Alternanthera philoxeroides (Martius) Grisebach – alligator weed

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ABSTRACT

Biological control of *Alternanthera philoxeroides*, alligator weed, began when George Vogt, USDA, conducted several surveys in South America during the 1960s. Three agents were released in the USA and two of them – the flea beetle *Agasicles hygrophila* and the moth *Arcola malloi* – were released in Australia in the 1970s. The flea beetle provides excellent control of alligator weed in aquatic habitats in warm temperate areas. However, alligator weed also grows in semi-aquatic and terrestrial situations and additional control agents are needed for those habitats. New surveys were conducted in South America from 2001 to 2005. Four insects have been tested but were not sufficiently host-specific for release in Australia as they completed their life-cycles on native *Alternanthera* species. Two others – the flea beetle *Phenrica* sp. and the fly *Ophiomyia marelli* – are being tested in quarantine. Several others – the stem-mining fly *Ophiomyia buski* and leaf-mining flies *Ophiomyia alternantherae* and *Pegomya* sp. – are candidates for future testing. The fungus *Uredo pacensis*, that has only been found in Bolivia, may also have potential.

Key words: biological control, native range surveys, host-testing, *Agasicles hygrophila, Arcola malloi, Disonycha argentinensis, Amynothrips andersoni, Uredo pacensis*, potential agents.

INTRODUCTION

Alternanthera philoxeroides (Martius) Grisebach (Amaranthaceae), alligator weed (Fig. 1), is a perennial herb from South America that spread to Australia, possibly in cargo ships, but was also deliberately introduced as an ornamental plant (Julien and Bourne 1988). It has been spread within and between catchments in Australia as a substitute culinary plant for *Alternanthera sessilis* (L.) R. Br. ex DC by the Sri Lankan community (Gunasekera 1999), on earth-moving equipment, in lawn turf and by boats (van Oosterhout 2007). In its native range of Argentina it occurs as an emergent species in shallow and ephemeral water bodies, especially roadside drains and low areas of floodplains. In Australia it occurs in similar situations and is particularly prevalent through the seasonally inundated floodplains of the lower Hunter River Valley of coastal NSW and associated drains (Fig. 2). It is entrenched along many rivers of the coastal plains and urban waterways, where it invades banks and may form floating mats (Julien *et al*. 1992; Julien 1995).

Alligator weed populations in Australia appear to be sterile hybrids (Sosa *et al.* 2008) and spread by clonal growth and fragmentation. Alligator weed grows as a terrestrial (Fig. 2), semi-terrestrial and aquatic plant (Fig. 5). It is highly competitive (Julien and Bourne 1988), although its competitive ability depends on duration of inundation (Schooler *et al.* 2010). Aquatic growth may be emergent (rooted to the substrate underwater) or free-floating over deep water, though mats are usually rooted to banks. Its biology and ecology are described in Julien *et al*. (1992) and Julien (1995).

Alligator weed occurs mostly on the eastern coastal strip (Fig. 3) and it covers only an estimated 4000 ha in Australia (van Oosterhout 2007), yet it was selected as a

Figure 1: *Alternanthera philoxeroides*, alligator weed. a) In aquatic habitats it has filamentous roots. b) In terrestrial habitats it has both filamentous and tap roots. c) Papery whitish floral head. d) Individual flower. Illustrations: S Fiscke, CSIRO.

Weed of National Significance (Thorp and Lynch 2000). It was nominated because of its potential for spread (Julien *et al*. 1995) that may be increased by use of physical control methods, a lack of suitable herbicides (Sainty *et al*. 1998) and its impact on agriculture and the environment (van Oosterhout 2007).

