Plant introductions in Australia: how can we resolve 'weedy' conflicts of interest?

John G. Virtue[1,3], Sarita J. Bennett[2] and Roderick P. Randall[1,4]
[1] CRC for Australian Weed Management
[2] CRC for Plant-based Management of Dryland Salinity, University of Western Australia, 35 Stirling Highway, Crawley, Western Australia 6009, Australia
[3] Animal and Plant Control Commission, GPO Box 2834, Adelaide, South Australia 5001, Australia
[4] Department of Agriculture Western Australia, Baron-Hay Court, South Perth, Western Australia 6151, Australia

Summary Over 27,000 exotic plant species have been introduced to Australia, predominantly for use in gardening, agriculture and forestry. Less than 1% of such introductions have been solely accidental. Plant introductions also occur within Australia, as exotic and native species are moved across the country. Plant-based industries contribute around $50 billion to Australia's economy each year, play a significant social role and can also provide environmental benefits such as mitigating dryland salinity. However, one of the downsides of a new plant introduction is the potential to become a new weed. Overall, 10% of exotic plant species introduced since European settlement have naturalised, but this rate is higher for agricultural and forestry plants. Exotic plant species have become agricultural, noxious and natural ecosystem weeds at rates of 4%, 1% and 7% respectively. Whilst garden plants have the lowest probability of becoming weeds this is more than compensated by their vast numbers of introductions, such that gardening is the greatest source of weeds in Australia.

Resolving conflicts of interest with plant introductions needs a collaborative effort between those stakeholders who would benefit (i.e. grow the plant) and those who would potentially lose (i.e. gain a weed) to compare the weed risk, feasibility of management and benefits of the species in question. For proposed plant imports to Australia, weed risk is presently the single consideration under international trade rules. Hence the focus is on ensuring the optimal performance of the border Weed Risk Assessment System. For plant species already present in Australia there are inconsistencies in managing weed risk between the States/Territories. This is being addressed with the development of a national standard for weed risk management. For agricultural and forestry species of high economic value but significant weed risk, the feasibility of standard risk management approaches needs to be investigated. Invasive garden plants need national action.

Keywords Plant introductions, naturalise, weed risk assessment, risk management.

PLANT INTRODUCTIONS

Plant species are introduced to new geographic areas beyond their native range through human-mediated dispersal (whether deliberate or accidental) or through natural dispersal processes (i.e. wind, water or wild animals). In this paper we focus on plant introductions due to human activities. We include in this the importation of new exotic species to Australia and the post-border movement of exotic (and native) species within Australia.

Since European settlement 216 years ago, there has been a dramatic change in the plant species present in Australia. The original 15,638+ native plant species (Hnatiuk 1990) have been joined by around 27,000 exotic species. The majority of these exotic species were intentionally introduced to Australia for the purposes of agriculture, forestry and gardening/amenity; industries of significance to Australia's economy and society.

The major downside to plant introductions is the potential for species to become weeds. In general this happens only to a minority of plant introductions in Australia. However, weeds cause major economic, environmental and social impacts. Hence a plant introduction may pose a conflict of interest.

This paper describes the benefits (as cultivated plants) and costs (as weeds) of plant introductions to Australia and how weed risks are currently dealt with at the border and post-border levels. Improvements to existing processes are suggested to achieve better resolution of 'weedy' conflicts of interest.

WHY INTRODUCE PLANTS?

Plants have been introduced to and distributed within Australia for human and livestock food, fibre, timber, herbal medicine, gardening/landscaping, floriculture and turf. In addition, environmental uses of plant

introductions include soil stabilisation, dryland salinity control and use of atmospheric carbon.

The introduction of exotic plant species to Australia reflects a predominantly European cultural and agricultural heritage, the cultures and cuisines of migrants from various continents, international collaboration in the research, development and exchange of plant germplasm, the absence or lack of development of suitable native Australian species for agriculture, better performance of exotic species in the absence of natural pests and predators, and an insatiable human appetite for the 'new' – particularly with regard to garden and food plants. It was not until the latter decades of last century that Australian natives became popular ornamental plants and *Eucalyptus* plantations were widely established. Australian food and pasture plants are still a rarity.

