Report Cover Page

ACERA Project		
1104D		
Title		
Post-border Investment Return		
Author(s) / Address (es)		
Dr Susie Hester, UNE Business School, Faculty of the Professions, University of New England, ARMIDALE NSW 2351; **Professor Oscar Cacho**, UNE Business School, Faculty of the Professions, University of New England, ARMIDALE NSW 2351		
Material Type and Status (Internal draft, Final Technical or Project report, Manuscript, Manual, Software)		
Final Report		

Summary

The Australian Government routinely invests in the management of pests and diseases that are established in the landscape, even though the benefits of these investments are not well understood. Public funding to manage established pests occurs in five investment areas: (i) national coordination; (ii) research and development; (iii) raising awareness of the impacts of pests; (iv) strategic investment in on-ground work; and (v) building community capacity to manage pests.

The aim of this project was to evaluate these different investment strategies with a view to informing the development of future Australian Government policies for management of established pests and diseases. This report details the various tools and techniques that may be used in investment evaluation, the trigger points at which investment might start and finish, and the measurement problems that invariably arise in impact evaluation because of data defficiencies. An attempt was made to use two case studies to explore, retrospectively, the benefits and costs of a range of publicly funded pest management activities, but this task proved difficult because key data were not always collected or reported in a way that would allow for meaningful impact evaluation.

The report also describes and applies a decision-analysis framework that may be used to understand the effect on a pest population of the various investment activities that are routinely funded.

To improve investment evaluation of publicly funded pest-management activities in the future we recommend that:

- data collection for the purposes of quantitative impact evaluation be given a high priority, and that the costs of data collection and management be included in project budgets.
- impact evaluation be addressed prospectively rather than retrospectively. Objectives of the different activities, and measures by which success could be evaluated should be clearly stated at the outset, and data should be collected on these measures during the project so that meaningful quantitative impact evaluation can be undertaken.
- the trigger for all investment in pest-management activities be determined by the level of public net benefits (public benefits minus public costs),
- the decision-analysis framework suggested in this report be used to inform both prospective and retrospective evaluation of pest management activities.
- where retrospective evaluation is the only option for pest-management evaluation, that a meta-analysis of all available data on selected programmes be undertaken.

ACERA Use only	Received By:	Date:
	ACERA / AMSI SAC Approval:	Date:
	DAFF Endorsement: ( ) Yes ( ) No	Date:

Post-border investment

ACERA Project No. 1104D

Susie Hester; University of New England

Final Report

11 March 2014

Acknowledgements

This report is a product of the Australian Centre of Excellence for Risk Analysis (ACERA). In preparing this report, the authors acknowledge the financial and other support provided by the Department of Agriculture, the University of Melbourne, Australian Mathematical Sciences Institute (AMSI) and Australian Research Centre for Urban Ecology (ARCUE).

The authors are grateful to Department of Agriculture staff who generously gave their time at the project workshop on 20th July 2012, Department of Agriculture, Canberra: Jeanine Baker, Mike Cole, Peter Langdon, Nin Hyne, Matt Kemp, Courtney Harris, Dan Thomas, Sam Marks and Bertie Hennecke. The authors also thank participants in a workshop to discuss return on investment in rabbit-management projects, held at UNE 5th February 2013: Tony Pople and Mike Brennan (Biosecurity Qld); Jeanine Baker (Department of Agriculture); Andrew Woolnough (Biosecurity Vic); Tarnya Cox (NSW DPI); Bruce Warburton (Landcare Research, NZ), Greg Mutze (PIRSA), and Paul Martin (UNE/IACRC). We also thank Bo Raphael for her assistance early in the project.

Disclaimer

Table of contents

List of Tables

List of Figures

1 Executive Summary

The Australian Government routinely invests in the management of pests and diseases that are established in the landscape, even though the benefits of this investment are not well understood. Public funding for the management of established pests and diseases occurs in the following five investment strategies:

- national coordination;
- research and development;
- raising awareness of the impacts of pests and weeds;
- strategic investment in on-ground work; and
- building community capacity to manage established pests and diseases.

The aim of this project is to evaluate these different investment strategies using a set of case studies with a view to informing the development of future Australian Government policies for management of established pests and diseases. The case studies were to be used to evaluate retrospectively the costs and benefits of alternative investment strategies. Another objective of the project is to develop a decision-analysis framework that represents the post-border management spectrum, including the establishment and spread phases for a range of pests and diseases, and under alternative management strategies.

This report presents the results of the analysis. It details the various tools and techniques that may be used in biosecurity investment evaluation, and discusses why benefit-cost analysis is the most appropriate technique for retrospective evaluation in the current context. The report includes a discussion of the trigger points at which investment might start and finish, and the measurement problems that invariably arise in impact evaluation because of data defficiencies and the complexity of the invasion process. Two case studies were used to explore, retrospectively, the benefits and costs of a range of publicly funded pest management activities, with a view to gaining insights into the relative size of payoffs for different investment strategies. Unfortunately this task proved difficult because, although the pests chosen (rabbits and salvinia) have had publicly funded pest-management for decades, data are not always reported for key parameters in a way that would allow for meaningful evaluation.

A decision-analysis framework for understanding the effect on a pest population of investing in various management activities is described in the report. The mathematical model is developed and its application is demonstrated using a plausible pest-management scenario solved on a spresdsheet.

In order to improve investment evaluation of publicly funded pest-management activities in the future we recommend that:

- data collection for the purposes of quantitative impact evaluation be given a high priority in future pest-management activities activities, and that the costs of collection be included project budgets. The suggested decision-analysis framework in this report could be used to guide data collection.
- impact evaluation be addressed prospectively (before the investment is undertaken) rather than retrospectively (after the programme has finished). Objectives of the different activities and measures by which success could be evaluated should be clearly stated at the outset, and data should be collected on these measures during the project so that meaningful quantitative impact evaluation can be undertaken.
- the trigger for all investment in pest-management activities be determined by the level of public net benefits (public benefits minus public costs), with cost recovery of private benefits undertaken when possible.
- the decision-analysis framework suggested in this report be used to inform both prospective and retrospective evaluation of pest management activities. This framework focuses attention on the key biological parameters. The effects of these activities depend on how these key parameters affect the population dynamics of the pest and thus pest impact.
- where retrospective evaluation is the only option for pest-management evaluation, that a meta-analysis of all available data on selected programmes be undertaken. This would allow exploration of significant relationships between measures of success (e.g population change or population density) and independent variables such as total budget, pest characteristics, types of investment activities etc.

2 Introduction

In Australia, the primary responsibility for managing pests, weeds and diseases in the post-border environment rests with the state and territory governments, local government and landholders. The Australian Government has taken a leadership role in coordinating national approaches to this management, and supports nationally significant activities, such as research and development. The Australian Government also supports on-ground actions of state and territory governments, regional bodies and landholders in managing the negative impacts of pests, weeds and diseases.

There is an underlying assumption, particularly in the post-border part of the biosecurity continuum (Figure 1), that the greatest return on investment is achieved by early intervention to contain or suppress spread compared to investing in management once the species is established in the landscape (VICDPI n.d.). Resources, however, continue to be invested in managing pests and diseases that are well-established in the environment because it is also assumed that there are benefits from management activities in this context. Activities in this part

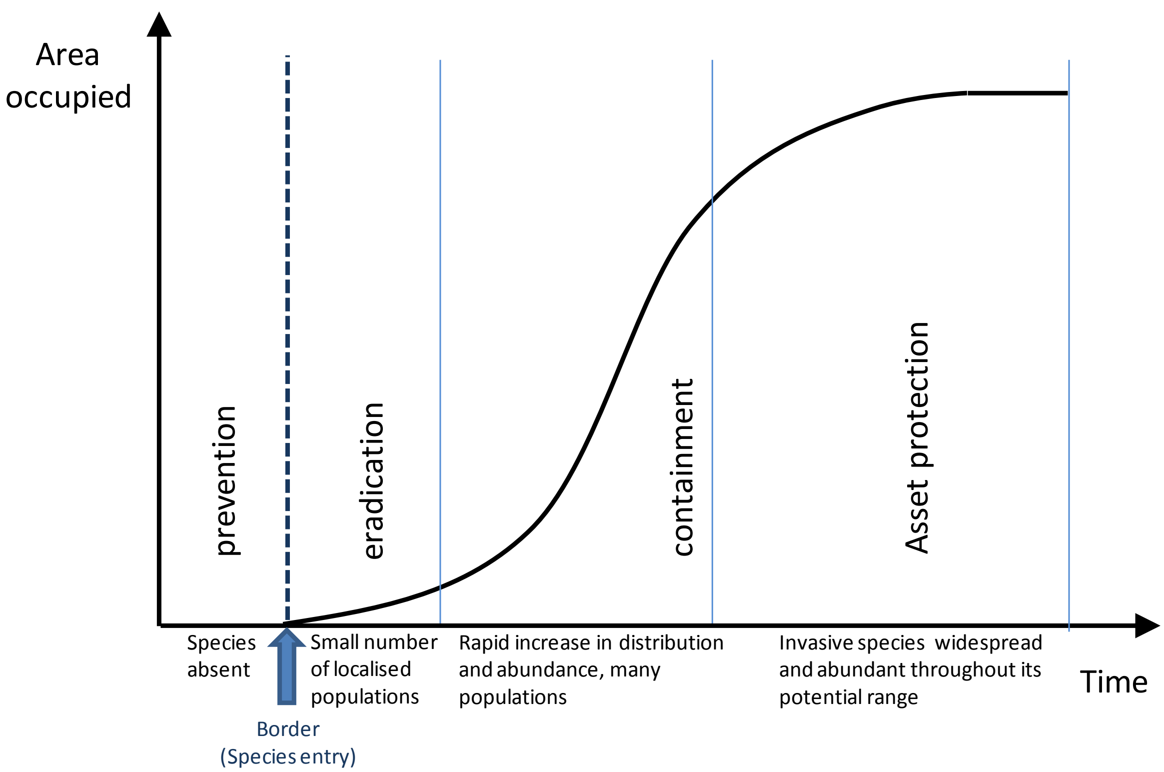

Figure 1. The biosecurity continuum showing relevant management activities as pest severity increases (modified from VICDPI n.d.)

of the biosecurity continuum are largely focused on asset protection (Figure 1), the actual benefits of which are not well understood.

