

Australia's Botanic Gardens weed risk assessment procedure

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Summary

The majority of agricultural and environmental weeds in Australia have originated from ornamental horticulture. Botanic gardens require a simple yet robust method for rapidly screening the relative weed risk of taxa in their collections. A ten question, multiple choice, additive weed risk assessment system was developed for application to taxa growing in gardens. The major city botanic gardens in Melbourne, Hobart and Perth used the system to score 100 taxa. Separately, a national survey and a literature review of the same 100 taxa were undertaken to obtain two independent datasets for assessing their level of weediness. Testing of the system showed that it has good discriminatory power and cut-off scores were chosen that have about 80% accuracy for both low weed risk and high weed risk species. There was poorer accuracy to distinguish medium weed risk species. The system has wider potential application for the nursery and garden industry as a tool to help reduce the number of high weed risk ornamental species in cultivation.

Keywords: Weed risk assessment, decision tool, botanic gardens.

Introduction

Most plant species introductions to a new country or region have been for use as ornamentals in gardens and landscaping. For Australia, at least 25 360 exotic plant species and 10 700 native plant species have been cultivated at some point as garden plants (Virtue *et al.* 2004, Randall 2006). Australia has over 3164 naturalised plant species, with 2124 and 552 of these having been cultivated exotics and natives respectively (Randall 2006). The proportion of weeds in Australia derived from exotic ornamentals is around 65% (Groves and Hosking 1996, Virtue *et al.* 2004). Hence ornamental horticulture has been the main source of weed species. Weeds pose a multi-billion dollar cost to Australia's economy (Sinden *et al.* 2004) and are a substantial threat to the

nation's biodiversity (e.g. Coutts-Smith and Downey 2006).

Botanic gardens are a key pathway for the introduction of new species to cultivation, whether exotic or native. Randall (2006) noted that, in Australia, 7200 taxa were only known to be in cultivation in botanic gardens. There are many reasons for growing plants in botanic gardens, including public amenity and pleasure, education, scientific research, species conservation, crop and cultivar development, and cultural heritage. However, the benefits derived from cultivating particular species need to be weighed against any risks that they may pose, such as threats to public safety and weed risk. Through displays and active promotion, botanic gardens facilitate the wider cultivation of new species with horticultural merit, some of which may eventually naturalise and become weeds. Botanic gardens, even those with good security, also have high public visitation rates and the theft and subsequent cultivation of propagules of displayed species is a concern. Even in the absence of human activity, botanic gardens may be in locations where there is a risk of natural spread of species (e.g. by wind, water or birds) to adjacent farmland, native vegetation or waterways. A notorious botanic gardens escape in Australia is that of *Mimosa pigra* L. from Darwin Botanic Gardens (Miller and Lonsdale 1987), now a Weed of National Significance. Botanic gardens, however, are also usually educational institutions with the opportunity to inform the public about many issues, including plant invasions. In 2001, representatives of botanic gardens, the nursery industry and invasive plant research and management organisations from across the United States (and the United Kingdom, Australia and New Zealand) met at the Missouri Botanic Garden. They developed the St. Louis Codes of Conduct, an attempt to reconcile conflicts regarding their display, education, and conservation missions concerning invasive species

(www.centerforplantconservation.org/invasives/).

In recognition of the important role of botanic gardens in weed management, education, and conservation, the Council of the Heads of Australian Botanic Gardens (CHABG) agreed in October 2004 to the development of common policies, procedures and a weed risk assessment methodology for Australia's botanic gardens (Spencer 2006). A national weeds workshop, with representatives from botanic gardens and the Cooperative Research Centre for Australian Weed Management (Weeds CRC), was held in July 2005. The workshop agreed on the need for a relatively simple, rapid, transparent, robust and nationally applicable tool to categorise species present in collections into weed risk rankings (i.e. low, medium, high). These could then be compared against the stage of introduction (e.g., new to cultivation; widely planted and naturalised) to determine the most appropriate management response. The border Weed Risk Assessment System used by Biosecurity Australia (Pheloung 2001) was not seen as appropriate due to botanic gardens' need to rank species, whereas post-border systems used to prioritise noxious weed control (e.g. Weiss and McLaren 2002, Virtue 2005) were too complex. The workshop resolved to test a simple weed risk assessment system that had been developed in 1999 and further refined at the Royal Botanic Gardens, Melbourne. This paper examines the performance of the weed risk assessment system for temperate Australia.

Methods

System development

The 1st International Workshop on Weed Risk Assessment in Adelaide, South Australia brought together experts from eight countries to identify key criteria for the prediction and prioritisation of weediness (Virtue 1999a, Groves *et al.* 2001). Subsequently, a draft scoring system to rank the weediness of garden plant species was developed for the Horticultural Research and Development Corporation by the first and fourth author, with assistance from Kate Blood, Craig Walton, Rod Randall and David Cooke (Virtue 1999b). This system, consisting of nine multiple-choice questions, was designed to be relatively simple to use and based on plant species' performance in gardens and/or as weeds. The system was further refined and used by South Australia's Garden Escapes Committee for ranking weed threats, and by the Weeds CRC for identifying low weed risk alternatives to known invasive garden plants in Adelaide. In 2003, Royal Botanic Gardens (RBG) Melbourne, Victoria, commenced further development and trialling of the system with horticultural and botanical staff. The system became known

as the Weed Risk Assessment Procedure (WRAP) and was part of an organisation-wide Weed Strategy. Despite the system's utility its wider use was not promoted, as there was a need for research to validate its outcomes for known weedy and non-weedy garden plants and determine relevant cut-off points for low, medium and high weed risk categories.

Botanic Garden assessments

A test dataset of 100 garden taxa (Table 1) covering a range of plant life forms, uses, families and weed histories was collated by the second author. Royal Botanic Gardens Melbourne, Royal Tasmanian Botanical Gardens Hobart and Kings Park Botanic Garden (Perth) scored these taxa using the WRAP (Appendix 1). The vast majority of taxa, or the species from which they were derived, had been in cultivation in Australia prior to the mid 20th century, with many first in cultivation in the mid 19th century. Species with invasive tendencies should have begun to demonstrate them after several decades.

