A weed risk assessment model for use as a biosecurity tool evaluating plant introductions

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New plant taxa from around the world continue to be imported into Australia and New Zealand. Many of these taxa have the potential to become agricultural or environmental weeds and this risk needs to be assessed before allowing their entry. A weed risk assessment system is described that uses information on a taxon's current weed status in other parts of the world, climate and environmental preferences, and biological attributes. The system is designed to be operated by quarantine personnel via a user-friendly computer interface.

The model was tested against experts' scores for weediness for 370 taxa present in Australia, representing both weeds and useful taxa from agriculture, the environment, and other sectors. The model was judged on its ability to correctly 'reject' weeds, 'accept' non-weeds, and generate a low proportion of taxa which could not be decisively categorised, termed 'evaluate'. More than 70% of the taxa were rejected or accepted. All taxa classified as serious weeds, and most minor weeds, were rejected or required further evaluation, while only 7% of non-weeds were rejected. The model was modified to New Zealand conditions and evaluated against the opinions of several groups of experts and against economic measures. The model produced a weediness score very similar to the mean of the experts scores. The latter were highly variable: agriculturalists tended to accept known weeds, conservationists tended to reject most adventive taxa, and only botanists produced scores similar to the model. The model scores also tended to be independent of economic value as measured in this study. The model could be adapted for use as a screening tool in any region of the world.

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Introduction

Weeds have major impacts on economies and natural environments world wide, including Australia (Groves, 1986) and New Zealand (Williams and Timmins, 1990). Many of these weeds have been purposely introduced as potential new crops, ornamentals, or as novelties (Esler, 1988; Lonsdale, 1994). To counter the threat to agriculture or the environment from new plant taxa, regulatory authorities have a statutory responsibility to ensure that all plant taxa proposed to be imported, which are not already prohibited and are not already established, be evaluated for their potential to damage the productive capacity or environment of these countries. There are many approaches to predicting weed potential (reviewed by Mack, 1996), but border authorities urgently need an objective, credible, and publicly acceptable risk assessment system to predict the weediness, or invasive potential, of the thousands of potential new entries.

There have been several symposia (e.g. Drake *et al.*, 1989) and a growing research literature on invasive plant taxa, but until recently there was considerable pessimism that potentially invasive species could be identified (Crawley, 1987). However, progress has recently been made in identifying the key characteristics of potential weeds in Australia (Noble, 1988; Scott and Panetta, 1993), New Zealand (Esler *et al.*, 1993), South Africa (Richardson *et al.*, 1990), Britain (Williamson and Fitter, 1996), and north America (Mack 1996; Reichard and

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Hamilton, 1997), or within closely related groups of taxa including herbs (Forcella *et al.*, 1986; Williamson, 1993) or woody seed plants (Rejmanek and Richardson, 1996). Predictions from a non-experimental approach are most accurate if they are based on information that includes the biology of the invading species, the bioclimatic features of the recipient and source regions, and the evolutionary history of both (e.g. Richardson *et al.*, 1990). A synthesis of this information can lead to general conceptual models of plant invasiveness (Rejmanek, 1995) which in turn can be applied to screening procedures such as decision trees to categorise potential plant imports (Panetta, 1993; Tucker and Richardson, 1995; Reichard, 1996; Reichard and Hamilton, 1997). Regulatory authorities responsible for biosecurity need a tool that synthesizes much of this disparate and sometimes theoretical information. One approach is a computer based spreadsheet model producing a score for weediness, which can then be converted to an entry recommendation for a specified taxon.

An acceptable biosecurity assessment system should satisfy a number of requirements (Hazard, 1988; Panetta, 1993). It should be calibrated and validated against a large number of taxa already present in the recipient country and representing the full spectrum of taxa likely to be encountered as imports into that country. It must effectively discriminate between weeds and non-weeds, such that the majority of weeds are not accepted, non-weeds are not rejected, and the proportion of taxa requiring further evaluation is kept to a minimum. As international trade agreements require that prohibited taxa should fit the definition of a quarantine pest before they can be excluded by quarantine regulations (Anon., 1994, 1995; Walton and Parnell, 1996), the system must be based on explicit assumptions and scientific principles so that the country cannot be accused of applying unjustified non-tariff trade barriers. Ideally the system should be capable of identifying which land use system the taxon is likely to invade, to assist in an economic evaluation of its potential impacts. Finally, the system must be cost effective to the prospective importer and the border control authority.

