WEEDS OF NATIONAL SIGNIFICANCE

Alligator weed control manual

Eradication and suppression of alligator weed (*Alternanthera philoxeroides*) in Australia

Elissa van Oosterhout
NSW Department of Primary Industries

An Australian Government Initiativ
DEFEATING THE WEED MENACE
national aquatic weeds management group
NSW DEPARTMENT OF PRIMARY INDUSTRIES

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Foreword

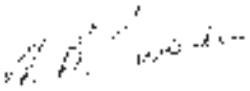
Alligator weed is one of the greatest threats to waterways, wetlands, floodplains and irrigation systems in Australia. As a weed that can grow both on land and in water and can tolerate a range of control methods – herbicides in particular – alligator weed has serious impacts worldwide and in Australia.

Since its introduction to Australia at least 60 years ago, alligator weed has infested many hundreds of hectares of land and water. Now we are witnessing a steady spread of this weed into previously uninfested areas, with the knowledge that it has the potential to become far more widespread in this country. It is now critical to contain the spread of alligator weed, taking the opportunity to eradicate small, new or isolated outbreaks and suppress larger infestations.

This publication brings together information and advice from over 30 years of research. The information has been reviewed by technical experts, managers and practitioners in order to extract the best and most effective advice for eradication, suppression and containment of alligator weed in Australia.

This manual provides the most comprehensive advice to those managing alligator weed in Australia, and I recommend it to all weed control authorities.

I thank those responsible for the production of this manual and for pursuing best practice in the face of such a recalcitrant and challenging weed.



Neale Tweedie

Chair
National Aquatic Weeds Management Group

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Introduction

Alligator weed is a perennial, stoloniferous plant that can grow both on land and in water. It poses one of the greatest threats to waterways, wetlands, floodplains and irrigation systems in Australia. Currently, alligator weed has serious impacts worldwide and in Australia, where it has great potential to become a far more widespread and serious weed.

Photo: Graham Prichard

Alligator weed. Photo: Brian Worboys

Alligator weed grows in water and on land. Photo: Daniel Kidd

About the manual

This manual presents best practice advice for the eradication and suppression of alligator weed in Australia. This advice is based on a review of over 30 years of published information and past and current field practices. To develop the best practice information presented here a technical reference group made up of researchers, managers and technical specialists reviewed the current knowledge and information over a series of workshops. Case studies provide examples of management strategies and control techniques.

Alligator weed in Australia

Alligator weed is native to South America; where its native range is thought to be the Parana River region and associated wetland areas of southern Brazil, Paraguay and northern Argentina (Sainty *et al*. 1998). Alligator weed was first recorded in Australia in 1946 by the National Herbarium of New South Wales, which stated that the weed was present in marshland near the Carrington shipyards at Newcastle (Julien 1995). It was originally suggested that alligator weed was brought to Australia in ships' ballast (Hockley 1974); however, literature accompanying the earliest herbarium records shows that the last ballast was dumped at Carrington in 1914. Therefore, there is a more recent theory that alligator weed was introduced to the Newcastle area via cargo from ships, possibly during the Second World War (Julien & Bourne 1988).

A Weed of National Significance

Alligator weed was recognised as a potentially serious aquatic weed in Australia during the 1970s, when its ability and potential to spread, coupled with a lack of effective controls, was realised (Julien & Bourne 1988; Bowmer, McCorkelle & Eberbach 1991). The National Weeds Strategy Executive Committee has classified alligator weed as a Weed of National Significance because of its impacts, its invasiveness, its capacity to spread and regenerate from single plant fragments, and its ability to tolerate a range of control treatments, including herbicides.

In Australia, alligator weed invades both aquatic and terrestrial systems, influencing agricultural and irrigation systems and affecting natural waterways, banks, riparian and floodplain environments, and wetland systems.

Computer-based modelling has indicated that 'almost every wetland in Australia is at risk of infestation by alligator weed' (Sainty et al. *1998: 196).*

Impacts

Alligator weed affects aquatic systems through excessive growth that restricts water use, alters aquatic ecology, excludes the growth of other plants, obstructs flows, causes problems associated with flooding and sedimentation, provides habitat for mosquitoes and degrades natural aesthetics. In terrestrial situations, impacts include degradation of agricultural land and pastures and contamination of crops, hay, turf, sand and soil.

Aquatic impacts

Floating mats of alligator weed crowd and out-compete native aquatic species, restrict light penetration and ultimately cause anoxic or anaerobic conditions. Prolific growth restricts flows and increases sedimentation, aggravating flooding by acting as a barrier and collecting debris. Floating mats can lodge against other structures and inhibit flow further, hindering access to, and use of, the waterway. Plant fragments can move through irrigation systems to contaminate crops and pastures.

Terrestrial impacts

Alligator weed will compete with, and displace, desirable pasture species, including kikuyu and clover (Julien & Bourne 1988). It is palatable and will be grazed by cattle and horses, but the grazing of alligator weed has been associated with photosensitivity and resultant skin lesions, liver damage and death in cattle, calves and lambs (Roberts & Sutherland 1989; Bourke & Rayward 2003).

Alligator weed forms dense monocultures, competing with and displacing native riparian vegetation, and infesting crops such as rice, turf, hay, and vegetables. Any irrigated or floodplain-based agricultural production is at risk in areas where alligator weed is present.

▲ *Alligator weed infests many crops.* Photo: Graham Prichard

▼ *Alligator weed degrades pastures.* Photo: Elissa van Oosterhout

▼ *Grazing alligator weed has been associated with photosensitivity, liver damage and death in livestock.* Photo: Graham Prichard

Prolific growth restricts flows. Photo: Mic Julien

Soil moved from infested drains can cause alligator weed infestations in cultivation. Photo: Brian Worboys

A major threat to irrigated and floodplain farming in Australia

In 1994, when alligator weed was discovered in the Barren Box Swamp in the Murrumbidgee Irrigation Area of NSW, the potential costs to the irrigation farming community were as high as $250 million a year. An annual control program would have cost $6 to $8 per ML (megalitre, i.e. 1 million litres) of water at the farm gate – an increase of 30% in delivery costs. By 2000 $3 million had been spent on control alone, and this figure has continued to rise (Agriculture & Resource Management Council of Australia & New Zealand 2000).

In the Hawkesbury–Nepean catchment alligator weed occurs upstream of the $35-million-a-year turf industry and the $50-million-a-year vegetable industry. Alligator weed has already eliminated small crops and turf farms in parts of the lower Hunter catchment (Agriculture & Resource Management Council of Australia & New Zealand 2000).

Alligator weed is a serious weed in 30 countries, including the United States, China, New Zealand, Thailand, Indonesia and India. It is a major weed of transplanted rice wherever rice is grown in the world (Agriculture & Resource Management Council of Australia & New Zealand 2000).

In North Carolina in 1999 alligator weed was infesting over 4000 ha of cropping land. In China alligator weed reduces the production of rice by 45%, wheat by 36%, sweet potato by 63%, and lettuce by 47%. Cotton, soybean and peanut growers also suffer significant losses due to alligator weed, but these have not been calculated. The weed also affects orchards, tea plantations, berry fields, and herb crops (Agriculture & Resource Management Council of Australia & New Zealand 2000).

Agricultural floodplain infested with alligator weed. Photo: Graham Prichard

Alligator weed has infested rice crops in Australia. Photo: Andrew Petroeschevsky

Alligator weed in a newly planted wheat crop. Photo: Birgitte Verbeek

A major threat to the use of waterways

Before 2000, Liverpool City Council in NSW spent $8000 annually to maintain a section of river free of alligator weed for use by rowers and to reduce the visual impacts of the infestation.

In the USA alligator weed has caused major navigation impediments on the Mississippi River. In China alligator weed affects hydroelectric power production, impedes fishing, and has seriously degraded famous scenic places.

Current distribution

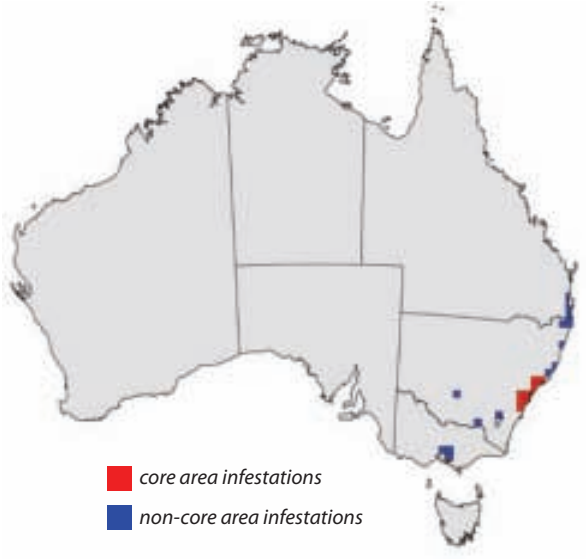
There are approximately 4000 ha of known alligator weed infestations in Australia. The current area of alligator weed infestation is small when compared with the potential distribution of the weed.

The National Alligator Weed Strategy classifies two main types of alligator weed infestation (core and non-core) in Australia and has made recommendations for the management and control of the weed in the corresponding areas. The two types of area are differentiated by the extent of the alligator weed infestations they contain.

Core-area infestations

To date, the Lower Hunter and Greater Sydney sub-catchments in NSW form the core areas of alligator weed infestation in Australia. In these areas the infestation is widespread, long established and continuous. Some core area infestations cover up to 100 ha, of which up to 90% is alligator weed. Eradication in most core area infestations is generally not feasible. Long-term management strategies aim for containment, reduction of impact by limiting spread, and suppression of biomass and density. There is a strong emphasis on preventing spread from the core areas.

Current distribution of alligator weed in Australia, not including domestic cultivations



A recent infestation threatening the Patterson River in Victoria. Photo: Lalith Gunasekera

Approximately 40 km of channels west of Barren Box Swamp and a substantial area of the swamp's perimeter were affected by alligator weed. Photo: NSW DPI

Aerial view of alligator weed in Barren Box Swamp in 1994. Photo: Murrumbidgee Irrigation

Turf farms are at risk of infestation by alligator weed. Photo: Brian Worboys

▲ *Long-established broadacre core infestations at Williamtown.* Photo: Graham Prichard

▼ *Non-core infestation in a stormwater retention basin at Port Macquarie (after treatment).* Photo: Elissa van Oosterhout

Part of the non-core infestations on Wilson Creek in northern NSW. Photo: Far North Coast Weeds

▲ *Non-core infestation in irrigated pasture at Taree (after treatment).* Photo: Elissa van Oosterhout

▼ *The original site of a long established non-core infestation at Lewis Creek in NSW (after treatment).* Photo: Elissa van Oosterhout

A recent non-core infestation near Bangalow in northern NSW – too extensive for immediate eradication. Photo: Elissa van Oosterhout

Non-core-area infestations

Any infestations occurring outside the core areas are by definition non-core-area infestations. These range from small, isolated infestations yet to spread beyond their point of introduction and with a high possibility of eradication, to infestations that have reached an extent where eradication is not feasible in the short to medium term but may be possible in the longer term if infestations are significantly suppressed and depleted.

Currently, non-core-area infestations occur at Lake Ginninderra and Yerrabi Pond in Canberra; Bangalow, Casino, Coffs Harbour, Taree, Port Macquarie, Lewis Creek and Hawks Nest in northern NSW; Wah Wah, Barren Box Swamp and Woomargama in south-west NSW; Mudgeeraba, Currumbin, Beenleigh, Rocklea and Caboolture in south-east Queensland; and Kew, Dandenong, Brunswick, Eumemmerring, Hallam, Darebin Creek, Carrum and the Patterson River in Victoria.

Domestic cultivation: 'backyard infestations'

In December 1995 alligator weed was discovered by an entomologist in a domestic vegetable garden in Brisbane, where it was being grown and used as a leafy vegetable in the mistaken belief that is was the popular Sri Lankan vegetable plant *mukunuwenna*, or sessile joyweed (*Alternanthera sessilis* – see *Similar-looking plants* in Part 1).

Over the next 4 years domestic cultivations were found throughout eastern Australia, from Port Douglas to Tasmania (three sites), in South Australia (five sites), Western Australia (25 sites) and the Northern Territory (two sites). Over 800 domestic sites were identified in Victoria, and seven infestations were located in natural waterways. In Queensland over 70 backyard infestations were found, and one backyard-associated infestation was found in the Logan River. In NSW domestic cultivations were found at Byron Bay, Wollongong, Dubbo, Parkes, Forbes, Peak Hill, Brewarrina, Grafton, Lismore and Armidale. The plant was so widely used that it was available at vegetable markets in Brisbane and by mail order from the Australian Capital Territory (Julien & Stanley 1999).

An intensive eradication and education program against the domestic cultivation of alligator weed managed to significantly reduce the number of backyard infestations; however there are cases where control is still occurring, and new domestic cultivations are being reported in urban areas (now there are over 100 sites under treatment in the greater Brisbane area alone).

Domestic cultivations pose high risks of spread through both intentional (residents giving plants to others) and unintentional (mowing and disposing of lawn and garden clippings) means. All backyard infestations should be subject to diligent control aiming for immediate eradication.

As part of the public awareness program, the Victorian Government has researched and promoted an alternative food plant, the related *Alternanthera denticulata* (common or lesser joyweed). This species is preferable to alligator weed as a vegetable plant and is native to Australia and Asia.

The weed being grown and used as a leafy vegetable. Photo: Lalith Gunasekera

Backyard infestation in an old vegetable garden bed. Photo: Lalith Gunasekera

Domestic cultivation of alligator weed. Photo: Lalith Gunasekera

Potential distribution

In Australia the potential distribution of alligator weed is extensive, with most non-arid areas capable of supporting infestations. Studies have shown that large tracts of Australia are suitable for infestation by alligator weed (Julien & Stanley 1999).

Potential distribution of alligator weed in Australia.
Map by Andrew Petroeschevsky

Part of the non-core infestation at Woomargama in the Murray Darling Catchment. Photo: Thomas White

In the USA and China, alligator weed infestations are larger and occur in a wider variety of habitats and climates than in Australia, indicating that there is potential for the weed to tolerate a broader range of conditions than it does in its current Australian distribution.

Alligator weed has the potential to spread further throughout Australia's inland waters. Of particular concern are its presence and potential impacts on water resources in the Murray Darling catchment. These infestations are now the subject of ongoing containment and eradication strategies that aim to prevent further spread through the Murray Darling system.

Management in the future

With much of Australia vulnerable to alligator weed it is essential that management aims to eradicate new, small and isolated infestations, and that long-term management of larger infestations is based on ongoing suppression and depletion, leading to future opportunities for eradication (see Part 2). Containment and prevention of spread is essential in every situation. Early detection is critical for taking advantage of opportunities to eradicate new infestations.

Legal status of alligator weed in Australia

The legal status of alligator weed in Australia reflects the serious potential for spread and the importance of containment and eradication of new infestations. All infestations in non-core areas must be controlled with the aim of eradication, and this is required by law in each State and Territory. There is also a strong emphasis on preventing spread from any infestations in non-core areas (see Table).

LEGAL STATUS OF ALLIGATOR WEED IN EACH STATE	
State	**Legal status**
ACT	C1 Notifiable and C4 prohibited pest plant under the *Pest Plants and Animals Act 2005*; presence of plant must be notified to chief executive; importation, supply and propagation prohibited.
NSW	Class 2 regionally prohibited weed and Class 3 regionally controlled weed under the *Noxious Weeds Act 1993*; Class 2 plants are notifiable and must be eradicated and land must be kept free of plants. Class 2 plants are banned from sale, trade or distribution throughout the whole of the State. Class 3 plants must be fully and continuously suppressed and destroyed. Class 2 throughout State except for the following local government areas that are Class 3: Auburn, Bankstown, Baulkham Hills, Blacktown, Burwood, Camden, Campbelltown, Canterbury, Sydney, Fairfield, Gosford, Hawkesbury, Hawkesbury River County Council, Holroyd, Hurstville, Kogarah, Ku-ring-gai, Lake Macquarie, Lane Cove, Leichhardt, Liverpool, Maitland, Manly, Marrickville, Mosman, Newcastle, North Sydney, Parramatta, Penrith, Pittwater, Port Stephens, Randwick, Rockdale, Ryde, Strathfield, Sutherland, Botany, Ashfield, Hunters Hill, Hornsby, Warringah, Waverly, Willoughby, Wollondilly, Woollahra, Wyong.
NT	Class A and Class C noxious weed under the *Weeds Management Act 2001*; to be eradicated; not to be introduced to the Northern Territory; restricted from sale in the Northern Territory.
QLD	Class 1 pest plant under the *Land Protection (Pest and Stock Route Management) Act 2002*; Class 1 plants established in the State are subject to eradication. It is an offence to introduce, keep or sell Class 1 plants without a permit.
SA	Class 1@ declared plant under the *Natural Resources Management (NRM) Act 2004*; prohibited entry to the State; to be destroyed throughout the State; sale and transport prohibited; notifiable throughout the State.
TAS	Declared under the *Weed Management Act 1999*; importation, movement and sale prohibited; all plants/infestations to be eradicated.
VIC	State Prohibited Weed under the *Catchment and Land Protection Act 1994*; all plants occurring in Victoria to be eradicated by Victorian Government; prohibited entry to State, movement, and sale.
WA	Category P1 and P2 Declared Plant under the *Agriculture and Related Resources Protection Act 1976*; cannot be introduced to the State; prohibited from sale, trade or movement throughout the State; to be eradicated.
Commonwealth	Alligator weed (*Alternanthera philoxeroides)* is prohibited entry to Australia under the Quarantine Proclamation 1998.