BIOLOGICAL CONTROL HISTORY

The first surveys for biological control agents in South America were made by G Vogt, USDA, from January to May 1960 (Vogt 1960) and January to June 1961 (Vogt 1961). Vogt collected over 30 insect species and a mite and suggested that five insects were 'major biotic suppressants' of alligator weed. Three of these were later studied in Argentina and the USA and subsequently released in the USA. The leaf-eating flea beetle *Agasicles hygrophila* Selman and Vogt (Coleoptera: Chrysomelidae) was released in 1964, the tip-distorting thrips *Amynothrips andersoni* O'Neill (Thysanoptera: Phlaeothripidae) in 1967 and the stem-boring moth *Arcola malloi* (Pastrana) (Lepidoptera: Pyralidae) in 1971. Releases of the flea beetle *A. hygrophila* and the moth *A. malloi* were made in Australia in 1977 and New Zealand in 1980, and of the flea beetle in Thailand (1981) and China (1986) (Julien and Griffiths 1998). These agents controlled aquatic mats of alligator weed in the USA (Coulson 1977), Australia (Julien 1981) and China (J Ding, *pers. comm*. 2010), but only in warmer regions where population development was not limited by winter cold. Cool temperatures contributed to lack of control in New Zealand (Stewart *et al*. 1999a, b). In Australia, although the moth *A. malloi* established widely, the key agent controlling the weed was *A. hygrophila*. Climate modelling for Australia and

Figure 2: Alligator weed growing in low-lying pastures in the lower Hunter Valley, NSW. Photo: G Pritchard, Port Stephens Shire Council.

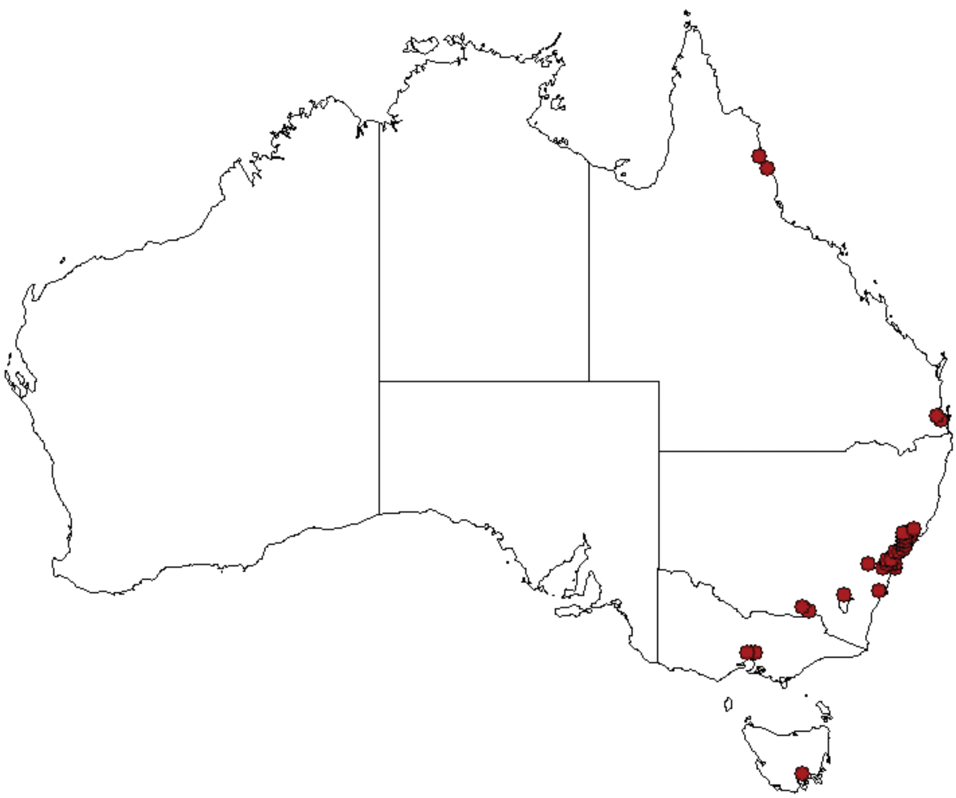

Figure 3: The distribution of alligator weed in Australia. Data source AVH. Specimen data reproduced from Australia's Virtual Herbarium with permission of the Council of Heads of Australasian Herbaria Inc.

elsewhere indicated that alligator weed had a much greater climatic tolerance than *Agasicles* (Julien *et al.* 1995).