Each of the gardens chose a slightly different way to evaluate the species. At Kings Park and Botanic Garden, five staff members split the species list and each assessed approximately 20 each. Before beginning the assessments, staff had met to work through the questions together so that all understood the WRAP. At the Royal Tasmanian Botanic Gardens, the Horticultural Botanist and the Botanical Resources Officer, in consultation with horticultural staff, as necessary, assessed the species list. The total assessment time was 20 hours for two reviewers working together, or 40 hours overall. At the Royal Botanic Gardens Melbourne, volunteer teams of the horticulture staff tested varying amounts of species, assembling literature and internet resources when required.

Weed status datasets

Independent datasets for the weediness of the 100 taxa, for comparison with the Botanic Gardens scores, were obtained in two ways; a national survey and a literature review.

For the national survey, members of the Enviroweeds listserver and the Weeds CRC's internal email list were invited to participate in a national survey in November–December 2006. A MS-Excel spreadsheet questionnaire was subsequently emailed to interested persons with the 100 taxa listed. Survey respondents were asked to rank taxa as 0 = non-weed, 1 = low risk weed, 2 = medium risk weed or 3 = high risk weed, for taxa and locations they were familiar with.

A literature review of current weed status in temperate climates was undertaken using book and internet sources to classify the 100 taxa, independent of the national survey and again using a 0–3

categorisation (hereafter 'Literature Weediness Categorisation'). Non-weeds (a score of '0') were those taxa that had not been recorded as naturalised in such climates around the world. Low risk weeds (a score of '1') were those taxa that were recorded as naturalised outside their native range in temperate regions but had rarely been targeted for individual control. Medium risk weeds (a score of '2') were those taxa that were not declared for control as a noxious weed (but may have had declarations prohibiting sale or movement), but were commonly found on weed lists in temperate regions and were commonly targeted for individual control (i.e. control information was readily available, such as recommended herbicides). High risk weeds (a score of '3') were those taxa that were declared for control as significant weed threats to temperate regions and/or had been short-listed as a significant weed of high impact in such regions. Temperate regions in Australia include Tasmania and Victoria, southern Western Australia and South Australia, and southern and eastern New South Wales (NSW) excluding coastal NSW north from Newcastle (Bureau of Meteorology 2008). Primary internet sources of information were Australia's Virtual Herbarium, Flora of New Zealand, Germplasm Resources Information Network and Weeds Australia (see References for urls). Primary texts used were Blood (2001), Cal-IPC (2006), Carr *et al.* (1992), Groves *et al.* (2003), Henderson (2001), Hussey *et al.* (1997), Muylt (2001), Richardson *et al.* (2006) and Roy *et al.* (1998). Herbicide registration information was obtained from PIRSA (2007).

Data analysis

Total taxa WRAP scores for each of the three botanic gardens were averaged (hereafter 'Average BG Score'). National survey results for each taxa were also averaged (hereafter 'Average Survey Ranking') and then categorised (hereafter 'Survey Weediness Categorisation') as:

- '0' = Average Survey Ranking of 0–0.75,
- '1' = Average Survey Ranking of 0.76–1.50,
- '2' = Average Survey Ranking of 1.51–2.25, and
- '3' = Average Survey Ranking of 2.26–3.

Correlations between Average BG Score and Average Survey Ranking, Survey Weediness Categorisation and Literature Weediness Categorisation were examined and tests for significant differences in Average BG Score for both categorisations were analysed using General Linear Model ANOVA.

To determine appropriate cut-offs between low and medium weed risk taxa, and between medium and high weed risk taxa, receiver operator characteristic (ROC) curves were generated. ROC curves are the

plot of sensitivity versus (1 – specificity) for all possible cut-off scores in a screening system (see Caley and Kuhnert 2006). Sensitivity is the proportion of true positives, in this case the number of actual weeds predicted divided by the total number of actual weeds in the dataset. Specificity is the proportion of true negatives, in this case the number of actual non-weeds predicted divided by the total number of actual non-weeds in the dataset. A particular advantage of ROC curves is that they are independent of the true positive and true negative proportions in the test data set, enabling meaningful comparisons between screening tests without being influenced by the base-rate prevalence of the event (i.e. weediness) (Caley and Kuhnert 2006). The better the performance of the screening system, the closer the ROC curve passes to the upper left-hand corner when plotted. The area under the curve is a measure of performance, with an area of 1 having perfect accuracy and an area of 0.5 having no discriminatory ability (Caley and Kuhnert 2006).

ROC curves were calculated and areas under the curve determined for both the national survey and weed status categorisations. Two types of comparisons were made:

- i. Sensitivity (Medium + High risk) versus [1 – Specificity (Non + Low risk)].
- ii. Sensitivity (High risk) versus [1 – Specificity (Medium risk)].

Results

Botanic Gardens assessments

Average BG Scores from the WRAP (Appendix 1) ranged from 3.7 to 26.0 (Table 1) and approximated to a normal distribution. Standard deviation in WRAP scores between botanic gardens ranged from 0.0 to 7.8, with a mean of 3.0.

Weed status datasets

For the national survey, the intention was that respondents would categorise taxa according to their weed potential in the Hobart, Melbourne and/or Perth regions. However, some answered for their regions in Australia, rather than for these capital cities. Subsequently, three non-temperate respondents were excluded and the Average Survey Ranking for each of the taxa was determined using data from the remaining seventeen temperate climate respondents (Table 1). The number of respondents categorising a taxon ranged from 1 to 17, with a median of 6 responses.

There were no major difficulties in obtaining the Literature Weediness Categorisation dataset (Table 1).

Correlations between WRAP scores and weediness

Table 2 shows highly significant correlations between the botanic gardens assessment scoring and all measures of

Table 1. List of taxa that were assessed by the three botanic gardens, ordered from lowest to highest Average BG Score.