Flowering peaks in mid to late summer. Photo: Mic Julien

Part 1: The alligator weed profile

Physical characteristics of alligator weed[1] (*Alternanthera philoxeroides*)

Alligator weed is a perennial stoloniferous herb that produces masses of creeping and layering and upright stems. It has the ability to grow in aquatic, semi-aquatic and terrestrial habitats in tropical, subtropical and temperate regions (Julien & Stanley 1999).

Stems

The stems of alligator weed are hollow when mature and can be single or branched to form dense mats. Stems may lie flat along the ground or grow vertically. Vertical stems are dark green and can be up to 80 cm long, or longer (up to 2 m) if supported on other vegetation. Prostrate stems can be light green, yellow or brown to red. When prostrate stems become buried in silt the nodes become thickened. Stems have pairs of leaves at each node.

Leaves

The spear-shaped leaves are in opposite pairs along the stems and are generally dark green, waxy, glossy and sessile (there is no obvious stalk attaching them to the stem).

Leaf size and shape vary considerably with growth habit and conditions. Leaves range from 2 to 12 cm in length and 0.5 to 4 cm in width, usually with an acute tip.

Vertical stems are dark green. Photo: Biosecurity Queensland DPI&F

Stems are hollow when mature.
Photo: Brian Worboys

Brownish red prostrate stems.
Photo: NSW DPI

Leaves are generally spear shaped, but size and shape can vary considerably.
Photo: Biosecurity Queensland DPI&F

Glossy, dark green leaves. Photo: Brian Worboys

Stems have pairs of leaves at each node. Photo: CSIRO

[1] Information in this section is from Julien (1995) unless otherwise referenced.

Line drawing by S. Fiske. Used with permission courtesy of CSIRO

Filamentous roots can occur at each node along a stem. Photo: Biosecurity Queensland DPI&F

Roots will penetrate into the soil and have been found more than 1m from the surface. Photo: Graham Prichard

Root storage tissues allow survival over dry periods. Photo: Brian Worboys

Roots

Alligator weed has an extensive underground root system. Filamentous roots can occur at each node along a stem. They are relatively fine and short in water but become thicker, starchy, rhizome-like and longer in soil. Taproots will penetrate into soil to a depth of 50 cm, but roots and stems have been found growing more than 1 m from the surface. Root storage tissues in terrestrial and semi-aquatic environments allow survival over dry periods and form a significant proportion of terrestrial biomass (Tucker, Langland & Corbin 1994).

Alligator weed is often referred to as having underground rhizomes. It is, however, thought that what appear to be underground rhizomes are either thickened roots, or stolons (above-ground creeping stems that root at nodes) that have become buried in silt and sediment over time. The whitish creeping underground stems are either new shoots making their way to the surface or old stems that have been buried over time.

Whitish stems under flood debris appear to be rhizomes, but are more likely to be stolons (above-ground creeping stems). Photo: Elissa van Oosterhout

Roots become thicker, starchy and rhizome-like in soil. Photo: CSIRO

Flowers

Papery white ball-like flowers occur on peduncles (stalks) 1 to 9 cm long. Each ball-like flower is an inflorescence made up of a number of smaller individual flowers. Alligator weed flowers in mid to late summer, peaking in January in aquatic situations and earlier (from November to January) in terrestrial situations. Seed production has not been observed in Australia.

Papery, white, ball-like flowers on stalks. Photo: Biosecurity Queensland DPI&F

The flower stalks are an important distinguishing feature of alligator weed. Photo: Bruce Auld

Each flower is made up of smaller individual flowers. Photo: Brian Worboys

Distinguishing features for identification

Alligator weed is generally distinguished from other similar plants by its combination of opposite leaves, hollow stems and papery white ball-shaped flowers on stalks (see *Similar-looking plants*).

Erect summer growth. Photo: Brian Worboys

Dense mats of stems, stolons and roots form above and below the soil. Photo: John Moorhouse

Growth habits

Alligator weed growth habits differ depending on habitat and conditions. Aquatic and terrestrial plants can be extremely different in size, shape and appearance. In both situations growth is generally erect under mid-summer conditions and prostrate under mid-winter conditions (Sainty *et al.* 1998). An infestation generally consists of a tangled mat of older, prostrate stems supporting younger upright stems bearing pairs of leaves on each node (Julien & Bourne 1988).

Terrestrial habit

In its terrestrial habit, alligator weed forms herbaceous stands with dense mats of stolons, taproots and filamentous roots beneath the soil. Mats of prostrate stems and filamentous roots can be up to 10 cm thick. Terrestrial growth is highly competitive and able to displace other plants (Julien & Bourne 1988; Julien 1995; Julien & Stanley 1999).

Terrestrial plants are subject to more stresses than aquatic plants, including moisture and temperature stress, inter-specific competition, and nutrient stress. These factors limit growth and affect the appearance of the plants (Sainty *et al.* 1998).

In general, terrestrial plants are smaller-leaved, more compact plants. Leaf area is on average four times smaller than aquatic plant leaf area, and terrestrial plants have fewer flowers (on average 0.8 flowers per stem compared with 1.0 flowers per stem on aquatic plants).

Plant biomass on land is less than in water; however, terrestrial alligator weed has the ability to form very extensive root systems, with the below-ground biomass measured at 10 times that of the above ground biomass. Terrestrial root masses are up to seven times heavier than aquatic root masses (on land the tops to roots ratio is 0.3, whereas in water the ratio is 5.6) (Schooler S, Cook T, Prichard G, Bourne A, Julien M, Effects of selective and broad spectrum herbicides on below-ground biomass of alligator weed, submitted to *Weeds Research*).

Prostrate winter growth. Photo: Rebecca Coventry

Infestations generally consist of a tangled mat of older stems supporting younger upright stems. Photo: Biosecurity Queensland DPI&F

Mats of stems, roots and leaves growing rooted in the bank. Photo: John Moorhouse

Stems can be rooted in the substrate in shallow water. Photo: Elissa van Oosterhout

The weed forms herbaceous stands. Photo: Biosecurity Queensland DPI&F

Larger leaves and elongated stems of an aquatic plant. Photos: Terry Inkson

Aquatic habit

As an aquatic plant, alligator weed grows rooted in soil near the water's edge or rooted in substrates beneath the water. It then produces large mats of stem, root and leaf material that can extend many metres across the water, forming a blanket across the water surface. Mats can exceed 1 m in thickness and can break away and become free-floating (Sainty *et al*. 1998; Julien and Stanley 1999). Mats that dislodge can free-float self-sufficiently in favourable conditions, and can also become lodged again and send roots into the substrate or banks. In favourable conditions, stem fragments that include nodes and buds can break away, become lodged downstream and develop roots and shoots to form a new infestation (Julien 1995).

Habitat

Alligator weed grows commonly in waterways, on the banks of waterways, on floodplains and poorly drained land and, less commonly, in drier situations above flood level. To date in Australia all infestations have occurred in cool and warm temperate and subtropical climates.

Infestations thrive in areas of high summer rainfall (Sainty *et al.* 1998) but can easily tolerate average moisture availability levels and dry periods. Alligator weed will grow in a range of soils and substrates from sand to heavy clay.

Alligator weed can tolerate saline conditions, surviving in flowing water with salinity levels 30% that of sea water (cited in Sainty *et al*. 1998). It has been found growing above the high tide zone on beaches in Sydney Harbour and Botany Bay; this indicates that it can survive sea-strength salinity for 'days' (Sainty *et al*. 1998:197).

Under aquatic conditions alligator weed competes successfully with most species, with the exception of water hyacinth. In pastures its creeping habit and tendency to form dense mats allows it to compete successfully for light and space. It can become dominant in wetter sections of pastures. Grasses will usually predominate on slightly elevated areas.

Floating stems extend across the water. Photo: Bob Trounce

Mats can free-float and take root further downstream. Photos: Andrew Petroeschevsky, Lalith Gunasekera

Alligator weed dominating wetter sections of pastures, with grasses predominating in slightly elevated areas. Photo: Elissa van Oosterhout

(Top) Alligator weed competes for light and space in pastures. Photo: NSW DPI

Banks and edges of waterways provide ideal habitat. Photo: Rebecca Coventry

Slower, prostrate growth can continue in dry conditions. Photo: Biosecurity Queensland DPI&F

Growth rates

When water and nutrients are not limiting, temperature and day length have most influence on growth. Growth rates differ in terrestrial and aquatic situations.

Terrestrial growth rates

In terrestrial habitats temperature and moisture availability are the most limiting factors for growth. Terrestrial growth is slower than aquatic growth. Root growth is affected by time and soil moisture, and growth of above-ground plant parts is affected by time, soil moisture and seasonal conditions. In a terrestrial pasture trial at Williamtown, uncontrolled alligator weed biomass increased steadily at a rate of 22% a year over a 9-year period (Julien & Bourne 1988).

Weights of the above-ground plant parts have been recorded to increase at a rate of 55% a year, and by 400% when soil moisture went from 0% to 100%. Weights of roots increased at a rate of 18% a year, and by 34% when soil moisture went from 0% to 100% (Julien & Bourne 1988:95).

Aquatic growth rates

In aquatic situations there is usually less interspecific competition; temperatures are modified and less extreme; nutrient levels are relatively high and there is no water availability stress. Aquatic growth rates therefore always exceed terrestrial growth rates at the same air temperatures (Sainty *et al.* 1998). Aquatic biomass can double in 41 days during the growing season. Although slow, growth can often continue over winter (Julien 1995).

Growing season

Alligator weed requires a warm growing season, and in Australia this can be between September and May, but the growing season is commonly referred to as November to May. Growth generally slows or ceases in temperate zone winters. However, if severe frost has killed the above-ground stem and leaf material, perennation can still occur because of the presence of the underground or underwater stems and roots. In subtropical climates growth can occur all year but is slower during the cooler months. After each growing season, above-ground stems lose their leaves and become prostrate, eventually forming a tangled mat that supports new vertical growth each season. New stems occur from axillary and terminal buds on the previous season's growth in spring.

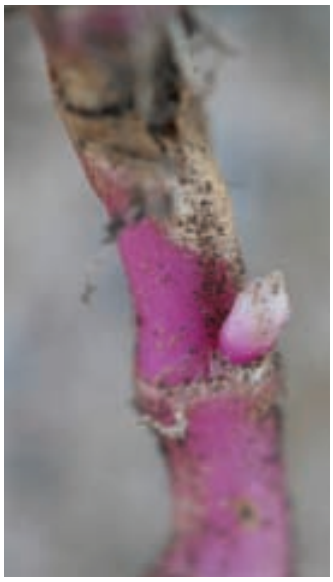
Stem density and production of new nodes peak during early summer; and stem length, weight and leaf area peak in January when temperatures are highest. Growth is faster and biomass greater when day length is longer.

Over the growing season maximum growth rates occur in early and mid-summer; peak densities occur in mid-summer (January or February); and biomass peaks in late summer. At peak production, 69 nodes per square metre per day were produced at an aquatic site and 54 at a terrestrial site (Julien, Bourne & Low 1992).

Photosynthesis is highest at the beginning of the growing season (November) and lowest at the end of the growing season (May). Transpiration is similar, being six times higher in November and three times higher in February than in May (Kelley & Hennecke 2006).

Roots occurring at a stem node on an aquatic plant. Photo: Brian Worboys

Roots occurring at stem node on a terrestrial plant. Photo: Brian Worboys



New shoot from a bud on a buried stolon. Photo: Brian Worboys

New stem growing from root material. Photo: Brian Worboys

Reproduction

It is generally accepted that alligator weed does not produce viable seeds under field conditions outside its native range (Julien & Stanley 1999). Alligator weed reproduction is entirely vegetative, and records suggest that all alligator weed in Australia is from the same parent material that has spread from the original point of introduction (Julien & Bourne 1998).

New plants (shoots and roots) can occur at any node along a stem (two axillary buds are present at every node); or from underground stems and root material, which are capable of developing roots and shoots.

Buds on stems at the bottom of a weed mat can remain dormant until exposed to light. Regeneration rates from root fragments are probably lower from smaller roots, and the exact size of the smallest root fragment that is able to regenerate is not known.

Spread

Stem and root fragments have the ability to produce roots and shoots and form new infestations, and therefore the potential for spread is enormous.

Natural spread occurs in aquatic infestations when sections of a mat or small plant fragments break away and float downstream (Julien & Stanley 1999) or are moved during floods. In terrestrial infestations, natural spread is through competition and eventual domination of other vegetation.

Accidental spread occurs commonly through human activities (on earthmoving machinery and watercraft; through the slashing and mowing of infested areas; in mulch, gravel extraction and turf; and even through

Alligator weed and water hyacinth spread by the recent flooding of the Hunter River. Photo: Brian Worboys

New shoots coming from very dry root material. Photo: Brian Worboys

control activities). Cattle and horses have been observed to spread fragments, both in their hooves and when pieces of plant material drop out of their mouths while grazing.

Purposeful spread (which is illegal in all States and territories) has also occurred through propagation as a garden vegetable or for the ornamental/aquarium plant trade.

Fragments are resilient

Alligator weed fragments are very resistant to desiccation (drying out). It is unlikely that fragments ever dry out enough to render them unviable under field conditions. Fragments are also able to withstand moderate damage (i.e. from earthmoving equipment or trampling by stock) and still form buds, shoots and roots. Even damaged fragments can remain viable for long periods of time, particularly when in contact with soil or mud (Kruger 2005).

Similar-looking plants

There are 12 other species of *Alternanthera* in Australia, four of which are native (see table). The other non-native *Alternanthera* species in Australia include various weed plants such as Khaki weed (*Alternanthera pungens*), sessile joyweed (*Alternanthera sessilis*) and some ornamental varieties.

The four native Australian species of *Alternanthera* are *Alternanthera angustifolia* (narrow-leaved joyweed); *Alternanthera denticulata* (common or lesser joyweed); *Alternanthera nana* (hairy joyweed); and *Alternanthera nodiflora* (common joyweed). These are easily distinguished from alligator weed because they have sessile flower clusters (i.e. their flowers clusters have no stalks), whereas alligator weed has flower clusters on its stalks. Weed authorities are promoting *Alternanthera denticulata* for culinary use.

A number of other plants are commonly mistaken for alligator weed in the field due to their similar appearance and growth habits (see table). On close inspection each is able to be distinguished from alligator weed.

Native *Alternanthera* species in Australia

	Alligator weed has:	**The four native *Alternanthera* species all have:**
Similar features	Opposite leaves	Opposite leaves
Distinguishing features	White ball-like flowers on stalks (peduncles)	Sessile flowers – the flowers have no stalks

Alternanthera denticulata (lesser joyweed)

- Native to Australia
- Occurs throughout Australia

Alternanthera denticulata.
Photo: Bruce Auld

Alternanthera denticulata. Photo: RG and FJ Richardson

Alternanthera nana (hairy joyweed)

- Native to Australia
- Not widespread, occurs in southern and inland Australia

Alternanthera nana.
Photo: Bruce Auld

Alternanthera nodiflora (common joyweed)

- Native to Australia and Europe
- Occurs throughout Australia but more common on Western Plains of NSW and in inland Australia

Alternanthera nodiflora.
Photo: Richard Medd

Alternanthera angustifolia (narrow-leaved joyweed)

- Native to Australia
- Not widespread, occurs mostly in dry inland Australia

no image available

Plants that look similar to alligator weed

Ludwigia peploides subsp. montevidensis (water primrose)

- Possibly native to South America but sometimes considered native to Australia.
- Occurs in NSW, Vic, SA, Qld

Water primrose. Photo: Jackie Miles, Max Campbell

Photo: Bruce Auld

	Alligator weed has:	Water primrose has:
Distinguishing features	• opposite leaves • white ball-like flowers on stalks (peduncles) • hollow stems	• alternate leaves • single yellow flowers

Veronica anagallis-aquatica (blue water speedwell)

- Native to Europe and Asia
- Widespread weed in temperate Australia

Blue water speedwell.
Photo: RG and FJ Richardson

	Alligator weed has:	Blue water speedwell has:
Similar features	• opposite leaves • hollow stems	• opposite leaves • hollow stems
Distinguishing features	• leaves with entire margins • white ball-like flowers on stalks (peduncles))	• leaves with finely toothed margins • leaves that clasp stems • spikes of pale blue flowers

Enydra fluctuans (Enydra, buffalo spinach)

- Native to Australia
- Occurs in NSW and QLD

Enydra fluctuans.
Photo: Graham Prichard

	Alligator weed has:	**Enydra has:**
Similar features	• opposite leaves • hollow stems	• opposite leaves • hollow stems
Distinguishing features	• white ball-like flowers on stalks (peduncles)	• flower heads in leaf axils • serrated leaf margins

Persicaria sp. (smartweeds, slender knotweeds) e.g. *Persicaria decipiens*

Smartweed. Photo: Bruce Auld

	Alligator weed has:	***Persicaria* species have:**
Distinguishing features	• opposite leaves • white ball-like flowers on stalks (peduncles) • hollow stems	• alternate leaves • elongated spikes of flowers in a range of colours (white, pink, purple)

Plants that look similar to alligator weed (CONT'D)

Gomphrena celosioides (Gomphrena weed)

- Native to South America
- Occurs in NSW, SA and Qld

Gomphrena weed.
Photo: RG and FJ Richardson

	Alligator weed has:	Gomphrena weed has:
Similar features	• opposite leaves	• opposite leaves
Distinguishing features	• white ball-like flowers on stalks (peduncles) • hollow stems	• an oval-shaped cluster of greenish-white flowers at the end of each branch between the pair of uppermost leaves

Hygrophila costata (Hygrophila)

- Native to the Americas
- Occurs in Qld and NSW

Hygrophila costata.
Photos: Sheldon Navie

	Alligator weed has:	*Hygrophila costata* has:
Similar features	• opposite leaves	• opposite leaves
Distinguishing features	• white ball-like flowers on stalks (peduncles) • hollow stems	• whorls of inconspicuous whitish flowers in the leaf axils (at the stem and leaf junctions)

Gymnocoronis spilanthoides (Senegal tea plant)

- Native to South America
- Occurs in NSW, Vic, Qld

National Alert List Species: all findings must be reported to the local weeds authority

Senegal tea.
Photo: www.biolib.de

	Alligator weed has:	Senegal tea plant has:
Similar features	• opposite leaves	• opposite leaves
Distinguishing features	• completely hollow stems • white ball-like flowers on stalks (peduncles) • leaves with smooth margins	• cane like ribbed stems that are hollow between the joints • half sphere-shaped (pom-pom like) white or pale purple flower heads in clusters at the ends of branches • leaves with irregularly toothed margins

Alternanthera sessilis (sessile joyweed)

- Native to Asia and Pacific
- Occurs in NSW, Qld and NT
- Used as a food plant
- Noxious weed in USA

Sessile joyweed.
Photos: Lalith Gunasekera

	Alligator weed has:	Sessile joyweed has:
Similar features	• opposite leaves	• opposite leaves
Distinguishing features	• white ball-like flowers on stalks (peduncles)	• sessile flower clusters – the flowers have no stalks

Part 2: Management strategies

Introduction

There are three main management strategies for alligator weed infestations: *immediate eradication*, *suppression leading to eradication* and *ongoing suppression*. The application of the strategies depends largely on the extent of an infestation.