Here, we first describe a model designed specifically for the Australian quarantine authority that satisfies many of these criteria: the Weed Risk Assessment model (WRA). We then report on a test of the applicability of a slightly altered version of the model that incorporates environmental differences between Australia and New Zealand: the New Zealand Weed Risk Assessment Model (New Zealand WRA). In testing the New Zealand WRA we examine the sources of expert bias that are inherent in the concept of weediness (Perrins *et al.*, 1992) and demonstrate that the model minimises these difficulties.

The model could be used to investigate the nature of weediness, but here we simply describe how it works and the steps we took to ensure it would function as a publicly acceptable screening tool.

Methods and results

Producing the WRA

The basis of the WRA is the answers to 49 questions (Appendix 1) based on the main attributes and impacts of weeds. These are combined into a scoring system which in the absence of any evidence to the contrary, gives an equal weight to nearly all questions (Appendix 2). These cover a range of weedy attributes in order to screen for taxa that are likely to become weeds of the environment and/or agriculture. The questions are divided into three sections producing identifiable scores that contribute to the total score (Appendix 2).

Biogeography (section A) encompasses the documented distribution, climate preferences, history of cultivation, and weediness of a plant taxon elsewhere in the world, i.e. apart from the proposed recipient country. Weediness elsewhere is a good predictor of a taxon becoming a weed in new areas with similar environmental conditions (Forcella and Wood, 1984; Panetta and Mitchell, 1991a,b). The question concerning the history of cultivation recognises the important human component of propagule pressure (Richardson *et al.*, 1994; Williamson and Fitter, 1996), but such data are obviously never available for the proposed new country. The global distribution and climate preferences, where these are available, are used to predict a potential distribution in the recipient country.

Undesirable attributes (section B) are characteristics such as toxic fruits and unpalatibility, or invasive behaviour, such as a climbing or smothering growth habit, or the ability to survive in dense shade.

Biology/ecology (section C) are the attributes that enable a taxon to reproduce, spread, and persist (Noble, 1988), such as whether the plant is wind dispersed or animal dispersed, and whether the seeds would survive passage through an animal's gut.

Availability of information is often very limited for new species which can restrain the utility of screening systems. To ensure that at least some questions were answered for each section, the WRA system requires the answers to two questions in section A, two in section B, and six in section C before it will give an evaluation and recommendation. The recommendation can be compared with the number of questions answered as an indication of its reliability, which obviously improves as more questions are answered.

Answers to the questions provide a potential total score ranging from −14 (benign taxa) to 29 (maximum weediness) for each taxon. The total score is partitioned between answers to questions considered to relate primarily to agriculture, to the environment, or common to both (Appendix 1). The total scores are converted to one of the three possible recommendations by two critical score settings. The lower critical score, 0, separates *acceptable* taxa from those requiring *evaluation*, and the higher critical score, 6, separates taxa requiring *evaluation* from those that should be *rejected*. Evaluation could mean either obtaining more data and re-running the model, or undertaking further investigations such as field trials (Mack, 1996).

To provide data for defining these score settings, six Australian scientists in a range of the fields ran the model to assess the weed potential of taxa they were familiar with, ranging from non-weedy beneficial taxa to serious weeds. In addition, all taxa that have a noxious status in Australia were assessed using the information provided by Parsons and Cuthbertson (1992). Assessors treated each taxon as if it had not yet arrived in Australia, such that serious weeds, for example, were assessed purely on their weed status outside Australia. The taxa were classified as agricultural or environmental weeds.

A benchmark against which to compare the model is problematic because there are no absolute values for weediness of individual taxa (Perrins *et al.*, 1992). However, those familiar with a taxon in a country can offer a meaningful opinion on the actual or potential weediness of the taxon in that country, against which to compare the score from the model. (The sources of bias in this procedure are examined in evaluating the New Zealand WRA.) A further 12 scientists therefore defined the weed status or usefulness of taxa they were familiar with. Taxa were given a rank of 0, 1 or 2 and this was used to classify them as non-weeds, minor weeds, and serious weeds, respectively. The mean score was used to assess the performance of the WRA model; again, potential bias is examined in testing the New Zealand WRA.

Results of the WRA

The majority of the 370 taxa (81%) are perceived as weeds in some context, but less than half are considered serious weeds. Useful taxa (63%) including both weeds (45%) and non-weeds (18%), and non-useful taxa (37%) were included in the sample. Weeds from all sectors—agriculture, environment, horticulture, garden and service areas—were well represented (data not shown).