Taxon	WRAP Scoring					National Survey			Literature Review
	Royal Tasmania Botanic Gardens	Royal Botanic Gardens Melbourne	Kings Park Botanic Gardens	Average BG Score	s.d.	Average Survey Ranking	n	Survey Weediness Categorisation	Literature Weediness Categorisation
<i>Boronia heterophylla</i> F.Muell.	5	2	4	3.7	1.5	1.00	4	1	0
<i>Araucaria heterophylla</i> (Salisb.) Franco	7	3	6	5.3	2.1	0.33	6	0	1
<i>Wollemia nobilis</i> W.G.Jones, K.D.Hill & J.M.Allen	6	10	2	6.0	4.0	0.00	3	0	0
<i>Camellia reticulata</i> Lindl.	4	7	9	6.7	2.5	0.80	5	1	0
<i>Clivia × cyrtanthiflora</i> (Van Houtte) H.P.Traub	4	4	13	7.0	5.2	0.67	3	0	0
<i>Platyserium bifurcatum</i> (Cav.) C.Chr.	1	6	15	7.3	7.1	0.33	3	0	0
<i>Rhododendron</i> 'Scarlet Wonder'	11	6	5	7.3	3.2	0.00	4	0	0
<i>Protea cynaroides</i> (L.) L.	5	9	9	7.7	2.3	0.00	4	0	0
<i>Rosa</i> 'Peace'	8	7	8	7.7	0.6	0.00	3	0	0
<i>Agonis flexuosa</i> (Willd.) Sweet 'After Dark'	10	3	11	8.0	4.4	1.00	2	1	1
<i>Impatiens balsamina</i> L.	8	9	7	8.0	1.0	1.29	7	1	1
<i>Brachyscome multifida</i> DC.	11	2	12	8.3	5.5	0.60	5	0	0
<i>Dahlia × hortensis</i> Guill 'April Port Wine'	7	2	16	8.3	7.1	1.50	2	1	0
<i>Hebe stricta</i> (Banks & Sol. ex Benth.) L.B.Moore	9	10	6	8.3	2.1	0.50	4	0	0
<i>Hydrangea macrophylla</i> (Thunb.) Ser.	9	7	9	8.3	1.2	1.50	6	1	1
<i>Rosa banksiae</i> W.T.Aiton	6	9	10	8.3	2.1	0.60	5	0	0
<i>Rhododendron indicum</i> (L.) Sweet	12	9	5	8.7	3.5	0.20	5	0	0
<i>Coleonema pulchellum</i> I.Williams	6	6	15	9.0	5.2	1.20	5	1	1
<i>Magnolia × soulangeana</i> Soul.-Bod.	8	5	14	9.0	4.6	0.60	5	0	0
<i>Aristea capitata</i> Ker Gawl.	6	11	12	9.7	3.2	0.50	2	0	0
<i>Gaura lindheimeri</i> Engelm. & A.Gray	9	7	13	9.7	3.1	1.75	4	2	3
<i>Lavandula × allardii</i> Hy.	6	10	13	9.7	3.5	0.80	5	1	0
<i>Macrozamia communis</i> L.A.S.Johnson	8	7	14	9.7	3.8	0.40	5	0	1
<i>Westringia fruticosa</i> (Willd.) Druce	10	12	8	10.0	2.0	0.50	4	0	0
<i>Cupressus sempervirens</i> L.	11	9	11	10.3	1.2	0.71	7	0	1
<i>Citrus limon</i> (L.) Burm. f.	5	10	17	10.7	6.0	0.43	7	0	0
<i>Solanum tuberosum</i> L.	9	12	11	10.7	1.5	0.75	10	0	2
<i>Pisum sativum</i> L.	9	10	14	11.0	2.6	0.80	7	1	2
<i>Hylotelephium spectabile</i> (Boreau) H.Ohba	12	10	11	11.0	1.0	1.25	4	1	1
<i>Betula pendula</i> Roth	13	8	13	11.3	2.9	1.00	7	1	1
<i>Malus × purpurea</i> (A.Barbier) Rehder	10	12	12	11.3	1.2	0.86	7	1	0

continued/...

Table 1. continued/...

Taxon	WRAP Scoring					National Survey			Literature Review
	Royal Tasmania Botanic Gardens	Royal Botanic Gardens Melbourne	Kings Park Botanic Gardens	Average BG Score	s.d.	Average Survey Ranking	n	Survey Weediness Categorisation	Literature Weediness Categorisation
<i>Nepeta</i> × <i>faassenii</i> Bergmans ex Stearn	13	11	10	11.3	1.5	1.00	3	1	0
<i>Fragaria</i> × <i>ananassa</i> Duchesne ex Rozier	11	11	13	11.7	1.2	1.00	3	1	1
<i>Strelitzia reginae</i> Aiton	12	11	12	11.7	0.6	0.33	3	0	0
<i>Syringa vulgaris</i> L.	9	15	11	11.7	3.1	1.00	3	1	1
<i>Bellis perennis</i> L.	15	8	13	12.0	3.6	1.60	5	2	2
<i>Narcissus</i> 'King Alfred'	14	10	12	12.0	2.0	0.50	4	0	1
<i>Cestrum elegans</i> (Brongn. ex Neumann) Schldl.	12	18	7	12.3	5.5	2.40	5	3	2
<i>Narcissus jonquilla</i> L.	14	10	14	12.7	2.3	1.10	10	1	1
<i>Celtis sinensis</i> Pers.	14	14	11	13.0	1.7	1.67	3	2	1
<i>Daucus carota</i> L.	12	9	18	13.0	4.6	1.43	16	1	2
<i>Lonicera nitida</i> E.H.Wilson	12	12	15	13.0	1.7	1.67	6	2	1
<i>Mentha suaveolens</i> Ehrh.	16	11	12	13.0	2.6	2.40	5	3	1
<i>Bartlettina sordida</i> (Less.) R.M.King & H.Rob.	12	16	13	13.7	2.1	1.00	3	1	2
<i>Quercus robur</i> L.	13	17	11	13.7	3.1	0.71	7	0	1
<i>Iris</i> × <i>germanica</i> L.	13	15	14	14.0	1.0	1.50	6	1	1
<i>Muscari comosum</i> (L.) Mill.	12	16	14	14.0	2.0	1.25	4	1	1
<i>Lomandra longifolia</i> Labill.	9	18	16	14.3	4.7	0.29	7	0	0
<i>Lycopersicon esculentum</i> Mill.	11	16	16	14.3	2.9	0.44	11	0	1
<i>Melissa officinalis</i> L.	18	13	12	14.3	3.2	1.00	4	1	1
<i>Pelargonium</i> × <i>domesticum</i> L.H.Bailey	17	13	13	14.3	2.3	1.10	10	1	1
<i>Prunus persica</i> (L.) Batsch	11	17	15	14.3	3.1	1.00	8	1	1
<i>Viburnum tinus</i> L.	12	17	14	14.3	2.5	1.14	7	1	1
<i>Eucalyptus nicholii</i> Maiden & Blakely	14	10	20	14.7	5.0	0.50	6	0	0
<i>Lavandula stoechas</i> L.	14	14	16	14.7	1.2	1.67	12	2	3
<i>Tipuana tipu</i> (Benth.) Kuntze	6	19	20	15.0	7.8	2.00	1	2	0
<i>Wachendorfia thyrsiflora</i> Burm.	11	20	14	15.0	4.6	1.50	2	1	1
<i>Canna</i> × <i>generalis</i> L.H.Bailey	16	16	14	15.3	1.2	1.43	7	1	1
<i>Grevillea rosmarinifolia</i> A.Cunn.	16	13	17	15.3	2.1	1.29	7	1	1
<i>Callistemon salignus</i> (Sm.) Sweet	15	16	17	16.0	1.0	0.67	6	0	1
<i>Cannabis sativa</i> L.	18	16	14	16.0	2.0	1.22	11	1	3
<i>Ulmus</i> × <i>hollandica</i> Mill.	16	17	15	16.0	1.0	1.00	5	1	1
<i>Fraxinus angustifolia</i> Vahl	15	16	18	16.3	1.5	1.64	14	2	2
<i>Phoenix canariensis</i> hort. ex Chabaud	8	21	22	17.0	7.8	1.29	7	1	1
<i>Punica granatum</i> L.	11	19	21	17.0	5.3	1.50	2	1	1