This section outlines the considerations to be made for new infestations (*rapid response measures* and *assessment of new infestations*) and then explains the various strategies for suppression and eradication.

Part 3 outlines the need for *Containment and prevention of spread*, which applies to all infestations.

Types of strategies

Eradication is not feasible in the extensive and long established infestations in core areas. Here management strategies are based on *ongoing suppression*, along with containment and prevention of spread. All other infestations should be controlled with the aim of eradication in the shortest possible time frame, taking advantage of the high possibility of *immediate eradication* of small, new or isolated infestations yet to spread beyond their point of introduction.

There are two approaches to eradication: *immediate eradication* and *suppression leading to eradication*. The extent of an infestation (the amount of plant growth above and below ground and the area of coverage) will determine which of these strategies should be implemented.

Install containment fences. Photo: Paul O'Connor

Restrict access and install signage. Photo: Brian Worboys

Eradication is not feasible in long-established, extensive infestations.
Photo: Graham Prichard

Install floating booms. Photo: Graham Prichard

A small area of infestation ideal for an immediate eradication strategy. Photo: Lalith Gunasekera

Infestations that are already too extensive for immediate eradication should be subjected to the *suppression leading to eradication* control strategy. This strategy aims to gradually deplete the plant's growth reserves over time, and it can bring an infestation to a point where eradication is possible after a number of years.

Containment and prevention of spread are critical for the management of all infestations, and all new infestations should have *rapid response measures* put in place.

Immediate eradication may be feasible for small clumps along a watercourse. John Moorhouse

If not managed quickly, an eradicable infestation will become more extensive and will require suppression for many years before it is possible to reconsider eradication, if it is possible at all.

Rapid response measures

There are a number of measures to be taken by the relevant weed control authority when an infestation is found:

- Notify the appropriate authorities (in most States landholders must notify local government authorities and local government authorities must notify State government authorities).
- Mark out the extent of the infestation, including outlying plants. This can be done with pickets and tape, white pegs, fencing, spray paint, etc. Record the location with mapping coordinates.
- Install containment and quarantine measures (see Part 3):
  - Prevent disturbance to the infestation. Inform land users not to slash, mow, cultivate or graze the area. This is very important, as a number of new infestations have been spread through slashing, cultivating, mowing or grazing.
  - Install fences or floating booms.
  - Restrict access and install signage if necessary.
  - Survey the broader area to determine possible sources of the infestation.

Infestation subjected to immediate eradication: site prepared for physical removal of underground plant material.
Photo: Iain Jamieson

Assessment of new infestations

Assess infestations quickly to maximise chances of successful eradication:

- Assess the number of plants or the area of the infestation, and the depth and development of the root systems. It may be useful to follow a plant's roots by digging down to see how deep and extensive the root system is.

Use the following descriptors as a guide to determine whether immediate eradication is feasible:

Immediate eradication is generally feasible for:

- small numbers of individual scattered plants (through deep manual digging)
- areas of infestation up to 5 m × 5 m (through deep manual digging)
- areas of infestation up to 10 m × 10 m with shallow roots (up to 30 cm deep) (through shallow mechanical excavation).

Immediate eradication may be feasible, depending on resources, for:

- scattered plants or clumps along stretches of watercourse: start *immediate eradication* at the top of the catchment and use the *suppression leading to eradication* strategy downstream or where roots are more than 1 m deep.

Suppression leading to eradication will generally be required for:

- any area of infestation with roots more than 1 m deep
- any area of infestation greater than 10 m × 10 m and with roots deeper than 30 cm.

These infestations will require suppression before eradication is feasible. Photos: Lalith Gunasekera, Graham Prichard

This large infestation on a dam was subjected to ongoing suppression with herbicide for a number of years before an eradication strategy was started using manual removal. Photo: Terry Inkson

The infestation after 3 years of treatment with herbicides.
Photo: Terry Inkson

Regrowth stems required one further season of herbicide treatment before manual removal techniques commenced. It is hoped that further follow up manual removal for a number of seasons will eradicate this infestation. Photo: Terry Inkson

Immediate eradication

Immediate eradication aims to eradicate a small, new or isolated infestation as quickly as possible by treating the above-ground or above-water growth with herbicide and physically removing the below-ground or underwater plant mass. Immediate eradication is time and labour intensive in the short term but is far more cost effective in the long term.

Because of the ability of meristems (growing points) in the plants' roots to remain viable underground, there is a requirement to physically remove every part of every plant, including the roots and underground stems.

A number of control techniques are used for immediate eradication. The primary technique is physical removal. Shallow mechanical excavation may be required, but deep manual digging is always necessary (see *Removal techniques* in Part 4).

It is very unlikely that immediate eradication will be achieved with herbicides alone; however herbicides are used to help with eradication. (See *Initial herbicide treatments to help with eradication* in Part 4.)

Always expect regrowth and carry out follow-up inspections regularly. Physical removal of regrowth may need to occur regularly over a period of years until all plant material is removed and no further regrowth can occur. Consider eradication of alligator weed successful only if no regrowth is found for **5 years after the last observed occurrence.** *Even when eradication has been achieved, monitoring is required on an ongoing basis. In one case where the infestation was thought to have been eradicated, regrowth occurred 10 years later.*

Extensive infestations should be subjected to ongoing suppression. Photo: Bob Trounce

Suppression leading to eradication

This approach aims to reduce the size and extent of both above- and below-ground plant growth, in conjunction with gradually depleting the plants' underground carbohydrate reserves over time. If this is carried out persistently, control inputs will be reduced over time as the infestation is brought to a greatly suppressed and depleted level. Over an average of 6 years this control strategy can deplete an infestation so that eradication is possible through physical removal of the remaining below-ground or underwater plant material.

This strategy is based on an *annual treatment program* of three applications of metsulfuron-methyl 600 g/kg at specific times each growing season (see *Metsulfuron-methyl for suppression* in Part 4).

Ongoing suppression

Ongoing suppression is the only realistic approach for the management of some core area infestations. As well as containment and prevention of spread, the main control strategy is the same *annual treatment program* of three applications of metsulfuron-methyl 600g/kg at specific times each growing season.

Alligator weed flea beetle (*Agasicles hygrophila*), a biocontrol agent, also contributes to *ongoing suppression* of aquatic infestations in core areas (see *Biological control* in Part 4). Biocontrol is **not** a control technique for eradication.

*Persistent application of the **annual treatment program** will bring an infestation such as this to a greatly suppressed and depleted level, so that eradication is possible after a number of years.*
Photo: Greg Mifsud

Part 3: Containment and prevention of spread

Introduction

This section presents advice for the containment of new and existing infestations and for the prevention of spread from infested areas. Quarantine and hygiene considerations, physical containment of infestations, and prevention of spread of fragments are all vitally important in reducing the spread of alligator weed in both core and non-core areas.

Quarantine and hygiene

Alligator weed can be accidentally spread through earthmoving equipment and activities, on mowers and slashers, on boats and trailers, and by grazing animals. In situations where physical removal techniques are used to control infestations, there is also a risk related to the movement and disposal of contaminated soil and plant material. Quarantine and hygiene measures are required to prevent such spread.

Quarantine

It is extremely important to prevent disturbances to alligator weed infestations, including slashing, mowing, earthmoving, cultivation or grazing. Infested areas should be signed and marked with highly visible markers and surrounding land users notified and asked to refrain from further use of the area.

Access may need to be physically restricted (i.e. use of electric fencing to prevent stock from grazing). In some circumstances it may be necessary to undertake formal quarantine procedures under State weed control legislation. Refer to the appropriate State or Territory weed control authority for details of relevant legislation.

Alligator weed is easily spread on earthmoving equipment. Photo: Graham Prichard

Slashing should not occur anywhere near an infestation. Photo: Graham Prichard

Mark infestations with highly visible markers and signage. Photo: Elissa van Oosterhout

Mowing close to an infested creek bank spread alligator weed throughout this property. Photo: Elissa van Oosterhout

Hygiene

If machinery is to be used for physical removal of alligator weed or if earthmoving is to be done in and around alligator-weed-infested areas, precautions must be taken to ensure that machinery and soil movement from infested areas to clean areas is limited and that proper washdown and disposal procedures are carried out.

In and near core areas, weed control authorities should have protocols in place relating to the accidental movement of alligator weed during earthworks and developments and on machinery. To minimise the risks of accidental spread, protocols (see box) should be formulated and followed by local government authorities, other government authorities (e.g. roads and transport, national parks), energy and communications suppliers, contractors and landholders carrying out work in the vicinity of alligator weed infested areas.

Hygiene protocols

The following are the types of protocols issued by the Lower Hunter Alligator Weed Taskforce:

- Before commencement, any agency responsible for implementing work must notify the local weeds officer.
- All operators and visitors to the site will be inducted as to their responsibilities in regards to alligator weed.
- The worksite will be signposted to alert visitors to the risks of alligator weed spread.
- Where possible, before commencement of work, the agency responsible will treat any alligator weed with a suitable herbicide.
- Only essential vehicles and machinery will be allowed to enter the site.
- Potentially contaminated spoil remaining at the site should be inspected and any emergent alligator weed treated at regular intervals.
- Potentially contaminated spoil removed from the site must be taken to a secure and approved disposal site [see *Disposal* for details].
- Any trucks transporting spoil must be covered and not overfilled, to ensure spoil is not scattered or spilled.
- All vehicles will be checked for fragments before leaving the site. If necessary they will be washed down (see below).
- The local weeds officer will be advised when the job is to be completed.
- At the completion of the work, all machinery will be washed down before it leaves the site.
- Any contaminated material at the washdown site will be removed to the designated secure disposal site.
- Local weed officers should monitor the work to ensure compliance.
- In the case of a breach of the requirements, weeds officers will issue a notice for work to cease until such time as the breach has been rectified.
- All of the above should be presented in a site weed management plan and approved by the local weeds officer before any work starts.

Accidental spread from earthworks

In a new subdivision in Maitland City Council local government area an excavator was used to place a sewerage line through a gully containing alligator weed. Weeks after the work was done alligator weed was found growing well away from the original infestation. Excavators had also been used to scrape up topsoil and stockpile it, and on closer inspection the 4000 m^3 of stockpiled topsoil was also contaminated with alligator weed from the gully. Maitland City Council now have strict protocols in place to ensure that this kind of accidental spread does not occur again, but it takes a large amount of time and commitment by weeds officers to ensure that the protocols are adhered to.

Washdown facilities

In the case of alligator weed it is best if washdown facilities can be set up at or near the site of the infestation. Where possible they should be on a hard, relatively flat but well drained surface, clearly signposted and screened to prevent fragments moving offsite. The washdown site must be recorded and easily identified for future monitoring for weed outbreaks. The landholder or trustee of the land should be notified of the location.

On-site washdown facilities generally use a water tanker or spray unit. Water can be pumped from dams or troughs if practicable. High pressure is required and

a gurney or pump can be used. High pressure – high volume water may be required for removing the large quantities of mud and plant material usually associated with alligator weed infestations.

Washdown procedures

All vehicles and machinery moving into, from or near an infested area should be washed down, including tractors, excavators, loaders, dump trucks, cars, trucks and 4WDs. Alligator weed is generally present in the mud stuck to the tyres, wheels, tracks, buckets, blades and undersides of machinery and vehicles. Some general principles of washdown procedures (adapted from Queensland Weed Seed Spread Project 2000) are presented below:

- Place the machine in a safe, stabile and immobile position.
- Stop the engine, apply the park brake, chock the wheels and lower all implements (eg. slasher) or secure/chock them if they require cleaning.
- Ensure the area is free of objects/obstructions that may cause injury (logs, powerlines, etc.)
- As necessary, remove guards/belly plates to gain access to areas for cleaning.
- Clean under guards and underneath machinery first, then do the upper body and implements.
- Toolboxes and storage compartment may also need cleaning.
- Replace guards and implements and move the machine off slowly, avoiding re-contamination and washing the remaining mud etc. off the tyres and tracks.
- Inspect the area and place all plant material in a sealable container for disposal.

Tip

If you are attempting mechanical removal of an infestation, always start with a clean machine that has been washed down by the operators before they start work. Hard, caked mud will be the most difficult to remove if it has been allowed to dry after previous work.

Water tankers can be used for onsite washdown. Photo: Brian Worboys

Alligator weed gets lodged in muddy excavator tracks. Photo: Brian Worboys

Thoroughly clean tyres and rims of wheeled tractors. Photo: Brian Worboys

The arm of the excavator may be used to lift each track off the ground. Photo: Brian Worboys

Tracks and track frames must be cleaned thoroughly. Photo: Brian Worboys

Note that different models and makes of machinery will require different parts and attachments to be cleaned. The condition of the machinery will also affect the level of cleaning required (e.g. rusting of parts may allow contaminants to enter sections that are usually sealed).

The following is a checklist of parts of tractors and excavators that should be inspected and washed down (adapted from Queensland Weed Seed Spread Project 2000):

Wheeled tractors

Clean and inspect the following areas:

- tyres and rims, including inner side of rim; between dual wheels; around wheel-mounted counter weights; in gashes or cuts in tyres
- chassis and body: inside chassis rail ledges and back axle-beam and undercarriage of this area; hollow sections in front of axle tubes; void spaces in rear brake assemblies; hollow sections in drawbars and in retractable/extendable three-point linkages; mud guards and wheel flares (if 4WD, check the front drive shaft guard for holes or poor attachment); power take-off area; power take-off shaft; universal joints; shaft covers and power take-off tubes
- attachments: all buckets, scoops, blades, carry-alls etc.; check all areas of blades for holes or double skins; remove and inspect cutting teeth, adaptors and wear plates on blades; inspect hydraulic arms and supports for hollows.

Track-type excavators

Tracks are the most difficult to wash down, and movement of tracked machinery over infested areas should be minimised whenever possible.

- Examine tracks and track frames carefully. The arm of the excavator may be used to lift each track off the ground to allow it to be rotated in order to remove all caught material.
- Remove inspection/cover plates to inspect and wash inside track areas.
- Check idler wheels (i.e. the wheels that support the tracks).
- Check hollow-section chassis channels.
- Check belly plate and rear plates.
- Check removable track-adjuster guards and lubrication points.
- Check blade/bucket. Ensure top and bottom edges of blade/bucket are not split, as soil can become very tightly packed in any holes. Ensure inside and outside of bucket are cleaned.
- Check cutter points and wear blades.
- Carefully check pivot points and adaptors and the rear of the front blade: soil can become compacted there and be difficult to dislodge.

Rope with floats contains fragments during physical removal. Photo: John Moorhouse

Alligator weed can grow over a boom. Photo: Rebecca Coventry

Physical containment

Physical containment of alligator weed with booms, screens and fences is important for the prevention of spread by fragments or floating mats. It is applicable in aquatic and semi-aquatic situations.

Booms

Floating booms have a number of roles in the management of aquatic alligator weed infestations. Their primary role is the collection of plant fragments, preventing downstream spread from an infestation.

Booms are particularly important where herbicides or biocontrol measures are being used, as both will cause plants to fragment. However, any aquatic infestation will fragment as it ages, and therefore booms are an important tool for containment and prevention of spread. If booms are substantial enough, they can also prevent the downstream movement of whole floating mats that break away from infestations. This use of booms is relatively long term – either for the length of an eradication strategy or for ongoing suppression – and therefore booms need to be relatively durable.

Floating booms should also be used to catch plant pieces that may break away whenever physical removal of bankside infestations is occurring. Small-scale booms made of rope with floats attached can be useful for this purpose.

The use of a floating boom to contain an actual aquatic infestation itself is not particularly effective, as the alligator weed can send stems out over the boom.

PVC and mesh boom commercially designed to contain alligator weed fragments. Photo: Graham Prichard

Commercial fence boom containing alligator weed fragments. Photo: Graham Prichard

Infestation at culvert in need of containment. Photo: Graham Prichard

Containment fence placed around infestation being treated with herbicides. Photo: Elissa van Oosterhout

Screen made from reinforcement mesh and shadecloth.

Shadecloth screen over culvert.

