Is delta arrowhead (*Sagittaria platyphylla*) a suitable target for biological control in Australia?

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Summary Delta arrowhead, *Sagittaria platyphylla* (Engelm.) J.G.Sm. (Alismataceae), an emergent aquatic macrophyphyte native to southern United States of America, is an invasive weed of shallow irrigation channels and natural waterways in Australia. Classical biological control is considered a desirable option due to the difficulty and expense of controlling the weed in irrigation systems as well as the need for alternative approaches for use in sensitive aquatic habitats. Based on criteria utilised to assess the feasibility of undertaking a biological control program and the likelihood of success, the prospects for biological control of delta arrowhead in Australia are considered high.

Keywords Biological control, *Sagittaria platyphylla*, delta arrowhead, aquatic weed.

INTRODUCTION

Biological control is a highly cost-effective method for the long-term management of exotic weeds and for many of Australia's most serious weeds, it is the only realistic option available. The overall benefit to cost ratio for Australia's investment in biological control was calculated to be 23:1 (Page and Lacey 2006) in 2005. However, of the 29 Australian programs assessed for their economic impact, only 14 returned positive net benefits in dollar terms. Hence, not all weeds make suitable targets for biological control. If the wrong target is selected and the project fails, millions of dollars invested in the importation, testing and release of ineffective agents may result in no or little return on investment (Cuda and Sutton 2000).

To minimise the risk of failure and to determine priorities for investment, various quantitative methods have been developed based on point scoring systems (Peschken and McClay 1992, Palmer and Miller 1996, Syrett 2002, Paynter *et al.* 2009, Lefoe and Ainsworth 2012) and more recently, a matrix assessment approach (Morin *et al.* 2013). The framework developed by Paynter *et al.* (2009) made considerable improvements on earlier systems by utilising a comprehensive analysis of 80 weed biological control programs to predict weed traits that contribute most to biocontrol success.

While each biocontrol prioritisation system may differ in the variables included and the methods used to score or rank weed targets, they all include attributes that relate to the impact of the weed and, feasibility and likelihood of success of biological control.

The emergent aquatic weed, delta arrowhead (*Sagittaria platyphylla*), was introduced into Australia from the southern United States of America (USA) by the ornamental and aquarium trade around the 1930s. It is now causing serious problems in shallow water bodies such as irrigation channels and drains, creeks, rivers and wetlands, particularly in south-eastern Australia (Figure 1). In 2012, *Sagittaria platyphylla* was declared a Weed of National Significance by the Commonwealth of Australia and Australian Weeds Committee. Within the Sagittaria National Strategic Plan, the development of a biological control program was listed as a high priority strategic goal (Australian Weeds Committee 2012). The purpose of this paper is to examine whether delta arrowhead is an appropriate target for classical biological control by addressing a combination of assessment criteria developed by Paynter *et al.* (2009) and Morin *et al.* (2013).

Figure 1. The author standing amongst delta arrowhead in the Broken Creek, Numurkah, Victoria.

MATERIALS AND METHODS

The assessment criteria used in this paper is largely based on three broad categories contained within the frameworks developed by Paynter *et al.* (2009) and Morin *et al.* (2013). The first category assesses the suitability of a weed as a target for biological control by determining the weed's origin, potential for conflicts of interest, available means of control and the importance of the weed at a national level. The second assesses the feasibility of undertaking a novel (new) biocontrol program, such as the difficulty of surveying the native range for candidate biocontrol agents and the effort required to import and conduct host-specificity testing. The third category considers the likelihood of success, such as the likelihood that biocontrol agents will establish in the new range and cause sufficient damage to weed populations to bring about the desired level of control.

RESULTS AND DISCUSSION

1. Weed importance and desirability of biocontrol

Infested area Delta arrowhead infestations are present in most Australian states except Tasmania and the Northern Territory. The species forms dense stands that rapidly expand to occupy entire shallow water bodies and is particularly problematic in the southern areas of the Murray Darling Basin. Currently in the Murray Valley and Shepparton Irrigation Areas in northern Victoria, up to 85% of creeks, drains and channels have severe infestations (Chapman and Dore 2009).

