2.5 Control of exotic and invasive freshwater plants and weeds

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Abstract

Weed control is possibly the most difficult type of maintenance required in urban wetlands. Assemblages of aquatic plants are highly variable and often unpredictable. Their management is further challenged due to the lack of effective control techniques (e.g. most effective herbicides are not permitted for use in the aquatic environment) and difficulties in killing or removing all parts of a weed species when inundated and/or within moist substrates.

Therefore the best strategy for weed control is prevention, which is achieved by early detection and an immediate response – and an overarching integrated approach to weed management encompassing: all weed species; a sound understanding of the mechanisms which make them successful invaders; identifying and managing their sources and spread; and continued education and learning opportunities.

This chapter highlights various weed categories in Australia and emphasises various approaches in waterweed control.

Introduction

The Australian Government estimates that weeds cost farmers around $1.5 billion a year in weed control activities and a further $2.5 billion a year in lost agricultural production (Australian Government 2013) – with the real cost of weeds to the environment difficult to calculate, but expected to be similar, if not greater than, in cost.

In Australia, weed species are classed into broad groups depending on their characteristics and impacts. Unsurprisingly, those species that impact on the economy are paid the highest priority. The most serious of weeds are categorised as Weeds of National Significance, with each state and territory managing its own categories of noxious and/or declared pest plant species.

Statutory obligations will always drive weed control prioritisation, however both environmental and pest native aquatic species have the potential to seriously degrade a wetland and/or reduce its functionality.

Weed control is possibly the most difficult type of maintenance required in urban wetlands. Engineered and other manmade wetland components typically have finite life cycles and expectations. In most cases their maintenance requirements are supported by extensive documentation such as: manufacturer's technical specifications and operational guidelines; various design calculations and predictions of catchment sediment loads and likely removal frequencies.

In contrast, assemblages of aquatic plants are highly variable and often unpredictable. This cannot be over emphasised in relation to the behaviour of invasive aquatic weed species. On a global basis, several aquatic plant species have provided spectacular examples of successful invasions. In many cases the phenomena of their population growth have been so rapid that they have been described as biological explosions (Arthington and Mitchell 1986).

Additional Information 1

While there are numerous Australian case studies on aquatic weed invasions, this is not one of them. A brief look at the career of Geoff Sainty, an Australian authority on water plants and publisher (through Sainty and Associates) of technical books is provided.

Geoff (Figure 1) and his associates have quietly beavered away at advancing our understanding of waterplants and waterweeds.

During his early career Geoff investigated how to control the invasion of waterplants (both native and introduced) within manmade irrigation channels of inland NSW.

At the time, the NSW Water Resources Commission had become increasingly perplexed over a deluge of complaints from landowners regarding impediments to the delivery of water within irrigation channels (located in the NSW Riverina region).

Geoff, with a background in horticulture, was asked to 'go find out what all the fuss was about'. He diligently met this challenge and thereafter embarked on sharing this knowledge.

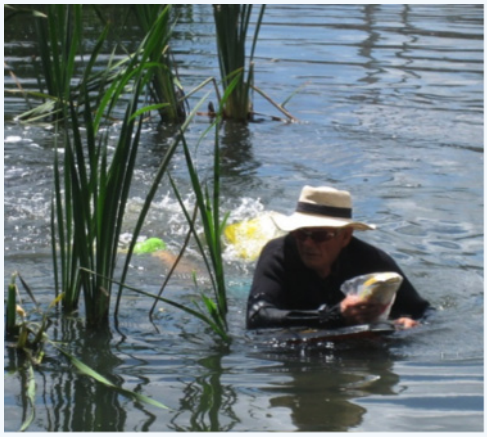


Figure 1. Geoff Sainty on a surf board with a GPS in hand, mapping macrophytes coverage in Lake Belvedere at Sydney Olympic Park.

The publication "Waterplants of NSW", co-authored by the late Surrey Jacobs (Senior Taxonomist, Royal Botanical Gardens) and funded by the Water Resources Commission, soon followed (now out of print, but if you can locate a copy, treat it like gold!).

In later years, various editions of "Waterplants of Australia: a field guide" (Sainty and Jacobs) became the bible of everyone working or interested in Australian wetlands.

We owe these two waterplant specialists and loveable larrikins, a great debt for the contributions they have made in furthering our understanding of both the value and threats that waterplants provide.

Figure 2. *Nymphaea jacobsii.*

Figure 3. The late Surrey Jacobs.

The impacts of invasive aquatic plants are many, but typically include:

- Reduced dissolved oxygen availability;
- Flow retardation;
- Degradation of habitat for native flora and fauna;
- Disruption of recreational activities and/or aesthetic amenity; and
- Negative economic, environmental and social impacts.

Weeds that have caused economic and social impacts have, unsurprisingly, attract the highest level of legislative attention; and have been the focus of most international and national scientific research.

Weed categorisation

In Australia weed species are classed into broad groups depending on their characteristics and impacts. As already inferred, the highest level of attention, and related legislation, are given to those species that have the potential to cause significant environmental, economic and social impacts.

This section describes various categories of weeds from an Australian perspective. The intent is to provide:

1. An overview of the implications of weed categories in terms of statutory obligations from both a national, state and territory perspective; and
2. An appreciation of why certain invasive aquatic weeds (which may well be a significant problem at a local or regional scale) do not qualify as significantly as one might expect.

Weeds of National Significance

Weeds of National Significance (WoNS) are nationally agreed priority plant species for control and management. These species are regarded as the worst weeds in Australia because of their invasiveness, potential for spread, and economic and environmental impacts. Seven aquatic plant species are currently listed as WoNS:

1. *Alternanthera philoxerioides* (alligator weed);
2. *Annona glabra* (pond apple);
3. *Cabomba caroliniana* (cabomba);
4. *Eichhornia crassipes* (water hyacinth);

5. *Hymenachne amplexicaulis* (Olive hymenachne);
6. *Sagittaria platyphylla* (sagittaria); and
7. *Salvinia molesta* (salvinia).

The determination of WoNS by the Australian Commonwealth government is the first attempt to prioritise weeds over a range of land uses at the national level. Despite Commonwealth intervention in weed issues, including actions to address WoNS, most weed problems are dealt primarily through state and local government initiatives and by land managers themselves (Thorp and Lynch 2000).

National Environmental Alert List Weeds

A further 28 weed species are identified as National Environmental Alert Weeds under the National Weeds Strategy. The Alert List complements the (WoNS) list and includes weeds that are in the early stages of establishment and have the potential to become a significant threat to biodiversity if they are not managed. Species were identified for the Alert List based on three criteria:

- Posing a high or serious potential threat to the environment;
- Having limited distribution within Australia at present; and
- Being amenable to successful eradication or containment programs.

Four aquatic plant species are currently identified as National Environmental Alert Weeds:

1. *Cyperus teneristolon* (cyperus);
2. *Equisetum* spp. (horsetails);
3. *Lagarosiphon major* (lagarosiphon); and
4. *Gymnocoronis spilanthoides* (Senegal tea plant).