Fine mesh containment fence. Above photos: Graham Prichard

▲ *Alligator weed is able to grow over or through a mesh fence.*

▼ *Ag-pipe and mesh boom designed to contain salvinia; this device would also contain alligator weed fragments.*

Photos: Elissa van Oosterhout

Fine mesh and star picket containment fence showing signs of wear and tear after 12 months' use. Photo: Elissa van Oosterhout

Alligator weed obstructing an irrigation drain. Photo: Brian Worboys

Types of booms

Floating booms range in size and capacity. Commercially available aquatic weed booms and oil-spill booms can be hired or purchased. Smaller scale booms can be made up in-house.

Fence booms. For alligator weed, a fence-type boom with a short hanging skirt is the most appropriate. Fence-type booms float upright at the water surface (40% above/60% below), and the same effect can be achieved using a mesh sleeve over plastic agricultural pipe (see *Ag-pipe and mesh booms* below). The gauge of the mesh must be fine enough to catch alligator weed plant fragments.

Ag-pipe and mesh booms. A floating boom that acts effectively as a fence boom can be made from unslotted agricultural pipe and effectively used over distances of 100 m, with regular checking and maintenance. Thread 5-mm-diameter wire cable through 100-mm-diameter unslotted black poly pipe, and attach the ends to star pickets. Seal the ends of the pipe with expanding foam. Treeguard mesh sleeves or similar plastic mesh tubing can be fastened around the pipe with plastic ties to form the curtain that sits above and below the water surface. Additional flotation may be required every 10 to 15 m.

Screens and containment fences

Screens and containment fences are used mainly to prevent spread of semi-aquatic infestations (e.g. alligator weed in stormwater drains, road culverts, irrigation drains, farm dam spillways).

If it is likely that water will flow in an area close to an alligator weed infestation, it is worth constructing a containment fence around the infestation or between it and the point of outflow.

Screens and fences can be constructed of fine-gauge mesh, shadecloth, or birdwire. Alligator weed fragments that get caught against a fence or screen may be able to take root; they are then easily capable of growing up and over, or through, the obstruction. Screens and fences must be checked regularly and cleared of fragments.

Maintenance

Booms and fences usually need to stay in place for the duration of the management effort (i.e. a number of years). They should be checked regularly and routinely after rain.

Preventing spread in irrigation systems

Alligator weed poses a major threat to both pressurised and flood-irrigated systems. Infestations present in water storages can contaminate crops and pastures when small plant pieces are dispersed through an irrigation system. Crops infested by alligator weed incur quarantine, loss of productivity, cost of control, and other restrictions associated with contamination by a noxious weed. Infestations also significantly reduce flows and efficiencies of irrigation systems.

Flood-irrigation systems

Control, containment and prevention of spread are major challenges in infested flood-irrigation systems owing to the open nature of supply channels and floodways and the ability of alligator weed to grow on land and in water.

Of greatest concern in flood-irrigation systems is that alligator weed can contaminate crops if supply channels are infested. Infestations have been found in crops at points where irrigation water enters the crop (See *Living and farming near alligator weed infested areas case study*). Other impacts include:

- obstruction of supply channels, causing collapse or channel bank breaching and flooding
- reduction of downstream supply flows. Infestations of between 2 and 10 m^2 can reduce flows by at least 50% (Julien 1995; Milvain 1995).

The Murrumbidgee Irrigation Area has been dealing with alligator weed since 1993 and has faced immense costs in control and management over this time. Flood-irrigation areas that are currently free of alligator weed need to have early detection programs in operation; a rapid response strategy in place in the case of finding an infestation; and an understanding of what is involved in containment, eradication and suppression.

Preventive measures

Hygiene and quarantine are important if stock, machinery or earth is moved from one area to another.

Irrigation bays should be checked for alligator weed before cultivation is done each season. (Near infested areas, irrigators should prevent grazing in bays and supply channels so that they can locate infestations.) Alligator weed can occur in dry channels that have not held water for years (Verbeek 2004).

Irrigators can place mesh screens in front of their water wheels or flow meters to catch any fragments that escape detection in channel screens. The use of any screens poses maintenance and cleaning issues, but screens should be used if alligator weed is known to be in the system.

Pressurised irrigation systems

Irrigators who pump directly from infested water sources such as creeks, dams or rivers face similar risks similar to those faced by flood irrigators in terms of contaminating crops and pastures and reducing efficiencies. In pressurised systems a build-up of alligator weed growth around the foot valves and strainers of pumps can significantly reduce flows and pressure at the discharge side of the system, reducing the efficiency of the pump and irrigation system (North Coast Irrigator Summer 2000).

Preventive measures

There are some preventative measures that will reduce these risks:

Installing footvalve filters. Commercially available mesh filters can be fitted to foot valves to filter debris and plant material from the water before it enters the intake pipe. In flowing water, an arrowhead-shaped screen pointing into the flow to divert water and plant fragments can be effective. In still water circular screens are effective, and there are automatic self-cleaning filters available that use a rotating spray bar to continually sweep algae, dirt and leaves from the filter screen.

Changing footvalve height. Alligator weed plant fragments tend to float on the water surface. By ensuring that the height of the foot valve is set well below the surface of the water, irrigators can reduce the chances of discharging plant fragments through the system.

Clearwater Self-Cleaning Suction Screen®
Image courtesy Clemons Sales Corporation

Part 4: Control techniques

Physical removal

Physical removal can eradicate small, new or isolated infestations.

Physical controls (mechanical or manual) are appropriate for small and isolated situations and are useful in removing initial invaders of a catchment if they can be located early enough … all above- and below-ground plant material must be removed. Care must be exercised during removal to ensure that broken plant sections are not dispersed on equipment or in downstream flow (Julien & Stanley 1999).

Excavation has successfully eradicated small infestations, but follow-up treatment of regrowth of missed plant material is necessary (Julien & Bourne 1988).

Australian experiences indicate mechanical and manual excavation should be contemplated for small infestations where all above- and below-ground material can be removed (Sainty et al. *1998).*

Risk of spread

The risks of spread associated with physical removal techniques come from the movement of fragments on machinery and the movement of fragments in contaminated soil that is transported away from an infestation. Any machinery involved in the physical removal of alligator weed must be washed down according to strict hygiene protocols to prevent the risk of spreading fragments. Any techniques that result in the removal of alligator weed-contaminated soil or plant material from a site must observe vehicle hygiene protocols and must be used under the appropriate permits to move a noxious weed (see *Hygiene* in Part 3).

Techniques based on the physical removal of alligator-weed-contaminated soil and plant material must account for secure disposal (see *Disposal*). There are high risks of spread associated with inadequate disposal of alligator weed and contaminated soil. It is easier to securely dispose of plant material than to treat and dispose of volumes of alligator-weed-contaminated soil.

Initial herbicide treatments

Infestations should receive initial herbicide treatments before being subjected to physical removal. This reduces the risks of spreading viable fragments, reduces the bulk of the above-ground biomass, and creates better visual access to the site. (See *Initial herbicide treatments to help with eradication*).

Herbicide should also be used to maintain a buffer area free of vegetation around the physical removal site, thus allowing for more effective location and removal of alligator weed regrowth.

Physical removal is feasible for this kind of aquatic infestation. Photo: Terry Inkson

Terrestrial regrowth after a number of initial herbicide treatments, ready for physical removal. Photo: Brian Worboys

Sites treated with herbicide in preparation for physical removal. Photos: John Moorhouse

Removal techniques

There are two main physical removal techniques:

- deep manual digging
- shallow mechanical excavation.

Deep manual digging

Deep manual digging should always be attempted on infestations up to 5 m^2. For larger infestations it is possible to use shallow mechanical excavation before the manual removal of the more deeply rooted individual plants.

Deep manual digging is an important technique for eradicating small, new and isolated infestations or older, depleted infestations that have been suppressed for a number of years. Deep digging for the purpose of eradication aims to remove every alligator weed plant from a site, including the underground stems and roots. There are many examples where this technique has allowed for successful eradication of new, small or suppressed infestations, but eradication is achieved only when the technique and its required follow-up efforts are performed very carefully.

Deep digging can be done manually in terrestrial and semi-aquatic infestations and (depending on the situation and the skill of the operator) in shallow or bankside aquatic infestations.

Terrestrial infestations

The experience of local weed authorities has shown that manual removal is successful. The ease and efficacy of manual digging to remove whole plants depend on the soil type. Harder, drier more compacted soils will be less conducive to manual digging. Most alligator weed infestations occur in situations where soils are relatively wetter and softer.

Carefully remove dead and dying biomass resulting from initial herbicide treatments by hand, and dispose of it securely (see *Disposal*). Use stakes or paint to mark regrowth stems. The regrowth stems are the places where digging should start.

Removal technique. The technique uses garden forks, small hand forks, crowbars, tarps, rakes, tubs and spray knapsacks. Experience proves that using shovels, spades or trowels cuts the roots, making them difficult to find, so the use of these tools should be avoided.

Use a three-pronged fork or crowbar in harder soils to loosen dirt around and under the plant.

Try to lift as much intact plant and soil as possible, and put the clods on a tarp. Lift the clods by hand if necessary.

Break up clods by hand, using your fingers to feel for root fragments.

The soil must be hand-sieved and the clods broken down until no more root fragments are found. A rake can then be used to sift through the spoil.

Alligator weed roots are relatively easy to distinguish with practice. They have a whitish centre and a greasy yellowy or brownish skin that can be easily scraped off with a fingernail. The roots are starchy, brittle and will snap cleanly; they are not stringy or woody. With some experience it is easier to pick alligator weed roots and stems from other plants, but if in doubt always remove the material.

Slowly and carefully follow the roots down to where they end. When the end of the root has been found, dig at least 20 cm further to ensure no other root material is present.

The hand-sieved soil should be left on the tarp next to where it came from and moved as little as possible at the site. (Spoil should be left at the site only if it will not be disturbed. Otherwise it will need to be securely disposed of – see *Disposal*.) Plant and root material should be placed in a tub and then bagged in sealed bags for transport before being dried and incinerated (see *Disposal*). It is easy to spill material from a tub, so the material should be bagged before it is moved.

Rake over the spoil again before you place it back into the hole. Holes tend to backfill naturally as the work is carried out, but the resulting depression can be left 'open' to observe any regrowth from the sides.

Maintain a buffer area free of vegetation around the site.
Photo: John Moorhouse

Deep manual digging aims to remove every plant, including underground stems and roots. Photo: Terry Inkson

Experience of local weed authorities has shown manual removal to be successful. Photos: Terry Inkson

Mark regrowth stems to be dug. Photos: John Moorhouse, Graham Prichard

Equipment for manual removal. Photo: John Moorhouse

Use a fork to loosen dirt around and under the plant. Photos: Elissa van Oosterhout, Terry Inkson

Try to lift as much intact plant and soil as possible. Photos: Elissa van Oosterhout, John Moorhouse

Lift clods by hand. Photo: Elissa van Oosterhout

Put clods onto a tarp. Photo: Terry Inkson, Elissa van Oosterhout

Break up clods by hand feeling for root fragments. Photos: Elissa van Oosterhout

Soil must be hand-sieved until no more root fragments are found. Photo: Elissa van Oosterhout

With experience it is easy to distinguish roots. Photos: John Moorhouse, Elissa van Oosterhout

Roots have a whitish centre and snap cleanly.
Photo: Terry Inkson

Use sand to backfill where it is not appropriate to leave the hole open. This will allow for easier removal of regrowth.

Check your footwear and tools for plant fragments before you leave the site.

Reinspect the area 2 to 4 weeks later. If the surface of the dug area is dry enough, sweep it over with a straw broom. Any regrowth that has come through will be obvious. Reinspect every 4 weeks to look for further regrowth from fragments. If no regrowth has been found after 3 months, hand-sieve the spoil and rake it again to check for fragments, then return it to the hole. Continue to make monthly inspections of the area, particularly over the growing season.

Note: In dry areas or during dry seasons there may not have been enough rainfall to stimulate regrowth from any remaining fragments. It may be useful to water the sieved soil and the hole to stimulate regrowth in order to find and remove it.

Place plant and root material in a tub. Photo: Elissa van Oosterhout

Dig down, following the roots to their ends. Photos: John Moorhouse, Elissa van Oosterhout

Feel for roots at the sides of the hole by brushing over the soil with your fingers.
Photo: Elissa van Oosterhout

Rake over the spoil again before you place it back in the hole. Photo: Elissa van Oosterhout

Holes will backfill naturally. If possible leave the resulting depression open. Photo: Elissa van Oosterhout

Using sand to backfill a hole at a public access site. Photo: Terry Inkson

Regrowth found three months after manual removal. Photo: John Moorhouse, Iain Jamieson

Successful eradication of a CSIRO glasshouse escape by using physical removal

An alligator weed infestation was found in July 1984 on the banks of a natural drainage gully that received washings from a CSIRO glasshouse where alligator weed was grown for the purpose of biological control research. Plant fragments that had fallen to the floor had been accidentally washed out via the floor drains.

*The gully was several hundred metres long and full of cumbungi reeds (*Typha *sp.) and other vegetation. By the time it was found, the alligator weed had established above the cumbungi. The infestation was pegged and mapped, and measurements were taken showing that most roots were within the top 10 cm of soil depth.*

Alligator weed and soil covering 132 m^2 were hand-dug to a depth of 10 cm. This showed deeper roots, and these were dug where they were obvious. All soil and plant material was bagged and dumped 70 m below the surface of an open-cut mine that was being backfilled. Excavation machinery was cleaned on site.

The drain was then excavated and the diggings spread on the banks. The banks were periodically sprayed with glyphosate to suppress other vegetation and allow easy identification of alligator weed regrowth. Manual digging and incineration of regrowth continued for 3 years; regular monitoring occurred for 5 years and successful eradication was the result (Sainty et al. *1998).*

Successful eradication through deep manual digging

Far North Coast Weeds eradicate patches of terrestrial alligator weed growing on the levee banks of Wilson Creek in northern NSW by manual digging. The infestations are sprayed with metsulfuron-methyl herbicide as many times as possible before a dig is undertaken (most receive about 6 sprays over a growing season prior to being dug). Surrounding vegetation is treated with glyphosate herbicide to create a bare area. The initial metsulfuron-methyl herbicide treatments kill roots and underground stems in the top 20 cm of soil, making the removal exercise easier, with less live material to remove. Roots and stems in the top section of soil are mostly dead, rotted or broken down to hollow skins, but deeper roots are still completely viable. It generally takes two staff members 1 day to work over an area of 5 m × 5 m containing plants and roots that may be down to 1.5 m deep.

This site has received five treatments of metsulfuron-methyl herbicide over a 12-month period before being dug.
Photo: Elissa van Oosterhout

Two staff members worked over this area in one day.
Photo: Elissa van Oosterhout

Large bankside site: the floating mass was manually removed and the bank treated four times with herbicide before manual removal of regrowth. Photo: John Moorhouse

Manual removal of regrowth after herbicide treatments. Photo: John Moorhouse

Aquatic infestations

It is usually possible to dig plants out by hand only in small, new aquatic infestations where the plants are rooted mainly in the banks or at very shallow depths.

Removal technique. In the case of small new aquatic infestations the floating plant growth should be carefully removed by hand before applying the initial herbicide treatments.

Floating mats can be rolled up if care is taken to collect stem fragments. Use floating booms to prevent pieces from floating away (a rope with floats is effective). Try to trace plant stems back to where they are rooted in the bank or substrate, rather than cutting the mat off at the bank and leaving many cut stems.

Once the floating material has been removed, the stems growing from the bank or substrate can be treated with herbicide.

After the initial herbicide treatments have taken effect, individual stems can be manually removed. The soil or substrate is generally soft enough to trace the stems and roots by sifting through the mud and clods with the fingers. Carefully break the mud and soil away from the stems and roots until they can be removed in one piece.

When working in shallow water down into the bed, it can be useful to use a pitchfork to gently extract the stems from mud and then follow them down into the harder substrate by hand to loosen and remove as much root material as possible.

Inspect the site regularly and manually remove any regrowth stems.

It's hard but it's worth it

Deep manual digging can be painstakingly difficult to begin with, but according to those with experience it gets easier with practice. The way alligator weed roots and stems feel becomes familiar to the point that it is possible to distinguish them underground from the roots of other plants just by feeling with your fingers. This technique takes advantage of the small window of opportunity to eradicate a small infestation quickly.

It's hard but it's worth it. Photo: Elissa van Oosterhout

Relatively fine roots can be easily distinguished with practice. Photo: Elissa van Oosterhout

Floating mats can be rolled back and collected whole.
Photo: John Moorhouse

Don't cut mats off at the bank; try to trace the main stems back to their growing points. Photo: John Moorhouse

Floating rope will contain fragments while physical removal is carried out. Photo: John Moorhouse

Trace stems and roots back through the mud. Photos: Elissa van Oosterhout

Remove as much plant material by hand as possible.
Photos: John Moorhouse, Elissa van Oosterhout

Stem fragments float

Alligator weed stems float. Loosening the substrate where plants are rooted often lets stems and fragments float to the surface for collection. It is also relatively easy to catch stem fragments that float away by using a floating boom on the water surface. It is useful to have someone watching from the bank to make sure the floating stem fragments don't escape.

Shallow mechanical excavation

Shallow mechanical excavation can be used to remove the above-ground biomass and some (or possibly all) of the below-ground growth of an infestation. Depending on the extent of the below-ground growth, shallow excavation can opportunistically remove the alligator weed to a point where eradication is possible. It has been used successfully to eradicate an isolated infestation in a stormwater retention basin (see the *Coolabah Reserve* case study in Part 5).

