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25228 Principles for prioritising exotic pests.
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Summary

This is a review of a range of current risk assessment protocols for live organisms, condensed into an overriding set of themes. The themes, extracted from protocols, are evaluated using qualitative and quantitative data to elucidate the ranking of pest species on the basis of their invasive ability in Australia and are generally confined to assessing a single taxon. Five overall themes are fundamental to the majority of protocols: pathways of entry; establishment; potential distribution; impact in environmental, economic and social systems; and feasibility of management (including surveillance, detection and control).

The themes separated into two areas: the first being the probability and potential of the species to invade and spread in Australia; and, the second being the impact on the environment, economy or social systems. Pathways, establishment, potential distribution and feasibility of control can be effectively analysed using a Bayesian network approach. A generic framework for such an analysis was prepared and is included in this report. The impact of an invasive pest is best assessed using multi-criteria decision analysis (MCDA). MCDA provides the opportunity to examine conflicting interests and objectives. The underlying trade-offs can be examined and the impact of alternate choices can be quantified in the final rankings. A set of parameters and measurement techniques for an MCDA, ranking the importance of invasive non-primary industry pests is proposed in this report.

A subset of the Weeds of National Significance list was used to assess the robustness of rankings within a single MCDA methodology. Different MCDA methodologies were examined using 11 different pests selected from the Northern Australia Quarantine Strategy pest lists. These pests were selected from different taxons to examine the feasibility of applying the MCDA framework across different taxa. Notes from two workshops are to be included in the appendices of this report.

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Prioritising the impact of exotic pest threats using Bayes net and MCDA methods.

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Disclaimer

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Glossary

The key terms used in this report are defined as follows:

Bayesian network: a probalistic model that represents a set of variables and their probabilistic interdependencies. A Bayesian network has assumed and/or explicit sets of understandings embedded in the network and is an ideal representation for combining prior knowledge (which often comes in causal form) and data.

ELECTRE: (Elimination and Choice Expressing the Reality) the earliest and simplest outranking methods used in multi criteria decision analysis.

Entry pathway: pathway by which a species is introduced to a novel habitat outside its natural habitat.

Establishment: A non native species forming self-sustaining populations outside its natural habitat.

Expert opinion*:* qualitative information provided by reputable professionals working in the area, usually elicited through structured interviews, cross referencing, clarification, peer review and secondary consultation.

Exotic pest**:** a species, outside its natural habitat (introduced either deliberately or unintentionally), that has the ability to establish, spread, out-compete natives, take over new environments and cause detrimental impacts in natural environments.

Impact: for the purposes of this study, and economic, environmental or social change, positive or negative, that is measured qualitatively or quantitatively.

Invasive species: an exotic species that establishes a wild population, spreads beyond the place of introduction and becomes abundant.

Outranking: method that focuses on a series of pair-wise comparisons of choices that incorporates the use of qualitative data. It assists decision makers in choosing the best alternative(s) from a given set of alternatives by comparing, in a comprehensive way, each pair of alternatives.

Parsimony: the practice of using the smallest number of parameters in a model to avoid over-fitting the model because each parameter adds additional uncertainty to the model.

PROMETHEE: (Preference Ranking Organization Method for Enrichment Evaluations) an outranking method used in multi criteria decision analysis that applies thresholds and preferences to performance criteria.

Spread: an increase in abundance and dispersal following successful establishment.

1. Summary

1.1. Aims

To review key themes used in current pest risk assessment protocols and identify areas not adequately addressed in these protocols.

To examine multi criteria decision analysis (MCDA) methods and their application to assessing the impact potential pests might have on Australian economic, environmental and social values and structure.

1.2. Summary

Invasive species can have significant impact on Australia's unique landscape in addition to causing economic loss. Determining which exotic species will disrupt native ecosystems can be difficult and, with many conflicting interests, assigning funding is not a simple decision. MCDA provides an opportunity to assess the relative significance of invasive species and to examine trade-offs by manipulating input criteria and weightings.

There are several areas pertinent to the probability of establishment that many existing pest risk assessment protocols do not focus on such as: the number and frequency of use for entry pathways; geographical proximity of the pest; propagule pressure; and physical limitations to the spread of the pest. Careful consideration of these parameters can elucidate the probability of establishment and spread.

The impact of a pest is often difficult to interpret because of conflicting interests or lack of objective data. A review of the current pest risk assessment protocols indicated that many of them did not address social and cultural concerns or the risk of increased threat of extinction of native species. It is in examining the complexities related to economic, environmental and social impacts that MCDA can be a useful tool for decision makers.

Over-simplified models yield results with less meaning compared to models that reflect the real-world characteristics more faithfully. However, decision makers are often faced with a lack of information on an invasive species, or expert opinion at best. A complex structural framework, incorporating such uncertainty or conflicting expert opinion may be equally unrealistic. The basic principle of parsimony should be maintained in selecting criteria to evaluate the objective (or objectives) of any assessment because it is always preferable to choose, from a set of otherwise equivalent models, the simplest one.

A simple MCDA framework, with the objective of prioritising pests on the basis on their economic, environmental and social impacts, was applied to subsets of the Weeds of National Significance (WoNS) and the AQIS/NAQS Target Pest List. Sensitivity testing of the robustness of the rankings was applied to the WoNS subset and revealed that the rankings rarely changed by more than a few places. Exceptions to this were weeds that were extreme outliers in one or more of the assessment criteria.

The data used to assess the subset of the Target Pest Lists was applied to several different published MCDA methods and the rankings compared. Changes in rank between species were evident, even when only 11 species were examined. This indicates that, *although rankings are relatively robust within an MCDA method, they vary between methods*. The use of outranking methods does provide an option to introduce preference and cut-off values for the criteria used to assess pests. The widespread use of this approach would be assisted with the use of commercial software or the development of a spreadsheet for outranking

methods like PROMETHEE (Preference Ranking Organisation Method for Enrichment Evaluations) or ELECTRE (Elimination and Choice Expressing the Reality).

The application of MCDA suggests that it is useful in clarifying strategic decisions for determining pest priorities and can be applied across taxa. A cautionary note is that the key stakeholders must decide on the most appropriate MCDA approach. This also incorporates recognition of the uncertainty introduced by the approach structure as well as that introduced from the criteria. This highlights the need for stakeholders to be actively involved in developing any framework. The outcome of using this support tool more widely would increase confidence in the decision process because it is a transparent and structured participatory process, whether it is used for assigning funding priorities or determining the best management technique.

1.3. Recommendations

- Expand the existing framework into a generic framework in conjunction with stakeholders by reaching a consensus on which attributes best describe the MCDA objectives and define preferred weightings and aggregation methodology.

- Validate various MCDA methodologies against real life problems, particularly in relation to conflicting interests and trade-offs between criteria.

- Examine the robustness of the results within and between the MCDA methodologies by applying sensitivity testing.

- Develop an accessible user friendly spreadsheet for either PROMETHEE or ELECTRE approaches for use by Federal, State and Territory agencies.

2. Introduction

2.1. Background

Determining which exotic species will disrupt native ecosystems can be difficult. Many interests compete for limited funding and there are often conflicting opinions about the potential benefits or risks a non-native species could provide to existing systems within Australia. For example, a novel bio-control agent may be introduced to control an existing exotic pest, or a new pasture grass could be introduced to expand grazing potential. Both introduction scenarios present substantial environmental or industry benefits and the associated risks of establishment are assessed very differently under the current Australian import frameworks relevant to each scenario.

The number of potential pests far outweighs the capacity to develop management strategies and this is especially true for environmental pests. The decision to include a pest on a priority target list has important consequences. Inclusion on a list focuses public attention on a pest, which may raise its profile in a self-perpetuating cycle. This has positive and negative effects. For instance, the identification of some key pests identified through PLANTPLAN has been valuable because this has prompted the development of diagnostic, surveillance and response strategies that are widely applicable to a whole class of related pests. Conversely, pests placed on lists without regard for key components of preparedness or management can lead to expenditure that is later found to be unwarranted because little can be done to prevent widespread establishment.

Considerable effort has been expended on compiling pest prioritisation lists for primary production areas. With the exception of the Department of the Environment, Water Heritage and the Arts (DEWHA) environmental alert listed weeds (http://www.weeds.gov.au/weeds/lists/alert.html) there is no pest prioritisation for non-primary production landscapes. Such landscapes include parks and biological preserves in all jurisdictions and areas of cultural and recreational significance. This is a serious omission, as the introduction of non-native species has already had a devastating effect on national parks and reserves in Australia, New Zealand, South Africa, and North America (Vitousek et al. 1996).

The impacts of invasive species on natural ecosystems include: reduction and extinction of native species through competition, predation, disease and genetic extinction; loss of native vegetation and/or altering vegetation structure; altering ecosystem processes; soil erosion; and changing fire regimes (Bomford 1991 Bomford 2003 Vitousek et al. 1996). Despite a relatively small proportion of exotic species becoming pests (Williamson and Brown 1986), several authors believe that all exotic species establishing wild populations have had impacts that outweigh any benefits (Laycock 1966 Roots 1979 cited in Bomford 1991 Bomford 2003). While it is the only realistic fiscal measure, the use of market values to estimate current or future worth of a natural environment is problematic and will remain a matter of subjective judgement.

Any framework for prioritising potential invasive species of non-primary production land depends on knowledge of what constitutes a successful invader in the first place. Past evidence shows that predicting likely invasive species based on a set of generalised species characteristics is often inconclusive (Hobbs and Humphries 1995 Mack et al. 2000). This is because successful invasion depends not only on invading species characteristics, but also on the characteristics of the environment being invaded and the interaction of human activities (Lonsdale 1999).

Predicting invasions with a narrower focus, such as within taxonomic groups, is more successful, but still remains an imprecise science. The predictability of a newly introduced species becoming a pest has been demonstrated for: weeds in Australia (Pheloung et al. 1999) and New Zealand (Williams and Newfield 2002); pines and woody weed species (Rejmanek and Richardson 1996); and fish in North America (Kolar and Lodge 2002) and California (Marchetti *et al.* 2004). The intention of this project is to condense key themes from risk assessment protocols used to evaluate a range of taxonomic groups and localities and examine a generic framework that could be applied to a range of potential pests.

3. Methods and Results

3.1. Review of current risk assessment protocols

Assessing and communicating the risks posed by invasive species is complicated. Resources, such as funding and time, are limited and determining priorities to prevent or manage an invasive species are not easily decided. Risk assessment protocols or prioritisation lists provide tools that can be used to support the exclusion of invasive species or assess the potential impact established pests. They provide a formal process for gathering, analysing, synthesising, comparing and communicating information. This assists the decision-making process because it is important to have defensible assessment processes, based on robust science so that species providing an economic (e.g. biofuels) and/or environmental (e.g. biocontrols) benefit can be introduced while future pests can be excluded.