Potential distribution The potential distribution of the species includes waterways and wetlands throughout southern Western Australia and South Australia, much of Victoria, and the entire east coast of New South Wales and Queensland (Australian Weeds Committee 2012).

Economic impacts Chemical treatment is not always effective and often two repeat applications at high dose rates are required. Goulburn Murray Water alone allocate $1.5 million per year to delta arrowhead control across the Goulburn Murray Irrigation District (M. Finlay pers. comm. 2014).

Environmental impacts In natural waterways, delta arrowhead threatens native aquatic flora and fauna by competing with native plant species, reducing biodiversity and acting as a barrier to the movement of native fish (Chapman and Dore 2009). Invasive European carp (*Cyprinus carpio* Linnaeus) have been observed feeding and uprooting plants (Kwong pers. obs.), which may facilitate dispersal of vegetative propagules downstream. However, quantitative data on delta arrowhead impacts on native ecosystems is lacking (Adair *et al.* 2012).

Available means of control Few effective options are available for the management of delta arrowhead, particularly in sensitive aquatic habitats such as RAMSAR-listed wetlands. Herbicide application is the major form of control, however repeat applications are often necessary as infestations readily re-appear following germination from persistent seed banks, sprouting from tubers or regrowth from submersed rosettes (Chapman and Dore 2009). Mechanical control involves the excavation of infested channels and drains but this expensive process is only utilised in extremes cases where the hydraulic capacity of water delivery infrastructure needs to be restored quickly (Adair *et al.* 2012).

National importance *Sagittaria platyphylla* is currently a declared weed under State noxious weed legislation in New South Wales, South Australia, Tasmania and Western Australia (Australian Weeds Committee 2012). As little beneficial aspects exist for the species, conflicts of interest arising from targeting delta arrowhead for biological control are unlikely.

2. Feasibility of biological control

Effort required to obtain and host-range test biocontrol agents The biological control of delta arrowhead is a novel target, meaning that it has never been the subject of a biological control program elsewhere in the world. As such, little cost savings can be achieved by 'piggy-backing' off efforts of prior programs, such as knowledge of the host specificity of candidate agents and demonstrated effectiveness against the target weed. Nevertheless, for a novel program the effort required to obtain natural enemies is considered minimal because of the ease of working in the native range and the availability of plant and insect taxonomists, plant pathologists and biological control expertise.

Knowledge of the natural enemies There is little information published in the literature on the phytophagous insects and pathogens associated with delta arrowhead in North America (Harms and Grodowitz 2010, Adair *et al.* 2012). Despite this, the natural enemy flora and fauna of the species is relatively well known following a series of comprehensive surveys conducted across much of the native range between 2010 to 2012 (Kwong and Sagliocco unpublished data). The most common and abundant insect encountered was the weevil, *Listronotus appendiculatus*

(Boheman). Larvae feeding within the fruits caused significant destruction of receptacle and developing achenes (Adair *et al.* 2012). The larvae of two other weevil species, *Listronotus sordidus* (Gyllenhal) and *Listronotus frontalis* LeConte, were associated with the root crowns, where they were found in dead and dying plants. It is suspected that both species also feed within the tubers, although this has only been confirmed for *L. sordidus* (Harms 2013). No pathogens were identified as potential biocontrol agents during the surveys, despite leaf spots being commonly seen on plants.

Plant phylogeny – relatedness of weed target to indigenous and/or valued plants Delta arrowhead belongs to the Alismataceae family. There are no indigenous *Sagittaria* occurring in Australia, although there are six native species from four other genera within the Alismataceae (Jacobs and McColl 2011). Historically, *Sagittaria* has been utilised as an aquarium and ornamental pond plant in Australia and some species are still traded in states where they are not listed as noxious weeds, however, they are of negligible economic value (Adair *et al.* 2012). With few native or economically-valued species closely related to delta arrowhead in Australia, the process of host-range testing will be shorter and cheaper compared to other weed targets with many close relatives, where a long host-test list will result in a more time consuming and expensive program.

