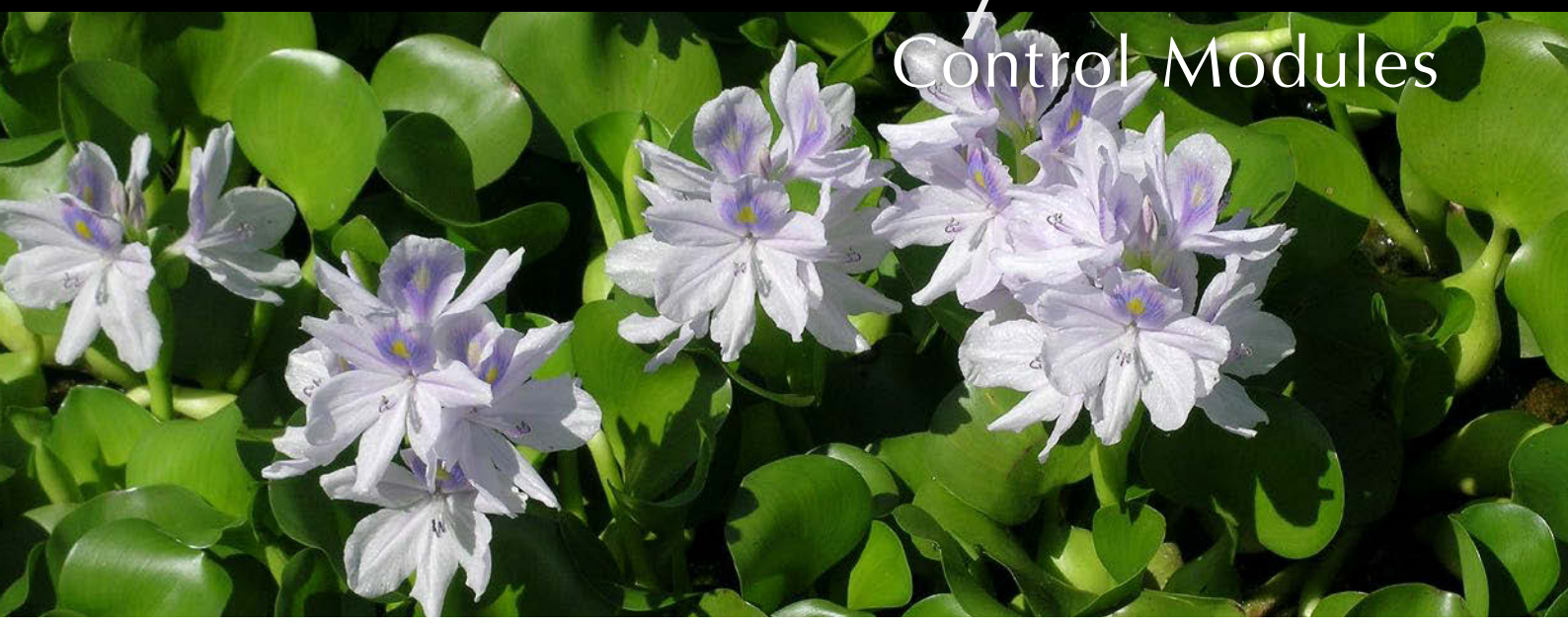
Weeds of National Significance

Water hyacinth

Control Modules



Control options for water hyacinth (*Eichhornia crassipes*) in Australia

CARING FOR OUR COUNTRY

NSW GOVERNMENT Department of Primary Industries

Water hyacinth

Control Modules

Control options for water hyacinth (*Eichhornia crassipes*) in Australia

Weeds of National Significance
2013

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Written and compiled by Rachele Osmond and Andrew Petroeschevsky

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Cover image courtesy Rob Richardson

Contents

Literature review

Kerinne Harvey

The following people contributed information and/or reviewed earlier drafts

Tobias Bickel, Qld Department of Agriculture, Fisheries and Forestry

Matt Buckman, Hinchinbrook Shire Council

Rod Ensbey, NSW Department of Primary Industries

Mic Julien

Reece Luxton, Clarence Valley Council

Phil Moran, Noosa District Landcare

Gary Owers, Richmond Valley County Council

Ian Schwartz, Moree Plains Council

Neil Smith, Department of Environment and Primary Industries – Victoria

Joe Vitelli, Qld Department of Agriculture, Fisheries and Forestry

Andrew Wills, Brisbane City Council

Michael Wood, Richmond River County Council

Introduction

Water hyacinth is a free floating aquatic plant that grows in still or slow moving fresh water bodies. Native to tropical and sub tropical South America, it has been introduced to all other continents except Antarctica. It has since become one of the world's worst aquatic weeds due to its ability to rapidly form dense floating mats on the waters surface. These mats have significant impacts to rivers, wetlands, lakes, dams and irrigation systems.

A Weed of National Significance

In 2012 water hyacinth was named as one of the additional twelve Weeds of National Significance due to its invasiveness, potential for spread and severe impacts. In response to this listing the national water hyacinth strategic plan was released in 2013. This plan provides a framework for the coordinated management of water hyacinth across Australia.

About these modules

These modules present best practice advice for the control of water hyacinth in Australia. This advice is based on a review of over 100 papers on water hyacinth management and ecology from Australia and overseas. The modules in this series have been designed to be used together, or individually as required and provide a basis for the development of site specific management strategies in Australia. The information contained in these modules provides identification, potential for spread, management, control and planning advice for a range of conditions and climates where water hyacinth is likely to occur in Australia.

Weed control contacts

State / Territory	Department	Phone	Email	Website
ACT	Dept of the Environment, Climate Change, Energy and Water	132281	environment@act.gov.au	www.environment.act.gov.au/environment
New South Wales	Dept of Primary Industries	1800 680 244	weeds@dpi.nsw.gov.au	www.dpi.nsw.gov.au/agriculture/pests-weeds/weeds
Northern Territory	Dept of Natural Resources, Environment, The Arts and Sport	08 8999 4567	weedinfo@nt.gov.au	www.nt.gov.au/weeds
Queensland	Biosecurity Queensland, Dept of Agriculture, Fisheries and Forestry	132523	callweb@daff.qld.gov.au	www.biosecurity.qld.gov.au
South Australia	Biosecurity SA, Dept of Primary Industries and Regions SA	08 8303 9620	nrmbiosecurity@sa.gov.au	www.pir.sa.gov.au/biosecuritysa/nrm_biosecurity/weeds
Tasmania	Dept of Primary Industries, Parks, Water and Environment	1300 368 550	www.dpipwe.tas.gov.au/weeds Scroll to the bottom of the page and click on 'weeds enquiries'	www.dpipwe.tas.gov.au/weeds
Victoria	Dept of Primary Industries	1800 084 881	customer.service@dpi.vic.gov.au	www.dpi.vic.gov.au/agriculture/pests-diseases-and-weeds
Western Australia	Dept of Agriculture and Food	08 9368 3333	enquiries@agric.wa.gov.au	www.agric.wa.gov.au
Australia wide	Australian Pesticides and Veterinary Medicines Authority	02 62104701	contact@apvma.gov.au	www.apvma.gov.au

Quarantine and legislation

Water hyacinth is a declared weed in all states and territories in Australia. It is illegal to sell, distribute and possess water hyacinth and in most cases landholders are required by law to control it when it occurs on their property. Its legal status is summarised in the following table.

State / Territory	Declaration status of water hyacinth (*Eichhornia crassipes*)
ACT	C4. Prohibited pest plant: A pest plant whose propagation and supply is prohibited.
New South Wales	Class 2,3,4 weed. C2 – regionally prohibited and notifiable weed. C3 – regionally controlled weed. C4 – locally controlled weed.
Northern Territory	Class A,C declared weed. Class A – To be eradicated. Class C – Not to be introduced to the Northern Territory.
Queensland	Class 2 plant – plants are established in the State and have, or could have, an adverse economic, environmental or social impact. Landowners must take reasonable steps to keep land free of Class 2 plants. It is an offence to keep or sell Class 2 plants without a permit.
South Australia	Under the Natural Resources Management Act 2004, destruction is mandatory throughout SA; sale, entry to the State and movement on public roads is prohibited; and landowners are required to report any infestation on their land.
Tasmania	Declared plants. Details on actual restrictions or measures for each declared weed is contained in the weed management plan for that weed.
Victoria	State prohibited weed (Do not occur in Victoria, or it is reasonable to expect that they can be eradicated from the state).
Western Australia	P1 P3. P1 – PREVENTION of trade, sale or movement. P3 – CONTROL – Serious weeds which cannot be eradicated in the short term, but must be kept under control.

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The water hyacinth profile

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The water hyacinth profile

Water hyacinth (*Eichhornia crassipes*) has been widely described as one of the world's worst weeds. It is a free-floating and highly invasive aquatic plant that rapidly forms dense and impenetrable floating mats in freshwater systems.

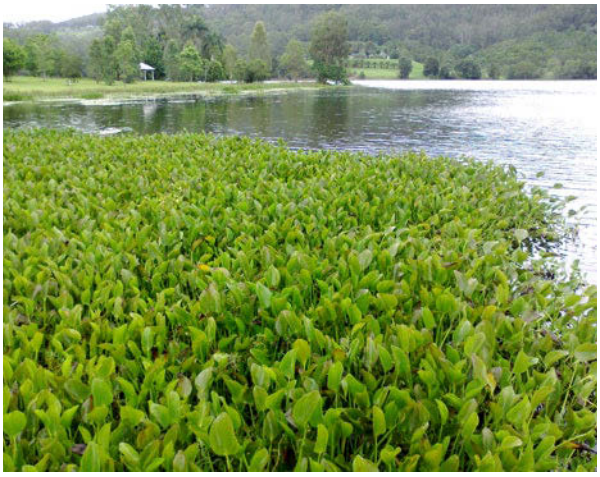
The problem

Water hyacinth is an aggressive invader and is a Weed of National Significance. An infestation can double in size every 5 days under ideal conditions, quickly covering the water surface and taking over an entire waterway. It can invade freshwater rivers, wetlands, dams, lakes, irrigation and drainage channels—potentially threatening the function and ecology of Australia's freshwater wetlands and waterways.

The ability for this plant to tolerate a large range of temperatures, nutrients and pH levels, gives it a superior advantage over other native freshwater plants that generally have slower growth rates and a much lower tolerance to changes in water environments.

Paul Marynissen

Water hyacinth invading the water treatment plant at Wyong South



Phil Moran

Water hyacinth in Wappa Dam

Nikki Shepherd

Water hyacinth amongst reeds along Gingham Watercourse

Brad Wedlock

Water hyacinth at Mary River barrage

Water quality

Water quality is affected in a number of ways following water hyacinth invasion. Dissolved oxygen levels are reduced beneath the floating mat by decreasing the natural transfer of oxygen from the air at the water surface. In addition, decomposing dead plant material can further reduce the amount of dissolved oxygen and increase the amount of sedimentation and silting in the water. All of these factor lead to a decrease in water quality.

The decreased water oxygen levels results in a changed aquatic habitat, as it reduces fish diversity and impacts on other aquatic flora and fauna communities.

Loss of biodiversity

Under high nutrient water levels, the growth of water hyacinth is dramatic, where it can quickly cover the entire water surface. Submerged plant communities are affected by the thick floating water hyacinth mats, as they block sunlight and absorb large amounts of nutrients that are required by these organisms to photosynthesise. This destruction of native habitat can lead to decreased fish, aquatic invertebrate and water bird populations as the availability of food diminishes. The natural ecology of Australia's wetlands is particularly vulnerable to water hyacinth invasion.

Paul Sullivan

Water hyacinth invading Gingham water hole

Water loss

The amount of water lost from a water body by a water hyacinth infestation can be up to three times larger than the natural evaporation rate of an uncovered water surface. These high levels are the result of high transpirations rates – water lost through the leaves. This can have large impacts on water storages with infestations of water hyacinth and river systems that may already be low on water.

Agricultural implications

Severe infestations of water hyacinth can prevent access to stock watering points and possibly reduce the amount of quality drinking water available to stock.

Water intakes of irrigation systems can be restricted or completely blocked by water hyacinth, increasing pumping time and pump maintenance costs.

Water hyacinth can also impact on commercial fishing activities, by getting caught in nets.

Terry Inkson

Water hyacinth infestation in a dam

The water hyacinth profile

Damage to infrastructure

During flood events, large mats of water hyacinth can move with flood waters. These large mats can be very heavy, up to 450 tonnes of wet weight per hectare, which can build up against, and cause damage to, bridges, culverts, roads and fences. This may obstruct the natural flow of water and possibly increase flood levels, contributing to the loss of infrastructure, livestock and equipment. Once flood waters subside, large mats of water hyacinth can be left stranded on crops and pastures, destroying the underlying plants, and can be very costly to remove.

Michael Wood

Water hyacinth plants collecting around Ballina wharf

Andrew Petroeschevsky

Water hyacinth mats relocated after flood

A. Purdy

Water hyacinth caught on a road sign after a flood

Recreation and aesthetics

Large mats formed on the waters surface can interfere with water activities such as boating, swimming and fishing. Passage of boats through waters infested with water hyacinth becomes difficult, with plant material potentially clogging motors or getting caught in propellers. Water hyacinth can completely block waterways, making water sports very difficult or dangerous.

Swimming becomes dangerous, as swimmers may become entangled in the mass of roots and runners beneath the waters surface. Reduced fish populations as a result of heavy infestations can minimise recreational fishing activities.

The natural beauty of an open water body can be greatly diminished by invasion of water hyacinth, as native plants, birds and aquatic animals are displaced. While water hyacinth may be an attractive water plant in small numbers, the implications it can have towards the environment and economy far outweigh any visual appeal.

Health and safety

Water hyacinth mats can be dangerous for recreational users of water and stock which may become tangled in the roots and stolons of plants if venturing into the water. Canoeists and kayakers can risk being caught or entangled in mats if their craft capsizes.

Mats may provide a breeding ground for mosquitos which can carry disease such as Ross River virus and Dengue fever.

Bulk removal and stockpiling of harvested water hyacinth material that contains heavy metals may also pose a small risk if not managed correctly.

History of spread

Origin

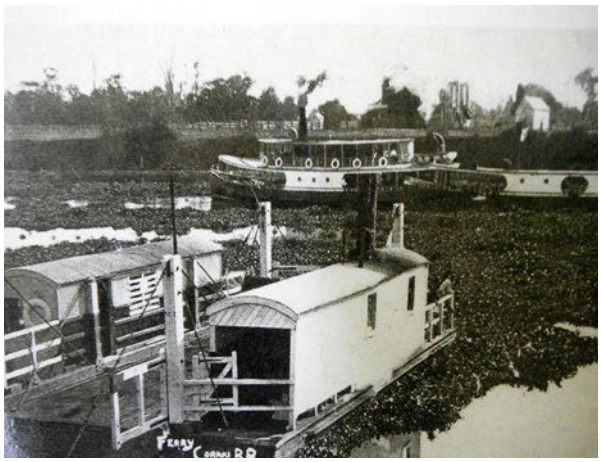
Water hyacinth is native to the Amazon basin in South America—originating in north-eastern Brazil, extending into Bolivia, Surinam, Columbia, Guyana and Venezuela. In its native range, it is mostly confined to slow-moving water areas such as coastal lowlands and the margins of lagoons. Natural predators feed on water hyacinth and help keep plant numbers low. Rarely does it become a problem, unless water nutrient levels are increased, generally caused by human activities.

Introduction to Australia and history of spread

Originally introduced into New South Wales and Queensland during the 1890s, its attractive purple flowers made it a favourable ornamental plant for use in lagoons, ponds and aquariums. Intentionally planted water hyacinth soon spread into neighbouring watercourses following flooding and by disposal of unwanted plants into waterways.

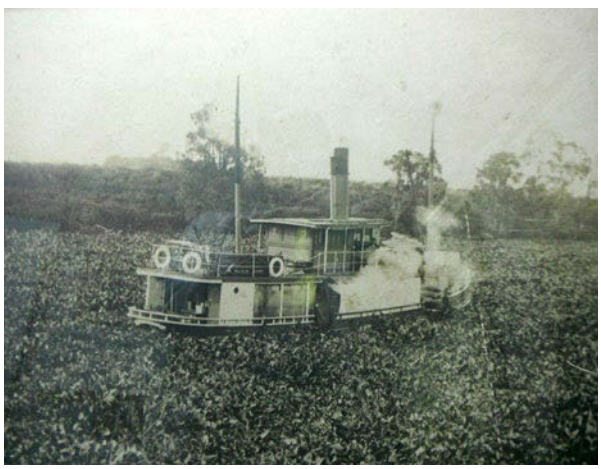
By the early 1900s it had spread along Queensland's east coast and the north-eastern regions of New South Wales. Extensive infestations of water hyacinth could be found throughout the northern coastal rivers of NSW, in particular the Macleay, Clarence and Richmond catchments, causing difficulties for water navigation. An outbreak occurred during the 1990s on the Hawkesbury River and is still subject to annual control programs.

In 1955 an infestation was reported on the Gingham Watercourse near Moree and following a series of flood events, by 1976 it had spread to cover over 7000 hectares of water, threatening to invade the Murray Darling River system. A successful control campaign followed, where the infestations were destroyed. Unfortunately re-establishment has since occurred from the large



Richmond River County Council

Coraki Ferry in water hyacinth



Richmond River County Council

Paddlewheeler in water hyacinth

The water hyacinth profile

seed bank that remained and it is still an ongoing problem in the area.

In Queensland, water hyacinth quickly spread throughout Brisbane and the south coastal areas following its release into the ponds and lagoons of public parks. It has since invaded many rivers and creeks throughout most of coastal Queensland, with the Burnett, Herbert, Fitzroy and Burdekin River catchments all experiencing significant infestations of water hyacinth.

In South Australia, water hyacinth was intentionally planted in the late 1930s in the Ramco lagoon and within two years had become a serious infestation. A quick response to the problem led to its eradication. Occasional outbreaks have been identified and removed from water bodies in Victoria, Western Australia and the Northern Territory.