The aim of this project is to evaluate, in general terms, the different investment strategies available to the Australian Government when eradication has not succeeded. We are concerned with cases where a pest or disease (hereafter pest) is established in the landscape, whether or not it has spread to the full extent of its range. The five investment strategies investigated in this report are:

1. national coordination;
2. research and development;
3. raising awareness of the impacts of pests and weeds;
4. strategic investment in on-ground work; and
5. building community capacity to manage established pests and diseases.

This report focuses on issues involved in measuring the impact of investments. Techniques and tools that have been used to understand various aspects of investing in biosecurity are outlined in Chapter 3. The most suitable techniques for the purposes of understanding the return on investment in the above five categories appears to be benefit-cost analysis, although the usefulness of this technique for retrospective evaluation depends on availability of data. Possible techniques were discussed at a meeting of project collaborators and key stakeholders[1]. Chapter 4 investigates each investment strategy in turn, and suggests trigger points for starting and finishing particular activities. These could be used as a starting point for continued debate about trigger points.

Meaningful estimates of the impact of an investment can only be obtained if data on key parameter values have been collected over the duration of the particular investment. In Chapter 5 we discuss why it is important to collect appropriate data and we suggest tools that focus attention on the data that should be collected. The decision-analysis framework developed and applied in Chapter 6 could be used for both prospective and retrospective impact evaluation. This approach could be used to estimate key parameters from available data, using groups of experts, or using simulation with consultation. Two case studies were chosen for retrospective evaluation of costs and benefits of alternative investment strategies; the European rabbit

[1] The meeting was held on Friday 20th July 2012, DAFF, Canberra. Present at the meeting were Jeanine Baker (DAFF), Mike Cole (DAFF), Peter Langdon (DAFF), Nin Hyne (DAFF), Matt Kemp (DAFF), Courtney Harris (DAFF), Dan Thomas (DAFF) Sam Marks (DAFF), Bertie Hennecke (DAFF), Oscar Cacho (UNE) and Susie Hester (UNE, ACERA).

(*Oryctolagus cuniculus*) and the water weed salvinia (*Salvinia molesta*). The case studies were chosen by project collaborators and key stakeholders, because management of these pests had been occurring for many years, and it was thought that available information would allow for analysis of return on investment. A review of both species, with emphasis on identifying available economic and cost data was subsequently undertaken by ABARES (Raphael and Walters 2012). A return on investment analysis was attempted in Chapter 7, but unfortunately lack of data meant this was not possible for many investment activities . Finally, recommendations for effective impact evaluation of pest management investments are given in Chapter 8.

3 Theories, techniques and tools for understanding investments in biosecurity

A range of theories, techniques and tools is available to investigate the different aspects of investing in biosecurity, such as measuring investment impact, prioritising and ranking alternatives, or selecting an optimal bundle of investments. These include benefit-cost analysis, multi-criteria analysis, bayesian belief networks, portfolio theory, simulation modelling and mathematical programming. Choosing the most appropriate technique or tool will depend on the problem and on the available data. In this section we review techniques that have been used to understand some aspect of investing in biosecurity, with a view to choosing the most appropriate of these for undertaking a retrospective analysis of return on investment when pests and diseases are established in the landscape.

3.1 Benefit-cost analysis

Benefit–cost analysis (BCA) is the standard method for economic evaluation of a project or management intervention, and for assessing the relative desirability of alternative projects. Under BCA, all benefits and costs associated with a project through time are identified and quantified in monetary terms. Because BCA usually involves comparing benefits and costs that arise at different points in time, they must be compared in present-value terms through 'discounting'. Discounting is the process by which a future cost or benefit is converted to a present-value and acknowledges that benefits or costs incurred in the future have less value than the same benefit or cost incurred now. The present value (PV) of net benefits received in time period *t*, is calculated as follows:

$$PV_t = \frac{(B_t) - (C_t)}{(1+r)^t} \qquad (1)$$

Where *B* is benefits, *C* is costs, and *r* is the discount rate, assumed to remain constant over time. Time is generally measured in years, with $t = 0$ representing the current year.

The net present value (NPV) of a project represents the sum of its flow of annual net benefits, where each is expressed in present-value terms. It is calculated by summing the values from PV in equation (1) over all years:

$$NPV = \sum_{t=1}^{T} \frac{B_t - C_t}{(1+r)^t} \qquad (2)$$

When NPV is used to rank and choose between alternatives, including between a given proposal and the status quo, the project or management option with the highest NPV would be selected.

The benefit–cost ratio (BCR) is another method that can be used to rank alternative policies or courses of action. A BCR is the ratio of the benefits of a proposal relative to its costs, where both are expressed in present-values terms:

$$BCR = \frac{\sum_{t=1}^{T} B_t (1+r)^{-t}}{\sum_{t=1}^{T} C_t (1+r)^{-t}} \qquad (4)$$

where B_t and C_t represent the benefits and costs, respectively, that accrue in year t, r is the discount rate and T is time horizon of the evaluation.

Undertaking a *full* BCA analysis requires data on *all* costs and *all* benefits. Calculating the cost (impact) of an invader and thus the benefits from preventing its spread usually involves understanding how an invasion would progress in space and time, in a given environment, if left uncontrolled. Thus the impact of a particular invader can vary substantially, depending on its characteristics, the structure, composition and functioning of the invaded community, environmental attributes such as climate and soil, and the different ways all these factors interact (Pyŝek and Richardson 2010).

Some benefits and costs are difficult to value because they are not directly traded in a market place and so do not get priced through the equilibrium of supply and demand. For example, in the biosecurity context it is difficult to value the benefits from preventing pest invasions in natural areas, where invasions might reduce genetic diversity and amenity value of these places. Economists use two kinds of methods to estimate non-market values. The first is based on revealed preferences (e.g. travel costs; hedonic pricing; and supply and costs of protection - the defensive expenditure approach) and the second is based on stated preferences (willingness to pay or accept e.g. choice modeling and contingent valuation). (See Sinden and Thampapillai 1995 for a review). Recently there has been a shift away from using stated preference techniques in non-market valuation, due to the risk of biased results, the lengthy time-frames and often high cost involved in undertaking these studies, and a shift towards using benefit transfer techniques (Rolfe and Bennett 2006). In an environmental-valuation context, benefit transfer involves the transfer of values from a site that has previously been the subject of a valuation study to a target site where values are required. This requires the analyst to find valuation studies for sites that have similar features to the site of interest. Physical, biological, demographic and economic characteristics of a site may influence the values obtained in survey-based methods.

Examples of some of the more encompassing benefit-cost analyses in biosecurity include Antony et al. (2009) for eradication of the red imported fire ant in Queensland and CIE (2001) for use of a biological control agent to control bitou bush in NSW. Instead of undertaking a full BCA, it is much more common to undertake partial BCA, where only the benefits and costs that can be easily valued are considered (e.g. Kompas and Che 2001; Regan et al., 2006; Cacho et al., 2008). Another alternative is to simply focus on cost, including avoided costs (e.g. Cooke et al. 2010). In these cases, the decision to take an action cannot be based solely on NPV. The unpriced factors need to be considered somehow when comparing alternative actions.

It is also common practice to embed benefits and costs into a simulation model in order to assess how these would change over time under particular pest-management policies, and uncertainty. Indeed most BCAs contain an element of simulation, particularly of pest-spread over time (see section 3.5; Cooke et al. 2010; Cacho et al., 2008).

BCA is an appropriate method to determine, retrospectively, the value of investment in various invasive species management projects. Its applicability, however, depends on data availability.

3.2 Multi-criteria Decision Analysis

Multi-criteria decision analysis (MCDA) encompasses a range of methods that explicitly take into account multiple (conflicting) criteria facing individuals or groups charged with making decisions between alternative courses of action. The overall goal of these methods is to determine a ranking of the alternative options, based on how each performs according to each criterion. To determine a ranking, these methods can incorporate both quantitative and qualitative data, include expert opinion, and allow a collaborative planning and decision-making environment (Mendoza and Martins 2006). Because of these characteristics, MCDA methods can overcome the problems associated with unstructured decision making by individuals and groups (Kiker et al. 2005). Multi-attribute value theory, multi-attribute utility theory, deliberative multi-criteria evaluation, goal programming and the analytic hierarchy process are all examples of MCDA methods. Belton and Steward (2002) provide an analysis of the strengths and weaknesses of MCDA methods and their theoretical foundations.

While application of MCDA to complex problems is well demonstrated in environmental decision making, it has only recently been applied in a biosecurity context. Examples of applications of

MCDA to biosecurity problems include Cook and Proctor (2007) and Hurley et al. (2010) for prioritizing the risk of exotic plant pest entry; Liu et al. (2010) for choosing between alternative management options for an insect pest; Darin et al. (2011) for prioritizing weed populations for regional eradication; and Walshe and Burgman (2010) for understanding the consequences of treatment protocols for an emerging disease. Cook and Proctor (2007) employ a deliberative multi criteria evaluation technique in which a citizen's jury of around 10 participants is asked to prioritise a set of 10 exotic plant pests, of varying agricultural, social and environmental impacts, for pre-border risk assessment. Jury members constructed an impact matrix, containing agreed values on the impact of each pest to Western Australia, for each criterion (impact on human health, flora and fauna, yield etc). Jury members were then asked to provide individual sets of criteria weights, and did so during an iterative phase of discussion and revision. Hurley et al. (2010) used a similar approach but employed MCAT (multi-criteria analysis tool) software (CSIRO Sustainable Ecosystems 2007) to aggregate the criteria weights with the impact matrix scores in calculating an overall risk rank. The decision tool developed by Darin et al. (2011) was based on the analytical hierarchy Process (AAP) of Saaty (1980), where an overall goal is set (e.g weed prioritization), and the decision is broken down into a hierarchy of sub-problems, with relative weights assigned to each criterion (Figure 2). The AHP process uses pair-wise comparisons of criteria to estimate the relative importance (weight) of each criterion in the overall decision – traditional MCDA methods would assign weights to all criteria at once (Darin et al. 2011).

Walshe and Burgman (2010) present multi-criteria analysis as the third and final step in a framework they develop to analyse the risk of emerging diseases and invasive species. Australian and World Health Organisation treatment protocols for Australian bat lyssavirus incidents are compared, using results from a workshop involving 16 public health professionals.