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Table 1. continued/...

Taxon	WRAP Scoring					National Survey			Literature Review
	Royal Tasmania Botanic Gardens	Royal Botanic Gardens Melbourne	Kings Park Botanic Gardens	Average BG Score	s.d.	Average Survey Ranking	n	Survey Weediness Categorisation	Literature Weediness Categorisation
<i>Salix matsudana</i> Koidz. 'Tortuosa'	18	16	17	17.0	1.0	1.71	8	2	3
<i>Cryptostegia grandiflora</i> R.Br.	14	14	25	17.7	6.4	1.62	9	2	0
<i>Agapanthus praecox</i> Willd. subsp. <i>orientalis</i> (F.M.Leight.) F.M.Leight	14	21	19	18.0	3.6	1.88	17	2	2
<i>Cyperus rotundus</i> L.	20	14	20	18.0	3.5	1.67	11	2	3
<i>Equisetum laevigatum</i> A.Braun	19	14	21	18.0	3.6	2.00	4	2	3
<i>Hakea sericea</i> Schrad. & J.C.Wendl.	17	21	16	18.0	2.6	1.09	11	1	3
<i>Ochna serrulata</i> (Hochst.) Walp.	11	19	24	18.0	6.6	1.94	8	2	3
<i>Asparagus densiflorus</i> (Kunth) Jessop	14	20	21	18.3	3.8	2.40	5	3	3
<i>Casuarina cunninghamiana</i> Miq.	18	18	19	18.3	0.6	1.00	9	1	1
<i>Acacia baileyana</i> F.Muell.	19	16	21	18.7	2.5	1.93	15	2	2
<i>Arundo donax</i> L.	15	20	21	18.7	3.2	2.00	6	2	3
<i>Cinnamomum camphora</i> (L.) J.Presl	15	20	21	18.7	3.2	1.22	10	1	3
<i>Foeniculum vulgare</i> Mill.	19	16	22	19.0	3.0	2.22	9	2	3
<i>Parkinsonia aculeata</i> L.	17	14	26	19.0	6.2	1.75	4	2	3
<i>Phyllostachys aurea</i> Riviere & C.Riviere	18	19	21	19.3	1.5	1.50	7	1	3
<i>Schinus molle</i> L.	15	23	20	19.3	4.0	1.92	12	2	2
<i>Lantana strigocamara</i> R.W.Sanders	22	17	20	19.7	2.5	1.56	14	2	3
<i>Araujia sericifera</i> Brot.	19	20	21	20.0	1.0	2.25	4	2	2
<i>Oxalis pes-caprae</i> L.	20	19	21	20.0	1.0	2.33	9	3	3
<i>Pinus radiata</i> D.Don	18	20	22	20.0	2.0	2.35	18	3	2
<i>Lolium perenne</i> L.	19	23	20	20.7	2.1	2.10	10	2	2
<i>Genista monspessulana</i> (L.) L.A.S.Johnson	22	23	18	21.0	2.6	2.53	19	3	3
<i>Mimosa pigra</i> L.	17	25	22	21.3	4.0	1.00	5	1	0
<i>Zantedeschia aethiopica</i> (L.) Spreng.	13	26	26	21.7	7.5	2.43	14	3	3
<i>Ailanthus altissima</i> (Mill.) Swingle	17	22	27	22.0	5.0	2.11	9	2	3
<i>Asparagus asparagoides</i> (L.) Druce	21	23	23	22.3	1.2	2.56	17	3	3
<i>Pittosporum undulatum</i> Vent.	19	24	24	22.3	2.9	2.16	17	2	2
<i>Cytisus scoparius</i> (L.) Link	23	23	22	22.7	0.6	2.48	18	3	3
<i>Echium plantagineum</i> L.	20	23	25	22.7	2.5	2.31	18	3	3
<i>Ligustrum lucidum</i> W.T.Aiton	20	25	24	23.0	2.6	2.67	10	3	3
<i>Ulex europaeus</i> L.	23	23	23	23.0	0.0	2.53	17	3	3
<i>Olea europaea</i> L.	18	27	25	23.3	4.7	1.83	12	2	3
<i>Acacia karroo</i> Hayne	25	21	27	24.3	3.1	1.67	3	2	3
<i>Rubus fruticosus</i> auct. aggr.	23	28	26	25.7	2.5	2.84	17	3	3
<i>Cortaderia selloana</i> (Schult. & Schult. f.) Asch. & Graebn.	23	25	30	26.0	3.6	2.38	15	3	3

weediness. However, there was considerable spread in the data, as evidenced in the regression of Average BG Score versus Average Survey Ranking (Figure 1). The Survey and Literature Weediness categorisations were significantly linearly correlated, but not identical and hence it was appropriate to use both in assessing the WRAP.

Analyses of variance of Average BG Score against both categorisations were highly significant ($P < 0.000$) with weediness levels being significantly different for both categorisation types, except for medium and high weeds for the Survey Weediness Categorisation (Table 3).

