ATTACHMENT B

Determining the weed potential of new plant introductions to Australia

A report on the development of a Weed Risk Assessment System commissioned by the Australian Weeds Committee and the Plant Industries Committee

P. C. Pheloung
Agriculture Protection Board, Western Australia

July 1995
Minor revision September 1995

Executive summary

1. A workshop and report in 1994 gave guidelines for a three tiered screening system to assess weed potential of plant introductions. Plant species which pass the **first tier** (they are not present on prohibited or allowed lists of species, and are potential quarantine pests) are to be assessed before entry by a formal Weed Risk Assessment (**WRA**) system, which is the **second tier** (page 5).
2. Further testing and development was carried out, with assistance from workshop participants representing all states, to demonstrate that the WRA system could satisfactorily meet requirements (page 8).
3. In this system, answers are sought for questions on historical, biogeographical and biological/ecological details of the candidate (page 11).
4. The score generated by the procedure determines which of three recommendations, **reject**, **evaluate** or **accept**, will result (page 11).
5. *Evaluation* may simply require re-running the system with more information, economic cost/benefit analysis or activation of the **third tier** which is temporary clearance to import for post-entry evaluation (page 9).
6. A routine WRA should take 1-2 days per species to complete, if library and computer resources are on hand, and less if the importer provides the required documentation. The volume of assessments will progressively decrease as the more common occurrences are dealt with and assigned to the schedules of prohibited and approved plant species (page 14).
7. The WRA system was tested by analysis of its performance for 370 plant species, representing weeds from agricultural, environmental and other sectors, and useful plants. The system was judged on its ability to correctly *reject* weeds, *accept* non-weeds and generate a low proportion of species requiring *evaluation*. The performance of the system was compared to that of two simpler systems (page 15).
8. In the optimised WRA system, all serious weeds, and most minor weeds, were rejected or required *evaluation* while only 7% of non-weeds were rejected. Less than 30% of the species required *evaluation* (page 18).
9. Although simpler systems were effective, the WRA system performed best. The simpler systems produced too many *evaluate* recommendations or rejected too many non-weeds. They were constrained by their lack of flexibility (page 19).
10. The WRA system has some capacity to detect environmental weeds and identify them as such (page 24).
11. The ability of the WRA system to make reliable recommendations has a sound quantitative basis, and the mechanism is transparent. These features are basic requirements for establishing phytosanitary conditions in accordance with the GATT SPS agreement (page 25).

Recommendations

1. That the WRA system be adopted for pre-entry assessment of weed potential of new plant introductions as the second part of a three tiered system.
2. That implementation of the WRA system be consistent with the requirements of AQIS and ANCA, in consultation with P Pheloung.
3. That more specific details of the protocol for evaluate recommendations, such as cost/benefit economic considerations and post-entry protocols to study weed risk, be established.

Structure of report.

1. Part I: The main report.
2. Part II: The Weed Risk Assessment manual.
3. Part III: An attachment of appendices containing the complete dataset.
4. A computer disk containing the computer based system (PC or Mac format, Microsoft Excel 5 is required to run the system).

Any part not included can be obtained from Paul Pheloung, Agriculture Protection Board, 3 Baron-Hay Court, South Perth WA 6151. (09) 368 3679.

Table of contents

Acknowledgments

This report is the culmination of a largely collaborative effort to gather and process information on several hundred plant species. The individual contributors, and their contributions, are acknowledged in Table 2.

The Australian Quarantine and Inspection Service (AQIS) provided funding for resources and technical assistance.

PART I

1. Background/ Introduction

1.1. Current systems for screening plant introductions

The Australian Quarantine and Inspection Service (AQIS) is the national organisation responsible for detecting and approving the introduction of plant species. In the past, AQIS has managed this by reference to schedules of prohibited species. The list of proscribed species has been under revision and a much expanded draft list (quarantine schedule 86P) is under consideration. There is a concern that, as was the case with *Kochia scoparia*, plants which are not identified as weeds, and therefore are not on such a list, will be allowed entry.

AQIS also has the power to intercept and hold indefinitely any species that it feels could become an economic pest in Australia, and has not already become widely established (see definitions, page 9). AQIS must base these decisions on expert judgement. Because of the volume of plant imports, it has become apparent that a well defined and reasonably simple system or protocol is necessary for estimating the risk of an introduction becoming a weed pest.

AQIS has used a simple point scoring system (Table 1) to assist in this task. The score is translated into one of three recommendations:

1. *Accept*
2. *Reject*
3. *Evaluate* (examine further)

An alternative, proposed by Panetta (1993), uses a decision tree approach to generate these recommendations (Figure 1). The structure of the flow chart clearly illustrates the categorising of plant attributes into:

1. documented distribution
2. documented weediness
3. noxious traits
4. biological traits relating to reproduction and dispersal.

Both systems emphasise the overriding influence of documented weediness, coupled with the presence of suitable habitats in Australia. They will be referred to as the AQIS system and the Panetta system in the remainder of this report.

1.2. 1994 Workshop and Report

In response to an initiative of the National Weeds Strategy, the Australian Weeds Committee (AWC) commissioned a workshop in 1994 (Screening Plants for Weediness: a procedure for assessing species proposed for importation into Australia). The purpose of the workshop was:

To review and agree on transparent administrative procedures for plant species introductions aimed to minimise the introduction of plants that will, on balance, be detrimental to Australia.

The workshop report (Panetta *et al.* 1994) gave guidelines for a three tiered plant screening process, to be applied progressively as required:

1. Identification of the species and its Australian distribution, with reference to current lists of *prohibited* and *permitted* species.
2. If the species is not listed and is not established in Australia, apply a pre-entry assessment procedure to determine the risk of the species becoming a weed Australia: the possible recommendations are *accept*, *reject* or *evaluate*. Rejected or accepted species are then added to the *prohibited* or *permitted* list. *Evaluate* recommendations may be resolved at this stage by repeating pre-entry assessment with more information, or an econmic cost benefit analysis.
3. If an *accept* or *reject* recommendation cannot obtained from the second tier, and the importer wishes to proceed, subject the species to post-entry evaluation so that, ultimately, the species can be placed on a *prohibited* or *permitted* list.

A computer based system was devised to identify plant species that are potential quarantine pests. This system was built on the principles embodied in the AQIS and Panetta systems. Operation of the system was demonstrated at the workshop, along with an analysis of its performance in rating 50 species varying in weediness.

The computer based system deals specifically with the second tier: pre-entry assessment of weed potential and will be referred to as the Weed Risk Assessment system (WRA).

Table 1. Scoring system currently used by AQIS for decision-making on the importation of plants (after Hazard 1988). Referred to in this report as the AQIS system.

	Criterion	Points
1.	Is the species a free-floating (surface or submerged) aquatic or can it survive, grow and reproduce as a free-floating aquatic?	20[A]
2.	Does the species have a history of being a major weed elsewhere in similar habitats (remember Australia is a big country of diverse habitats)?	20
3.	Does the species have a close relative of similar biology with a history of weediness in similar habitats?	10
4.	Are the plants spiny?	10
5.	Does the plant have spiny diaspores (ie. burrs)?	10
6.	Are the plants harmful to humans and/or animals?	8
7.	Do the plants produce stolons?	5
8.	Do the plants have other forms of vegetative reproduction?	8
9.	Are the diaspores wind-dispersed?	8
10.	Are the diaspores dispersed by animals and/or machinery?	8
11.	Are the diaspores dispersed by water?	5
12.	Are the diaspores dispersed by birds?	5

[A] Scores totalling ≥20, between 12 and 19, or <12 indicate grounds for rejection, further examination or acceptance, respectively.