Noxious Weeds

Noxious weeds (synonymous with 'declared' plants and pest plants in some states and territories), are those species that are controlled and/or managed under state and territory legislation. Weeds are declared noxious because their control is considered to provide a benefit to the community over and above the cost of implementing control programs.

Noxious weeds are typically, but not always, those weed species that have:

- Potential to cause harm to the community and individuals;
- Potential to spread within an area and to other areas;
- A limited distribution with the potential to become more widespread and will cause impact on agriculture, human health or the environment; and
- Can be controlled by reasonable means.

Each state and territory has prescribed a range of categories for noxious weeds, which range from the prohibition of sale and trade, through to enforced control.

WoNS and national alert species are also categorised as noxious weeds or declared plants in all states and territories in which they occur, or have the potential to occur.

Relevant legislation, weed categories and aquatic plant species for each state and territory is summarised at the end of this chapter.

Environmental Weeds

Environmental weeds are those with the capacity to reduce the diversity of native species, or potentially adversely affect the function of natural ecosystems. They do not meet the criteria for declaration as noxious, in that they are not likely to impact on human health, agriculture and cause associated economic impacts.

Most of these species were initially introduced as garden or aquarium plants, and have spread through wind, water and animal dispersal, as garden escapes or dumping of pond/aquarium materials. Some species have been inadvertently introduced through other means such as the transport and agricultural sectors.

Examples include members of the Cyperaceae family, including: *Isolepis prolifera* and *Cyperus* spp.; members of the Juncaceae family, including *Juncus articulatus*, *J.acutus* (spiny or sharp rush)[1]; *Zantedeschia aethiopica* (arum lily)[2], *Nymphaea mexicana* (Mexican waterlily) and *Hydrocotyle bonariensis* (pennywort). Pennywort, which has the capacity to encroach into areas containing native macrophytes, is shown in Figure 2.5.1.

[1] spiny rush is regionally controlled or restricted in Victoria.
[2] arum lily is a declared plant in Western Australia.

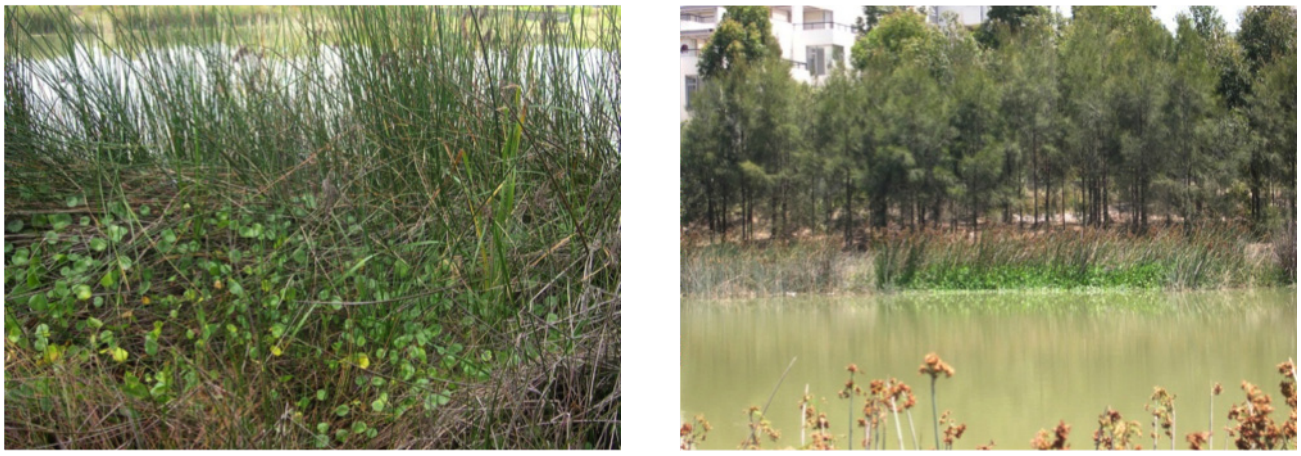


Figure 2.5.1. *Hydrocotyle bonariensis* in Narawang Wetland within Sydney Olympic Park.

Pest Native Plants

Pest native plants deserve specific attention due to their capacity to impact on many of the typical functions expected of a wetland within the urban environment, especially wetlands designed and constructed for stormwater treatment purposes.

Pest native species are most often occurring within their natural range, are capable of prolific growth and tolerant of urbanised conditions. Pest native plants can become problematic where management objectives include activities to enhance:

- Macrophyte diversity: as these species can form dense monocultures and outcompete the growth of other native species;
- Public amenity: which may provide of habitat for mosquitos, which may facilitate nuisance populations or public health concerns where mosquito species have the potential to act as a vector for disease;
- Aesthetic amenity:
  - monocultures of some native pest species become unsightly in cooler months when they senesce, or
  - where open water zones are a desired feature and dense floating or submerged growth of pest plant species detract from this visual objective;
- Stormwater quality treatment as:
  - senescence of dense stands of macrophytes can often cause large quantities of organic matter (in dead plant materials) to be cycled in the wetland,
  - impedances or blockage of flows for infrastructure; and
  - diminished water quality through reducing light levels in the water column.

Examples of emergent pest native species include:

- *Typha* spp. (cumbungi);
- *Phragmites australis* (common reed); and
- *Paspalum distichum* (water couch) see Figure 2.5.2.

Examples of free floating pest native species include:

- *Azolla* spp.;
- *A. filiculoides* and pinnata; and
- *Spirodela* and *Wolfia* spp. (duck weed).

Examples of submerged or floating attached species include:

- *Potamogeton* spp. (pond weed, Figure 2.5.2); and
- *Ludwigia peploides* (water primrose).

Control of Aquatic Weeds and Pest Plants

Prevention

Early detection and immediate management intervention is critical in controlling invasive aquatic plants by preventing them from becoming established. Targeted control of invasive species as they first emerge in a wetland will substantially decrease the effort and associated costs of managing larger infestations.

Key to the success of early detection and management intervention include:

1. Identification: correct taxonomic identification of both invasive and native species in a wetland;

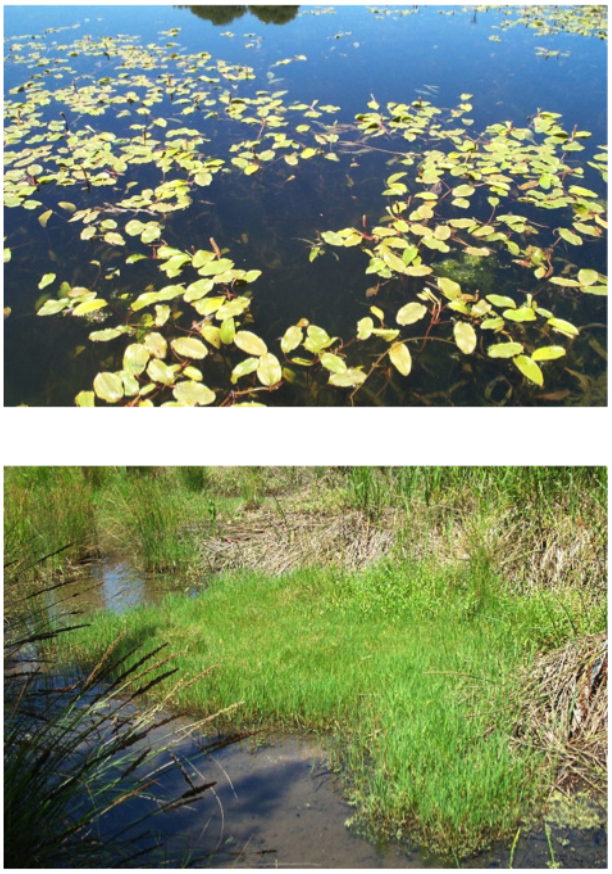


Figure 2.5.2. Top: *Potamogeton ochreatus* (floating pondweed). Bottom: *Paspalum distichum* (water couch) at Sydney Olympic Park.