ROC curves

Figure 2 shows receiver operator characteristic curves for the Survey and Literature Weediness Categorisations, indicating discriminatory power between (medium and high risk weeds) versus (non-weeds and low risk weeds). Figure 3 repeats this for discriminating between high and medium risk weeds. Table 4 lists the overall performance of these curves and the percentage of correct classifications for particular cut-off scores.

Discussion

Testing of the WRAP has shown that it is a relatively simple yet sufficiently robust weed risk assessment model to inform decision-making on which plant taxa should be included or excluded from cultivation in botanic gardens. Whilst there was some variability, the reasons of which will be discussed below, overall the WRAP gave statistically significant separation between independently-derived weediness categorisations. Discriminatory power between (non-weeds and low risk weeds) and (medium and high risk weeds) was particularly good, with a mean area under the ROC curve of 89.5% comparing favourably to Australia's border WRA system with an area of 89% (Caley and Kuhnert 2006). The poorer discriminatory power between medium and high risk weeds (mean area under the ROC curve of 74%) was not surprising, given both a smaller dataset for this comparison, likely greater subjectivity in the national survey for distinguishing these two categories, and high impact environmental weeds generally being under-represented in noxious weed lists (Groves *et al.* 2005) for the survey categorisation.

Cut-offs

From a botanic gardens perspective, cut-offs need to maximise accuracy for non-weed and low weed risk taxa so that species selection is not unnecessarily constrained. From a weed management perspective, cut-offs need to maximise accuracy for high weed risk taxa as such species pose the greatest long-term costs to Australia's primary industries, natural

Table 2. Pearson's correlation coefficient between the botanic gardens assessment scoring and measures of weediness. All coefficients significant ($P < 0.000$).

	Average BG Score	Average Survey Rank	Survey Weediness Categorisation
Average Survey Rank	0.761		
Survey Weediness Categorisation	0.727	0.956	
Literature Weediness Categorisation	0.743	0.750	0.733

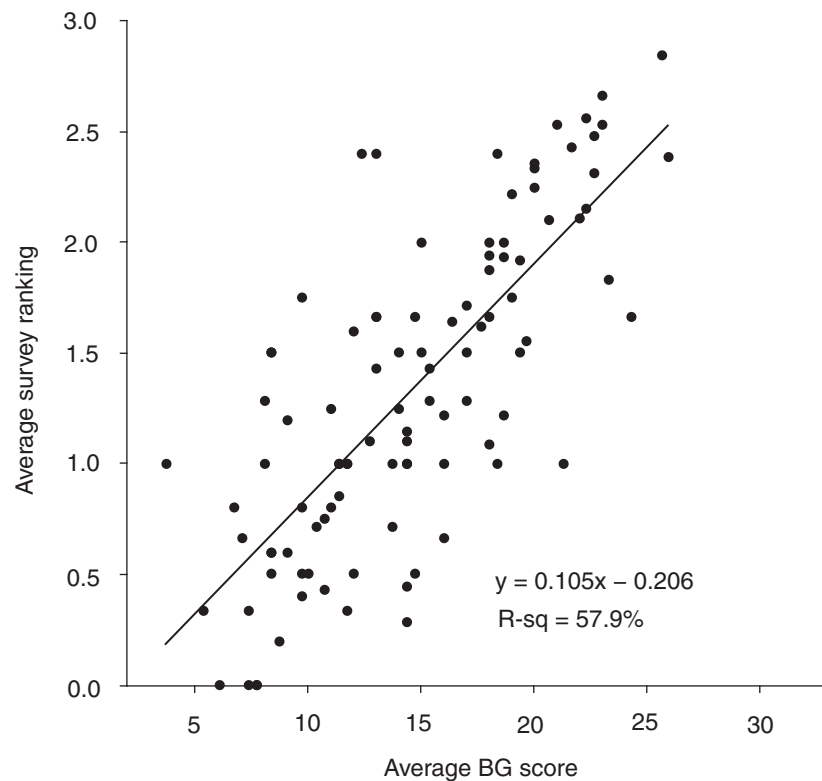


Figure 1. Relationship between Average BG Score and Average Survey Ranking.

Table 3. Average BG Scores for Survey and Literature Weediness Categorisations. Different letters indicate significant differences ($P < 0.05$).

Weediness Categorisation	Average BG Score			
	Survey		Literature	
	mean	n	mean	n
0 (non)	10.0 a	25	10.1 w	26
1 (low)	13.1 b	36	12.9 x	32
2 (medium)	17.9 c	25	16.3 y	14
3 (high)	20.8 c	14	20.0 z	28

environment and communities through their impacts and control. The suggested cut-offs for the WRAP are as follows:

- Low weed risk = 2 to 15
- Medium weed risk = 16 to 18
- High weed risk = 19+

This takes account of the differences in performance between the Survey and Literature Weediness Categorisations. A lower cut-off of >15 gives the probability of correct classification of both (non-weeds and low risk weeds) and (medium and high risk weeds) at around 80%