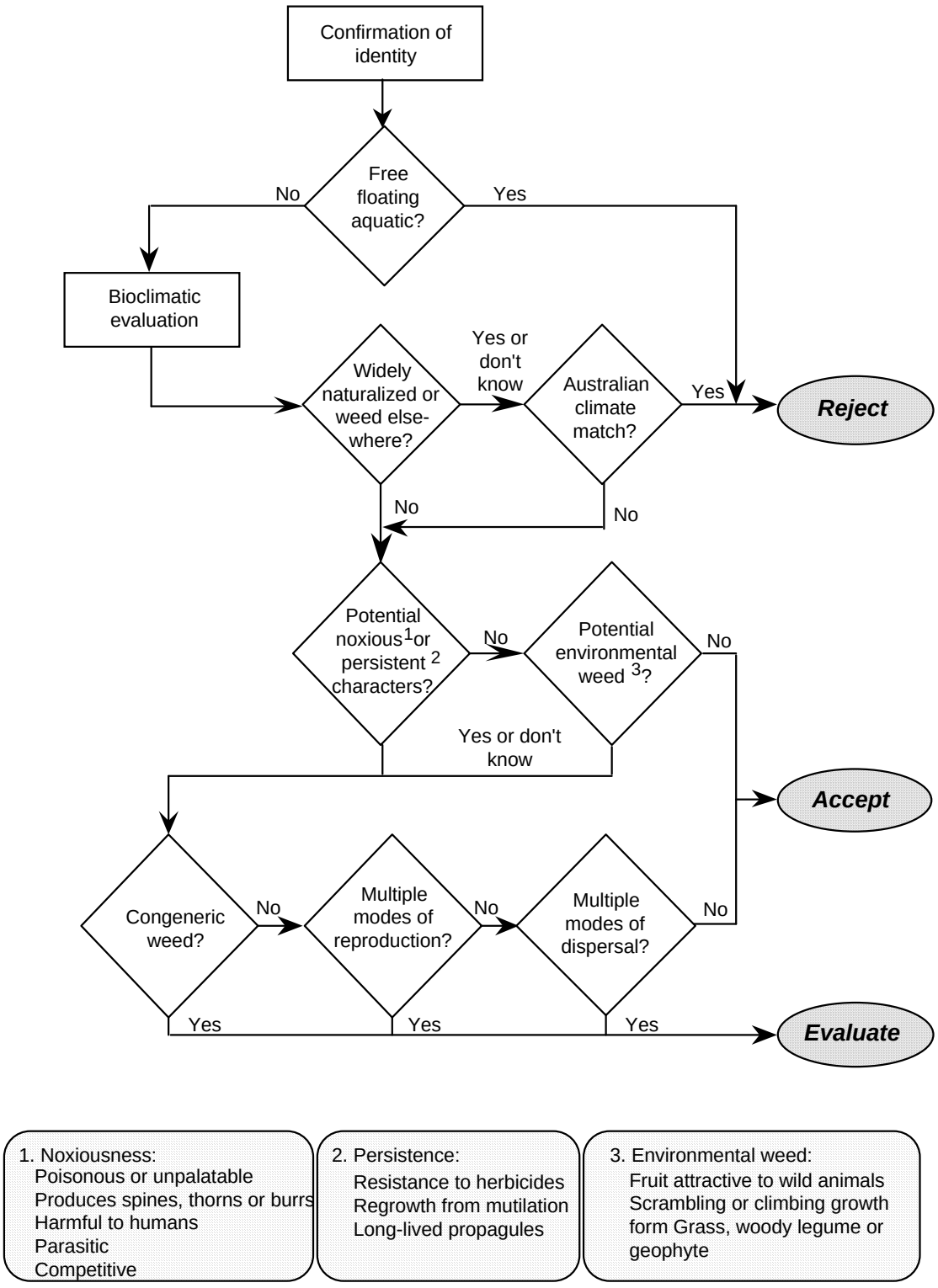

Figure 1. A screening system for proposed plant introductions (modified after Panetta 1993).

1.3. Guidelines followed during development of the WRA system

Further testing and development was carried out, with assistance from workshop participants representing all states, to demonstrate that the WRA system could satisfactorily meet requirements.

This work was endorsed at the 1994 workshop and, subsequently, the Plant Industries Committee (PIC) resolved that testing and development of the WRA system be completed and a report prepared, by July 1995. AQIS provided funding to facilitate the process.

An acceptable WRA system must meet a number of requirements that were specified at the workshop, and by PIC:

1. The system should be calibrated and validated against a large number of species, already present in Australia, representing the full spectrum of species likely to be encountered as imports. A number of workshop participants volunteered their services to assist in this process.
2. It must be shown that the screening procedure is reasonably effective at discriminating between weeds and non-weeds.
3. The dataset resulting from this process should be used to adjust the scoring system such that the majority of weeds are not accepted, non-weeds are not rejected and the proportion requiring *evaluation* is kept as small as possible.
4. International trade agreements require that prohibited species should fit the definition of a quarantine pest (see box). The assessment procedure should be fully transparent and based on sound scientific principles so that Australia cannot be accused of applying unjustified non-tariff trade barriers.
5. Resources needed to operate the system should be realistic - the cost in time and money to the importer and the administering body (AQIS) should be as low as possible.
6. The system should be capable of identifying environmental weeds (weeds of conservation or bushland weeds) and identifying them as such. This could be necessary since such weeds may not fit the definition of a quarantine pest as it is commonly interpreted (see box). These items could be referred to ANCA for further action.
7. In the majority of cases, the decision will be made for a species, but the system should be capable of dealing with species at the genus or subspecies level. Some allowance must be made for well-defined subspecies or varieties which have economic benefits and attributes that render them less weedy than other members of the species. For convenience, the term species is used in this report to refer to the more general concept.
8. The system should provide significant improvement over others currently in use.

International trade agreements (Anon 1992) require plants that are denied entry to a region to conform to the definition of a quarantine pest:	
Pest:	Any species, strain or biotype of plant, animal or pathogenic agent, injurious to plants or plant products.
Quarantine Pest:	A pest of potential economic importance to an area endangered thereby and not yet present there, or present but not widely distributed and being officially controlled.
Official	Established, authorised or performed by a national plant protection agency.
Control	Suppression, containment or eradication of pest populations.

1.4. Applying the tiers

The first tier of the screening system determines whether a plant requires WRA. Part of this is determining if the plant is a potential quarantine pest (see box on page 9). If a species is already widely distributed, then new introductions are unlikely to have any further effect, unless it can be clearly shown that the new introduction is significantly different genetically, and the difference has pest implications.

If the pest is present but not widely distributed, official control of the existing infestations is essential. Otherwise, quarantine serves no useful purpose. Regulatory organisations are expected to make rational and realistic judgements (Panetta and Scanlan 1995) about what species should be officially subject to official control. Prohibited entry of a plant should be based on such judgements.

The second tier is the WRA system, but a protocol for assessing the economic benefits of an introduction is necessary, in the event that WRA recommends *evaluate*.

Evaluation includes a number of options:

1. Repeat the WRA system, using updated information,
2. An economic cost/benefit analysis to justify the risk,
3. The third tier: post-entry evaluation in the form of field studies supervised by an expert panel to examine more directly weed potential (and verify potential benefits).

These steps are progressively more time consuming and costly, so the aim is to apply them sequentially and reach a decision to *accept* or *reject* (or simply terminate the process) as soon as possible.

The tiers correspond to the first two stages described in an FAO document on guidelines for Pest Risk Analysis (Anon 1995). The flow chart in Figure 2 shows how WRA fits into the overall protocol for screening plant introductions.

The FAO report cites the following factors as examples of economic importance:

1. Type of damage
2. Crop losses
3. Loss of export markets
4. Increases in control costs
5. Effects of ongoing Integrated Pest Management (IPM) programmes
6. Environmental damage
7. Capacity to act as a vector for other pests.