Since the biological control agents were not able to control the weed across all habitats (semi-aquatic, seasonally flooded floodplains, terrestrial situations) nor in cooler climates (Julien and Bourne 1988; Julien and Stanley 1999; Julien *et al.* 1995), additional or better-adapted agents were required. Attempts to introduce a cold hardy biotype of *A. hygrophila* to the USA in 1979 were unsuccessful (Buckingham *et al.* 1983). A terrestrial insect, the flea beetle *Disonycha argentinensis* Jacoby (Coleoptera: Chrysomelidae), was released in Australia (Julien and Chan 1992) and New Zealand (Stewart *et al.* 1999a) but failed to establish in either country.

No systematic surveys had been conducted for plant pathogen natural enemies of alligator weed. Barreto and Torres (1999) reported the occurrence of *Nimbya alternantherae* Holcomb & Antonopoulus and *Cercospora alternantherae* Ellis & Langlois in Brazil. *C. alternantherae* failed to cause disease symptoms *in vitro*. However, *N. alternantherae*, which occurs in the USA (Holcomb and Antonopoulos 1976) and in China (Xiang *et al.* 1998), has potential as a mycoherbicide (Pomella *et al.* 2007).

PLANT TAXONOMY

Alligator weed has three morphotypes in Argentina – *A. philoxeroides* f. *philoxeroides* (Mart.) Griseb., *A. philoxeroides* f. *angustifolia* Süssenguth (Pedersen 1999) and a third, provisionally named *Santa Fe* (Sosa *et al.* 2004). In Argentina, there are small populations of fertile tetraploids and fertile hexaploids but most populations there are sterile hexaploids. The fertile forms produce viable seeds and seedlings in the field (Sosa *et al.* 2008). Cytogenetic analyses using GISH (genomic *in situ* hybridisation) indicated that the Argentine alligator weed populations sampled (including the three forms mentioned above and populations with different ploidy levels) and its close relative *Alternanthera aquatica* (D Parodi) Chodat share at least a third of their chromosomes, and are therefore likely part of a complex of hybrids (E Greizerstein *et al.*, unpub.).

Alligator weed populations in Australia comprise sterile hexaploid forms (Sosa *et al.* 2008). Current genetic analyses using ISSR indicate that a number of different genotypes exist in Australia with similarities to samples from Argentina of the forms *A. ph* f. angustifolia and *A. ph.* f. philoxeroides, suggesting multiple introductions from Argentina (D Gopurenko *et al.*, *pers. comm.* 2010).

EXPLORATION

Exploration for new biological control agents, especially for cold-tolerant and terrestrially oriented agents, was carried out from October 2001 to April 2005. Surveys for insects were conducted in central and northern Argentina, southern Uruguay and southern Paraguay by A Sosa and H Cordo, USDA-ARS South American Biological Control Laboratory (SABCL) at Hurlingham, Buenos Aires, and occasionally with M Julien, CSIRO Entomology, Brisbane.

Surveys for plant pathogens were conducted throughout the native range of alligator weed in Argentina from December 2004 to May 2005 by G Traversa, Universidad Nacional del Sur (UNS), Bahia Blanca, Argentina, together with entomological surveys by A Sosa. A survey was also conducted in Bolivia by Traversa and Sosa in August 2007, specifically to search for the rust *Uredo pacensis*. At least two surveys per growing season were conducted in Argentina to look for this rust in the northwestern provinces during the summers of 2007 to 2009.

CANDIDATES

The most important biological control agent in use in Australia and elsewhere is the flea beetle *Agasicles hygrophila* (Fig. 4). However, this insect has aquatic orientation, for reasons unknown, thus high and damaging populations occur only on floating mats of the weed. Such mats, that used to extend to 70 m over water (Fig. 5), no longer occur in the active range of this beetle in Australia (Fig. 6) (Julien 1981). Although patches may extend several metres over water at the beginning of the growing season, the flea beetles achieve high enough populations to reduce them by mid summer. Maddox (1968) and Stewart *et al.* (1999a, b) describe the biology of *A. hygrophila,* while host-specificity tests on 14 plant species in the USA determined host-specificity (Maddox, *pers. comm.* 1974; Maddox and Resnik 1969), which was further confirmed by tests in Australia using the test plant list shown in Sands *et al.* (1982).