The three key industries which utilise plant introductions in Australia are agriculture, forestry and gardening. Table 1 shows the annual value of production by various sectors within these industries. The total of around $50 billion per year demonstrates the importance of these industries to the Australian economy. Table 2 lists the number of exotic species introduced for these industries. Randall (2004) had data-based a total of 27,009 exotic plant introductions by April 2004, 99% of which have been deliberately cultivated in Australia (Table 2).

Table 1. Value of Australian agricultural and forestry products in year to 30 June 2002 (ABS 2004) and value of garden plants in year to 30 June 2003 (NGIA 2004).

Products	Gross value at market ($ million)
Cereals, pulses, oilseeds	10,370
Fruit and nuts	2,130
Vegetables	2,266
Sugar cane	989
Cotton	1,327
Grapes	1,577
Dairy (milk)	3,717
Meat (sheep and cattle)	9,260
Wool	2,713
Wood and paper[A]	15,077
Garden plants	1,850
Total	51,276

[A] Includes products from native forests and eucalypt plantations.

Exotic plants form the basis of most Australian agricultural systems, including grain, vegetable, fruit and fibre crops and various livestock industries. Southern (and some northern) pastures for meat, milk and wool production largely rely on exotic grasses and legumes (Table 2). In 2002, ABS (2004) estimated the total area of agricultural activity to be 447 million (m) ha, of which 5% (22.4 m ha) was sown pastures and 5% crops. Income from agriculture forms the economic backbone of rural communities throughout Australia, generating employment and maintaining a way of life for many. The number of plant introductions for potential pasture has considerably outweighed those for human food use (Table 2).

Over 600 exotic species have been introduced to Australia with forestry potential (Table 2), but only *Pinus* spp. are commercially significant. In 2002 there were 1.6 m ha of forestry plantations in Australia (ABS 2004). Sixty percent of these plantations were radiata pine (*Pinus radiata* D.Don), whilst 39% were eucalypts (ABS 2004), mainly Tasmanian blue gum (*Eucalyptus globulus* Labill. ssp. *globulus*).

The $1.85 billion annual turnover in plant sales by the gardening industry (Table 1) is indicative of its social importance to the community. Gardening is one of the most popular recreational and cultural activities in Australia. Most Australians value the aesthetics, beauty and amenity of ornamental plants, the majority of which are exotic. Hence it is not surprising that the vast majority of plant introductions to Australia have been for gardens (Table 2).

Whilst the economic and social benefits of plant introductions are clear, significant environmental gains can also be made. Dryland salinity is estimated to currently cost $250 m y^{-1} in the Murray-Darling Basin and $664 m y^{-1} in Western Australia, including costs to agriculture, infrastructure and protection of vegetation (NLWRA 2001). Agricultural land affected by dryland salinity is predicted to increase from 4.7 m ha today to 13.6 m ha by 2050 (NLWRA 2001). Broadscale re-establishment of perennial, deep-rooted plants is therefore urgently required if there is to be any hope of reducing the increase in dryland salinity and rising watertables. Diverse, profitable, perennial pasture and crops are needed.

Perennial plants, particularly grasses, have extensive root systems which can stabilise soils and both exotic and native species have been planted to reduce soil erosion. Deep-rooted perennials reduce soil acidification in annual legume pastures, by recovering leached nitrate in the subsoil. Wide-scale planting of woody crops would substantially increase the utilisation of atmospheric carbon in Australia, providing a means to reduce overall greenhouse gas emissions.

Table 2. Weed status by industry sector of exotic plant species introduced to Australia, April 2004. Complied by Randall (third author).

Industry sector	No. of species introduced (*I*)	Naturalised[A]		Weeds[B]		Agricultural[C] weeds		Noxious[D] weeds		Natural ecosystem[E] weeds		Combined agricultural, noxious and natural ecosystem weeds[F]	
		No.	*% of I*	No.	*% of I*	No.	*% of I*	No.	*% of I*	No.	% of I	No.	*% of I*
Food crops	221	85	*38*	105	*48*	26	*12*	8	*4*	55	*25*	58	*26*
Pasture (Poaceae)	490	150	*31*	180	*37*	82	*17*	7	*1*	116	*24*	124	*25*
Pasture (Fabaceae)	499	163	*33*	196	*39*	66	*13*	11	*2*	115	*23*	126	*25*
Pasture (the rest)	97	36	*37*	41	*42*	11	*11*	3	*3*	20	*21*	23	*24*
Total pasture	1,086	349	*32*	417	*38*	159	*15*	21	*2*	251	*23*	273	25
Forestry[G]	633	149	*24*	226	*36*	35	*6*	30	*5*	103	*16*	108	*17*
Gardening	25,360	1,831	*7*	2,520	*10*	660	*3*	273	*1*	1,279	*5*	1,366	*5*
Accidental[H]	207	186	*90*	185	*99*	84	*45*	24	*13*	121	*65*	141	*76*
Accidental and intentional[I]	1,051	776	*74*	828	*79*	443	*42*	137	*13*	592	*56*	640	*61*
Total introduced[J]	27,009	2,779	*10*	3,480	*13*	954	*4*	343	*1*	1,765	*7*	1,953	*7*

