Managing the weed risk of cultivated *Arundo donax* L.

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Summary Proposals to grow *Arundo donax* L., giant reed, as a biomass crop provoke controversy due to its global reputation as a serious riparian invader. However, we contend that proposals should be considered where there are clear economic and environmental benefits and where it is appropriately sited, cultivated and regulated to minimise risk of spread. Various studies show *A. donax* having considerable potential as a highly productive biomass crop that can utilise waste water unsuitable for food production. Invasion of *A. donax* is primarily through vegetative spread in flood events. In Australia viable seed production has not been detected and genetic studies indicate clonality. There is a wide difference in weed risk between riparian and non-riparian systems. The risks of invasion of cultivated *A. donax* could be adequately managed, through location of plantings outside areas subject to flooding, buffer zones around plantings, annual surveys to detect and remove any escapes, and hygiene protocols for harvest, transport and processing. These should be made mandatory via noxious weed declaration of *A. donax* and then use of permits with strict management conditions allowing cultivation at low risk sites in the landscape.

Keywords Giant reed, biofuel, weed risk assessment, risk management, AFLP, containment.

INTRODUCTION

Arundo donax L., giant reed, Poaceae, is a robust, perennial, polyploid, C_3 grass 3–9 m tall, growing in many-stemmed, cane-like clumps. Its native range extends from eastern Asia to southern Europe, inclusive of tropical, temperate and Mediterranean climates. It has been introduced around the world as an erosion control plant to stabilise channel banks, as a windbreak and as an ornamental.

Arundo donax has slow lateral spread via short, horizontal rhizomes, but Boland (2006) observed much faster lateral spread via layering of stems on wet substrates. Long distance dispersal by water of vegetative fragments (dislodged stems and rhizomes) is the primary means of range expansion (Boland 2006). *A. donax* is well adapted to the high disturbance dynamics of riparian systems (Bell 1997) and has become a riparian weed in many countries, most prominently in California where coordinated control has been undertaken on a broad scale (Dudley 2000). *A. donax* has been listed as one of the 100 World's worst invasive alien species (Lowe *et al.* 2000).

In Australia, *A. donax* is not presently a major weed. Introduced in the mid 1800s, it has been widely planted. There are scattered naturalisation records for all mainland states and the Northern Territory (CHAH 2010), but it is probably under recorded by herbaria due to its large size. It has been declared a Class 4 noxious weed in local government areas in Sydney, New South Wales.

In recent years *A. donax* has been investigated for potential as a fast-growing biomass crop. In field trials, annual shoot dry matter (DM) yields have been greater than other grass and woody biomass crops, with similar or lesser water and nutrient inputs (Lewandowski *et al.* 2003, Angelini *et al.* 2009). In South Australia (SA) shoot DM yields of >45 t ha^{-1} $year^{-1}$ were measured under irrigation with sewerage or winery wastewater and 12 t ha^{-1} $year^{-1}$ under natural rainfall (Williams and Biswas 2010). *A. donax* has shown very high tolerance to salinity, with potential to be grown under irrigation using intercepted saline groundwaters or on low-lying farmland that is under threat of rising saline water tables (Williams and Biswas 2010).

Various potential uses of *A. donax* shoot biomass include as a feedstock for commercial pyrolysis applications (e.g. energy and biochar production), bioethanol and pulp/paper (Williams and Biswas 2010). In addition, annual carbon accumulation in the rhizomes is approximately equivalent to that allocated to shoots (Williams and Biswas 2010). The use of *A. donax* is controversial as it has an international reputation as a weed but is showing good prospects as a biomass crop. Could it be possible to grow *A. donax* with a low risk of it escaping to become a weed?

We analysed the weed risk of *A. donax* in Australia, comparing invasion in riparian and non-riparian ecosystems. We also undertook genetic studies to seek evidence of sexual reproduction. Lack of seed production would be a significant constraint to dispersal ability. Viable seed production has not been recorded in Australia and Williams *et al.* (2008) found no viable embryos for 400 seeds sampled from each of five stands in SA.

MATERIALS AND METHODS

Weed risk assessment *Arundo donax* was assessed using the SA Weed Risk Management System (SAWRMS) (Virtue 2010) for its potential to invade two land uses: riparian and terrestrial natural ecosystems (native vegetation not subject to flood events). For both land uses it was assumed that, on average at the regional scale, there were no routine weed management practices.

