

Without expected benefits, is weed assessment a frustrating search for the wrong needle in the wrong haystack?

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Summary Processes currently used to assess exotic plant introductions are precautionary by nature and as such promote the likelihood that plants with the potential to be highly beneficial to Australia are excluded from introduction. Benefit-cost analysis, characterised by the consideration of expected costs and expected benefits, provides alternative decision criteria for introduction decisions. With access to sufficient data and use of more sophisticated assessment techniques, there is the potential for benefit-cost analysis to be adopted as an alternative and guide the development of policy which increases economic welfare to the whole community.

Keywords Benefit-cost analysis, risk, border assessment, uncertainty.

INTRODUCTION

The benefits of introduced plant species are demonstrated by their significant contribution to agricultural and nursery industries, which are based primarily on introduced plant species. On the other hand, costs from introduced plants can be substantial as highlighted by reference to just three of the many well known weedy species, Paterson's curse (*Echium plantagineum* L.) in Australia, black wattle (*Acacia mearnsii* De Wild.) in South Africa and common crupina (*Crupina vulgaris* Cass.) in the United States. With the benefit of hindsight, the distinction between the plants which have contributed significant benefits and those which have contributed substantial costs is apparent. But from an *ex ante* perspective how do you decide in which category an exotic plant is likely to fall when introduced to a new environment and so whether the plant should be introduced?

In general, current approaches to this decision are consistent with the *Precautionary Principle*, an approach which espouses prevention of serious and irreversible damage before harm can be scientifically, or economically, assessed (Rogers 1998). Approaches used by Biosecurity Australia, the American Animal and Plant Health Inspection Service of the United States Department of Agriculture (USDA) and the Food and Agriculture Organisation of the United Nations (UN) are consistent with the precautionary approach to introduction decisions.

Increasingly, economic approaches are being considered in weed management and weed evaluation decisions (Panetta *et al.* 2002, Cacho *et al.* 2003a, Odom *et al.* 2003). At the same time, there is recognition that an alternative approach to plant introduction decisions may sometimes be required. Plants with the potential to stem the recharge associated with increasing salinity (recharge management plants) are among the plants for which an alternative decision approach may be warranted (Bennett and Virtue unpublished).

There has been some application of an economic perspective to weed management decisions and there are plants that appear to warrant an introduction assessment process which is not precautionary in nature. Despite this, an economic approach has not been applied to plant introduction decisions. Issues with the estimation of expected costs and expected benefits (Hughes and Madden 2003, Simberloff 2003) appear to undermine its potential as a decision framework from the perspective of many weed managers and plant ecologists.

Expected costs and benefits, which characterise an economic approach, are estimated as the probability of occurrence multiplied by the cost or benefit of the occurrence. The ability to estimate the uncertainty parameters is key to this assessment. Estimation has been achieved in a variety of ways in previous economic assessments of weed management problems. Plants with the potential to stem recharge when introduced into farming systems provide a basis on which to consider probabilities in assessment of potential weediness and associated policy options. Findings might similarly be applied to genetically modified plant varieties and introduced animal species.

This paper provides an overview of existing plant introduction decision processes and in this context, an economic framework as a potential alternative approach. Examples of the incorporation of uncertainty within an economic framework are presented together with discussion of the implications for policy associated with plant introduction decisions.

TO INTRODUCE OR NOT TO INTRODUCE?

Current processes Introduction of plant and animal species to non-native regions is subject to access

permission in most jurisdictions of the world. Agencies responsible for providing permission use standard frameworks to assist them to determine whether the introduction has the potential to become a pest (plant or animal) when introduced. The rigour of assessment processes varies. The procedures of Biosecurity Australia (Weed Risk Assessment (WRA)), the American Animal and Plant Health Inspection Service (APHIS) and the Food and Agriculture Organisation (FAO)^a of the United Nations are among the best documented. Table 1 presents the considerations of each of their processes in terms of an economic, or triple bottom line, approach, which includes financial, environmental and social elements.