2. Knowledge: of what species already occur, or have a high probability of occurring within the wetland. This includes the statutory obligations that the landowner or manager is required to be compliant with; and
3. Understanding: the various characteristics that result in the species being a successful invader.

1. Identification

Incorrect identification of aquatic plants can lead to the inadvertent eradication of similar but non-target species, the application of ineffective control strategies, and the failure to recognise newly introduced invasive species.

Not everyone charged with the responsibility of wetland management (inspections, monitoring and scheduling maintenance or other targeted management actions) will have skills in aquatic botany. However, this can be overcome through the use of aquatic plant identification guides and training. Where funding for training is not an option, an alternative is to visit sites where invasive aquatic species are known to occur, and gain a better understanding of what they look like at various stages of their life cycle, and the typical habitats in which they thrive.

A number of aquatic weeds can be mistaken for native species with similar habit and leaf arrangements – especially when they are not in flower or seeding, and cannot be identified confidently. Most waterplant and/or weed species guides will offer some key distinction between native and weed species of a similar nature.

However, even the most seasoned aquatic plant taxonomist may not be able to identify a species when they are juvenile, or lack flowers or seeds. Where there is any doubt in identifying a species found in your wetland, there are two options available:

1. Collect a specimen and seek botanical advice, or
2. Engage a specialist to visit the wetland and assess the species in situ.

The latter option should always be undertaken when the species is suspected of being a WoNS, state, regional or locally notifiable weed species. In this instance, the relevant authority should be contacted and assistance sought.

2. Knowledge

At the very least, an understanding of the following native and introduced aquatic plants should be researched and understood in order to adequately serve the inspection's purpose, and further identify when specialist assistance is required.

- Those species that already occur, or are known to have occurred in the wetland, and/or its catchment (and therefore have the potential to re-emerge or re-enter the wetland), and;
- Those species that occur outside the catchment but within the region, that have the potential to invade the wetland through wind, animal or anthropogenic dispersal.

Under most circumstances this can be achieved through undertaking a desktop review of the following:

- 'Works as Executed' documentation for construction or other rehabilitation/ modification activities previously undertaken in the wetland;
- Compliance or other monitoring activities that may have been undertaken within the area of interest (including upstream or other locations in close proximity to the wetland);

- Local or regional government listings, mapping or other vegetation surveys conducted; and
- Past ecological surveys undertaken for developments or other impact assessments where floristic survey data has been collected and reported on.

Additionally, consultation with local volunteer groups (bush regeneration and the like) operating within the catchment or adjacent catchment areas will provide both recorded and anecdotal information that should prove useful.

The above recommended sources of information may require expenditure of resources not originally planned for. However the benefit of going through this process will, in most circumstances, be paid back through enhanced information about potential problems and enable informed and timely management responses to be formulated.

3. Understanding the species

A number of common features underpin the success of invasive aquatic plant species. Table 2.5.1 provides a summary of key features that should be considered in the planning and design of weed control programs. Further discussion on integrating cultural considerations in weed control programs is provided in the following section.

Table 2.5.1. Summary of characteristics and management implications.

Characteristic	Description	Considerations for management
Vegetative reproduction	The most common, and in many cases the only method of reproduction, which includes growth from rhizomes (lateral spread) and regrowth from pieces of the plant	Disposal of plant propagules during control program to prevent further spread – and the establishment of new invasions sites
Prolific seed generation	Plants that produce large quantities of small seeds. For example some *Juncus* species are capable of producing hundreds of thousands of seeds per plant. Other plants that produce large quantities of seed include include *Cyperus*, grass and annual species	Removal of plants before seed capsules release seeds and potentially providing a continued source of re-infestation in the substrate, requiring either of both: (i) removal and replacement of substrate which contains the seed bank, or (ii) ongoing control of the species over the longer term
Rapid rates of reproduction	For example salvinia, water hyacinth, and many annuals	Reducing conditions that favour growth, in particular nutrients and early identification and removal
Small vegetative propagules	Typically small plant fragments and seeds that have multiple dispersal mechanisms (i.e. on waterfowl, wind, and water)	Examination of prevailing winds, movement of wildlife, and inflows to understand the source of propagules that cause further infestations. Develop integrated weed control strategies to minimise or prevent ongoing sources of weed infestations
Ability to be spread through human activities	Plants propagules are inadvertently introduced or spread between sites on vehicles, equipment, PPE, etc.	Hygiene protocols make use of best practice plant hygiene measures in order to minimise the potential for spread of weeds into and out of the wetland

Control Methods

Manual removal

This method is the most ideal solution in terms of minimising impacts to non-target species and general environmental impacts. Manual removal will only be feasible where:

- Early identification of aquatic weed species as they emerge; and
- The density and extent of the infestation is capable of being removed by means of physical labour and hand held tools.

When manually removing aquatic weed growth, all potential forms of propagative materials must be removed (including: rhizomes/roots, plant pieces capable of regrowth, flowers, and seed capsules). Where the weed infestation has occurred long enough for the onset of seeds, regular monitoring and hand removal of juvenile species as they emerge will be required. This may be required over several growth cycles (depending on the species and seed longevity) and why early identification and immediate control is so important.

Manual removal of weeds is typically limited to those species that occur at the wetland's verges or in shallow water zones. The capacity to control or manipulate water level in the wetland will substantially increase the range and extent of species that can be controlled manually.

Where water level control is not an option, manual chemical control can be used on sufficiently sized stems or culms of plants, which can be cut and the pith of the stem painted with an approved herbicide for use in aquatic environments (e.g. *Typha* spp. which has thick culms). However this is only likely to provide a method of suppression, as plants of this size are also likely to have a well-established network of rhizomes, parts of which may remain viable and capable of regrowth.

Mechanical removal

Mechanical methods are most commonly used to remove large quantities of aquatic weeds through harvesting of floating, floating attached and submerged species, or removal of substrate containing weed infestations. Mechanical removal involves the use of specialised cutting, collection and removal equipment, including the use of custom designed boats or other machinery.

Mechanical control can deliver instant results, but without a longer term or follow up strategy will only deliver short term results. Mechanical control is usually only a method that offers suppression of a weed infestation, not eradication, and may be required at a regular and costly frequency.

Mechanical control may however be the only feasible on-going solution to suppress growth of floating, floating attached or submerged aquatic weeds where water level control is unavailable.