In the SAWRMS a score for Comparative Weed Risk is generated from multiplying separate scores (each ranging between 0 and 10) for three criteria of 'Invasiveness', 'Impacts' and 'Potential Distribution'. Invasiveness considers the establishment, reproductive and dispersal abilities of weed species, providing an indicator for rate of spread. Impacts consider the types and magnitude of economic, environmental and social effects that the weed can have. Potential distribution is the geographic area that could be invaded by the weed.

The SAWRMS also generates a score for 'Feasibility of Containment' by multiplying separate scores (again, each ranging between 0 and 10) for the three criteria of 'Control Costs', 'Current Distribution' and 'Persistence'. Control costs consider the weed management costs of detection and on-ground control compliance needs. Current distribution considers how widespread the weed is at present. Persistence refers to the expected duration of a control program.

Information to answer questions within the SAWRMS was obtained from a review of literature, field and laboratory data generated for this project, weed risk analyses undertaken by other jurisdictions and personal observations of stands of naturalised *A. donax*. Potential distribution was modelled in CLIMATCH (Crombie *et al.* 2008), using overseas distribution data from USA, Central and South America, the Mediterranean, South Africa, central Asia, India, China and New Zealand (Virtue *et al.* 2010) to match to a climate surface of Australia. Rainfall parameters were excluded as *A. donax* is recorded as a predominantly riparian species in its native and introduced regions.

Genetic variation analysis Amplified fragment length polymorphism (AFLP) analysis was conducted for 167 *A. donax* samples from South Australia and five from interstate. AFLP analysis was used to identify genetic variations by looking for differences in the lengths of randomly amplified DNA fragments between individuals. Differences indicate sequence differences in the DNA and hence variation between individuals.

DNA was extracted from around 2 cm^2 of the freshest/youngest leaf material using the DNeasy Plant Mini Kit (Qiagen, Australia). The DNA was digested with Mse and Pst restriction enzymes to cut the DNA into fragments at specific sites, and then adaptors (tags on the ends used for amplification) were ligated to the ends of the fragments. PCR reactions were conducted with primers corresponding to the restriction site +1 base (Mse+C and Pst+A) overhang. A second round of PCR was conducted with primers corresponding to the restriction site + 3 bases for more selection. In this reaction, the Mse primer incorporated a fluorescent tag so that the amplified fragments could be measured. The primers used were Pst+ACG and either Mse+CAA+Vic (Green) or Mse+CAT+Fam (blue). Peaks in AFLP analysis data represent genetic markers and the presence or absence of 340 such markers in individuals was compared.

RESULTS

Weed risk assessment Table 1 summarises the Comparative Weed Risk and Feasibility of Containment (FoC) scoring for *A. donax* for the riparian and terrestrial land uses. A matrix in the SAWRMS compares these scores to identify the most appropriate management action. See Virtue *et al.* (2010) for further detail and supporting evidence.

Arundo donax posed a very high weed risk to riparian areas but a negligible risk to terrestrial areas. The key reasons for the difference was limited capacity for dispersal in the absence of floodwaters due to *A. donax* only reproducing vegetatively (see below), and substantially slower growth due to lower moisture and nutrient levels in non-riparian areas. *A. donax* poses a high weed risk to riparian ecosystems across a wide

Table 1. Weed risk assessment of *Arundo donax* for Australia using the SAWRMS.

	Riparian	Terrestrial
Invasiveness	4.7	3.3
Impacts	6.8	2.1
Potential distribution	6.0	0.5
Comparative weed risk	192 (very high)	4 (negligible)
Control costs	4.7	2.7
Current distribution	0.9	0.9
Persistence	3.6	1.8
Feasibility of containment	16 (high)	4 (very high)
Management action	Destroy infestations	Monitor

range of climate zones in Australia, with potential for substantial impacts on biodiversity, access, fire regime, water use and infrastructure.

The recommended management action of 'destroy infestations' for the riparian land use indicated that weed authorities should consider control of any existing *A. donax* and not permit its cultivation in such areas. Conversely, the 'monitor' management action for the terrestrial land use indicated a high feasibility of containment and the need for regular review of any change in weed potential. In this regard there are no significant concerns with growing *A. donax* in terrestrial areas, provided ongoing protocols are in place to prevent spread to riparian areas.