Current distribution

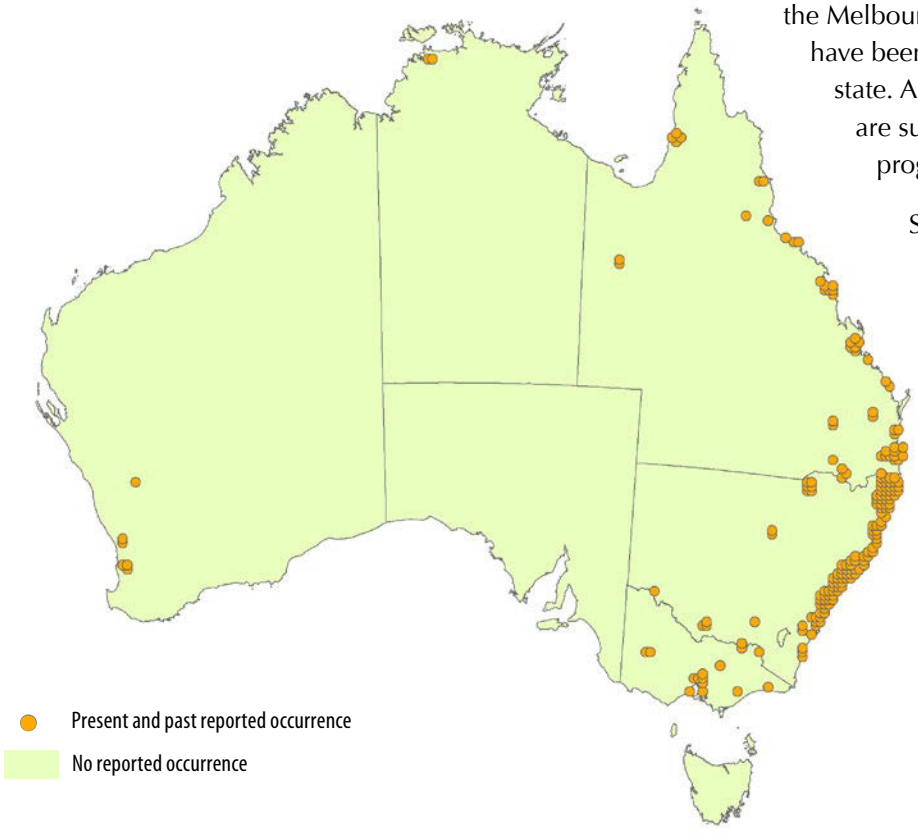
Water hyacinth currently occurs along the east coast of Australia from Kiama in New South Wales to Cape York Peninsula in Queensland.

Scattered infestations of water hyacinth occur along much of the NSW coast. Major infestations still occur throughout the Macleay, Clarence and Richmond catchments of northern New South Wales.

In Queensland, water hyacinth frequently occurs along the coastal areas, with some smaller infestations occurring on inland freshwater systems. Ongoing control efforts continue along the Gold Coast, Brisbane River, Sunshine Coast, Burnett and Townsville regions of Queensland. Water hyacinth tends to inhabit impounded waterways such as floodplain drains and weirs.

In Victoria, water hyacinth occurs in small scattered infestations mostly on water bodies around the Melbourne area, although outbreaks have been detected throughout the state. All water hyacinth infestations are subject to eradication programs.

South Australia, Western Australia, Tasmania and the Northern Territory currently have no known infestations of water hyacinth.



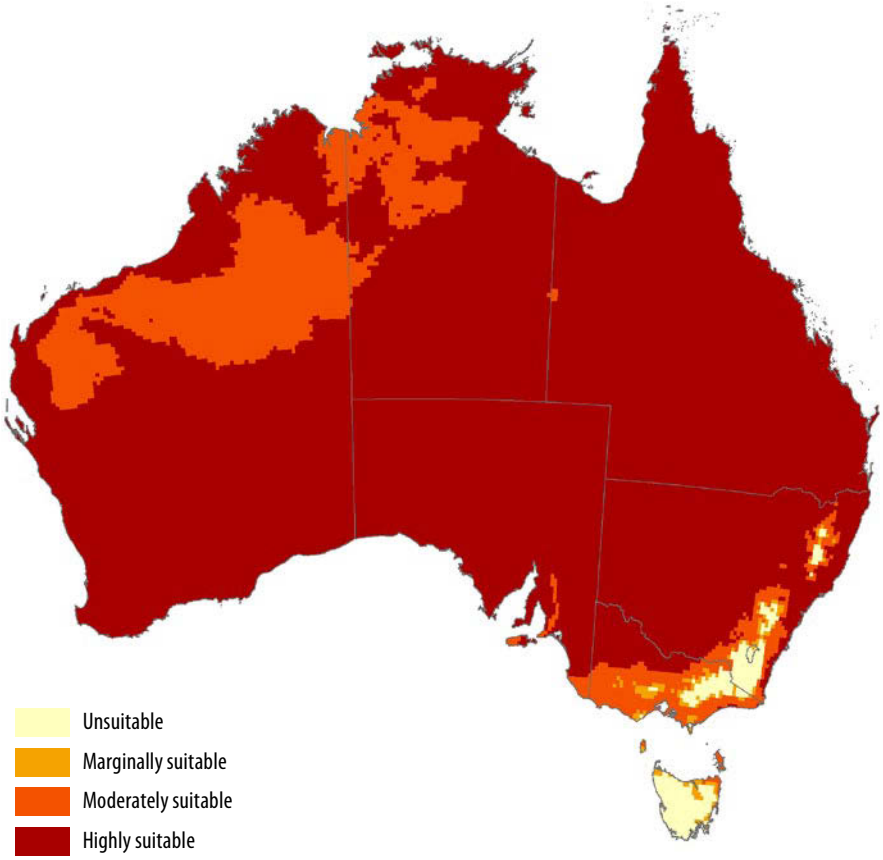
Map showing all reported cases of water hyacinth in Australia

Potential threat and distribution

Water hyacinth has naturalised and established along most of the tropical and sub-tropical coastline of Queensland and New South Wales. However, it only occupies a small percentage of its potential range. Based on predicted climate modelling, Australia's climate is highly suitable for water hyacinth growth and it has the ability to invade and establish in any still or slow-moving freshwater body on the mainland. Observations have also shown water hyacinth is capable of surviving extreme winter conditions in Japan, indicating that it may also have the potential to invade the colder climates of Australia, including Tasmania.

Areas of environmental significance that are currently under direct threat from water hyacinth include the Murray Darling Basin and the Gwydir wetlands in New South Wales.

While it is illegal to sell water hyacinth in Australia, it can still be found occasionally for sale in nurseries, although more commonly at local markets across the country, and on internet sites. It is still a popular ornamental plant amongst water garden enthusiasts and unfortunately new incursions are often the result of plantings in outdoor ponds, water features and dams. These plants can be easily spread to nearby watercourses during flood events, or from inappropriate disposal of unwanted plants.



Potential distribution of water hyacinth in Australia

The water hyacinth profile

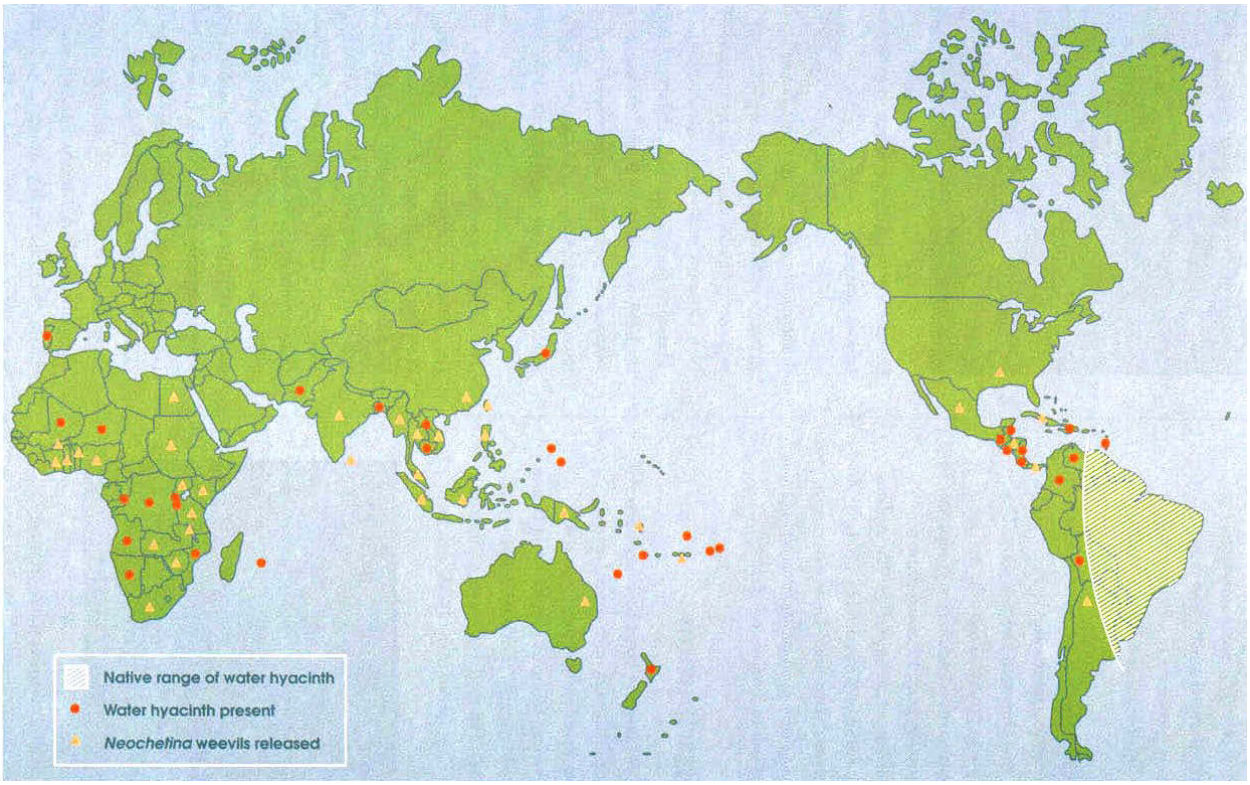
World status

Originally from the Amazonian region of South America, water hyacinth has invaded the tropic and sub-tropical regions of over 50 countries, spread over 5 continents. Regions particularly affected by water hyacinth include south-east Asia, south-eastern USA, central and western Africa and Central America.

Introduced to the USA in the 1880s, it was distributed as a garden ornamental and quickly escaped cultivation. It is now an invasive pest throughout south-eastern USA, from Florida extending west through to Texas and California, Hawaii and the Virgin Islands.

In Egypt, water hyacinth was originally recorded in 1880; however, it was not until 1975–1985 that it became a problem—following the construction of the Aswan High Dam. Prior to this, water hyacinth was flushed out into the Mediterranean Sea with the annual flooding of the Nile River.

It is a devastating weed that is prevalent throughout many water bodies in Africa and the Middle East, where it has affected the livelihoods of millions of people who rely on the water for income. Major infestations occur on Lake Victoria in East Africa, where more than 12,000 ha of the lake is infested with water hyacinth, Lake Malawi and the Zambezi River basin in southern Africa, and the Tano lagoon and River Niger in West Africa.



World distribution of water hyacinth (Source: Julien et al. 1999)

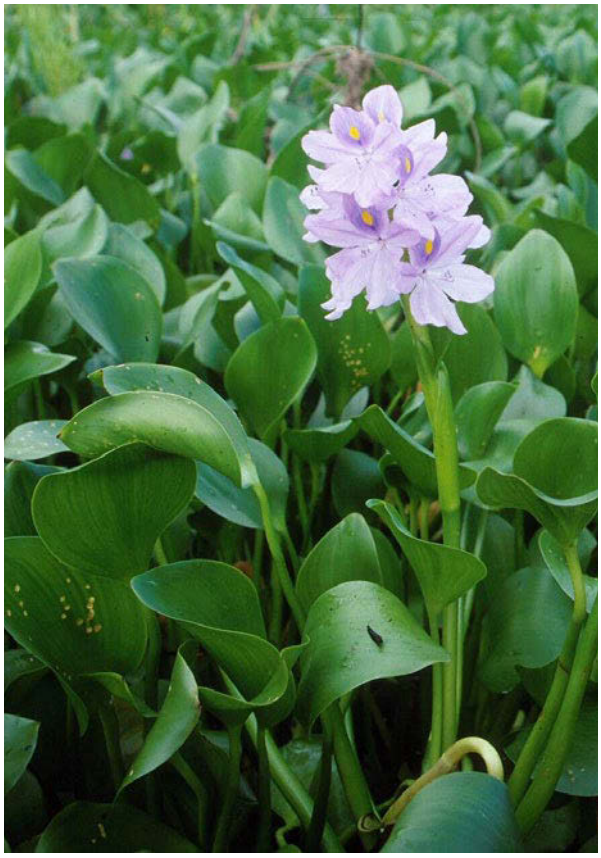
Identification

Habit

Water hyacinth is a free-floating perennial aquatic plant that forms large mats in still or slow-moving freshwater, particularly in impounded waterways. It is erect and herbaceous, consisting of a cluster of several broad leaves and attractive purple flowers.

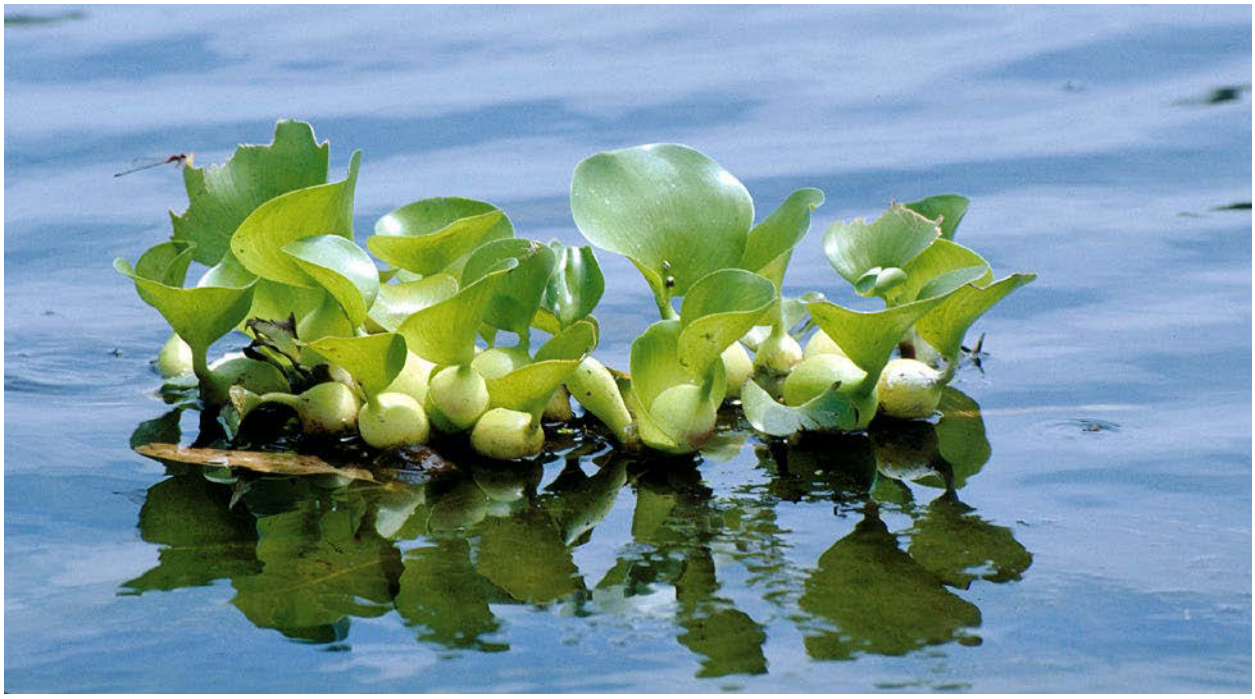
Ian Schwartz

Water hyacinth forming a large floating mat



Mic Julien

Flowering water hyacinth plant



Weeds CRC

Water hyacinth plant showing leaves with bulbous petioles

Leaves

Leaves are bright green, waxy, smooth and fleshy. They occur as a rosette at the base of the plant and consist of two parts—a petiole (leaf stalk) and a leaf blade. The leaf blade has smooth edges, is glossy, circular to heart-shaped and up to 30 cm in diameter.

Two types of leaves occur – those with petioles that are bulbous (swollen) and those that are non-bulbous (not swollen) (see Figure 1). Each petiole contains large air cells, enabling the plant to float. The greater the amount of air, the more bulbous the petiole is.

Leaves with bulbous petioles – enlarged/swollen petioles up to 25 cm long. This type of leaf is more characteristic of plants growing in infestations with low plants numbers or along the open-water edge of infestations.

Leaves with non-bulbous petioles – leaves are up to 60 cm long, slender and erect. This leaf type is more typical of plants in crowded, dense infestations.

Figure 1a

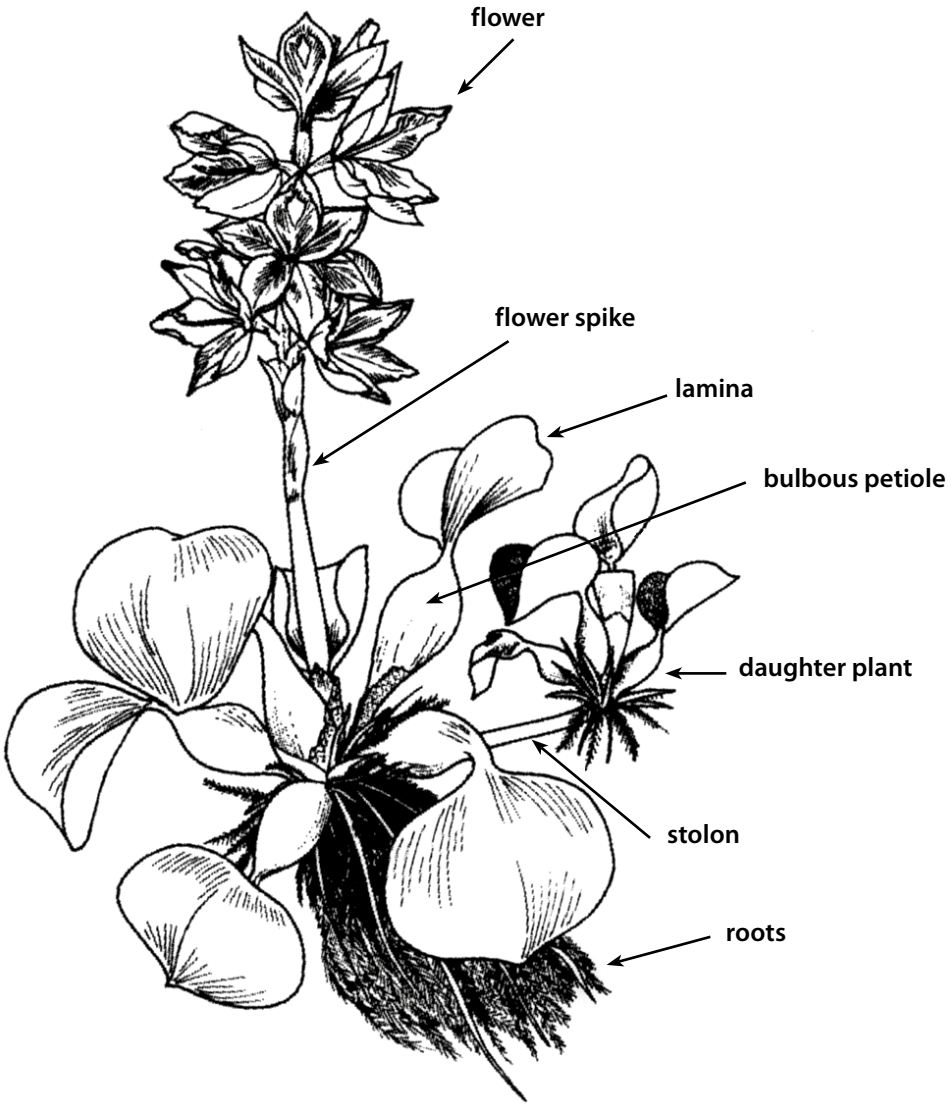
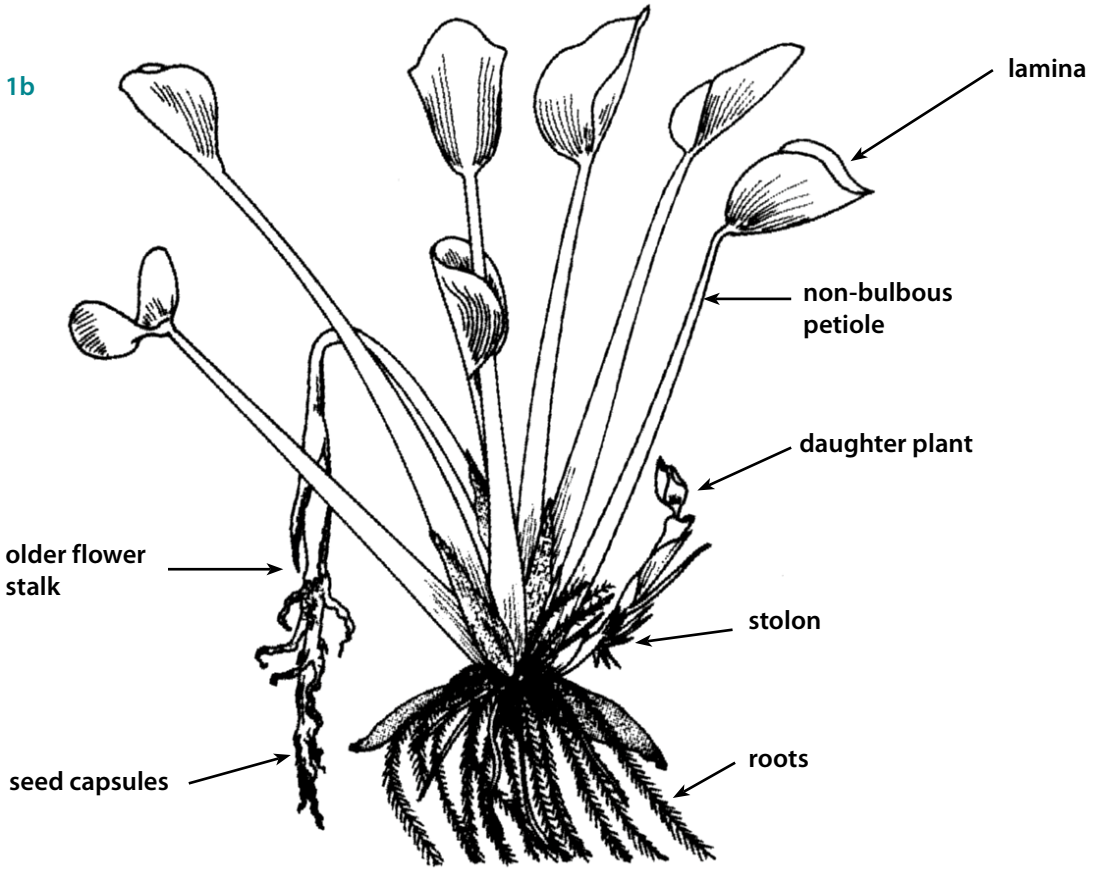