Where the maintenance of open water zones is required and water level control, or other effective means of control, are limited the on-going cost of mechanical control must be allowed for within maintenance or other management funding. As such, accurate performance monitoring of mechanical control, and monitoring of weed regrowth, will be critical in determining the most effective weed control methods and frequency, and identifying any efficiencies that may result in optimal control results.

Chemical control

A key impediment to aquatic weed management is a lack of effective herbicides that are registered for use in aquatic environments within Australia. Those that are, are usually ineffective for out-right eradication of infestations and will need repeat applications.

Glyphosate based products, which are registered for use in aquatic environments, may not always be effective on the target species. For example, alligator weed will close off cellular passage from the affected plant parts to prevent access of chemicals to the rest of the plant, hence remaining viable. Further, those plant pieces that have been sacrificed are not always destroyed, and will often form a new infestation where they eventually become stranded.

The repeated introduction of herbicides into a water body is also not desirable given the environmental sensitivity of aquatic ecosystems, and the potential for effects on non-target species.

The use of chemical control should be carefully researched to ensure that the use of any herbicide is permissible within the aquatic environment, and will be effective on the target species.

Only experienced personnel or contractors with appropriate certification to use herbicides are to be engaged in chemical control of weed infestations. All use of herbicides must be undertaken strictly in accordance with the label instructions.

As already inferred, chemical control can be undertaken manually, including initially cutting/scraping and then painting/wiping of herbicide

onto the foliage. This is only feasible for smaller infestations and where access to the targeted plants is possible.

Herbicides that may be effective on target species, but are only registered for use in a terrestrial environment, may be able to be used where water level control is possible. However a permit will need to be obtained. This will require liaison with the relevant weed authority, and demonstration of the ability to hydrologically isolate the targeted weed infestation (i.e. capacity to dewater and isolate the weed infestation from downstream aquatic ecosystems).

An example includes Metsulfuron (and its proprietary derivatives) which has proved to be effective in killing alligator weed, but is only permitted for use in terrestrial environments.

Biological control

Biological control is a complex research based exercise which involves the introduction of host-specific insects found in the weed's country of origin; testing the host range under quarantine conditions; releasing and monitoring the control agent and weed populations (Schooner and Chan 2011).

Biological control is limited by way of population dynamics, in that the control agent will rise and fall in response to the amount of target species available. Hence outright eradication is not possible as when the availability of the target species decreases the control agent will generally also then decline.

Further limitations exist in the tolerance range of climatic conditions for many control agents, and seasonal reintroduction of the control agent is required where conditions are not suitable for its survival year round. For example, tropical or sub-tropical control agents used in temperate zones, where prevailing winter temperatures lie outside their tolerance range.

Hence biological control is only really practical as a form of integrated weed control management for weed infestations that occur over large areas, or a number of locations within a localised area.

An example of biological control *Cyrtobagous salviniae* (salvinia weevil) – see following.

Additional Information 2

Salvinia molesta (salvinia)

One of the most notable and widely studied aquatic species is *Salvinia molesta* (salvinia). A native of southeastern Brazil, salvinia has become a serious weed throughout Africa, India, Sri Lanka, South-East Asia, the Philippines, Papua New Guinea, New Zealand, Fiji, Hawaii and mainland United States.

Salvinia is regarded as one of the worst weeds in Australia, and accordingly is categorised as a Weed of National Significance. It was first recorded as a weed near Sydney in 1952, and a year later near Brisbane. It has since infested most coastal streams from Cairns in northern Queensland to Moruya on the south coast of New South Wales, with remote infestations affecting the Top End of the Northern Territory and regions of Western Australia (Australian Government 2013).

The scale of its economic, social and environmental impacts is perhaps best exemplified through its invasion of the Sepik River, one of the largest rivers in Papua New Guinea.

The Sepik region relies on the river for communication, transport, food and trade. In just two years (1977–1979) salvinia covered an approximate area of 80 km^2 of the backwaters of the river. The physical impact of this infestation was reflected in the slowing down to complete elimination of water transport and decline of key food and trade resources (Mitchell *et al*. 1980).

Such was the magnitude of this infestation a program of management was formulated by the United Nations, central and provincial governments, and local inhabitants. The success of this program was attributed to trials and eventual widespread introduction of the salvinia weevil (*Cyrtobagous salviniae*) and working closely with the communities of the Sepik region.

The salvinia weevil was also introduced into Australia by the CSIRO in 1980 to combat the growing threat of this species.

Figure 1. *Salvinia molesta*.

Figure 2. Boats hindered by salvinia in the backwaters of the Sepik River (Petr 2000).

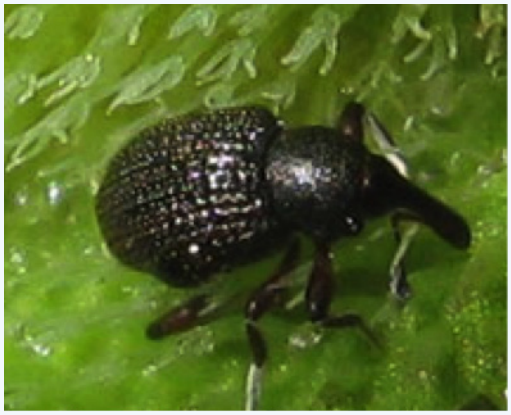


Figure 3. Salvinia weevil (*Cyrtobagous salviniae*).

Cultural control

In addition to the above outlined control methods, 'cultural control' should be integrated into all weed control programs. Examples of cultural controls include:

- Reducing nutrient inputs (or catchment controls);
- Preventing spread of weeds through weed control programs in the catchment; and
- Educational programs, including the nursery and aquarium trade, and within the community where garden escapes, dumping of garden/pond/aquarium refuse, or inadvertent cultivation of weed species is problematic (e.g. alligator weed).

Catchment controls

Aquatic plant species become more abundant in response to specific environmental factors, including high light intensity, warm water temperatures, and high levels of dissolved nutrients, especially phosphorus and nitrogen. If management plans include modification or removal of factors that favour invasions, long-term control becomes more efficient and effective (Quinn *et al*. 2009).

Integration of weed control

Aquatic weed management is challenged by the continued influx of new propagules from catchment inflows. However, all methods of dispersal should be considered, particularly when re-infestations require ongoing resources and funding. Dispersal mechanisms and management considerations include:

- Water dispersal: assessment of weed sources in all inflows to the wetland;
- Wind dispersal: assessment of weed sources which may be blown in from land that does not necessarily contain inflows to the wetland;
- Wildlife: seeds and plant species can either be ingested (and thereafter excreted) by fauna, or attached to water bird plumage and other wildlife. Assessment of wildlife habitat areas that may introduce propagules, including but not limited to both:
    - Local or resident birds that use other wetlands or watercourses. Noting that migratory species may extend the area of study considerably and should only

be considered where more obviously regional and local sources have not been identified, and

- Wildlife corridors, which may provide a preferential route for birds, arborial or land dwelling fauna (and which are not necessarily connected by prevailing winds or watercourses); and

- Humans: seeds and plant species can be inadvertently introduced into the wetland by a wide range of anthropogenic dispersal which should be considered, including:
  - Vehicle and other machinery tyres or undercarriages, and
  - More directly on humans, through the treads of footwear, on clothing or PPE, with the smallest of seeds able to be transported in ones hair.