3. Likelihood of success

Habitat stability Many of the world's most successful biological control programs have been against aquatic weeds (Julien and Griffiths 1998), possibly because permanent aquatic habitats are relatively more stable environments than terrestrial ones (Paynter *et al.* 2012). In Australia, delta arrowhead occupies a diverse range of aquatic habitats, from infrequently-disturbed wetlands and billabongs to highly-disturbed irrigation channels and drains. Biological control may be less effective in highly-disturbed aquatic environments where unnatural hydrological regimes may interfere with the persistence of biocontrol agents. Hence, strategies to integrate biological control with other management techniques may be required in these situations.

Weed life cycle Annual plants are considered more difficult targets for biological control because populations of the agent(s) may not be sustained over time if the weed is annual or ephemeral (Morin *et al.* 2013). Delta arrowhead is a perennial plant that has multiple means of maintaining persistent populations through vegetative reproduction via stolons and tubers.

Reproduction and genetic variation Biological control has been most successful against clonal weed species with limited genetic diversity (Burdon and Marshall 1981). Delta arrowhead has two modes of reproduction. Sexual reproduction involves the prolific production of achenes over an extended flowering season (spring through to autumn). The dispersal of achenes downstream, possibly by waterfowl, enable the species to spread long distances. Once established, population expansion via vegetative reproduction is rapid. A recent genetic study revealed that delta arrowhead populations introduced into Australia have maintained substantial molecular genetic diversity comparable with native populations (Kwong and Broadhurst unpublished data). As the majority of this diversity resides within rather than among populations or countries, this suggests that invasive Australian populations were founded by multiple lineages and that neither inter- nor intra-specific hybridisation has occurred to a large degree. Furthermore, the genetic study was able to assign Australian populations to clusters within the native range, enabling source genotypes, and to a lesser degree, geographic origins to be identified.

Weed in the native range Levels of herbivory and disease, and abundance of the target weed in the native versus exotic ranges may indicate if natural enemies play a role in limiting populations in the native range. A biogeographical study conducted between 2010–2012 (Kwong unpublished data) found a nine and 29-fold decrease in the number of phytophagous arthropod and pathogen species respectively associated with delta arrowhead in the exotic range. Australian plants also experienced less herbivory than their native counterparts in the USA, but reproductive output was significantly greater in Australian plants. Plant density was lower in native USA populations, particularly in natural habitats, while Australian infestations were more extensive. The biogeographical study demonstrated that delta arrowhead has been released from natural enemies that would otherwise play some part in the regulation of populations in the native range.

Is delta arrowhead a suitable target for biological control? Considerable progress has been made in recent years to improve the process for selecting suitable targets for biological control. Paynter *et al.* (2012) stated that, 'Success appears almost guaranteed against 'good target' weeds which possess the best combination of factors for successful biocontrol (aquatic, clonal species that are not major weeds in their native ranges)'.

Delta arrowhead fulfils many of the criteria that make it a suitable candidate for biological control. Firstly, biological control is warranted because it causes major impacts, is difficult and costly to control and has no beneficial aspects. Secondly, the feasibility of biocontrol is high because there are a number of promising candidate agents available and with no native *Sagittaria* species in Australia, the risk of non-target damage is low. Finally, the likelihood of success is high because delta arrowhead is an aquatic, clonal species that is not a major weed in its native range. Despite the species' ability to reproduce sexually, genetic variation within Australian populations is still considerably low and hence the potential for mismatch of agent and weed genotypes is unlikely to be a major obstacle.

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REFERENCES

Australian Weeds Committee (2012). Weeds of National Significance, Sagittaria (*Sagittaria platyphylla*) Strategic Plan. Australian Weeds Committee.