Shallow excavation is also used to remove large amounts of herbicide-treated biomass and allow for visual assessments of regrowth before further suppression or deep manual digging. This technique was used in a shallow waterway to remove a thick layer of mud and dead and dying alligator weed that had been treated with herbicide while water levels were low. This allowed manual digging to be carried out on deeply rooted regrowth.

Shallow mechanical excavation is appropriate in terrestrial and shallow aquatic infestations where some disturbance to streambeds, banks or soil can be tolerated and is permissible. It may not be appropriate for some bankside infestations where disturbance is detrimental.

The purpose of this technique is to remove the biomass and provide a clear area to allow for more effective treatment of regrowth plants, either for eradication or for suppression.

Machinery and operators

Earthmoving equipment such as excavators, backhoes and bobcats has been used to carry out shallow mechanical excavations. Any machinery used in an alligator weed infestation must be washed down on site according to strict hygiene protocols (see *Washdown procedures*). Operators should be briefed on the nature of alligator weed and should be amenable to taking longer to do the job carefully and precisely. It is wise to have observers on foot to guide operators to the exact location of the alligator weed.

Carefully break mud and soil away from the stems and roots.
Photo: Elissa van Oosterhout

Treat the bankside growth with herbicide once you have removed the floating plant material. Photo: Far North Coast Weeds

Manually remove regrowth following herbicide treatments. Photos: Terry Inkson, Great Lakes Council

Shallow excavation was used to remove a thick layer of herbicide-treated stems in a shallow aquatic site. Photo: Thomas White

Shallow mechanical excavation was the first stage of an eradication strategy for this infestation. Photo: Thomas White

The initial scrape should be shallow. Photo: Terry Inkson

Careful shallow excavation should result in a clean, bare surface. Photo: Graham Prichard

Machinery must be washed down. Photo: Thomas White

Excavation was done after the initial herbicide treatment. Photo: Thomas White

Excavation technique

To reduce the risk of spreading viable fragments, always apply initial herbicide treatments and await their effects before excavating.

Make an initial scrape of 10 cm to allow you to inspect the alligator weed root depth.

If large amounts of root material are present, further excavations can be made to a depth of 20 cm. It is not advisable to excavate to greater depths, because of both the sheer volume of contaminated soil that must then be treated and disposed of and the site disturbance over large areas. The result of a careful shallow excavation should be a clean soil surface.

Inspect the site 3 weeks after the excavation to look for regrowth from more deeply rooted plants. It will then be possible to assess whether the remaining plants can be manually dug out or whether further suppression with herbicide is necessary.

A sealed or lined dump truck, trailer or skip can receive the excavated soil and plant material. Take care avoid dropping or spilling soil as it is carried or tipped, and cover the load securely for transport.

Stream-bank situations

Shallow mechanical excavation has been used in stream-bank situations to eradicate isolated infestations. Isolated disturbances to banks may be tolerated to protect the rest of a catchment from infestation. If shallow excavation is used near stream-banks, to minimise the risk of spread it is important to avoid moving excavated material across the stream from one bank to another (i.e. don't allow the backhoe or excavator to be positioned on one bank and reach across to the other bank to scrape up material).

Permits and approvals may be required to excavate in riparian and stream-bank areas. Check with your relevant State or Territory authorities.

Disposal

Disposal of alligator weed plant material or contaminated soil is a major concern after physical removal. Without treatment and secure disposal there are high risks that plant material or contaminated soil will reinfest disposal sites or be spread to uninfested areas through the growth of viable fragments at disposal sites, accidental or intentional reuse as soil, compost or fill, or careless handling and transportation of the removed weed.

Any removed plant material or contaminated soil should be treated to kill viable alligator weed fragments (see *Treating and disposing of plant material* and *Methods of treating contaminated soil*) and then securely disposed of to reduce the associated risks of reinfestation and spread (see *Secure disposal of treated soil*).

Take care moving and transporting soil and plant material.
Photo: Graham Prichard

Treating and disposing of plant material

Plant material that results from manual removal (not containing soil) can be dried and incinerated.

Drying and incinerating

Plant and root material can be dried in an industrial dehydrator or oven or spread out on a hard surface and turned regularly until dry, and then burned in an incinerator. Plant material must be completely dry. Burning wet or undried plant material will not kill fleshy parts of the plant such as the roots and stems.

Plant materials that have been manually removed will be dried and burned. Photo: John Moorhouse

Warning: *Disposal methods that require plant material or contaminated soil to be transported away from an infestation should involve all necessary precautions associated with vehicle hygiene (see Part 3). Proper handling should ensure that no plant fragments or contaminated soils are dropped or spilled. Soil and plant material should be transported in sealed containers where possible. Permits to transport a noxious weed are also required under State legislation.*

Proper handling is required for transporting plant material.
Photo: Terry Inkson

Industrial dehydrator used to dry plant material. Photo: Elissa van Oosterhout

Powder-dry plant material going into an incinerator. Photo: Fiona McPherson

Plant material is dried in a trailer kept securely in a depot and wheeled out into the sun during the day. Photo: John Moorhouse

Manually removed root material suitable for boiling or microwaving. Photo: Elissa van Oosterhout

Tips on drying

- *Drying and incineration is appropriate for relatively small amounts of plant material.*
- *No special equipment is required if drying is done on a hard surface and material is turned by hand.*
- *Incineration is equivalent to secure disposal.*

Boiling or microwaving

Boiling (for half an hour) or microwaving (on high for 5 minutes) roots and plant material will kill them. The material can then be dried and burned.

Commercial biological waste processors

Some research facilities that deal with relatively small amounts of alligator weed plant material use commercial biological waste processors as secure disposal facilities. For example, these companies provide and collect wheelie-bin-sized containers that can hold up to 100 kg of material. The contents are then either cremated or chemically dissolved.

Composting

Composting can be used to treat and kill large amounts of physically removed wet plant material. Recent studies have shown that composting by methods compliant with the *Australian Standard for Compost, Soil conditioners and Mulches* (Standards Australia 2003; no. AS4454) can effectively kill alligator weed. The composting process must ensure that all plant material is exposed to temperatures of greater than 55°C for a minimum of 3 consecutive days in order to kill the alligator weed. Unless these conditions can be **guaranteed**, the compost derived from the process should **not** be reused as a compost or soil conditioner, but should be disposed of securely.

Black plastic heat sandwich

A heavy-duty black plastic sandwich has been used at Kooragang Island to dry alligator weed plant material. The sandwich is pegged out on a slope to allow drainage of moisture, and the heat between the layers dries the alligator weed to a crisp. The dry material can then be incinerated. Care must be taken to prevent the spread of fragments. This type of drying should be done on a hard surface (as shown in the picture) rather than on a grassed area.

Using a black plastic heat sandwich to dehydrate alligator weed. Photo: Rob Henderson

Composting of larger amounts of material can be done in windrows, but they must be located on **hardstands** (impenetrable surfaces such as concrete), and the material must be **thoroughly and regularly turned**. There is a high risk that alligator weed fragments will grow from the base or the surface of the windrows if they are not completely turned.

The risk of alligator weed surviving a composting process is minimised by doing the following:

1. Ensure the compost is adequately mixed and turned during each composting phase.
2. Add organic material such as lawn clippings and garden prunings to increase temperatures and thus complete decomposition (> 45 °C) and pasteurisation (> 55 °C).
3. Completely turn the compost at least four or five times during the composting cycle.
4. Use temperature probes to ensure the required temperatures are achieved.
5. Monitor windrows and surrounding areas for alligator weed outbreaks.

Note: *The common practice of leaving small amounts of plant material in black plastic bags in the sun before disposing of them at a refuge tip or in green waste will not achieve the required conditions for proper composting to occur, and fragments are likely to survive.*

Treatment and secure disposal of contaminated soil

Where mechanical removal has produced large amounts of alligator-weed-contaminated soil, the two steps of treatment and secure disposal are important for minimising the risks of re-infestation and spread.

1. Treatment

Treat the contaminated soil to kill any viable alligator weed fragments it contains. This can be done a number of ways, depending on the volume of contaminated soil and the available resources (see *Methods of treating contaminated soil*). All treatment methods carry the risk that alligator weed fragments may survive the treatment process.

2. Secure disposal

Because of the risk of fragments surviving, treated soil should be disposed of to a secure site and not reused as soil, compost or fill. Reuse of treated soil poses a high risk of spreading viable plant fragments.

Methods of treating contaminated soil

There are a number of ways to treat alligator-weed-contaminated soil, depending on the volume and the resources available. They include spreading and drying, steaming, and composting.

Spreading and drying. Spreading and air-drying is useful where contaminated soil can be spread on a hard surface for some time and then turned regularly to allow it to dry out completely. The material can be picked over by hand to remove dried plant material that can then be incinerated. Remaining dry soil should then be disposed of securely (see *Secure disposal of treated soil*).

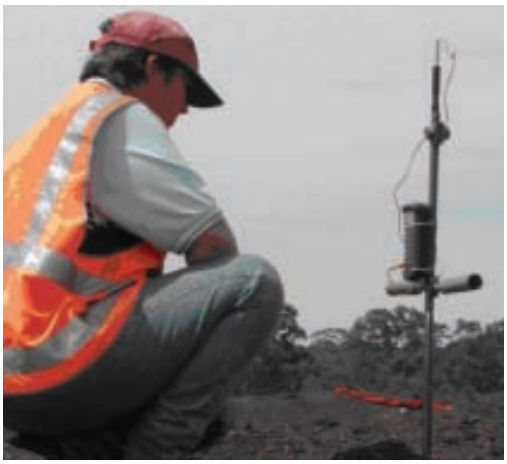
Oven-drying is useful for moderate amounts of contaminated soil. Industrial dehydrators can be used for this purpose. Soil should be broken up and spread on trays to ensure that all material is completely dried. Dried soil should then be disposed of securely.

Tips on composting

- *Composting is appropriate for treating large amounts of alligator weed plant material, as long as the derived compost is securely disposed of and* **not** *reused.*
- *Specific temperatures must be achieved throughout the whole volume of material being composted.*
- *There is a high risk of human error and potential for alligator weed to survive the composting process.*

Alligator weed regrowth at the base of a compost windrow.
Photo: Chris Dorahy

Alligator weed regrowth at the surface of a compost windrow. Photo: Rebecca Coventry



Using a temperature probe to check that required temperatures are achieved in composting. Photo: Chris Dorahy

Alligator-weed-contaminated soil requiring treatment and secure disposal. Photo: Terry Inkson

Soil-drying tips

- *Drying is appropriate for moderate amounts of contaminated soil.*
- *It can be done without specialised equipment but requires a hard surface.*
- *Soil and plant material must be completely dried out: any remaining soil moisture will allow alligator weed fragments to remain viable.*
- *Dry contaminated soil must still be securely disposed of.*

Contaminated soil drying on trays in an industrial dehydrator at 80 °C for 24 h. Photo: Elissa van Oosterhout

Steaming. Autoclaves or pasteurisation units can be used to steam-treat contaminated soil. Volumes depend on the equipment available. Steaming is appropriate for treating small amounts of alligator weed contaminated soil, but it may be difficult to locate suitable equipment. Steam-treated soil must still be securely disposed of.

Composting. In situations where shallow mechanical excavations have been carried out it is possible to use composting to treat the alligator-weed-contaminated soil, provided that soil comprises no more than 20% of the material to be composted.

Secure disposal of treated soil

Treated soil (i.e. composted, dried or sterilised soil) must be disposed of to a secure site and should not be reused as soil, fill or compost. Disposal is generally by burial, and sealed burial substantially decreases the risks of reinfestation. Sites should be regularly monitored.

Secure disposal sites. The type of secure disposal site required will vary according to the amount of material requiring disposal. Disposal sites can range from an allocated section of a warehouse where material is stored in drums or containers to in-ground burial pits or silage-type pits. In all cases, a secure disposal site should be:

- clearly signposted, with access restricted to authorised personnel
- not near any watercourse, and not hosed or swept out into any drainage system
- close to washdown facilities if vehicles are used to transport alligator weed
- unlikely to be disturbed or excavated in the future
- monitored regularly for outbreaks of alligator weed.

In-ground pits can be used to bury contaminated soil. Photo: Terry Inkson

There may be OH&S issues associated with working around deep pits. Photo: Terry Inkson

Silage-type pits have been used for alligator weed disposal. Photo: Thomas White

Contaminated soil can be wrapped in triple-layered black plastic before burial. Photo: Terry Inkson

Lift and load containers or parcels mechanically. Photo: Terry Inkson

Burial sites and silage-type pits. In-ground pits have been used with mixed success to bury contaminated soil. It has been common practice to bury untreated contaminated soil or plant material in pits, provided that they are deeper than 3 m. However, alligator weed fragments have been known to shoot and grow through several metres of soil, particularly when the soil is loose or friable or rubble-based fill. Burial of untreated or unsealed soil or plant material contains a much higher risk of regrowth than burial of sealed, treated soil or plant material.

There may be occupational health and safety issues associated with working around deep pits. Silage-type pits that get gradually deeper have been used to overcome this issue.

HazChem® barrels or sealable 200-L drums can be used for burial. These containers should be filled manually for hygiene reasons (i.e. to avoid dropping and spilling fragments), but they must be lifted and moved mechanically for OH&S reasons. Triple-layered black plastic can be used to line burial pits and wrap soil, but take care to seal the wrapping as well as possible and to avoid cutting or splitting the plastic.

Burial pits should not be lower than the watertable. Any available moisture will increase the risk of viable fragments shooting. Some experts maintain that a minimum of 4 m of hardpacked fill or backfill should cover the disposal pit.

Note: *If earthmoving equipment and transport vehicles are involved, the risk of spread are increased and hygiene is critical.*

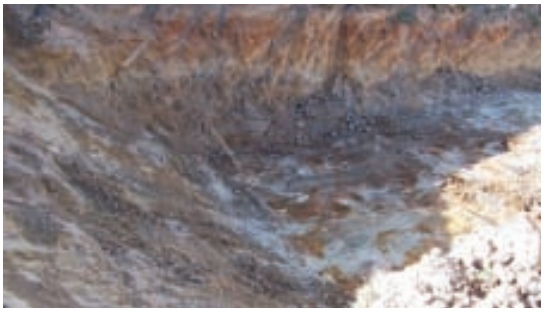
Successful burial – nothing left after 10 years

At Barren Box Swamp, a number of 3-m deep pits were excavated 5 and 10 years after alligator weed plant material had been buried sealed in black plastic bags. The aim was to determine the viability of the buried material. None of the broken down alligator weed material was viable.

Excavation of alligator weed buried in black plastic to determine viability 5 years after burial. Plant material was completely broken down and no longer viable. Photos: Pat Spence

Silage-type pits: time will tell

Recently at Woomargama, in NSW, a silage-type pit lined with plastic was used to bury large amounts of contaminated soil at a depth of 3 m. This disposal site will be monitored for outbreaks. It carries a relatively high risk of viable fragments re-establishing, because of the sheer volume of contaminated material that has been moved around; the use of plastic sheeting rather than sealed containers; and the fact that the pit is shallow at one end.



Plastic sheeting was use to line and cover the contaminated soil in the silage pit. Photos: Thomas White

Herbicides

The following sections outline the three registered herbicides and differentiate their specific roles in either suppressing infestations or helping with eradication. Take extreme care to apply herbicides legally, effectively and safely in and around water.

Using herbicides in and around water

Each State and Territory has regulations for the use of herbicides in and around water. Check with the relevant government authorities for the requirements in each State. Use only herbicide products that are registered for use in aquatic situations or allowed to be used under permit issued by the Australian Pesticides and Veterinary Medicines Authority (APVMA). Always use herbicides strictly in accordance with the directions specified on the label. Keep detailed records of all herbicide applications (this is a legal requirement in most States and Territories) and ensure that all persons applying herbicides are appropriately qualified, as required by each State or Territory.

The role of herbicides in alligator weed control

It has been known for some time that alligator weed is very tolerant of herbicides owing to its abilities to limit the translocation of active chemicals to its underground plant parts and to exude whatever small amounts of chemicals do reach the root systems.

Translocation

Translocation occurs in the phloem of the plant and moves organic materials from the leaves to active growth points and storage organs. The mechanism by which alligator weed prevents underground translocation is not fully understood. Translocated herbicides will move through the above-ground parts of alligator weed plants, killing them, but only very small amounts of the herbicide are moved to the underground plant parts. The very small amounts of active chemical that do reach the root systems are either degraded into other substances or exuded from the roots and underground stems, with the result that toxic quantities of the herbicide are not accumulated and growth is not inhibited. Rapid regrowth always results (Bowmer, McCorkelle & Eberbach 1991; Tucker, Langland & Corbin 1994).

Regrowth occurring at nodes on herbicide-treated stem fragments.
Photo: Terry Inkson

Regrowth occurring from aquatic stems treated with herbicide.
Photo: Elissa van Oosterhout

Regrowth after glyphosate treatment. Photo: Graham Prichard

'No single herbicide treatment effectively eradicates alligator weed.'

Bowmer, McCorkelle & Eberbach 1991

Many herbicides have been trialled over many years for alligator weed control, and it is now clear that there are important roles for specific herbicides in suppressing and depleting alligator weed and in assisting with eradication.

Herbicides registered for use on alligator weed

Three herbicides have registration for use on alligator weed: metsulfuron-methyl, glyphosate and dichlobenil (see table below). Metsulfuron-methyl products are registered only for use on terrestrial alligator weed, and they may be applied to aquatic infestations only under the conditions of a current APVMA permit. Glyphosate herbicides have product-specific label-registered-use patterns for either aquatic alligator weed or terrestrial alligator weed. Dichlobenil has a general label-registered-use pattern for aquatic weeds. The table opposite lists current permits held for the use of various herbicides on alligator weed. Copies of current permits can be downloaded from the APVMA website at www.apvma.gov.au.