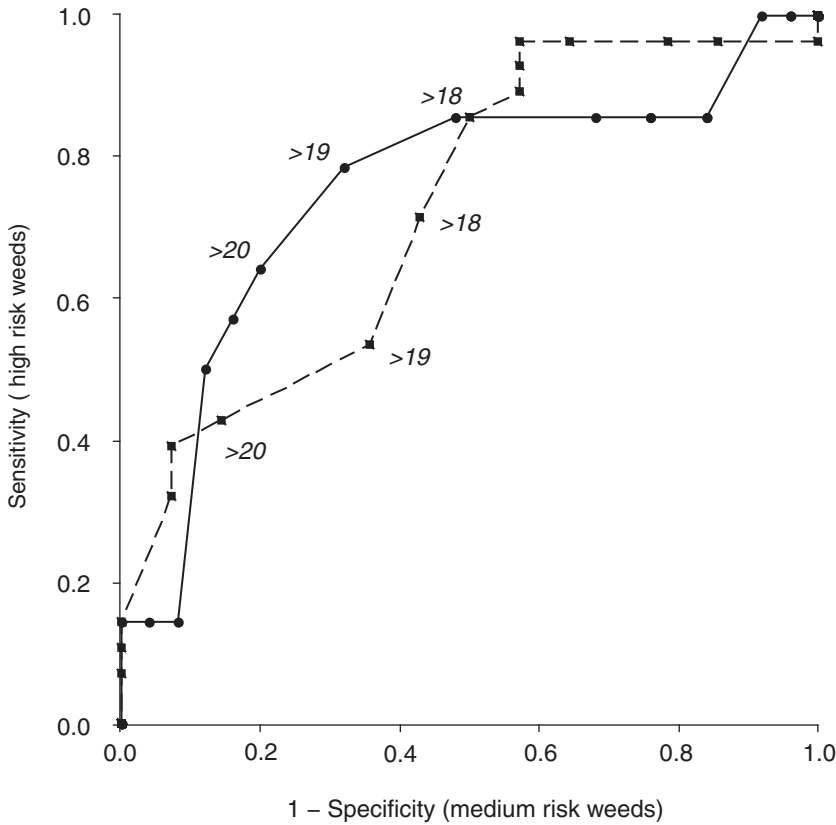


Figure 3. ROC curves for the Survey (solid line) and Literature (broken line) Weediness Categorisations, indicating discriminatory power between high and medium risk weeds. Points where WRAP cut-off scores of >18, >19 and >20 occur are shown.

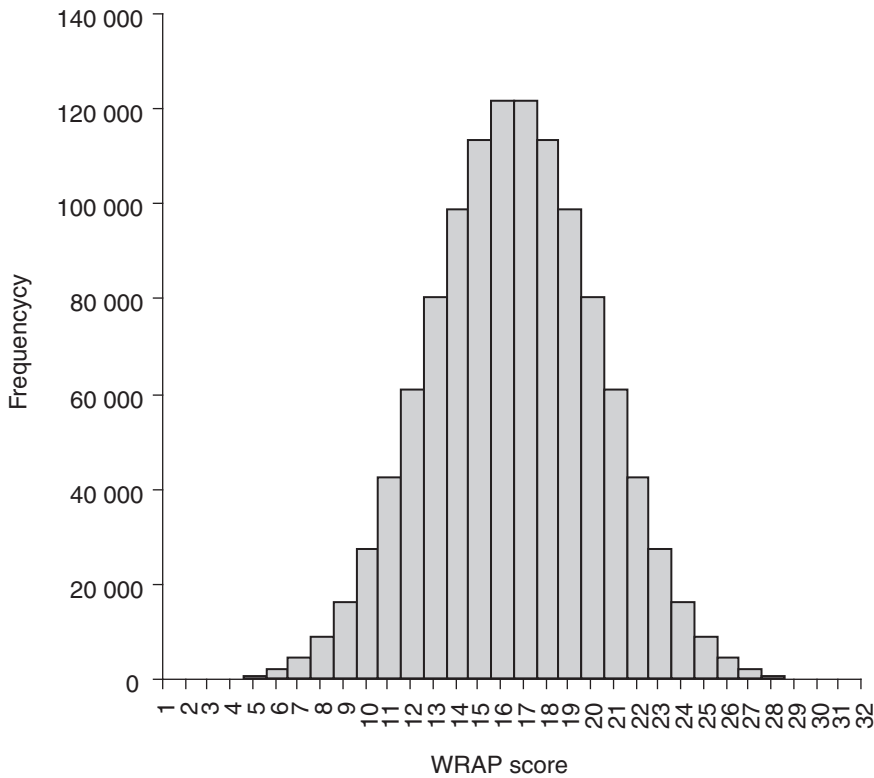


Figure 4. Frequency distribution of all possible scoring combinations within the WRAP.

are entirely new to cultivation in Australia (but legally present as germplasm in the country) should go through this system anyhow, as they are effectively at the same introduction stage as a new species proposed for import.

Variation in scoring could also be due to environmental differences, particularly climatic, between the botanic gardens. This would be expected to influence plant performance and current weed status, and hence WRAP scoring. It also appears that botanic gardens varied in their assessments of some tropical taxa (e.g. *Tipuana tipu*, *Crypostegia grandiflora*), with some scoring impacts higher than what would be realised in the temperate climates in which the test gardens occur. Botanic gardens need to have ready access to knowledge and information on particular taxa and assess for their bioregion (rather than state or national scale) to ensure that scoring is sufficiently robust. Another source of variability in responses might be regional differences in cultivated varieties (cultivars) and differences in invasive ability among cultivars of some species. When assessing a species all cultivars should be considered equally invasive. However, if an assessor is only familiar with less invasive cultivars, the results may be biased. Assessors should clearly identify, when known, what cultivated varieties are used and/or assessed in their regions.

Interpretation of individual questions would have been a source of variation amongst the botanic gardens. However, help notes for the WRAP (Appendix 1) were available during the testing to reduce uncertainties relating to language and comprehension.

Both sources of weediness classification for the independent dataset had limits. A total of 17 respondents was low for the national survey. However this was sufficient to give a robust categorisation of weediness for well-known species, such as noxious weeds and commercial crops. For lesser known species there were understandably fewer respondents and hence the categorisation was more tenuous, in which case the literature weediness categorisation provided greater certainty. However, literature may have been missed which could have caused a taxon to be classified differently, such as recent naturalisation or development of control techniques.

Application of the WRAP

The WRAP meets the criteria of being a relatively simple, rapid, transparent, robust and nationally applicable tool for use by botanic gardens in selecting and managing their living collections. A database based on the WRAP has been developed and puts the assessment system into a wider risk management context (Spencer 2006). This will enable all Australian

botanic gardens to conduct and share assessments. The scoring system is Stage 2 of a three-stage process (Appendix 1). Stage 1 requires correct taxonomic identification and categorises species that have previously been assessed as high risk by a previous WRAP or government declaration. Stage 3 is a decision matrix based on weed risk and stage of introduction, which gives management options on a taxon basis. A general principle that has been established is that species that rank as high weed risk anywhere in Australia should not be grown in any Australian botanic garden.

Most botanic gardens have staff with high levels of botanical and horticultural training. Some of these staff may be assigned to conservation responsibilities and could undertake the assessments as part of their job responsibilities. Other gardens, however, may lack sufficient personnel to make such job reassignments. Depending on expertise and whether information about the species is abundant, an assessment may take a few minutes to several hours. If a species is new to cultivation, completing the WRAP with more than educated guesses may be very difficult.

Information sharing is critical to overcoming some of these difficulties. Staff in another garden in Australia, or even elsewhere in the world, may have extensive experience with the species. With the increasing connectedness of the world over the internet, even in countries with emerging economies, communication should be facilitated. Botanic gardens should establish a list server or other communication methods should be developed and worldwide participation from garden staff and other horticulturists should be encouraged. While such personal experience lacks the assurance of other information sources such as scientific analysis, it may be all that is possible for some species.