[A] Specimens lodged in Australian herbaria (Hosking 2003 and Randall 2004).
[B] Listed as weeds in Australia in various texts (Randall 2002 and Randall 2004).
[C] From Groves *et al.* (2003) and Randall (2004).
[D] From www.weeds.org.au
[E] Species cited as 'Environmental Weeds' in Randall (2004).
[F] This is less than the sum of all weed types as some species occur as more than one type.
[G] This includes species used for forestry purposes overseas but not currently in commercial production in Australia (Randall 2004).
[H] Species cited as 'Contaminants' (e.g., of imported grain, fodder, ballast, packing materials, livestock) in Randall (2004).
[I] This is the upper limit of accidental introductions. Species are likely to have been introduced to Australia as contaminants, but are also known to have been deliberately cultivated in Australia (Randall 2004).
[J] This is less than the sum of all industry sectors as some species occur in more than one sector.

INTRODUCTIONS CAN BECOME WEEDS

Some introduced plants escape from cultivation and form self-sustaining populations, which persist in the absence of (or despite) human intervention. Similarly, accidental plant introductions (i.e. contaminants) may establish wild populations. Such species are termed 'naturalised'. As these naturalised populations increase in density and area they can cause negative economic, ecological and social impacts, and hence be considered 'weeds'. Such impacts may include a reduction in crop and pasture yields, reduction in natural biodiversity, interference with the physical movement of people, vehicles, animals and water, a reduction in the quality of agricultural products, detrimental health effects on both people and animals, and changes in ecosystem processes such as fire regimes. The annual economic cost of agricultural weeds in Australia is around $4 billion (Sinden *et al.* 2004). The economic cost of weed invasions in natural ecosystems is very difficult to estimate (Sinden *et al.* 2004), but would probably be of the same order of magnitude as agricultural weeds if comprehensive, national control programs were to be undertaken.

Since European settlement, the overall transition rate from plant introduction to naturalisation for exotics in Australia is 10% (Table 2), a relatively small minority. However, this rate (or probability of naturalisation) varies considerably with the nature of the introduction (Table 2). The vast majority of species which were likely to have arrived accidentally have naturalised, probably reflecting their adaptation to growth and dispersal in intensively managed agricultural and urban ecosystems. Pasture species have naturalised at an overall rate of 32%, with similar rates for legumes and grasses. This relatively high rate is not surprising given that homologous climates and

persistence are key factors for which they have been selected. The higher rate of naturalisation of food crops (38%) is surprising given their domestication, but this probably reflects their widespread planting. Introduction frequency is highly correlated with naturalisation rate ('propagule pressure' of Williamson 1996 and Mulvaney 2001). The forestry naturalisation rate of 24% is over three times greater than that for gardens. These two industry sectors share the same species and the difference probably lies in the garden plants having a much wider variety of plant types, a low emphasis on climatic tolerance in selecting species and a low average planting rate per species. However, what the garden plants lack in probability of naturalising they make up for through sheer numbers of species. Garden plant introductions are the main source of plant naturalisations and consequently new weeds in Australia (Table 2 and Groves and Hosking 1996).

Table 2 has higher proportions of species being documented as 'weeds' (column 4) in Australian literature than being recorded as naturalised. One likely reason for this is a lack of herbarium specimens for some species considered weeds, particularly in agricultural ecosystems where botanical surveys are rarely undertaken. Other reasons may be that some species are of short-term nuisance value but do not form persistent populations (e.g. volunteers of a previous crop emerging in a subsequent crop) or that the species only persist in highly-modified, unnatural conditions (e.g. glasshouses, nursery containers).