Host-testing of the moth *A. malloi* (Fig. 7), using the test plant list in Sands *et al.* (1982), determined that it was safe for release in Australia. It was released in 1977 and has become established (Julien *et al.* 1979), but does not overtly contribute to control. Its biology was reported by Maddox (1970) and Brown and Spencer (1973).

***Disonycha argentinensis* Jacoby (Coleoptera: Chrysomelidae).** This flea beetle was host-tested in Australia in 1979 and released in 1980 (Sands *et al.* 1982). It

Figure 4: The alligator weed flea beetle *Agasicles hygrophila.* Photo: J Greene, CSIRO

Figure 6: The reduction in alligator weed as a result of damage by *Agasicles hygrophila*, July 1979. Photo: M Julien, CSIRO.

failed to establish in the field (Julien and Chan 1992) and a satisfactory explanation for this was never determined. Its biology was studied by Sands *et al.* (1982) and Cordo *et al.* (1984). Because this insect was terrestrially oriented and occurred widely in the native range of alligator weed in Argentina, it was decided to make another attempt to establish it in Australia. Host-testing in the 1970s did not include closely related native plants and hence further host-testing was conducted, including several *Alternanthera* species from New Zealand on behalf of Landcare Research. A colony of adults from Buenos Aires and Tucuman provinces, Argentina, were imported to a quarantine facility at Brisbane in March 2005. In subsequent tests *D. argentinensis* fed and developed on native *Alternanthera* species including *A. angustifolia* R. Br., *A. denticulata* R. Br. (three different forms), *A. nana* R. Br., *A. nodiflora* R. Br., *A. sessilis* (L.) R. Br. ex DC. (Australian material), *A. sessilis* (New Zealand material, but not native to NZ), *A. ficoidea* (L.) P. Beauv., *A. pungens* Kunth and a taxon of South American origin referred to as '*A. sissoo*' (this name does not appear to have been formally published). As a consequence, *D. argentinensis* was not released.

Amynothrips andersoni **O'Neill (Thysanoptera: Phaeothripidae).** The host-specificity of this insect was studied in Argentina and Uruguay (Maddox 1973) and its biology was studied in the USA (Maddox and Mayfield 1979). During surveys from 2001 to 2005, this thrips was a very common and widespread natural enemy wherever alligator weed was found in Argentina. It was present almost year-round and as an adult in winter (Maddox and Mayfield 1979).

A. andersoni has both brachypterous (short-winged, flightless) and macropterous (long-winged, able to fly)

Figure 5: Alligator weed growing on Georges River at Chipping Norton, Sydney, March 1978. Photo: M Julien, CSIRO.

Figure 7: The alligator weed moth *Arcola malloi.* Photo: CSIRO.

forms (O'Neill 1968). Adults are black and about 2 mm long, immature stages are red. Adults and larvae suck plant juices from the tender developing tips of alligator weed. The host-range appears to be restricted to plants in the genus *Alternanthera*, specifically alligator weed and its close relative *A. aquatica* (Maddox 1973).

In March 2005 *A. andersoni* was sent to Australia in two shipments, with 229 adults and 240 nymphs in the first and 20 adults and 126 nymphs in the second. The material, from Buenos Aires in central Argentina and Tucuman in north-western Argentina, comprised mainly the macropterous form (79%). In host tests conducted in Brisbane, feeding and oviposition occurred on *A. nodiflora, A. denticulata* and *Ptilotus polystachyus* (Gaudich.) F.Muell. Although new hatchlings died on *P. polystachyus*, populations were sustained on the other two Australian natives.