HERBICIDES REGISTERED FOR USE ON ALLIGATOR WEED

Herbicide	Registration	Situation	State/LGA	Rate
Metsulfuron-methyl 600 g/kg	**Label registration for terrestrial applications only**	Alligator weed in native pastures, rights of way, commercial and industrial areas.	NSW and Qld only	Boom spray 80 g/ha Handgun 10 g/100 L
	Off-label permit registration is required for aquatic applications	According to individual off-label permits (see table below).	According to individual off-label permits (see next table)	10 g/100 L water
Glyphosate 360 g/L Product labels referring specifically to 'alligator weed – floating form only' indicate that the product is not registered for use on terrestrial alligator weed.	**Product-specific label registration for aquatic applications** For example: **Weedmaster® Duo** **Roundup® Biactive™**	Alligator weed, floating form only, in all bodies of fresh and brackish water flowing, non-flowing or transient; also on margins of streams, lakes, dams and in channels and drains. Not within 0.5 km upstream of potable water intake in flowing water (river or stream) or 0.5 km of a potable water uptake in standing body of water (lake or dam).	All States	Handgun/knapsack 10 mL/L water
Product labels that do not refer specifically to alligator weed indicate that the product is registered for use on terrestrial alligator weed under its general weed-control use pattern.	**Product specific label registration for general weed control** For example: **Roundup®** **Wipe-Out 360**	Many grasses and broad-leaved weeds. For general weed control in domestic areas (home gardens), commercial, industrial and public service areas, agricultural buildings and other farm situations.	All States	10 mL/L water
Dichlobenil 67.5 g/kg	**Label registration for aquatic weeds**	In standing water only (not moving); not in water to be used for crop irrigation, livestock watering or human consumption. Do not graze treated areas.	All States	1.7–2.3 kg/100 m^2 on exposed soil 170–230 kg/ha or 1.7–2.3 g/100 m^2 for water less than 1 m deep 230–340 kg/ha or 2.3–3.4 kg/100 m^2 in water more than 1 m deep.

LGA: local government area

CURRENT PERMITS HELD FOR USE OF HERBICIDES ON ALLIGATOR WEED				
Permit	**Herbicide**	**Situation**	**State/LGA**	**Rate**
Permit 7033 Expires 30.06.09	Dichlobenil 67.5 g/kg Metsulfuron-methyl 600 g/kg	Alligator weed in Byron Creek, Wilson River. Alligator weed in Byron Creek, Wilson River.	Far North Coast Weeds Far North Coast Weeds	22 g/m^2 10 g/100 L water
Permit 6028 Expires 30.06.08	Glyphosate 360 g/L	Alligator weed in aquatic and terrestrial areas and within 500 m of the Seaham Weir Pool Potable Water Intake only.	Port Stephens Council	1:100
Permit 8211 Expires 30.06.10	Metsulfuron-methyl 600 g/kg	Alligator weed in non-potable waterways.	Newcastle City Council local government area	10 g/100 L water
Permit 6709 Expires 30.06.08	Metsulfuron-methyl 600 g/kg	Alligator weed in aquatic situations (non-potable waterways).	Scone, Muswellbrook and Singleton shires boundaries Upper Hunter Weeds Authority	10 g/100 L water
Permit 7249 Expires 30.06.09	Metsulfuron-methyl 600 g/kg	Alligator weed in non-potable aquatic situations.	Sydney Olympic Park	10 g/100 L water
Permit 7360 Expires 30.06.08	Metsulfuron-methyl 600 g/kg	Alligator weed in aquatic situations, including potable water catchment of Grahamstown Dam.	Port Stephens and Maitland City council	10 g/100 L water
Permit 8127 Expires 30.06.08	Metsulfuron-methyl 600 g/kg	Alligator weed in non potable waterways: Eumemmerring Creek, Hallam Drain System, Merri Creek, Darebin Creek.	Victoria	10g/100L water
Permit 8674 Expires 30.09.10	Metsulfuron-methyl 600g/kg	Alligator weed in non-potable situations.	Maitland City Council	10 g/100 L water
Permit 9138 Expires 01.02.09	Metsulfuron-methyl 600 g/kg	Alligator weed in aquatic areas within the Camden area.	Council of Camden	10 g/100 L water
Permit 7182 Expires 30.06.09	Dichlobenil 67.5 g/kg Glyphosate 360 g/L Metsulfuron-methyl 600 g/kg	Alligator weed in home-garden situations in residential areas (urban backyards). Alligator weed in home-garden situations in residential areas (urban backyards). Alligator weed in home-garden situations in residential areas (urban backyards).	NSW only NSW only NSW only	25–37 g/m^2 10 mL/1 L water 1 g/10 L water
Permit 5924 Expires 30.11.07	Metsulfuron-methyl 600 g/kg	Alligator weed in riparian areas and residential backyards.	ACT	10 g/100 L water
Note: These permits are held by specific weeds authorities. Other intending users need to obtain permits from the APVMA. These permits are listed as examples of the current permits that exist for the application of herbicides to alligator weed.				

LGA: local government area

About metsulfuron-methyl

Metsulfuron-methyl is a selective broad-leaved-weed herbicide that is active at very low concentrations (as little as 5 g/ha for some weeds). Many grasses and cereals are able to tolerate this herbicide. The chemical compounds inactivate a key enzyme system that is required for the synthesis of amino acids. Persistence in the soil is determined by pH and drainage. Metsulfuron-methyl will persist for longer in alkaline conditions and where drainage is impeded (Bowmer, McCorkelle & Eberbach 1991).

Metsulfuron-methyl will cause a slow, steady kill of the above-ground parts of alligator weed, which take 1 to 2 months to die back. It can then take another month for the underground root reserves to generate regrowth, and the regrowth can achieve pre-treatment levels 3 months after treatment during the growing season. Regrowth is slower than after glyphosate.

Only minute proportions of metsulfuron-methyl are translocated to the underground plant parts (Bowmer, McCorkelle & Eberbach 1991).

About glyphosate

Glyphosate is a non-selective systemic herbicide that is absorbed by the foliage and green stems. It moves through a plant from the point of contact into the root system and disrupts the production of essential amino acids that synthesize proteins and help in cell division in plants. Glyphosate causes rapid desiccation and browning-off in the above-ground parts of alligator weed, but it is poorly translocated to underground tissues. Regrowth occurs rapidly (sometimes within 1 week of treatment).

Research shows that only very small proportions of leaf-applied glyphosate are translocated to the underground plant parts and retained. The quantity that is translocated does not inhibit underground stem and root growth, and 25% of the glyphosate that does reach the roots is exuded by the plant (Bowmer, McCorkelle & Eberbach 1991).

Glyphosate is inactivated upon contact with soil with sufficiently high clay content. In water it binds to dissolved and suspended clay particles and bottom sediments and becomes inactive, breaking down to carbon dioxide, water, nitrogen and phosphorus over several months.

About dichlobenil

Dichlobenil is a non-selective residual herbicide for pre-emergent control of annual grasses and broad-leaved weeds in certain aquatic and terrestrial situations (see label registrations). Dichlobenil inhibits actively growing meristems and translocates rapidly to the shoots after soil uptake. Dichlobenil is an old compound widely used for weed control in deep-rooted fruit crops. It evaporates rapidly from moist soil (Bowmer, McCorkelle & Eberbach 1991).

In the 1990s dichlobenil was touted as an excellent chemical for eradication of alligator weed. However, due to its ability to suppress shoots only in the top layers of soil, there is always a possibility that deeper underground plant parts will remain viable and undetected. Because the herbicide lasts for up to six months, it can give an impression that the infestation is eradicated. Once the residual effects of the herbicide have worn off, new shoots can get to the surface. For eradication to be successful in the long term all underground plant material must be found and removed, and it is usually found more easily if regrowth is allowed to occur. Dichlobenil therefore should not be used in eradication strategies, but it does have a role in suppression strategies.

Dichlobenil is highly toxic to fish and other aquatic life. Because of its residual nature, dichlobenil must not be used if the area to be treated is to be used for livestock grazing, or if the water to be treated is to be used for crop irrigation, livestock watering, human consumption, or commercial fishing or shellfish enterprises.

Using herbicides for suppression

Recent research and field practices have shown that **metsulfuron-methyl is the most effective herbicide for alligator weed suppression in both aquatic and terrestrial situations**. Glyphosate products have a number of drawbacks for long-term suppression. Dichlobenil can help with long-term suppression.

Using metsulfuron-methyl for suppression

An annual treatment program consists of three applications of metsulfuron-methyl 600 g/kg over the growing season. If used correctly this program will provide ongoing suppression of alligator weed, and it can suppress and deplete an infestation to the point where eradication through physical removal may be possible. The metsulfuron-methyl annual treatment program should be used for:

- suppression leading to eradication
- ongoing suppression.

Gradual depletion. This success of the annual treatment program is based on the theory of gradual depletion. Because of the ability of alligator weed to prevent the translocation of herbicide down into its roots and underground storage tissues, plants will regrow each time they are treated with herbicide. If the plants are treated with herbicides three times each growing season they will be forced into three regrowth phases (one after each treatment). Each time the plants regrow they are using up and gradually depleting their stored energy. The first two sprays cause the greatest depletion. The third spray at the end of the growing season creates some further depletion, and because it corresponds with the decline in the plants' photosynthetic patterns it also increases the possibility that some amount of herbicide will be translocated down into the roots. Over time, the plants become less vigorous and regrowth begins to take longer between the repeat spray treatments.

Eventually there is not enough above-ground growth to direct energy to the underground storage tissues at the end of the growing season. If this is repeated over a number of seasons, the energy is gradually drained from the plants. Stored energy is used to start the next season's above-ground growth, so if the treatment is repeated for a number of years, over time the plant's energy reserves will be depleted to a non-viable level.

The annual treatment program:

1. *Apply the first foliar treatment of metsulfuron-methyl 600 g/kg in November (early in the growing season. This could be earlier in subtropical areas).*
2. *Apply the second foliar treatment of metsulfuron-methyl 600 g/kg in February.*
3. *Apply the third foliar treatment of metsulfuron-methyl 600 g/kg at the end of the growing season, in May.*
4. *Carry out an annual treatment program for a number of years (six on average) and consider the possibility of eradication through physical removal.*

Note: Make the second and third foliar spray treatments only if there has been sufficient regrowth. In dry conditions the plant may be suppressed and depleted to the point where only two applications are possible over the growing season. This may also occur after a number of years of treatment (2 years on average), when it may be possible to apply only two sprays over the growing season, as the weakened plants take much longer to reach the required level of regrowth. A minimum of two sprays per growing season should always be maintained until the point where eradication through whole-of-plant removal is possible.

Metsulfuron-methyl provides ongoing suppression of alligator weed on the Williams River. Photo: Elissa van Oosterhout

Repeated spot spray treatments of metsulfuron-methyl suppress and deplete isolated patches of alligator weed on the Paterson River. Photo: Brian Worboys

The annual treatment program causes regrowth that gradually depletes the plant's underground energy stores. Photo: Brian Worboys

Aquatic infestation after first treatment with metsulfuron-methyl. Photo: Graham Prichard

Awaiting regrowth for the third treatment with metsulfuron-methyl in an aquatic infestation. Photo: Elissa van Oosterhout

Level of regrowth required for herbicide re-treatments

As a guide, second and third foliar applications should be applied only to those alligator weed plants with:

- *at least five or six sets of leaves*
- *10 cm stem length, or*
- *30 cm crown width (in the case of prostrate regrowth).*

Regrowth can be prostrate after herbicide treatment. Photo: Andrew Docking

Managing the presence of other vegetation. In suppression strategies there are advantages and disadvantages of having other vegetation growing among an alligator weed infestation. If other plants are present it can be hard to locate the alligator weed and can also prevent good contact of herbicide with the alligator weed foliage. On the other hand, the presence of other vegetation (particularly wetland or pasture species) will help suppress the alligator weed in the long term. If alligator weed plants are difficult to find or contact with foliar sprays, carefully mow the area 2 or 3 weeks before you treat it with herbicides. This will promote alligator weed regrowth; the metsulfuron-methyl will then not affect the growth of the grasses and other monocots, which will become dominant after the alligator weed has been suppressed. Mowing can be used before each of the three spray applications as part of the *annual treatment program*. Wait for the correct level of alligator weed regrowth before you spray.

Any mowing or slashing must be done extremely carefully to avoid spreading fragments of alligator weed beyond the control site. Mowing by brush cutter is the best approach, and all equipment and machinery should be washed down on site after use.

The risks of spread from mowing and slashing of alligator weed make this technique inappropriate for use in eradicable infestations, where it is better to use glyphosate to help make the plants visible (see *Using glyphosate to improve visibility*).

Glyphosate may be more acceptable in domestic situations. Photo: Lalith Gunasekera

A containment fence to prevent movement of herbicide-treated fragments. Photo: Paul O'Connor

Fragments caused by herbicide treatments upstream. Photo: Tony Cook

Using glyphosate for suppression

Glyphosate has a number of drawbacks: it causes increased fragmentation in aquatic infestations; reduces competition from other vegetation; and creates bare areas that are at risk of erosion. Metsulfuron-methyl is superior to glyphosate for suppressing alligator weed, particularly for suppressing and depleting infestations over long periods of time.

However, there are some situations where glyphosate may be the only option:

- In domestic or high public-use areas: it may be more acceptable to use glyphosate rather than metsulfuron-methyl, although the resulting bare patches may not be well received.
- In an aquatic infestation not covered by an off-label permit for metsulfuron-methyl.

Field experience has shown that using glyphosate in aquatic situations leads to greater fragmentation of stems, allowing potentially viable stem fragments to float further downstream, with the risk of spreading the infestation. Consider whether floating booms or containment fences can be used if you need to use glyphosate in aquatic situations.

In the above situations glyphosate can be applied in the same way as metsulfuron-methyl (as per the annual treatment program), but is likely to require more applications (probably five or six) over each growing season.

You have to retreat at least twice as much with glyphosate compared to metsulfuron; metsulfuron is better for longer term control; glyphosate has better public perception.

National Alligator Weed Workshop

Glyphosate should not be used for ongoing control and management. It should only be used once or twice over the same area at the very beginning to allow you to find the alligator weed; or used to treat the surrounding vegetation once you have achieved high levels of suppression and you're looking at eradication techniques. The lack of competition (from other vegetation) will always give alligator weed the advantage.

National Alligator Weed Workshop

Fragmentation caused by glyphosate in aquatic areas should be highlighted as a major issue … the potential for further spread of alligator weed is immense … fencing and booms should be in place before treatments to prevent further spread.

National Alligator Weed Workshop

We noticed that glyphosate caused fragmentation of alligator weed stems, and we found regrowth downstream in all the creeks that we treated … we stopped using glyphosate on aquatic infestations … metsulfuron has a very low rate of fragmentation.

National Alligator Weed Workshop

Metsulfuron should be recommended over glyphosate because it is selective and not all of the vegetation is destroyed – if embankments on creeks or rivers [have] reasonably competitive species present then there is much less chance of alligator weed fragments taking root than if they were deposited on bare soils.

National Alligator Weed Workshop

Treat all new infestations with metsulfuron-methyl immediately. Photo: Biosecurity Queensland DPI&F

A visual buffer zone is created by using glyphosate. The alligator weed itself is treated with metsulfuron-methyl. Photo: NSW DPI

Using dichlobenil for suppression

Dichlobenil can be applied with the last foliar spray treatment of metsulfuron-methyl or glyphosate each year, but only in terrestrial infestations that are not to be grazed, or in aquatic infestations in still water that is not to be used for crop irrigation, livestock watering or human consumption. The cost of dichlobenil is prohibitive for treating areas bigger than 1 ha.

Dichlobenil is a pre-emergent herbicide; it stays in the soil for several months and gives a very good level of suppression.

National Alligator Weed Workshop

Dichlobenil affects the top 10 cm of soil and prevents any new shoots from coming up through the soil's surface. Any roots, underground stems and storage organs will remain unaffected at depths lower than 10 cm. So you need to be careful that you don't assume you have eradicated it, because regrowth will occur from the viable underground material once the residual effect has worn off.

National Alligator Weed Workshop

Using dichlobenil

Dichlobenil is useful for suppression but is not compatible with eradication strategies, as it can prevent regrowth from any remaining underground plant tissues for up to 6 months. If you are using physical removal-based eradication you must find and remove any remaining plant material; therefore, dichlobenil should not be used.

Initial herbicide treatments to help with eradication

Both glyphosate and metsulfuron-methyl can be used in aquatic and terrestrial situations as tools to help with eradication, prior to physical removal of plants. Dichlobenil is not appropriate for initial treatments in an eradication strategy.

Using metsulfuron-methyl for initial treatments

In any infestation where eradication is the objective, an initial foliar treatment of the above-ground plant growth with metsulfuron-methyl should be done to reduce the amount of viable plant material at the site. Make sure the infestation is clearly demarcated before you treat the alligator weed.

Using glyphosate to improve visibility

If the infestation is growing in amongst other vegetation, you can use glyphosate to remove all the other vegetation. This allows for better visibility for mechanical or manual removal. In small infestations you can create a visual buffer zone by using glyphosate.

Using a glyphosate/metsulfuron-methyl tank mixture

Experts agree that use of the registered* tank mixture of glyphosate and metsulfuron-methyl should be avoided because of the greatly reduced effect of the metsulfuron-methyl on glyphosate-affected plants. Many operators apply the tank mixture to terrestrial alligator weed infestations in the belief that it will both treat the alligator weed and create a bare area to allow better visibility for follow-up treatments. Experts now recommend these herbicides be used separately.

