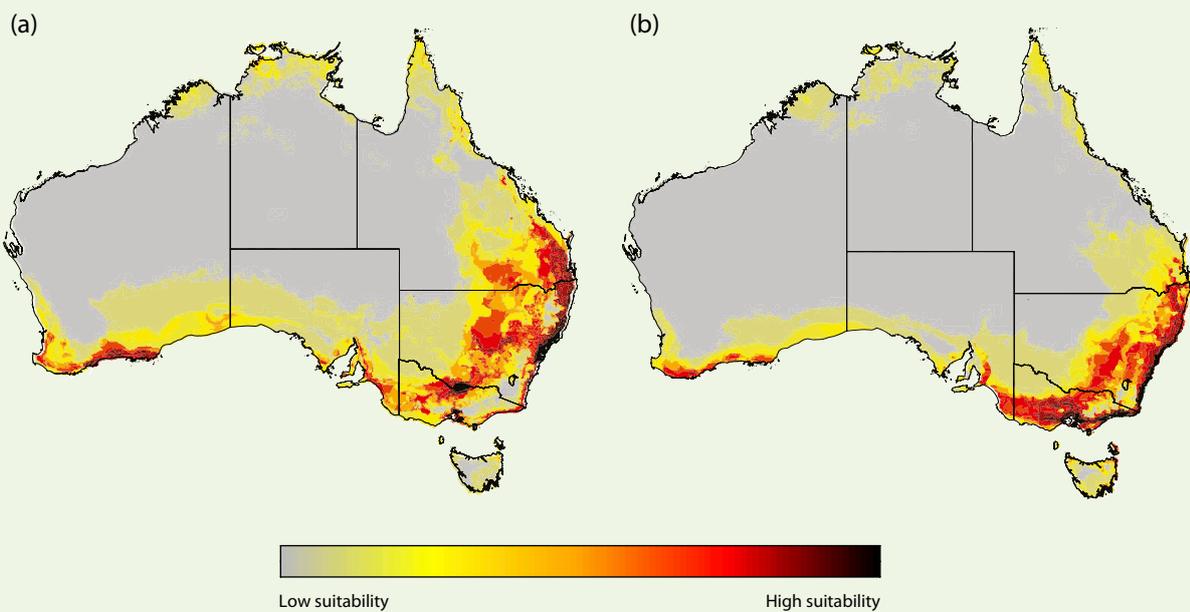


Figure 1.2 Areas of habitat suitability for *sagittaria* under (a) current climatic conditions and (b) predicted climatic conditions in 2050 (Duursma et al., 2013, www.weedfutures.net).

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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*.



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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 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.



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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).

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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.



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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.

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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. Kähler

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.



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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.



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Seeds (achenes).



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Mature fruit.

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Roots and tubers

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



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Close up of tuber.



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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.



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



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



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.

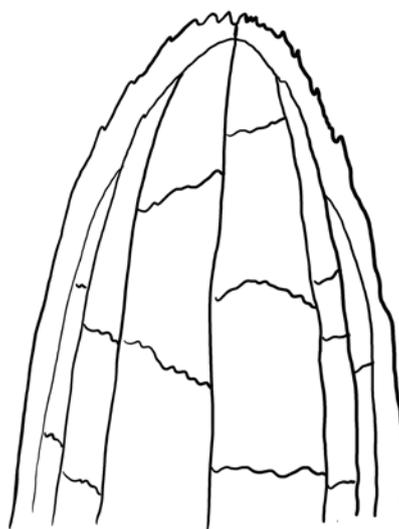
weed and water plantains are widespread and abundant in Australia.

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.



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 <i>S. platyphylla</i>	ARROWHEAD <i>S. montevidensis</i> ssp. <i>calycina</i>	ALISMA <i>Alisma lanceolatum</i>	WATER PLANTAIN <i>Alisma plantago-</i> <i>aquatica</i>	STAR FRUIT <i>Damasonium minus</i>	CREEPING BURHEAD <i>Echinodorus</i> <i>cordifolius</i>	RIBBON WEED <i>Vallisneria australis</i>
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 <i>S. platyphylla</i>	ARROWHEAD <i>S. montevidensis</i> ssp. <i>calycina</i>	ALISMA <i>Alisma lanceolatum</i>	WATER PLANTAIN <i>Alisma plantago-</i> <i>aquatica</i>	STAR FRUIT <i>Damasonium minus</i>	CREEPING BURHEAD <i>Echinodorus</i> <i>cordifolius</i>	RIBBON WEED <i>Vallisneria australis</i>
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

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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.