The cumulative frequency distributions of WRA scores, for each of the survey classifications (Figure 1), were used to investigate the effect of different pairs of critical scores on the distribution of WRA recommendations. The range of scores for non-weeds overlaps the range for serious weeds, so it is impossible to define any set of critical scores that reject all serious weeds while accepting all non-weeds. However, it is possible to ensure that none of the serious weeds are accepted by setting the accept score at 0 or less. Similarly, less than 10% of non-weeds will be rejected if the reject score is greater than 6. This would mean that 29% of the taxa assessed in this study would fall between these extremes and require evaluation. Lowering the minimum reject score to 6 would reduce this proportion to 22% but increase the proportion of rejected non-weeds to 15%, which is less desirable, since some of these are regarded as useful (Figure 1). Consequently, the critical scores,
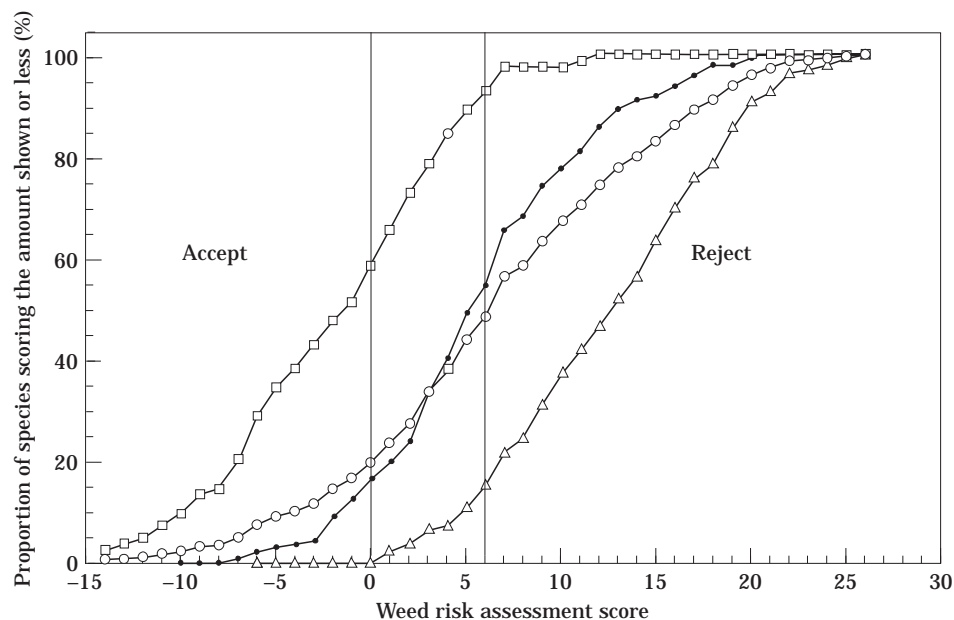
Figure 1. Cumulative frequency of taxa receiving a particular WRA score or less for each survey classification. Survey categories: (−△−), serious weeds (139); (−●−), minor weeds (147); (−□−), non-weeds (84); (−○−), all plants (370).

0 and 6, were used to convert the WRA scores into the recommendations–'accept', 'evaluate' and 'reject'. These settings recommended all serious weeds and most minor weeds (84%) be rejected or evaluated, and only 7% of non-weeds be rejected. Less than a third (29%) of all taxa required evaluation.

The experts' classifications are well correlated with WRA score (r=0·686, $P<0·01$) and with the components of the total score (Table 1). The biological/ecological attributes (reproduction, dispersal and persistence) show a significant relationship to documented behaviour of the plant elsewhere in the world (biogeography) (Table 1). Overall, the WRA model is well correlated with the expert classifications, and all components make significant contributions.

Table 1. Correlations of the internal components of the WRA score and the total score, with the mean experts classification and the biogeography component of the total score. All $P<0·01$

	Experts	Biogeography
Total score	0·686	
Biogeography	0·617	
Undesirable attributes	0·435	0·278
Biology/Ecology	0·503	0·458

Table 2. Correlations of the agriculture and environment components of the WRA score and the total WRA score, with the experts classification of taxa as weeds of agriculture or environment. All $P<0·01$

WRA score	Experts classification	
	Agriculture	Environment
Agriculture	0·583	0·414
Environment	0·441	0·509
Total score	0·533	0·520

Of the taxa classified as weeds in the survey, 31% were regarded as both environmental and agricultural weeds, 35% were environmental weeds only, and 15% were agricultural weeds only. The remaining 19% were weeds in other categories. These classification were significantly correlated with the corresponding component of the WRA score (Table 2).

Adapting the WRA to the New Zealand WRA

The questions changed to fit New Zealand conditions covered climate and soils: 'arid climates' was replaced with 'equable climates' and soils: 'infertile soils' was replaced with

'a range of soil conditions' because infertile soils are not as extensive in New Zealand. As anticipated, several questions that remained the same needed to be answered differently for Australia and New Zealand; e.g. in Australia there are many parrots which destroy seeds, and so certain new plants are more likely to have natural enemies in Australia than in New Zealand. None of the modified questions required alterations to the scoring system, so that the outcome scores were directly comparable. The outcome of these changes was the New Zealand WRA model.