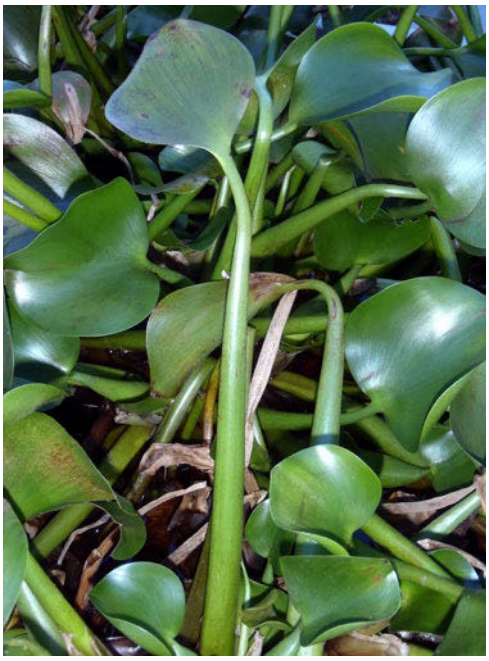
Figure 1 a & b. Water hyacinth can show variation in form depending on growth conditions (adapted from Julien, Griffiths & Wright 1999)

Figure 1b



North West Weeds

Water hyacinth leaves with bulbous petioles



Water hyacinth leaves with non-bulbous petioles

The water hyacinth profile

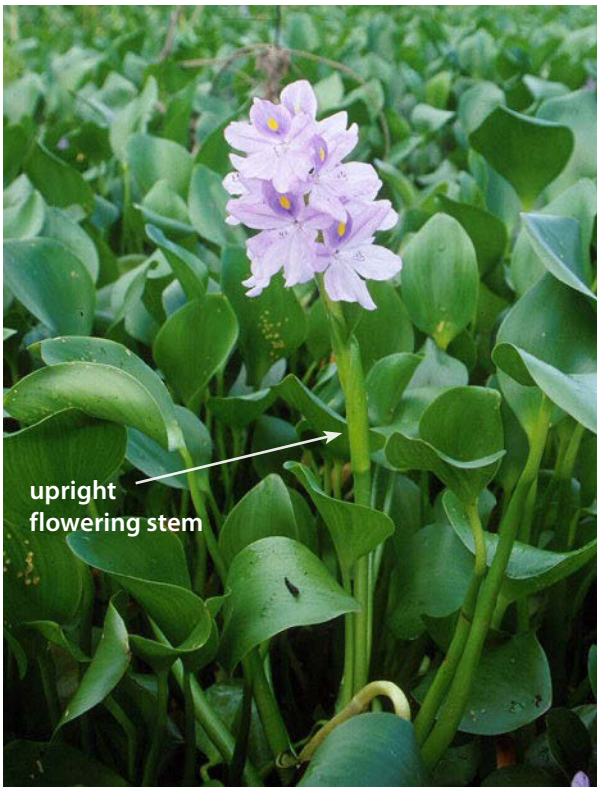
Stems

Two types of stem occur:

- upright stems up to 60 cm long, with flowers,
- horizontal vegetative stolons, or runners, about 10 cm long that produce new plants.

Andrew Petroeschevsky

Water hyacinth stems can be vegetative stolons that produce new plants



Mic Julien

Upright water hyacinth stem with flower head

Flowers

Between 3 and 35 (more commonly about 8) flowers occur along a spike about 15 cm long, that usually extends above the leaves. The flower head is attached to a stem (up to 60 cm long) that has two leafy bracts positioned below the flower spike.

Each flower is funnel-shaped, has 6 petals, is bluish-purple in colour, 4–7 cm long and 4–6 cm wide. The upper petal is a deeper purple with a yellow spot in the centre. Flowers are able to self fertilise and under ideal conditions, can appear throughout the year.

Individual flowers only last a few days. Once all of the flowers on the spike have matured and withered, generally after about 18 days, the spike bends down into the water and releases its seeds.

Tobias Bickel

Water hyacinth, showing the cluster of flowers along the stalk

Fruit and seeds

The seed capsule is narrow and 1–1.5 cm long, containing up to 300 oval-shaped seeds that are 1–1.5 mm long.

Roots

Roots are black to purple in colour, fine, fibrous and feather-like. In deep water they can be up to 1 m long and may trail freely behind the plant. In nutrient rich water, roots are usually much shorter. In shallow water the roots may become attached to the muddy bottom, allowing the plant to persist for several weeks after water levels drop.

Jan Mitchell

Feather-like water hyacinth roots

Kim Curtis

Large water hyacinth plant out of the water

The water hyacinth profile

Lifecycle

Reproduction

Water hyacinth can reproduce from both seed and vegetative growth.

Under favourable conditions, water hyacinth is capable of growth and reproduction all year round, although flowering mostly occurs during spring and summer months. Seeds are typically responsible for reinvasion of an area already treated.

New plants can flower within 3–4 weeks, producing thousands of seeds that are released into the water. The small seeds sink to the muddy bottom where they can remain dormant for up to 20 years.

Fluctuations in water level stimulate germination, with shallow water or mud, high light intensity and temperatures between 20–30°C being the optimum conditions for germination and seedling emergence. Most germination occurs on the moist soil at the waters edge, or on the bottom mud once a water body has been drained or dried up. Once the water body has refilled, seedlings break free from the mud and float to the water surface, quickly developing a new root system.

Vegetative growth is the most common form of reproduction and is largely responsible for the rapid growth and spread within an infestation. Daughter plants are produced from horizontal stolons that quickly develop root systems. Daughter plants eventually become independent from the mother plant when the connecting stolon decays or breaks. Vegetative growth can occur all year, but is most prolific during the spring and summer months.

Growth rates

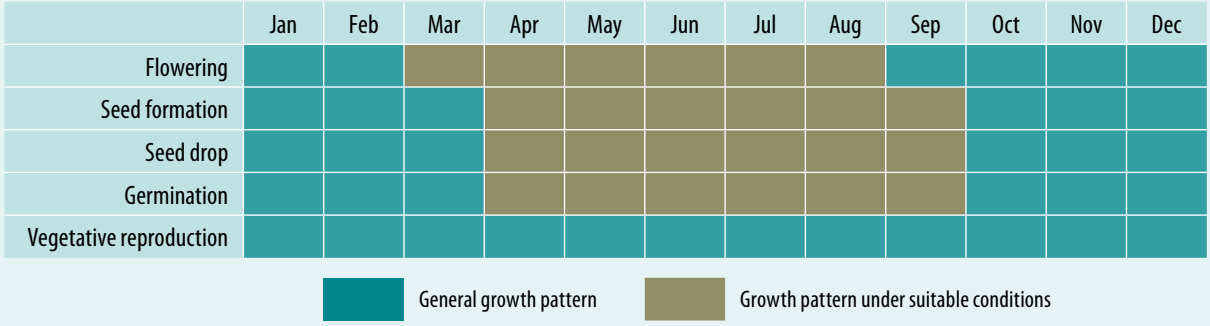
Under optimal temperature and nutrient conditions, water hyacinth can experience dramatic vegetative growth. New daughter plants can be produced in as little as 5 days and populations can double in size in as little as 6 to 18 days. Each plant is capable of producing 2–4 daughter plants, resulting in exponential growth. A heavy infestation of water hyacinth may contain up to 2 million plants and weigh up to 450 tonnes per hectare.

Seed bank

In ideal situations, water hyacinth can produce up to 3000 seeds in each flower spike, with a single plant able to produce a number of flower heads per year. These seeds can potentially remain viable in the muddy soil for up to 20 years, germinating once conditions are right.

The formation of a seed bank provides water hyacinth with resilience and an improved ability to respond to varying conditions. Even though water hyacinth is predominantly a tropical plant, its ability to survive in temperate conditions may be the result of having a long-lived seed bank. Even though on-going cold weather can kill water hyacinth plants, the re-emergence of seedlings

Growth calendar



during spring may be a direct result from the establishment of the seed bank during the previous growing season.

Dispersal

Throughout a catchment, the greatest method of dispersal is from the movement of plants during periods of high water flow and flooding. Large floating mats can break up and move to new areas within a catchment, and then rapidly increase in size from vegetative growth. A single plant can begin a new infestation.

Seeds can be responsible for the introduction of water hyacinth into a new area, which may be moved by water or from contaminated mud stuck to birds, machinery or footwear. Birds may also be capable of moving small plants from dams and ponds into nearby waterways.

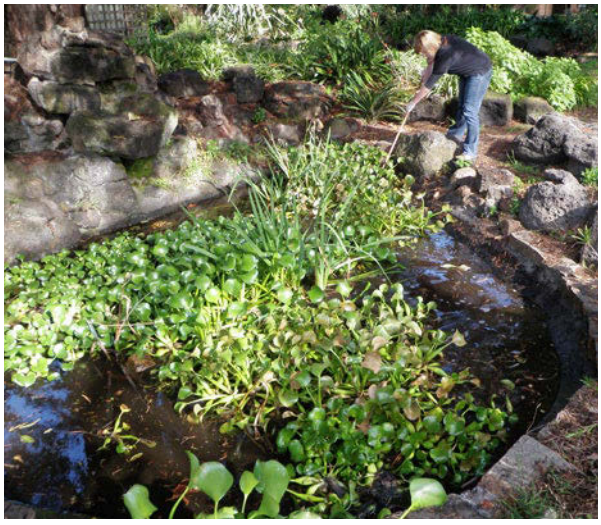
Most spread has been the result of human activity, such as deliberate plantings and dumping of unwanted plants into waterways and possesses the greatest risk of developing new infestations. Despite a national ban on sale, it still remains a popular pond ornamental. New incursions are being found on the dams of lifestyle block in semi-rural and peri-urban areas.

Contaminated fishing equipment, water craft and boat trailers is potentially another means of spread between water bodies.

Habitat

Water hyacinth prefers still or slow-moving freshwater systems such as ponds, dams, lakes, rivers and wetlands. Plants require a body of water to establish and spread, but can also survive for many months on damp soil where water levels have receded.

While it does require optimal conditions for rapid growth and spread, it is able to withstand a wide range of climates and conditions.



DEPI Victoria

Despite a national ban, water hyacinth has been sold as a pond ornamental

The water hyacinth profile

Paul Sullivan

Water hyacinth infesting Gingham Channel, near Moree

Paul Marynissen

Water hyacinth growing in the water treatment plant, Wyong South

Nikki Shepherd

Water hyacinth in flower, Gingham wetland

Temperature

The ideal temperature for water hyacinth growth is 28–30°C, but it can still maintain good growth rates at temperatures between 22 and 35°C. Preferring tropical or sub-tropical climates, it can comfortably grow in temperate climates, but temperatures below 10°C will slow or stop growth. It can survive mild frosting, but severe frosts and prolonged cold weather may result in plant death. Seeds however, can successfully survive winter.

Nutrient levels

Water hyacinth can tolerate low water nutrient levels but will only experience slow growth. It will readily invade and thrive in waterways that have high amounts of nutrients, requiring high levels of phosphorus, nitrogen and potassium for optimal growth. Studies have shown that in nutrient rich sites, water hyacinth biomass can increase eightfold compared to water bodies that are nutrient poor.

Areas that have excessive nutrient levels due to human intervention, such as run-off areas downstream from agricultural or urban land, may experience population explosions of water hyacinth.

Water hyacinth does not tolerate saline water and will not grow in estuarine or sea water which has 3.5% salt. Plants exposed to water as little as 0.006-0.008% salt will die after 28 days of exposure. Death of water hyacinth plants is almost immediate when exposed to 2.0% salt. Optimal growth is in neutral water with a pH around 7.0, but can withstand water pH levels between 4.0 and 8.0.

Water hyacinth is an extremely tolerant and hardy plant that can readily absorb a range of minerals from the water column, including heavy metals, without affecting its health or growth rates.

Reece Luxton

Water hyacinth plants moved over the weir on Alumy Creek into the Clarence River; plants look stressed (left) due to high saline levels in the river

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Module 2

Management considerations for water hyacinth

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Management considerations for water hyacinth

[*Adapted from van Oosterhout (2006), pp. 17–20*]

The most appropriate management strategy for water hyacinth is not always obvious and will depend on the site. Factors such as the nature and use of the waterway, climate, size and age of the infestation, presence or absence of an upstream infestation, as well as current and ongoing resources available, all need to be considered in the control and management of water hyacinth.

A number of different control methods are available which include registered herbicides, mechanical and manual removal, biological control and water level manipulation, or a combination of these. Any treatment used will need to be site-specific and include provisions for ongoing monitoring and follow-up control.

Prevention and early detection

Prevention is the cheapest form of weed control. There are a number of procedures that can be implemented to reduce the risk of a water hyacinth invasion. Strategies can include:

- Regularly check water bodies for suspect plants and have them identified. A key time is following flooding and during spring and summer months when growth is optimal.
- Check high risk areas, including:
  - ponded or slow-moving water bodies,
  - areas known to receive high levels of nutrients (i.e. runoff from agricultural, horticultural or industrial land), and
  - areas close to human activity and urban development. For example, boat ramps, waterways close to parks or residential areas and near bridges.
- Control new infestations as quickly as possible, preferably before they flower and set seed. Monitor and follow-up to avoid future reinvasion.

Jan Mitchell

Water hyacinth caught on the under carriage of a ute

Nikki Shepherd

John D Rothlisberger

Wash down prior to leaving site

- When using water facilities, such as dams, lakes, and rivers; make sure all clothing, boats, trailers, water vessels and any related equipment is free of plant material prior to leaving.
- Community education to increase awareness, capacity for early detection and decrease the plants ornamental use.

Lee Amidy

Community awareness notices

Early detection is critical for the management of water hyacinth. If an infestation is small and discovered early, eradication or containment may be possible. Ideally treat infestations when small and BEFORE plants have flowered and set seed. Once a seed bank has established, eradication efforts will become much more difficult. Small infestations may be removed manually, or sprayed with a registered herbicide.

Frequent monitoring and removal of new plants that have germinated from the seed bank will help ensure the infestation does not re-establish.

Detecting new incursions and acting swiftly, plus regular monitoring and control, will increase the likelihood of eradicating water hyacinth from a site.

Nature of waterways

Water hyacinth can infest any still or slow-moving freshwater body such as dams, lakes, creeks, rivers, wetlands, drains and channels. Each waterway will have different uses and values, such as primary production, conservation, recreation or consumption. The most appropriate control and management strategy required will depend upon the type of the waterway, its use and access to the site.

Rivers and streams

Rivers and streams are generally slow moving, but can also be subject to flooding, particularly in wet tropical climates where water hyacinth thrives. Under ideal conditions (warm temperatures, high nutrients, still water), water hyacinth numbers can build up quickly. Floods usually increase nutrient content in the water due to run-off and therefore further benefit water hyacinth growth.

One of the biggest threats in this situation is the spread of water hyacinth throughout the catchment. Physical barriers such as booms or containment fences may be required to reduce the risk of further infestations downstream; however, this will only serve as a barrier during normal periods of flow and not during floods. In all climates, a long-term monitoring and maintenance program should be in place to treat any reinvasion from the seed bank.

Michael Wood

Water hyacinth in Seelim Creek, off Richmond River

Management considerations

Tropical climates

In tropical climates, water hyacinth is likely to flourish and experience year round growth. During the monsoon season, annual flood events can break apart large mats and flush them downstream, where it may end up in brackish estuarine waters, where it will not survive. Flood waters can also leave plants scattered throughout the catchment and wash mats onto freshwater floodplains, where it will continue to grow providing damp soil conditions persist. This movement of water hyacinth into the flood plain can also create new infestations in floodplain water bodies such as billabongs.

Philip Blackmore

Water hyacinth amongst water primrose, Dumaresq River

Nikki Shepherd

Water hyacinth amongst reeds, Gingham Watercourse

Physical removal using aquatic weed harvesters may be required if the mats are large and thick, or if the infestation occurs in an environmentally significant area. Physical removal should occur in the winter months when growth is slow and not during the peak growing period as growth of water hyacinth will be faster than its removal. As growth will be at its minimum during winter, management costs may be lower. Missed plants may be treated with foliar application of a registered herbicide.

Foliar application with a registered herbicide is an option for infestations that are small to medium in size. In many cases, biological control agents may already be present in the water hyacinth. Check for signs of biological control activity at the site. If no activity is found, assess if release of biological control agents may be an option (see Module 5: Biological control).