The short-winged form of this thrips had been released in the USA in 1967 (O'Neill 1968); identification was confirmed from museum specimens held there (L Mound, *pers. comm*. 2005). To determine whether the short-winged form had different host-specificity, a shipment of 11 adults and 34 nymphs of *A. andersoni* from Georgia, USA, was received into quarantine in Brisbane during July 2005. Host-testing confirmed that this short-winged form had the same host-specificity as the Argentine long-winged material, therefore *A. andersoni* was considered unsuitable for release in Australia.

***Systena* spp. (Chrysomelidae: Alticinae).** Five species of *Systena* were collected from alligator weed. *S. testaceovittata* Clark, *S. s-littera colligata* Weise and *S. tenuis* Bechyné fed on other plant species as well as alligator weed in the field. *S. silvestrii* Bechyné was found only in northern Argentina in Chaco, Salta and Misiones provinces and was collected on *A. aquatica* as well as alligator weed, but as very few specimens were found rearing was not possible. *S. nitentula* Bechyné was the most abundant species (Cabrera *et al*. 2005) and was found only on the *angustifolia* form of alligator weed and on *A. aquatica* in Brazil. It was common in northern Argentina, southern Paraguay and southern Brazil, mostly in terrestrial habitats.

Adults of *S. nitentula* are 34 mm long and feed on leaves. Larvae feed on and inside stems, crown and roots; pupation is in the galleries made by larvae in the stems and roots and in the substrate. The life-cycle was about 40 days in the laboratory (Cabrera *et al*. 2005). Field observations in Argentina indicate that the insects are mainly associated with alligator weed growing in dry conditions. Adults collected from Orán, Salta province, Argentina, were sent to Australia, 45 adults on 14 January and 22 on 7 April 2009. In quarantine tests in Brisbane *S. nitentula* fed and developed colonies on *A. angustifolia, A. denticulata* (two colour forms and one form from New Zealand), *A. nana, A. nodiflora* and *A. sessilis* (one form from Australia and one from New Zealand). Therefore, this insect was not considered suitable for release in Australia.

***Clinodiplosis alternantherae* Gagné (Diptera: Cecidomyiidae).** Feeding by the larvae of this midge in the new stem tip tissues causes tip galls and tip deformation. Pupation occurs in the gall; adults lived for just a day in the laboratory. The life-cycle was three to four weeks. The midge was the most common insect found throughout the range of alligator weed in Argentina, Uruguay, Paraguay and Brazil, attacking all forms of alligator weed. It also attacked *A. aquatica* in Argentina, Paraguay and Brazil. No other plant species were observed to be attacked in the native range. Colonies collected near Buenos Aires in 2006 and 2007 were sent to Australia for host-specificity testing. The midge was found able to complete its life-cycle on several Australian native and some exotic *Alternanthera* species, so was not considered suitable for release.

***Phenrica* possibly *litoralis* (Bechyné).** This flea beetle has been found only in Misiones province in northern Argentina on alligator weed growing in terrestrial situations. Adults are about 2 mm long, feed on leaves and lay eggs under leaves and on stems near the soil surface. Larvae feed on older leaves; pupation occurs in the substrate. The life-cycle appears to be about six weeks. Adults collected from San Ignacio, Misiones province, were imported to Australia in January 2010. Host-testing determined that this insect is not specific and can feed and develop on a range of *Alteranthera* species including Australian natives and on plants from several other families.

***Ophiomya marellii* (Bréthes) (Diptera: Agromyzidae).** This node galling fly occurs widely across the range of alligator weed in Argentina on the various forms. Galls were found on stem nodes in the substrate or older sections of above-ground stems. The insect has mostly been collected from terrestrial habitats but appears to withstand temporary submergence (Sosa *et al*. 2004). A number of parasitoids collected from galls have been submitted for identification. The biology and life-history of *O. marellii* was provided by Marelli (1926) and Spencer (1963). During January 2010, collections of galls from Santa Fé and Entre Rios provinces and five locations in Buenos Aires province were imported into quarantine in Brisbane. Adults and parasites emerged, and adults were placed on Australian alligator weed to try to develop a colony for host-testing.