The above list exemplifies why any weed control program should not just look at the conspicuous sources of infestations. Integrated approaches to weed management can be very basic or complex, and will depend on the severity of the infestation.

For example: the source of the weed species may be readily identifiable, and only require a modest level of coordinating control programs in the wetland and one or two other catchment sources.

Where the weed species is widespread and problematic (i.e. known from numerous sources, and likely to be dispersed through a number of mechanisms) the approach will require a greater level of effort in: facilitating control programs, consultation with landholders and educational programs; and securing adequate funding to enable such.

Regardless of the situation, an integrated approach to controlling or minimising ongoing sources of weed infestations will outweigh the economics on ongoing weed control in isolation.

Aquarium and Nursery Trade

The aquarium and nursery trade has been implicated in introductions of aquatic weeds in wetlands and waterways. Many potential and existing weed species have and continue to be sold in the aquarium trade. Based on the author's experience, the more recent popularity in aquatic landscaping has also provided a new avenue of potentially environmental weed species from the nursery trade.

The Australian National Aquatic Weeds Coordinator works with nurseries to voluntarily curb the trade of particularly invasive aquatic species (NGIA 2007). However, this is a large portfolio to cover, and local, state and territory authority's resources are typically stretched and unable to assist in monitoring the aquarium and nursery trade at a local or regional level.

Anyone involved in managing or maintaining a wetland has a vested interest in ensuring locally aquarium and nursery traders are not distributing aquatic weed species. A day spent undertaking reconnaissance of nursery and aquarium traders in your local area is recommended. Where found, issues should be directed in the first instance to either the Australian National Aquatic Weeds Coordinator, or relevant state or local authority.

A secondary contact for assistance is the Nursery and Garden Industry Australia (NGIA), which joined the National Aquatic Weeds Management Group (NAWMG) to help implement a range of initiatives designed to tackle the issue of aquatic weeds. One such project is a weed risk assessment of water plants sold in aquariums and nurseries. This project aims to identify future water weed threats and remove such plants from sale (NGIA 2007).

Case Study: Narawang Wetland—Vegetation Management Plan 2011

Andrew Jack, Sydney Olympic Park Authority

Overview

Narawang Wetland within Sydney Olympic Park extends along the western edge of Hill Rd and forms a 1.6km corridor mosaic of 26 freshwater constructed ponds and native plantings. The wetland was developed following remediation and construction works between 1997 and 1999. Paths and boardwalks give access through the 20-hectare wetland and link the Parkland with regional pedestrian/cycle access routes.

Ponds comprise 22 habitat ponds, 3 irrigation storages and an ornamental lake. The wetland provides primary habitat for the endangered Green and Golden Bell Frog. The pest fish *Gambusia holbrooki* is present throughout the wetland; a cyclic drainage program is implemented annually whereby a number of the habitat ponds are drained, dried and refilled each spring to reduce Gambusia numbers. This program also provides a window when intensive vegetation management works can be undertaken within and around habitat ponds.

Work Program

Narawang Wetland – all areas

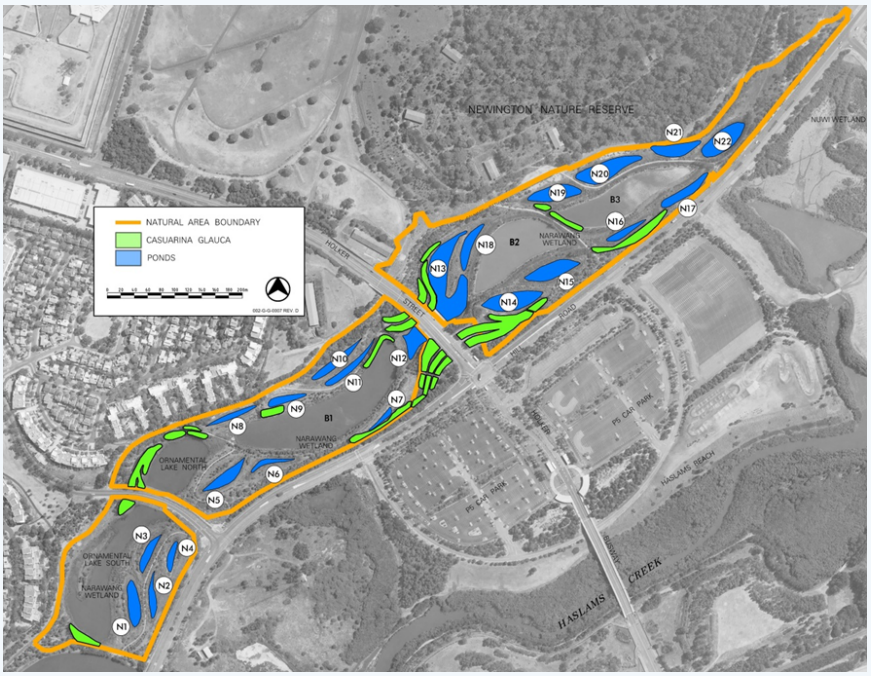
Use of brush-cutters or spray application of herbicide is not permitted without specific approval from the Authority, and in accordance with approval conditions.

Outcomes sought: A series of ponds connected by dense tall grasses/sedges providing optimum habitat for wetland fauna species, meeting landscape presentation standards, free of noxious and invasive weeds and requiring low-level ongoing weed management

Actions

1. Conduct periodic sweeps of the contract area for noxious, invasive and unsightly weeds including but not limited to those listed in SOPA Declared Invasive Environmental Weed March 2011 table (see overleaf). A minimum of one sweep per quarter is required; some areas will require additional management to control persistent species, to protect and encourage the establishment and spread of replacement plantings, or to maintain high presentation standards close to high use and/or highly visible public areas.
2. Manage areas mapped as pathways (see Maps 1A, 1B & 1C) to high presentation standards.
3. Fully and continually suppress Alligator Weed (see Maps 1D & 1E for known locations) as directed by SOPA. Flag any unmapped locations and immediately notify SOPA.
4. Prevent establishment of exotic grasses including kikuyu where they are not already established. Treat patches of kikuyu before they exceed 1 metre square, by hand-weeding. Contain spread of existing large infestations of exotic grasses.
5. Control casuarina spread. Periodically remove casuarina seedlings and suckers outside of mature clumps before they reach 1.5m high (and up to 5m high in initial sweep). This includes removal of suckers to address 'clump creep'. Cut saplings close to ground level. Cut stumps are not to exceed 5cm height. Paint freshly-cut stumps which are away from mature clumps, with glyphosate herbicide. Suckers adjacent to mature plants are not to have herbicide treatment – hand pull or cut at ground level.
6. Maintain planted shrubs, grasses/groundcovers and sedges to allow establishment. Periodically remove threats including invasive grasses and weeds. Remove guards and stakes from established or dead plants.
7. Identify and report weed species presenting new threats.
8. For all areas, advise SOPA immediately if any of the following weeds are detected: Alligator Weed (other than mapped locations); Ludwigia; Salvinia; Water Hyacinth; Coolatai Grass; Chilean Needle Grass; Serrated Tussock; Tussock Paspalum.