Testing the New Zealand WRA

We assessed the ability of the model to identify weeds of a range of land use systems when used in a country for which it was not originally designed, in this instance New Zealand.

We also tested the New Zealand WRA—in a manner that was equally relevant to WRA—by asking whether it was better than an expert's opinion? 'Better' we define as efficacy, ease of use, and cost of use but only efficacy was tested, i.e. the capability to score correctly with respect to the benchmark, and with a low variation when used by several individuals.

We tested whether the New Zealand WRA was more biased by economic or environmental considerations than the collective opinion, as represented by an average score, of a group of experts representing a wide range of interests. This potentially large element of subjectivity was tested with a series of cross-checks on variation and bias using three data sets referred to the same taxa.

Firstly, the New Zealand WRA model was run on 198 taxa used in testing the WRA model that are also present in New Zealand (the majority of which are adventive), plus any additional noxious plants in New Zealand (Esler *et al.*, 1993). Responses to the model questions for the resulting 291 taxa were made by one of us (P.A.W) as if they were not yet in New Zealand, using the international literature, floras, and databases. The scores of −14 to 29 for each taxon were standardised from 0 to 1 for comparison with the other data sets, using the thresholds: accept $<=0.326<$ evaluate $<=0.465<$ reject.

The WRA database contains replicate scores from the six independent Australian experts. These were used to estimate the variance of the model scores, on the assumption that a similar degree of variability would be found in the scores from experts using the New Zealand WRA model.

Next, 13 New Zealand experts, 12 of whom were not involved with the model, classified many of the same 291 taxa into the categories of non-weed, minor weed, and major weed. The categories were not defined, and neither were the taxa classified as environmental or agricultural weeds as in Australia. However, respondents were asked not to consider economic value, i.e. we were interested only in their opinion as to whether taxa were weeds in any land-use system. This classification was transformed into the numbers 0, 0.5 and 1.0, respectively. The experts were classified by one of us (P.A.W.) as botanists (seven), agriculturalists (three), and conservationists (three). This classification was unknown to them, to avoid any conscious bias. This allowed an evaluation of speciality bias with respect to classification, and how it affected variation. Each expert reviewed between twenty-seven and 291 taxa, with most doing between 140 and 250 taxa. Two hundred and seventy-four taxa were classified by more than one expert.

Finally, 195 taxa for which data were available were scored for relative economic value, based on the average of three evaluations. (1) The area of the taxon cultivated from 1842 to 1991 was obtained from New Zealand statistics as processed by Halloy (1994). The logarithm of this area was standardised to a range of 0 to 1. (2) An estimate of an economic value of any type was scored as 0 to 5 by one of us (S.R.H.) then standardised 0 to 1. (3) Taxa were scored according to their presence or absence in the New Zealand Nursery Register 1995/1996, on the assumption that a listing represents value as an ornamental but not as a major economic plant. Scores were 1 if the taxon was present, 0.5 if only the genus was present but with probability of the taxon being present, 0 if the genus was absent. This value was standardised 0 to 0.2.

The data were divided into five classes, and the taxon score outcomes for New Zealand WRA and the experts were compared within each class. Whether the experts accept (+) or reject (−) more taxa than the New Zealand

WRA within each economic class is expressed as percentages.

Lastly, the total scores for the WRA and New Zealand WRA models derived in the two countries were compared for the 198 taxa common to both.

Results of testing the New Zealand WRA

The combined scores and their variability show a strong similarity between the scores from the New Zealand WRA model (0·538) and the mean scores for the 13 experts (0·545), and for the deviations, and the distributions (Table 3). When converted to outcomes the results are again very similar. That the higher proportion of taxa rejected by both the New Zealand WRA model and the experts score (mean 62·0%) is higher than might be expected from a random selection of taxa partly reflects the addition of all the noxious weeds of New Zealand to the database.

Replicate answers to the New Zealand WRA model are less variable (CV 8·2%) than the mean expert scores (CV 58·7%) (Table 3). The high variation in taxon scores is explained by the variability among the individual respondents, even within expert groups. Agriculturalists gave the lowest scores for weediness (0·438), conservationists the highest (0·673). Conservationists' scores were also less variable than those of the other groups (19·5% cf. 31·3% and 33·8%). The outcome is that conservationists tend to reject most taxa while agronomists accept a higher proportion. The 5–6% of taxa in the

'evaluate' category of the three expert groups, as against 21% for the model, shows that all expert groups have a tendency to either accept or reject a larger proportion of taxa than the model (Table 3).