Other leaf- and stem-mining flies

***Ophiomyia alternantherae* (Spencer) (Diptera: Agromyzidae).** This leaf-mining fly, described by Spencer (1963, 1990) was found on all forms of alligator weed in Argentina (Sosa *et al*. 2004). Larvae feed inside the leaf, forming galleries in which pupation occurs. Several unidentified hymenopteran parasitoids emerged from harvested leaves.

***Ophiomyia buski* (Frost) (Diptera: Agromyzidae).** This stem-mining fly (Spencer 1963) is uncommon and has been collected at only a few sites both from the *angustifolia* and *philoxeroides* forms of alligator weed in Argentina. Larvae tunnel in the epidermis of internodes, causing linear mines about 1 mm wide and up to 2 cm long.

***Pegomya* sp. (Diptera: Anthomyiidae).** Another leaf-miner appears to be a new species of *Pegomya*. The larvae feed on the mesophyll portion of the leaf, leaving the epidermis intact. Pupae are larger than those of *O. alternantherae* and pupation occurs on the ground, suggesting that this insect favors terrestrial environments. It has been found on two occasions at different sites in Buenos Aires province. The biology, life-histories and host-ranges of these insects have not yet been studied.

Fungi

Currently, the only fungus identified with potential for classical biological control of alligator weed is the rust *Uredo pacensis* Lindquist (1957), which was found to be abundant at Coroico, La Paz province, Bolivia. This rust has not been found in Argentina, southern Paraguay, southern Brazil or Uruguay. We are seeking ways to obtain material and conduct host-specificity tests in Australia. The first test will determine if the rust will accept the Australian populations of alligator weed. Another rust, *Uredo nitidula* Arthur (1920), has been recorded on alligator weed from Guatemala but there have been no surveys to seek it.

Various other fungi have been isolated from alligator weed in Argentina but none are suitable as classical biological control agents (G Traversa, *pers. comm*. 2009). One, *Nimbya* sp., was found in Argentina and has been isolated in Australia. It is under study as a bioherbicide (Gilbert *et al*. 2008).

DISCUSSION

Excellent control of alligator weed was achieved with the flea beetle *A. hygrophila* in aquatic habitats and warm temperate regions, particularly central coastal NSW (Julien *et al*. 1979). However, much of the alligator weed in Australia grows in riparian and floodplain terrestrial habitats that are only occasionally covered with water, where the flea beetle cannot thrive. Although the moth *V. malloi* is relatively common, in Australia it has not reached densities capable of adequately controlling the weed. Consequently, recent studies aimed to provide agents that would attack alligator weed across a broader range of habitats. Two known agents not established in Australia, the flea beetle *D. argentinensis* and the thrips *A. andersoni*, and two new potential agents, *S. nitentula* and *C. alternantherae*, all failed host-specificity tests as they attacked native *Alternanthera* species. Several species, a node-galler and another flea beetle, are in quarantine in preparation for host-specificity testing. Two others, a stem- and a leaf-miner, could be tested in the future.

None of the insects yet to be tested are particularly exciting; they do not form large and damaging populations in Argentina and it is not obvious that they are restricted there by parasitism, predation or disease, though these controls cannot be ruled out. One other potential biological control agent remains to be assessed, the rust *U. pacensis*. The fact that it has been found only in Bolivia suggests that it might be a *formae specialis* on the Bolivian form of alligator weed. In addition to completing host-testing of the four insects, future effort should be directed to obtaining the rust from Bolivia and determining if it will attack Australian populations of alligator weed. If it does and is shown to be host-specific, it may be the best hope as a significant biological control agent for Australia.

Due to the difficulty of containing and managing alligator weed infestations, its environmental and economic impacts and consequently its status as a Weed of National Significance, it is likely that adequate funding will be available to complete the testing of the candidate agents listed above. However, the presence of closely related native species means that finding an effective and suitably host-specific agent remains the primary issue in determining the success of biological control of alligator weed in the temperate climates and terrestrial habitats in Australia.

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