9. Vegetation within 1m of frog fence maintained below 100mm in height; prune branches close to fence to prevent tearing of fence fabric.
10. Infill planting in bare areas to enhance connectivity and screening as directed by SOPA.
11. Prune vegetation affecting paths, line of sight, signs and other infrastructure.
12. Manage woody vegetation along rail tracks to maintain no less than 1m clearance from either side of the track and no less than 2.1m clearance above the rail.



Ponds and Wetlands

Outcomes sought: Ponds and fringing vegetation unshaded, where possible by maturing trees, screened from adjacent paths and roads, supporting a range of dense vegetation and open water, to maximise habitat value for frogs, birds and other animals.

Actions

1. Maintain all ponds and wetlands as Juncus acutus free. Target while small and easily crowned out. Do not allow establishment or seed development.
2. Prevent establishment of typha, phragmites and *Isolepis prolifera* in ponds and wetlands where these are not already widely established. Confirm tadpole status of pond prior to entering pond. Cut Typha and Phragmites below water level, pile cut vegetation on bare / sparsely vegetated ground close to the pond.
3. In ponds N20 & N21 – periodically remove macrophytes along the pond-edge of the platforms to maintain accessibility for school dipnetting programs.
4. Contain further spread of Kurnell Curse around Ornamental Lakes. Prevent establishment in new areas.
5. Undertake intensive vegetation management in and around ponds which are scheduled for draining, while they are drained, as advised by SOPA.

Environmental Protection

1. All team members must complete an **Ecology Induction** and implement best practices .
2. Comply with strict hygiene procedures in undertaking works. Before entering and leaving the worksite, ensure boots, tools, bags, bins, clothing, etc, are free of mud and seed, and disinfected (bleach solution), to minimise the risk of introducing exotic plant species, fungus (including chytrid fungus), diseases, etc, into the worksite or to other areas.
3. Be alert for **Green and Golden Bell Frog**:
   - Do not enter ponds unless authorised by SOPA.
   - Treat weeds while they are small – before they become habitat, and to minimise the habitat disturbance caused in treating or removing large stands.

- Seek SOPA approval before: **major macrophyte thinning; aquatic weed removal** other than isolated plants or small clumps; removal of vegetation >1x1m **within 5m of a pond**.
- Seek SOPA approval before: removing **herbaceous terrestrial weeds** >2x2m – generally not approved between May and August.
- Do not use brushcutters/whipper snippers in Narawang without SOPA approval. Remove tuft grasses by chipping out or crowning.
- Leave large *Juncus acutus* crowns and Typha in piles on site to decompose (after deseeding, if necessary). Pile where they are unobtrusive, and won't fall or blow into waterbodies. Remove all other green waste from site daily; check for frogs before removal, do not pile overnight.

1. Prevent transfer of **gambusia** (particularly into the Brickpit and NWF) & azolla between ponds, (risks are: transplanted macrophytes, muddy boots, tools, etc). On any one day, access ponds in the following order:
   - Gambusia-free: Brickpit; NWF; habitat ponds on Kronos and Little Kronos Hills; habitat ponds at Wentworth Common; habitat ponds at Blaxland Riverside Park, SWQCP, Haslams Reach leachate Ponds.

     NB: Ponds A1, A5- Wentworth Common; BN2, NW2, Z1 & W3 – Brickpit; GC7, GW3 – Kronos; SWQCP (contains azolla but not gambusia).
   - Gambusia infested: all other ponds, Triangle Pond, Teal Pond, Narawang Wetland Lakes, Narawang Wetland habitat ponds, Haslams Creek, Powells Creek, Underpasses connected to Triangle Pond, Wharf Pond.
   - Gambusia and azolla infested: Boundary Creek, EWQCP and Lake Belvedere.
2. **Do not use spray application of herbicide in primary frog habitat areas without SOPA approval**. If approval given, apply **herbicide** in accordance with chemical best practices, Pesticides Act and SOPA Pesticide Use Notification Plan. Do not use spray application on weeds taller than 50mm other than isolated weeds in mulch or paths.
3. Do not remove dead or live **trees over 5 metres tall**, or **mangroves over 1.5 metres tall**, or **undercut shrubs** without SOPA approval.

Conclusion

The best strategy for weed control is prevention, which is achieved by early detection and an immediate response. In order for early detection to be effective, those responsible for managing the wetland must inspect the wetland regularly and be able to:

- Identify all macrophytes planted or growing in the wetland;
- Identify other common native species occurring in the local area; and
- Identify all aquatic weed species known to occur within the wetland and its tributaries and catchment, and in the in the local area.

Understanding the weed or pest plant species, why it is successful and how it may be feasibly controlled, is a key component of ensuring the most appropriate form of control is implemented.

There is rarely one solution in isolation that will provide a sustainable form of weed management. An integrated approach will substantially decrease the longer term efforts and funds required to both:

- Maintain the wetland's objectives; and
- Fulfil statutory obligations that may be required.

There is a wealth of publicly available information both nationally, and state or territory specific, which should be actively searched for and reviewed. This information includes:

- Government databases relating to the legislative status and statutory obligations of landowners and managers of land on which WoNS, alert weeds, noxious weeds and declared pest plants are found;
- Management strategies and specific weed control management plans; and
- Research initiatives, including but not limited to those being undertaken by: the Australian Cooperative Research Centre for Biosecurity (www.crc.gov.au); CSIRO (www.csiro.au); and Rural Industries Research & Development Corporation (www.rirdc.gov.au).

Further references, such as those that provide information about specific control measures and their success would be useful, or specific weed species.

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Appendix: Relevant Legislation and Weed Categories

Australian Capital Territory

Relevant legislation: *Pest Plants and Animals Act* 2005 (PPAA Act).

There are four different categories of pest plants in the ACT scheduled under the PPAA Act:

Category 1 **(C1)**: A pest plant whose presence must be notified to the Chief Executive.

Category 2 **(C2)**: A pest plant that must be suppressed.

Category 3 **(C3)**: A pest plant that must be contained.

Category 4 **(C4)**: Prohibited pest plant: A pest plant whose propagation and supply is prohibited.

The following aquatic noxious weeds are currently scheduled under the PPAA Act:

Alternanthera philoxeroides, alligator weed	C1	C4
Annona glabra, pond apple		C4
Cabomba caroliniana, cabomba, fanwort	C1	C4
Egeria densa, leafy elodea		C4
Eichhornia crassipes, water hyacinth		C4
Equisetum spp., horsetails	C1	C4
Gymnocoronis spilanthoides, Senegal tea	C1	C4
Hymenachne amplexicaulis, hymenachne		C4
Lagarosiphon major, lagaroshiphon	C1	C4
Myriophyllum aquaticum, parrots feather	C1	C4
Salvinia molesta, salvinia	C1	C4
Pistia stratiotes, water lettuce	C1	C4

SOURCE: www.act.gov.au/browse/topics/environment/weeds-and-pests

New South Wales

Relevant legislation: *Noxious Weeds Act* 1993 (NW Act). There are five different categories of noxious weeds in NSW:

State Prohibited **(C1)**: weeds that pose a potentially serious threat to primary production or the environment and are not present in the State or are present only to a limited extent. C1 weeds are also notifiable.