The objectives of such protocols are to develop priority lists and are usually an estimate of relative rankings of risk, based on a prediction of whether or not a species is likely to be invasive. However, the final ranking is the result of a focus on specific areas. Thus the ranking can alter depending on the focus. For example, concerns may focus on a pathogen that affects a specific localised Australian species or on the scale of the impact on entire ecosystems. The relative rankings are valid provided the respective impacts are able to be correctly identified and quantified, although the results must only be considered in context of the intended application.

Twenty such risk assessment protocols were examined to determine the core themes covered within the data gathering process (Appendix 1: Risk Assessment Protocols Evaluated1). These core themes were then used in developing a Bayes net assessment protocol for assessing the likelihood of a pest reaching and establishing in Australia.

Current prioritisation assessment protocols for invasive species tend to be based on species' attributes and there is often variation in scope, type and quality of information available. For example, predictions on a cryptic species, environmental or economic impact are often reliant on expert opinion rather than on specific data (e.g. Martin et al. 2005). Expert opinion is of substantial use, but the effect of linguistic (context and definitions) and epistemic (knowledge about) uncertainty needs to be accounted for when determining risk (Regan et al. 2002). The difficulty of measuring environmental and social impact in financial terms has been noted by many authors using risk assessment. Lack of life history data for many species can also be problematic, with closely related species often being used as surrogates.

Evaluation of pest risk assessment protocols were distilled into five themes (Table 1):

- Pathways of entry
- Invasiveness
- Potential distribution
- Impact on environmental, economic and social systems
- Feasibility of management (including surveillance, detection and control).

Table 1 Percentage of risk assessment protocols considering the listed themes**.**

Principles assessed (qualitatively or quantitatively)	% assessments considering the criterion (N=21)
A. Entry/Pathways	
1. Current global distribution	43
2. Geographical proximity to country undertaking risk assessment	24
3. Rate of international transport	10
4. Number of potential entry sites	33
B. Establishment	
1. Invasiveness elsewhere	67
2. Domestication	24
3. Establishment among existing communities	52
4. Reproductive mode	62
5. Dispersal Capabilities	76
6. Propagule Supply	19
C. Potential Spread	
1. Climate match	52
D. IMPACT	
Environmental	
1. Reduction in or limiting to indigenous species	81
3. Impacts on faunal/floral health	86
4. Physical limitations	24
5. Negative ecosystem changes	76
6. Positive interaction with other invasives	33
Economic	
1. Cost of controlling or managing pest	52
2. Loss of primary production	52
3. Loss of tourism	19
Social	
1. Human health	76
2. Amenities	29
3. Heritage values	19
E. FEASIBILITY	
1. Technical capability (control / eradicate)	48
2. Stakeholder support	38
3. Cost sharing / responsibility	19
4. Risk of eradication to natives	10
5. Unexpected benefits	5
Full table shown in Appendix 1	

Entry pathways
The current global distribution of the potential pest was examined in 43% of risk assessment protocols. Few examined the number of potential entry sites (33%), the proximity to Australia (24%) and even less considered international trade routes or the frequency with which these routes are used (10%).

Establishment
Establishment was examined more thoroughly by the majority of assessments. However, criteria such as propagule pressure and domestication were less frequently examined (19 and 24% respectively).

Potential spread
Despite the published literature highlighting the relationship between climate match and probability of dispersal, only 52% of assessment protocols examined climate match in relation to probable spread. This is despite published reports that the most effective predictors of invasiveness are that: the species was invasive elsewhere; had a fast growth rate; and climate of the introduced region matches that of the native range (e.g. Bomford and Hart 1999 Herron et al 2007).

Impact
The majority of assessments examined possible effects of a pest on the environment, the economy and the human community. Physical limitations, such as natural barriers preventing additional impact on the environment were assessed infrequently (24%) and about one third (33%) of assessments questioned whether a pest would provide environmental benefits such as decreasing salinity, stabilising soil or providing a resource to an indigenous species. Over half (52%) assessed the economic impact of controlling a pest or its effect on primary production. Nineteen percent considered potential impacts to tourism. The impact to human health was a high priority with 76% of assessments considering possible impacts in this area. Loss of amenities and cultural impacts were less frequently assessed (29 and 19% respectively).

Feasibility of prevention or management
Given its importance for successfully preventing establishment or managing a pest over the longer term it was surprising that only 48% of assessments examined the feasibility of eradication or control. The long term nature of managing a non-primary industry exotic pest also requires stakeholder support yet only 38% of assessments considered the level of potential support. The need to consider cost-sharing or possible damage to native species was often not considered, with only 19 and 10% of protocols examining these areas, respectively.

Consequently, it appears there is a need to provide additional focus on areas where subjective assessments can cloud issues or where current assessments fail to clarify possible effects. By adopting methods that address these two issues concurrently stakeholders and decision makers can only improve the decision making process.

We propose that the best approach for an assessment system is to expand the assessment of entry, establishment and spread to include criteria that will encompass trade routes, propagule pressure, climate and the probability of reaching Australia. The probability of spread once established will include an assessment of the feasibility of control. These will be examined using a Bayesian net approach to provide a probability of spread once in Australia. Multi-criteria decision analysis (MCDA) was then used to assess environmental, economic and social impacts. This assessment was combined with the probability of spread to give a score that can be used to prioritise pests according to their potential impact.

3.2. Development of a generic framework for determining establishment and spread of a pest

The key components of a generic risk analysis divide the framework into two parts. The first part can be described as the potential for the organism to establish and spread. The second part provides an opportunity to prioritise the pests by considering the performance of specified criteria against stated objectives, e.g. ranking which pest has a higher impact environmentally, economically or socially, or the effect of strategic management decisions on these parameters. The first part can best be analysed using a Bayesian net approach. This approach organises the use of expert opinion through clearly posed questions about the likelihood of clearly defined events (Maguire 2004) and is a well used method for assessing the establishment and spread of a species. The assumptions used to determine risks associated with pathways and establishment of potential pests are logically and transparently described within the context of probabilities for each stage.These can be combined to produce an overall probability of an event occurring.

The second part of the assessment is open to subjective interpretation of conflicting interests and/or changing objectives. Such data sets can best be explored using MCDA. MCDA is used to identify fundamental objectives and alternatives, to quantify the impact of alternative choices on stated objectives, to examine trade-offs and to elicit and apply value judgments. The result is a ranking of alternatives that inform policy decisions, because the performance of each alternative in meeting each criterion is characterised, along with the uncertainties associated with that performance. This increases stakeholder understanding of the nature of the value conflicts and trade-offs among criteria so that recommendations and valuations can be made with confidence.

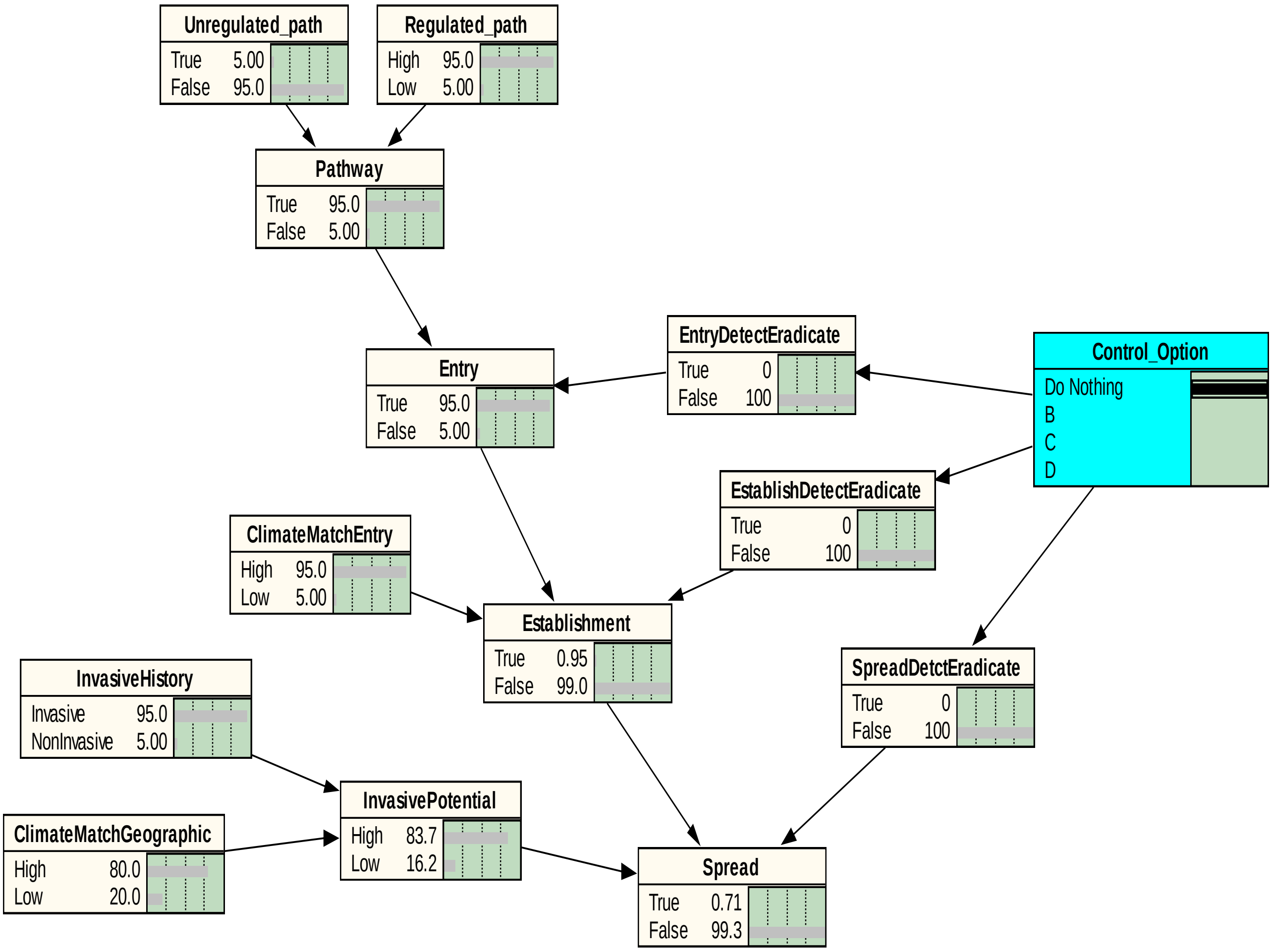

Figure 1 Hypothetical Bayesian net analysis to estimate the probability of spread of an invasive pest showing criteria considered in assessing potential spread of a pest in Australia (Burgman et al. 2007). ‘True’ / ‘False’ and ‘High’ / ‘Low’ represent possible states against which a percentage probability of the state is specified, based on data or expert judgement.