If infestations are small, manual removal may be possible during the winter months when growth has slowed. All infestations should be monitored and controlled regularly to treat any regrowth from the seed bank.

Sub-tropical climates

In sub-tropical climates, conditions may be suitable for year round growth, although water hyacinth growth rates will generally be slower in the cooler winter months. Flood events are not as frequent and may allow infestations to build up over time.

Physical removal of infestations during winter months is an option. While this can be expensive, it may be necessary if an infestation occurs in high value conservation or recreational areas and in priority outlier sites where immediate removal is necessary. Follow-up treatments with a registered herbicide will also be required.

For small infestations, on-going herbicide treatments, combined with small levels of manual removal from the edges of the waterway may be necessary.

Temperate climates

In temperate climates, where growth slows significantly during winter months, physical removal may be possible during these times, complemented with herbicide follow-up treatments during the spring and summer growing months, prior to seed-set. The costs of physical removal will also be lower during this time.

Irrigation

In irrigation systems, water hyacinth can potentially cause water losses from storage areas and clog pump intakes. To avoid clogging of irrigation pumps, physical barriers such as mesh containment fences or booms can be used to keep water hyacinth away from pumping equipment. Small infestations can be manually removed, preferably during winter, followed-up with herbicide application on any reinvasions prior to flowering. If herbicides are used, check the label for withholding periods for irrigation purposes. Constant monitoring and treatment of re-emerging seedlings is necessary to reduce the seed bank.

Water supplies – stock use, domestic use and potable water

Treatments used will depend on the size of the water storage and the water hyacinth infestation. In heavy infestations, physical removal may be required if wanting to quickly restore the function of the waterway and to regain access for humans and stock. Herbicides can be used; however, when water is to be used for stock or human consumption, always check the herbicide label for restrictions and withholding periods for stock watering and human consumption (see Module 3 on herbicide use). Booms can be used to keep infestations away from potable water off-take areas.

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Removing water hyacinth by hand from a backyard pond

Management considerations

Conservation areas

In areas with high conservation values, such as wetlands, mechanical removal is the best option to initially restore the function of the waterway, although expensive. This should be followed up with manual removal and potentially biological control. These methods may also be combined with minimal herbicide treatments. If using herbicides, choose a herbicide that has negligible impacts on water quality and aquatic wildlife, such as Roundup Biactive®.

DEPI Victoria

Bird nesting boxes amongst a water hyacinth infestation

DEPI Victoria

DEPI Victoria

Removing water hyacinth plants by hand where herbicide can not be used, in winter

Following initial treatments, water hyacinth levels should always be monitored and any re-emerging weeds should be removed completely or restricted to only low coverage levels to help minimise the effects on other wildlife and native plants. Access can sometimes be difficult and this is when biological control, providing climatic conditions are suitable, may be an important component of the control program.

Recreation – dams and lakes

In dams and lakes that are used for recreation purposes, to restore the function of the water body as quickly as possible, physical removal of water hyacinth is best conducted by during winter months when growth is slowest. Registered herbicides can also be used to treat the infestation (see Module 3: Chemical control options).

Regular monitoring and treatment of regrowth from the seed bank should be conducted for at least 30 years given the longevity of the seed bank of water hyacinth. Monitoring should be more frequent during the active growing spring and summer months, and also after periods of drought followed by high rainfall that increase water levels above previously exposed dry shorelines.

People using water recreational facilities should be aware of weed hygiene practices to avoid spreading water hyacinth, and other weeds, to new sites. Signage should be erected at boat ramps and camping areas as a reminder for people to check watercrafts, trailers and sporting equipment for plant material prior to leaving. Recreational use of the water body should be restricted while weed control is being conducted.

Ponds and water gardens

Water hyacinth should be removed manually, dried and buried above flood levels. If disposing of the pond water and sediment, it should be discarded away from any watercourse and preferably buried above flood levels.

DEPI Victoria

Water hyacinth being removed by hand and left to dry on the bank

Fish stocks

In dams and lakes that are stocked with fish, herbicide or mechanical removal of water hyacinth are options for control. Mechanical removal may be the best option to quickly restore the function of the waterway, while herbicide treatments are more economically viable options.

Under a dense infestation of water hyacinth, dissolved oxygen in the water column may already be severely reduce due to the thick surface coverage and inability for gaseous exchange to occur at the water surface. As a precautionary measure, it may be useful to have the water oxygen levels tested and consult with fish or water quality experts prior to deciding which method to use.

If water oxygen is at a level that is conducive with poor water quality and fish health, then herbicide applications may be the most feasible option to control the infestation. Otherwise, if dissolved oxygen levels are suitable for fish survival, consider mechanical removal as the primary method of control, or treat only 50% of the infestation at a time with herbicide, followed-up with small scale herbicide treatments.

For medium to small infestations, herbicide control is a suitable option to remove the initial infestation, followed with small scale manual or mechanical removal and spot spraying.

Management of mature mats

In large established infestations, mature floating mats can be thick and heavy and difficult to remove. Thick mature mats will often have a secondary incursion of grasses, sedges and vines that grow within and on top of the water hyacinth mat. These plants grow out from the waters edge, anchoring the mat the edge. When this occurs, the mat will generally rise and fall with water levels during flood events, failing to dislodge from the edge.

In these situations, large-scale physical removal may be required to detach the mat from the edge with aquatic weed harvesters which then push the mat to the edge for removal from the water by an excavator. Spraying an entire large mature infestation with an approved herbicide may not always be feasible because:

- other vegetation present within the mat may restrict herbicide coverage of the water hyacinth, resulting in a poor kill rate, or
- there are accessibility issues with the site.

The presence of endangered species or vegetation communities in or around the water body will affect the treatments that can be used. Physical removal using an excavator or harvesting equipment may be the most appropriate method to use in these circumstances, which can remove the bulk of the weed mat. This would have minimal impacts to the surrounding ecological community and protect the natural assets of the watercourse.

In hard to access areas, small boats or small weed harvesters may be used to break mats apart and

push them towards the edge for removal. Registered herbicide can be used to treat areas inaccessible by the harvester, spot spray small infested areas and plants emerging from the seed bank.

Michael Wood

Casuarina saplings and other vegetation growing amongst mats of water hyacinth in over 8 metres of water

Michael Wood

Michael Wood

Harvester on the water breaking up mats of water hyacinth

Long-term monitoring and follow-up treatments are required to reduce the seed bank over time. Herbicide treatments should ideally be applied early in the growing season, usually spring, prior to flowering and seed-set.

Seed bank management

The seed bank is a reserve of viable seed in the soil that has been produced by the plant over a number of years and represents a major component of its lifecycle. Water hyacinth has an extremely persistent seed bank, with studies indicating that seed viability can range from 5 to over 30 years in suitable conditions. This characteristic indicates how long it can remain persistent in an area even after it has been treated and is no longer being introduced. This will help to determine how long a monitoring program should be in place following initial control treatments.

Understanding the dynamics of the soil seed bank and incorporating management strategies that address this, will ensure success in the long-term management of water hyacinth. Germination usually occurs along the muddy edges of lagoons that experience fluctuating water levels and has also been observed on rotting mats of water hyacinth, where high levels organic matter are available.

Seeds require a number of conditions to germinate, which will vary from site to site. They include:

- warm temperatures,
- high light intensity, and
- the presence of moist soil or organic matter.

Water levels during normal seasons may be too deep for seed germination and the re-establishment of water hyacinth. Studies have indicated that germination mostly occurs in muddy soil and shallow water following periods of fluctuating water levels—where water levels have dropped and the soil has dried out, then been submerged by water again following high rainfall periods.

Sometimes it can take a number of years before conditions are right for dormant seeds to germinate. Monitoring programs should be structured to coincide with seasonal conditions that are favourable for water hyacinth germination, including:

- seasons of low rainfall, followed by seasons of high rainfall – fluctuating water levels,
- periods of high growth during summer, and
- following flood events.

Reduction of the seed bank

Up to 3000 seeds can be produced by a single water hyacinth plant, which either sink or accumulate in the floating mat. Considerable numbers of seeds are continuously added to the seed bank annually, making ongoing control necessary to avoid reinfestation. To gradually reduce of the water hyacinth seed bank, time control measures to take place prior to flowering and seed-set. Successful control will only happen with active management and monitoring for many years, based on the potential lifespan of the seed bank.

Manipulating water levels

Where water levels can be manipulated within a body of water, it can be used as a tool for managing the seed bank of water hyacinth. This option should only be used in small enclosed water bodies where human manipulation of water levels is possible such as water storage facilities and irrigation channels, and where other methods can be integrated to treat emergent seedlings.

Germination of water hyacinth seeds is normally stimulated by muddy, moist soil or shallow water levels, together with warm temperature and high levels of light. When water levels are lowered to generally less than 1 m, a mass germination event of dormant seeds may occur. As water hyacinth can flower and set seed within 12 weeks of germination and sometimes earlier, prompt herbicide treatment or manual removal of seedlings is necessary to prevent flowering. Reducing water levels in early spring will help promote germination.

Water level manipulation is not well understood and must be conducted carefully. This option should only be considered if supplemented with follow-up treatment of emergent seedlings with a registered herbicide prior to flowering and seed-set, or in small areas hand or mechanical removal.

Ongoing monitoring and follow-up treatments will still be required, otherwise efforts will be counter-productive and the infestation will re-establish.

Nikki Shepherd

Water hyacinth seedlings germinating as the water level drops

Andrew Petroeschevsky

Tiny water hyacinth seedlings, held up with a boom

Management considerations

Long-term reduction and suppression of infestations

In most cases, eradication of water hyacinth from a site is not feasible. Hence, continuous suppression and long-term reduction may be the most likely goal for control programs.

For long-term control of water hyacinth, infestations will require the establishment of a well resourced maintenance program. Removal of all water hyacinth from a water body will not guarantee eradication. Initial treatments can help to restore the function of the waterway in a short period of time; however, these waterways need to be closely monitored for emergent seedlings that will need to be treated.

In wetland and conservation areas, where there are areas where accessibility is difficult, if eradication is not possible, long-term suppression of populations is vitally important to help restore biodiversity and environmental integrity.

Closely monitored long-term maintenance regimes will slowly diminish the seed bank over time, provided emergent plants are treated prior to flowering and seed-set.

It is important not to become complacent with maintenance programs, as only one plant is needed to restart an infestation.

Michael Wood

Michael Wood

Swan Bay: Water hyacinth being removed using an aquatic weed harvester (top) and a long-reach excavator (bottom)

Michael Wood

Swan Bay: Maintenance by spraying of herbicide by RRCC staff

Michael Wood

Swan Bay: Before water hyacinth harvest

Michael Wood

Swan Bay: After water hyacinth removal

Michael Wood

Mynumi Lagoon: Before spraying water hyacinth

Michael Wood

Mynumi Lagoon: After spraying

Michael Wood

Mynumi Lagoon: Harvesting water hyacinth

Michael Wood

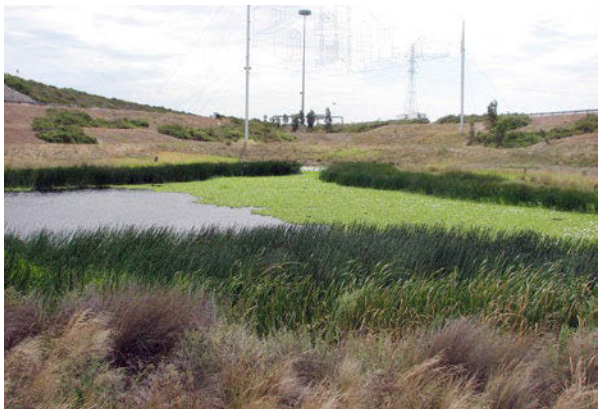
Mynumi Lagoon: After water hyacinth removal

Eradication

Eradication of water hyacinth is often rare due to the plants rapid growth rates and longevity of the seed bank. Eradication is generally only likely if infestations are small, occur on an enclosed body of water and have been detected prior to flowering and seed-set.

For eradication to be successful, the source of the infestation needs to be identified and treated. The allocation of ongoing resources is required for regular monitoring and follow-up treatments of emerging plants from the long-lived seed bank. Monitoring should be conducted regularly and more frequently during the active growing season until all plants have been removed.

Even if eradication has been successful, reinvasion from another source is always possible.



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Western Ring Road, Melbourne: Before (top) and after eradication

Management considerations

Preparing a management plan

The management of water hyacinth requires diligent planning and control efforts due to its long-lived seed bank, high vegetative growth rates and ability to produce large amounts of viable seed within 12 weeks of germination.

Ad hoc and uncoordinated control efforts have in many cases, failed to provide effective long-term control. Aquatic weeds spread across boundaries and to be effective, control efforts need to be long-term, planned, coordinated and adequately resourced across regions.

When preparing a management plan, the following factors should be considered.

- **Early intervention**
  Regular monitoring of water courses should help identify any new incursions early. Small and isolated infestations should be controlled immediately to prevent establishment and reduce the capacity for spread. Ongoing monitoring of the site after plants have been removed is necessary as reinvasion is likely if plants have matured and set seed.
- **Map and record populations**
  A topographic or aerial image is a useful base map for recording infestations. Alternatively, virtual mapping and geographical information programs are available online. If a map of the waterway is not available, hand drawn maps are still useful. Keeping a photographic record of the site is the most valuable tool in assessing visual changes to the infestation size over time.

  Monitor the site regularly and record information such as date, size and area of the infestation. Other information such as potential environmental or conservation risks, treatments applied, rainfall and flooding events may also be useful to note.
- **Identify the source of infestation**
  The original source may be upstream, or even from off-stream sources. Check nearby areas such as billabongs, lagoons and garden ponds as these may be the source of a new incursion. Contain and control the source of infestation as soon as possible.
- **Contain the infestation where possible**
  Containment is important for small and new infestations, and also for large infestations where there is a risk of spread to new areas, particularly when downstream locations have conservation or environmental values. Booms and containment fences are useful to contain water hyacinth to an area, reducing its ability to spread downstream.
- **Determine priority areas for control**
  Small or new infestations that have the highest chance of eradication should have the highest priority for control. Other areas of priority may include wetlands with high conservation values, environmentally significant areas and waterways under direct threat from an upstream infestation.
- **Assess resource availability for ongoing control and maintenance**
  Due to the long-lived seed bank, all water hyacinth infestations, small and large will require long-term monitoring, maintenance and control. Adequate on-going resources should be included in any management plan to minimise reinvasion from the seed bank. Co-ordination of resources across districts should also be considered.

- **Check for permit requirements**
  Permits may be required if control treatments are likely to cause disturbance to an aquatic environment or where modifications to the banks of waterways to allow machinery access are required. Check with local and state government before commencing any form of control.
- **Determine site specific control methods**
  The nature and use of the waterway, climate, size of the infestation and time of the year will all affect which control methods, or combination of methods to use. Take advantage of the cooler winter months, which slow down the growth rates of water hyacinth. Physical removal is best undertaken during winter, particularly for larger infestations; with herbicide application best applied early in the growing season (usually spring) and prior to seed-set. Leaving control too late into the growth season will have less impact.

  Check for the presence of biological control agents, as they may already be present. If new releases are required, they should be conducted as early as possible.

  Carry out regular monitoring and follow-up control activities. During the peak of the growing season (usually summer), monitoring should be conducted more frequently.
- **Identify and minimise nutrient sources**
  High water nutrient levels, particularly of nitrogen and phosphorus, can lead to the rapid growth of water hyacinth. Discharge from sewerage treatments plants, storm water and agricultural runoff are the main preventable forms of nutrient input. Strategies that target these sources can assist in water hyacinth control.
- **Have aquatic weed hygiene procedures in place**
  All weed control activities should include hygiene practices to prevent further spread or new incursions. Properly wash down all boats, trailers, harvesters, excavators and equipment, including hulls and propellers to remove all plant material.
- **Prevent seed-set in adult plants**
  Conduct control activities prior to flowering and seed-set to reduce new seed being added to the seed bank. Continued monitoring and follow-up control at optimum times will eventually diminish the seed bank over time. Long-term commitment and resources are required for this to be possible.
- **Monitor the success of control treatments**
  Record when and where control treatments were carried out. It may be useful to record this information on the original map. Review the success and limitations of the control strategies used. Photographs taken at the same reference point can also be a useful visual 'before and after' tool. Monitor the site regularly and make adjustments to the management plan as required.
- **Follow-up monitoring and control**
  In all cases, long-term monitoring will be required due to the longevity of the seed bank. The frequency of monitoring will be dependent on the time of the year and the plants growth cycle. Monitoring should be conducted at more frequent intervals during the flowering period to avoid further seed addition to the seed bank. Ensure adequate resources are allocated.

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Module 3

Chemical control options

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Chemical control options

Herbicides are an effective method of control of water hyacinth that can be used in a variety of situations. Chemical control is generally a cost effective option that can be utilised in an integrated control program for optimum results. Consideration should also be given to a long-term monitoring, follow-up and maintenance program.

Management considerations

There are currently four herbicides registered for use on water hyacinth in Australia, with product registration varying between the States. The choice of herbicide will be dependent upon the use of the waterway, if biological control agents are being used as part of an integrated management strategy and the preferred application method. All registered herbicides are applied as a foliar spray on actively growing plants.

Water hyacinth will always require multiple herbicide applications in a season, regardless of the chosen herbicide. The first application may give a good initial knockdown; however, due to the nature and growth of the plant; regrowth and reinvasion from the seed bank is very likely. However, providing initial controls are effective the management of regrowth is often less intensive than the initial treatment. Due to the long seed life regular monitoring and follow-up treatments will be required to control new water hyacinth growth in future seasons.

Correct application

Herbicides are not as effective if they are not applied correctly. To get the best results from herbicides, it is important that they are applied as a foliar spray at the correct rate, at the right stage of plant growth and that complete herbicide coverage of the plant is achieved.

Each herbicide has a different mode of action and will affect the plant in different ways. They each have specific requirements that will give the best results (see herbicide table later in this module). For all herbicides, it is important that they have follow-up treatments. One herbicide application will not eradicate an infestation.

Jan Mitchell

Water hyacinth after spray with diquat, note some green petioles are appearing

Michael Wood

After aerial spray, note some water hyacinth was shielded from the herbicide by other vegetation

Timing of applications

For optimal control, herbicides should be applied before flowering to young green material that is experiencing active growth. In tropical and sub-tropical climates, periods of active growth are more common during the spring and summer months, but can occur year round depending on the

seasons. Flowering usually begins late summer and early autumn.

In temperate regions, plants experience most growth during the spring and summer months, with flowering normally starting early autumn.

Size of the infestation

Herbicides can be used on all sized infestations ranging from large and dense, to small and scattered. The location and size of the infestation will help to determine which application method to use.

For large scale infestations, aerial or helicopter boom spraying may be the most affective. Diquat and 2,4-D acid are the only herbicides available for aerial application and glyphosate can be used in boom applications. In large, dense infestations, mechanically removing the bulk of weed material can be an option prior to spraying if aerial application is not feasible.

Medium sized infestations with weed mats that can't be reached from the shoreline can be sprayed using boats fitted with hose and hand gun spray equipment. However, dense infestations can be impenetrable for many water craft with the added risk of boats potentially getting trapped.