Each of the processes considers the costs of an introduction in terms of both financial and environmental impacts, and both the WRA and FAO processes in terms of social impacts, though not comprehensively. Social considerations are limited to whether ‘perceived social costs such as unemployment’ will result (FAO 1996) and whether a plant will cause allergies or be otherwise toxic to humans (Pheloung 1995). Each of the three processes consider the uncertainty of costs through:

- scoring in relation to the likelihood of spread (United States Department of Agriculture 2002);
- whether the species has a history of repeated introductions outside its natural range (Pheloung 1995); or
- identification of factors which will influence the spread potential after establishment (FAO 1996).

None of these processes considers benefits and none explicitly considers the uncertainty with which impacts will be realised in the area to which introduction is intended. This precautionary approach to introduction decisions may ensure the prevention of irreversible harm, but it promotes the likelihood that species which offer substantial, though uncertain, benefits to society will be denied import access.

An alternative An economic approach presents an alternative framework for considering if a plant should be categorised as a weed, and as such introduced or not. The decision criterion of the current processes can be interpreted as ‘if the costs could be high, exclude, if costs will not be high, include’. An economic framework determines if expected costs associated with a plant’s introduction exceed the expected benefits, relative to what will happen in the absence of the proposed action (i.e. a plant introduction). ‘If expected costs, including expected negative externalities, exceed expected benefits, including expected positive externalities, a plant would be classified as a weed and denied entry’. The essential elements of this alternative decision criterion are:

Table 1. Plant introduction assessment considerations.

		WRA ^a	APHIS ^b	FAO ^c
Financial	Costs	✓	✓	✓
	Benefits	–	–	–
Environmental	Costs	✓	✓	✓
	Benefits	–	–	–
Social	Costs	✓	–	✓
	Benefits	–	–	–

Source: ^aPheloung (1995), ^bFAO (1996), ^cUSDA (2002).

- both costs and benefits;
- costs and benefits which are imposed on others (negative and positive externalities); and
- explicit incorporation of the uncertainty associated with costs, benefits and externalities.

This framework can be illustrated using plants with the potential to reduce the recharge associated with salinity.

SALINITY MANAGEMENT OPTIONS

New exotic plants A number of exotic plants have been identified which, if introduced into Australian farming systems as alternative pasture species, have the potential to reduce dryland salinity. Dryland salinity in Australia, which costs as much as \$3.5 billion annually (CRC for Plant-based Management of Dryland Salinity 2002) has resulted primarily from the removal of deep-rooted native perennials from the Australian landscape and their replacement with shallow rooted annuals (Hajkovicz and Young 2002, Hodgson and Hatton 2003 Cacho *et al.* 20034). Shallow rooted annuals allow excess water to pass the root zone and recharge water tables which causes water tables to rise and mobilise stored salts. These salts are deposited in lower lying discharge areas of the landscape as the water table regains balance resulting in reduced agricultural production, lost biodiversity, damage to infrastructure and costs to urban communities.

The exotic plants identified are deep rooted perennial grasses and herbaceous legumes, and present the opportunity for reducing on-farm recharge of groundwater tables. A decision to introduce these plants has the potential to contribute significant net benefits as a result of reduced salinity, but also has the potential to add to Australia’s already significant weed burden. The current Australian WRA process is likely to exclude the introduction of the identified plants on the basis of the possible costs of their weediness.

Decisions under uncertainty The decision to introduce an exotic recharge management plant can be

illustrated in a decision framework from Hardaker *et al.* (1998) as in Figure 1. In the absence of a plant being introduced, the costs of salinity (C_0) increase. This cost is considered part of the base case (outcome I) against which the alternatives (outcomes II–V) should be judged. As illustrated in Figure 1, once a border decision to introduce is made, the net impact on economic welfare is dependent on the probability that the plant spreads outside managed pasture areas (X_1 , X_2) and the probability that the plant reduces recharge (Y_1 , Y_2). Do the outcomes associated with the alternatives (II–V) add to or take from society’s economic welfare in the base case?