Unlike commercial enterprises that also introduce new species, botanic gardens do not need a quick return on investment. Despite the temptation to display a new species with unknown invasive ability, there is no similar degree of urgency. Botanic gardens can test the species in nurseries and non-display areas until staff are comfortable working through the WRAP based on personal observations.

The WRAP contains core elements of Australasia's post-border weed risk management protocol (Anon. 2006). However it is not a replacement for either the border WRA system that regulates what enters Australia (and Western Australia), nor State-based systems to prioritise weed control programs, which require more complex analyses. Its performance for tropical Australia remains as yet untested, but nonetheless it shows considerable promise for wide use. Agreement has been reached to apply the system to both

Australian botanic gardens and zoos. There is also considerable scope to expand its usage to Australia's nursery and garden industry, which has been calling for a nationally agreed and scientifically-based weed risk assessment process (Nursery and Garden Industry Australia 2006). The long-term outcome for Australia should be a significant reduction in the number of new, medium and high weed risk species.

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APPENDIX 1. Botanic Gardens Weed Risk Management.

STAGE 1 – DETERMINE SPECIES IDENTITY

Using published sources, government and university experts, herbaria, and other sources, be absolutely certain that you know what species you are assessing. If that species is prohibited from import into Australia, already considered noxious within Australia, formally categorized by governments as high risk potential environmental weeds, and/or previously assessed by any Australian Botanic Garden as high risk, the species is automatically

considered high risk. There is no need for further assessment in Stage 2.

STAGE 2 – SCORE WEED RISK POTENTIAL

Score the following questions in the database to obtain an overall assessment of the plant's weed risk potential for your region. The questions are best answered by a group of staff with horticultural and weed knowledge if possible, citing any references, persons, or sources of significant information used to assess the plant. Con-

sider the help notes below when responding to these questions. The questions can be answered for how the plant behaves in the garden, and/or how it behaves as a weed. Assess it for its likely behaviour in your region (i.e. taking account of climate and soil constraints).

Plants that are sterile (i.e. cannot set viable seed) and have no vegetative spread default to negligible weed risk. Such plants would not be expected to naturalise and become weeds.

IMPACTS

1. WEED HISTORY – What is the weed history of the plant? (☑)	Score:
<input type="checkbox"/> It is a weed in your region.	4
<input type="checkbox"/> It is a weed elsewhere in Australia.	3
<input type="checkbox"/> It is a weed overseas.	2
<input type="checkbox"/> It is not known to be weedy, but other forms of the plant and/or plants in the same genus are weeds in Australia and/or overseas.	1
<input type="checkbox"/> The genus is not known to be weedy.	0
2. COMPETITION – How well does the plant outcompete other types of plants? (☑)	Score:
<input type="checkbox"/> If not controlled it can grow to dominate the following <u>three</u> size classes of plants: <input type="checkbox"/> trees (or emergent aquatics) <input type="checkbox"/> shrubs (or surface aquatics) <input type="checkbox"/> groundcovers (or submerged aquatics)	4
<input type="checkbox"/> If not controlled, it can grow to dominate <u>one</u> of the above size classes of plants. OR at certain times of the year it can dominate <u>two</u> size classes.	2
<input type="checkbox"/> If not controlled, it can dominate <u>one</u> of the above size classes at certain times of the year.	1
<input type="checkbox"/> It is not competitive, and is readily dominated by most other plants if they are not controlled.	0
3. HEALTH – Is the plant a health risk to people and/or animals? (☑)	Score:
<input type="checkbox"/> Is it highly toxic and has caused deaths.	3
<input type="checkbox"/> It can cause significant physical injuries or illness.	2

9. NATURAL SPREAD – Are the plant’s propagules (seed or vegetative) likely to spread long distances to susceptible habitats by natural means? (☑)	Score:
<input type="checkbox"/> Propagules are likely to be dispersed by <u>two or more</u> of the following: <input type="checkbox"/> <i>flying animals</i> <input type="checkbox"/> <i>ground animals</i> <input type="checkbox"/> <i>water</i> <input type="checkbox"/> <i>wind</i> AND susceptible habitats (e.g., farmland, native vegetation, road and rail corridors, waterways) are within 1 km of the gardens	4
<input type="checkbox"/> Propagules are likely to be dispersed by <u>two or more</u> of the above means AND susceptible habitats are within 5 km of the gardens, OR , Propagules are likely to be dispersed by <u>one</u> of the above means AND susceptible habitats are within 1 km of the gardens.	3
<input type="checkbox"/> Propagules are likely to be dispersed by <u>one</u> of the above means AND susceptible habitats are within 5 km of the gardens.	2
<input type="checkbox"/> Propagules are not normally spread long distances from parent plants BUT the Botanic Garden abuts susceptible habitats.	1
<input type="checkbox"/> Propagules are not normally spread long distances from parent plants and the Botanic Garden is buffered from susceptible habitats by urban development.	0
10. HUMAN SPREAD – Are the plant’s propagules (seed or vegetative) likely to spread long distances due to human activities? (☑)	Score:
<input type="checkbox"/> The plant is appealing and easily to propagate. Visitors to the gardens may intentionally take propagules (e.g., seeds, cuttings, fruit etc.) to grow elsewhere.	3
<input type="checkbox"/> Propagules are likely (or known) to be dispersed by <u>two or more</u> of the following means: <input type="checkbox"/> <i>people (accidentally)</i> <input type="checkbox"/> <i>vehicles/machinery</i> <input type="checkbox"/> <i>contaminated produce</i> <input type="checkbox"/> <i>in soil</i>	2
<input type="checkbox"/> Propagules are likely (or known) to be dispersed by <u>one</u> of the above means.	1
<input type="checkbox"/> Propagules are not normally spread long distances from a parent plant.	0

Consideration should also be given independently to the question of potential introgression of plants (breeding) with the local flora.