3.3 MCDA Methodology

MCDA techniques can be used to identify a single most preferred option, to rank options, to list a limited number of options for subsequent detailed evaluation, or to distinguish acceptable from unacceptable possibilities (Dodgson 2000). There are many MCDA methods and they differ in how they combine and use data, but the basic framework is a clear definition of the desired outcome, breaking the problem down to its facets, determination of which criteria best represent these facets and how they should be aggregated (Figure 1).

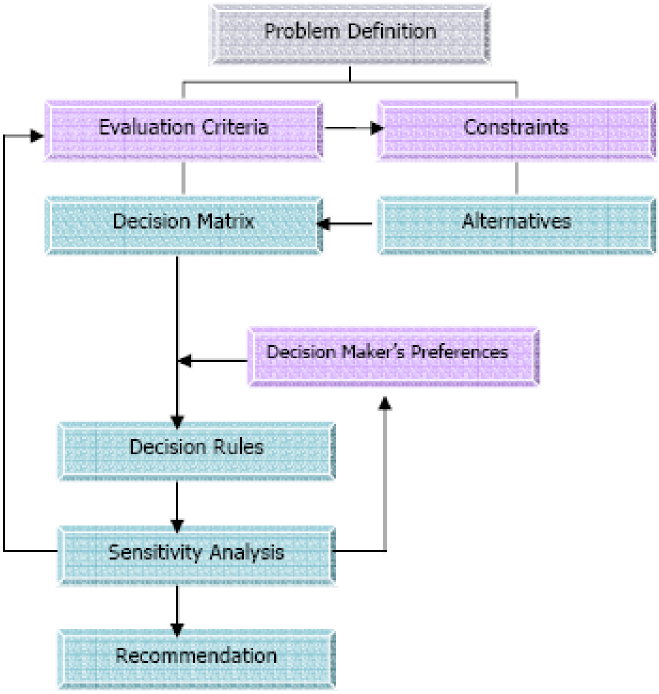

Figure 2 Schematic diagram of MCDA process (source: Malczewski 1999).

The MCDA Weighted Sum Aggregation Technique (WSAT) method adopted in this approach is that proposed by Belton and Stewart (2002) and involves the following basic steps:

- define objectives (problem)
- creation of a decision hierarchy and criteria to assess alternative strategies or pests
- weighting the criteria relative to their importance to the objective, and evaluating each alternative with respect to each criteria
- determining the overall priority of each alternative and obtaining a ranking of alternatives
- investigate trade-offs and conduct a sensitivity analysis to better inform decision makers.

Like any system based on comparisons of different alternatives, MCDA is subject to criticisms. It is possible that different hierarchies, applied to identical problems, can cause major changes in results even if the hierarchy is changed in minor ways. In addition, there is no statistical theory underlying the process. It has been suggested that these concerns are mostly theoretical or speculative and the process works well in practice, even if minor rank-reversals occur. However, the criticisms do highlight the need to undertake sensitivity testing and estimate uncertainty associated with any of the criteria examined.

Weighting criteria

Different criteria have different levels of importance depending on the objectives of the decision strategy. Consensus on a weighting in group decision making is frequently achieved by the experts/stakeholders shifting their opinion until mutual consent is reached. Such shifts are the result of laborious negotiations, which escalates the cost of reaching the consensus as each criterion must be negotiated independently from the others. MCDA does not require consensus building, but rather encourages agreement on action. The process assists stakeholders in seeing where the best potential for action(s) lie (Maguire and Boiney 1994).

Individual preferences in weightings provide an opportunity to examine the variance associated with a criterion and the confidence stakeholders would have in the subsequent ranking of that alternative (see Cook and Proctor 2007).

There are a number of approaches to determine weightings. One often-used approach is to divide a number of points (typically 100) between the criteria, in line with their perceived weighting relative to each other. Alternatively, a more qualitative approach may be used (e.g. ‘essential’ versus ‘desirable‘ versus ‘irrelevant’).Weightings should be established prior to the evaluation of individual MCDAs to ensure that stakeholders understand how a decision has been reached. Some examples include:

- *Ranking:* the simplest method for evaluating the importance of weights, it requires every criterion under consideration to be ranked in the order of decision makers preferences. The method is very attractive because of its simplicity, but as more criteria are used this method becomes less useful and it does not provide any information on the importance of criteria in relation to each other.

- *Rating:* requires the decision makers to estimate weights on the basis of a predetermined scale. Like the ranking method, the disadvantage of this method is that it is often difficult to define the theoretical foundation, making the assigned weights difficult to justify.

- *Development of a pair-wise comparison matrix:* scales the weightings (e.g. 1 to 9, representing low through a series of steps to high importance). The advantages of this method are the only two criteria have to be considered at a time and it can be implemented in a spreadsheet environment (Kirkwood 1997). On the other hand, the relative importance of evaluation criteria is determined without considering the scales for different criteria measurements. Another disadvantage is that if you have many criteria the number of pair-wise comparisons will be very large.

- *Trade-off analysis method:* decision makers are required to compare two alternatives with respect to two criteria at a time and assess which alternative is preferred. There is an assumption in this method that the trade-offs the decision makers are willing to make between any two criteria will not depend on the other criteria (Malczewski1999). The weakness of this method is that the decision maker is presumed to obey the assumptions of independence between criteria and can make fine grained preference judgements between criteria. On the other hand, the method can be implemented within the spreadsheet environment (Kirkwood 1997).

Aggregating the criteria – decision rules

Several aggregation methods exist and may produce different rankings when applied to the same matrix. This may cause some concern to stakeholders and decision makers, but there is no ‘right’ ranking and the results of an MCDA should always be viewed as a decision support tool and not taken literally. Types of algorithms used include weighted summation or weighted product (for the case of trade-off utility modelling or goal programming), concordance and discordance analysis (outranking methods). Examples of the approaches used include:

- *The Weighted Summation Aggregation Technique (WSAT):* essentially this technique produces a unique score that allows relative comparisons across all alternatives. The advantage of this method is that it is a proportional linear transformation of the raw data, which means that the relative order of magnitude of the standardised scores remains equal. However, the assumption of additive utility, when dealing with comparable multidimensional criteria, may not be valid.

- *The Weighted Product Aggregation Model (WPAM):* uses multiplication instead of addition to rank alternatives. Each alternative is compared with others in terms of a number of ratios, one for each criterion. Each ratio is raised to the power of the relative weight of the corresponding criterion in order to compare two alternatives. This model eliminates any units of measurement.

- *The Analytical Hierarchical Process (AHP):* decomposes the problem into a hierarchy of easily comprehended sub-problems, each of which can be analyzed independently. Once the hierarchy is built, the decision makers systematically evaluate the various elements, comparing them to one another in pairs. This method is subject to the possibility of different hierarchies being applied to identical problems, causing major changes in results even if the hierarchy is only changed in minor ways. The process is also vulnerable to rank reversals if additional alternatives are added. There are also concerns about the absence of underlying statistical theory in this process despite it following established rules.

- *Outranking relationships:* an outranking relation allows a decision maker to conclude that one alternative outranks another if there are enough criteria confirming that the first is at least as good as the second. Outranking methods include ELECTRE (Elimination and Choice Translating Reality), PROMETHEE (Preference Ranking Organisation METHod for Enrichment Evaluations) and TOPSIS (Technique for Order Performance by Similarity to Ideal Solution). Some of the advantages are that it uses the least amount of information and it can consider both objective and subjective criteria. However, complete ranking of the alternatives may not be achieved because the method requires comparison across alternatives and some alternatives may be incompatible or completely equal under the weightings, preferences and cut-offs that are used.

MCDA is regarded as a process to determine the best feasible solution according to criteria representing different effects and values. Criteria frequently conflict with each other and there may be no solution that satisfies all criteria at the same time. MCDA provides an opportunity to explore different solutions and the effect on the various alternatives being examined. There are many methods and determining which is the most appropriate depends on the preferences of the stakeholders and decision makers who must be active participants in defining the problem, objective and criteria to be included.

WSAT is the simplest and most commonly used application of a MCDA (see: CRC Australian Weed Management (2005)) *A Draft Strategy for the Research and Development Component of the Defeating the Weed Menace Programme: A Consultancy Report to Land and Water Australia*). The value of an alternative is given by:

$$V(w, v) = \Sigma_i w_i v_j$$

Where:

V = weighted value or overall score for a given alternative

W_i = weight for a given criterion i

V_j = score for criterion i for a given alternative. This method was applied to a subset of the Weeds of National Significance (WoNS) list to investigate how altering the weightings applied to each criteria changed the ranking of the weeds (see section 3.6) because it is the most commonly used application of MCDA.

Ranking alternatives

The outcomes on economic, social and environmental factors are ranked using a simple weighted summation technique. The alternatives can then be ranked depending on composite scores. The alternative with the greatest composite score is the best alternative. Exploration of trade-offs can be made by examining the weightings applied to each criterion and determining how the rankings change.

Stability of ranking through sensitivity testing

The weighting given to each criterion is significant in determining priorities. Thus, it is important to establish the stability of the rank order of alternatives. This requires sensitivity analyses through development of scenarios showing different criteria weights and determining a new set of rank order priorities based on these scenarios. Decision makers can then use the output from the MCDA (including sensitivity analysis) as a key input to making informed, transparent and repeatable decisions.

3.4 **Using MCDA to prioritise exotic pests**

It is assumed that the probability of a pest spreading in Australia has been estimated by experts using an appropriate Bayesian network based on the species' attributes (see Figure 1). Predictions from the Bayesian network together with the MCDA score are used to rank the hypothetical pests according to overall impact and invasive potential by multiplying the probability of spread with the impact score. The alternatives can then be ranked, from highest to lowest score. Sensitivity analyses through development of scenarios using different criterion weights should be undertaken to determine the robustness of the final ranking and the criteria that have most effect in determining that ranking.

It is important to remember that despite MCDA returning a numerical value, the values are dependent on the assumptions used to formulate them. Thus, although the values themselves are arbitrary, except in relation to each other, they are based on a series of logical steps and stated criteria and can be used as a key input to making informed, transparent and repeatable decisions.