Adair, R., Keener, B., Kwong, R.M., Sagliocco, J-L. and Flower, G.E. (2012). The biology of Australian weeds 60. *Sagittaria platyphylla* (Engelmann) J.G. Smith and *Sagittaria calycina* Engelmann. *Plant Protection Quarterly* 27, 47-54.

Burdon, J. and Marshall, D. (1981). Biological control and the reproductive mode of weeds. *Journal of Applied Ecology* 18, 649-58.

Chapman, M. and Dore, D. (2009). Sagittaria strategic plan 2009. Unpublished report to Goulburn Murray Water, Goulburn Broken Catchment Management Authority and the Tri-state Sagittaria Taskforce. (RuralPlan Pty Ltd, Goomalibee, Victoria).

Cuda, J. and Sutton, D. (2000). Is the aquatic weed hygrophila, *Hygrophila polysperma* (Polemoniales: Acanthaceae), a suitable target for classical biological control? Proceedings of the X International Symposium on Biological Control of Weeds, ed. N.R. Spencer, pp. 337-48. (Montana State University, Bozeman, Montana, USA).

Harms, N.E. (2013). 'Final report of *Sagittaria platyphylla* natural enemy activities 2013'. A report for Aquatic Ecosystem Research Foundation, Marietta GA, USA and Department of Primary Industries, Frankston, Victoria, Australia. (US Army Engineer Research and Development Centre, Environmental Laboratory, Vicksburg, Mississippi, USA).

Harms, N.E. and Grodowitz, M.J. (2010). 'Survey of insect herbivores associated with aquatic and wetland plants in the United States'. (US Army Engineer Research and Development Center).

Jacobs, S.W.L. and McColl, K.A. (2011). 'Alismataceae'. Flora of Australia 39, pp. 3-39. (Melbourne, ABRS/CSIRO Australia).

Julien, M. and Griffiths, M. (1998). 'Biological control of weeds: a world catalogue of agents and their target weeds', Fourth edition. (CABI Publishing, Oxon, UK).

Lefoe, G. and Ainsworth, N. (2012). Prioritising Victorian government investment into weed biocontrol. Proceedings of the 18th Australasian Weeds Conference, ed. V. Eldershaw, pp. 359-60. (Weed Science Society of Victoria Inc., Melbourne).

Morin, L., Heard, T.A., Scott, J., Sheppard, A., Dhileepan, K., Osunkoya, O. and van Klinken, R. (2013). 'Prioritisation of weed species relevant to Australian livestock industries for biological control'. North Sydney NSW 2059.

Page, A. and Lacey, K. (2006). Economic impact assessment of Australian weed biological control. CRC Weed Management Technical Series No. 10, p. 164.

Palmer, W. and Miller, E. (1996). A method for prioritizing biological control projects with reference to those of Queensland. Proceedings of the IX International Symposium on Biological Control of Weeds, eds V.C Moran and J.H. Hoffmann, pp. 313-7. (University of Cape Town, South Africa).

Paynter, Q., Hill, R., Bellgard, S. and Dawson, M. (2009). Improving targeting of weed biological control projects in Australia. Landcare Research Contract Report: LC0809/072.

Paynter, Q., Overton, J.M., Hill, R.L., Bellgard, S.E. and Dawson, M.I. (2012). Plant traits predict the success of weed biocontrol. *Journal of Applied Ecology* 49, 1140-8.

Peschken, D.P. and McClay, A.S. (1992). Picking the target: a revision of McClay's scoring system to determine the suitability of a weed for classical biological control. Proceedings of the VIII Internation Symposium on Biological Control of Weeds, eds E.S. Delfosse and R.R. Scott, pp. 137-43. (Lincoln University, Canterbury, New Zealand).

Syrett, P. (2002). Biological control of weeds on conservation land: priorities for the Department of Conservation, Landcare Research Contract Report LC0102/038. (Landcare Research, New Zealand).