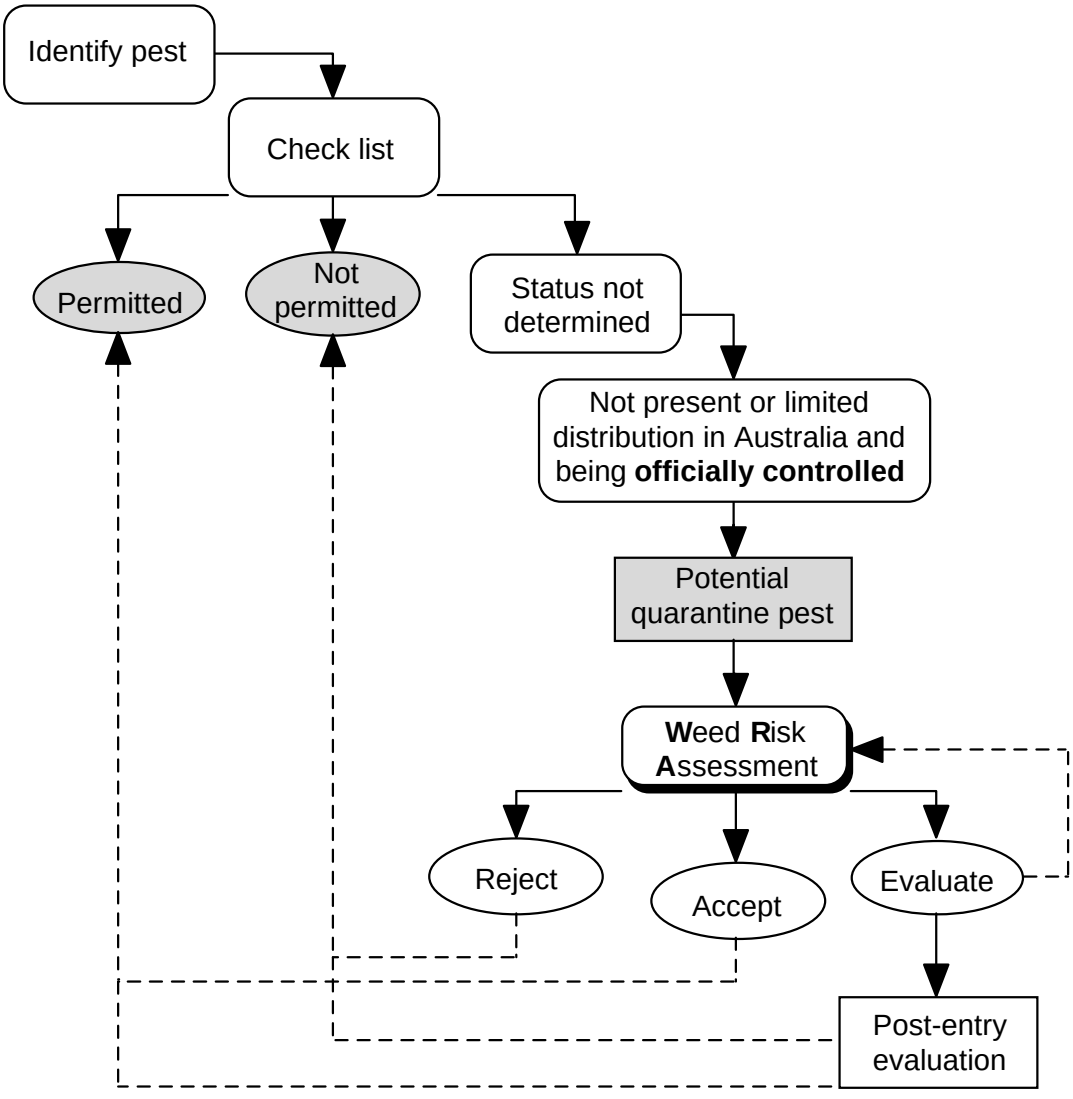

Figure 2 Flow chart for screening plant introductions.

2. The Weed Risk Assessment (WRA) System

2.1. Structure

Answers are sought for questions on historical, biogeographical and biological/ecological details of the candidate (Part II Form A).

These answers are almost entirely in the form of *yes*, *no* or *don't know*, and are used to produce a score related to weediness. The complete system is described in Part II and the question sheet is given in Part II, form A.

The score generated by the procedure is used to determine which of three recommendations, *reject*, *evaluate* or *accept* (the latter allowing clearance to import and release), will result.

The WRA system is set up to run on a computer but can be operated on paper. A full description is given in Part II. It is incorporated into a computer based environment to accelerate the process, help enforce objectivity, and automatically maintain a database of assessed species. A complete set of responses for each species is stored in a database and can be reviewed at any time, and reassessed if details of the scoring system are changed.

2.1.1. The scoring system

The WRA system generates a numerical score based on 49 questions that is positively correlated to weediness (Part II, Forms A and B). It is, in essence, an expanded form of the system currently used by AQIS (Table 1). However, in addition to being more comprehensive, it introduces added flexibility: there is no requirement to answer all questions, and positive (non-weedy) traits are taken into account.

The system attempts to take account of all the information that would be utilised by the AQIS and Panetta systems, with expansion of some broader questions from these systems into several smaller steps.

A minimum number of questions must be answered from each of the three main sections:

1. **Biogeography:** the documented distribution, climate preferences and weediness in other parts of the world. The distribution and climate preferences should be used to predict a potential distribution in Australia using available prediction systems. The default, if this is not done, is to assume the species will readily grow unaided in Australia (Part 2, questions 1-3).
2. **Undesirable attributes:** these are the noxious or invasive characters comparable to the second tier in Panetta's system (Figure 1; Part 2, questions 4.1-4.12).
3. **Biology/ecology:** these are the attributes that contribute to the capacity of the species to reproduce, spread and persist (Part 2, questions 5-8).

In most cases, one point is added for a weedy attribute and one point is deducted for a non-weedy attribute. Grading the relative importance of the various questions was avoided as

being too subjective. Assessment of potential distribution, based on climate matching, is used to weight the responses to four questions on weed status in other parts of the world: a good climate match increases the value of a 'Yes' response to these questions.

2.1.2. Converting the score to a recommendation

The three possible recommendations (*accept*, *evaluate* or *reject*) are determined by two critical score settings. The lower critical score separates acceptable species from those requiring *evaluation* and the higher critical score separates species requiring *evaluation* from those that should be rejected. The positioning of these critical scores was determined by a calibration process using information on weeds, non-weeds and other economically important plants that are present in Australia (Section 3.1).

An attempt was made to classify the questions according to their relevance in identifying attributes associated with agricultural, environmental and nuisance weeds (Part II, Form A). Nearly half of the questions (22) were classified in this way, but the remainder of the questions were considered relevant to all sectors. In addition to an overall score, scores derived from questions of agricultural and environmental relevance are also generated to give an indication of the sectors likely to be affected. For example, if the agricultural score is negative, but the environmental score is positive and the overall result is *reject*, then the species is probably a potential environmental weed only.

The system described is best suited to intentional imports of plant propagules. Another important category is weed contaminants in imports of approved seed varieties or plant material not intended for sowing. AQIS is currently reviewing its policy on contaminants. The WRA system could be the basis of such a system, but may need to have different ways of interpreting the score, based on a measure of the risk that the pest will reach a favourable site for establishment.

2.2. Rationale for questions

The selection of questions was based on the accumulated wisdom of ecological and weed research and was discussed in detail in the workshop report (Panetta *et al.* 1994).

It is widely accepted that a weed in some part of the world has a good chance of being weedy in other areas with similar environmental conditions. This consideration has the greatest influence on the recommendation. It is also possible for a species that has not been particularly weedy to become so in a new situation. A number Australian noxious weeds (Parsons and Cuthbertson 1992) are not documented weeds elsewhere. The remainder of the system attempts to identify such candidates by identifying biological attributes.

The system seeks to produce recommendations according to the principles embodied in Panetta's system:

1. Weeds from other parts of the world should not be allowed entry if the climate in Australia is similar,
2. Otherwise, species with biological attributes suggestive of invasive plants or weeds should be subjected to *evaluation.*
3. Otherwise, species should be accepted.

In view of the difficulty in definitively measuring weed potential, the precautionary principle should be applied to all decisions such that, if information important to the determination of weed potential is not available, the species should not be accepted.