Placing a monetary value on the economic, environmental or social value of non-primary industry resources is a stumbling block to assessing the impact of a pest. The use of surrogates as indicators is a cost-effective, rapid and crude measurement of assessing the effects a pest may have on biodiversity. However, indicator relationships cannot always be assumed, because their response can also be weak, absent or even the inverse of what might have been expected. This is particularly true when indicator and target species differ in their habitat associations because different factors govern their distributions.

The major objective of this study is to consider use of MCDA to investigate the potential impact of an invasive pest on the economic, environmental and social structure currently present in Australia. The framework presented here is not intended to be a comprehensive list of criteria that would be used to assess such impacts and the following areas represent some basic indicators for measuring impact on natural systems that could be adapted for use in MCDA.

<u>Loss of conservation areas</u>

One way of estimating the loss of conservation area is to identify known conservation areas falling in the region of potential spread for the pest. This can be calculated as a percentage of total conservation area or a percentage of the total land mass for Australia. Conservation land can be loosely defined; however for consistency, 'Class 1 – Conservation and Natural

Environments' from the 'Australian Land Use and Mapping (ALUM) classification (http://adl.brs.gov.au/mapserv/landuse/alum_classification.html). This classification and affected conservation land as a proportion of Australia's land mass was used for this study.

Decrease in biodiversity

There are many ways to measure decreases in biodiversity. When dealing with large numbers of species, species richness tends to become a reasonable surrogate for biodiversity. Higher taxon richness (using genera or families) is an attractive parameter. It is suitable for use for a greater number of surveys if it allows the taxonomic coverage to be broadened without increasing costs. The choice of taxonomic rank (Class, Order or Family) to survey must be made with care and there are potential pitfalls (see Williams and Gaston 1994).

Nonetheless, the approach shows promise and several studies now support the idea of a relationship between the numbers of higher taxa, such as families, and the numbers of species among areas (Balmford et al*.* 1996 Williams et al*.* 1997). Rare or Threatened Australian Plants (ROTAP) is a list of rare or threatened Australian plant taxa developed and maintained by the CSIRO. Additional resources include Department of Environment, Water, Heritage and the Arts (http://www.environment.gov.au/cgi-bin/sprat/public/sprat.pl) or State/Territory conservation agencies. Such sources could also provide additional information, such as identifying a geographic range for a rare or endangered plant that is susceptible to the pest.

Health risks

Infections, poisonings or injury caused by pests can be quantified through costs associated with isolation, quarantine and treatment. However, other health effects are less easily quantified. Cases of mild irritations or allergies are often not reported or not associated with a specific pest. Where identified the frequency or severity of cases can be used as a parameter to estimate the health risk to humans, animals or plants. Some species may act as vectors or hosts for pathogens, weeds can provide habitat for mosquitoes that carry disease. The abundance and distribution of these vectors can be used as surrogate estimates of health risks.

Access to wild cultural resources

Wild resources refer to native flora and fauna and their direct use value to indigenous peoples, traditional sites and opportunities associated with cultural and eco-tourism. Many indigenous sites have been placed under protection, but many others, particularly indigenous foods remain unprotected and widely scattered over a region. The loss of access by indigenous cultures to significant fauna and flora can be represented by loss of access to known heritage sites. For example, a total of 2,724 heritage places have been identified in the Fitzroy Catchment, Queensland (Windle and Rolf, 2003). Listed sites falling within a region identified as susceptible to infestation can be used as a surrogate for indigenous cultural impact. To some extent this remains an arbitrary value, but one that can be consistently applied across all alternatives. An alternative, given that many cultural resources are not listed or scattered widely, is to estimate the potential loss of indigenous or other protected areas falling in the region of potential spread for the pest in the same way that affected conservation area is estimated.

Public concern

The level of public concern (or acceptance of a pest) can be measured through levels of media interest, participation in public for a, consultation with community groups, such as Frog watch, Waterwatch and Landcare. While there is a risk of a particular pest obtaining a high profile in the media through perceived rather than actual impacts, this does not alter the fact that the pest has become a community concern. Using ‘public concern’ as an indicator is a problem because it is usually a retrospective value rather than a predictive tool. However, it may still be valid for lists dealing with established species. Indicators could include a review of common national media sources over a stated time period, to provide a frequency for which articles or letters to the editor related to the pest appear. A review of the internet can provide a frequency of public fora and workshops devoted to discussions about the pest of interest. The frequency of these events can be added to the frequency of media articles to provide a proxy value for public concern.

Value of land affected

The cost of managing an invasive pest is not only the cost of controlling or eradicating the pest on a per hectare basis; it also includes the cost of restoring ecosystem services to their condition prior to the invasion. Crude measures of change in value of the land affected remains a useful estimator. The value is calculated from a dollar value per hectare of the natural land affected multiplied by the percentage of that land type predicted to be affected by the pest. Such a value does not take into account the potential for areas to be important on a local, State/Territory, national or international scale. Stakeholders may feel more comfortable with breaking down affected areas into smaller land use categories (such as: World and Natural Heritage areas; Ramsar Treaty Wetlands; Significant Wetlands of Australia; special State and Territory conservation areas; areas identified under the Regional Forest Agreements) and other natural and conservation areas. This allows different weightings to be applied to each.

Benefit to industry or indigenous species

International commerce in live organisms presents a policy challenge for trade globalisation. Sales of live organisms create wealth, but some non-indigenous species cause harm whether introduced deliberately or accidentally. Calculating net positive gains from any of these incidents is complicated because only a small proportion of all introduced species escape, spread and cause harm. Invasive species are rarely eradicated and their damages are borne for long periods, further compounding the problem. Benefits come from the economic activity exotic species generate or retrospectively create through becoming a resource for indigenous species (food, shelter etc).

Industry stakeholders will have an expectation of economic returns which can be used in a risk assessment. Valuing unexpected benefits to indigenous species is not as easy. Where there are published reports of such benefits to indigenous species the percentage area where such an interaction occurs may be used as a proxy value representing potential benefit. The percentage value can be calculated as the overlap of the species involved in a beneficial relationship compared to the total predicted area over which the invasive species could spread or the total land mass of Australia. Several This can be done with specialised GIS software or via user-friendly tools that the comparison of complex spatial information without the need for specialised training or technical support e.g. http://adl.brs.gov.au/mcass/index.html (**Figure 3**).

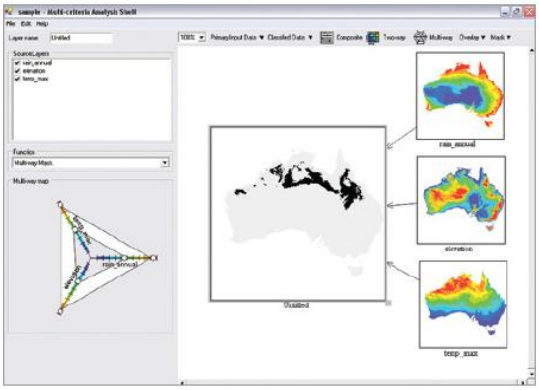

Figure 3 Example of MCAS-S software output showing how intersecting regions can be identified. In this example, the MCAS-S multi-way Mask function is used to produce black areas on the map representing regions that regions that satisfy all class values specified by the white area of the multi-way map (radar plot) in the interface panel, and the grey areas represent regions that do not satisfy these conditions.

3.5 The MCDA framework

A simplified schematic of the key processes is shown to conceptualise the context in which MCDA will be used (Figure 4).

People:

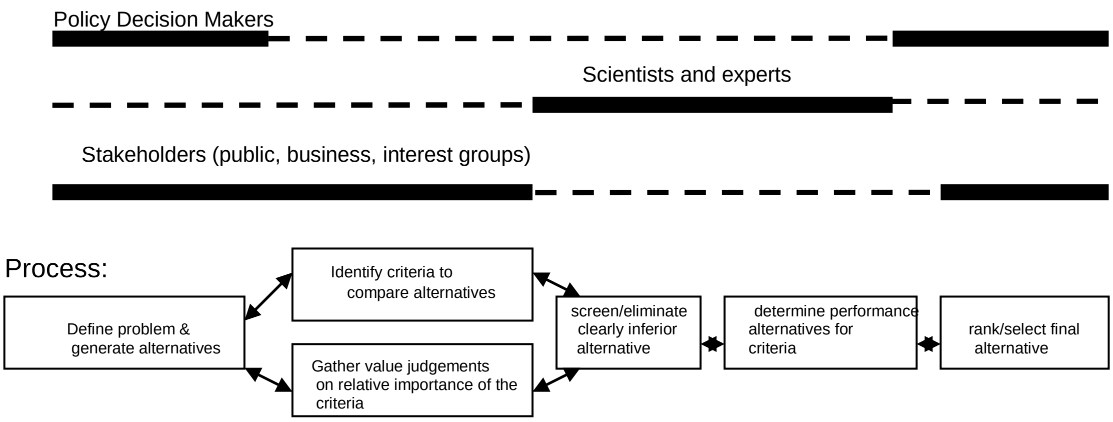

Figure 4 Diagrammatic representation of the people and processes required to formulate a robust and successful MCDA and where the majority of involvement occurs (adapted from Kiker et al. 2005).

In the example described (Tables 2 to 4), the pests become the alternatives to be evaluated against a set of criteria used to describe the magnitude of the impacts on the environment, the economy and the community. Values for each criterion are collated into the initial matrix (Table 2). At this point it is often possible to identify pest species that have an overwhelming impact in all categories and further simplify the matrix as these species become a high priority. More frequently, the final ranking will depend on how each criterion is standardised and weighted by the stakeholders. For example a simple addition of the values in Table 2 would result in ranking the pests as $pest_2$, $pest_1$, $pest_n$, $pest_3$. Without standardising the criterion across the alternatives (e.g. from 0–100 or 0–10), unintentional bias for a specific criterion can be introduced.

Table 2 Simplified matrix of alternatives and criteria used to prioritise the pest with respect to impact.

Criteria	Alternatives			
	$Pest_1$	$Pest_2$	$Pest_3$	$Pest_n$
Environment				
# Species declining	34	71	23	15
# Key environmental assets affected	3	0	10	1
Economy				
Cost per hectare ($)	400	450	100	400
Social				
Cultural	1	2	1	5
Loss of recreational area	0	1	3	0

The initial matrix is standardised. In this example standardisation has been achieved by scaling all values as a percentage of the highest value (Table 3). For example, the number of species declining for pest one becomes (34 x 100)/71). The result is a standardised dimensionless matrix, which is only suitable for some MCDA methods.

Table 3 Standardised matrix of alternatives and criteria used to prioritise the pest against impact, with each alternative scaled as a percentage of the highest value.