For specific categories of weeds in Table 2, the overall probability of weediness for plant introductions is 4%, 1% and 7% for agricultural, noxious and natural ecosystem weeds respectively. If legally-declared (i.e. noxious) weeds are considered the representative set of high impact weed species in Australia, then only 1% of plant introductions pose this risk. The higher rate for natural ecosystem weeds than agricultural weeds may reflect a wider range of environments (i.e. disturbance regimes and resource levels for plant growth) for exotic plant species to exploit. Alternatively, there may be a greater tendency to call a naturalised species a 'weed' in such circumstances because it is an unwanted alien in Australia's unique, natural environment.

The relative differences between the industry sectors for naturalisation rates are generally similar across weed categories (Table 2). The exceptions are for noxious weeds, which have a relatively higher rate of weediness for forestry species and a relatively lower rate for pasture species. On a per-species basis accidental introductions are most likely to become weeds and garden plants the least. However, when the absolute numbers of introductions are considered then most of Australia's weeds have been garden plants at some stage.

From Table 2 it is clear that there are weed risks involved in new, intentional plant introductions. Only a small proportion have naturalised to date, but this varies considerably between industry sectors and the total numbers of species within sectors is also important. A smaller proportion again have become the most serious, high impact weeds. Hence there are generally select cases where actual and potential 'weedy' conflicts of interest occur (i.e. where there is a risk a new plant species introduction will spread from plantings and subsequently impact as a weed). In most cases the landuse where the plant species becomes a weed will be different from the landuse in which it was deliberately grown. We need to find ways to identify and resolve such conflicts of interest to gain the most optimal, overall outcome for Australia.

RESOLVING THE CONFLICTS

The ideal approach to resolving conflicts of interest for a plant species introduction would be a collaborative effort between those stakeholders who would benefit (i.e. grow the plant) and those who would potentially lose (i.e. gain a weed). They would compare the weed risk, feasibility of management and benefits of the species in question and develop workable, scientifically-based decisions on whether or how to proceed with the introduction. The following discussion looks at how conflicts of interest over plant introductions are resolved at the border and post-border levels in Australia, and improvements to the processes are suggested.

Australia's border For any weed, agricultural or environmental, the most cost-effective and technically feasible management action is preventing the plant's introduction in the first place (ARMCANZ *et al.* 1997). Yet there are some current concerns that potentially high-value, new agricultural species are subsequently being missed due to a precautionary approach to plant introductions to Australia (Bennett and Virtue in press).

Australia's quarantine system for plant species imports was dramatically improved in 1997 with the shift to a permitted list in conjunction with adoption of the Weed Risk Assessment System (hereafter the Pheloung system) rather than a limited prohibited list of species (Pheloung 2001, Walton 2001). The system scores the weed risk of a plant using up to 49 yes/no/don't know questions, with acceptance for import if the score is 0 or less, rejection if greater than 6 and further evaluation if within this range. It should be noted that Australia is a signatory to the World Trade Organisation's

Agreement on the Application of Sanitary and Phytosanitary Measures (i.e. the 'SPS Agreement'), which has rules on how the Pheloung system is applied. Plant species must be permitted if they are already present in Australia beyond a 'limited distribution' (e.g. in cultivation and/or naturalised) and not under 'official control' (e.g. legally declared noxious). This means that many of Australia's non-declared weeds and species in gardens with known weed potential can still be imported. Also under the SPS Agreement, decisions to import species can only be based on scientific assessments of risks to human, animal and plant health (including weed risk). Economic benefits cannot be considered in making decisions (to avoid protectionist trade barriers) and hence the potential advantages of new plant species imports cannot be considered.

Improving the technical basis of the Pheloung system is the best current option for reducing the level of disagreement between plant importers and weed managers within Australia. Various studies (e.g. Smith *et al.* 1999 and Daehler *et al.* 2004) have shown that the Pheloung system has a good level of accuracy for predicting 'true' weeds (when testing known weeds using the system), but it can be overly conservative and predict too many known non-weeds to be weeds (i.e. false positives). The Pheloung system has been the subject of various technical reviews in Australia in 2004 and improvements should aim to maximise the rates of true positives (real weeds) and true negatives (real non-weeds) and minimise species requiring further evaluation. This latter group of species is effectively a rejection, at the moment, as no agreed process currently exists to undertake further evaluation.