2.3. Information required to operate the WRA system

A routine WRA should take 1-2 days per species to complete, if library and computer resources are on hand, and less if the importer provides the required documentation. The volume of assessments will progressively decrease as the more common occurrences are dealt with and assigned to the schedules of prohibited and approved species.

Australian assessors are not likely to have detailed knowledge of new plant introductions. Assessment must be based on information obtained from the literature. Primary sources would be Holm *et al.* (1979) for a quick summary of weed status throughout the world (mainly weeds of agriculture), Hnatiuk (1990) for presence of particular species in Australia, and world floras for native and naturalised distributions (to determine climate preferences).

Electronic resources for information acquisition are becoming increasingly accessible and useful. Abstracting systems available on compact disk, such as CAB and Biological Abstracts, provide a comprehensive, up to date synopsis of current literature. Other weed databases are coming online, particularly the World Weed Database evolving from the work of Holm *et al.* (1979). These electronic forums provide a means of rapidly obtaining relevant unpublished or obscure information, particularly on species that have become weeds in natural ecosystems. It is also necessary to have access to the most up to date information on the presence and distribution in Australia.

The worldwide distribution can be used to determine the degree and extent of similar climates in Australia. At least two programs, (*Climex*, CSIRO Division of Entomology, Qld; *Climate*, Department of Agriculture, WA) can perform this task without difficulty. If a formal analysis is not done, a good match should be assumed unless the natural distribution of the species clearly does not coincide with Australian climates; this would probably only include cold, high latitude regions. Simplified maps of the 20 or so major climatic zones of the world can be found in good atlases. Such maps can be used to provide answers to the remaining climate related questions.

To facilitate the process and reduce costs, the importer can provide much of the necessary information with substantiation as required. Since assessment should precede the arrival of the species at the barrier, an accurate and unambiguous identification of the plant is essential.

Information on the species likely to be encountered will be variable and often sparse. In recognition of this, the questions attempt to cover a wide range of attributes with no requirement that any particular question be answered (the climate section will default to the worst case if not answered). Nevertheless, a minimum number of questions from each section must be answered or the system will indicate that more information is required.

It has been suggested that a fully answered set of questions should always result in *accept* or *reject*. This is not the case, or the intention. For many species, there will be uncertainty that cannot be resolved without direct evaluation under Australian environmental conditions.

3. Calibrating and testing the WRA system

The WRA system was tested by analysis of its performance for 370 plant species, representing weeds from agricultural, environmental and other sectors, and useful species. The system was judged on its ability to correctly *reject* weeds, *accept* non-weeds and generate a low proportion of species requiring *evaluation*. The performance of the system was compared to that of the AQIS and Panetta systems.

The modifications and tests were based on comments and input from workshop participants and others. A survey of scientists was done to define the weed status of each species. The species were given a rank from 0 to 2, which was used to classify them as *non-weeds*, *minor weeds* and *serious weeds*, respectively. This classification is subjective and may contain errors but should provide a good basis for measuring the performance of the WRA system.

3.1. The assessed species

The WRA system, as it was presented at the June 1994 workshop, was circulated to a number of participants who had volunteered to assist. The volunteers were professional scientists in the fields of ecology, botany and agronomy. They were asked to use the system to assess the weed potential of species they were familiar with, ranging from non-weedy beneficial species to serious weeds. All species that have a noxious status in Australia were assessed using the information provided in Parsons and Cuthbertson (1992). Contributors to the list of assessed species are given in Table 2 and the complete list of assessments is given in Part III.

Assessors were asked to treat each species as if it had not yet arrived in Australia. Species that are serious weeds in Australia, for example, were to be assessed purely on their weed status outside Australia.

At least one contributor did not rigidly adhere to ignoring Australian weed status in the course of making assessments. Consequently, responses to the 'Weed Elsewhere' section (Section 0, Form A) were carefully checked for serious inconsistencies and altered in such cases. Holm *et al.* (1979) and Parsons and Cuthbertson (1992) were the authorities used.

Some attempt was made to examine the results for

1. obvious errors
2. big differences where more than one assessment was made of the same species
3. aberrant recommendations

The responses of the original assessors were used in all but the clearest cases of an inconsistent response.

3.2. Modifications based on expert comment

Several of the workshop participants, and others, provided critical comment on the system (Table 2). These comments were invaluable in modifying the system. They helped to highlight areas of ambiguity or vagueness in the wording of the questions. The analysis of

system performance is based on the modified version. An appraisal of the comments provided, is given in Part III.

Table 2 Contributors to development of the Weed Risk Assessment System

Contributor		species assessed		Critical
		WRA	Survey	comment
Bryan Hacker & Bruce Pengelly	CSIRO (tropical pastures) Qld	5	102	v
Craig Walton & Darren Phillips	AQIS ACT	-	117	v
Dane Panetta	Alan Fletcher Research Station Qld	-	353	v
David Cooke	Animal and Plant Control Commission SA	113	219	v
Jon Dodd	Agriculture Protection Board WA	-	289	v
Mark Boersma	Dept. of Primary Industries and Fisheries Tas	25	137	v
Mark Lonsdale	CSIRO (entomology) NT	187	-	v
Michael Mulvaney	Australian Heritage Commission ACT	31	274	v
Roger Cousens	Dept. of Agriculture WA	-	263	v
Richard Carter	Animal and Plant Control Commission SA	-	233	
Rod Randall & Paul Pheloung	Agriculture Protection Board WA	301	128	v
Stephen Halloy	Invermay Agricultural Centre NZ	-	-	v
Surrey Jacobs	National Herbarium NSW	-	348	v

In some cases, a modification would require that the response to a question be reconsidered. To the extent possible, the responses to questions were modified to account for rewording and other alterations. Ideally, the program would need to be recirculated so that contributors could reassess their species based on the modifications. This was not feasible within the available time so the validation of the system is based largely on responses supplied for the system as originally circulated.

A number of important suggestions, which were not adopted in the modifications, deserve comment here:

- *Grasses should not be grouped together as guilty of weediness by association*

  In fact, this is one of the more reliable indicators of weed risk since such a large proportion of the grass family is weedy. The risk must be offset against the potential

economic benefits that arise from the same attributes that are linked to invasiveness (eg. readily established, spreading and self-sustaining). These considerations are more appropriate at the *evaluate* stage, if the species falls into this category.

- *A different set of questions should be asked, based of the vulnerable sector (rangeland, cropping, horticultural, ornamental etc).*

  The pre-entry assessment should function as a simple generic process that considers weed potential without regard to the sector at risk or the economic benefits. It is expected that all species for which the weed potential is low or uncertain will be subject to *evaluation*, if not accepted. The intended use of the plant can be considered as part of the process of *evaluation*.

3.3. Classifying the assessed species

Twelve scientists, some of whom also provided assessments and comments, responded to a request to complete a survey composed of all the species assessed by the WRA system (Table 2). Contributors were asked to classify each plant for weediness and usefulness on a 0 - 2 scale. They were asked only to give responses for species that they were familiar with and to take account of the Australian experience. The contributors were also asked to classify weeds according to the sector affected (agriculture, environment, etc.). The complete results of the survey are given in Part III.

The survey was intended to provide a reference measure of the weed status, in Australia, for the assessed species. The weed status of each plant is derived from the collective opinion of one to twelve experts. The analyses are based on species for which at least two opinions were provided. The results of the survey are summarised in (Table 3). Although the majority of species (81%) are perceived as weeds in some context, less than half are considered serious weeds. A good sample of non-weeds and useful species, some of which are also considered to be weeds, were included. Weeds from all sectors (agriculture, environment, etc.) were well represented.