While MCDA methods are increasingly recognized as a useful approach for choosing, prospectively, between alternative options in a biosecurity context when multiple stakeholders and criteria are involved, it would be far less suitable for retrospective analysis of investment analysis because weights for the different outcomes are not required to make a decision.

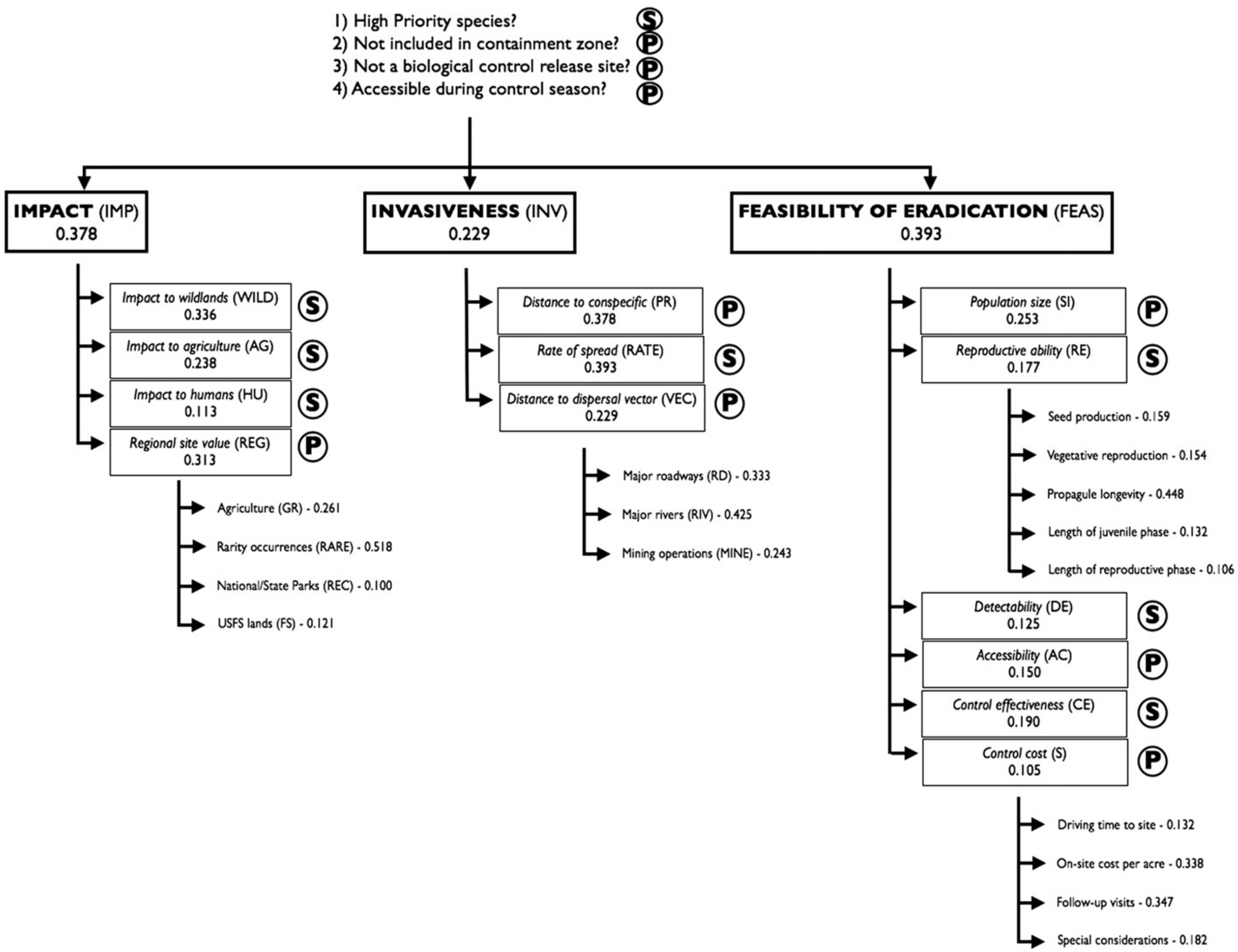

Figure 2. The weed prioritisation decision of Darin et al. (2011) is broken down into major criteria (boxes in bold), sub-criteria (boxes not in bold), and sub-sub-criteria where applicable (not boxed) used to rank weed populations organized in a hierarchy with species-level questions designated 'S' and population-level questions designated 'P.' Weights included below or alongside all criteria. Source: Figure 2 in Darin et al. (2011).

3.3 Bayesian Belief Networks

Bayesian Belief Networks (BBN) are a useful way of understanding the complex relationships, issues and trade-offs that are usually present in decision-making in an environmental context. Belief networks are able to consider uncertainty, support expert reasoning and judgement, handle different types of information, forecast systems that will possibly be subject to structural changes, provide implementations that allow models to be easily structurable, and facilitate expression and trade-off of several types of issues including environmental, social and economic aspects (Varis 2006).

As a first step in developing a BBN, the cause and effect relationships among the key variables of interest in a system are depicted graphically through an 'influence diagram' such as that depicted in Figure 3a. Dependencies between variables, called 'nodes', are represented by one-way arrows. In addition to nodes and arrows, a BBN includes a set of conditional probabilities that represent the belief that a node will be in a given state, given the states of the connecting nodes. These conditional probabilities can be estimated from existing data using regression or some other statistical technique. Where data are unavailable, probabilities can be elicited from expert opinion, stakeholders and ecological theory. The table of conditional probabilities for each node in a BBN contains entries that consider every possible combination of the states of its parent nodes (Dambacher et al 2007) (Figure 3b). Constructing a BBN is usually an iterative process, initially based on the beliefs of the analyst, on existing literature and on consultation with stakeholders.

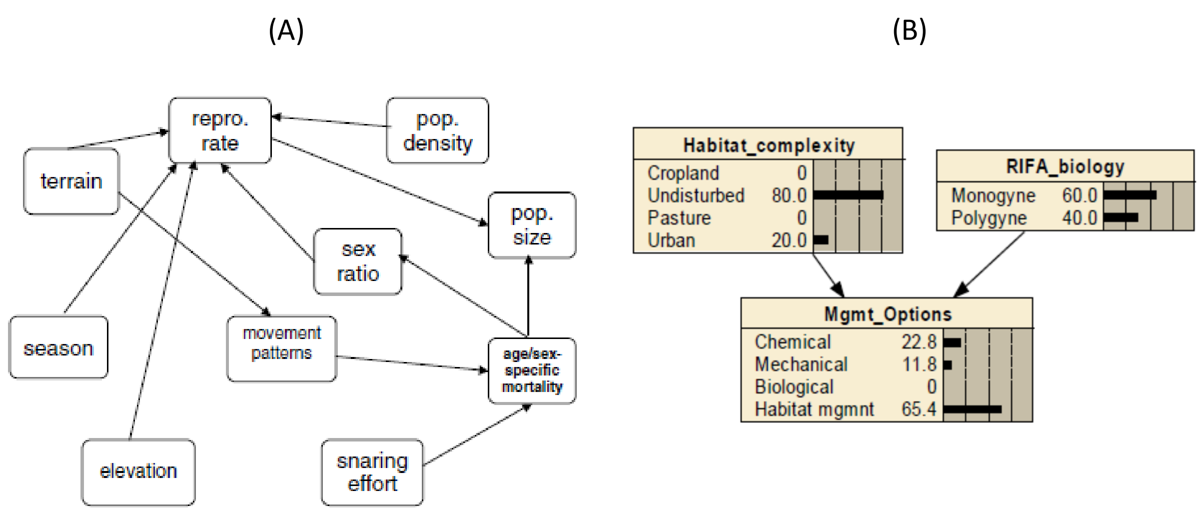

Figure 3. Examples of a BBN: (A) a Bayesian influence diagram of relationships among factors determining the impact of snaring on pig population size. Source: Maguire (2004); (B) a BBN showing the factors that a management agency might believe determine the probability of success of red imported fire ant control option, Source Dambacher et al. (2007)

Additional iterations might lead to nodes being added, amalgamated or deleted, and to conditional probabilities being changed. Cain (2001) provides a detailed account of constructing and optimizing BBN. It is important to note that that a BBN represents a snapshot in time, not a dynamic model, and the arrows represent conditionality, not feedback or flows of energy or materials (Maguire 2004).

The BBN method is valuable because it leads to the development of a transparent and structured approach to thinking about a complex problem. In addition, a BBN can also be ‘solved’ by adding ‘decision nodes’ and ‘utility nodes’ to the existing network, thus building a Decision Network (DN). Decision nodes represent alternative actions that are linked to variables or events that management can control, while utility nodes assign values to outcomes, and correspond to quantities that management may wish to maximize or minimize (Dambacher et al. 2007). A range of tools is available that make the development of BBN easier, these include Netica (Norsys Software Corporation n.d.) and GeNie (Decision Systems Laboratory n.d.).

BBN have recently been applied to invasive species management, including to the management of red imported fire ant (Dambacher et al. 2007) and the feral domestic cat (Loyd and DeVore 2010). They have been used to predict the risk of a weed invasion at the landscape scale (Van Klinken et al. 2008), and to prioritise management and survey effort across space and time for networks of invasive species (Chadès et al. 2011). BBN in the biosecurity context appears well-suited to forecasting expected outcomes of management (e.g. whether eradication will work, where surveillance effort should be focused, and where a particular invasive might have the greatest economic and social impact). However, this technique may not be as well suited to understanding the impact of past invasive-species management programmes.

3.4 Portfolio Theory

One criticism of benefit-cost analysis (section 3.1) is that it assumes the variance in future returns across projects is equal, which is rarely the case - each project under consideration is likely to have different risk attributes. Because of this it is important to consider both the expected outcomes and the variability in the outcomes of each project or activity. It is also important to consider the opportunity for financial risk reduction that comes from a diversification of decision choices (Galligan et al., 1991). Portfolio theory (Markowitz, 1952; Roy, 1952; Elton, 2003) allows the decision maker to balance risk and return from a given investment, and was originally developed in the context of the stock market to help investors find portfolios of investments that would simultaneously maximize expected returns on investment while minimizing risk.