For small and scattered infestations that occur close to the waters edge, a knapsack with hand gun can be used, or alternatively a hose and handgun fitted to a quad bike can be used.

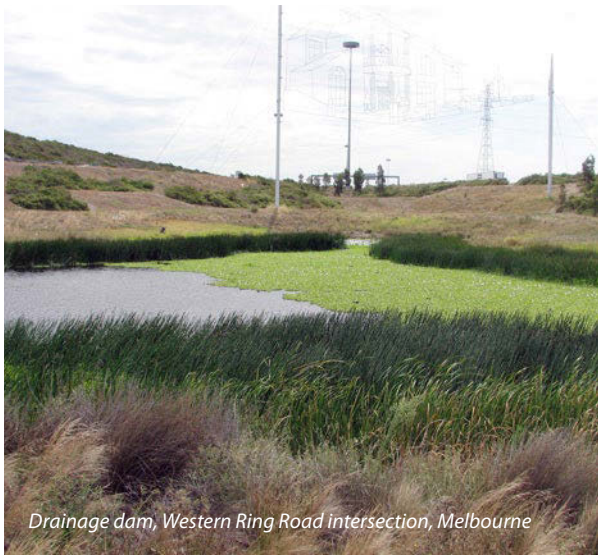
Use of the waterway

The use of the waterway will help to determine which herbicide and application method to use. Always check the label to see that the herbicide is registered for the type of aquatic areas it will be used in.

For conservation areas, mechanical removal could minimise herbicide use should sensitive vegetation communities be present. If herbicides are used,

Nikki Shepherd

Michael Wood



DEPI Victoria

Different sized water hyacinth infestations

plants should be spot sprayed preferably with a glyphosate registered for aquatic areas. Adding a colour dye to the mix can also help to see where the product has been sprayed to avoid overuse in these situations.

In waterways that are used for human consumption or potable water, the only herbicide available in these situations is diquat and strict withholding periods do apply.

Use of herbicides in and around water

When using chemicals in or around water, extreme care is required and they must be applied strictly in accordance with the registered label. Using herbicides in aquatic areas is strictly regulated and a licence may be required if using herbicides in or near water. Check with relevant government authorities for details.

When using herbicides in aquatic environments:

- check to see if a licence is required prior to using herbicides,
- only use herbicide and surfactant products registered for use in aquatic situations,
- consider if alternative methods of control may be more appropriate,
- only use a herbicide strictly in accordance with the label directions,
- keep detailed records of all herbicide applications. This is a legal requirement in most States and Territories, and
- check and abide by any withholding periods that are on the herbicide label.

Andrew Petroeschevsky

Spraying water hyacinth from a boat

Water quality

While herbicides can be a useful tool to reduce water hyacinth infestation levels, water quality may be affected by the dead and decaying sprayed plant material. The breakdown of this material can potentially reduce dissolved oxygen levels and affecting fish and other aquatic species. However, dissolved oxygen levels may already be low in waterways that contain heavy infestations of water hyacinth, as the thick weed mat can prevent the natural exchange of oxygen at the water surface.

To help maintain water quality and dissolved water oxygen levels, when using herbicides to treat heavy infestations, only treat 50% of the infestation at a time. Treating medium and small infestations with herbicides is unlikely to have any substantial impacts on water quality.

Seasonal timing of spray applications may also help to minimise water deoxygenation. For example, in the wet tropics, spraying of herbicides is best conducted either early or towards the end of the wet season. If spraying in the dry season, it would be worthwhile to spray in sections.

Contamination

Water contamination may occur when herbicides are not used as directed and applied at higher than registered rates. It is important to follow the label and only apply to water hyacinth as directed. Some spray equipment may need to be calibrated to ensure the herbicide is being applied at the registered rate.

A. Purdy

Spraying in sections – only the right half of this water hyacinth infestation has been sprayed

Follow-up treatments

All herbicide control, regardless of the chosen herbicide, will require additional treatments. Chemical control does not always give a 100% kill rate, plus any dead and decaying plant material returns nutrients to the water, making an ideal environment for the rapid growth of surviving plants.

Infestations will normally require several follow-up treatments during the growing season. Emergence of new plants that have germinated from the seed bank is also likely, making monitoring and follow-up treatments even more critical.

Using herbicides with biological control agents

If integrating herbicides with biological control, then herbicide choice will be important, as biological control agents are more susceptible to some chemicals than others. Herbicides that have the least impact on the biocontrol agents used on water hyacinth are glyphosate and 2,4-D acid.

For more information see Module 6: Integrated control options.

Reece Luxton

Reece Luxton

Reece Luxton

Alumy Creek: Water hyacinth infestation before spraying (top); 4 weeks after spray (centre); 6 months after spray (bottom)

Herbicides registered for use on water hyacinth

There are currently four herbicides registered for the control of water hyacinth in Australia. These are diquat, glyphosate, 2,4-D acid and amitrole, which are discussed in more detail below.

Diquat

Diquat is commercially available in two different concentrations 200 g/L and 20 g/L. The higher concentration 200 g/L diquat has a number of registered products available that are usually labelled as Diquat 200 non-residual herbicide. This concentration is suitable for high volume spray, boom and aerial applications.

Diquat is a fast-acting and non-selective contact herbicide that destroys only the vegetative part of the plant that comes into contact with the herbicide. It gives a fast knock-down on actively growing green plants. It becomes inactive once it comes into contact with soil and must be mixed with clean water. Dirty water contains suspended soil particles that can interfere with the herbicides action and may cause it to be less effective.

Diquat is the only herbicide that is registered for use on water bodies used for potable water; however, strict withholding periods are in place. If treating a large infestation of water hyacinth using diquat, it may be useful to treat only 25% of the infestation at a time. This will help minimise oxygen depletion by reducing the amount of decaying weed material in the waterway at any one time.

Use a wetting agent, as recommended on the label, to assist with herbicide effectiveness. Best results are achieved when the herbicide is applied evenly over the foliage of the plant.

The lower concentration products (20 g/L) are specified for use as a spot spray application or as chemical edgers. Diquat should not be applied using misting machines or controlled droplet applicators (CDA).

Glyphosate

Glyphosate is a non-selective herbicide that is applied by foliar spray to actively growing green plants. There are a number of products registered for use on water hyacinth, with varying strengths. It is important to choose a glyphosate product that is specifically registered for use in aquatic areas.

Being a non-selective herbicide, glyphosate will also kill any other plants that are growing within the weed mat, including grasses and sedges. Uptake of the herbicide is by absorption through the foliage and green stems. Glyphosate is a systemic herbicide that once absorbed into the plant, will move from the point of contact through to the roots.

It can take a number of weeks for water hyacinth plants to completely brown-off, die and sink. Repeat applications are often required to treat plants that were missed in the initial treatment and also from plants that regrow. Glyphosate is safe to use in an integrated control program with biological control agents.

Glyphosate is non-residual and becomes inactive immediately upon contact with soil. In water it becomes inactive by binding to dissolved and suspended clay particles and bottom sediment. Over several months it is

broken down into carbon dioxide, water, nitrogen and phosphorus.

If plants become submerged when spraying, the herbicide will wash off the plant surface and reduce its effectiveness. Rain within 2 hours of application will also wash the herbicide from the plant and may require re-treatment.

Due to its non-selective action, glyphosate can be a useful herbicide to use in situations where it is desirable to remove other vegetation from the area, such as harbourage areas and when secondary infestations occur within the water hyacinth mat. This should only be used on plants where glyphosate is registered for use. Conversely, when trying to minimise non-target impacts, an alternative herbicide should be considered.

2,4-D acid

2,4-D acid is the only formulation of 2,4-D that is registered for use in aquatic areas and is only registered for water hyacinth in Qld, NSW, WA and NT. It is a systemic herbicide that is absorbed by the leaves of the plant and then moves throughout the entire plant.

This herbicide is selective to broadleaf weeds and affects the growth mechanisms of the plant where it disrupts plant cell growth. Damage includes leaf withering, stem curl-over and eventual death. Visual effects of the herbicide are usually seen within days, with plant death and sinking normally occurring within 3 weeks following application.

To avoid non-target damage to other plants and spray drift, do not spray in windy conditions. 2,4-D is not suitable for using on water that is used for human consumption. When used as directed, 2,4-D is highly effective on water hyacinth and under normal conditions leaves no residual in the water. This formulation of 2,4-D is safe to use on the water hyacinth where there is biological control activity. This herbicide can be useful if wanting to minimise herbicide damage to any grasses and sedges located in the water hyacinth infestation.

Follow-up treatments are required throughout the growing season from the regrowth of plants.

On-going monitoring and maintenance treatments will be required long-term.

Amitrole

Amitrole is a non-selective systemic herbicide that is absorbed by the foliage and then moves throughout the rest of the plant. This herbicide prevents chlorophyll development in the plant, resulting in plants turning white normally within 7–14. Plants die and sink normally 2–6 weeks after application.

Amitrole gives good initial knockdown results and is only registered for spot spraying in drains and channels and the margins of streams, lakes and dams.

Follow-up treatments are required.

Herbicides registered for the control of water hyacinth

Herbicide	Registered use	Application	Rate	Comments
Diquat 200 Active constituent: Diquat 200 g/L Registered products: • Desiquat Non-residual Herbicide • Dia Kill 200 Herbicide Diquat 200 Herbicide • Diquat 200 Non-residual Herbicide • Reglone Non-residual Herbicide • Sanction 200 Non-residual Herbicide Poison schedule 6	Water hyacinth in aquatic areas Registered for use in all states **Withholding period:** Do not use treated water for human consumption, livestock watering or irrigation purposes for **10 days** after application	High volume spot spray, boom spray or aerial application DO NOT spray if plants are stressed or covered with dust or soil DO NOT spray with misting machines or CDA applicators Apply in dull weather or at the end of the day for best results	400 mL per 100 L of water 5–10 L/ha	Apply as an overall spray wetting foliage thoroughly Use higher rates for heavy infestations or for deep or dirty water A repeat application may be necessary 7–14 days later for dense infestations
Diquat Active constituent: Diquat 20 g/L Registered products: • Vegetrol Herbicide® • Watrol Non-residual Herbicide® Poison schedule 6	Water hyacinth in aquatic areas Registered for use in all states **Withholding period:** Do not use treated water for human consumption, livestock watering or irrigation purposes for **10 days** after application	High volume spot spray DO NOT spray if plants are stressed or covered with dust or soil DO NOT spray with misting machines or CDA applicators	4.0 L per 100 L of water 50–100 L/ha	Apply as an overall spray. Thoroughly wet foliage. Do not apply to weeds covered in mud or dust
Glyphosate Registered products: • Numerous products registered specifically for use in aquatic areas Poison schedule 5	Water hyacinth in aquatic areas Registered for use in all states	High volume application with handgun, knapsack or boom DO NOT use additional surfactant unless stated in the label and it is approved for use in aquatic situations		Apply to actively growing plants prior to flowering. Use higher rates on dense infestations Do not treat plants that are stressed or heavily covered in dust or silt Re-treatment may be required if plant becomes submersed or rain occurs within 2 hours of application

Herbicide	Registered use	Application	Rate	Comments
Active constituent: Glyphosate 360 g/L		Handgun	1–1.3 L/100 L water	
		Boom	6–9 L/ha	
		Knapsack	150 – 195 mL/15 L water	
Active constituent: Glyphosate 450 g/L		Handgun	800 mL–1 L/100 L water	
		Boom	4.8–7.2 L/ha	
		Knapsack	125–160 mL/15 L water	
Active constituent: Glyphosate 500 g/L		Handgun	720–940 mL/100 L water	
		Boom	4.32–6.48 L/ha	
		Knapsack	145 mL/15 L water	
Active constituent: Glyphosate 510 g/L		Handgun	700–900 mL/100 L water	
		Boom	4.2–6.3 L/ha	
		Knapsack	110–140 mL/15 L water	
Active constituent: Glyphosate 540 g/L		Handgun	670–900 mL/100 L water	
		Boom	4–6 L/ha	
		Knapsack	100–130 mL/15 L water	
Active constituent: Glyphosate 700 g/kg		Handgun	500–700 g/100 L water	Herbicide is in granular form
		Boom	3–4.5 kg/ha	
		Knapsack	75–100 g/15 L water	
2,4-D acid Active constituent: 2,4-D 300 g/L Registered product: Affray 300 Herbicide Poison schedule 5	Water hyacinth in waterways, non-potable water, drains, dams, margins, lakes and streams Registered for use in NSW, Qld, WA and NT only	Knapsack spray	50 mL/10 L water	High volume overall spray Coverage: 10 L spray solution/100 m^2 Spray prior to flowering Avoid causing submersion of sprayed plants
		High volume hand gun spray	1 L/200 L water	Overall spray Coverage: 200 L spray solution/1000 m^2 Spray prior to flowering Avoid causing submersion of sprayed plants

Continued on next page/…

Herbicide	Registered use	Application	Rate	Comments
2,4-D acid continued		Sprinkler sprayer	1 L/20 L water	Overall spray Coverage: 20 L spray solution/1000 m^2 Spray prior to flowering Avoid causing submersion of sprayed plants
		Helicopter application	5 L/200 L water per ha	Overall spray Use nozzles designed to produce coarse droplets, angled back at 45° to minimise spray drift Spray prior to flowering Avoid causing submersion of sprayed plants
Amitrole Active constituent: Amitrole 250 g/L Registered products: • Aggrav8 Herbicide • Amitat Herbicide • Amitrole 250 Herbicide • Amitrole T Herbicide • Weedeath Poison schedule 5	Water hyacinth in drains and channels, margins of streams, lakes and dams Registered for use in all states	High volume spot spray	280 mL/100 L water	Apply immediately prior to flowering

Application methods

Foliar spray is the only application method available for use on water hyacinth and can be applied using methods such as knapsack, hand gun, sprinkler sprayer, boom or aerial application. The chosen method will depend upon the size of the infestation and the choice of herbicide.

Applying herbicides using a hose and handgun power spray from a boat or the bank is the most common technique used in treating water hyacinth. In larger infestations, aerial spraying is used.

Use nozzles that are designed to produce spray droplets with very coarse to extremely coarse droplet sizes (>300 µm). Use nozzle types such as Air Induction, low pressure fans, flooding flat fan nozzles and other nozzle types commonly used for 'flood' applications to soils. Always follow the nozzle manufacturer's recommendations for spray pressure, spacing and height above the water surface.

Knapsack spraying

Knapsack spraying delivers a low-pressure foliar spray using a hand-held wand with nozzle attachment. Knapsacks can be either hand held or as a back-pack and usually about 15 L in capacity. This method of application is useful for spot spraying along water banks and amongst other vegetation, particularly in areas where access by boat or other watercraft is difficult. Knapsack spray units are readily available and can be used either on foot or with a quad bike. This method is useful for spot spraying small amounts of water hyacinth on regrowth along the water's edge or on seedlings.

Sprinkler spraying

This method of application uses a knapsack and modified wand to create a sprinkler effect that delivers the herbicide onto the plant with larger droplets and lower pressure compared to the standard knapsack and wand deliver system.

Nikki Shepherd

Spray units on quad bikes

Nikki Shepherd

Spray unit on a quad bike with a handgun on hose reel for hard to access areas

Chemical control options

Reece Luxton

Spray hoses on a modified floating device, manoeuvred across water by ropes

Reece Luxton

Spraying from a boat with hand guns off a hose reel

This method uses a longer wand, so has further reach and the sprinkler end rotates and produces a larger spray bandwidth.

An irrigation micro sprinkler is connected to the end of a long hollow fibreglass rod, about 3 m long, that is attached to the knapsack compression spray tank. Herbicide is applied at low pressures using a slow sweeping action over the top of plants, ensuring an even coverage over the foliage.

Hose and hand gun

High volume foliar application delivers large amounts of herbicide mixture to the plants and can be used to treat medium and small sized infestations. This method of application is not suitable for large infestations as access will be difficult. Units can be fitted to either boats or other watercraft and to vehicles operating from the shoreline.

In some situations, a venturi injection system may be used which can allow direct use of the water body to create the herbicide mixture. This allows larger areas to be treated without the need to carry a tank onboard. This is only suitable in small to

medium infestations where there is open water that can be utilised. It is important that the water is clean and only extracted from the upper levels as dirty water can impact on the effectiveness of herbicides.

Boat with spray unit

Boats can be fitted with high volume handgun spray units and can be used to access medium sized infestations in areas where aquatic mechanical harvesters are not able to access, or where bank spraying is not possible. Boats can be limited by heavy infestations, snags and shallow water.

4WD or tractor with spray unit

Land based vehicles fitted with spray units are ideal for edge-spraying, shallow and/or narrow watercourses and follow-up treatments from the shoreline. A long-hose can be useful to access areas on foot, where the vehicle is unable to go, such as rough or timbered riparian areas. Land-based spraying can be used in conjunction with boat spraying to optimise spray activities.

Boom spraying

Some water craft can be adapted and fitted with a boom for treating water hyacinth. This type of spray equipment is generally adapted in-house by local weed authorities and can be difficult to adapt to aquatic situations.

Boom spraying is best suited to infestations located in channels and drains. Best results are achieved when the nozzles used are mounted for 100% (or double) overlap (meaning the edge of one spray pattern extends to the centre of the adjacent nozzle).

Andrew Petroeschevsky

Spraying water hyacinth with tank and spray unit in the boat

Nikki Shepherd

Amphibious vehicle with spray unit on board

Aerial application

The only herbicides registered for aerial spraying are diquat and 2,4-D acid. Aerial spraying on a water body can be conducted using a helicopter. This is an expensive form of application and may require a permit from the relevant environmental authority. Aerial spraying using glyphosate would require a minor use permit from the AVPMA.

There are a number of difficulties associated with aerial spraying in waterways, including potential over-spray and drift of chemicals onto riparian vegetation. Accessibility into narrow waterways and flying height are also additional factors that need to be considered when deciding if aerial spraying is an option. Aerial spraying can be suitable for large infestations in open bodies of water such as lakes and dams.

When using aerial spraying, there are other factors to consider such as season and the surrounding land use. To help minimise water quality issues in the tropics, time applications to occur either early or towards the end of the wet season, or if spraying in the dry season, spray the infestation in strips.

Nikki Shepherd

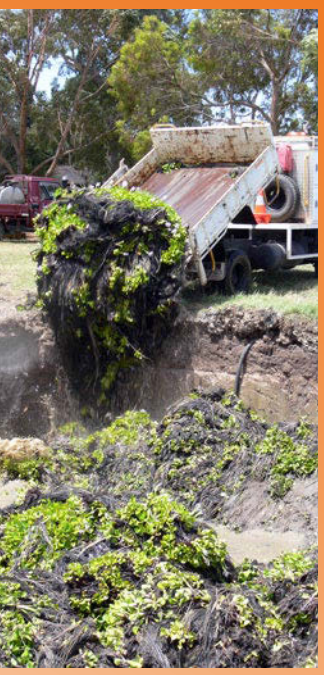
Preparing for aerial spraying

Nikki Shepherd

Aerial spraying water hyacinth from a helicopter, Gingham Watercourse

Module 4

Physical control options



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Physical control options

[*Adapted from van Oosterhout (2006), pp. 22-25; 50–55*]

Physical control is the removal or containment of water hyacinth using mechanical methods such as machinery, containment booms or fences and manual removal. Choosing which method or combination of methods to use will depend on the size of the infestation, resources available and the use of the waterway. Physical control can often be effectively integrated with herbicide controls.