Genetic variation analysis The genetic fingerprinting of *A. donax* identified two clades present in Australia. Most of the SA samples, a sample from Brisbane (Queensland) and a sample from Kununurra (Western Australia) were grouped into a single clade with low genetic divergence (less than 1% genetic diversity), indicating clonality. A second clade consisted of both samples from Sydney and four samples from SA. This indicates at least two separate introductions of *A. donax* into Australia. Similar clonality has been measured in genetic studies in the USA (e.g. Ahmad *et al.* 2008).

DISCUSSION

Arundo donax has an international reputation as a significant weed outside its native range and is subject to noxious weed laws in California, South Africa and New South Wales. However, the potential weed risk of *A. donax* in Australia differs considerably between riparian and non-riparian areas. In riparian areas it poses a very high weed risk due to the capacity for flood events to disperse vegetative root and shoot fragments to new areas of suitable moist habitat, in which it can form tall, dense monocultures. In areas not subject to flooding, *A. donax* will readily persist in a wide range of climate conditions, but clumps have very slow lateral spread and humans are the main potential dispersal agent (e.g. deliberate planting, earthworks).

Given its substantial weed risk to riparian areas in the landscape, *A. donax* plantations should be located well away from such areas and managed to minimise the inadvertent dispersal of vegetative material during its establishment, growth, harvest and transport. However, its lack of seed production makes its containment much more manageable than many other invasive commercial crops. The initial development of an *A. donax* industry is also an opportune time to establish containment procedures.

RISK MANAGEMENT GUIDELINES

The following is suggested for each State/Territory to consider in determining their policy on *A. donax*.

Declaration of *A. donax* Declarations for control, movement and sale under the provisions of the various State and Territory noxious weed acts would give a legislative basis for regulating the cultivation and containment of *A. donax*.

Permits for commercial cultivation These could be provided by the relevant noxious weed agency to landholders on a case by case basis, enabling permit holders to grow and harvest *A. donax*, provided they abide by permit conditions to prevent inadvertent spread (see below). Site inspections should be undertaken at least annually to ensure that permit conditions are being met.

Location of plantings outside riparian zones *A. donax* should not be established in parts of the landscape where there is a risk of it spreading to and within riparian areas. We suggest a 1 in 50 year flood frequency as the guideline to determine exclusion boundaries. A possible exception could be where soil engineering is proposed to create levees to prevent entry of floodwaters and/or substantially slow their velocity so that the probability of stem or root fragments of *A. donax* dislodging is low.

Containment and buffer zones Outside flood-prone areas *A. donax* should still be planted a minimum of 20 m from drainage lines. A buffer zone of a minimum of 10 m should also be established around the perimeter of plantings, with encroachment of *A. donax* into this zone prevented by physical and/or herbicidal control.

Control of any escapees An initial survey should map any existing *A. donax* (planted and wild) in proximity to a proposed plantation. A minimum of a 1 km land radius, 5 km length of the drainage line/watercourse downstream from the planting site and 5 km length of roadsides away from the site should be surveyed. This would provide a baseline for monitoring and detecting any future spread.

Control of any escapees should be through physical removal, including all rhizome material. With annual monitoring, establishment of large infestations requiring herbicide treatment (with glyphosate) would be very unlikely. Annual surveys should be undertaken (covering the same sites as in the initial survey) to detect any escapes of *A. donax*. If found, these should be mapped and promptly treated by physical removal or herbicides. The cost of surveys and any required control could be met by an industry levy.

Harvest, transport and processing Harvesting equipment should be cleaned of any fragments prior to leaving a plantation. *A. donax* declared under a noxious weeds act would require a permit for transport on roads, with annual inspection required along designated routes. Harvested material should only be moved in sealed containers (or fully tarped enclosed loads). The processing and use of *A. donax* material would need to ensure that it loses its capacity for vegetative regeneration from dormant buds in leaf axils.

CONCLUSION

Whilst *A. donax* is clearly a serious weed threat to riparian ecosystems, our analysis indicated it could be grown as a low weed risk biofuel crop in non-riparian zones provided this was done under strict management guidelines within a noxious weed legislative framework.

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