There are differences in recommendations between the New Zealand WRA model and the average experts' evaluation (Figure 2). Sixty-four percent of taxa did not change, and overall 93% of taxa either rejected by the model or requiring evaluation were also not accepted by the experts. Only 4% of taxa that were accepted by the model were rejected by the expert averages. Two differences between the New Zealand WRA outcomes and the expert outcomes (Figure 2) require examination.

(1) A greater permissiveness in the model as compared with the experts could allow introduction of weeds if the model alone were used as a screening tool. Eight percent of taxa were accepted by the model but classed as 'reject' or 'evaluate' by the expert averages. Taxa accepted by the model but rejected by experts include: *Chasmanthe floribunda* (Salisb.) N. E. Brown, *Echium candicans* L., *Eragrostis tef* Trott and *Scabiosa atropurpurea* L. Taxa rated as 'evaluate' include *Betula pendula* Roth, *Festuca rubra* L., *Gliricidia sepium* (Jacq.) Walp and *Lathyrus ochrus* L. These taxa have several features in common. They received a low number of responses (two or three), their expert score variation was high (data not presented), and most had model scores on or near the thresholds. It is significant that no taxon with an average expert score of major weed was accepted by

Table 3. Comparisons of scores from NZWRA and the expert groups: (a) the average of all taxa scored and the variation; (b) the average level of variability of scores for individual taxa from NZWRA and the experts for taxa with two or more scores; (c) the outcomes for all taxa expressed as a rounded percentage

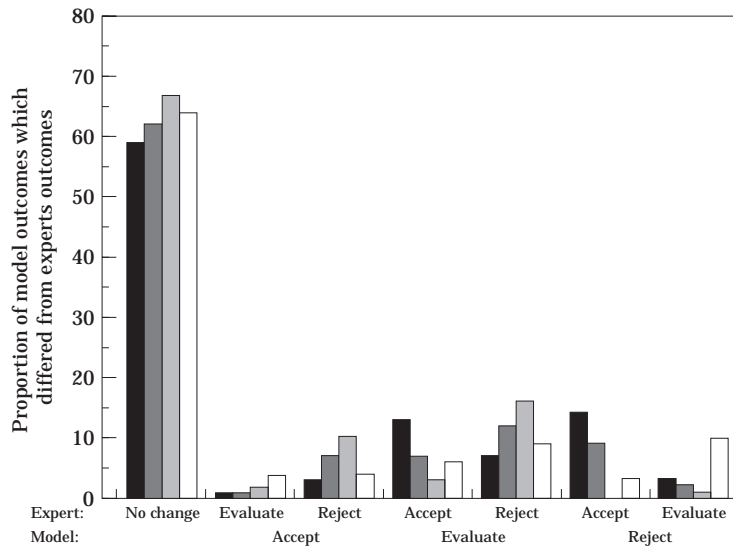|	NZ Model	Mean expert	Botanists	Agriculturalists	Conservationists
(a) **All taxa scores**					
N	291	291	288	251	291
Mean	0·538	0·545	0·520	0·438	0·673
SD taxa score	0·204	0·238	0·307	0·311	0·258
(b) **Individual taxa**					
N	291	291	208	181	224
Mean SD of score	0·041	0·231	0·115	0·099	0·087
CV % of score	8·2	58·7	31·3	33·8	19·5
(c) **All taxa outcomes**					
Accept	16	17	25	35	7
Evaluate	21	20	5	6	4
Reject	63	63	70	59	89

Figure 2. A comparison of the outcomes from the NZWRA model vs. the outcomes from the expert groups, expressed as a percentage of the total outcomes for each group. ■, agriculturalists (251); ■, botanists (288); ▨, conservationists (291); □, all (291).

the New Zealand WRA model, nor any taxon rated as a noxious plant in New Zealand.

(2) A greater severity of assessment by the model than by the experts could result in benign taxa being rejected. The model was more cautious than the experts in 19% of instances (56 taxa). Eight taxa rejected by the New Zealand WRA but accepted by the expert average included *Acer negundo* L., *Wedelia trilobata* (L.) Hitchc. and *Ailanthus altissima* (Miller) Swingle, species that are weeds in other parts of the world. The expert average scored 'evaluate' for another 30 taxa rejected by the model, including *Trifolium pratense* L., *Citrullus lanatus* (Thunb.) Matsum. et Nakai, and *Lolium perenne* L. The last-named taxon is the mainstay of New Zealand pastoral farming. Another 18 taxa rated as 'evaluate' by the model but accepted by the expert average included such agricultural crops as *Helianthus annuus* L., *Solanum tuberosum* L. and *Zea mays* L.