Physical removal of water hyacinth is quite an expensive and laborious task; however, it does provide a few advantages over other control methods, including:

- There are no withholding periods and the water can be used immediately following control. This can be suitable for water bodies that are used for irrigation or stock and human consumption purposes.
- Immediate eradication of small infestations where small man made water bodies can be made inactive by filling in the site (for example a small dam).
- Reduced long-term monitoring costs when the seed bank is removed from a water bodies banks.

Michael Wood

Dense infestation of water hyacinth, Swan Bay

- Removal is immediate, opening up space available for boating or recreational activities or immediate improvement in water quality or habitat value.
- There are no issues with diminished water quality as it minimises the amount of dead plant material left in the water to decompose.
- The removal of nutrients to reduce growth rates for reinfestation.

All control activities undertaken must have a long-term monitoring, maintenance and follow-up control plan in place, to restrict seed bank build up and reduce the risk of reinvasion.

Physical barriers

Physical barriers such as floating booms and containment fences can be used in conjunction with all types of control measures and can be used to:

- contain an infestation to one area, to help minimise the cost and time required for chemical treatments or physical removal,
- separate areas that require different treatments,
- reduce the risk of further invasion downstream, where it could have potential long-term environmental impacts,
- separate a population of water hyacinth for the breeding of biological control agents,
- allow staged removal, and
- encircle and drag water hyacinth to an excavator with weed bucket for removal.

Floating booms

Floating booms are used to keep areas of water hyacinth contained in one area and are best used on calm and sheltered waters. Regular monitoring and maintenance is required as damage can be caused to the boom by floating debris and/or stock if allowed access to the area.

Small areas of water hyacinth can be contained with temporary booms made with nets or rope, which are useful to move scattered plants into one area when manually removing plants, or treating with a registered herbicide. Larger infestations will generally require stronger and more permanent booms.

Floating booms can range in size and capability, usually varying between 0 and 50 mm above the surface of the water. Booms can be purchased commercially, borrowed or hired from marine or waterways authorities, or made in-house.

Booms need to be strong and durable enough to hold the weight and movement of a water hyacinth infestation. It should also be designed to let go in flooding waters, to prevent losing the boom. Dislodged booms together with a water hyacinth mat may cause considerable damage to infrastructure downstream.

Depending on the purpose of the boom, it can be placed across the main channel of water flow, across inlets or still sections of water on an enclosed water body. At peak times of growth, booms may not be strong enough to hold a rapidly growing infestation and should only be used to contain sections of the infestation where control activities are being undertaken.

Commercial booms

Industrial strength booms are available commercially and are designed specifically for aquatic weed control. Booms used for oil spill control may also be beneficial to use. Commercial booms are generally able to cover a larger span of water compared to 'in-house' designs, and be used on a permanent basis. Industrial booms are made with built-in buoyancy chambers, can be used in shallow and deeper water, are more durable and come in a range of sizes and capacities.

Fence booms float up-right, creating a fence-like vertical barrier in the water (40% above,

Paul Sullivan

Boom used to contain water hyacinth, Gingham Channel

Andrew Petroeschevsky

Boom used to prevent water hyacinth moving into other vegetation

Paul Sullivan

Water hyacinth boom used in ephemeral water course, Gingham

60% below). The height of the boom can vary, depending upon requirements, is lightweight and constructed using square, flat sections.

Aquatic weed booms are similar to curtain booms as they have a hanging fine mesh curtain, or skirt 30–50 cm below the water surface to contain weeds and their root systems, while still allowing water to flow through. These types of booms can help to prevent small seedlings of water hyacinth from pushing underneath the floating boom.

Andrew Petroeschevsky

Boom used to contain water hyacinth seedlings

Kim Curtis

Water hyacinth in a dam at Kyogle being with held by a boom

Ag-pipe booms

Ag-pipe booms can be made 'in-house' from un-slotted agricultural or poly pipe to contain small–medium sized infestations. A good size to use is 38 or 50 mm diameter pipe, threaded with 5 mm diameter wire cable through the centre of the pipe. The cable ends are then attached to steel pickets to create a floating boom. Expanding foam, or similar, may be used to seal each end of the pipe to prevent it from filling with water and sinking. A hanging mesh curtain can be used with tree guard mesh or similar plastic mesh tubing as a sleeve and fasten around the pipe with plastic ties; however, it is not always necessary. Depending on the length and diameter of the boom, additional flotation (for example, polystyrene floats) may be required.

Andrew Petroeschevsky

Boom with ag-pipe and cable

Michael Wood

Ag-pipe boom used to contain regrowth of water hyacinth

Shrinking boom technique

This is a useful management tool when using herbicides or physical removal on an enclosed body of water, as it allows work to be carried out over a number of days and with fewer resources. It also allows herbicides to be applied in a way that is less likely to cause water deoxygenation, leading to poor water quality and fish death.

Once an area has been sprayed and killed or physically removed, gradually constrict the boom around the infestation. This process is repeated until the main body of the infestation has been treated. Follow-up treatments will be required at regular intervals for regrowth from the seed bank.

Containment fences

Containment fences are normally used on areas were water is flowing, such as across small creeks, causeways, culverts, spillways, drains and channels. Water hyacinth, and other water weeds, get trapped by the fence and stopping them from spreading further downstream.

Fences can be made of wire mesh (10 × 10 mm size) and constructed across the waterway. The mesh is anchored on either side with steel pickets and held in place with tensioned wire. They are generally temporary structures and are not designed to withstand flooding events. Due to the weight and mass of large infestations of water hyacinth, fences should be monitored regularly for signs of wear and damage, and to remove any debris. During the monsoon season, in tropical and sub-tropical climates, fences should be checked more frequently and be opened or removed prior to flooding.

An alternative to fences can be a poly pipe boom that will hold the water hyacinth in place until it can be sprayed or removed, and is less likely to be damaged by flooding.

Michael Wood

High tensile wire used for a shrinking boom

Michael Wood

Wire boom – used for the shrinking boom technique

Andrew Petroeschevsky

Containment fence across Gingham Watercourse

Physical control options

Jan Mitchell

A physical barrier along a fence will prevent seedlings moving off-site if water levels increase

Maintenance

Booms and containment fences should be checked regularly for signs of damage caused by floating debris or strain from the weed mat. To be effective, these structures may need to be in place throughout the duration of the management program (i.e. a number of years or even permanently). Maintenance checks should occur more frequently following periods of rain. Any damaged areas should be repaired and debris removed. When possible, remove or open containment fences and booms before flooding occurs.

Limitations

- Small plants, seeds and seedlings can be small enough to move through the mesh of fences and underneath booms.
- Booms and fences require regular on-going maintenance.
- During flooding, the weight and volume of the weed mat can damage or break the boom or fence.
- Must be used with another form of control.

Manual removal

This method involves manually removing water hyacinth by hand or with rakes and pitchforks or nets from a water body. It is best suited for:

- small plant numbers that are in the early stages of an infestation,
- the removal of plants in small, confined areas such as garden ponds, small dams or drains,
- small numbers of scattered plants that are growing in shallow water or along the edges of a waterway, and
- follow-up to chemical or mechanical control to remove floating or newly germinated seedlings.

Removal techniques

All plant material should be manually removed from the water and either placed in a bag for off-site removal, burial on site if a suitable location is available or spread out above the flood level to dry out and decompose. Waders or wetsuits are often required to make access easier for removal along the waters edge. Canoes or kayaks can also be beneficial if retrieving scattered plants from deeper water.

Pitchforks, scoops, rakes, shovels, bins, scoop nets and bags can be used to assist in collection. To make collection easier, use a boom made with net or rope, to gather as much water hyacinth into one area as possible. If the infestation occurs in a river or stream, start at the further most point upstream where the weed occurs, gradually working down-stream, collecting all water hyacinth plants along the way. Care should be taken to remove all weed material.

The weight of water hyacinth can make it difficult to remove large amounts at any one time. Garbage bins or heavy duty bags may be taken on board canoes and kayaks to place collected plants. Watercraft can also be used to push scattered plants closer to shore for easier collection.

Trawler net threaded top and bottom with high strength ropes with floats and weights, can

be used on small to medium size infestations utilising a 4WD vehicle or tractor to tow rafts of approximately one cubic metre from the water and up a gentle sloping bank for disposal.

Very small infestations or individual plants may be disposed of on-site by composting or being buried above the water level after they have dried out.

Manual removal as follow-up

If conducted frequently and regularly, manual control can be an effective and useful tool to remove emergent seedlings following mechanical or chemical control. It is the best method to use for removing water hyacinth from garden ponds and water features. During the peak growth seasons, monitoring should be conducted weekly and then monthly once the peak growth period has ended. It is particularly important to be vigilant when water levels fluctuate, as a seed bank normally dormant in deep water may become active if the water level recedes.

Due to the longevity of the seed bank, long-term control goals should be made to include regular monitoring and follow-up treatments. This should help to reduce the number of seed producing plants and decrease the seed bank over time.

Timing

Manual removal can be conducted all year round for small infestation or when it is being used as a follow-up measure. To avoid growth being faster than removal, consider undertaking manual control in the winter months when growth has slowed. Remove plants prior to flowering and seed-set to avoid addition of seed to the seed bank.

Limitations

Manual removal is very labour intensive and not suitable for medium to large infestations of water hyacinth. This option is not feasible if water hyacinth is growing faster than it can be removed.

DEPI Victoria

Manual removal of water hyacinth

DEPI Victoria

Manual removal of water hyacinth where herbicide cannot be used

DEPI Victoria

Manual removal of a water hyacinth mat

Mechanical removal

Mechanical removal of water hyacinth requires purpose built aquatic weed harvesters that can either remove the bulk of the plant material from the water surface or break thick mats apart and move them closer to the bank for removal by an excavator or other similar machinery.

Michael Wood

Mechanical harvesting, Swan Bay

Michael Wood

Mechanical harvesting, Mynumai Lagoon

The high machinery operating costs involved in broad scale mechanical removal can make this an extremely expensive option. In addition to the aquatic harvester, additional ancillary machinery is required on shore to help remove, process or bury the water hyacinth.

In areas that are difficult to access or too shallow, other means of control may be required. Mechanical control can be large scale or small scale and can be used in conjunction with herbicide control or hand removal.

However, in areas or states that have isolated infestations that are not large in scale, mechanical removal of water hyacinth can be an effective approach to:

- Eradicate an infestation in made systems where the site will be made inactive and/or shut down.
- Minimise future control and monitoring costs by excavating seed contaminated soil from the banks of a water body, only leaving dormant seeds in deep water. This option requires integration with either chemical control, aquatic harvesters or hand removal to treat plants outside the reach of an excavator in deeper waters.

Estimating capability of removal

Before undertaking mechanical removal, it is important to know:

- whether the rate of removal will be faster than water hyacinth growth rates,
- where and how the weed will be disposed of; associated costs of the whole operation, and
- the commitment of on-going resources for monitoring and follow-up control to ensure the whole operation is worthwhile.

Ideally, mechanical control should be conducted during the cooler winter months as growth rates are at their slowest. The size of the infestation will help to determine the size of machinery required and the amount of time it will take to remove the entire

infestation. Choosing the right sized machinery is important. If the machine chosen is too small, then it may not be effective.

Growth rates and timing

In tropical and sub-tropical climates, water hyacinth can grow all year round, with peak periods of growth occurring in the spring and summer months. In temperate climates, growth rates peak during summer and then slow significantly during the cooler winter months.

For the best results, the optimum time for undertaking mechanical and manual control is during the winter periods of slow growth. During this time, weed removal should be faster than water hyacinth growth rates and is also before flowering and seed-set in spring.

In states or areas that experience temperate climates with cold temperature variations, mechanical removal is most effective when undertaken in autumn, when water levels are at their lowest. This allows contaminated sediment to be removed well below the water bodies minimum annual water level, resulting in reducing the potential of seed germination, as seeds remains dormant at water depth.

In some locations, weed mats have been dislodged from the waters edge during the spring months. The weed mat has then been free to be flushed downstream with flood waters. While this method has been used on occasion, there are potential risks and dangers to downstream infrastructure and it should only be considered if there are minimal risks.

Mechanical harvesting

Mechanical harvesting may be appropriate when:

- the infestation is so large and extensive that other options of control are not feasible; for example, complete coverage of the water surface,
- restoring the function of the waterway is a priority, for example boating and recreation or environmental purposes, such as bird life or fish,
- the use of herbicides is limited, such as areas of high value conservation or potable water intake,
- large and mature infestations are present with secondary infestations of vines, sedges and grasses growing throughout and have anchored the mat to the bank,
- the harvested water hyacinth can be adequately disposed of,
- funding is available, and
- nutrient removal is desired to reduce reinfestation.

A number of weed harvesters have been purpose-built for aquatic weed control. Harvesters vary in their size, capacity, manoeuvrability and cost. Paddlewheel-driven harvesters normally collect the weed onto a conveyor that moves it to an onboard storage area. Due to the weight and bulk of many water hyacinth infestations, traditional weed harvesters such as this are generally limited in their capacity to remove the weed directly from the water.

Instead of collecting the weed material from the water, aquatic weed harvesters have been used to break weed mats into sections and push them to the bank for removal by other machinery on-shore, usually an excavator. When the weed mat has become anchored to the shore from bank side grasses and vines growing out onto the water hyacinth, aquatic harvesters can also be used to break the bank-bindings and then push the weed mat to an on shore excavator for removal.

Bank side herbicide spraying undertaken a few weeks prior to mechanical removal can kill the grasses and vines, making is easier to detach the mat from the bank. Dense infestations close to shore can also be broken up and removed by a land-based excavator equipped with a large rake or weed bucket.

Physical control options

Michael Wood

Harvester breaking up mats of water hyacinth

For each site and infestation level, to keep the operation as cost effective as possible, it is important to match the size of the harvesting machine to the capabilities of the excavator. If not matched appropriately, one machine will be sitting idle for much of the time.

Smaller boats fitted with mesh rakes or blades to the bow, are useful in pushing small water hyacinth mats to the excavator. These modified boats, which act like an aquatic bulldozer, are also effective in pulling weeds from the bank and collecting smaller patches of weed in areas inaccessible to the harvester.

Michael Wood

Harvester pushing a water hyacinth mat to shore

Michael Wood

Harvester unloading collected water hyacinth mats onto a bank

Michael Wood

Harvester pushing large mats to excavator

Michael Wood

Transfer of plant material from shore by loader

Ancillary plant and machinery

The amount of ancillary machinery required will depend on the size and location of the infestation.

Shore based excavators

Excavators can be expensive and can be used for either large scale or small scale operations.

Excavators remove water hyacinth directly from the water and either deposits it in stockpiles above the shore line or directly into a dump truck. They are located on the bank and can be fitted with a modified weed bucket, long-reach arm or extension arm and weed rake to assist with removing the weed material.

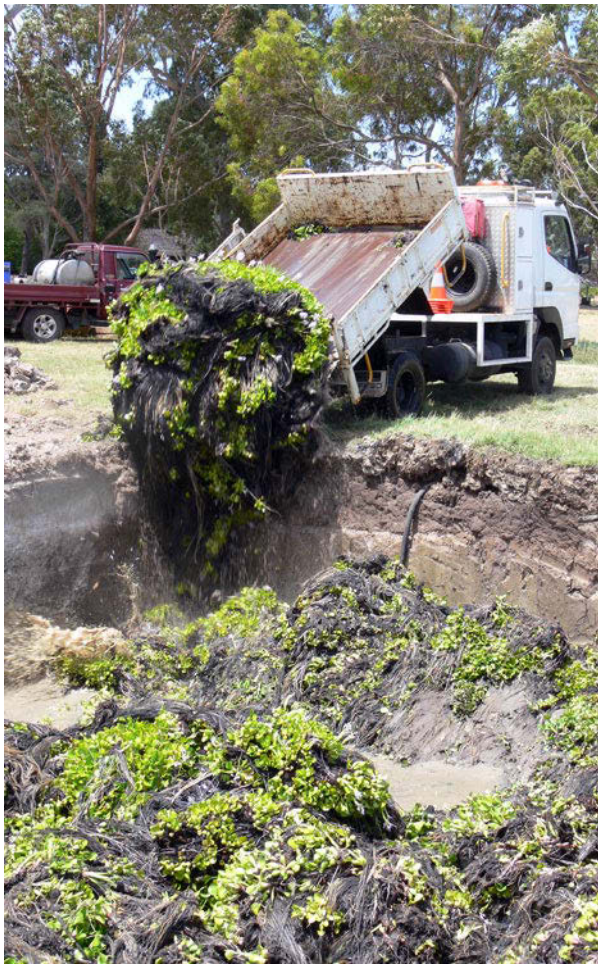
Excavators can be used in conjunction with aquatic harvesters or small modified boats that push or drag the weed mats to within reach of the excavator.

In cases when there are no existing ramps where excavators need to be placed, on-shore site hardening may be required as heavy machinery and trucks may get bogged due to the large volume of water involved. In extreme situations, road base may need to be added. Permits from relevant authorities to undertake any earthworks on banks will likely be required. Excavators may also need to create benches on steep banks to allow for safe operation, these can be restored on project completion. This may not be an issue in states that

Different type of harvester

DEPI Victoria

Excavator loading plant material directly onto truck



DEPI Victoria

Dumping plant material into pit

Michael Wood

Excavator attachment – slotted bucket

DEPI Victoria

Excavator attachment – clawed bucket

DEPI Victoria

Excavator with a small arm

experience temperate climates and undertake the works in autumn, when the site in likely to be dry.

Small boats

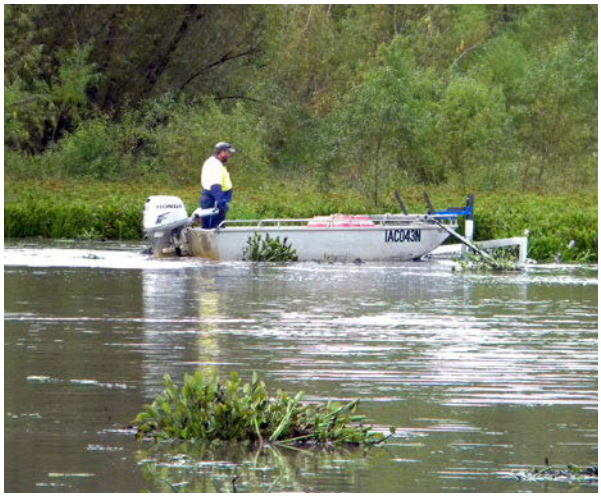
Modified small boats with bow mounted mesh scoops or rakes may also be used to push or move small amounts of water hyacinth from hard to access and shallow water. These vehicles are useful in supplementing the work of the aquatic harvester as they are more manoeuvrable and remove weeds from the bank and around snags.

DEPI Victoria

Long armed excavator

DEPI Victoria

Excavator with a longer arm attachment



Reece Luxton

Boat with an 'aqua dozer' pushing mats of water hyacinth

Andrew Petroeschevsky

Truxor with large screen attachment

Two small boats joined with a net between have been successful in moving water hyacinth mats up to the size of a tennis court, to the bank for removal by an excavator.