Markowitz’s mean-variance approach to portfolio selection is the traditional and widely used approach (Elton 2003), and assumes that investors aim to maximize the expected utility (total satisfaction) of the returns from an investment portfolio, where expected utility can be measured by means and variances. The mean-variance approach results in construction of an ‘efficient frontier’ consisting of an efficient set of portfolios. An alternative to this approach includes:

- Roy’s ‘safety first method’, a simpler decision model that concentrates on limiting the risk of bad outcomes and which recommends one particular portfolio above all others;
- selecting the portfolio that has the highest expected geometric mean; stochastic dominance (first-, second-, and third-order);
- selecting portfolios on mean, variance *and* skewness; and
- Value at Risk (VaR) where downside risk is emphasized,

(see Elton 2003 for more details on each).

While originally developed for investment in financial markets, the principles of portfolio theory apply equally well to any situation where a choice must be made between a collection of items, projects, enterprises or policies, and thus is applicable to decision making in a biosecurity context. Examples of applications of portfolio theory to biosecurity problems include Prattley et al. (2007) for surveillance of exotic animal diseases; and Galligan and Marsh (1988) for veterinary interventions in dairy cattle. In Prattley et al. (2007), portfolio theory is applied to the allocation of a fixed amount of biosecurity resources to different surveillance scenarios for exotic animal diseases, using the safety-first and mean-variance techniques. Disease risk varies spatially by region and temporally within regions, and there is uncertainty surrounding the level of disease risk. Results show how resources should be optimally allocated to surveillance for each exotic disease or geographical area, and time period, according to the degree of disease risk and uncertainty. In Galligan and Marsh (1988) portfolio theory was used to determine the optimal mix of veterinary services for a dairy herd. A risk-efficient frontier was produced, showing expected risk and return for each intervention, allowing the farmer or veterinarian to select a particular level of intervention according to their risk preference.

Portfolio theory could be used to select a portfolio of biosecurity projects if information were available on the risk attributes of each project over time. In the current context, where the aim is to retrospectively evaluate projects, this information is, unfortunately, not readily available.

3.5 Simulation modelling and mathematical programming

Computer–based simulation models are simplified representations of a system and have many uses, including analysis and evaluation of policy. A simulation model might consist of a single equation that can be solved in a spreadsheet programme, or might contain a large number variables, include uncertainty, and be solved using programming languages.

In the context of decision-making in biosecurity, simulation models, particularly bioeconomic models, have been used to get parameter values for BCAs (section 3.1) in order to understand the economics of various pest control options (eg. Buhle et al. 2005; Leung et al. 2005; and Cacho and Hester 2011). In Buhle et al. (2005), matrix population models were used to project the growth of oyster drills and this information was then used to find cost-effective control strategies for this pest. The authors found that the relative costs of controlling particular life-stages substantially influenced solutions to the cost minimization problem. Leung et al. (2005) tackled the issue of control post-border vs prevention at the border. They use a simulation model containing ecological and biological parameters to develop rules of thumb that can be used to guide policy and decision-making, particularly where decisions need to be made quickly. Cacho and Hester (2011) use a spatio-temporal simulation model to show the trade-off between cost and probability of success in eradication programs. Simulation models are made significantly more complex by adding spatial information about a pest, for example whether habitat suitability varies across a landscape or whether the pest is clumped in a particular landscape.

Simulation models may also be used to find parameter values for mathematical programming models. Mathematical programming is the name for a range of methods (e.g linear, non-linear, dynamic and integer programming) that are used to find the optimum value of an objective function (e.g profit or cost) so that particular constraints (e.g. resource use) are met. Examples of mathematical programming models developed to assist biosecurity decision making include Hastings et al. (2006) who use linear programming to determine optimal removal strategies for a marine pest; Yokomizo et al. (2009) who use stochastic dynamic programming to determine the effects of population dynamics and density-impact curves on optimal management effort ; and Baxter and Possingham (2011), who use stochastic dynamic programming to find the optimal allocation of resources to broad-scale surveys, targeted surveys or research to improve species distribution models and hence the accuracy of future surveys.

The usefulness of simulation and mathematical models in the current context appear to be in conjunction with BCA where data are not available, to get reasonable values of certain parameter values. These can be derived based on biological principles and simulation.

3.6 Summary

The range of techniques listed in this section was discussed with collaborators and key stakeholders during a project workshop in July 2012. Given the retrospective nature of the evaluation, BCA with or without simulation, appears to be the most appropriate technique, although this will depend on data availability.

4 Investment Strategies and triggers for investment

Governments routinely invest in biosecurity activities when the outcomes of these activities are considered to be *public goods*, that is, once undertaken, no one can be excluded from benefiting from the activities. Biosecurity examples of public goods would include funding quarantine operations, investing in a new biological control agent, undertaking weed clearing in national parks, and running media campaigns to promote awareness of particular pests. Because of their nature, not enough of these goods and services would be ‘produced’ if left to the competitive market, compared to the amount required by society, hence the need for government intervention.

Given the public-good aspect of many biosecurity activities, the trigger for government investment should be based on an assessment of public net benefits (public benefits minus public costs) and private net benefits (private benefits minus private costs). A framework for this assessment in given in Figure 4. When public net benefits of an investment are positive (and possibly above a particular benefit-cost ratio) but private net benefits are negative, government intervention is warranted, as would be the case in area D of Figure 4. This scenario occurs, for example, when a pest invades a natural environment, impacting on amenity and biodiversity, but with minimal impact on private land, such that there is no incentive for private landholders to undertake control. In the case of a pest that has an impact on both public and private land,

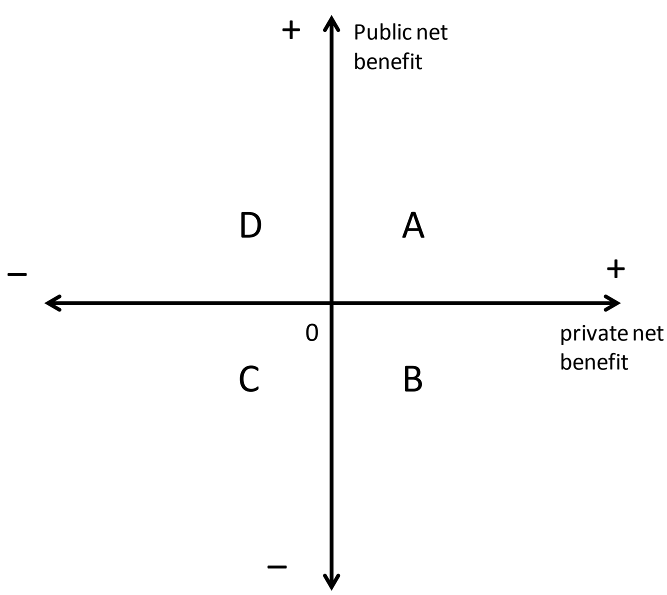

Figure 4. A framework for discussing public investment in biosecurity, modified from Pannell (2008), Figure 10.

where both private and public net benefits of control are positive (A in Figure 4) then government investment could be targeted to encourage private actions to make effective use of limited budgets. For example, wild dog control by private landholders might increase and be more effective if a national coordinator is appointed to coordinate control, give advice on control methods and strategic management options. Investment by the government in some kind of pest-management activity may still be warranted if private net benefits are relatively low. Government investment in biosecurity activities would normally not be warranted in areas C or B, but the government may find it desirable to invest in education or extension for cases that fall in area B. For areas A and D it is the relative levels of private and public net benefits that would drive the choice of government investment strategy – see Pannell (2008) for more details. The framework illustrated in Figure 4 is a useful way of thinking about triggers for action, but it is not always easy to find where specific investment proposals would fit within the diagram. It is also important to consider uncertainty when applying Figure 4.

When a pest or disease is established in the landscape the areas in which the Australian Government currently invests are:

- National coordination;
- Research and development;
- Raising awareness of the impacts of pests and weeds;
- Strategic investment in on-ground work; and
- Building community capacity to manage established pests and diseases.

Despite government investment in these categories having become routine, there remains a need to explore the values of these types of investments. There is also little formal exploration of the triggers for investment in each area – when and why such investment should take place, and when it should cease. Exploring both the value of investment and triggers surrounding this investment should improve future decision making about the management of pests that are widespread in the landscape. In this section we explore the motivations for, objectives and outcomes of investing in the different investment categories in general terms. Analysis of specific case-studies is found in Section 7

4.1 National coordination

A national, or cross-border approach to coordinating the management of a pest has become the typical approach in Australia. This approach is used for pests that are either widespread across the country, or established in several jurisdictions with the potential to become more widespread and whose impacts on agriculture, the environment and social welfare are significant. Examples of pests managed using a national approach include wild dogs, feral pigs, rabbits, some weeds and plague locusts. Examples of national initiatives that focus attention on pests include the Vertebrate Pests Committee and the National Feral Animal Control Program. In addition, national biosecurity and disease control responses are in place through Animal Health Australia, the Australian Wildlife Health Network, Product Integrity/Animal and Plant Health, Plant Health Australia (PHA) and Biosecurity Australia (House of Representatives Standing Committee on Agriculture, Fisheries and Forestry 2005).

A nationally coordinated approach to pest management is thought to have a number of advantages (House of Representatives Standing Committee on Agriculture, Fisheries and Forestry 2005):

- increased consistency of approach
- national best practice implementation
- national direction
- increased knowledge about pest animal populations and distribution
- more efficient use of resources.

Under the Weeds of National Significance (WoNS) initiative, national coordination is primarily about providing guidance and facilitating action for each species in order to establish containment lines, strengthen networks to prevent new infestations, and contribute to reducing outliers and the size of core infestations (Hennecke and Raphael 2012).

The objectives of national coordination appear to be focused around improved knowledge flow and avoidance of effort duplication through coordination of activities to manage spread and impact of a species.