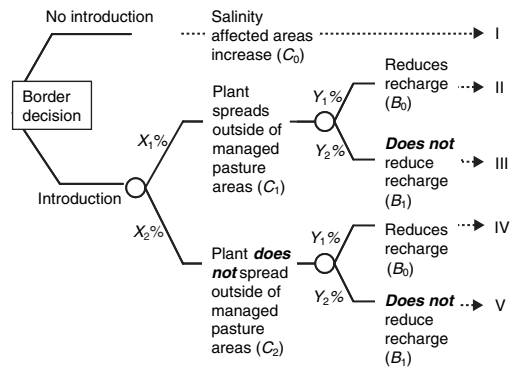


Figure 1. An introduction decision under uncertainty.

Inclusion of uncertainty Inclusion of uncertainty in pest and weed management decisions is generally achieved in terms of risks, that is, risks of invasion, risks of establishment and risks that controls will not be effective. In this context the uncertainty is defined as exposure to unfavourable consequences (Hardaker *et al.* 1998). In an economic framework however it is necessary to consider the uncertainty of both favourable and unfavourable events. It is therefore preferable to consider the probabilities or likelihoods, and not risk, of an occurrence within an economic framework. These terms imply no preconceived value judgement regarding an impact’s favourable or unfavourable nature.

Odom *et al.* (2003) provide a review of studies that measure the impact of weeds and other pests on the natural environment. In this review of 20 studies^B, only eleven had explicitly included uncertainty, including five which did so only descriptively. The extent to which costs and benefits associated with plant populations are realised will however also be dependent on the way the plant spreads. Ten of the 20 studies reviewed by Odom *et al.* include spread functions ranging from population models to constant rates of spread, arbitrary functions and spread on the basis of historical data. Two of the studies to have included both quantification of uncertainty and spread functions, provide interesting approaches to the inclusion of uncertainty.

The first avoids the need to estimate probabilities. Jetter *et al.* (2000) assess the net benefits of proposed eradication of a 1997 invasion of red imported fire ants (*Solenopsis invicta* Buren) in California. Spread of fire ants is uncertain and the success of eradication efforts is uncertain. To estimate spread, the authors considered previous infestations, such as in Texas, and consulted scientists. From this, alternative spread functions over 10 years for three scenarios were adopted. The three scenarios were low (10% of total), medium (25%), and high (40%) infestation of total susceptible areas. The authors however recognised the difficulties of

estimating the likelihood of success of eradication efforts and approached the problem in terms of thresholds. The study provides estimates of the probability of eradication success required for the expected net benefits of eradication to be positive. These breakeven probabilities were found to be surprisingly low, ranging from a 1.72% chance of eradication success required in the low impact scenario to only 0.67% in the high impact scenario to warrant an eradication effort.

The second study of interest is an assessment of the introduction of a biological control agent, a rust introduced from Australia, to control Orange Wattle (*Acacia saligna* (Labill) H.L.Wendel.) in an area of the Western Cape of South Africa. Orange Wattle, also known as Port Jackson Willow, is an Australian native whose invasion is stimulated by fire. This assessment by Higgins *et al.* (1997) includes multiple probability parameters. Probabilities associated with fire frequency, seed decay and germination and plant mortality following fire, plant mortality following infection by the rust, and mortality of an alternative plant following a fire incident are all incorporated within a population model as point estimates around which a range of values is incorporated. These point estimates and ranges are based on previous studies and consultation with known authorities. This research indicated that the benefits of biological control can outweigh the costs of its introduction.