Truxor®

The Truxor® is an amphibious machine that operates on tracks that is able to cut and collect aquatic weeds in narrow channels and hard to access areas. It is more manoeuvrable than larger aquatic harvesters and has a range of attachments such as scoops and screens, or a platform for portable spray equipment that can be fitted depending on requirements.

Michael Wood

Truxor moving large mats of water hyacinth

Paul Sullivan

Truxor type machine

Michael Wood

Truxor

Physical control options

Ramps

Boat ramps can be used to launch harvesters and modified boats. They are also useful for placing earth moving equipment such as excavators for weed removal.

Dump trucks

Trucks are generally used to transport the weed above the flood level. Dump trucks can only be used for on-site transportation to the stockpile as they drain water and may not be allowed on public roads. If being moved to an on-site location, material may need to be spread out to dry. Self propelled wheeled side tip sugarcane buggies have been used successfully to transport weed; however, care must be taken when side tipping as they are designed to lean against a cane bin and could topple.

Wet water hyacinth can be compacted to reduce the water content prior to transportation, which can help to reduce transportation costs. If being moving directly off-site, material can only be removed in a sealed truck to avoid leakage or spillage and may require a permit for transportation.

Support vehicles

Backhoes and bobcats are sometimes required to transfer plant material to dump trucks or garbage trucks and to move weed piles around on shore. Traxcavators can be used to collect and carry water hyacinth away from the excavator and heap into windrows, particularly if the site becomes boggy. Control of water runoff from the weed piles is important to avoid bogging of the site and to stop nutrients re-entering the wetland.

Booms

Booms can be used to move water hyacinth into one area in a place convenient for removal by other machinery.

High tensile strength booms

High tensile strength booms can be used to catch, hold or encircle weed rafts to allow weed to be dragged to an excavator for removal. Booms can be constructed from two 12 mm galvanised steel or stainless steel cables joined by 300 mm long chain at one metre intervals with floats attached. Draw cables can be shackled to the boom at ends and pulled by machinery.

Paul Sullivan

Boom being used to drag an infestation to the shore for removal

Small scale mechanical removal

Small scale removal can be used as an ongoing follow-up to large scale control activities, using smaller modified boats to push weed mats closer to shore where they can be removed by other means, small harvester and Truxors®.

Equipment and machinery that are often used for other aquatic weed removal such as suction dredges and mechanical scoops do not tend to be as effective on water hyacinth due to the sheer bulk of the plant material.

Disposal of harvested water hyacinth

Physical removal of water hyacinth requires appropriate disposal to ensure it does not continue to grow or infest another area. The high volume and weight of weed material that is removed from the water can make removal off-site to a waste management facility very costly. However, if eradication of water hyacinth is a priority, then allocation of resources to remove the weed completely from the site will be important.

Weed mats can be left to dry on-site in most instances before being transported to a waste management facility. Off-site removal may also be required if water hyacinth has been removed from a polluted water body and there are ecological or health concerns from absorbed contaminants in the plants. A permit for transporting noxious weeds may be required if transporting off-site.

Water hyacinth has been known to survive for months in mud away from water. Harvested plants must be either buried nearby on site or piled away from the shore line, above the flood level and spread out to dry completely, or left in piles to decompose. Due to the high water content in water hyacinth, piles will leak water for some time. To stop water from flowing back into the water body, taking viable seeds and other contaminants with it, it may be necessary to bund the piles. Large stockpiles may be burnt, but is not a requirement.

Permits or licences may be required to compost large amounts of organic waste at the site and in some states an Environmental Impact Statement is needed. Always check with State and local government authorities for requirements.

Problems may arise if the water hyacinth is contaminated with other noxious weeds, such as hymenachne or alligator weed, which can be easily spread when the hyacinth is moved. Stockpiles will need to be processed at a sanitised and quarantined area, where they can be treated with herbicide to minimise the risk of contamination by other noxious weeds.

Limitations of mechanical removal

- High equipment costs compared to chemical control.
- Some machinery is not suitable for shallow water or areas with accessibility issues or highly sensitive vegetation.
- Time consuming.
- Labour intensive.

DEPI Victoria

Loading plant material for disposal directly onto a truck

Follow-up, monitoring and control

The large seed bank of water hyacinth means that reinfestation will most likely occur following treatment. There is no point in allocating money and resources to initially clean up an infestation unless a long-term monitoring and follow-up control plan is in place.

Small-scale mechanical removal, together with manual removal and herbicide treatments provided on a regular basis are effective and is a relatively low-cost approach to achieving eradication or the on-going management of water hyacinth.

During the peak growth seasons, monitoring should be conducted weekly and then monthly once the peak growth period has ended. It is particularly important to be vigilant when water levels fluctuate, as a seed bank normally dormant in deep water may become active if the water level recedes.

Due to the longevity of water hyacinth seed, a monitoring program should be developed that continues indefinitely.

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Module 5

Biological control

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Biological control

The following information has been extracted mainly from Julien *et al*. (1999), Julien (2001), Julien *et al*. (2001) and Julien (2012).

Biological control agents can play an important role in helping to reduce the impacts of existing infestations, particularly when eradication of the infestation is not feasible. During the 1970s, 80s and early 90s, four insect species introduced from South America were released by CSIRO into NSW and Qld to assist in the control of water hyacinth. These insects were:

- Two weevil species, *Neochetina eichhorniae and Neochetina bruchi*
- Two moth species, *Niphograpta albiguttalis and Xubida infusella*

All have become established, but only three (the weevils and the moth *N. albiguttalis*) are widely established and are currently distributed through much of Qld and NSW. The impact these insects have had on water hyacinth infestations has been varied. The most success has come from the two weevils in the tropical and sub-tropical regions of the country. There are many limitations that exist with the current biocontrol agents, particularly in sub-tropical and temperate climates, which are explained later in this module.

Management considerations

Biological control will not eradicate a water hyacinth population. If conditions are suitable, it may suppress plant growth and reproductive ability, thereby reducing the weed's population to a more manageable size. Biological control reduces reproduction by suppressing flowering and therefore seed-set, and by reducing production of daughter plants (off-shoots).

Biological control should be considered for all infestations that cannot be reasonably eradicated and are within the climatic areas suitable for weevils. If biocontrol is being used in a control program, it should ideally be implemented early. In many situations it may not provide control on its own, or in the timeframe required. However, it should be considered a part of an integrated management strategy.

Site specific management goals will help determine which course of action to take and which options for control are the most suitable. If eradication of water hyacinth from a site is the goal, or an infestation requires immediate removal, then biological control should not be a consideration.

Given the current agents available, biocontrol is most suited to:

- infestations located within an enclosed body of water, in tropical and sub-tropical climates,
- areas with high conservation values where infestations require ongoing suppression with limited herbicide treatments,
- infestations that have developed over a number of years, have a large seed bank and cannot realistically be expected to be eradicated, and
- medium to large sized infestations – following large scale mechanical or herbicide control to help maintain infestation at low levels.

The weevils

The two water hyacinth feeding beetles are similar in appearance and can only be distinguished in the field with difficulty. Their feeding patterns and plant impact is also similar. When released together, it has been suggested that the two species may complement one another. Also when released together, it is likely that the species most suited to the current conditions will predominate.

To date, the two weevils have shown the most success in the tropical and sub-tropical areas of Qld. Both weevil species have been released throughout Qld and NSW and are well established.

Neochetina eichhorniae

Description

Neochetina eichhorniae were the first agents released for the biocontrol of water hyacinth in Australia. Adult are 4–5 mm long, grey in colour and very similar in appearance to *N. bruchi*.

Lifecycle

Small, slender and soft eggs are laid into the leaf and petiole (leaf stalk) tissue of water hyacinth, just beneath the surface of the leaf. The eggs can often be seen as a slight swelling on the leaf surface and normally hatch within 7–10 days. The larvae tunnel inside the petioles and crown and develop over a period of 30–45 days, feeding on plant tissue and damaging the axillary buds during this time.

The larvae go through three stages of development and in the final stage, move towards the upper root area, where it makes a cocoon. Adults emerge from the cocoon after about 20 days and start to feed on the youngest succulent leaves within 24 hours.

This whole process takes between 96 and 120 days in its entirety, depending upon temperature, with adults able to live between 140 and 300 days. The females lay 5–7 eggs per day to a total of about 300 eggs.

Neochetina bruchi

Description

First released into Australia in 1990, adult beetles are 4–5 mm long and tan brown in colour and only slightly larger than *N. eichhorniae*.

Lifecycle

Small, oval, whitish eggs are laid by female weevils into the feeding/chew holes on the petioles (leaf stalks) and hatch in about 7 days. The hatched larvae tunnel into the petiole or crown to feed. The larvae undergo three stages of development in about 33 days. The larvae in the final stage of development will leave the crown and move to the roots where they make a cocoon. Adults will emerge from the cocoon about 20 days later, with the whole cycle taking between 72 and 96 days depending upon temperature and available nutrients.

Paul Sullivan

Neochetina bruchi (left), N. eichhorniae (right), and feeding scar

Mic Julien

Neochetina bruchi eggs

Females can generally lay between 300 and 700 eggs in her lifetime. *N. bruchi* weevils can live to about 100 days.

Weevil temperature and nutrient preferences

Weevil development is mainly dependent upon temperature and available nutrients. For the weevil *N. bruchi*, the optimum temperature for adult feeding and egg laying is 30°C. High temperatures and low humidity may decrease egg production and reduce adult survival, while temperatures below 15°C halt development of the eggs and they will often fail to hatch. Very low temperatures will also affect the survival of adults and populations may decrease in size.

Mic Julien

Weevil feeding scars on water hyacinth leaves

Paul Marynissen

Weevil damage in water hyacinth petioles

Both weevil species are inactive over winter. *N. eichhorniae* requires temperatures of 25°C degrees for females to lay eggs and above 20°C for the eggs to hatch.

Weevil development is also influenced by the nutrient status of the host plant. *N. bruchi* develop better in conditions where high levels of nutrients are readily available, while *N. eichhorniae* tend to feed on plants of lower nutritional quality.

Weevil feeding characteristics and plant damage

Once weevils have established at a site, one of the earliest impacts they have on a water hyacinth population is suppressing flower production, leading to reduced seed production.

The damage and feeding patterns for both weevils are similar. Damage to the water hyacinth plant comes from feeding by both larvae and adults.

The newly hatched larvae tunnel into the petioles and move down into the crown of the plant. Here they feed on the newly forming axillary buds until they are ready make their way to the upper roots and form a cocoon. The presence of larvae can be determined by streaks of dark dead tissue located just beneath the surface of the petiole. If you break open such a plant, larvae may be found in the plant tissues.

Adult weevils are nocturnal, mostly moving around and feeding at night. During the day they remain concealed in the crown of the plant. At night adults feed on the fleshy outer layers of the youngest, softest leaf and petiole. Characteristic squarish feeding scars appear on the foliage, exposing the plant to water-logging and secondary infections from bacteria and fungi.

Heavy feeding from weevils can cause the leaves to dry and curl, and the petioles become spindly and brittle. Plant growth is stunted and the production of flowers, shoots and leaves are reduced. Damaged

and rotting petioles eventually become waterlogged and sink, reducing the size of the weed mat.

Presence of weevils

To determine if weevils are present in an infestation, there are a number of signs to look for. These can include:

- Characteristic feeding scars on the leaves and petioles of plants. A good place to look for feeding scars is around the join of the leaf blade and the stem.
- Visual presence of adult weevils. Weevils are nocturnal insects and hide in the crown of the plant during the day. To find adult weevils, tear open the plant to expose the crown.

A plant with many feeding scars indicates a healthy population of weevils has established. Scars on the youngest central leaves of a plant, indicates that weevils are currently active. Scars on older leaves, indicates that weevils were active some weeks ago. Scars on all leaves indicate that there is a good on-going weevil population.

The moths

Both moth species are native to South America and have been known to cause considerable damage to water hyacinth plants. The moths were released into Qld and NSW mostly during the 1970s and 80s. Following establishment of the moth *Niphograpta albiguttalis*, the impact on water hyacinth infestations was often temporary and patchy. The other moth, *X. infusella*, has established at just one site in south-eastern Qld.

Rearing of these agents has ceased and there are no plans for any future release of the two moths. A brief description of each moth has been given below; however, all future reference to biological control agents throughout the series of modules will refer to the weevils, *Neochetina eichhorniae* and *Neochetina bruchi*.

Xubida infusella

The moth, *Xubida infusella*, is extensive and very damaging to water hyacinth throughout its native range of Central and South America. It was first released in Australia in 1981 at two locations and failed to establish. It was released again in 1996 at various locations between northern NSW and northern Qld and established at one site only where the impact is minimal.

Niphograpta albiguttalis

Originally release into Australia in 1977, it naturally spread and is now thought to be widely established throughout northern NSW and Qld. Damage caused by the moth is often patchy and the impact is temporary.

Description

Adult moths are 6–10 mm long and have a wing-span of 17–25 mm. Wing colour ranges between golden-yellow to charcoal grey, with brown, black and white markings. They are difficult to see in the field.

Lifecycle

Creamy white circular eggs are laid into the leaf tissue, mainly at feeding sites, and hatch about 4 days later. Larvae have five stages of development over a 2–4 week period, where they continue to tunnel deeper into the petiole. White cocoons are

Mic Julien

Niphograpta albiguttalis

developed inside a chamber within the petiole that has been chewed by the larvae. Adult moths emerge from the cocoon within 7–10 days and live for approximately 4–9 days. The entire lifecycle can take between 3 and 4 weeks.

This moth tends to attach to the small bulbous form of water hyacinth that occurs on the edge of expanding mats or in new loose infestations. The larvae tunnel in the roundish petioles causing visible discolouration. On breaking the petiole open larvae may be found.

Expectations, timeframes and limitations

Due to climatic preferences the weevils have shown more success in Qld compared with the cooler climates of NSW. The water hyacinth weevils need considerable time and favourable climatic and environmental conditions to build sufficient populations that can impact on an infestation. Weevil establishment and damage is usually fastest in tropical climates, which can vary between three to six years from release. In these climates plant nutrition and flooding will more likely be the limiting factors rather than temperature.

In cooler climates the temperature becomes the most important factor in biological control establishment and performance. Weevils will not breed during the cooler months so populations will naturally take longer to establish. Accurate estimates are not known but anecdotal reports suggest it can take up to six years in subtropical climates for populations to reach sufficient numbers. In most situations in subtropical climates the level of control will be limited to suppression of plant flowering, seed production and rate of spread, rather than mat collapse. In temperate climates it is unclear if weevils can reach sufficient numbers to provide control.

The weevils on their own will rarely cause sufficient levels of damage to control mats of water hyacinth, unless ideal conditions are present. Full control of mats would only be expected in larger water bodies in tropical and sub-tropical climates that are neither prone to flushing or drying out. The stable conditions provided in such environments allow populations to build to sufficient numbers to provide control. Disruption to the biological control cycle can be caused by seasonal flooding that flush the weed and dry seasons that can dry up water bodies. Where such conditions persist it will be difficult for the insect populations to increase to the levels required to reduce the weed infestation.

The biocontrol process (van Oosterhout 2006)

In favourable conditions, weevil populations can increase quickly, feeding on nutritious plant material. Gradually the food supply decreases to the point where plant quantity and quality declines resulting in a diminishing weevil population. Once weevil numbers are low, any remaining water hyacinth regrows. Weevil numbers will then increase in response to the increased food supply, and the whole cycle happens again.

This cycle of peaks and troughs continues until equilibrium, or 'biocontrol' balance is reached, which can takes years to occur (see Figure 2). This point of equilibrium may not even be reached in some situations where conditions are not particularly favourable, such as cool climates and areas where seasonal flushing of waterways takes place.

Mass rearing programs in Australia

While the weevils are already well established in Qld and NSW, there are times when new releases are required. This is generally when new infestations are found, or when populations need to be reintroduced following flood events or other disturbances (e.g. drought).

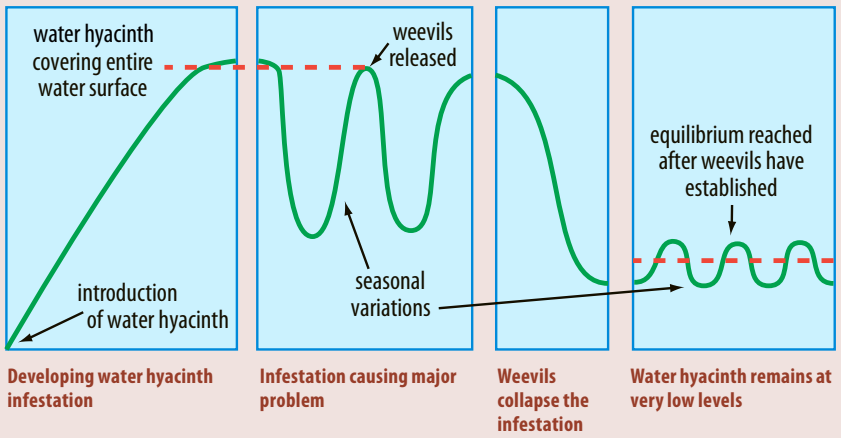

Figure 2. Peaks and troughs in a water hyacinth infestation and after release of weevils. Red dashed lines indicate levels of infestation (adapted from Harley & Forno 1992).

New weevil populations can be established by either releasing adult weevils or by introducing 'host' water hyacinth from a purpose built rearing facility that contains adults, larvae eggs and pupae. The advantage of the later method is that all stages of the insects' development are included in the redistribution. To ensure sufficient quantities of insects are included, approximately two garbage bins full of plants must be moved with the shipment.

Weevils can be sourced from either in the field, or from a purpose built rearing facility. The Brisbane City Council currently operates the only large scale water hyacinth weevil rearing facility in Australia. Weevils sourced from purpose built facilities are normally supplied with host water hyacinth plants.

Paul Sullivan

Pools used to breed water hyacinth weevils, Brisbane

Field harvesting of insect populations from naturalised infestations can be utilised if weevils can't be sourced from a rearing facility. However, weevils should be extracted from the collected plants to avoid the spread other aquatic weeds and pests. It is convenient, cost effective and ensures weevils are well adapted to field situations, but it is a labour intensive task. Insects can either be hand picked from plants or the plants themselves can be collected in the field and later subjected to a tub extraction process to collect weevils. This process is described below.

To collect weevils using the submerged extraction process:

- place infested water hyacinth plants in troughs (approximately 1–2m^2) filled with water,
- place a wire mesh over the surface of the hyacinth and push below the surface, and
- hold the mesh below using weights (bricks or rocks).

Adult weevils will shortly begin floating to the surface and they can be collected with a small sieve and placed in a collecting container. Weevils should keep floating to the surface for another 20–40 minutes.

Paul Sullivan

Collecting weevils that float to the surface by submerging plants

Collected weevils can be placed in small plastic containers with several water hyacinth leaves but care must be taken to keep containers with collected weevils out of direct sunlight as overheating will kill the weevils.

The transferring of host plants from one field site to another is not recommended as this practice can spread other aquatic weeds and pests.