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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 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	✓	✓	✓	✓	✓(x)				✓	✓	✓	✓
Fruit production	✓	✓	✓	✓	✓(x)				(✓)	(✓)	✓	✓
Active growth	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Emergent	✓✓ (✓)	✓✓ (✓)	✓✓ (✓)	✓✓ (✓)	✓✓ (✓)	✓	✓	✓	✓✓ (✓)	✓✓ (✓)	✓✓ (✓)	✓✓ (✓)
Rosette	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓

✓✓ more pronounced growth at this time than other times of active growth.

(x) no flowering or fruit production in north Queensland at this time of year.

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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



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

Raelene Kwong

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 hermland, rushy riverine swamp, floodplain grassy wetland, spike-sedge wetland, and floodway pond hermland/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 health 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).

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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*).

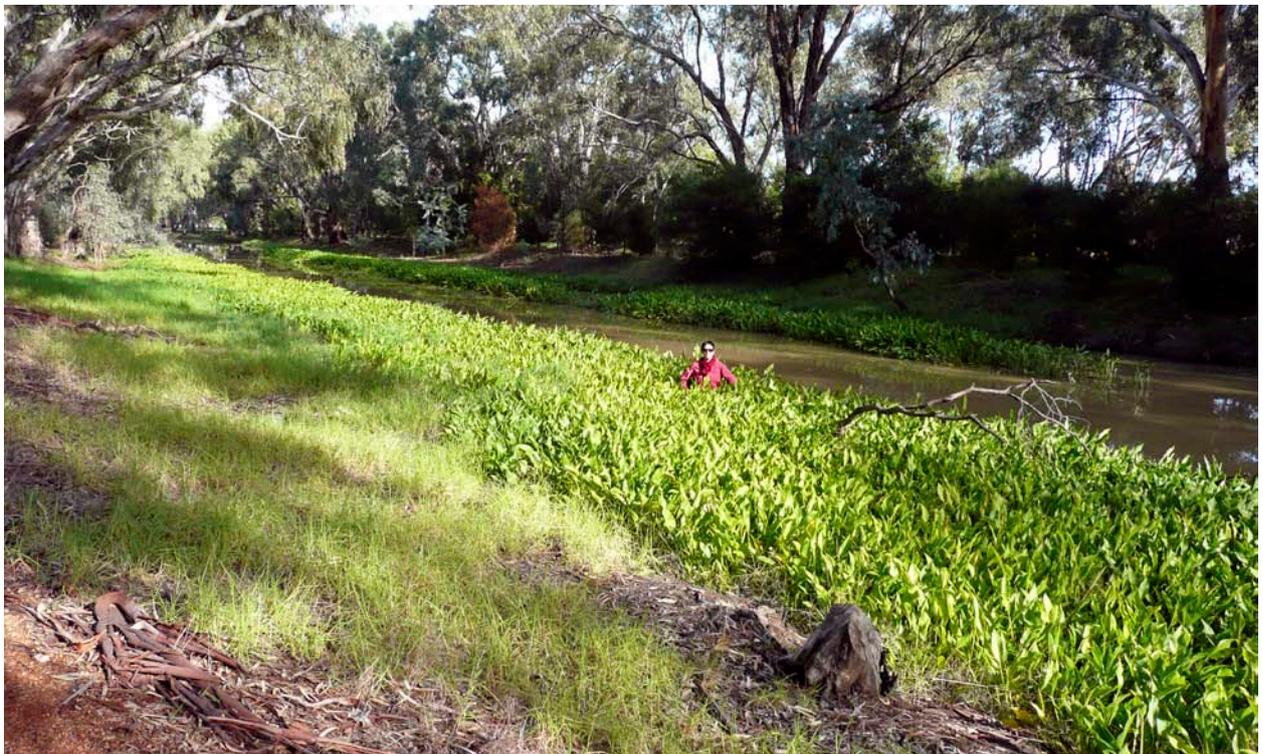
Members of the sagittaria genus are alternate hosts in North America to the aster leaf hopper, *Macrostelus fascifrons* Stål (Hemiptera: Cicadellidae), a vector of aster yellows phytoplasma, oat blue dwarf virus and clover phyllody virus. Although the leaf hopper is not present in Australia, infestations 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.



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

Raelene Kwong