A study of the management of Karnal bunt (a disease caused by the fungus *Tilletia indica* Mitra affecting wheat, rye and triticale) in the United States provides a further example of ways to incorporate uncertainty. It illustrates that management decisions can vary considerably when probabilities are incorporated directly within benefit-cost analyses rather than independently. The approach taken by Glauber

and Narrod (2003) does not focus on the probabilities of an individual event, but rather assesses the overall probability of a pathway to an incursion occurring. The probability of an outbreak of Karnal bunt, is expressed as:

$$p^* = 1 - (1-p_1)(1-p_2)(1-p_3)(1-p_4) \quad (1)$$

where p_i ($i = 1 \dots n$) represents the probability of each of a range of events contributing to the overall pathway probability. For example, p_1 may represent the probability that Karnal bunt infected seed is transferred into an unaffected area, p_2 may represent the probability of infected harvesting machinery being used and so on. Monte Carlo analysis with 10,000 iterations for each management option was undertaken across the 30 identified uncertain events. The probabilities of the parameters included a range of triangular, beta and lognormal distributions and incorporated data from previous USDA risk assessments. This multiplicative approach allows consideration of the factors that drive the probability of an event discretely as well as recognising how management options may alter the probabilities of individual influences differently to the overall event.

The approach of Glauber and Narrod (2003) to the assessment of Karnal bunt suggests that X_i from Figure 1, the probability that the plant spreads outside its managed pasture area, could be determined in the following way:

$$X_1 = 1 - (1-X_a)(1-X_b)(1-X_c) \dots (1-X_n) \quad (2)$$

and

$$X_2 = (1-X_1) \quad (3)$$

where there are n factors contributing to whether a plant will spread outside managed pasture areas, such as:

X_a = probability that the plant is rhizobia promiscuous^c;

X_b = probability that events which contribute to seed spread occur (e.g. flood, wind); and

X_c = probability that the plant has no predators.

The full list of factors to contribute to such an estimate for plant spread is likely to be comprehensively included within the Biosecurity Australia's WRA protocol, requiring however more than a score (yes = 1, no = -1, don't know = 0) which is weighted. Using the decision framework shown in Figure 1 would require an equivalent process be undertaken to estimate Y_i ($i = 1, 2$), the probability the plant does or does not reduce recharge. In practice, because there are likely to be far

more outcomes than II-V, X_i and Y_i are each likely to represent a vector of multiple probabilities.

Given estimation of the probabilities X_i and Y_i and estimation of C_i , B_i and C_0 the necessary decision rule to introduce a plant, then becomes:

$$B_i Y_i - C_i X_i - C_0 > 0 \quad (4)$$

Equation (4) stipulates that the net difference of an introduction's expected costs ($-C_i X_i$) and expected benefits ($B_i Y_i$) minus the costs that would have been incurred irrespective of the introduction (C_0) must be greater than zero.

However both plant spread and salinity mitigation are dynamic processes. As such the decision rule over m years and at a discount rate of r , becomes:

$$\sum_{t=1}^m (B_{it} T_{it} - C_{it} X_{it} - C_{0t})(1+r)^{-t} > 0 \quad (5)$$

where C_i , C_0 and B_i in each time period are determined by growth, spread and impact functions. Only in this form, where probabilities are included and dynamic processes are determined by appropriate functional forms, is uncertainty fully incorporated within the decision framework. If this decision rule is taken further to consider the problem spatially, the decision criterion for s areas can be represented as in Equation (6) where a represents each different area or type of area (agricultural, natural ecosystems etc):

$$\sum_{a=1}^s \sum_{t=1}^m (B_{ita} Y_{ita} - C_{ita} X_{ita} - C_{0ita})(1+r)^{-t} > 0 \quad (6)$$

The decision criterion in this form accommodates costs, benefits, uncertainty and externalities.

Policy implications Fundamentally, a decision criterion such as this could help determine whether a plant should be introduced on the basis of its economic outcome for society. Quite simply, if the net benefits are positive, the plant should be introduced and if not, entry should be denied. This is consistent with the principles endorsed by the Australian Weed Committee, for weed management, which state that eradication efforts should be undertaken where there is a clear and significant benefit (Panetta *et al.* 2002).