Criteria	Alternatives			
	$Pest_1$	$Pest_2$	$Pest_3$	$Pest_n$
Environment				
# Species declining	47	100	32	21
# Key environmental assets affected	30	0	100	10
Economy				
Cost per hectare ($)	89	100	22	89
Social				
Cultural	20	40	20	100
Loss of recreational area	0	33	100	0

The weightings for each criterion can then be used to provide a final weighted matrix (Table 4). In this example, using a total weighting of 100, split between the five criterion, stakeholders have determined that the loss of key iconic areas has the highest relevance (weighting = 50), followed by loss of biodiversity (weighting = 25), effects on culture (weighting = 15), with the economic perspective and loss of recreational resources assigned equal value and lowest priority (weighting for both = 5). The final matrix is then the result of the standardised value multiplied by the weighting for each criterion.

Table 4 Simplified matrix of alternatives and criteria modified by the weighting applied to each criterion used to prioritise the pest against impact.

Criteria	Weighting	Alternatives			
		$Pest_1$	$Pest_2$	$Pest_3$	$Pest_n$
Environment					
# Species declining	25	2350	5000	1600	1050
# Key environmental assets affected	50	450	0	1500	150
Economy					
Cost per hectare ($)	5	445	500	110	445
Social					
Cultural	15	525	1000	500	2500
Loss of recreational area	5	0	165	500	0
Final WSAT score		3770	6665	4210	4145

In the above example, prior to considering the weightings agreed to by the stakeholders the priority ranking was $pest_2$, $pest_1$, $pest_n$, $pest_3$. Once weighting has been applied the priority ranking changes to $pest_2$, $pest_3$, $pest_n$, $pest_1$. This reflects the objective of considering environmental and cultural impacts over economic. Alternative scenarios, with differing objectives, can be evaluated with each step being transparent.

The final step is then to take the weighted values for each pest and multiply it by the probability of that pest establishing and spreading (from the Bayesian net assessment). This score becomes an assessment of the reality of the pest spreading and causing an impact and allow the pests to be ranked according to their risk of spreading and the impact they may cause.

Each step is clearly outlined and provides an opportunity to evaluate alternatives for different weightings and priorities. While it can be argued that the structure imposes a precise value on an imprecise process it is transparent and repeatable. Decision makers can evaluate the effects of changing weightings on the rankings and determine which pests are higher priorities for a stated objective.

3.6 Applying the Bayesian net and MCDA framework to existing lists

The following MCDA framework is based on four main criteria, chosen to represent the most simplistic approach for prioritising pest species across taxa. The four criteria examined were: economic cost (or benefit); conservation areas affected; indigenous and other protected areas affected; and public opinion. This framework is not intended to be a working method to prioritise pests in terms of risk to Australia's economic, environmental and social impacts but was designed to provide a simple dataset within the context of 'impact risk' that could be used to evaluate the application of MCDA to the area.

Economic cost (benefit)

The information used to score the economic criteria was sourced from published literature or industry or health cost statistics available on web pages. No attempt was made to estimate the environmental, cultural or indirect social costs of a pest. This decision was to avoid ‘double dipping’, i.e. double counting the impact in the economic criteria and again in the environmental or public opinion criteria.

Conservation area

This criterion did not address the number of indigenous species that could decline as a result of the pest spreading into the Australian landscape. It was estimated simply as the proportion of conservation area to total Australian land mass that would be affected by the uncontrolled spread of the pest. Similarly, the number of rare or endangered species under threat or the number of iconic areas potentially lost was not considered in the assessment. Conservation area potentially affected did not evaluate the breakdown of different areas affected (e.g. Ramsar treaty wetlands; other significant wetlands; areas forming Regional Forest Agreements, National Parks, Crown land). Further sub-grouping environmental land affected could be a useful step in some MCDAs so that different weightings can be applied to different classes of land use.

Indigenous or other protected areas affected

This criterion was estimated as the proportion of indigenous (or other) area to total Australian land mass that would be affected by the uncontrolled spread of the pest. No attempt to assess the number of heritage listed or iconic sites that would be affected was made.

Level of public concern

The level of public concern was estimated from the number of Australian media articles found on the internet over a five year period 2001–2006. There was no cross checking for duplicated articles reprinted by various media outlets, nor was there any attempt to group articles into those supporting the establishment of the pest versus those opposing it. However, it was noted that those pests with a high public profile were often associated with polarised community opinions.

Applying the framework to 37 weeds from the WoNS list

The four criteria framework, with values estimated as outlined above, was applied to 37 of the Weeds of National Significance (WoNS) (http://www.weeds.org.au/natsig.htm). The objectives of the WoNS assessment and this framework are different and they cannot be directly compared. Assessment of the WoNS avoided emphasizing the dominance of Australian dryland areas that would arise from using only the total land area infested whereas this framework relies heavily on the size of affected areas, ignoring sub-division into environmental, agricultural or peri-urban landscapes. The social aspects were also investigated using media articles. Initially all weights were equal, although a Monte Carlo analysis randomly varying the weightings between the criteria was undertaken to examine the effect on rankings (data not shown).

These methodological differences resulted in some large differences in ranking. It should also be noted that a sub-set of the WoNS list was examined and the WoNS rankings were not altered to reflect a smaller sub-sample size. However, when these rankings were compared to the original WoNS ranking there was a positive Pearsons correlation (Pearson’s r = 0.35). Although, as expected, there was no evidence of a linear relationship between the WoNS ranking and the Bayes/MCDA ranking (

Table 5).

Table 5 Comparison of the WoNS and Bayes net/MCDA priority ranking (highest to lowest). Weightings used in the MCDA are set at equal value. Neither ranking is the 'right one'; each protocol has a different focus.

Scientific name	Common Name	WoNS Rank	Bayes/MCDA Rank
Prosopis spp.	mesquites	2	1
Xanthium spinosum	Bathurst burr	40	2
Parkinsonia aculeata	parkinsonia	1	3
Xanthium occidentale	Noogoora burr	45	4
Echium plantagineum	Patersons curse	32	5
Tamarix aphylla	Athel pine	13	6
Cryptostegia grandiflora	rubber vine	5	7
Rubus fructosis	blackberry	3	8
Acacia nilotica	prickly acacia	7	9
Jatropha gossypifolia	bellyache bush	21	10
Hyericum perforatum	St John's wort	42	11
Alternanthera philoxeroides	alligator weed	20	12
Lycium ferocissimum	African boxthorn	24	13
Ulex europaeus	gorse	18	14
Zantedeschia aethiopica)	arum lily	69	15
Chrysanthemoides monilifera	bitou bush/boneseed	8	16
Parthenium hysterophorus	parthenium	16	17
Mimosa pigra	mimosa	10	18
Onopordum spp.	onopordum thistles	52	19
Senna obtusifolia/tora	sicklepod	30	20
Cytisus scoparius	Scotch broom	31	21
Solanum elaeagnifolium	silver leaf nightshade	39	22
Genista monspessulana	broom	14	23
Sececio jacobaea	ragwort	55	24
Lantana camara	lantana	4	25
Gomphocarpus fruiticosus	narrow leaf cotton bush	63	26
Orabanche spp.	broomrape (all spp)	60	27
Eragostis curvula	African love grass	50	28
Cortaderia spp	pampas grass	47	29
Senecio madagascariensis	fireweed	66	30

Cuscuta campestris	golden dodder	36	31
Nassella trichotoma	serrated tussock	15	32
Sporobolus natelensis/pyr	giant rats tail grass	58	33
Anredera cordifolia	madeira vine	41	34
Salix spp.	willow	14	35
Macfadyena unguiscati	cat's claw creeper	23	36
Hyptis suaveolens	hyptis	22	37

Model conceptualization—accounting for reality and uncertainty

Over-simplified models naturally yield computational results with less meaning compared to models that reflect the real-world characteristics more faithfully. On the other hand, lower-level dynamic and interactive decisions, such as time dependent responses to new incursions, are often reliant on expert opinion and/or paucity of information. In these cases it may be of more use for decision makers to accept a higher level of uncertainty in the model conceptualisation in order to compare trade-offs and make strategic decisions. In contrast, strategic decisions where timeframes are not so limiting, such as evaluating performance responses to ongoing incursion management, provide an opportunity to include more quantitative and objective data. The structural framework of the model can become correspondingly more complex in order to educe the trade-offs existing for managing an established incursion. However, the basic principle of parsimony maintained and it is always preferable to choose, from a set of otherwise equivalent models, the simplest one. By doing that, developing the model will become much easier and inconsistencies, ambiguities and redundancies will be minimised.

However, the source of uncertainty remains an important concept. Uncertainty is introduced by the input information and it is also introduced unwittingly by the structure of the model itself. Decision makers frequently consider the implications introduced by uncertainty in the input information, but the effects of structural uncertainty are more easily overlooked. Recognising structural uncertainty can only assist decision makers and lead to improving strategic decisions.

Some aspects of model and input uncertainty can be examined using the framework presented here. For example, the uncertainty introduced by including a criterion such as public opinion, which is often associated with conflicts of interest and media focus, can affect the final ranking markedly depending on how it is estimated. Although the majority of plants were not affected by rank changes when public opinion was excluded from the assessment, two weeds noticeably changed ranking, with St John’s wort changing priority from 11 to 25 when public opinion was excluded (Figure 5). Rather than reflecting the lack of importance of this criterion this result highlights the importance of measuring the criterion appropriately. A single measurement, based on media reports over a set time frame, does not capture sufficient qualitative information to value public opinion.

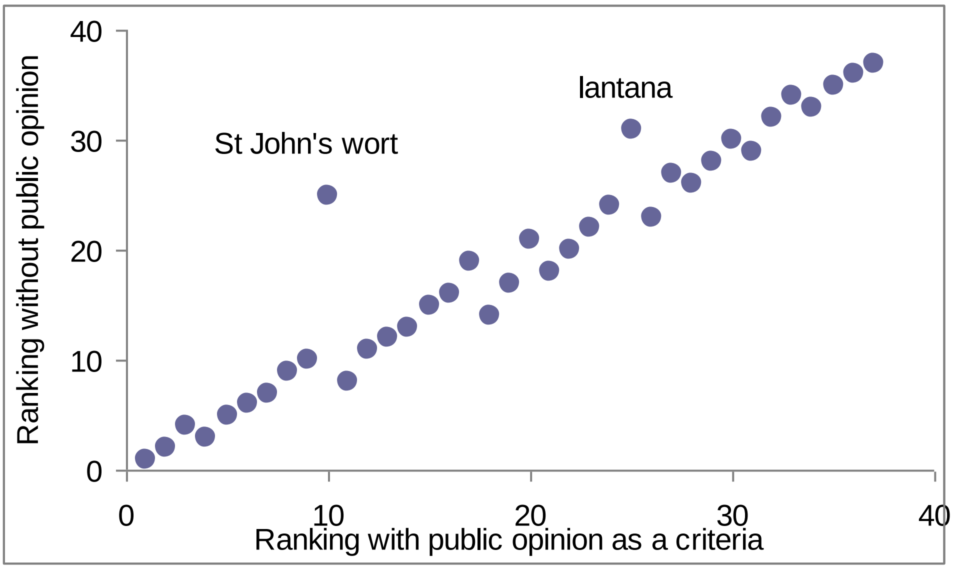

Figure 5 Bayes net/MCDA ranking with and without public opinion included as a criterion for assessing the impact of a pest.