Table 3 Summary of survey results for species which were scored by at least two respondents

	number	% of all species
Species surveyed	370	
Weeds and useful species		
Serious Weeds	160	43
Minor Weeds	141	38
Non-weeds	69	19
Very useful	78	21
Moderately useful	154	42
Not useful	138	37
Useful non-weeds	67	18
Useful weeds	165	45
Distribution of weeds according to category		
Agricultural	138	38
Environmental	198	54
Horticultural	24	7
Garden	31	9
Service areas	115	31

3.4. Performance

3.4.1. Critical values

In the optimised WRA system, all serious weeds, and most minor weeds, were rejected or required *evaluation* while only 7% of non-weeds were rejected. Less than 30% of the species required *evaluation.*

The frequency distributions of WRA scores for each of the survey classifications are shown in Figure 3. Figure 4 presents the same data as cumulative frequency and also shows how environmental or agricultural weeds are partitioned by the system. This data was used to investigate the effect of different pairs of critical values 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 values 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 maximum *accept* score at 0. 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 species 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 4). Consequently, the critical scores, of 0 and 7, were used convert the WRA scores into the recommendations, *accept*, *evaluate* and *reject*.

The results are summarised in Table 4 and a complete list of the species, partitioned into WRA recommendations and survey classifications, is given in Table 9. A number of useful species, particularly grasses, are rejected. In many of the cases, this is because few or no questions were answered in the last two sections of the WRA system. It is likely that specific information on the dispersal and persistence properties of these species could lower the score into the *evaluate* range.

3.4.2. Comparing the systems

The species were also scored using the AQIS and Panetta systems. Although these systems were effective, the WRA system performed best. The simpler systems produced too many *evaluate* recommendations or rejected too many non-weeds. They were constrained by their lack of flexibility.

For many of the species, information required by the AQIS or Panetta systems was not available. The precautionary principle was applied in such cases for the AQIS system: if a question was not answered then the result is *evaluate*. In the Panetta system, the path taken where an answer was not supplied is shown in Figure 1. Lack of information has meant that the Panetta and AQIS systems accepted fewer species than the WRA system (26, 36 and 73 species, respectively).

In all systems, *accept* recommendations were more likely as plant usefulness increased (Figure 5). The systems performed similarly in rejecting at least 80% of the species not considered useful. However, the proportion of useful species allowed entry was highest for the WRA system (30%).

A comparison of system recommendations is shown in Figure 5. In this figure, the partitioning of assessment recommendations is shown for each survey classification. All systems were effective in rejecting most (85-91%) of the serious weeds. The Panetta system was most severe, rejecting about 26% of non-weeds and 75% of minor weeds. The WRA system was the least severe in dealing with non-weeds: nearly 60% were accepted and only 7% were rejected.

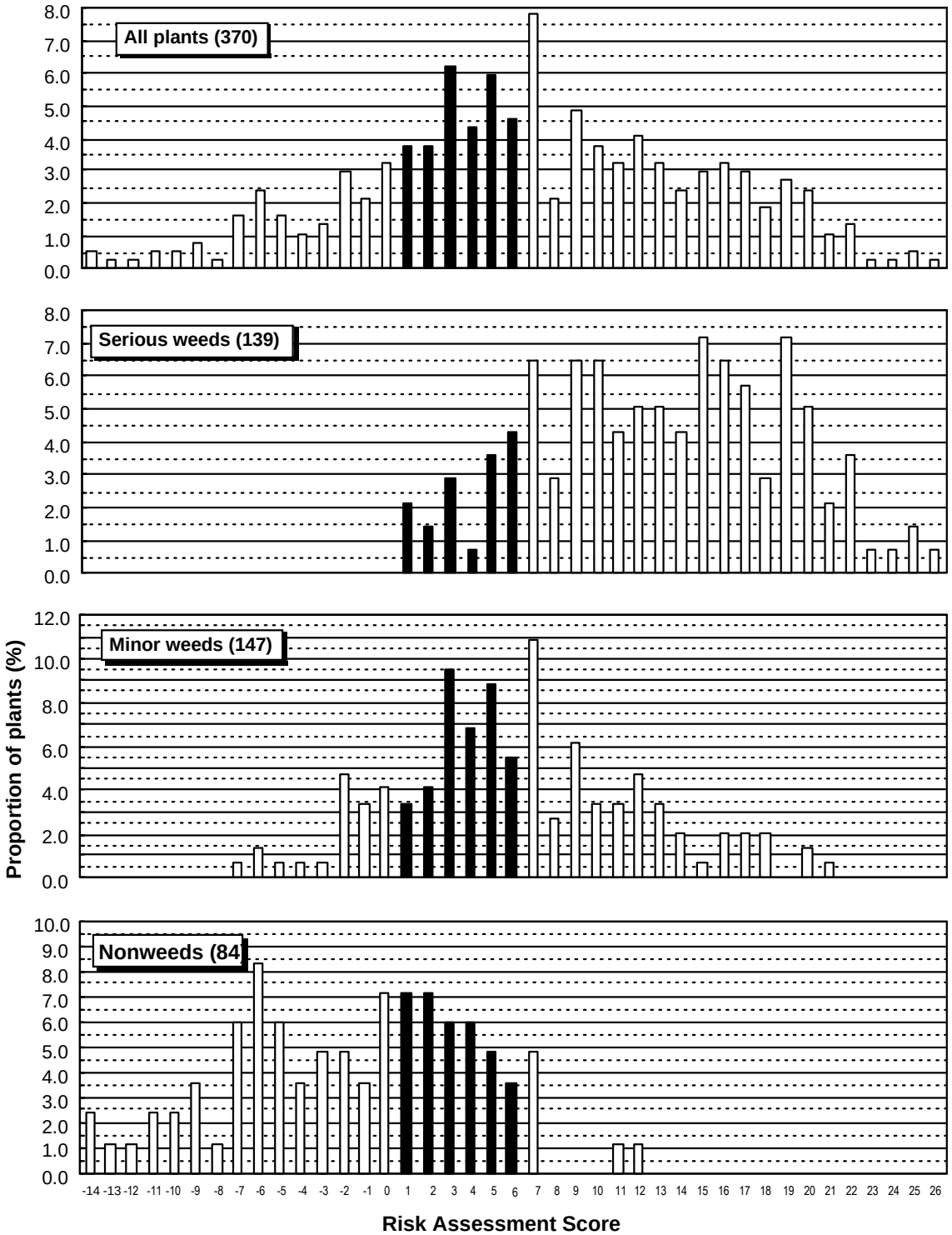

Figure 3 Frequency distributions for all assessed species and each of the survey weed classifications. Serious weeds were those which scored 2 in the survey, minor weeds scored 1 and non-weeds scored 0. This analysis was done for species graded by at least two respondents in the survey. The black columns refer to *evaluate* recommendations, bounded by critical WRA scores set at 0 and 6.