It is difficult to define a ‘typical’ national coordination programme. For the WoNS, a national coordinator was appointed for each species, and they were responsible, often with support from a management group, for developing and implementing strategic plans as part of phases 1 and 2 of management (Figure 5). During these phases national coordination involves developing foundational materials, establishing strategic, coordinated control programs and establishing a national network of partners (the Management Group) to deliver the national strategic plan (AWC 2012). At the end of Phase 2, when the majority of the national coordination tasks have been completed the roles of the national coordinator and the Management Group come to an

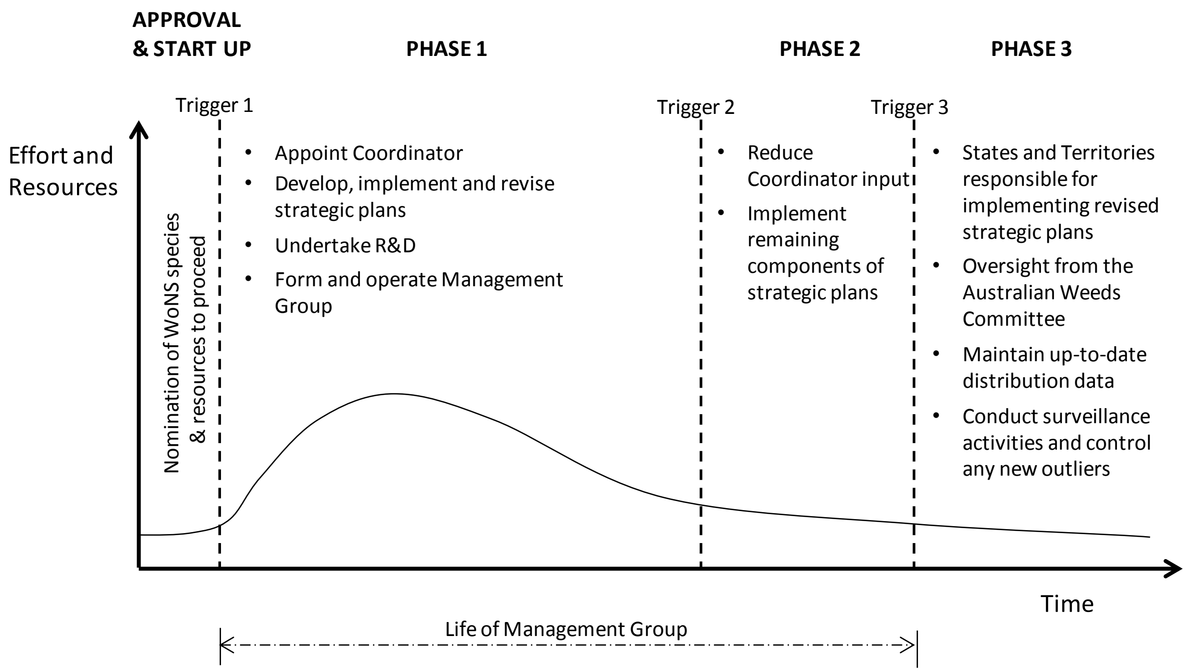

Figure 5. Diagrammatic representation of effort and resource use at a national level when implementing a WoNS strategic plan. Modified from AWC (2012), Figure 1.

end. In their place, States and Territories collaborate as required for cross-border and national actions, for particular weeds and the Australian Weeds Committee (AWC) oversees the implementation of revised strategic plans.

A national approach to wild dog control in Australia provides another model of national coordination. A facilitator was appointed in 2006 to promote a nationally consistent strategic approach to wild dog management through a 'nil-tenure' approach. The facilitator played an important role in developing cooperative wild dog management plans utilising all forms of control at local, regional and state government levels to effectively manage the impacts of wild dogs (Chuddleigh et al. 2011). The coordinator supported and complemented the skills of regional coordinators, coordinated activities across management groups and shires, and improved extension and flow of information across jurisdictions.

To value the outcome of national coordination we need to measure the effect of this activity compared to what would have happened with out it – the counterfactual. Benefits (or avoided costs) may have resulted from shared knowledge and improved knowledge flow, and from coordination of management activities. It is difficult to find measures by which national coordination could be evaluated from within the programmes themselves. The objectives of national coordination described above suggest it should result in ‘better’ management of the pest. Improved management could be measured in terms of:

1. cost savings – is it now cheaper to manage the same amount of pest, or we are able to manage more of the pest with the same budget
2. reduced spread and/or population density of the pest,
3. reduced impact on agriculture, the environment and social welfare.

Linking the effects of national coordination to each of these measures is a difficult task, because there is a range of factors and influences that could cause measures to change and their actual effects may differ from original plans. Hennecke and Raphael (2012) evaluated the effectiveness of national coordination for each of the WoNS in terms of whether it resulted in a reduction in weed spread. A reduction in weed spread was defined as a decrease in distribution or a distribution which stays the same. Results from their spatial analysis of 1998 (start of WoNS) and 2011 datasets showed all but one species *increased* in distribution. By this measure, national coordination would not be deemed successful, although the authors did note other potentially important influences on distribution – habitat/ecological considerations, changed control methods – and the difficulty in isolating the effect of national coordination from these. The problem is finding the counterfactual as discussed later.

Chuddleigh et al. (2011) evaluated the impact of the national wild dog facilitator and found a benefit-cost ratio of between 5 and 8 depending on the time horizon. The authors only included the impacts of wild dogs on agriculture. They based their findings on a review of previous studies and then translated these to a national measure.

No other published studies that evaluate national coordination of pest-management programmes were located, despite the large number of pests whose control is being approached in this way.

Given the previous discussion, suggested trigger points for national coordination for control of pests that are established in the landscape are as follows:

- **Start**. This could be determined by an assessment of public net benefits, and would include measuring the severity of the pest, in terms of current and potential impact, taking into account current and potential distribution on public and private land, the number of jurisdictions affected, and monetary values of damage.

- **Finish –** The question of whether a particular program should continue indefinitely is not always easy to answer. Where the objectives of national coordination are to implement processes that improve efficiency and knowledge flow, then it could be argued that national coordination should be of a fixed duration. Processes should be put into place so that, over time, the role of the coordinator can be reduced (see Figure 5). This often means that networks and community groups are put in place to carry out actions into the future (see section 4.5 on building community capacity). Strategic plans to manage pests should contain estimates of the time it will take to reach certain national coordination milestones, as is the case with WoNS species. National coordination should be able to cease at this time if implementation of the strategic plan has been successful, and certainly should cease if national coordination has failed to achieve objectives.

4.2 Research and Development

Investment in research and development (R&D) is aimed at discovering solutions to problems, and creating new products or knowledge. When R&D is unlikely to result in intellectual property such as patents that can be owned, there will be an under-investment in R&D by the market from society's viewpoint and government intervention will be warranted. This will occur if the R&D is a public good – no one can be exluded from using the research outputs – and thus the full benefits from undertaking the research wouldn't be received by the organisation funding the activity. This public good characteristic is often present in biosecurity R&D and is the reason why governments routinely intervene to fund it. In Australia, public funding of biosecurity R&D during 2011 was at least $139m with an additional $770m invested into infrastructure to support the R&D during 2007-11 (IGAB 2012). The Australian Government funds biosecurity research in four national biosecurity research and development priority areas. These are to:

1. Minimise the risk of entry, establishment, or spread of pests and diseases
2. Eradicate, control or mitigate the impact of established pests and diseases
3. Understand and quantify the impacts of pests and diseases
4. Cost-effectively demonstrate the absence of significant pests and diseases (IGAB 2012).

In this project our focus is on government funded R&D that is undertaken as part of priorities 2 and 3. Examples of typical research when a pest is established in the landscape include the development and testing of new pest control techniques, including biological control agents, understanding the population ecology of a pest, and understanding and quantifying the impacts of pests.

To value investment in R&D we need to measure the benefits of R&D activities compared to the cost of undertaking them. The costs of R&D projects are usually available from project proposals. To calculate benefits of an R&D project it is first necessary to understand the counterfactual – what would have happened without the research, and then to estimate the value of changes that resulted from the research. Ideally, the aims of the research and measures by which its success can be evaluated would have been elucidated before project commencement. When this is not the case evaluation is more difficult. Outcomes also become more difficult to value if any of the impacts are on the characteristics of natural assets such as biodiversity and amenity. While research projects are of a limited duration, the outcome of research can persist for many years, even indefinitely, if it improves knowledge or leads to the introduction of a biological control agent that continues to persist in the pest population.

R&D into new pest management techniques, such as biological control, is usually aimed at directly reducing the impact of a particular pest and thus its outcome could be measured in terms of distribution and/or density. For example, research into biological control for rabbits, a pest of both agriculture and the environment, has resulted in several widely released agents. Over time, researchers have recorded changes in rabbit abundance and linked dramatic falls in abundance with release of the agents. (T5) Cooke et al. (2013) used these data to estimate loss-expenditure curves and thus calculate the benefits of biocontrol compared to what would have happened without biocontrol agents. Even without the benefits to the environment included, the value of the R&D that led to the development of the biocontrol agents is evident, with the benefits of biocontrol greatly outweighing the costs.

Indeed, when information on pest ecology leads directly to a more effective application of a control technique measuring the impact should be possible, if adoption rates are known. R&D that aims to improve our understanding of the population ecology or impact of a pest is more difficult to value when the outcome is an improvement in knowledge about a pest. Where this knowledge is subsequently used in pest management it may be difficult to estimate its effects and isolate the way this knowledge was applied (see Section 5 on the measurement problem).

Given the previous discussion, suggested trigger points for investment in R&D for control of pests that are established in the landscape are as follows:

- **Start**. Initially there should be an assessment of whether a market failure exists – whether the research is of a public good nature and therefore the market lacks the incentives necessary to undertake what society deems to be the optimal amount of research. There also needs to be an assessment of the public net benefits (public benefits minus public costs) of the research that is proposed. If the public net benefits are high, then there is a good case for the research to go ahead.

- **Finish**: Research projects are normally of a fixed duration, usually measured in years, although it is important to note that the direct and indirect impacts of a successful research project may last much longer, in some cases indefinitely. Trigger points for finishing investment in a particular research are only relevant for those research projects that are not on track to meet their objectives and/or budgets. In some cases when enough R&D has been undertaken, it might be better to spend resources on extension of research findings and building community capacity that encourages adoption.

4.3 Raising awareness of the impacts of pests and weeds

Raising awareness of the impacts of pests is undertaken to promote a desire within the community to assist in the control of pests, and to educate and give the public knowledge on how to act. Information from the public can be useful in determining density and distribution of a pest (ie. passive or community surveillance). Raising awareness can maintain momentum for private control and enhance the effect of control by pest-management authorities.