Weightings can also indicate the significance between the facets contributing to the objective, e.g., sets of criteria addressing a related portion of the objective. This allows decision makers to examine trade-offs as for different facets of the objective. The effects of altering weightings can be readily examined using a simple spreadsheet. For example, stakeholders may be interested in determining how priority rankings would alter dependent on whether the priority was placed on the economic or conservation impacts (Table 6). Of the top 10 priority weeds under a high economic priority, eight (80%) remained high priority if the emphasis was shifted to conservation area priority. Of the top 20 economic priority weeds, 17 (85%) remained in the top 20 when the weighting was shifted to reflect a conservation priority. The resultant rankings elucidate trade-offs, and allow decision makers to identify pest species that remain consistently high priorities, as well as those that markedly shift rank under different weightings.

Table 6 Bayes net/MCDA priority ranking (highest to lowest) to examine trade-offs between economic and conservation impacts. Weightings set at: Economic priority, economic = 75, conservation and indigenous/other set at 10, public opinion = 5; Conservation priority, economic = 10, conservation = 75, indigenous/other = 10, public opinion = 5.

Scientific name	Common Name	Economic priority	Conservation priority
Rubus fructosis	blackberry	1	8
Echium plantagineum	Patersons curse	2	5
Prosopis spp.	mesquites	3	2
Xanthium spinosum	Bathurst burr	4	1
Xanthium occidentale	Noogoora burr	5	3
Parkinsonia aculeata	Parkinsonia	6	4
Cryptostegia grandiflora	rubber vine	7	11
Tamarix aphylla	athel pine	8	6

Acacia nilotica	prickly acacia	9	16
Alternanthera philoxeroides	Alligator weed	10	10
Ulex europaeus	gorse	11	13
Parthenium hysterophorus	parthenium	12	19
Jatropha gossypifolia	bellyache bush	13	18
Lycium ferocissimum	African boxthorn	14	9
Hypericum perforatum	St John's wort	15	20
Onopordum spp.	onopordum thistles	16	15
Senna obtusifolia/tora	sicklepod	17	22
Solanum elaeagnifolium	silver leaf nightshade	18	21
Sececio jacobaea	ragwort	19	24
Zantedeschia aethiopica	arum lily	20	7
Cytisus scoparius	Scotch broom	21	14
Chrysanthemoides monilifera	bitou bush/boneseed	22	12
Mimosa pigra	mimosa	23	23
Lantana camara	lantana	24	30
Genista monspessulana	broom	25	17
Gomphocarpus fruiticosus	narrow leaf cotton bush	26	26
Orabanche spp.	broomrape (all spp)	27	28
Eragostis curvula	African love grass	28	29
Cortaderia spp	pampas grass	29	25
Nassella trichotoma	serrated tussock	30	33
Senecio madagascariensis	fireweed	31	27
Cuscuta campestris	golden dodder	32	31
Sporobolus natelensis/pyr	giant rats tail grass	33	34
Anredera cordifolia	madeira vine	34	32
Salix spp.	willow	35	35
Macfadyena unguiscati	cat's claw creeper	36	36
Hyptis suaveolens	hyptis	37	37

Similarly, it is possible to examine the robustness of rankings when there is a conflict of interest among stakeholders. For example, if stakeholders have varying views on the weightings for economic and environmental impacts a sensitivity analysis on the rankings can be undertaken by running the priority ranking for each set of weightings. A simple sensitivity analysis was undertaken by randomly varying the economic weighting between 45 and 75, weighting for public opinion set at a constant of five, conservation weighting randomly varied between 20 and 50, and indigenous/other weighting comprising the difference between a total of 100 less the sum of all other weightings. Rank changes for such widely varying stakeholders' opinions can then be examined to determine how the priority ranking would change (Figure 6). The ranking remains robust for the majority of pests, with only a single pest weed changing rank by 11 places.

Where the transparency in the ranking process is readily apparent, stakeholders are assured of their contribution to the process. Decision makers can also clearly determine the contributing factors for a pest changing ranking by more than five places and determine appropriate management in such cases.

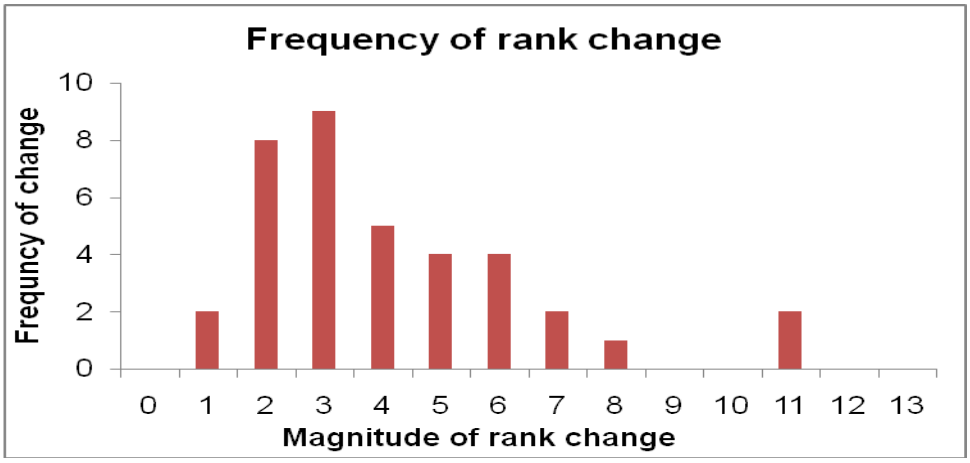

Figure 6 Sensitivity testing on weightings for economic and environmental criteria.

Generic application of the Bayes/MCDA framework

Eleven potential pests were selected from the AQIS Northern Australia Quarantine Strategy (NAQS) Targeted Pest lists (http://www.daff.gov.au/aqis/quarantine/naqs/target-lists). The species were chosen to represent several taxa and impacts. The criteria used to assess these pests were those used to assess the 37 weeds from the WoNS list. The values used in the Bayes net were estimated from published literature, GISP, PaDIL or government fact sheets. This same literature, in conjunction with industry statistics where available, was used to estimate the economic impact of the pest in Australia. Where industry values for economic or health losses were not available for Australia, losses in other countries where infestations occurred were scaled to reflect the size of the corresponding Australian industry or population distribution and this value was used. Weightings for the impact criteria in the MCDA analysis were economic = 25, conservation = 35, indigenous/other = 35, public opinion = 5.

Existing maps showing the potential distribution of the species if no management was attempted were used where possible. If no maps were available then the potential distribution in Australia was estimated from matching the climate of the home range and any known infestations using CLIMATE software (see Appendix 4 for examples). These maps were used to estimate the proportion of Australia potentially infested and the proportion of conservation or indigenous/other area affected. The potential infected area was assumed to be that area where six or more of the CLIMATE variables matched between known establishments and the Australian climate.

Phytophthera colocasiae (taro leaf blight) was included as a control because, while the disease can be devastating to the taro industry Australia has a relatively small, localised taro industry and any native taro species are restricted in range. Thus, it would be expected that this pest would have a low priority compared to other pests when the focus is primarily on the economic and environmental impact. The results of the Bayes/MCDA framework reflected this assumption (Table 7).

Five different published MCDA methodologies were applied to the data set outlined above (Table 7). The first consisted of the WSAT method used to rank the priority of the WoNS subset described above. The second was also a weighted summation technique but differed from the WSAT model in the calculation of a utility function before applying the weightings. The utility function also normalised the criteria across the pests, but utilised a different equation to do so (see Ablovatski 2004). AHN, TOPSIS and PROMETHEE models were also used to rank the 11 pest species. This provided an opportunity to examine how weighted sum, analytical hierarchical and outranking methods changed the ranking of pests when the same data set was used. The PROMETHEE model used weightings of 0.316, 0.317, 0.317 and 0.05 for economic impact, conservation area impact, indigenous/other area impact and public opinion. The values to indicate a preferred option (p) were 1, 0.01. 0.01 and 10 respectively. This defined the value at which pest was assumed to be dominant in a pair-wise comparison, i.e. if the criterion value was less than or equal to a preferred value then it assumed to be dominant. Likewise, the cut-off, or indifference options (q) were 5, 0.1, 0.1 and 100. The range between the preferred and indifferent values was then scaled, with criterion values closer to the p-value being ‘more preferred’ than pest with criterion values closer to the q-value.

Table 7 Comparison of rankings when different MCDA models are applied to the same dataset.

Scientific name	Common name	WSAT ranking	SAW ranking	AHN ranking	TOPSIS ranking	PROMETHEE ranking
Anoplolepis gracilipes	Crazy Ant	1	5	5	3	8
Heterobostrychus aequalis	Oriental Wood borer	2	3	2	5	7
Aedes albopictus	Asian mosquito	3	2	4	4	4
Phytophthera ramorum	Sudden Oak Death	4	1	6	1	1
Achatina fulica	Giant African Snail	5	4	7	7	3
Quadrastichus erythrinea	Erythrina gall wasp	6	10	1	2	9
Puccinia psidii	Eucalyptus rust	7	6	3	6	5
Cryptotermes dudleyi	Drywood termite	8	9	8	10	11
Cryphonectria cubensis	Cryphonectria canker	9	7	9	8	2
Subramanianospora vesiculosa	Casuarina blisterbark	10	8	10	11	10
Phytophthera colocasiae	Taro leaf canker blight	11	11	11	9	6

Even over 11 pest species the rankings can change, with the rankings from the PROMETHEE model showing some marked rank reversals. This may be a function of PROMETHEE requiring additional input from the decision makers. One option is said to outrank another if it outperforms the other on enough criteria of sufficient importance (as reflected by the sum of the criteria weights) and is not outperformed by the other option in the sense of recording a significantly inferior performance on any one criterion. The preference and indifference values applied influence decisions on whether a criteria weight is set at zero or 1 and there are various functions that can be applied to criterion values that fall between a preferred and an indifference performance value. Decision makers also need to determine which function best describes the performance of the criterion, e.g. linear scaling or even a Gaussian function where the preference increases with the difference between the scores as expressed in the formula:

$$H_j(d_j) = 1 - e^{-\frac{d_j^2}{2 s_j^2}}$$

Thus, the use of an outranking method such as PROMETHEE or ELECTRE can be much more difficult to apply but do allow input that provides decision makers with an option to invoke strict preference and indifference choices.