Storage and transportation

Weevils that are distributed with host plants can be transported in either 40 L tubs (garbage cans) or hessian sacks. Providing material sourced contained healthy weevil populations it would be reasonable to expect each tub or bag would contain many individuals of all insect stages. To ensure plenty of weevils will be released, aim for two or three tubs/bags of plants per release site. To prevent overheating the tubs/bags should be kept cool and moist, and out of the sunlight. Transportation in air conditioned vehicles is recommended.

Adult weevils that have been hand picked or collected using the tub extraction technique can be transported in concentrated numbers in small containers containing small amounts of plant material. To prevent overheating containers should be placed inside a polystyrene box or esky, kept moist and out of direct sunlight.

A. White

Insects can be stored and transported in small containers with leaf material (reproduced with permission – Julien et al. 1999)

Weevil release strategies

Adults or weevil infested material can be simply tipped from containers into the infestations. Ideally at least 250 weevils should be released together in one area. This helps keep the weevil population as close together as possible and increases breeding rates. However, releases with as few as 50 adults are likely to result in establishment if conditions are good; i.e. with warm temperatures and healthy plants that are not disturbed.

Selecting the right site maximises the initial survival and establishment rate of weevils. The following factors should be considered when undertaking releases:

- **Other controls:** release sites should be located away from areas where herbicide or mechanical control methods occur as these methods may interfere with establishment.

- **Plant condition:** releases should be made on plants that are in good condition. Also select sites where the weed mat is stable and unlikely to be washed downstream.
- **Aspect:** weevils should be released into an open sunny area.
- **Catchment location:** weevils should be released as high up the catchment as possible except in impoundments where the weed will be concentrated near the dam wall which is a good place for release.
- **Infestation size:** in an extensive infestation it is best to undertake releases at multiple sites across the infestation area. Larger quantities of weevils will be required; as an example, if 1000 weevils were available divide them into 4 releases of 250 each. Weevils can be released into 1 × 1 m quadrats, which helps contain them whilst populations are growing.

Charlie Mifsud

Releasing weevils in to a large water hyacinth infestation

Monitoring

Monitoring programs are necessary to measure the establishment, extent and impact of the weevils at release sites. Counts of adult weevils and feeding scars on the plant are simple techniques to check for presence or increases in population of weevils. Time series photography can be used to monitor increases in damage over time, including both reductions in plant flowering and density of infestations. All three techniques used together will provide the most reliable information on the weevils' performance.

Counting feeding scars and weevils

The presence of feeding scars provides a good indicator that weevils are present provided that the feeding scars occur on the youngest one or two leaves. Counting feeding scars over time can provide an indication that the population of weevils is increasing or decreasing. It is also useful to record numbers of adult weevils per plant whilst counting feeding scars. For example, collect a plant, select the youngest leaf and assess the number of feeding scars, then pull the leaves part to expose the crown and search for adults hiding in the nooks and crannies of the crown and upper roots. Repeat this for half a dozen plants spaced well apart to obtain a better overall understanding. Repeating this over time will indicate if the weevil population is changing. Feeding scars on the new uncurling leaf normally indicate weevil activity within the last 48 hours, whilst scars on the second newest leaf indicate activity within the last week.

Kim Curtis

Water hyacinth showing weevil scars on leaves

Record the number of adults present and graph the results over a period of time (normally years) to show increases and decreases in populations over time. For tropical areas monitoring can be undertaken all year round. In temperate and subtropical climates monitoring should begin when scars are first noticed in early to mid summer.

It is not possible to generalise about the level of weevil populations required to control hyacinth as the relationship between insect populations and the damage that leads to control will vary with each site and the local environment. Counts of weevils and feeding scars are instead indicators of the presence of and changes to population numbers over time.

Time series photography

Time series photography using images taking before and after release can provide a reliable visual record of the impact of the weevils at the release site. When selecting photo points and taking photos consider the following:

- Select a photo point site that is elevated, has a good view of the infestation and can be easily found, even after several years.
- When taking follow-up photos carry of copy of the initial photo as a reference.
- When taking photos include in all images key natural landmarks that are unlikely to change.
- Use similar lens settings for each image.

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Module 6

Integrated control options

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Integrated control options

Integrated control is utilising a number of complementary control methods at different times, to give the best possible results to minimise the impact of weeds. Selection of integrated controls is based on a range of site specific factors, including hydrology of the system, size of infestation, climate, nutrients and objective of the control program.

Having a site specific integrated weed management plan will address the appropriate control methods to use, and include how and when best to apply each method to achieve optimum results. The management plant should also include how the infestation will be monitored and maintained, the duration of the maintenance program, as well as how it will be resourced in the long-term.

The most commonly used integrated control strategies for water hyacinth are:

- biological combined with herbicide control,
- chemical and mechanical control, and
- chemical and/or mechanical control, combined with water level manipulation for seed bank management.

Biological and herbicide control

Combining biological control with herbicide control in a water hyacinth infestation can help to keep infestations at a level where it will have minimal impact on the waterway.

Biocontrol takes time to establish within an infestation and may take many years for results to be seen. Ideally biocontrol agents should be utilised early in the management strategy and plans should be in place to coordinate and integrate control treatments for maximum benefit. Biological control should always be used to complement other control methods, as it is unlikely to provide the level of control required to effectively suppress an infestation on its own.

The management goals of a water hyacinth infestation will help to determine the options available for control and which course of action to take. If the infestation requires immediate control measures, then biocontrol may not be an option. The integration of biocontrol together with other herbicide control is best suited to established infestations and where eradication is not feasible.

Biological control combined with herbicides works best in tropical climates, as weevils continue to breed and develop year-round. In sub-tropical areas, breeding slows down during the cooler winter months and the weevils have less impact on water hyacinth during this time. In temperate climates, biocontrol agents have been known to establish, although their impact on water hyacinth infestations is not clear.

The integration of biocontrol with herbicide use has, in many instances, been successful provided the weevils are given an untreated area to move to following treatment. This type of integrated control has not been fully documented in Australia; however, anecdotal evidence suggests that there are some situations where it has suppressed infestations.

Weevils are reportedly able to tolerate the application of certain herbicides and for best results, require an area that is left untreated to support the insect population. This allows weevils a place to breed and move from sprayed to unsprayed plants. Providing a healthy population of weevils remain, in some instances, they can help suppress growth of remaining plants, or more rapidly recolonise on new plants should the infestations re-emerge.

When integrating biocontrol with herbicide usage, there are a couple of options to choose from depending on the site. Ideally, a site should be left untreated as a refuge for biocontrol agents. If this is not possible and maintaining a biocontrol population is important, herbicide application should be timed to coincide with the adult phase of the weevils' growth to allow movement from the treated plants.

The successful integration of biological with chemical control may, gradually over time, help to reduce the amount of herbicide follow-up treatments required. There are a number of factors that need to be considered so that each control method will complement one another and not impact on the effectiveness of the other.

Factors to consider include:

- Is the site suitable for biological control?
- Is leaving an untreated refuge area an option?
- Location of floating booms to section off untreated areas.
- Size of the untreated areas.
- Choice of herbicide.
- Timing of herbicide treatments.
- Monitoring.

Site suitability

There are a few situations where biocontrol may NOT be suitable. These can include:

- areas where only a small infestation is present, less than 1 hectare in size, for example dams,
- infestations that are new and isolated, and can be eradicated, and
- infestations that need to be continually suppressed to keep water hyacinth at very low densities.

In situations that require immediate removal of the weed from the water surface, including areas with high conservation value and high recreational use, herbicide and/or mechanical treatment may be required initially to remove the bulk of the weed. Biological control may then be used as part of the ongoing management strategy.

Ideally, where an infestation contains large old thick mats, the bulk of the infestation should be removed by mechanical methods and followed up with herbicides to treat any remaining fragmented plants. This creates more favourable conditions for future biological and herbicide control. Biocontrol agents can recolonise on the weed material that is left on the bank following mechanical removal.

Leaving untreated boomed areas vs. optimal spraying times

As each infestation site is different, it will have different requirements and need site specific control and management plans in place.

In situations where the protection of biological control agents is important, but it is not feasible to leave an area untreated as a refuge, then timing herbicide applications to coincide with the weevils adult phase of growth would be beneficial. This is of particular importance in sub-tropical areas where cool winters are experienced and weevil reproduction has slowed. Herbicide applications that treat the entire infestation should ideally be conducted from spring through to autumn in sub-tropical climates and may occur all year round in tropical climates.

In infestations where an untreated area is possible, spray treatments on the remaining infestation can occur when plants are young and actively growing.

Floating booms

The purpose of the boom is to section off a suitable refuge area for the insects that will be left untreated. Providing the protected area sustains a healthy weevil population it will help weevil numbers quickly increase in response to new water hyacinth growth. Booms will also alert spray crews to not spray in these areas.

This area should ideally be about 30 m^2 in size (A. Wills, pers. comm. 2013) to maintain a population of weevils required for control. If the untreated area is too small, the quality of the plants will start to deteriorate and the weevils may disperse from the area in an attempt to find a healthier food source, potentially affecting population size at the site.

Weevils can be released, if required, into the untreated area of the infestation. Maintaining this

area will allow the movement of weevils to and from untreated and treated area as necessary. Weevils will start to move to the untreated area once plants start to wilt, die and sink following herbicide treatment. Once new and healthy plants have regrown from the seed bank, weevils will then move to this and the whole process repeats itself. These boomed areas also provide a nursery where plants can be collected and redistributed in other areas of the infestation.

The location of the floating booms and untreated areas should be carefully considered at the onset of the integrated program. Ideally the location should be in permanent ponded or low flow water bodies in areas that are easily quarantined, sheltered and not subject to seasonal flushing from flood water and located in the upstream reaches of the main infestation.

Choice of herbicide

There are a number of herbicides registered for use on water hyacinth. When using herbicides with biological control it is important to consider which herbicide to use that will have minimal effects on the weevil population. Research has indicated that some herbicides may have an effect on the weevils, although most toxicity appears to be related to the type of surfactant used with the herbicide. Of the four herbicides registered for use on water hyacinth, research conducted overseas has indicated that glyphosate is the least toxic to weevils. Observations from the field have also indicated that healthy populations of weevils have remained following applications of 2,4-D acid.

When choosing which herbicide to use, always check the label for rates and direction for use, and observe any applicable withholding periods.

Paul Sullivan

Boom used to make a weevil nursery site

Avoid using any oil based surfactant products in the herbicide mix to help increase the survival rate of weevils.

Timing of herbicide applications

In situations where the entire infestation is to be treated with herbicide, application timed to coincide with the adult stage of a weevil population can help to achieve good results of integrating biological control. In tropical climates this is year round and should ideally be conducted when plants are actively growing. In sub-tropical climates, the mobile adult stage is present throughout most of the year but is most prevalent during the spring to autumn months. Spray activities should ideally be conducted from late spring through to autumn in sub-tropical areas.

In temperate climates, there is a distinct slowing of weevil development during the winter months and the proportions of adults are low during this time. While the impact of biocontrol is not clear at this stage, it may still be worthwhile to utilise optimal spraying times on infestations for the benefit of biological control. This would ideally be during the late summer and early autumn months.

In situations where an untreated area can be boomed off to allow biocontrol agents a refuge, spraying the remaining infestations should coincide with the optimal time to treat water hyacinth plants.

For optimum results on water hyacinth, the best time to spray is when the plants are young and healthy which is usually early spring. Spraying when the plants are older, when leaves are taller and wilting does not give the same level of control.

A. Purdy

Right half of water hyacinth infestation treated with herbicide

Spraying at this time is more suitable for tropical and sub-tropical climates as adult weevils should be present during this time. If in doubt, check for the presence of adult weevils prior to spray applications. Weevils are nocturnal by nature, which may help to protect them from spray applications during the day.

Application

In heavy, thick infestations where the full surface of the water surface is covered treat only 50% of the infestation at a time with herbicide, in two separate treatments. While this is the ideal, if there are practical reasons to prevent this from occurring, this should not prevent herbicide treatment.

The size and density of the infestation will help to determine which application method to use. If the infestation is small and the majority of plants are located along the shoreline, herbicides can be applied from the edge using a hose and hand-gun.

Alternatively, if infestations are further into the waterway and cannot be reached from the shore, boats equipped with spray equipment or aerial spraying can be used. For further information on herbicide application refer to Module 3: Chemical control options.

Monitoring and maintenance

Ongoing monitoring of weevil populations and surveillance of weed growth will be necessary to ensure the control program is keeping the infestations at low, manageable levels.

Using herbicides to help maintain low levels of water hyacinth in an infestation may also be beneficial to the long-term survival and health of the weevil population. This is because the regrowth of water hyacinth from the seed bank provides young, healthy and nutritious plants for the weevils to feed on which then stimulates weevil reproduction and their ability to quickly increase their population size.

A benefit of biocontrol, is once the weevil population becomes established, they suppress plant flowering and set seed, helping to reduce the seed bank. It is important to monitor weevil numbers to ensure establishment, track increases in population or to determine if populations remain after flood events. Re-releases may be necessary if the populations have been lost during flood events. Refer to Module 5: Biological control for information on monitoring and releasing weevils.

Conduct monitoring and follow-up control throughout the year. Treat emergent seedlings and regrowth with herbicides as required. Monitoring programs should be ongoing and long-term.

Integrated chemical and mechanical control

The site and severity of the infestation will help to determine which control method will be the main form of control to use on water hyacinth. The integration of mechanical and chemical control can be used to complement one another in a variety of different circumstances. Each situation is different and before commencing treatments, analyse the situation and determine the best approach for long-term control.

Large mature mats

In situations where large, mature mats are present and a secondary infestation of other plants are growing within the mat, attaching it to the bank, a non-selective herbicide such as glyphosate can be used along the shore lines. This will help to weaken the bank bindings, making mechanical cutting easier, freeing the mat from the edge. In tropical and sub-tropical areas, herbicide application to the shorelines can occur in the early autumn months, prior to mechanical removal.

Mechanical removal can then be used to remove the bulk of the weed mat from the surface, helping to create more favourable conditions for herbicide

Michael Wood

Michael Wood

Michael Wood

Michael Wood

Mynumi Lagoon: integrated treatment of water hyacinth over time

treatments. Removing water hyacinth using mechanical methods agitates the water, stirring up sediment and nutrients in the water. This creates an ideal environment for regrowth to occur from any missed plant fragments or plants. This disturbance can also help to stimulate the seed bank and new growth from dormant seed is possible.

Any plant fragments left from the mechanical removal or regrowth can be treated with herbicides or removed by hand. The choice of herbicide to use will depend on the waterway and any withholding periods on the label should be observed.

In tropical and sub-tropical climates, mechanical removal should ideally be conducted in the winter months when the growth of water hyacinth is slowest. Water levels are generally lower during this time, making accessibility easier. In cooler, temperate climates, water levels are generally at their lowest during autumn.

Alternatively, in large infestations that have just established, initial treatment of the water hyacinth mat can be treated with aerial spraying to treat the bulk of the infestation. Diquat and 2,4-D acid can be used for aerial applications. The choice of herbicide will also depend on the use of waterway. Herbicide treatments should occur ideally in spring when the plants are young and healthy. See Module 3: Chemical control options for more information on herbicides.

Michael Wood

Spraying remaining water hyacinth after harvesting

Integrated control options

Following herbicide treatments, the dead and decaying material can be mechanically removed. Any regrowth can be treated with small scale herbicide or mechanical removal treatments. In situations where biological control is present, the agents are able to recolonise from the material left on the bank and then move onto any regrowth.

Michael Wood

Excavator removing plant material after spray

Monitoring and follow-up treatments of the infestation will be ongoing. Maintain the infestation to low levels with herbicide treatments preferably early in the growing season (spring) prior to flowering and seed-set.

Medium sized infestations

If the function of the waterway needs to be restored quickly, removal of the bulk of the weed via mechanical control may be the best option, followed by chemical control to treat any remnant water hyacinth. Follow-up treatment of regrowth can be sprayed with a registered herbicide.

Alternatively, if immediate restoration of the waterway's function is not a priority, it may be more economically feasible to use herbicide treatments initially. Aerial spray the main area of the infestation and any areas inaccessible by air can be removed with small-scale mechanical removal equipment such as a Truxor®. Follow-up with herbicide or mechanical treatments as required.

Booms

Booms are a useful management tool when using herbicides or physical removal. It allows the infestation to be concentrated into an area, allowing easier application of herbicide or removal via mechanical means. Using booms can help to reduce the amount of resources required for control.

This technique works by placing a boom around an infestation and then moving the boom so that it shifts the weed into one localised area. Ideally this area should be located where conducting herbicide treatments or mechanical removal are most convenient. Once the boomed area is sprayed or mechanically removed, the boom is gradually constricted around the infestation.

Monitor and follow-up control will be required at regular intervals to treat any regrowth from missed plants or new growth from the seed bank.

Phil Blackmore

Containment boom, for concentrated treatment

Small infestations

Depending on the type of waterway, small infestation can be mechanically removed, with follow-up manual removal or treated with herbicide as part of follow-up.

Alternatively, the infestation could be initially treated with herbicides and any regrowth around the edges mechanically or manually removed.

Water level manipulation and herbicide or mechanical treatments

The purpose of integrating water level manipulation and herbicide or mechanical treatments is to stimulate the germination of the seed bank through a drying and wetting cycle of the waterway then exploit this germination with treatment. This method of control should only for use to reduce the seed bank and must be accompanied by the herbicide or mechanical treatment of seed and seedlings.

Germination of water hyacinth seeds is normally stimulated by fluctuating water levels, muddy, moist soil or shallow water levels, together with warm temperature and high levels of light. Reduced water levels in the early spring months (or autumn in southern states) will help promote germination.

This option should only be used in small, enclosed water bodies where human manipulation of water levels is possible such as dams, water storage facilities and irrigation channels, and where emergent seedlings can be treated. It is an important tool to be considered where eradication is the goal or to reduce future treatment and monitoring costs.

One approach can be to mechanically remove all contaminated sediment from all bank fringes, extending as far as possible into the centre of the water body once the water level is at its minimum.

Hand or mechanical removal can also be used to remove any plants that are inaccessible from the bank's fringes. This approach reduces the potential of seed germination, as seeds remain dormant in deep water.

Alternatively, seedlings that have emerged can be treated with a registered herbicide prior to flowering. The choice of herbicide will depend upon the use of the waterway. For waterways that have conservation values, a glyphosate registered for aquatic areas such as Roundup Biactive® may be used. Alternatively, if the water body is for irrigation or potable water purposes, diquat is a more appropriate herbicide to use. Always follow directions on the label for rates and observe withholding periods.

Reece Luxton

Mass germination of water hyacinth seeds

Jan Mitchell

Excavator scooping out mud and sediment to remove the seed bank

Water level manipulation is not well understood and must be conducted carefully. This option should only be considered if a well-planned integrated program is developed prior to water level manipulation. Regardless of the program planned, it must be supplemented with a strict follow-up program that treats emergent seedlings with a registered herbicide prior to flowering and seed-set.

Alternatively this approach could be utilised where a waterway may naturally experience periods of wet and dry. Although water levels are not being intentionally manipulated, mass germination may occur in these situations and seedlings should be treated to avoid new infestations.

Ongoing monitoring and follow-up treatments will still be required an indefinite period of time following the initial treatment of seedlings, even after water levels have returned to normal.

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Water hyacinth

Control Modules