The outcomes for the individual expert groups reflect the overall differences shown in Figure 2. For example, 14% of taxa rejected by the model were accepted by the agriculturalists, e.g. *Lupinus polyphyllus* Lindley and *Pinus contorta* Loudon, whereas none of these were accepted by the conservationists (Figure 2). For all these taxa, comments as in (1) apply, i.e. the model provides a more consistent answer which would not be unexpected by the experts themselves were they able to ignore economic value.

Scoring by the model and by the experts varied according to the economic value of the taxon (Figure 3). The mean expert score showed very little bias, with only a slight tendency to accept more taxa (16·7%) of intermediate economic value (<0·4) than the New Zealand WRA model. Individual expert groups, by contrast, showed distinct and contrasting patterns. Botanists (N=7) tended to accept more of the non-valuable taxa (value 0, 11·2%) and reject more of the higher-value taxa (value <6·6, 41·75%, and value <0·8, 33·3%). Agriculturalists (N=3) accepted more taxa of all economic classes and especially those of the highest economic class (value <0·8, 66·7%). Conservationists (N=3) showed no clear trend, and were just as likely to reject a taxon of low economic value as one of high value. The high variability of this data and the small sample size require caution in interpretation. However, on an individual basis, economic value sometimes created a subjective bias towards acceptance.

The scores for taxa common to both the WRA and New Zealand WRA tests were higher in the latter model by an average of 1·60, with a standard deviation of 2·98. However, only 12 taxa (6%) were changed sufficiently to alter their recommendation status. In most instances the recommendation was changed from 'evaluate' to 'reject', and in one from 'accept' to 'evaluate'.
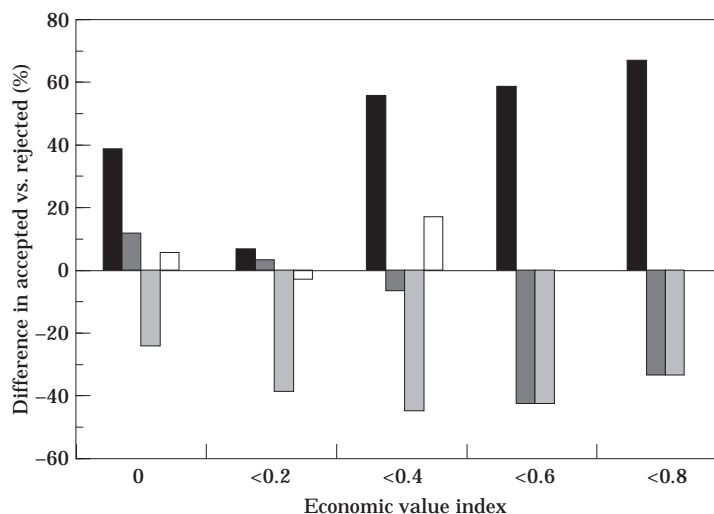
Figure 3. Differences between outcomes from the NZWRA and experts within each economic class. Positive values show experts accepted more taxa than the model and negative values the opposite. ■, agriculturalists; ■, botanists; ■, conservationists; □, all.

Discussion and conclusions

The small differences between WRA and New Zealand WRA models were brought about largely by an improved taxon database, such as evidence of a taxon's weediness in other countries, rather than as an outcome of the slightly different questions in the two models. These behaved the same for most taxa, and the different tests applied to both models can be regarded as applying to both. The small differences also illustrate the overriding importance of biogeography and history of weediness as predictors of weediness for both herbs (Forcella and Wood, 1984) and woody plants (Reichard and Hamilton, 1997).

The model identifies a wide range of weeds, and does not accept taxa known to be major weeds in Australia or New Zealand. The few minor weeds accepted lie very close to the critical scores, and as these scores are not inviolate they may be adjusted in time as experience is gained. Indeed, allowing the critical scores to be moved under different circumstances—including the general attitudes towards weeds in different countries—represents a strength of the model. By splitting the total score, the model also allows an estimate of whether the weed is more likely to impact on agricultural or natural environment systems, which may assist regulatory authorities in making a recommendation. These features suggest that the model could be altered and still be expected

to produce satisfactory results in other bioclimatic regions of the globe where protocols are lacking (Ruesink *et al.*, 1995). However, expert systems designed for particular biomes (Tucker and Richardson, 1995) are still likely to be more accurate in their predictions of weediness, because successful invaders are strongly habitat dependent (Thompson *et al.*, 1995).