To our knowledge this is the first time a generic risk assessment has been used to rank any of the pests in the AQIS/NAQS targeted pest lists. All pests on the list are recognised to be of serious concern should they establish in Australia and every effort is being undertaken to prevent such an incursion.

However, if decision makers are required to direct funding across a range of taxa on a priority basis the use of a generic framework is essential. Frameworks would need to adequately conceptualise the stakeholder objectives, but as can be seen from the examples presented above, decision makers would need to determine what MCDA model best represented the concerns and objective.

Cook and Proctor (2007) reported on the application of a deliberative multi-criteria evaluation to an invasive species prioritisation in Western Australia and noted that the outcome of the process differed from the current resource allocation. In their study the active participation of the stakeholders was critical to the entire process and provided an opportunity to evaluate the use of semi-quantitative and qualitative estimates by a jury panel of informed stakeholders. The selection of stakeholders would influence the outcome of any MCDA and would need considerable thought when issues involve the environment and/or have far reaching effects. However, MCDA provides the opportunity to merge qualitative and quantitative data to explore alternative options as well as rank species on their potential to become serious pests. It also provides an opportunity for decision makers to assess the willingness of stakeholders to protect environmental and cultural resources.

4. Conclusions and Issues

This study focused on two areas. The first was a review of existing pest risk assessment protocols to determine the key themes used in assessment and the extent to which they were addressed. The outcome of this review identified five main themes, with the main short coming in all protocols being a failure to transparently address conflicting interests or potential trade-offs between the key themes.

The second area was to examine MCDA methods and their application in addressing conflict and trade-offs when assessing the priority ranking of pests in relation to their negative impact on Australia's economic status, environmental health and social/cultural values. To our knowledge Cook and Proctor (2007) were among the first to apply MCDA methods to the threat posed by invasive pests. Their study and this report highlight the importance of stakeholder selection, participation and timeframes. Both also highlight the need for MCDA methods to be based on scientific principles and to be transparent, even when qualitative data is used.

The criteria presented in the example framework of this report are overly simplistic, but provide the opportunity to explore the impact of differing MCDA methods on pest priority rankings for a set of weeds that have been extensively documented as well as across taxa. The outcome highlighted the importance of method selection and sensitivity testing within and between methods.

Additional criteria could contribute to a more realistic assessment of the stated objective of prioritising pests in relation to their expected impact without becoming overly prescriptive. For example: additional criteria could elucidate the environmental impacts more realistically by examining the number of indigenous species affected or the different type of cultural sites lost. Social impact could include criteria examining a series of social concerns, e.g. academic; industry; political; special interest group (see Appendix 2 for example Objectives Hierarchy).

Another key component not addressed in the example framework here would be a more detailed consideration of the geographic area affected. Despite climate being a suitable match over a large geographical region for some potential pests a specific host or micro-habitat may not be present. For example: although *Puccinia. psidii* (Eucalyptus rust) does have a very wide host range, it would require species of *Eucalyptus* and other *Myrtaceae* as hosts to establish over the predicted range in Australia (Figure 7). Thus superimposing host and pest distribution can assist in clarifying potential affected areas.

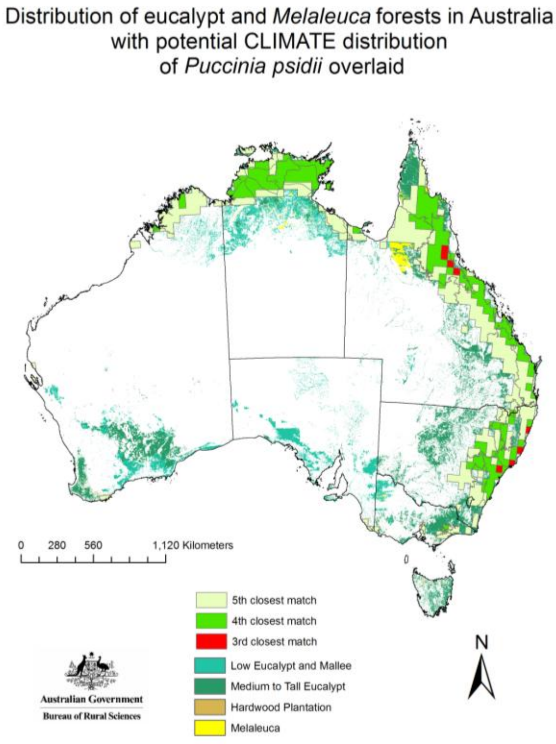

Figure 7 Distribution of eucalyptus and melaleuca forests in Australia with the CLIMATE predicted distribution of *P. psidii* overlaid.

An MCDA model is not developed through a straightforward sequential process where the decision maker's role is passive. It is an iterative process employed to analyse the preferences of the decision maker and represent them as consistently as possible in an appropriate decision model. Thus, while it can be repeatable for a given set of criteria and data, it is also an evolutionary process open to continual revision and information input.

MCDA, while ideal for assessing trade-offs and conflicts of interest, must also address issues surrounding paucity of data and the requirement for transparency and repeatability. Generic frameworks for cross-taxa assessment must address the objectives of the stakeholders; retaining the principles of parsimony without becoming overly simplistic. An important characteristic of these assessment models is that results cannot be definitively validated because they incorporate subjective elements. For this reason, it is important to be aware of the uncertainties that are inherent in the final decision measure used for each species.

Uncertainty can arise from two sources. The first can be termed ‘structural’ uncertainty, or uncertainty arising from the framework itself. The second is the intrinsic uncertainty inherited from the component factors themselves. Uncertainty can loosely be defined under six categories (see Warren 2006). The first four relate to structural uncertainty, while the last two relate to information uncertainty:

1. Uncertainty in the objective or problem definition
2. Uncertainty in the model conceptualisation
3. Uncertainty in the model macro-structure, or the uncertainty introduced by major computational components of a model such as inference or the information aggregation procedures in numerical induction models
4. Uncertainty in micro-structure and parameters, or the uncertainty introduced through the analytical components used, e.g. arbitrary parameters, aggregation

optimism/pessimism parameters in some aggregation operators, or the prior conditional probabilities in Bayes Nets

5. Uncertainty related to species evidence, e.g. the amount of information available or even conflicting evidence
6. Intrinsic uncertainty within information elements themselves or the uncertainty inherited from variable definition and/or measurement. This may be a qualitative concept associated with an inherently vague, approximate, indirect or subjective variable.

Awareness of these different types of uncertainty will minimise the pitfalls that can occur in making assessments. It also provides the opportunity to transparently account for unavoidable uncertainties related to information uncertainty and how best to elicit expert opinion.

5. Future Directions

Modelling complex decisions can be broken down into four components for MCDA. These can be identified as:

1. Defining the problem and objectives, including the facets, factors or attributes that can be used to describe them
2. Identifying any inter-relationships that exist between the attributes to avoid introducing biases by confounding the attributes
3. Evaluating and determining performance measures (criteria) for component factors and their importance weightings (if any)
4. Aggregating the criteria into a global numerical decision measure.

Decision makers play an active role in all four of these steps. Consequently, before a generic MCDA framework could be adopted decision makers would need to define the objective, reach consensus on the attributes used to describe that objective and be comfortable with the weightings and aggregation methodology.

Application of the proposed framework would need to be validated against some practical examples. It would be useful to examine the robustness of the results by applying several different aggregation methodologies to the criteria as well as undertake sensitivity testing on the weightings (if any).

The outcome would be a framework that decision makers have confidence in and can be used as a support tool to evaluate pest priorities under a range of scenarios e.g. different management techniques and funding options.

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Appendix 1: Risk Assessment Protocols Evaluated

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Table 1 Evaluation of 21 assessments currently used around the world to prioritise the risk of establishment, spread and impact from a pest, greyed cells and ticks highlight criteria considered in each assessment protocol.

	Weeds of National Significance 2000	QLD Pest Prioritisation, Walton 02	SA Virtue&Melland 2003	PLANTPLAN	Sth Africa Roberston 2003	Vic PPPP Weiss and McLaren 2002	WRA Pheloung et al 1999	Risk Assessment for the Importing and Keeping of Exotic Vertebrates in Australia	AusVetPlan 2003	Invasive Alien Species Wittenburgh 2001	NHT Finfish Risk Assessment	Hayes and Silwa 2003 Marine Pests	ICES Code of Pracitce Marine Organisms 2004
A. ENTRY / PATHWAYS													
1. Current global distribution	√							√	√	√	√		
2. Geographical proximity to country undertaking risk assessment									√				
3. Rate of international transport												√	
4. Number of potential entry sites								√	√	√		√	
B. Establishment													
1. Invasiveness elsewhere		√			√		√	√	√	√	√		√
2. Domestication		√									√		
3. Establishment among existing communities	√		√			√	√					√	√
4. Reproductive mode		√	√			√	√		√	√	√		√
5. Dispersal Capabilities		√	√		√	√	√	√	√	√	√		√
6. Propagule Supply										√	√		√
C. POTENTIAL Spread													
1. Climate	√	√	√			√	√	√	√	√	√		√
D. IMPACT							√						
Environmental				√									
1. Reduction in or limiting to indigenous species	√	√	√		√	√	√	√	√	√	√	√	√
3. Impact on faunal/floral health	√	√	√		√	√	√	√	√	√	√	√	√
4. Physical limitations		√	√		√	√	√						√
5. Negative ecosystem changes		√	√	√	√	√	√	√	√	√	√	√	√
6. Positive interaction with other invasives		√	√			√	√			√			√
Economic													
1. Cost of controlling or managing pest		√		√	√		√	√		√			
2. Loss of primary production	√	√	√			√			√	√	√	√	√
3. Loss of tourism		√				√			√	√			√
Social													
1. Human health	√	√	√	√	√	√	√	√	√	√	√	√	√
2. Amenities	√	√	√			√				√	√		
3. Heritage values	√	√				√				√			
E. FEASIBILITY													
1. Technical capability (control / eradicate)	√	√	√		√				√	√			
2. Stakeholder support	√	√			√					√	√		
3. Cost sharing / responsibility	√	√			√				√				
4. Risk of eradication to natives		√											
5. General Benefits													√
Note: this chart does not differentiate whether the question used qualitative or quantitative assessments in any of the categories examined													