Awareness can be raised many different ways. For an agricultural pest, awareness activities might include field days, on-farm visits, rural media items, workshops and education activities through farmer organisations. If the pest also has an environment or social welfare impact then activities might include mail outs, stalls at shows, billboards, media campaigns, interaction with citizen science programmes and other community groups. Websites, smart phone Apps and social media are also routinely used to inform the community. The website FERALSCAN (http://www.feralscan.org.au) is a good example of how the community can assist in the control of a range of vertebrate pests that are widespread in Australia. Information from the public on pest sightings, damage and pest-control activities can be uploaded onto an online map. Pest-control agencies are able to use the information contained in the maps to inform management. Community members are also able to access the maps as well as other useful resources.

Despite the routine nature of investing in public awareness activities, no published evaluation procedures were located for this activity. The expected outcome of investing in awareness-raising activities appears to be improved knowledge by the public which will in turn lead to better management of the pest. As in the case of national coordination, improved management could be measured in terms of cost, spread and impact. The difficulty, however, will be in isolating the effect of public awareness on these measures from the effect of the other pest-management investments. One recent study by Cacho et al. (2012) used data from the red imported fire ant (RIFA) eradication campaign to value the return on investment in community awareness activities in that programme. They generated a probability map and calculated the amount of search that would have been required by pest-management agencies to detect all the known ant colonies in a particular period if reports from the public had not been available. The authors were able to use a large dataset of information on community awareness activities for their analysis. This amount of information is rarely available in pest-management programmes.

Suggested trigger points for raising public awareness for pests that are established in the landscape are as follows:

- **Start**: Whenever a pest management program is initiated, it should include community engagement if the pest is easily identified by the public or if the campaigns can be targeted at specific groups (e.g veterinarians or livestock producers).
- **Finish**: There is evidence that community awareness 'depreciates' overtime (Cacho et al. 2012) so investment in this activity may need to be ongoing while a control programme is active.

4.4 Strategic investment in on-ground work

Strategic investment in on-ground work is undertaken to directly affect the population distribution and/or density of a pest to reduce its impact on agriculture, the environment or social welfare. Activities might include weed-control programmes in a national park, removing invasive insects from public places and private dwellings, or subsidising a rabbit-ripping program on a farm. Publicly funded on-ground control often takes place as part of a larger management plan for a pest, possibly in conjuntion with private control works, community engagement and national coordination and to support R&D extension.

In the current context of controlling established pests, on-ground control would not be undertaken with a view to global or even regional eradication (island eradications may be an exception), rather, it is undertaken to reduce impact. The reduced impact is likely to be sustained for the duration of the control and for a period of time afterwards, depending on the ecology of the pest. Eventually, if control measures cease, pest numbers are likely to increase again. This does not mean that the on-ground control has not been valuable – there is value in delaying the spread of a pest because the damages caused by the pest are also delayed (Cacho et al. 2008).

Public investment in on-ground control should only occur where public net benefits are positive (areas A and D in Figure 4) or where the investment is likely to lead to positive public net benefits in the future (area B in Figure 4). An example of the latter case would be publicly funded wild dog control on a farm leading to positive spillover effects on neighbouring farms and a national park, which would be in addition to the private benefits received by the farmer.

Measuring the value of investing in strategic on-ground work again involves measuring and valuing the changes caused by the control compared to the counter-factual – what would have happened without it. Ideally, the baseline, pre-control situation would be well understood and documented before control takes place, and data would be collected during on-ground control that would allow change to be measured. These data might include measures of pest abundance, presence or absence; measures of biomass (in agriculture) or floral diversity and quantity (natural enviroment); and measures of faunal abundance. As with evaluation of other investments, it is important to isolate the effect of the specific control activity from other changes that might be taking place simultaneously.

The next step is to value the changes that take place as a result of the control and reduction in pest numbers – for example improved carrying capacity on a farm, improved biodiversity in a forest, improved amenity value at a beach etc. As discussed in previous sections, impacts on natural assets can be difficult to value because these are not traded in a market, and so information about their price (value) is not readily available. Nevertheless, there is a range of techniques available in this situation, and these were discussed in Section 3.1.

Suggested trigger points for publicly funding strategic on-ground control for established pests are as follows:

- **Start**: Investment should only occur if the public net benefits (public benefits minus public costs) are positive or likely to become positive as a result of the investment.
- **Finish**: An argument could be made to continue on-ground control for as long as public net benefits remain high or above a particular level. Alternatively there may be a target pest abundance that, when reached, could signal the end of the control effort. It is important to note that even if pest numbers rise again following control, there is benefit in delaying the increase in population.

4.5 Building community capacity to manage pests

Investing in building community capacity to manage pests is aimed at empowering the community to undertake their own pest control without the need for ongoing public funding, by adopting ‘best practice’ management. Ideally, building community capacity results in a larger number of individuals and groups undertaking pest control, in a consistent and collaborative way, thus increasing the area or population being controlled and the effectiveness of that control. The theory of building community capacity is discussed by McGinty (2003) and Chaskin et al. (2001). Improving the capacity of community members may lead to a reduction in the need for public funding for ongoing control. It is often the case that the strategy of investing in building community capacity is implemented by a national coordinator involved in management of a particular pest (Section 4.1). As national coordination tasks are completed there can be a greater reliance on community groups to maintain momentum with ongoing pest control (Figure 4).

The PestSmart Toolkit (http://www.feral.org.au/pestsmart/) is an example of an online resource that has been developed to help communities adopt best-management practices in their control of key vertebrate pest species including rabbits, wild dogs, foxes, carp, feral cats and rabbits. Information is provided in fact sheets, case-studies, technical manuals, scientific reports, YouTube video clips and a smart phone app. The West Coast Integrated Pest Management Program is an example of a community-based group using the information provided in PestSmart to assist to coordinate pest control on a landscape scale. This group was initially funded by a Natural Heritage Trust grant. Members control foxes and rabbits on private land and there are positive spillover effects for a nearby conservation park – reduced predator pressure which should allow for reintroductions of locally extinct fauna and recovery of native flora. Other examples of building community capacity include landholder-driven field days and pest-management demonstration sites.

Building community capacity ultimately aims to improve the management of a pest and reduce its effect on agriculture, the environment or social welfare. As was the case with national coordination, improved management could be measured in terms of:

1. cost savings – it is expected that less government funding will be required to manage the same amount of pest, or more of the pest can be managed with the same level of investment.

2. reduced spread and/or population density of the pest,

3. reduced impact on agriculture, the environment and social welfare.

Unfortunately, isolating the impact of this investment from the effects of national coordination, raising awareness, R&D and on-ground work that is likely to be simultaneously occuring, will be a difficult task, especially when analysed retrospectively. Ideally, before investing in building community capacity, information would be collected on key variables that are likely to change following the investment. Recording these data would indicate the baseline against which the investment outcome may be compared.

Despite the difficulties in measuring the impact of building community capacity, we suggest the following trigger points:

- **Start**: Building capacity is usually included as part of landscape-scale pest management efforts. Nevertheless, the investment should only occur if the public net benefits (public benefits minus public costs) are positive or likely to be positive as a result of the investment. This is likely to be the case if building community capacity can make a significant difference to pest distribution.
- **Finish:** Because the nature of the investment is to give the community the skills to undertake pest control without the need of ongoing public funding it is likely that the investment in this activity by the government will be for a finite period. Evaluation measures set before commencement of an activity should be regularly monitored and revised if necessary to inform the end-point or the activity.

4.6 Summary

Important questions for the government when deciding to undertake investment in pest management are i) is the investment value for money? and ii) at which point should a programme start and finish? Answers to both questions depend on valuing the outcome of the activity in the future and comparing it to what would have happened without it. As discussed in this section, this is usually a difficult task. There are difficulties in isolating the impact of a particular activity, and if this can be done, there are often issues with the values that should be put on per-unit changes in environmental attributes such as biodiversity and amenity value.

In summary, public funding of pest management activities should go ahead, budget permitting, if there are large public net benefits. To calculate the likely level of public net benefits, reliable data on key variables in the pre-investment period need to be compared with estimates of how these variables are likely to change following implementation. We now develop these ideas in more detail in Section 5.

5 The measurement problem

Evaluating return on investment is aimed at producing evidence of the effectiveness and value of a particular investment activity. In this project we are concerned with retrospective evaluation of pest-management projects that might typically be funded by the Australian Government within five investment strategies. Section 4 detailed the likely objectives of investing in each strategy and how these outcomes might be measured. When pests are established in the landscape, investment usually occurs as a bundle of different activities – national coordination, R&D, some onground work and awareness raising, for example. The outcome of investment activities in isolation and as a whole is to influence, either directly or indirectly, the abundance of a pest. To measure the value of individual investments there are two key issues to address: firstly, disentangling the effects of a package of investment activities on pest management; and secondly, where these effects can be isolated, understanding how a particular management activity changed pest abundance overtime, compared to what would have been the case without the particular measure. The second measurement problem deals with establishing a baseline, or counterfactual, against which success of the investment activity can be assessed

The first issue is difficult or impossible to deal with retrospectively if appropriate data have not been collected before and during implementation. Where data have been collected, meta-analysis is possible, where a dependent variable is related to attributes of interest. Meta-analysis is discussed in more detail at the end of this section.

The impact evaluation literature (Ravallion 2001, Gertler et al 2011) offers useful insights into the measurement problem we face. Impact evaluation methods have been developed over several decades to support evidence-based policy. The drive for these developments has come largely from international agencies such as the World Bank (Gertler et al 2011). These agencies face the challenge of measuring the effect of development policies on poverty, education, health and so on. A number of statistical methods and sampling techniques have been developed to disentangle the effects of these policies from other factors that influence development outcomes. Below we express these methods in terms of investment policies for control of invasive species.

As we discuss in the next section, there is no substitute for planning for impact evaluation as part of a program design, so that the right data are collected during the program to estimate actual impacts and return on investment. But first we explain the problem of estimating a conterfactual that cannot be observed but needs to be inferred.

Impact evaluation is essentially a problem of missing data (Khandker et al. 2010, p.25). In our case this is because we cannot observe the outcomes of managed infestations had they not been subject to management. The question we want to answer is: “what is the impact *Y* of a program *P* on an outcome of interest *X*?” In our case the outcome *X* is the size of an invasion (area infested) and the program *P* could be a particular investment or a combination of investments to control the invasion.The expected impact is:

$$Y = E(X \mid P = 1) - E(X \mid P = 0) \qquad (1)$$

This means the effect of the program is the difference between the size of the invasion with control (P=1) and the size of the invasion without control (P=0). If the program is effective we expect Y < 0 (the size of the invasion will be smaller with the program than without the program). The problem is that, in evaluating the investment *ex-post*, we can only observe the first term on the right hand side. The invasion has been treated, so its size in the absence of treatment (P=0) is unknown. In this example, $(X \mid P{=}0)$ is the counterfactual.