The benchmark used to evaluate models, the opinions of 12 experts in Australia and 13 in New Zealand, appears satisfactory. It covered a wide range of opinions yet produced average scores similar to the model's. All components of the model contribute significantly to this score. The scores were also similar to those derived using the simpler systems of Hazard (1988) and Panetta (1993), but was superior to these in rejecting fewer non-weeds and giving a definitive 'reject' or 'accept' outcome in a greater proportion of instances (Pheloung, 1996). As the system is simple and spread-sheet based it can be used by lay people who wish to import plants and it has an educational role because it shows the effect of individual questions on the total score.

The model is much less variable than expert opinion and it enforces objectivity. Provided the attribute information can be obtained, then using the model would be more cost effective than seeking the opinions of a similar number of experts. In some parts of the world, both the attribute data and the

availability of experts may be limiting, but any smaller number of experts—especially if they were from one interest group—would be likely to give a biased answer with respect to a particular sector (Perrins *et al.*, 1992).

The bias displayed by different groups of experts differs between the two countries for which we have information. Conservationists in Britain, for example, are less inclined than the average to consider a taxon to be a weed (Perrins *et al.*, 1992; Williamson, 1993), presumably because many weeds have redeeming features such as colourful flowers. In contrast, New Zealand conservationists are inclined to consider such taxa as weeds. Those with botanical training distinguish clearly between the native and alien floras, often to the exclusion of the latter in the compilation and collection of botanical data (Raven and Engelhorn, 1971). The interplay between these two floras is a major issue on oceanic islands (Simberloff, 1995) such as New Zealand, and all alien taxa are considered weeds to the extent that they are perceived to impact on native ecosystems, irrespective of any redeeming features (Williams and Timmins, 1990). The situation could well be different, yet unpredictable, in other countries. In Argentina and Chile for example, some wild adventive taxa have an economic value because of their potential to provide food for poor people (E. Rapoport, personal communication to P.A.W.), and there is less inclination to consider them to be weeds. In contrast to these differing judgments, the model would be less influenced by the economic value of a taxon than any group of experts.

The model distinguishes between many useful and non-useful taxa, but some useful taxa are rejected. This is to be expected, because planned introductions are chosen for their ability to survive (Ruesink *et al.*, 1995), and the questions asked by the model are based primarily on biological and ecological criteria which identify attributes common to both useful agricultural taxa and weeds (Lonsdale, 1994). These may differ only in a small number of characteristics within any single life form (Perrins *et al.*, 1992). Any model designed to screen primarily for invasive weeds must reject taxa that are useful yet invasive, e.g. in the New

Zealand context *Agrostis stolonifera* L., *Lupinus polyphyllus* and *Pinus contorta*. Where a taxon may have significant economic benefits, a further evaluation of its weediness potential may include experimental studies (Williamson, 1993; Scott and Panetta, 1993). Economic value should be scored in a transparently separate exercise and balanced against weediness in appropriate risk assessment evaluations (Walton and Parnell, 1996).

We conclude that the weed risk assessment model with explicit scoring of biological, ecological, and geographical attributes is a useful biosecurity tool for detecting potentially invasive weeds in many areas of the world.

Acknowledgement

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Appendix 1

Questions forming the basis of the Weed Risk Assessment model (WRA)

Weed Risk Assessment system question sheet: Answer yes (y) or no (n), or don't know (leave blank), unless otherwise indicated

Botanical name:	Outcome:
Common name:	Score:
Family name	Your name:

History/Biogeography				
A	**1**	*Domestication/ cultivation*	1.01 Is the species highly domesticated? If answer is 'no' got to question 2.01	
C			1.02 Has the species become naturalised where grown?	
C			1.03 Does the species have weedy races?	
	2	*Climate and*	2.01 Species suited to Australian climates (0–low; 1–intermediate; 2–high)	2
		Distribution	2.02 Quality of climate match data (0–low; 1 intermediate; 2–high)	2
C			2.03 Broad climate suitability (environmental versatility)	
C			2.04 Native or naturalised in regions with extended dry periods	
			2.05 Does the species have a history of repeated introductions outside its natural range?	
C	**3**	*Weed*	3.01 Naturalised beyond native range	
E		*elsewhere*	3.02 Garden/amenity/disturbance weed	
A			3.03 Weed of agriculture/horticulture/forestry	
E			3.04 Environmental weed	
			3.05 Congeneric weed	
Biology/Ecology				
A	**4**	*Undesirable*	4.01 Produces spines, thorns or burrs	
C		*traits*	4.02 Allelopathic	
C			4.03 Parasitic	
A			4.04 Unpalatable to grazing animals	
C			4.05 Toxic to animals	
C			4.06 Host for recognised pests and pathogens	
C			4.07 Causes allergies or is otherwise toxic to humans	
E			4.08 Creates a fire hazard in natural ecosystems	
E			4.09 Is a shade tolerant plant at some stage of its life cycle	
E			4.10 Grows on infertile soils	
E			4.11 Climbing or smothering growth habit	
E			4.12 Forms dense thickets	
E	**5**	*Plant type*	5.01 Aquatic	
C			5.02 Grass	
E			5.03 Nitrogen fixing woody plant	
C			5.04 Geophyte	