Do not apply tank mixtures of glyphosate and metsulfuron- methyl to alligator weed – glyphosate works faster and plants shut down before the metsulfuron has a chance to work. You are just wasting metsulfuron. It is far more effective and efficient to use these chemicals on their own – treat the alligator weed with metsulfuron-methyl and spray the surrounding areas with glyphosate for better visibility.

National Alligator Weed Workshop

* Each herbicide in a tank mixture must be registered for use on at least one of the target weeds. See the table on page 64 for product-specific glyphosate registration details.

Steam instead of herbicide?

Recent developments in Applied Steam Technology may provide an alternative to the use of herbicides in alligator weed eradication and suppression strategies. Theoretically the application of steam to alligator weed would have the same role as metsulfuron-methyl herbicides – either as an initial treatment to kill above-ground or floating plant material in an eradication strategy or for the gradual depletion of plants in a suppression strategy (using the annual treatment program as described on page 67). As is the case with herbicides, steam will not kill underground stems or roots. Trials are now planned to test the use of steam as an alternative treatment for use in alligator weed suppression strategies and for initial treatments prior to physical removal.

Applying steam to a Sagittaria infestation. Photo: Justin Sheed

The flea beetle was released into this infestation at Chipping Norton in 1978. Photo: Mic Julien

The flea beetle reduced the infestation right back to the edge of the water body. Photo: Mic Julien

Stems collapse, rot and sink. Photo: Elissa van Oosterhout

Biological control

In Australia, biological control agents play specific roles in the ongoing suppression of aquatic alligator weed in climates favourable to their activity. This role is appropriate in **core area** infestations where suppression with herbicides is not practicable because of difficult access or the sheer extent of the infestation.

The flea beetle

The flea beetle (*Agasicles hygrophila*) is the primary biocontrol agent for alligator weed and was first released in Australia in 1976 (Julien, Broadbent & Harley 1979). Adults and larvae feed on the leaves and stems of aquatic alligator weed and pupate in the stem hollows. Newly developed adults cut exit holes in the stems, causing stem damage and allowing rot-causing organisms to enter the plants. Eventually the emergent stems collapse and the floating weed mat rots, breaks up and sinks.

The flea beetle Agasicles hygrophila. Photo: John Green

The flea beetle has provided good suppression in aquatic infestations in the Sydney region, successfully reducing large floating infestations on permanent water bodies back to edge infestations (Julien 1981).

> *Each year the weed regrew in spring and summer to develop mats over the water, but before they could cover more than a metre or so they were again reduced by an increase in the control agents.*
>
> **Julien & Stanley 1999:7**

Unfortunately, the plants can regrow from the root systems remaining in the banks, as the flea beetle will not establish populations on, or suppress, terrestrial alligator weed. Nor has it successfully suppressed infestations in small or ephemeral waterways, drains or swamps (Julien & Bourne 1988).

The flea beetle is limited to warm temperate and subtropical areas, and the predicted range of alligator weed in Australia far exceeds the predicted range of the flea beetle (Julien, Skarratt & Maywald 1995). Suppression by the flea beetle occurs where winters

Alligator weed affected by flea beetle affected needs to be contained. Photo: Graham Prichard

are mild and can take several seasons after the beetle is released. In cooler areas the insect may survive, but lower temperatures limit population increase and suppression does not occur. Populations of insects can't survive where frost or ice kills the tops of the alligator weed stems. New populations may recolonise each year from warmer areas but fail to increase to damaging levels before the next winter (Coulson 1977 in Julien & Stanley 1999).

Role of the flea beetle

For the above reasons and because the core areas of infestation in Australia happen to be within the appropriate climatic zones suitable for the flea beetle, the beetle's role is limited to ongoing suppression of aquatic infestations in core areas. Its greatest benefit is the control it affords in infestations where it is not practical or affordable to implement an annual herbicide treatment programs.

The flea beetle is therefore not compatible with eradication strategies or suppression leading to eradication strategies in non-core areas. As with herbicide treatment, attack by beetles causes alligator weed plants to fragment, creating potential issues of spread in non-core infestations. Plant fragments in areas where flea beetles are active must be contained if downstream spread is an issue.

Beetles won't eradicate alligator weed – they are only appropriate in areas that can't be otherwise controlled. In core area infestations managers should continue herbicide control programs wherever possible and the beetles will persist and reinvade whenever they have the opportunity.

National Alligator Weed Workshop

Flea beetle starting to take effect 4 December 2004. Photo: Graham Prichard

Most stems browned off 9 January 2005. Photo: Graham Prichard

Weed mat starting to sink 31 January 2005. Photo: Graham Prichard

New regrowth appearing by late summer 27 February 2006. Photo: Graham Prichard

Flea beetles are found at all known aquatic alligator weed infestations in core areas, and they do not need to be re-released in the field. There is a lag phase between when beetle populations build up in around November and when the beetles have an effect on the alligator weed. The alligator weed can often appear unaffected until around February. This lag phase can be a problem if flows need to be maintained or waterway access needs to be kept clear.

The alligator weed moth Arcola malloi. Photo: Mic Julien

Damage caused by the moth. Photo: Mic Julien

Alligator weed moth (*Arcola malloi*)

A moth (*Arcola malloi*) was also released in Australia in 1977 and became established within a few years (Julien 1981). The moth contributes to control in aquatic habitats and is well established, but although it does attack terrestrial alligator weed plants it has no controlling impact on terrestrial infestations in Australia.

The moth sometimes reaches controlling populations within 1 year, but its numbers generally build up more slowly than those of the flea beetle (Julien & Stanley 1999).

The moth larvae tunnel inside the stems, damaging the vascular tissues. This complements the effects of the flea beetle in aquatic situations, but it has no significant effect on terrestrial infestations (Julien 1995; Sainty *et al.* 1998). In a number of small infestations the moth has caused total destruction of emergent stems.

Other agents

Another flea beetle (*Disonycha argentinensis*) was released in Australia in 1980 and 1981. This flea beetle was orientated towards terrestrial habitats but failed to become established (Julien & Chan 1992; Julien & Stanley 1999). Further investigations into potential biological control agents for both aquatic and terrestrial alligator weed are currently under way.

Part 5: Case studies

Pinpoint mapping: keeping track of a moving target on the Hunter River

Written by Brian Worboys
Edited by Elissa van Oosterhout

Introduction

This case study presents a method of mapping alligator weed developed by Brian Worboys and Maitland City Council. The method was developed to allow better use of time and resources when controlling extensive alligator weed infestations in core areas, but it would also help in managing scattered infestations or plants in non-core areas.

Maitland City Council local government area is within the Lower Hunter core area for alligator weed distribution in Australia. The weed is widespread and long established in the area, occurring in both terrestrial and aquatic situations. This situation has called for extensive, ongoing, high-cost control efforts. The infestation-mapping method described here has reduced the time spent looking for and treating infestations and has provided a record of the control treatments carried out at any given site. It also enables assessment of the effectiveness of an ongoing control effort over time and allows for monitoring and recording of the spread of alligator weed, particularly in aquatic situations (along lengthy stretches of riverbank).

What is pinpoint mapping?

Pinpoint mapping uses a global positioning system (GPS), a field laptop, a geographic information system (GIS) and a mapping program to record and track alligator weed infestations or plants. This technique can successfully pinpoint an infestation the size of a single stem.

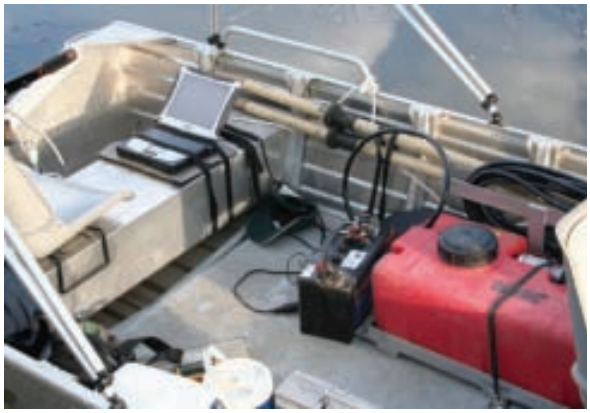
The GPS is connected to the field laptop or is incorporated in the field laptop as one unit. (Maitland City Council's field laptop has the GPS incorporated as one unit.) The GIS MapInfo® and a mapping and inspection program called WeedMap® are installed on the laptop. Both programs are used in conjunction with the GPS to map, record and track weed infestations.

MapInfo® provides the geographic information required to map and record an infestation after the GPS has located exact coordinates. The WeedMap® program is then used to record the inspection and the control treatments that are carried out.

In Maitland City Council's local government area, pinpoint mapping is used to record alligator weed infestations along extensive stretches of riverbank. Inspections and mapping are done by boat, so the equipment and the method must be robust and easy to use in the field. Control treatments are carried out simultaneously and recorded as part of the inspection and mapping effort.

The alligator weed problem

In the Maitland City Council local government area (LGA), alligator weed infestations occur along the Hunter and Paterson River systems. The Hunter River is a major watercourse that runs through Maitland. The Paterson River forms a boundary between the Port Stephens and Maitland City Council LGAs. Both rivers supply irrigation water to the vegetable and turf farms



Pinpoint mapping set-up. Photo: Brian Worboys

Pinpoint mapping locates alligator weed regrowth in amongst other vegetation. Photo: Brian Worboys

Panasonic Toughbook® laptop with built in GPS and GIS software. Photo: Brian Worboys

A 4.2-m aluminium boat is used. Photo: Brian Worboys

Spray rig. Photo: Brain Worboys

on the floodplain and the grazing lands in the foothills. Alligator weed infestations range in size from one or two plants to 2 or 3 m^2.

Infestations occur along a 40-km stretch of riverbank on the Hunter River and a 17-km stretch of riverbank on the Paterson River. Maitland is subject to seasonal flooding and there is a high possibility for alligator weed from upstream areas to be washed out onto the highly productive floodplain, as well as downstream and into adjacent river systems.

Currently there are approximately 180 infestations scattered along the 57 km of riverbank on the Hunter and Paterson Rivers. (Before pinpoint mapping there were over 400 scattered infestations.) A number of years ago it became obvious that an effective and efficient control program was needed to manage, suppress and contain these infestations.

Alligator weed infestations along the Hunter River. Photo: Brian Worboys

Why is pinpoint mapping necessary?

In accordance with the gradual depletion strategy, it is important that each and every plant or infestation is treated with herbicide three times during the growing season each year. However, the problem of finding alligator weed amongst taller vegetation or similar-looking vegetation makes this difficult, particularly from a boat.

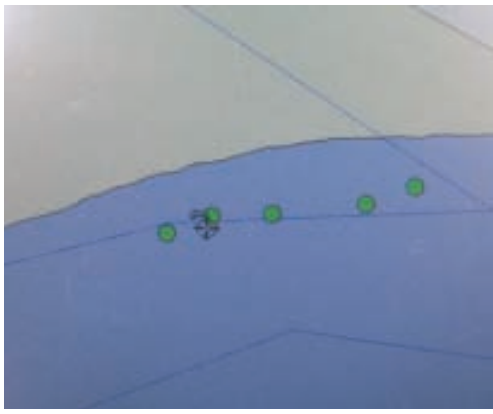
With the pinpoint mapping system every infestation that is found is recorded, treated and easily located for its follow-up treatments. With such accurate and effective control treatments there has been a reduction in the size and number of infestations along the riverbanks.

Methods and equipment

Maitland City Council has used various methods to record infestations along the Hunter and Paterson Rivers over the last 10 years, and a number of improvements have been made over this time. The equipment currently used is as follows:

- GPS – incorporated in laptop by manufacturer
- laptop – Panasonic Toughbook CF 19®
- software
  - MapInfo® GIS
  - WeedMap® mapping and recording program.
- spray rig – 50-L tank with pump, with hose and hand gun
- boat – 4.2 m aluminium V-bottom boat with 25-hp motor





Recorded infestations show as green dots on a map of the river that adjusts according to the boat's movement, shown as a black cross.
Photos: Brian Worboys

1996 – 2000

In the early stages a Garmin II Plus® GPS unit was used to pinpoint infestations and the coordinates and size of infestations were recorded on pen and paper. The points would then be entered onto an Excel spread sheet and incorporated onto Council's GIS system (MapInfo®) in a specific layer.

The process worked well at the time but had limitations and problems. Time and accuracy problems occurred with hand-recording of the coordinates and entering them into the GIS system. Inaccurate recordings could result in time lost looking for absent infestations. (All it takes is one wrong number and the record could end up way off target and be lost.)

2000 – 2003

The Garmin II Plus® GPS unit continued to be used but was connected to a laptop running MapInfo. The laptop was strapped to the boat seat and connected via a cable to the GPS. Council's GIS staff created a program in MapInfo® to run with the GPS. The rivers, property boundaries and previously recorded alligator weed infestations could then be displayed on screen. Records show as dots along a map of the river and the boat's location is also shown, allowing the GPS to guide the inspection to each previously recorded infestation. As the boat moves along the river the GPS adjusts the position on the map on screen.

To allow fast recording into MapInfo® a code system was developed for the weed species (this system is also used to record other weeds simultaneously), the area and density of the infestation, and the land use.

2003 – present

With the rugged locations the laptop was used in, Council decided to purchase a Panasonic Toughbook® Laptop Computer. The unit is able to handle dusty, wet, hot or cold conditions without failing. The laptop was purchased with a GPS incorporated in the unit.

In late 2003 Council purchased the WeedMap® software program from Rapid Map Global. This program assists with all aspects of noxious weed control at a local government level. The program has the capacity to operate with the GPS and MapInfo® in recording and displaying the control treatments that have been carried out at each recorded infestation.

Inspecting, recording and treating

Two operators are able to carry out inspections and recording and control treatments, with one operator driving the boat and observing and the other operator observing from the bow. A 50-L spray unit is carried in the boat and used to treat the infestations. All infestations are spot-sprayed with metsulfuron-methyl herbicide under the Council's off-label permit.

With all systems working on the laptop the boat travels along the river as close as possible to the river bank, moving in and around trees and any obstructions as slowly as possible, with the motor just idling. At each green dot on the map (as shown in the photo above) the boat is driven in to the bank to find the recorded infestation or plant. If alligator weed can't be found the record is retained to enable follow-up inspections later in the growth season. When new infestations are seen the size and extent are checked on foot, and the infestation is immediately recorded and treated.

If the riparian vegetation is too dense, the observer walks along the bank while the boat operator continues to look from the riverside. New infestations are often found this way and are recorded and treated before they become established.

If the hose cannot reach an infestation from the boat, a small 4-L atomizer spray bottle is filled from the tank on the boat and used to treat the infestation.

Key points

The combination of a GPS, GIS, mapping program and laptop has enabled Council to effectively and efficiently manage alligator weed infestations along the Hunter and Paterson Rivers. With the ability to reinspect and treat every known infestation three times over the growing season, Council has reduced the number of infestations along the riverbanks.

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Two operators are needed for inspection, recording and treatment.
Photo: Brian Worboys

New and regrowth infestations are treated immediately.
Photo: Brian Worboys

The observer looks from the bank when the vegetation is dense.
Photo: Brian Worboys

Coolabah Reserve: immediate eradication by using shallow mechanical excavation

Written by Graham Prichard
Edited by Elissa van Oosterhout

Introduction

This case study shows how an isolated infestation at Coolabah Reserve in the Port Stephens Council local government area was carefully and successfully eradicated by using an integrated approach involving herbicides, mechanical removal and manual removal.

Coolabah Reserve stormwater basin

Port Stephens Council local government area contains approximately 3500 ha of land affected by alligator weed, with over 300 individual infestations on record. These infestations make up part of the core area infestations of alligator weed in Australia (see *Current distribution* in Introduction). Within this core area approximately 30 new infestations are recorded each year, most resulting from spread by floodwaters and machinery. When new infestations are isolated from the main areas of infestation they are treated intensively with the aim of eradication. This was the case with the Coolabah Reserve infestation.

The Coolabah Reserve stormwater basin is an 800-m^2 stormwater retention basin with a piped inlet and outlet points. The basin is in a suburban area and is surrounded by a mown grass buffer area.

The infestation

In January 2004 following an alligator weed identification workshop conducted by the Port Stephens Council Weeds Unit for council field staff, horticultural staff reported alligator weed in the Coolabah Reserve stormwater basin, an area with no previous history of alligator weed infestation.

The site was inspected the following day and the new outbreak was confirmed. The infestation was surrounding the inlet pipe entering the basin and covered an area of approximately 60 m^2. Dense growth of cumbungi rushes (*Typha orientalis*) had slowed the spread of the alligator weed through the basin, and it had not reached the outlet pipe. The infestation was considered small enough and had been detected early enough for immediate eradication to be feasible.

There were no possible upstream sources of introduction, and the cause of the outbreak was suspected to have been the use of reach mowers to slash the surrounding grassy embankments. (This method of spread has since been addressed, and hygiene protocols are now part of Council's slashing operations.)

An isolated infestation was found growing in the Coolabah Reserve stormwater basin. Photo: Graham Prichard

The alligator weed was close to the inlet, growing amongst dense cumbungi rushes. Photo: Graham Prichard

A 10 m × 10 m area was excavated to a depth of 150 mm. Photo: Graham Prichard

The result was a smooth bare surface. Photo: Graham Prichard

Machinery required careful on-site washdown. Photo: Graham Prichard

The control strategy

Immediate eradication was the objective for this isolated outbreak in a previously alligator-weed-free area. The control strategy involved herbicide applications, mechanical removal of plant material and soil, and manual removal of regrowth with ongoing monitoring.