Regionally Prohibited **(C2)**: weeds that pose a potentially serious threat to primary production or the environment of a region and are not present in the region or are present only to a limited extent. C2 weeds are also notifiable.

Regionally Controlled **(C3)**: weeds that pose a serious threat to primary production or the environment, are not widely distributed in the area and are likely to spread in the area or to another area.

Locally Controlled **(C4)**: weeds that pose a threat to primary production or the environment or human health, are widely distributed in an area and are likely to spread in the area or to another area.

Restricted **(C5)**: weeds that are likely by their sale (or sale of their seeds) or movement within the State, or an area of the State, to spread in the State or outside the State. C5 weeds are also notifiable.

Noxious weeds are declared on either a Local Control Authority (LCA) basis or for the whole of the State. The following aquatic noxious weeds are currently listed under NWA Act. Weeds declared on a State wide basis are denoted by an **(S)**:

Alternanthera philoxeroides, alligator weed	C2	C3	
Annona glabra, pond apple	C1(S)		
Cabomba caroliniana, cabomba			C5(S)
Egeria densa, leafy elodea			C5(S)
Eichhornia azurea, anchored water hyacinth	C1(S)		
Eichhornia crassipes, water hyacinth	C2	C3	C4
Equisetum spp., horsetails	C1(S)		
Gymnocoronis spilanthoides, Senegal tea	C1(S)		
Heteronanthera spp.	C1(S)		
Hygrophila costata, hygrophila	C2		
Hygrophila polysperma, hygrophila	C1(S)		
Hymenachne amplexicaulis, hymenachne	C1(S)		
Lagarosiphon major, lagaroshiphon	C1(S)		
Limnocharis flava, yellow burrhead	C1(S)		
Ludwigia longifolia, longleaf willow primrose			C4
Ludwigia peruviana, Peruvian primrose		C3	C5
Myriophyllum spicatum, Eurasian milfoil	C1(S)		
Pistia stratiotes, water lettuce	C1(S)		
Sagittaria montevidensis, arrowhead			C5
Sagittaria platyphylla, sagittaria			C4
Salvinia molesta, salvinia	C2		C5
Stratioties aloides, water soldier	C1(S)	C3	
Trapa spp., water caltrop	C1(S)		

SOURCE: www.dpi.nsw.gov.au/aboutus/about/legislation-acts/noxious-weeds

Northern Territory

Relevant legislation: *Weeds Management Act* 2001 (WMA Act).

There are three classes of weeds scheduled under the WMA Act, as follows:

Class **A**: to be eradicated.

Class **B**: growth and spread to be controlled.

Class **C**: not to be introduced to the Territory, includes all Class A and B weeds.

Aquatic weeds currently legislated under the WMA Act include those listed below:

Alternanthera philoxeroides, alligator weed	A		C
Annona glabra, pond apple	A		C
Cabomba caroliniana, cabomba	A		C
Cabomba spp. other than C. caroliniana	A		C
Egeria densa, leafy elodea	A		C
Eichhornia crassipes, water hyacinth	A		C
Elodea canadensis, Canadian pond weed			C
Equisetum arvense, horsetail			C
Hymenachne amplexicaulis, hymenachne		B	C
Lagarosiphon major, lagarosiphon			C
Limnocharis flava, yellow burrhead			C
Myriophyllum spicatum, Eurasian milfoil			C
Neptunia oleracea, *N.plena*, water mimosa	A		C
Pistia stratiotes, Water lettuce		B	C
Salvinia molesta, salvinia		B	C
Salvinia spp. other than S. molesta			C
Trapa spp., water caltrop			C

SOURCE: www.nt.gov.au/weeds

Queensland

Relevant legislation: *Land Protection (Pest and Stock Route Management) Act* 2002 (LPA Act). There are three classes of plants declared under the LPA Act, as follows:

Class 1 **(C1)**: Plants that can cause adverse economic, environmental and social impacts. Once established in Queensland, plants are subject to eradication from the state. Landowners must take reasonable steps to keep land free of Class 1 pests.

Class 2 **(C2)**: Plants established in Queensland that can have adverse economic, environmental or social impacts. The management of these plants requires coordination and they are subject to programs led by local government, community or landowners. Landowners must take reasonable steps to keep land free of plants.

Class 3 **(C3)**: Plants established in Queensland that have, or could have, an adverse economic, environmental or social impact. The primary objective of this class is to prevent sale, therefore preventing the spread of these species into new areas. Landholders are not required to control plants unless their land is adjacent to an environmentally significant area and they are issued with a pest control notice.

Noxious aquatic weeds currently declared under the LPA Act include the following:

Alternanthera philoxeroides, alligator weed	C1	
Annona glabra, pond apple		C2
Cabomba caroliniana, cabomba, fanwort		C2
Cabomba spp. other than *C. caroliniana* (fanwort)	C1	
Egeria densa, leafy elodea		C2
Eichhornia azurea, anchored water hyacinth	C1	
Eichhornia crassipes, water hyacinth		C2
Equisetum arvense, horsetails	C1	
Gymnocoronis spilanthoides, Senegal tea	C1	
Hygrophila costata, hygrophila	C1	
Hymenachne amplexicaulis, hymenachne		C2
Lagarosiphon major, lagaroshiphon	C1	
Limnocharis flava, yellow burrhead	C1	
Ludwigia peruviana, Peruvian primrose	C1	
Myriophyllum spicatum, Eurasian water milfoil	C1	
Neptunia oleracea, *N. plena*, water mimosa	C1	
Pistia stratiotes, water lettuce		C2
Salvinia molesta, salvinia		C2
Salvinia spp. other than *S. molesta*	C1	
Stratiotes aloides, water solider	C1	
Trapa spp., water caltrop	C1	

SOURCE: www.daff.qld.gov.au/plants/weeds-pest-animals-ants/weeds/declared-plants

South Australia

Relevant legislation: *Natural Resources Management Act* 2004 (NRM Act).

Declared plants are grouped into 11 classes, although several different provisions of the NRM Act can apply to more than one class, as follows:

C1: Generally requiring notification and destruction of the plant throughout the whole State (sometimes only in part of the State).

C2, C4: Generally requiring notification in at least part of the State and control of the plant throughout the whole State.

C3, C5, C7: Generally requiring control of the plant in part of the State.

C6, C8-9: Special provisions apply.

C10-11: Restricted sale only.