Three suggestions to deal with this group are (i) formal development of the so-called '3rd Tier' of assessment for such species, involving experimental analysis of species, (ii) raising the cutoff score for acceptance based on how many questions are answered, or (iii) redesigning the Pheloung system to give a greater distinction between criteria assessing the likelihood and consequence of a species becoming a weed (i.e. the two standard components of risk). In the latter case this may help to distinguish whether species will naturalise, from the impacts that would occur if they did. Pasture breeders are particularly concerned that annual legumes are rejected for import based on the high likelihood of naturalisation (which is the intention anyway), yet existing species in Australia are not considered to have significant impacts (Emms 2004). Characteristics for predicting weediness in the Pheloung system are also those that are important for a successful pasture species, such as climate similarity, high seed production and persistence traits (Bennett and Virtue in press).

Whilst the feasibility of including the potential benefits of new agricultural plant introductions at the border import stage is being examined (Kalisch Gordon 2004), there are considerable hurdles. These include accurately predicting benefits (i.e. avoiding false positives as with weed risk assessment), the time-lag between when the plant is used and when it becomes a weed, and weighing up short-term agricultural use (i.e. likely changes to new species, varieties) versus long-term environmental impacts.

An immediate means to improve the workings of the Pheloung system to the benefit of both weed managers and plant importers is to increase resources for its use within Biosecurity Australia (BA). There have been unsatisfactory delays in assessments of species held by Genetic Resource Centres and in reviewing the list of permitted genera (Spafford Jacob *et al.* 2004). Whilst independent weed risk assessments by BA are important, there could be greater efficiencies and outcomes achieved through closer working relationships with plant importers, particularly researchers (Bennett and Virtue in press).

Introductions within Australia Significant 'weedy' conflicts of interest are happening now in Australia, across all industries mentioned in this paper. Examples are olives (*Olea europaea* L.) (Crossman *et al.* 2002), pasture grasses (Grice 2004), pines (Virtue and Melland 2003) and a long list of garden plants (Randall 2001). Whilst there has been a strong, national focus on preventing further introductions of potential weeds to Australia, the same cannot be said for within the country. There are a large number of species either causing weed problems or with weed potential that are being cultivated across Australia (Table 2). There are also native species being translocated across the country which create weed threats in new environments (Bennett and Virtue in press). To date, inconsistent action has been taken to address these 'weedy' conflicts of interest within Australia. Weed management is a constitutional responsibility of the States and Territories. Due to differences in noxious weeds legislation, structural arrangements and resourcing for weed management programs, post-border assessment and management of weed risk varies considerably across Australia. However, steps are now being taken to address this.

A national standard has been developed for weed risk management (Virtue *et al.* 2004). This will foster the development of uniform systems to assess weed risk and feasibility of control, for use by plant proponents and weed managers. A similar approach needs to be developed for assessing the potential utility (benefits) of a species in a region. Then weed

risk, feasibility of control and potential benefits can be clearly compared to make informed decisions on species introductions. For introductions aimed at salinity mitigation, the relative environmental threats of weeds versus salinity need to be compared – weeds may not always be the greatest threat (Bennett and Virtue in press).

For agricultural and forestry species of high economic value but significant weed risk, the feasibility of generic risk management approaches needs to be investigated. Single species approaches have been developed for olives in South Australia (APCC 1999) and leucaena, *Leucaena leucocephala* (Lam.) de Wit in Queensland (Shelton *et al.* 2001, Craig Walton pers. comm. 2004), which include restrictions on planting location, management to limit seed dispersal and plant spread and noxious weed declaration for feral populations. The practicality and long-term effectiveness of risk management, particularly its applicability to smaller plants such as pasture grasses, and whether farmers will cooperate without legal enforcement, needs closer examination.

Given the large choice of species already available to the gardening industry there is little argument for the individual benefit of a species which poses a significant weed risk. The economic power and public support of the industry has led to a political hesitancy to deal effectively with the issue. It is time to act, with a well-resourced, joint State/Commonwealth approach using provisions of the federal *Environment Protection and Biodiversity Conservation Act, 1999*. The focus should be on recent introductions which have yet to naturalise, or which have limited naturalised distribution, in preference to species already widespread as weeds (where restriction of sale will do little to solve the existing weed problem).

Finally, there is a need to increase our understanding of the plant traits of high impact weeds. This may enable plant breeders to select species and varieties of low potential weed impact.

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