With the costs and benefits of both salinity and salinity management (van Buren and Pannell 1999) and plant establishment and spread likely to be dispersed over time and space the need to consider whether policy can play a role in bridging the gap between those bearing the costs and those reaping the benefits of a plant introduction (Kalisch 2004) is warranted. The explicit inclusion of uncertainty

in an introduction decision framework assists such policy prescription further through consideration of the concept of ‘certainty equivalents’.

A certainty equivalent is the highest sure sum an individual would be willing to accept to bear the probability of a negative outcome (Hardaker *et al.* 1998). In the framework shown in Figure 1, this quantum will be the difference between the most negative outcome of II, III, IV and V and outcome I. As such, this quantum defines how much a society that is risk averse to an introduction could demand in exchange for accepting the uncertainty a plant introduction presents when there are expected net costs. Conversely, in the case of expected net benefits, the certainty equivalent concept quantifies how much a group would be willing to pay for the right to introduce a plant. The certainty equivalent concept offers the opportunity to consider policy provisions associated with an introduction. These provisions might include the necessity to insure against future weed damage, lodging a performance bond against adverse outcomes or a direct payment to risk-averse parties. Consider a group who wants to introduce a plant to reduce salinity. They may be asked to insure against the damages that others may claim as a result of the plant’s future weediness, an amount which would be in the order of the maximum certainty equivalent.

DISCUSSION AND CONCLUSIONS

Theoretically, an economic framework provides a rigorous decision framework, even under uncertainty. The framework with uncertainty allows not only simple, ‘yes – no’ introduction decisions, but also, ‘yes with conditions’ introduction decisions. Difficulties in the application of this framework have been identified. Particular concern has been raised by Simberloff (2003) and Hughes and Madden (2003) in relation to estimating probabilities associated with uncertain events as well as by Simberloff and Stiling (1998) and Frank (1998) in relation to using historical data to guide probability estimation. As illustrated in the literature, particularly in relation to assessment of Karnal bunt by (Glauber and Narrod 2003) and with the example of recharge management plants, their concern is founded to the extent that a large amount of data is required of both plant and environment characteristics for estimation of probabilities, costs and benefits.

Decisions regarding pests, including plants, should however be considered in terms of finding a needle in a haystack. If you use no framework at all, you will not even know to look in the haystack. If you consider just one part of the search (costs), you’ll look in just one part of the haystack. If you consider all components of a scenario, your search will be in the right part of the

haystack, but only if you consider the probabilities will your search be in a small enough area to get close to the needle. The better your information on probabilities the closer you’ll get to the needle.

Therefore, in the interests of maximising economic welfare and because plant ecologists and weed managers are likely to be no less frustrated by looking for a needle in a haystack than economists, recommendations in relation to introduction decisions would include:

1. consideration of benefits as well as probabilities so that expected costs and expected benefits are estimated;
2. protocols for the collation of data, which include explicit consideration of costs **and** benefits **and** the probabilities (including growth and spread functions) associated with each, be established;
3. explicit consideration of uncertainty be recognised as a guide to development of policies associated with introduction decisions, with and without management provisions; and
4. there be further work to identify rules of thumb which can be implemented for decision making, using an economic approach, in the same way that the WRA currently does, using the precautionary approach.

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FOOTNOTES

- ^A The specific United Nations FAO secretariat responsible is the Secretariat of the International Plant Protection Convention (IPPC). This secretariat is not charged with the responsibility of introduction decisions however their process is applied to plant protection in relation to international agreements.
- ^B A total of 62 studies were reviewed. Twenty studies were selected as useful contributions to the economic literature.
- ^C Leguminous plants which require rhizobia for nodulation may be amenable to a specific rhizobia class or be amenable to a range of rhizobia, that is, rhizobia promiscuous.