	Weeds of National Significance 2000	QLD Pest Prioritisation, Walton 02	SA Virtue&Melland 2003	PLANTPLAN	Sth Africa Roberston 2003	Vic PPPP Weiss and McLaren 2002	WRA Pheloung et al 1999	Risk Assessment for the Importing and Keeping of Exotic Vertebrates in Australia	AusVetPlan 2003	Invasive Alien Species Wittenburgh 2001	NHT Finfish Risk Assessment	Hayes and Silwa 2003 Marine Pests	ICES Code of Pracitce Marine Organisms 2004
A. ENTRY / PATHWAYS													
1. Current global distribution	√							√	√	√	√		
2. Geographical proximity to country undertaking risk assessment									√				
3. Rate of international transport												√	
4. Number of potential entry sites								√	√	√		√	
B. Establishment													
1. Invasiveness elsewhere		√			√		√	√	√	√	√		√
2. Domestication		√									√		
3. Establishment among existing communities	√		√			√	√					√	√
4. Reproductive mode		√	√			√	√		√	√	√		√
5. Dispersal Capabilities		√	√		√	√	√	√	√	√	√		√
6. Propagule Supply										√	√		√
C. POTENTIAL Spread													
1. Climate	√	√	√			√	√	√	√	√	√		√
D. IMPACT							√						
Environmental				√									
1. Reduction in or limiting to indigenous species	√	√	√		√	√	√	√	√	√	√	√	√
3. Impact on faunal/floral health	√	√	√		√	√	√	√	√	√	√	√	√
4. Physical limitations		√	√		√	√	√						√
5. Negative ecosystem changes		√	√	√	√	√	√	√	√	√	√	√	√
6. Positive interaction with other invasives		√	√			√	√			√			√
Economic													
1. Cost of controlling or managing pest		√		√	√		√	√	√	√			
2. Loss of primary production	√	√	√			√			√	√	√	√	√
3. Loss of tourism		√				√			√	√			√
Social													
1. Human health	√	√	√	√	√	√	√	√	√	√	√	√	√
2. Amenities	√	√	√			√				√	√		
3. Heritage values	√	√				√				√			
E. FEASIBILITY													
1. Technical capability (control / eradicate)	√	√	√		√				√	√			
2. Stakeholder support	√	√			√					√	√		
3. Cost sharing / responsibility	√	√			√				√				
4. Risk of eradication to natives		√											
5. General Benefits													√
Note: this chart does not differentiate whether the question used qualitative or quantitative assessments in any of the categories examined													

Appendix 2: Multi-criteria Workshop 1

WORKSHOP ON MULTICRITERIA ANALYSIS FOR PEST PRIORITISATION
Part 1: Criteria for Assessment
July 9, 10 am to 4 pm, Department Agriculture, Fisheries and Forestry, Canberra

Mark Burgman (ACERA) opened the workshop and introduced Dr Lynn Maguire, Professor of the Practice of Environmental Decision Analysis and Director of Professional Studies at Duke University, North Carolina USA, who led the workshop.

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Objectives Hierarchy (courtesy Lynn Maguire)

<u>OBJECTIVES HIERARCHY from 9 July Workshop</u>

NON-PRODUCTION IMPACTS

- BIODIVERSITY
- ECOSYSTEM SERVICES
  - Water Quality
  - Pollution Absorption
  - Productivity
  - Quantity
- URBAN INFRASTRUCTURE
- AMENITIES
  - Recreation

HUMAN HEALTH
HERITAGE VALUES

PRIMARY PRODUCTION IMPACTS
AGRICULTURE
HORTICULTURE
FORESTRY
FISHERIES
PET TRADE

COST EFFECTIVE

LEGAL
POLITICAL CONSISTENCY

Each element of the objectives hierarchy represents something of value to at least some of the organizations concerned with plant pests, although not all organizations place the same priority on each of these elements. To make these objectives operationally useful for decision making, such as allocating funds among pest control projects, each objective needs an observable attribute, or measure, that can be used to gauge the performance of alternative plans for action. Articulating more specific objectives for a particular pest control problem and defining measures that could be used to evaluate the performance of alternative management actions was the focus of the second workshop in Melbourne on 30 July.

Appendix 3: Multi-criteria Workshop 2

Workshop on Multicriteria Analysis for Pest Prioritisation
Part 2: Assessment and Weighting of Pest Criteria. Monday July 30

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Appendix 4 Maps showing landuse and the potential distribution for 2 of the AQIS NAQS targeted pests considered in this study.

Figure 8 Landuse map used to estimate conservation and indigenous/other protected land area affected by a pest incursion

(source:http://www.nlwra.gov.au/library/scripts/objectifyMedia.aspx?file=pdf/79/93.pdf).

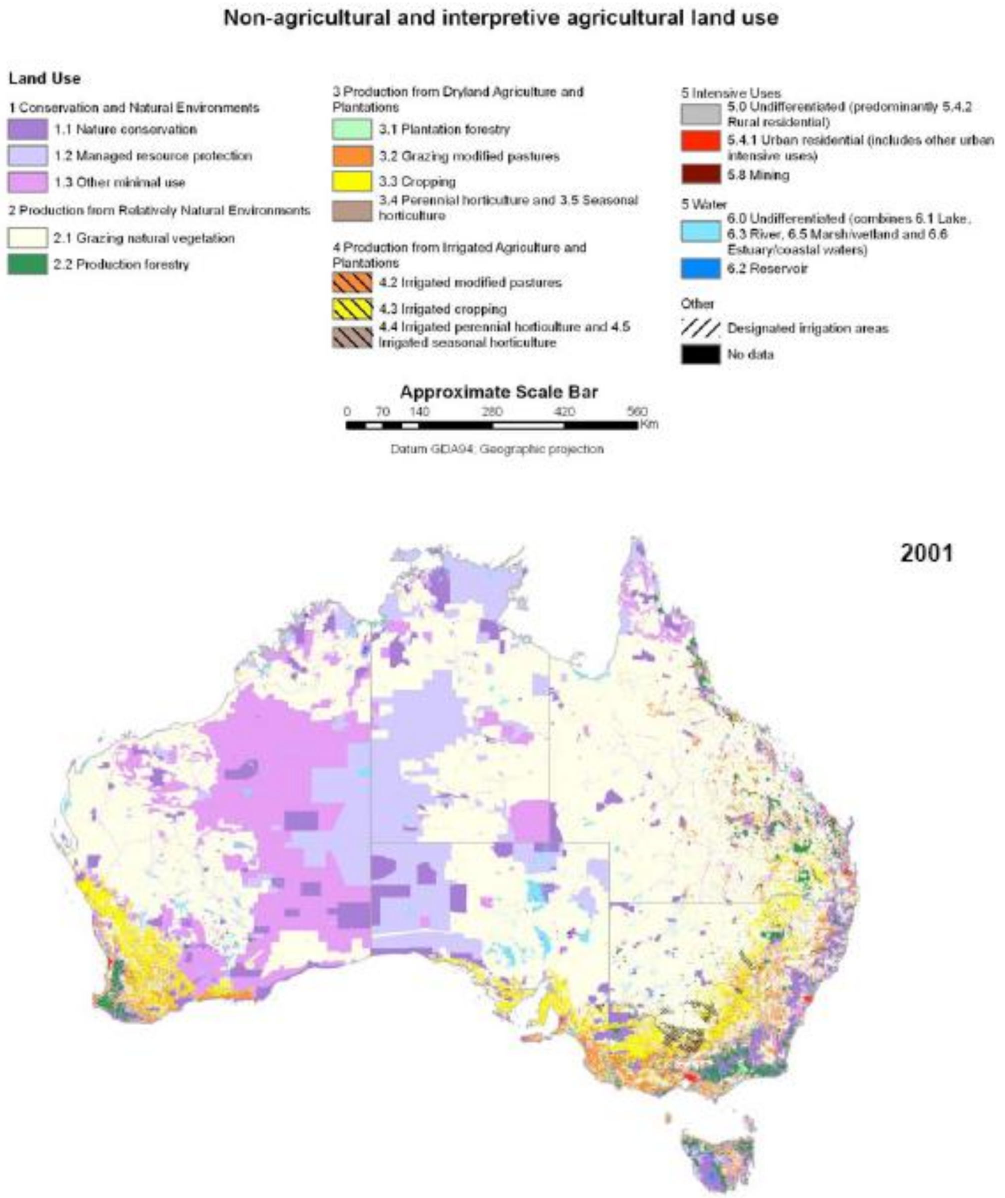

Figure 9 *Anoplolepis gracilipes* (crazy ant) potential distribution based on known infestations and home range (Climate software, 2004). Colours represent areas of highest (red) to lowest (grey) climate match. Areas of potential infestation for MCDA analysis based on climate match of six (pale blue) or more.

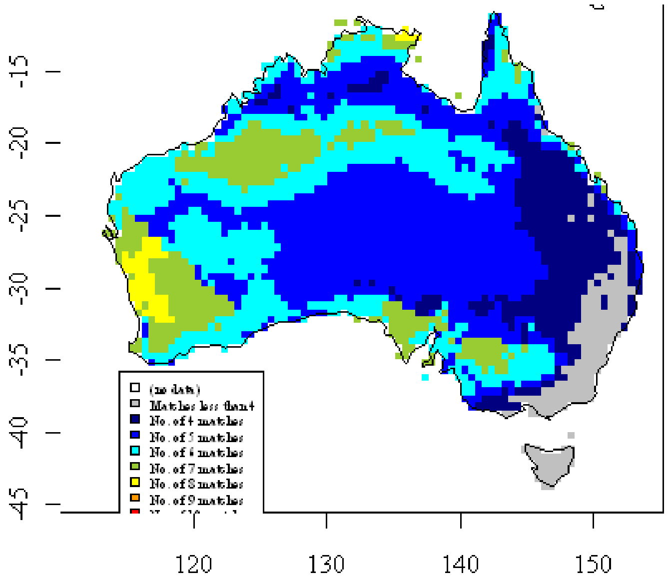

Figure 10 *Phytophthera colocasiae* (taro leaf blight) potential distribution based on known infestations and home range (Climate software, 2004). Colours represent areas of highest (red) to lowest (grey) climate match. Areas of potential infestation for MCDA analysis based on climate match of six (pale blue) or more.