HELP NOTES TO BE READ IN CONJUNCTION WITH THE QUESTIONS

IMPACTS

Question 1 – Weed history

The best predictor of weediness is if a plant has been a weed elsewhere. Similarly if its close relatives are weeds then its weed risk is greater. A weed is defined as a self-reproducing, undesirable plant of agriculture, bushland, waterways, forestry or gardens. Include weeds that have been eradicated in the past. ‘Forms’ includes cultivars and infraspecific taxa. ‘Your region’ requires definition for the area under consideration of each user. Check sources for weed lists to determine if a species has been described as a weed or invasive (hence requiring control to limit the species’ negative impacts), rather than simply naturalised.

Question 2 – Competition

A major impact of weeds is their competitiveness against other desirable plants. This competition may be by depriving the other plants of light, moisture and/or nutrients, or by producing toxic chemicals. Very strong competitors can dominate other types of plants (eg. garden plants, other weeds, native plants, crop and pasture

plants). ‘Dominate’ = influence the community by its size, abundance and coverage. This question looks at how dominant the plant becomes if it is not controlled (i.e. not pruned, cut, sprayed, dug, mulched, grazed or burnt). Plants which may be dominant at certain times of the year only could include deciduous species, annuals, and perennials which resprout from the roots each year. Plants may be less competitive if they are poorly suited to the climate, or are attacked by pests or diseases. Emergent aquatics have shoots that grow above the water surface. Surface aquatics have shoots/leaves that float on the water surface. Submerged aquatics have shoots which stay below the water surface. If the question cannot be answered then give a default score of 2.

Question 3 – Health

Some weeds are toxic or cause physical injuries. For example, spiny grass seeds can injure feet and eyes of animals. Pasture weeds such as Salvation Jane/Pater-son’s Curse (*Echium plantagineum* L.) cause chronic liver damage in livestock.

Question 4 – Movement

Some weeds cause problems because they block the physical movement of people, animals, vehicles and/or water. This may

be due to a plant having spiny foliage or fruits, forming tall, dense thickets, or tangled foliage. Some weeds can slow movement of people gardening or bushwalking. Weeds can prevent access of farm and native animals to food, water and shelter. Weeds may puncture car tyres, prevent boating access, and obstruct farm machinery. Weeds can interfere with water flow in irrigation canals, creeks and rivers.

Question 5 – Environmental effects

‘Transformer’ weeds can cause substantial environmental changes. Plants that accumulate flammable leaf litter (eg. grasses, pines) can change the normal fire regime in bushland. Plants that increase soil nitrogen (eg. legumes) can leave bushland prone to invasion from exotic weeds. Plants with salty leaf litter (eg. salt cedar) can increase salinity of the surface soil, so that the original plants die out. Plants can provide habitat for feral animals that are pests (eg. blackberry sheltering rabbits). Some species are capable of high levels of water uptake, even when surface water is limited, to the detriment of native plants. Plants that are less palatable to native animals may have an impact even when not visually dominant because they decrease the animal population size that can be sustained. This may then lead to a

decrease in other native animals that prey on them.

Question 6 – Ease of kill

Weeds that are hard to kill are more expensive for landholders to control. Consider how easy it is to remove a plant from the garden, or where it is a weed, before it dies naturally.

POTENTIAL DISTRIBUTION

Question 7 – Hardiness in local conditions

A plant is more likely to naturalise in similar climates to where it grows elsewhere in the world. Maintenance includes watering, fertilising, pest and disease control, frost protection, wind protection and mulching. Special conditions include pots, shadehouses, and raised beds.

INVASIVENESS

Question 8 – Reproduction

Invasive plants often have a quick time to reproduction, seed which germinates

readily and vegetative spread. New plants produced by vegetative means are defined as shoots with their own root system. There may still be some connection to the parent plant. Vegetative reproduction includes bulbs, bulbils, corms, tubers, rhizomes, stolons, root suckers, root fragments and shoot fragments.

Question 9 – Spread of propagules

Consider long distance dispersal as greater than 100 m. The more means of long distance dispersal then the faster a plant is likely to spread. Propagules include seed, spores, bulbs, bulbils, corms, tubers, rhizomes, stolons, root fragments and shoot fragments. Flying animals include birds and bats. Ground animals include sheep, cattle, horses, dogs, foxes, rabbits, kangaroos and ants. Consider both external spread (eg. spiny burrs attaching to hairs), and internal spread (eg. seeds which pass through the gut) by animals. 'Susceptible habitats' are areas where plants are likely to naturalise, including poorly controlled

areas (rail and road transport corridors) or with an ideal niche (waterways, vacant lots, remnant bushland and farms). The closer such habitats are to a Botanic Garden the higher the probability of propagules being spread to them.

Question 10 – Human spread

Intentional spread by people is the stealing of propagules (including seeds and cuttings) from Botanic Gardens to grow plants elsewhere. Attractiveness of and accessibility to plant species will be a major influence on peoples' behaviour. Trends in garden design and uniqueness of species will also be factors to consider. People accidentally spread propagules which attach to shoes or clothing, or which are in dumped garden waste. Vehicles and machinery includes mowers, slashers, cars, trucks, boats and earth moving and farm machinery. Contaminated produce includes mulch, hay, crop seed and topsoil.

STAGE 3 – DETERMINE RISK MANAGEMENT ACTION

The following matrix recommends management actions for plant taxa based upon weed risk and stage of introduction. Factors to consider in relation to Botanic Gardens value include a need for scientific research, education, heritage, ex-situ conservation and/or landscape functionality (i.e. an important item of the collections policy).

		Stage of Introduction			
		Proposed new introduction to living collection (already in Australia as seed only)	Currently grown only in botanic gardens AND/OR specialist collections	Sold in nurseries AND/OR infrequently naturalised (but not widely grown)	Widely grown AND/OR widely naturalised
Weed Risk	Low	Grow • monitor	Grow • monitor	Grow	Grow
	Medium	Don't grow, unless strong Botanic Gardens value • contain • monitor • interpretative signage	Don't grow, unless strong Botanic Gardens value • contain • monitor • interpretative signage	Grow, provided there is a clear need for the plant within the collection • contain • monitor • interpretative signage	Grow • interpretative signage
	High	Don't grow, unless grown for research purposes (under quarantine and with the approval of the relevant State/ Territory weeds authority)	Remove, unless grown for research purposes (under quarantine and with the approval of the relevant State/ Territory weeds authority) • interpretative signage	Remove, unless strong Botanic Gardens value • interpretative signage (if on public view and retained for special reasons)	Remove, unless strong Botanic Gardens value • interpretative signage if on public view and retained for special reasons