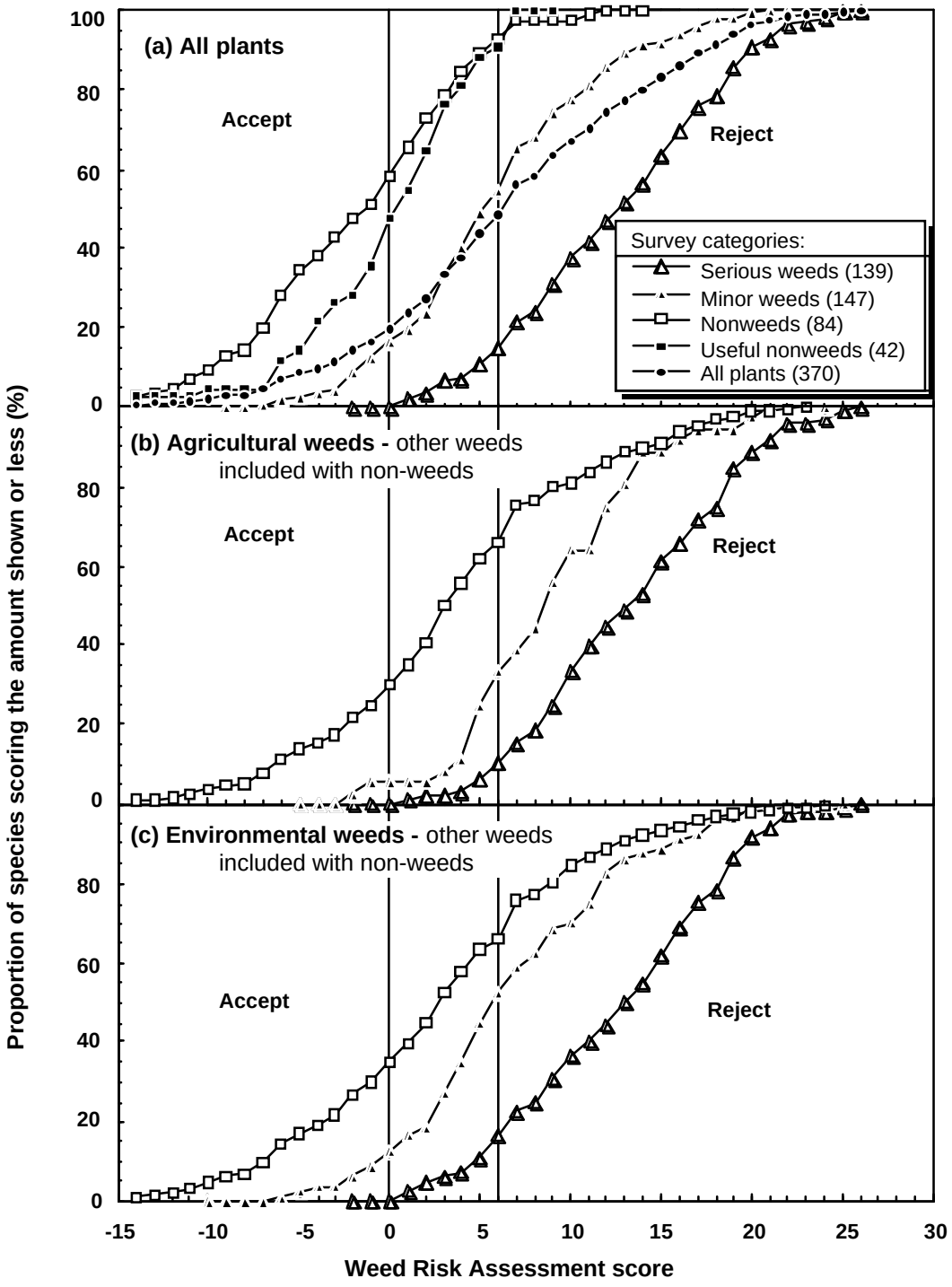

Figure 4 Cumulative frequency of species receiving a given WRA score or less for the survey classifications, as described in Figure 2. Useful species were those which scored 2 and were not considered weeds

Table 4 Distribution of recommendations for the three assessment systems. The classifications are from the survey results. The critical scores used to determine recommendations for the WRA system are described in the text.

	System		
	AQIS	Panetta	WRA
% of all species (n=370)			
Serious weeds not accepted	99	100	100
Minor weeds not accepted	95	93	84
Non-weeds not rejected	89	74	93
Useful species not rejected	73	45	74
Species to be evaluated	39	20	29
% of agricultural weeds (n=132)			
Serious weeds not accepted	99	100	100
Minor weeds not accepted	94	94	94
Non-weeds not rejected	64	42	66
% of environmental weeds (n=190)			
Serious weeds not accepted	99	100	100
Minor weeds not accepted	96	98	88
Non-weeds not rejected	66	47	66

All three systems produced *evaluate* recommendations for a proportion of the species. The proportion was 39, 20 and 29% using the AQIS, Panetta and WRA systems, respectively (Table 4). This could be misleading since the selection of species is not necessarily typical of the species likely to be encountered as imports. It is more informative to consider the number requiring *evaluation* within each survey classification (Figure 5). In all systems, a low proportion (9-14%) of serious weeds required *evaluation*. For reasons discussed above, the AQIS system had a very large proportion of non-weeds and minor weeds requiring *evaluation*. *Evaluation* should predominate in the minor weed classification. The WRA system was closest to achieving this objective since this category contained the greatest proportion of species requiring *evaluation*.

Evaluate recommendations increased and *reject* recommendations decreased as the usefulness of the plant increased (Figure 5), particularly for the AQIS and WRA systems.

As an overall indicator of system performance, recommendations are summarised in Table 4 and correlations are given in Table 5. All system recommendations are significantly correlated to the survey classifications, but the WRA system shows the best relationship.

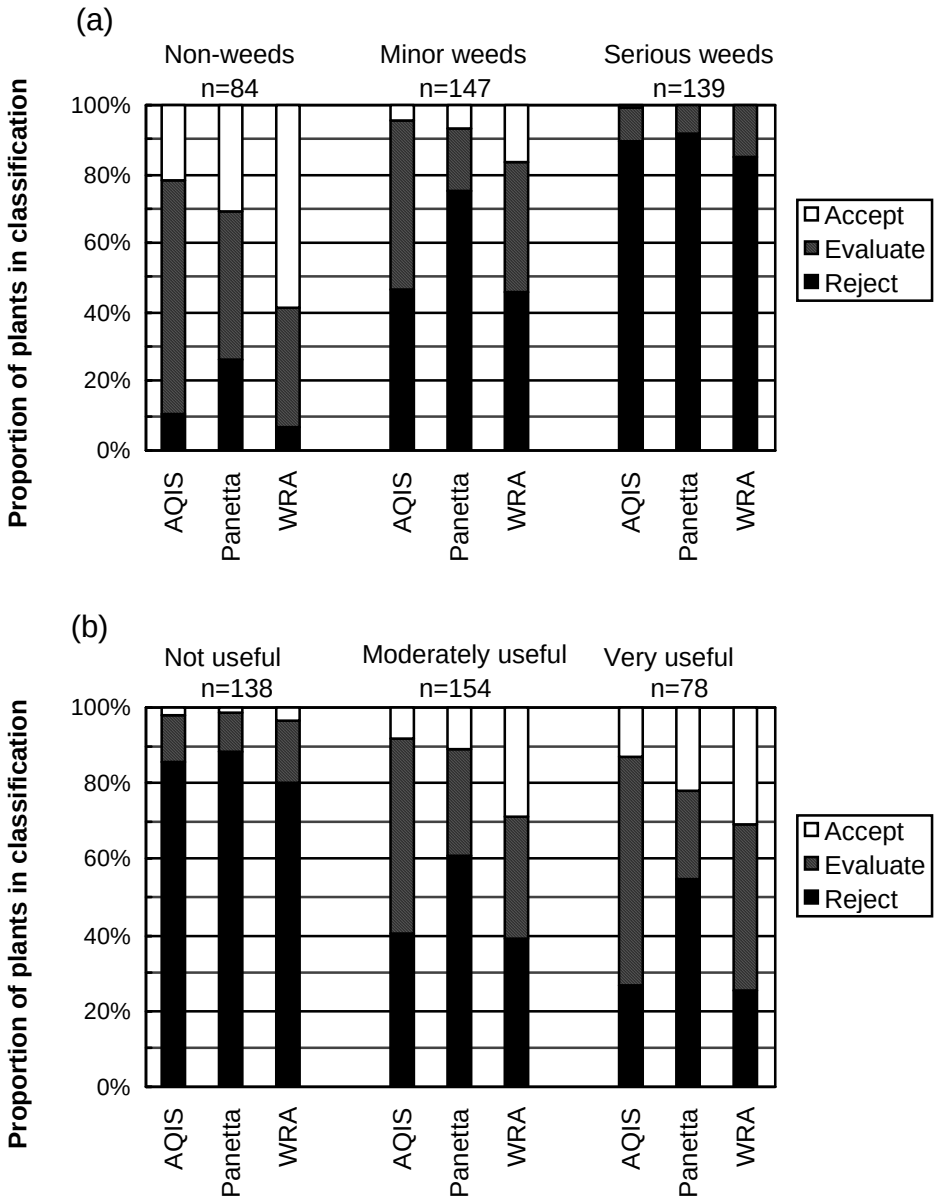

Figure 5 Partitioning of assessment recommendations, as produced by the AQIS, Panetta and WRA systems, within the three survey classifications for weediness (a) and usefulness (b).