Initial herbicide treatments

The infestation was immediately sprayed with herbicides before any mechanical removal, to improve visibility, reduce the amount of above-ground plant material, and lower the risk of viable fragments being spread further.

Initial treatments with glyphosate and metsulfuron-methyl herbicides were used to treat the alligator weed and effectively clear the drainage area of vegetation in preparation for mechanical removal. The initial treatments were followed 4 weeks later by another application, which helped with further knockdown of the alligator weed and the other vegetation.

Shallow mechanical excavation

In August an excavator was brought in to remove the wet plant material and soil over an area of 100 m^2 (10 m × 10 m). It was apparent that the alligator weed had not sent down deep roots, so the excavation was kept to a depth of 150 mm. After one day's work, the final result was a bare smooth surface in one corner of the basin.

Council weeds officers went in on foot to guide the excavator operator to the exact extent of the infestation and to ensure that no alligator weed was missed.

The excavation required diligence and skill to prevent the spread of the alligator weed and to carefully remove as much plant and root material as possible. A secure disposal site was required to dispose of the 12 t of contaminated soil (Port Stephens Council has a nominated disposal site for alligator-weed-contaminated soil: see *Disposal* in Part 4). A water cart was brought in for on-site washdown of all the machinery and vehicles. After the work had been completed the machinery and vehicles were washed down and inspected.

Some alligator weed plants growing around the inlet pipe could not be dug by the excavator and had to be dug by hand. These were deeper rooted, with some roots going into the dry soil to a depth of 250 mm.

Manual removal and follow-up

After the excavation the site was frequently checked for regrowth. It wasn't until 4 months later in January that regrowth was found, coinciding with warmer temperatures stimulating the remaining fragments. The fragments were removed manually.

Current alligator weed levels

Since the last piece of alligator weed was removed 12 months after the infestation was discovered, (January 2005) there has been no regrowth and the program has been deemed successful to date. The site is monitored on an ongoing basis, and eradication will be declared a success when monitoring show no signs of regrowth for at least 5 years.

Key points

The outbreak was detected early through field staff training. Council staff in other sections of the council (engineering, horticulture, machinery operators) are now aware of alligator weed control protocols (e.g. prevention of spread, hygiene).

Mechanical removal was successful because of the prior applications of herbicide; the slower plant growth in August; and the careful execution and follow-up to ensure that all plant material and regrowth was removed. This method has been used since at other sites to achieve successful eradication.

Small amounts of regrowth were found 4 months later and manually removed. Photo: Graham Prichard

The eradication program has been deemed successful to date.
Photo: Elissa van Oosterhout

The site is monitored on an ongoing basis. Photo: Elissa van Oosterhout

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'Crystal Brook' grows irrigated wheat, canola and rice in the Murrumbidgee Irrigation Area. Photo: Birgitte Verbeek

Alligator weed was found on an irrigation bank. Photo: Birgitte Verbeek

On further inspection alligator weed was found growing in the irrigation bay. Photo: Birgitte Verbeek

Living and farming near alligator weed infested areas: Barren Box Swamp

Written by Birgitte Verbeek with Julian Zanatta
Edited by Elissa van Oosterhout

Introduction

This case study presents the importance of being able to identify alligator weed. It also demonstrates the vigilance and persistence that are critical for preventing the spread of alligator weed from known infestations onto private property in flood-irrigation systems.

The 283-ha property 'Crystal Brook' is owned and operated by Julian and Josephine Zanatta and is located on the edge of the Barren Box Swamp near Griffith in NSW. The property is adjacent to the by-wash area of the Swamp near the entry point of Mirrol Creek. The property grows irrigated wheat, canola and rice. The family bought this property in 2001, but having lived in the Griffith region for many years they were aware of the nearby alligator weed problem. Julian attended a field day on alligator weed at the Swamp in 2001 to update his knowledge about the weed.

Irrigation staff found alligator weed in the Swamp in 1993. Local authorities and Murrumbidgee Irrigation immediately began containing, suppressing and eradicating the alligator weed in the swamp.

Alligator weed fragments were found amongst the newly planted wheat crop. Photo: Birgitte Verbeek

The plants on the bank were immediately sprayed with herbicide. Photos: Birgitte Verbeek

Regrowth was found in the follow-up inspections. Photo: Birgitte Verbeek

The Mirrol Creek by-wash area was one of the originally heavily infested sites in the swamp, and constant herbicide treatments have suppressed the infestation to scattered plants. Murrumbidgee Irrigation staff undertake regular inspections of the swamp and its associated channel systems and treat any outbreaks with metsulfuron, glyphosate or dichlobenil as appropriate.

Finding the infestation

In May 2003 Murrumbidgee Irrigation staff members were conducting routine ground inspections for alligator weed within the Swamp at the by-wash area adjacent to 'Crystal Brook'. At this location a levy bank (10 to 12 m high) separates the swamp from the property. Staff members were checking over the bank and observed many terrestrial infestations in a drainage area about 20 m wide between the irrigation bays and the Swamp levy bank. On further investigation they found more plants growing on an irrigation bank that separated the drainage area from an irrigation bay that had recently been cultivated. One particular plant on the bank had obviously been cultivated over, and sections of the plant had spread throughout the irrigation bay. On further inspection within the irrigation bay area (2 ha) many segments of alligator weed were growing. Unfortunately the irrigation bay had been cultivated and sown to wheat several weeks before.

Murrumbidgee Irrigation staff immediately sprayed the plants they found on the bank with a tank mix of glyphosate and metsulfuron-methyl and then contacted Julian, officers from NSW Agriculture, and the Griffith City Council Weeds Inspector to advise them of the problem.

An onsite meeting was arranged on 12 May and a management plan was devised. Fortunately the infested irrigation bay had been the last bay to be sown, and after the property owners found out about the alligator weed infestation they ensured that all the cultivation equipment was thoroughly cleaned before it was used on other parts of the property.

Current alligator weed levels

In October 2006 there were two remaining alligator weed plants in the irrigation bay. Further herbicide treatments were undertaken and no further regrowth has been observed to date. However, because the remaining underground plant material has not been physically removed there is a risk that regrowth will occur. The infestation is currently at a point where physical removal could be the key to successful eradication.

The management strategy

The aim of the management plan was to eradicate alligator weed from the irrigation bay. To do this, the bay was taken out of production and managed so that treatment of alligator weed was the priority. The bay is still not in use, as further herbicide treatments, physical removal and follow-up work are still required before Julian can be confident that the infestation has been eradicated.

Herbicide treatments

On 1 July the infested irrigation bay was treated with 1.5 L/ha of glyphosate herbicide and 10 g of metsulfuron-methyl herbicide with a water rate of 70 L ha. The spray rig used was washed down with a pressure sprayer before being moved off the area to remove any soil and plant material.

After this initial treatment the area was inspected for regrowth and all areas of regrowth were pegged for future reference, with 16 areas identified for future monitoring and treatment. These plants were then spot-sprayed with the glyphosate and metsulfuron-methyl tank mix.

To begin with, regrowth plants were re-treated soon after they emerged, but after a number of months of treatment Julian was convinced that a better result occurred when the plants were allowed some time to regrow before being re-treated. (This is in line with current best practice advice to wait till there is at least 10 cm of vertical growth before treating with herbicides).

Regrowth was re-treated once it reached the required height.
Photos: Birgitte Verbeek

By October 2006 there were only two remaining areas of regrowth.
Photo: Birgitte Verbeek

On advice from local weed managers who had been suppressing alligator weed in the area for many years, Julian commenced using dichlobenil (Casuron G®) from March 2004. This chemical was applied to the 16 pegged regrowth areas. After two applications regrowth occurred in only three areas. These areas were treated a third time.

By October 2006 there were only two remaining areas of regrowth in the irrigation bay. Julian attributes this result to the sustained use of dichlobenil; although this is a typical result from this chemical there is always a risk that viable plant material remains underground.

Physical removal opportunity

Having suppressed the infestation to only two plants, there is now a chance for Julian to undertake physical removal of the remaining regrowth by using deep manual digging. Julian intends to irrigate the affected bay to stimulate growth and to determine whether he has won the battle of eradicating the weed in this area. Production in the irrigation bay will commence after monitoring shows that no regrowth has occurred over at least two seasons after physical removal has taken place, but careful monitoring will continue for at least 5 years after the last observed occurrence of the weed before eradication can be deemed successful.

Key points

Early detection and persistence have prevented a major ongoing problem with alligator weed on 'Crystal Brook'. However, because the property is close to the known infestations within Barren Box Swamp, vigilant monitoring and rapid response to new outbreaks of alligator weed will remain important. The main lesson for irrigators is 'look before you cultivate'.

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Containment and suppression of a non-core infestation: Currumbin District Horse Club

Written by Lyn Willsher, Greg Mifsud and Paul Mason
Edited by Elissa van Oosterhout

Introduction

The Currumbin District Horse Club is in the Southern Gold Coast area of south-east Queensland. The horse club is located on low-lying land close to Currumbin Creek and contains several drainage lines that feed the creek. Because of the low-lowing, flat nature of the land water moves slowly in the drainage lines and the area experiences flooding in high rainfall events.

The alligator weed problem

A weed control officer from Gold Coast City Council first identified alligator weed at the site during a routine inspection in May 2006. Patches of both terrestrial and aquatic alligator weed were present over 5 of the 12 ha of the horse club site. Aquatic alligator weed was abundant in the drainage lines, and the terrestrial form occurred in the pasture at various locations in the paddocks. One of the drainage lines containing alligator weed was surrounded by marine couch and the other is lined with mangroves and contains brackish water.

Alligator weed was abundant in the drainage lines. Photos: Greg Mifsud

Current alligator weed levels

All known alligator weed plants at the site have been treated with herbicide. Although the site currently looks relatively clean it is expected that alligator weed will regrow following periods of rain and warmer weather. Follow-up inspections and further suppression and control work will be necessary for many years.

The management strategy

The primary and most immediate aim of the management strategy is to prevent the further spread of alligator weed to other sites. Possible means of spread were identified as movement of stem fragments on slashers and vehicles, and movement offsite in horses' hooves, tack and horse manure. Actions are currently being put into place to prevent movement by these vectors.

The long-term aim is eradication of alligator weed from the site, as in Queensland it has been declared a Class One species (see table on page 15). It will take many years of suppression before it is feasible to consider eradication on the site. For eradication to be a likely

One infestation was occurring in brackish water amongst mangroves. Photo: Greg Mifsud

The potential for spread of alligator weed in manure, hooves, tack and vehicles, and by slashing, was high. Photo: Greg Mifsud

long-term objective, constant vigilance will be required from the Gold Coast City Council, the Queensland Department of Primary Industries and Fisheries and the Currumbin District Horse Club and its members.

Management issues

A number of issues had to be incorporated into the management of alligator weed. First, the site is used to agist horses and also by club members to exercise and train horses, resulting in constant movement of horses on and off the property on training days. Fortunately the club is not actively involved in holding large competitions that involve the movement of horses to and from other regions or States.

Containment issues arising out of site usage include the potential spread of alligator weed through removal of horse manure from the site; potential spread of alligator weed through transportation in horses' hooves, tack and vehicles; and potential spread of alligator weed through slashing and maintenance works.

Another issue associated with weed management at a public recreation site is the need to communicate management practices to all site users to ensure that they are informed and supportive of management practices. The use of herbicides in waterways supporting mangrove communities also had to be considered, as well as the use of herbicides in paddocks being actively grazed by stock.

Planning

After identifying the alligator weed, Gold Coast City Council pest management staff and Queensland Department of Primary Industries and Fisheries land protection staff carried out a joint site inspection. They needed to establish the scope of the infestation, the key stakeholders who need to be consulted, possible sources of the infestation, management issues associated with the site, and management priorities and resource requirements. The key stakeholders were identified as representatives from the horse club, fisheries officers from Department of Primary Industries and Fisheries, slashing contractors, pest management staff from Gold Coast City Council and land protection staff from the Department of Primary Industries and Fisheries.

A central contact for the horse club was established, and that person was kept informed of management decisions. Two-way communications of issues relating to site management was encouraged.

Assessing the infestation

Weed management officers from Gold Coast City Council surveyed the surrounding area over 2 days to determine the extent of the infestation. A number of terrestrial infestations were found on a small number of surrounding private properties. To date, staff have been unable to locate the source of the infestation. From information provided by a horse club member, it is thought that the alligator weed has been localised at the site for some time but only recently become more widespread when some earth was moved from one paddock to another. It is thought that slashers were responsible for spreading the alligator weed locally on the site.

It was decided at the initial on-site planning meeting that the first priority for management of the site was to prevent the further spread of alligator weed off site. Several actions were taken to prevent further spread, including changes to the slashing practice, consultation with horse club representatives, and control of alligator weed in drainage lines.

Signs were erected at the site. Gold Coast City Council

Shallow mechanical excavation was considered but not pursued further because of a number of issues, including the cost; the need to transport and dispose of contaminated soil; and drainage and water logging issues associated with the excavation of low-lying land.

Quarantine and hygiene

Council designed, constructed and erected signs for the site to explain how alligator weed is spread and give details of the hygiene practices that need to be adopted by site-users to prevent the spread of alligator weed. Signs cover topics such as vehicle washdown, picking out horses hooves before leaving the site, and not removing manure from the site.

It was possible that alligator weed had been spread over the site through routine maintenance work carried out by a contract slasher operator. To minimise the risk of further spread by slashing, the council opted to use their own slasher at the site so they could be certain that adequate machinery hygiene practices were followed. To track down any other possible infestations that may have been spread by the contract slasher, council staff inspected other sites that the slasher had gone to after working at the horse club site. No further infestations of alligator weed were found.

Council also took the opportunity to use the site to educate its staff about the alligator weed threat. They held a site-inspection tour with staff from Engineering Services, Catchment Management, Natural Areas, Beaches and Water Cycles to educate them in the identification of alligator weed and the correct response if new infestations are found.

Gold Coast City Council recently requested that horse club members refrain from using affected paddocks to allow council pest management staff unlimited access to the paddocks to apply herbicide.

It was established that the horse club members were removing horse manure from the site to keep the sheer volume of manure down in the heavily used paddocks. Removal from the site is undesirable because of the potential for weed spread, so Council is currently investigating locating a skip on site where manure can be deposited.

Disposal of the contaminated manure is still a concern, as most waste facilities will not accept the manure, and management practices at the only facility that will accept the manure will potentially facilitate the spread of the plant material. At this point in time Gold Coast City Council is investigating the possibility of placing the manure into a soil sterilisation unit. These units are designed to heat soil up to approximately 200 °C to destroy harmful bacteria and microbes. Alligator weed can be killed at temperatures of around 60 to 70 °C, and it is hoped that the soil steriliser will kill any plant material found in the manure. It is likely that the treated manure will then be deposited at the appropriate landfill site.

Herbicide control in the vicinity of mangroves

Fisheries officers from the Department of Primary Industries and Fisheries were consulted about the possibility that using herbicides on the aquatic infestations in the drainage lines could have some effect on the mangrove trees. Following a site inspection with Fisheries officers, it was decided that licensed operators would apply glyphosate herbicide to the aquatic infestations, as containment of the alligator weed was the highest priority. To date there appear to be no ill effects on the mangrove trees.

The aquatic form has been treated twice to date with glyphosate herbicide at a rate of 1:100 by volume, applied with a vehicle-mounted Quickspray® unit. The initial treatments were done in July and August and required 400 L and 20 L of herbicide mixture, respectively. The first treatment took two staff 3.5 hours – a total of 7 hours. The August treatment was a spot-spraying application and took a further 2.5 hours to ensure no material was overlooked. A subsequent treatment was applied in October and required 400 L of herbicide mixture and took a total of 4.5 hours for two staff to complete. The timing and amount of herbicide used for this subsequent treatment are indicative of the rate at which alligator weed can grow, even after an initial knockdown application of herbicide.

Herbicide control of terrestrial infestations

The terrestrial alligator weed in the paddocks was initially treated with a mixture of glyphosate herbicide (rate 1:100) and metsulfuron-methyl herbicide (1 g/10 L). The tank mix was used to knock down all vegetation growth so that any alligator weed growing amongst the pasture grasses could be seen and treated. These treatments were conducted once in July (100 L) and twice in August (total 70 L). The time taken to treat these sites varied, with two staff applying herbicide over 3 hours in July and one staff member taking approximately 4 hours to treat the infestation on the second occasion.

Spot-sprays of metsulfuron-methyl herbicide at a rate of 1 g/10 L were applied in July with 15-L hand-powered knapsacks. This treatment followed the initial knockdown and treated those plants that were found growing under the pasture grasses. This type of application is time-consuming and took two staff members approximately 5 hours to ensure complete coverage of the area.

The terrestrial infestations on the surrounding private properties were treated with a mixture of metsulfuron-methyl herbicide (1 g/10 L) and glyphosate herbicide at a rate of 1:100, using a hand-powered knapsack. The properties were treated in October with a total of 17.5 L of prepared herbicide, in November with 2 L of herbicide, and in February with 1.5 L of herbicide. The first application took the operator approximately 3 hours, whereas the subsequent applications take approximately 1 hour each.

Key points

Because of the nature of both the location of this infestation and the usage of the site, both internal and external consultation has been essential. Good communication with key stakeholders has helped to change slashing practices, educate horse club members about weed hygiene, involve the owners of affected private properties, keep all stakeholders informed, and share management ideas among different agencies.

Future management

An off-label permit will be applied to allow the use of metsulfuron-methyl on the aquatic infestations. From now on, an annual treatment program of three applications of metsulfuron-methyl will be used on both the aquatic and the terrestrial plants for ongoing suppression, until such time that the number of plants is reduced to the point that eradication through physical removal can be considered.

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