Aquatic weeds declared under the NRM Act, include:

Alternanthera philoxeroides, alligator weed	C1@
Annona glabra, pond apple	C11+
Cabomba caroliniana, cabomba	C11+
Egeria densa, leafy elodea	C1@
Eichhornia crassipes, water hyacinth	C1@
Elodea canadensis, Canadian pond weed	C1@
Equisetum arvense, horsetail	C1@
Gymnocoronis spilanthoides, Senegal tea	C1@
Hydrocotyle ranunculoides, hydrocotyle	C1@
Hymenachne amplexicaulis, hymenachne	C11+
Lagarosiphon major, lagarosiphon	C1@
Ludwigia peruviana, Peruvian primrose	C1@
Myriophyllum spicatum, Eurasian milfoil	C1@
Ranunculus sceleratus, poison buttercup	C1@
Sagittaria platyphylla, sagittaria	C1@
Sagittaria montevidensis, arrowhead	C1@
Salvinia molesta, salvinia	C1@
Stratiotes aloides, water soldier	C1@
Trapa natans, water caltrop	C1@
@ Control required throughout the State (trade & movement usually restricted) *+ Control not required (usually restricting trade and/or movement only)*	

SOURCE: www.pir.sa.gov.au/biosecuritysa/nrm_biosecurity

Tasmania

Relevant legislation: *Weed Management Act* 1999 (WMA). Weeds are declared under the one category known as "declared plants" for Tasmania.

Declared plants **(D)**: details on actual restrictions or measures for each declared weed is contained in the weed management plan for that weed.

Current declared aquatic weeds include those listed below.

Alternanthera philoxeroides, alligator weed	D
Annona glabra, pond apple	D
Cabomba caroliniana, cabomba	D
Ceratophyllum demersum, hornwort	D
Egeria densa, leafy elodea	D
Eichhornia crassipes, water hyacinth	D
Elodea canadensis, Canadian pond weed	D
Equisetum arvense, horsetail	D
Gymnocoronis spilanthoides, Senegal tea	D
Hydrilla verticillata, hydrilla	D
Hymenachne amplexicaulis, hymenachne	D
Lagarosiphon major, lagarosiphon	D
Myriophyllum aquaticum, parrots feather	D
Rorippa sylvestris, creeping yellowcress	D
Sagittaria montevidensis, arrowhead	D
Sagittaria platyphylla, sagittaria	D
Salvinia molesta, salvinia	D
Trapa spp., water caltrop	D

SOURCE: Dept. Primary Industries, Water & Environment (www.dpipwe.tas.gov.au) under Invasive Species, Weeds.

Victoria

Relevant legislation: *Catchment and Land Protection Act* 1994 (CaLP Act). There are four categories of weeds under the CaLP Act:

State Prohibited Weeds **(S)**: do not occur in Victoria but pose a significant threat if they invade, or are present, pose a serious threat and can reasonably be expected to be eradicated. If present, infestations of a State Prohibited Weed are relatively small. They are to be eradicated if possible from Victoria or excluded from the State. The Victorian Government is responsible for their eradication, but under Section 70(1) of the CaLP Act it may direct land owners to prevent their growth and spread.

Regionally Prohibited Weeds **(P)**: are not widely distributed in a Region but are capable of spreading further. It is reasonable to expect that they can be eradicated from a Region and they must be managed with that goal. Land owners, including public authorities responsible for Crown land management, must take all reasonable steps to eradicate Regionally Prohibited weeds on their land.

Regionally Controlled Weeds **(C)**: are usually widespread and are considered important in a particular Region. To prevent their spread, continuing control measures are required. Land owners have the responsibility to take all reasonable steps to prevent the growth and spread of Regionally Controlled weeds.

Restricted Weeds **(R)**: Includes plants that pose an unacceptable risk of spreading in Victoria or to other parts of Australia if they were to be sold or traded in Victoria, and are a serious threat to another State or Territory of Australia. Trade in these weeds, and their propagules, is prohibited.

Aquatic weeds currently legislated under the CaLP Act include the following:

Species, Common Name	Mallee	Wimmera	Glenelg-Hopkins	North Central	Corang-amite
Alternanthera philoxeroides, alligator weed	S	S	S	S	S
Annona glabra, pond apple	R	R	R	R	R
Cabomba caroliniana, cabomba	R	R	R	R	R
Eichhornia crassipes, water hyacinth	S	S	S	S	S
Equisetum spp., horsetail	S	S	S	S	S
Hymenachne amplexicaulis, hymenachne	R	R	R	R	R
Juncus acutus, spiny rush	R	C	C	C	R
Lagarosiphon major, lagarosiphon	S	S	S	S	S
Salvinia molesta, salvinia	S	S	S	S	S

(Table continued on the next page)

Species, Common Name	Port Phillip Westernport	Goulburn Broken	North East	West Gippsland	East Gippsland
Alternanthera philoxeroides, alligator weed	S	S	S	S	S
Annona glabra, pond apple	R	R	R	R	R
Cabomba caroliniana, cabomba	R	R	R	R	R
Eichhornia crassipes, water hyacinth	S	S	S	S	S
Equisetum spp., horsetail	S	S	S	S	S
Hymenachne amplexicaulis, hymenachne	R	R	R	R	R
Juncus acutus, spiny rush	C	C	C	C	C
Lagarosiphon major, lagarosiphon	S	S	S	S	S
Salvinia molesta, salvinia	S	S	S	S	S

SOURCE: www.dpi.vic.gov.au/agriculture/pests-diseases-and-weeds/weeds/invasive-plants/weed-classification-victoria

Western Australia

Relevant legislation: *Biosecurity and Agriculture Management Act* 2007 (BAM Act). The BAM Act integrates previous Acts into one cohesive set of legislation. Under the BAM Act all declared pests are placed into one of three categories as follows:

Exclusion **(C1)**: Pests that are not established in Western Australia and control measures are to be taken, including border checks, in order to prevent them entering and establishing in the State.

Eradication **(C2)**: Pests that are present in Western Australia in low enough numbers or in sufficiently limited areas that their eradication is still a possibility.

Management **(C3)**: Pests that are established in Western Australia but it is feasible, or desirable, to manage them in order to limit their damage. Control measures can prevent a C3 pest from increasing in population size or density or moving from an area in which it is established into an area which currently is free of that pest.

Aquatic weeds declared under the BAM Act, include:

Alternanthera philoxeroides, alligator weed		C2	
Annona glabra, pond apple	C1		
Cabomba caroliniana, cabomba		C2	
Egeria densa, leafy elodea		C2	
Eichhornia azurea, anchored water hyacinth	C1		
Eichhornia crassipes, water hyacinth		C2	
Elodea canadensis, Canadian pond weed	C1		
Equisetum spp., horsetail	C1		
Gymnocoronis spilanthoides, Senegal tea	C1		
Hydrocotyle ranunculoides, Hydrocotyle			C3
Hydrocotyle verticillata, Hydrocotyle	C1		
Hymenachne amplexicaulis, hymenachne	C1		
Lagarosiphon spp., lagarosiphon	C1		
Limnocharis flava, yellow burrhead	C1		
Ludwigia peruviana, Peruvian primrose	C1		
Myriophyllum aquaticum, parrots feather		C2	
Myriophyllum spicatum, Eurasian milfoil	C1		
Pistia stratiotes, Water lettuce		C2	
Ranunculus repens, creeping buttercup	C1		
Ranunculus sceleratus, poison buttercup	C1		
Sagittaria montevidensis, arrowhead	C1		
Sagittaria platyphylla, sagittaria		C2	
Salvinia molesta, salvinia		C2	
Salvinia spp. other than *S. molesta*	C1		
Trapa spp., water caltrop	C1		
Zantedeschia aethiopica, arum lily			C3

SOURCE: www.biosecurity.wa.gov.au