Table 5 Rank correlations for the three assessment system recommendations and the survey classifications.

	Survey	AQIS	Panetta
AQIS	**0.60**		
Panetta	**0.53**	0.47	
WRA	**0.65**	0.66	0.47

3.4.3. Components of the WRA system

The effectiveness of the three sections of the WRA system were examined to determine the contribution made to the overall recommendation. Most combinations are significantly correlated (Table 6), but undesirable attributes are the most poorly related to other components of the system. The biological/ecological attributes, reproduction, dispersal and persistence, do show some relationship to documented behaviour of the plant elsewhere in the world (biogeography). Overall, the WRA system is well correlated to the survey classifications, and all components make significant contributions. Biogeography is the best measure of weed potential in Australia, and this is consistent with other studies (Panetta 1993, Scott and Panetta 1993).

Examination of the relative value of the individual questions has not been attempted here. It is expected that if the system were adopted, such details would be evaluated so that questions can be reworded, added, deleted or replaced on the basis of accumulated experience.

Table 6 Correlations of the WRA score, its components, and the survey classifications.

	WRA	Bio-geography	Undesirable attributes	Biology /ecology
Biogeography	0.80			
Undesirable attributes	0.46	0.28		
Biology/ecology	0.80	0.46	0.19	
Survey	0.69	0.62	0.44	0.50

3.4.4. Agricultural and environmental weeds

The WRA system has some capacity to detect environmental weeds and identify them as such.

The weeds were partitioned into the two main categories, agricultural and environmental weeds. Figure 4 shows the cumulative frequency distributions for each subset. Of the species 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 (Table 3).

There were no obvious differences in the ability of any of the systems to make appropriate recommendations for weeds of either category (Table 4). It is difficult to make reasonable comparisons the performance of the AQIS and WRA systems because of the large proportion of *evaluate* recommendations generated by the AQIS system. In comparison to the overall performance, a higher proportion of agricultural weeds and, to a lesser extent, environmental weeds were identified by the WRA system, which implies that weeds in other sectors (amenity, horticultural, etc.) were less effectively identified.

Rank correlations of the system recommendations against the survey classifications were similar for agricultural and environmental weeds. Correlations for the WRA and AQIS systems did not differ significantly (Table 7).

The WRA score could be partitioned into agricultural and environmental components (section 2.1.2). Each score partition was best correlated to the corresponding survey category (Table 8).

Table 7 Rank correlations of the assessment systems recommendations with the survey categories.

	Survey	
	agricultural	environmental
AQIS	0.47	0.45
Panetta	0.34	0.39
WRA	0.48	0.46

Table 8 Correlations of the WRA score with the survey categories.

	Survey	
	agricultural	environmental
WRA - agricultural	0.58	0.41
WRA - environmental	0.44	0.51
WRA- all weeds	0.53	0.52

3.5. Conclusions

The ability of the WRA system to make reliable recommendations has a sound quantitative basis, and the mechanism is transparent. These features are basic requirements for establishing phytosanitory conditions in accordance with the GATT SPS agreement.

The success rate of the WRA system in predicting weed potential, using the survey classifications as a guide, was good (r=0.69***). No serious weeds were accepted and the majority of minor weeds were also not accepted. Less than 10% of non-weeds were rejected but some of these were considered useful species. It is expected that most of these would get an *evaluate* recommendation if more of the assessment questions were answered.

The WRA system performed best overall although, in many respects, the AQIS system performed similarly. However, the AQIS system has the disadvantage of making no provision for lack of information pertaining to the questions, resulting in a recommendation to *evaluate* a large proportion of the species. The Panetta system was the most severe, largely due to the more rigorous treatment of the *weed elsewhere* question. Panetta was reluctant to relax the rigour of this question because of the precautionary principle and the reasonable expectation that widely naturalised species, newly introduced to Australia, could become weedy.

There were no obvious differences in the performance of the systems in screening for weeds of agriculture or the environment, although there was some evidence that the WRA system was able to categorise species on this basis. In other words, the WRA system could be made to identify species that are likely to be of concern in one sector only.

The WRA *evaluate* recommendation identifies plants which are likely to impose an economic cost if they become established, including the cost of enviromental damage. Where possible, quantitative cost/benefit analysis, using risk analysis techniques, could be used to decide if the risk is accapetable.

Table 9. Partitioning of species by WRA score and survey classification

Score	Serious Weeds	Minor Weeds	Non-weeds
Accept			
-14			**Camellia japonica** Abelia chinensis
-13			Cedrus atlantica
-12			Magnolia campbelli
-11			Araucaria araucana Chamaecyparis pisifera
-10			Acer palmatum **Lens culinaris**
-9			Antirrhinum majus Meconopsis betonicifolia Paphiopedilum insigne
-8			Stapelia nobilis
-7		Buddleia crispa	Abies nordmanniana Lupinus albus Paulownia fortunei Romneya coulteri Welwitschia mirabilis
-6		Aloe ferox Cistus ladanifer	Aesculus hippocastanum Berberis thunbergii Encephalartos lehmannii Gnetum gnemon **Raphanus sativus** **Trifolium alexandrinum**
-5		Aristolochia elegans	Lilium mackliniae Lophophora williamsii **Pisum sativum** Rafflesia arnoldi **Secale cereale** Taxus baccata
-4		Buddleia davidii	**Cucumis melo** **Prunus amygdalus** **Triticum aestivum**
-3		Chamaecyparis lawsoniana	**Fagopyrum sp** Pandanus latifolia **Panicum coloratum** Taxus wallichiana
-2		Chasmanthe floribunda **Digitaria decumbens** Melilotus alba Reseda odorata Scabiosa atropurpurea **Vicia narbonensis** Viola arcuata	Ephedra fragilis Eragrostis tef Lupinus "Russell" hybrids **Themeda triandra**
-1		Cichorium intybus Lathyrus sativus Orbea variegata Phleum pratense Psoralea patens	**Lupinus angustifolius** **Trifolium hirtum** **Vigna radiata**
0		Chamaecytisus proliferus Lycium chinense Malcolmia africana **Pinus radiata** Poa trivialis **Stylosanthes scabra**	**Arbutus unedo** **Cicer arietinum** **Hordeum vulgare** **Lycopersicon esculentum** Trifolium semipilosum **Vicia villosa**

Table 9. Partitioning of species by WRA score and survey classification

Score	Serious Weeds	Minor Weeds	Non-weeds
Evaluate			
1	Cinnamomum camphora Salix babylonica Themeda quadrivalvis	Achillea ptarmica Chloris truncata Eschscholzia californica Gazania linearis Homeria elegans	Avena byzantina **Avena sativa** Cineraria lyrata Erythroxylum coca **Trifolium incarnatum** **Trifolium resupinatum**
2	Pinus halepensis **Olea europea**	**Agrostis stolonifera** Echinochloa polystachya Freesia leichtlinii X alba **Poa pratensis** Stylosanthes hamata **Trifolium subterraneum**	Cajanus cajan **Dactylis glomerata** **Glycine max** **Solanum tuberosum** Stylosanthes montevidensis **Zea mays**
3	Gleditsia triacanthos **Leucaena leucocephala** Protoasparagus densiflorus Soliva pterosperma	Bromus unioloides Cannabis sativa Cassia floribunda Chloris gayana Dolichos sericeus **Festuca arundinacea** Festuca rubra Freesia refracta Gorteria personata Grindelia camporum Limonium sinuatum Panicum miliaceum Paspalum plicatulum Zoysia japonica	**Desmodium heterophyllum** **Helianthus annuus** **Setaria italica** **Sorghum bicolor** **Trifolium fragiferum**
4	Cucumis myriocarpus	Albizia lebbek Arundo donax Erythrina crista-galli Lycium barbarum Monadenia bracteata Panicum virgatum Phalaris canariensis Prunus cerasifera **Trifolium pratense** **Trifolium repens**	Coix lachryma-jobi Stylosanthes viscosa **Trigonella foenum-graecum** Vigna hosei **Vigna luteola**
5	Cotoneaster pannosa Datura stramonium Raphanus raphanistrum Rapistrum rugosum Watsonia bulbillifera	**Asparagus officinalis** **Cynodon dactylon** Dipsacus fullonum Hymenachne acutigluma Hyparrhenia hirta **Lablab purpureus** **Lathyrus hirsutus** **Lolium multiflorum** Paspalum nicorae Reseda phyteuma Robinia pseudoacacia Toxicodendron radicans Urochloa panicoides	**Medicago sativa** Pelargonium asperum **Pueraria phaseoloides** **Sorghum sudanese**
6	Desmodium uncinatum Echium vulgare Eragrostis curvula Homeria pallida Pentzia suffruticosa Wedelia trilobata	Bothriochloa pertusa Bromus mollis Gomphocarpus physocarpus **Lolium perenne** Lupinus cosentinii Lythrum salicaria **Macroptilium lathyroides** **Panicum maximum var. jacq**	Eleusine coracana Stenotaphrum secundatum **Tanacetum cinerariaefolium**