C	**6**	*Reproduction*	6.01	Evidence of substantial reproductive failure in native habitat	
C			6.02	Produces viable seed.	
C			6.03	Hybridises naturally	
C			6.04	Self-fertilisation	
C			6.05	Requires specialist pollinators	
C			6.06	Reproduction by vegetative propagation	
C			6.07	Minimum generative time (years)	1
A	**7**	*Dispersal*	7.01	Propagules likely to be dispersed unintentionally	
C		*mechanisms*	7.02	Propagules dispersed intentionally by people	
A			7.03	Propagules likely to disperse as a produce contaminant	
C			7.04	Propagules adapted to wind dispersal	
E			7.05	Propagules buoyant	
E			7.06	Propagules bird dispersed	
C			7.07	Propagules dispersed by other animals (externally)	
C			7.08	Propagules dispersed by other animals (internally)	
C	**8**	*Persistence*	8.01	Prolific seed production	
A		*attributes*	8.02	Evidence that a persistent propagule bank is formed (>1 yr)	
A			8.03	Well controlled by herbicides	
C			8.04	Tolerates or benefits from mutilation, cultivation or fire	
E			8.05	Effective natural enemies present in Australia	

A = agricultural, E = environmental, C = combined.

Appendix 2

Weed risk assessment scoring sheet for the WRA.

Form B. Weed Risk Assessment Scoring Sheet

	a	b	c	d	e
Section	Question	Response¹	Score²	N score	Y score
A C	1.01			0	-3
C	1.02			-1	1
C	1.03			-1	1
	2.01				
	2.02				
C	2.03				
C	2.04				
	2.05				
C	3.01				
N	3.02				
A	3.03				
E	3.04				
C	3.05				
B C	4.01			0	1
C	4.02			0	1
C	4.03			0	1
A	4.04			-1	1
C	4.05			0	1
C	4.06			0	1
N	4.07			0	1
E	4.08			0	1
E	4.09			0	1
E	4.10			0	1
E	4.11			0	1
C	4.12			0	1
C E	5.01			0	5
C	5.02			0	1
E	5.03			0	1
C	5.04			0	1
C	6.01			0	1
C	6.02			-1	1
A	6.03			-1	1
C	6.04			-1	1
C	6.05			0	-1
A	6.06			-1	1
C	6.07				
A	7.01			-1	1
C	7.02			-1	1
A	7.03			-1	1
C	7.04			-1	1
E	7.05			-1	1
E	7.06			-1	1
C	7.07			-1	1
C	7.08			-1	1
C	8.01			-1	1
C	8.02			-1	1
A	8.03			1	-1
A	8.04			-1	1
C	8.05			1	-1

Total score³	
Outcome⁴	
Agricultural score⁶	
Environmental⁶	

(Callout for questions 2.01–2.05): These response for these questions is 2 unless a climate analysis is done

(Callout for questions 3.01–3.05): Refer to lookup table

Lookup table for section 3.
Locate value of inputs and lookup output for each question

Yes to questions 3.01 - 3.05										default
Inputs	2.01	0	0	0	1	1	1	2	2	2
	2.02	0	1	2	0	1	2	0	1	2
Results	3.01	2	1	1	2	2	1	2	2	2
	3.02	2	1	1	2	2	1	2	2	2
	3.03	3	2	1	4	3	2	4	4	4
	3.04	3	2	1	4	3	2	4	4	4
	3.05	2	1	1	2	2	1	2	2	2

No to questions 3.01 - 3.05			
Input	2.05	?	N	Y
Results	3.01	-1	0	-2
	3.02-3.05	0	0	0

Procedure

1. Record appropriate responses in column b.
2. Look up score in columns d & e and record result in column c.
3. Calculate total score.
4. Lookup and record recommendation.
5. Verify that minimum number of questions from each section are answered.
6. Compute Agricultural (A&C) and Environmental (E&C) scores: if either score is less than 1, the outcome pertains to the other sector.

Lookup table for 6.07			
years	1	2	4
score	1	0	-1

Score	Outcome
< 1	Accept
1-6	Evaluate
> 6	Reject
Section	Minimum # questions⁵
A	2
B	2
C	6
Total	10