To understand the missing data problem suppose we had historical data on a sample of infestations for a program that has concluded. Let X_{0i} represent the size an infestation that was not subject to control (Pi=0) and X_{1i} represent the size an infestation that was subject to control (Pi=1). Using these data we could estimate the difference between treated and untreated infestations, the difference is:

$$D = E(X_{1i} \mid P_i = 1) - E(X_{0i} \mid P_i = 0) \qquad (2)$$

If the two infestations were of comparable size at the start of the program, D < 0 would indicate the program had some success. Although the conditioning seems redundant in equation (2) it helps understand the bias that can be introduced by simply taking the difference between treated and untreated infestations. The bias (B) is the difference between D and Y:

$$B = D - Y = E(X_{1i} \mid P = 0) - E(X_{0i} \mid P_i = 0) \qquad (3)$$

The bias is the difference between the final size of the treated infestation if it had not been treated and the observed final size of the untreated infestation. We could correct for this bias if we knew $E(X_{1i} \mid P_i = 0)$, the counterfactual mean, but we cannot get a sample estimate of this expression. We cannot observe the final size of an infestation that was subject to control if it had not been controlled, because the event did not occur.

If there is no bias then the impact *Y* can be estimated directly by calculating *D*. The bias arises if there are underlying differences between infestations in the absence of the program. In other words, if the sample of infestations that were subject to control differs from the sample of infestations that were not subject to control in some way (for example by being more accessible or invading a different type of environment) then bias would exist.

In theory, the best way of avoiding bias would be to assign control randomly to infestations. Then controlled and uncontrolled infestations would have had the same expected size, so that $E(X_{1i} \mid P_i = 0) = E(X_{0i} \mid P_i = 0)$. In practice it is not possible to experiment in this way, agencies must decide whether to control or not particular infestations based on measures such as potential damages and area at risk.

In fact, it is likely that selection bias occurred for infestations that were targeted for control, as resources would normally be applied to the infestations that are likely to cause most damage or spread faster. This means that the program could have a positive effect (reduction in invasion spread) even when equation (2) may suggest otherwise when $B > 0$.

To correct for possible selection bias and other differences between infestations, our regression equations would need to account for variables that describe specific features of the infestation. For the *i*th infestation in our sample we would like to estimate:

$$X_i = a + bP_i + cZ_i + \varepsilon_i \qquad (4)$$

where *a*, *b* and *c* are regression parameters and *Z* stands for variables that influence invasion spread (such as initial invasion size, features of the environment invaded, climatic factors, human population density etc.), and ε is the error term. If the program is effective we expect $b < 0$, as the presence of the program will result in a smaller infestation.

The real situation is more complex than this, as there is a time dimension that has not been considered (at what point in time after control started do we measure X?). Another possible problem is that ε may not be normally distributed, requiring data transformations or more complex regression methods.

We are interested in the impact of five different investment types, so rather than one single control program *P* we have 5 possible programs that may be enabled or disabled for a particular infestation:

$$X_i = a + \sum_j b_j P_{ij} + cZ_i + \varepsilon_i \qquad (5)$$

The parameters b_j would indicate the effect of each investment type *j*. Program participation (P_j) may be treated as a binary (0,1) variable, or it may be represented by the actual amount invested in program *j* if the data are available. Possible interactions between investment types may also need to be considered requiring equation (6) to be extended:

$$X_i = a + \sum_j b_j P_{ij} + cZ_i + \sum_j \sum_k P_{ij} P_{ik} + \varepsilon_i \qquad (6)$$

Meta-analysis (e.g Gurevitch and Hedges 1999; Raitzer 2003; Bertheau et al. 2010) could be used to estimate these parameters. In the current context, this type of statistical analysis could combine the results of all available programs that have invested in management of a particular pest, to find significant relationships between a measure of success (e.g population change or population density) and independent variables such as total budget, pest characteristics, types of investment activities etc. Investment activities where pest control was not successful, or less successful than expected, should also be included where available.

The importance of understanding what would have happened without the investment is illustrated in Figure 6. Consider a pest-management program that aims to reduce pest distribution over time as measured by invasion area (*A*). Assume that, at the start of the programme the expected trajectory of *A* for a well-executed programme is given by the lower line in Figure 6 – area invaded decreases over time. But suppose the actual outcome was an increase in the area invaded over time (solid line in Figure 6). This does not mean the

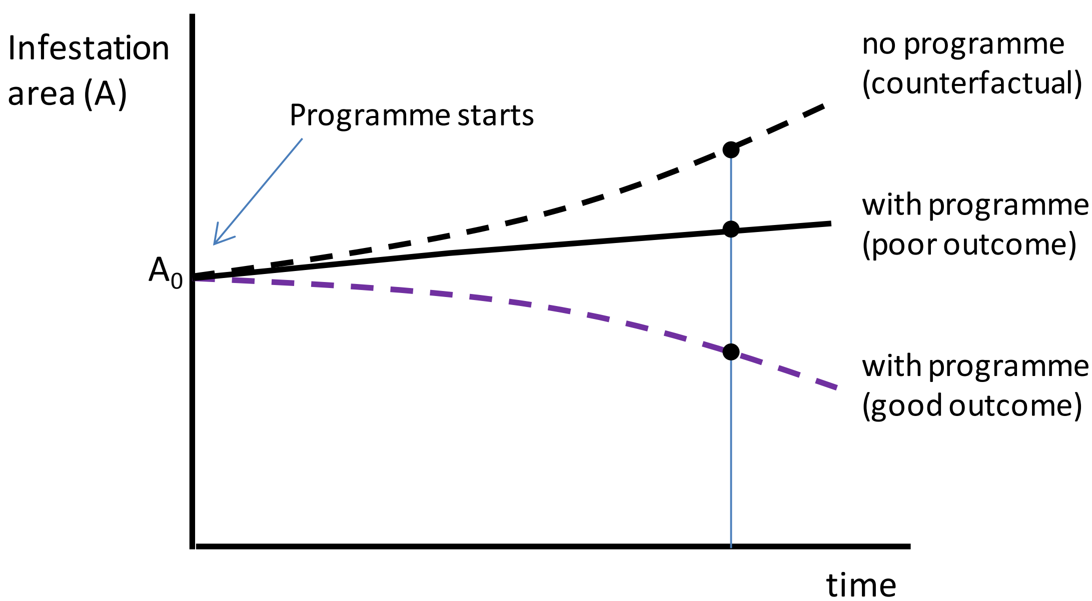

Figure 6. The solid line shows the outcome that occurs with the management programme, the lower line shows the planned result of management, and the top line shows what would have happened.

programme was a failure, as unforseen random effects will influence outcomes. So it is important to compare the actual outcome (an increase in *A*) with what would otherwise have been the case. In this example, the counterfactual shows that in the absence of the pest-management programme, area invaded would have increased more rapidly over time (top line in Figure 6). Actual benefits of the investment could be calculated from the shaded area B in Figure 6 and then compared to the costs of undertaking the programme (see Gong et al. 2009 for more details). Implementing this sort of comparison requires modelling to predict possible outcomes or to explain observed outcomes.

5.1 Improving prospective impact analysis – Conceptual Models and Result Chains

Measuring the counterfactual retrospectively (after the program has been implemented), is usually a difficult and thus costly process, especially if the data needed to estimate the counterfactual were not collected prior to commencement of the management activity. Ideally, baseline data for evaluation are collected prospectively, before the activity commences. Gertler et al. (2011) give the following reasons why prospective impact evaluation is likely to achieve credible evaluation results:

- Baseline data can be collected to establish pre-investment measures of variables of interest,
- Measures of success can be well-defined before commencement of a program,
- Valid counterfactuals can be defined.

It is important to not that there are costs involved in collecting data. These can be significant for some projects and especially if data is to be collected retrospectively. Data collection costs should not be ignored when designing projects and associated budgets. Some thought should also be given to the database that will be used to collect and store data – a properly designed database will reduce the cost of data 'cleanup' prior to data analysis.

Efforts to manage widespread pests are undertaken in landscapes that are a unique blend of natural, agricultural, and urban environments, and the social, cultural and political factors that characterise them. This complexity and key interactions within the landscape must be properly understood if project evaluation is to be meaningful. This means identifying the underlying assumptions about the landscape and about the interventions to be used (Margoluis et al. 2009). Conceptual models are useful in this regard. They are a visual depiction of the major influences within the system under study and are useful for planning, simulation and identifying relevant indicators for monitoring and evaluation. An initial conceptual model can be used to show the existing conditions before the pest management intervention takes place, and can then provide a framework for articulating goals, objectives and how the investment is expected to influence the target measure of success (e.g pest population density) (Margoluis et al. 2009).

Results chains (e.g Figure 7) are useful tools that can be derived from conceptual models. A results chain shows the hypothesised relationship between actions and desired impacts by extracting a line of association from a conceptual model and then filling in gaps to make the underlying logic clear (Margoluis et al. 2009). Gertler et al. (2011 p26) state that "Results chains are useful for all projects, regardless of whether or not they will include an impact evaluation, because they allow policy makers and program managers to make program goals explicit, thus helping them to understand the causal logic and sequence of events behind a program".