Table 9. Partitioning of species by WRA score and survey classification

Score	Serious Weeds	Minor Weeds	Non-weeds
Reject			
7	**Cenchrus ciliaris** Ehrharta calycina Zizyphus spina-christi	**Acer negundo** **Andropogon gayanus** Berkheya rigida Cenchrus setiger **Clitoria ternatea** Crotalaria goreensis **Desmodium intortum** Digitaria pentzii Eremocarpus setigerus Gymnocoronis spilanthoides Hirschfeldia incana Hyparrhenia rufa **Lolium rigidum** **Macroptilium atropurpureum** **Macrotyloma axillare** Melinis minutiflora **Panicum bulbosum** Setaria palmifolia Spartina anglica Stevia eupatoria Stylosanthes humilis Xanthium strumarium	**Panicum antidotale** **Panicum coloratum var. makarikariense** **Paspalum virgatum** **Vigna unguiculata**
8	Calepina irregularis Cardaria draba Ludwigia peruviana Onopordum illyricum	Bromus catharticus Calluna vulgaris Echinochloa colona Leucanthemum vulgare	
9	Avena fatua Carthamus leucocaulos Chondrilla juncea Coccinia grandis Conium maculatum Echium plantagineum Foeniculum vulgare Myagrum perfoliatum Pueraria thunbergiana	Alnus glutinosa Melilotus indica Panicum repens **Paspalum dilatatum** Phalaris minor **Setaria sphacelata** Sorghum almum **Urochloa mosambicensis** Vicia sativa	
10	Amsinkia spp Cyperus rotundus Equisetum arvense Heliotropium amplexicaule Homeria miniata Ligustrum lucidum Lycium ferocissimum Scolymus maculatus Senecio pterophorus	Brachiaria decumbens Citrullus lanatus Ecballium elaterium **Paspalum notatum** Pennisetum purpureum	
11	Ambrosia confertiflora Cenchrus echinatus Heliotropium europaeum Hypericum perforatum Kochia scoparia Onopordum acaulon	Ailanthus altissima Eragrostis tenuifolia Erica lusitanica Pennisetum pedicellatum Toxicodendron succedaneum	Dactyloctenium aegyptium

Table 9. Partitioning of species by WRA score and survey classification

Score	Serious Weeds	Minor Weeds	Non-weeds
Reject (continued)			
12	Asphodelus fistulosus Cortaderia richardii Echinochloa crus-galli Glyceria maxima Marrubium vulgare Orobanche ramosa Picnomon acarna	Axonopus compressus Centaurea nigra Chloris barbata Diplotaxis tenuifolia Euphorbia lathyris **Pennisetum clandestinum** Silene vulgaris	Stylosanthes guianensis
13	Brachiaria mutica Centaurea calcitrapa Chrysanthemoides monilifera Oxalis latifolia Sida rhombifolia Thunbergia grandiflora Zantedeschia aethiopica	Andropogon virginicus Gomphocarpus fruticosus Iva axillaris Paspalum distichum **Phalaris aquatica**	
14	Ageratina adenophora Ambrosia tenuifolia Cytisus scoparius Euphorbia terracina Nassella trichotoma Salvia reflexa	Citrullus colocythis Euphorbia heterophylla Pennisetum polystachion	
15	Acanthospermum hispidum Calotropis procera Cenchrus incertus Eichhornia crassipes Holcus lanatus Homeria flaccida Juncus acutus Senecio madagascariensis Solanum elaeagnifolium Sporobolus africanus	Pennisetum macrourum	
16	Cabomba caroliniana Carduus nutans Chromolaena odorata Cortaderia selloana Cryptostegia grandiflora Cynara cardunculus Protasparagus plumosus Sagittaria graminea Silybum marianum	**Panicum maximum var. trichoglume** Reseda lutea Typha latifolia	
17	Alternanthera pungens Ambrosia artemisiifolia Carthamus lanatus Centaurea solstitialis Convolvulus arvensis Dittrichia graveolens Myrsiphyllum asparagoides Sarothamnus scoparius	Anthemis cotula Hypericum tetrapterum Sorghum X almum	
18	Cyperus aromaticus Cyperus eragrostis Parthenium hysterophorus Pistia stratiotes	Ceratophyllum demersum Genista monspessulana Hypericum androsaemum	

Table 9. Partitioning of species by WRA score and survey classification

Score	Serious Weeds	Minor Weeds	Non-weeds
Reject (continued)			
19	Allium vineale Ambrosia psilostachya Baccharis halimifolia Carduus pycnocephalus Eriocereus martinii Pyracantha angustifolia Senecio jacobaea Ulex europaeus Xanthium occidentale Xanthium spinosum		
20	Acroptilon repens Cortaderia jubata Lagarosiphon major Opuntia robusta Opuntia stricta Opuntia vulgaris Protasparagus aethiopicus	Hydrilla verticillata Pennisetum villosum	
21	Cirsium arvense Cirsium vulgare Lantana camara	Allium triquetrum	
22	Alternanthera philoxeroides Cuscuta campestris Egeria densa Opuntia aurantiaca Scolymus hispanicus		
23	Elodea canadensis		
24	Onopordum acanthium		
25	Sagittaria montevidensis Sorghum halepense		
26	Ageratina riparia		

4. References

Anon. (1992). International Plant Protection Convention. Rome, FAO.

Anon. (1995). International Standards for Phytosanitary Measures. Sections 1. Guidelines for Pest Risk Analysis (draft standard). Rome, FAO.

Hazard, W. H. L. (1988). Introducing crop, pasture and ornamental species into Australia - the risk of introducing new weeds. Australian Plant Introduction Review **19**, 19-36.

Hnatiuk, R. J. (1990). Census of Australian vascular plants. Canberra, Australian Government Publishing service.

Holm, R. J., Pancho, J. V., Herberger, J. P. and Plucknett, D. L. (1979). *A geographical atlas of world weeds*. New York, John Wiley and Sons.

Panetta, F. D. (1993). A system of assessing proposed plant introductions for weed potential. Plant Protection Quarterly **8**, 10-4.

Panetta, F. D., Pheloung, P. C., Lonsdale, M., Jacobs, S., Mulvaney, M. and Wright, W. (1994). Screening plants for weediness: a procedure for assessing species proposed for importation into Australia. A report commissioned by the Australian Weeds Committee.

Panetta, F. D. and Scanlan, J. C. (1995). Human involvement in the spread of noxious weeds: what plants should be declared and when should control be enforced? *Plant Protection Quarterly* **10**, 69-74.

Parsons, W. T. and Cuthbertson, E. G. (1992). Noxious weeds of Australia. Melbourne, Inkata Press.

Scott, J. K. and Panetta, F. D. (1993). Predicting the Australian weed status of southern African plants. Journal of Biogeography **20**, 87-93.

Part II. Weed Risk Assessment manual

Part III. Appendices