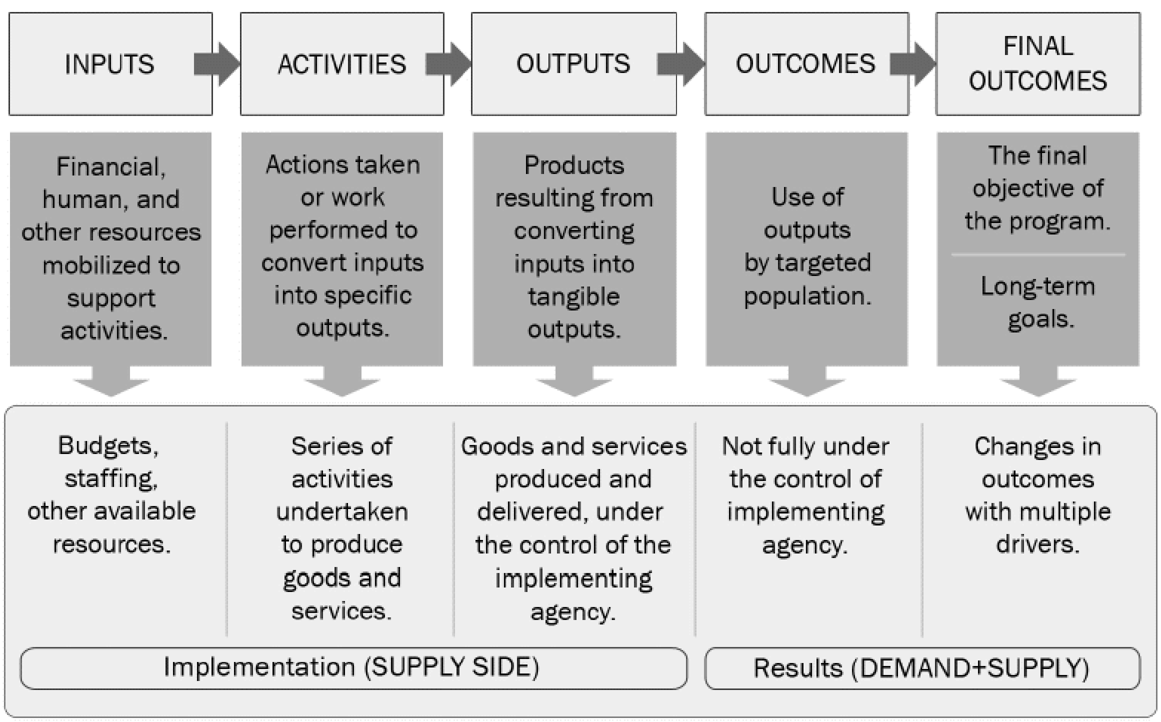

Figure 7. A generalised results chain that could be adapted to different types of investment activities. Source: Gertler et al. (2011) Figure 2.1, p25.

To demonstrate the use of results chains in the current context, we use the example of investment in building community capacity to undertake pest control. We assume that the aim of the investment is to introduce community members in a particular catchment to the latest information on pest control and management and to give them the skills to undertake their own

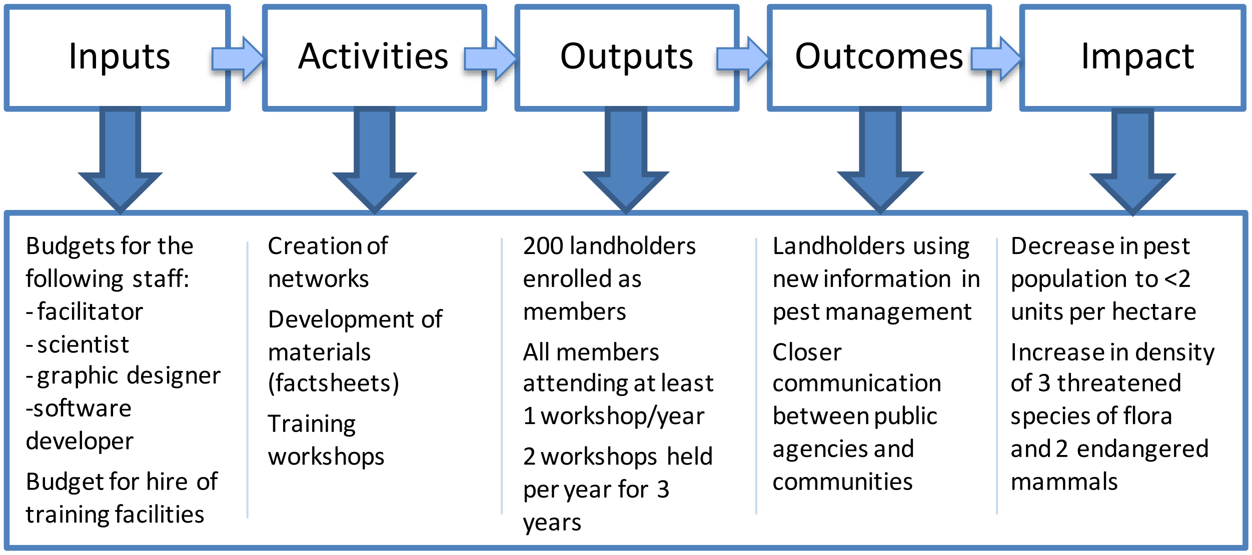

Figure 8. An example of a results chain for building community capacity in pest management (modified from Figure 7).

vertebrate pest control into the future. The results chain for this investment is shown in Figure 8. *Inputs* include a budget for a facilitator, scientists, graphic designers and software developers. *Activities* undertaken by these individuals include creation of community networks, development of factsheets, and training workshops. The *outputs* of these activities provide the performance measures that may be used to quantitatively measure the impact; outputs may include the number of landholders that become members of the community group, for example. *Outcomes* involve adoption of the outputs – how landholders use the new pest-management information contained in factsheets and the skills learnt at the workshops in their ongoing pest management. *Impact* could be measured as a reduction in pest population or density, or possibly eradication from the catchment. The point is that objective(s) are clearly stated at the outset and that *indicators* are defined at each stage of the results chain so that the causal logic of programme outcomes is observed (Gertler et al. 2011).

5.2 Summary

The key issue with impact evaluation is understanding the importance of collecting appropriate data on key indicators of success for specific projects or activities under evaluation throughout the duration of a project. Collecting appropriate data may even be impossible in retrospective evaluation, but if it occurs prospectively it will alleviate the two measurement problems discussed in this section: disentangling the effects of a package of investment activities on pest management; and estimating the counterfactual. Conceptual models and results chains are useful tools in impact evaluation because they focus attention on key assumptions, they make program goals explicit, allowing causal logic and sequence of events in a program to be understood.

6 Decision-Analysis Framework

6.1 Conceptual model

A proposed framework for understanding the effect on a pest population of investing in various management activities is illustrated in Figure 9. It shows how the population of a pest may be altered through both private and public actions. Without interference, the population of a pest would continue to grow over time, with the rate of growth determined by key biological parameters such as survival, fecundity, and dispersal represented as γ_J, γ_A, γ_F and δ. Investment in pest management is aimed at influencing these parameters so that overall population is reduced. Management actions can be funded by private or public resources. The effectiveness of private and public actions on population growth are denoted α_1 and α_2, respectively in Figure 9. Both parameters will be a function of detectability (λ), the ease with which a species can be detected. Ideally, public investments in managing pests will also have a positive influence on private actions, denoted $\beta_{2,1}$. For example, the government might release a new biocontrol agent which increases mortality of rabbits. This may encourage additional private

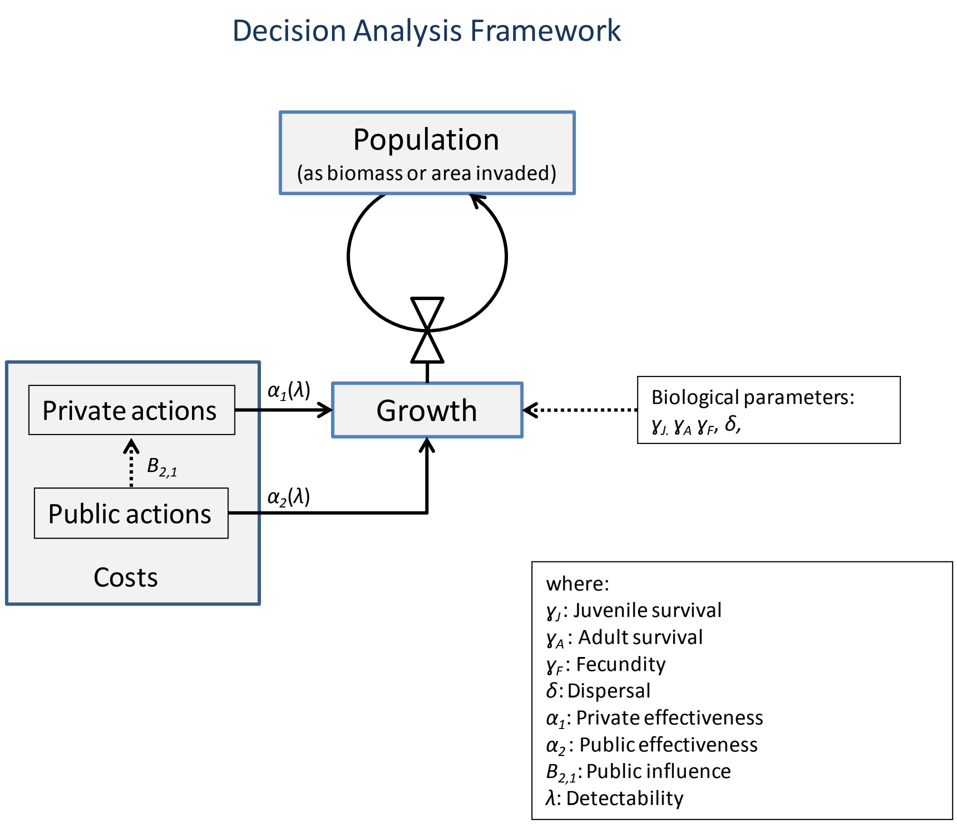

Figure 9. A Framework for discussing public intervention in pest control

control actions such as destruction of warrens and on-farm rabbit control.

Investment in each of the five categories of interest is ultimately aimed at affecting key parameters. In addition to survival and fecundity parameters there may be others depending on the biology of the particular pest. These parameters could be related to the level of public control inputs as shown in Figure 10A. When there is no investment into the various possible management activities (public control input = 0) population growth is unaffected, but as the level of public control input increases the growth rate of the population decreases (solid line in Figure 10A). This line may move to a lower position (dashed line in Figure 10A) when public inputs improve private control through $\beta_{2,1}$. Private actions might include spraying weed seedlings or poisoning juvenile vetebrate pests, for example. The costs associated with public investment into the various management activities will increase as the level of control input increases, similar to the relationship shown in Figure 10B. The parameters required to estimate the functions shown in Figure 10 could be estimated from data available in published journals or through publicly available databases such as the Global Eradication and Response Database (Kean et al. 2014) and the Global Invasive Species Database (ISSG n.d.).

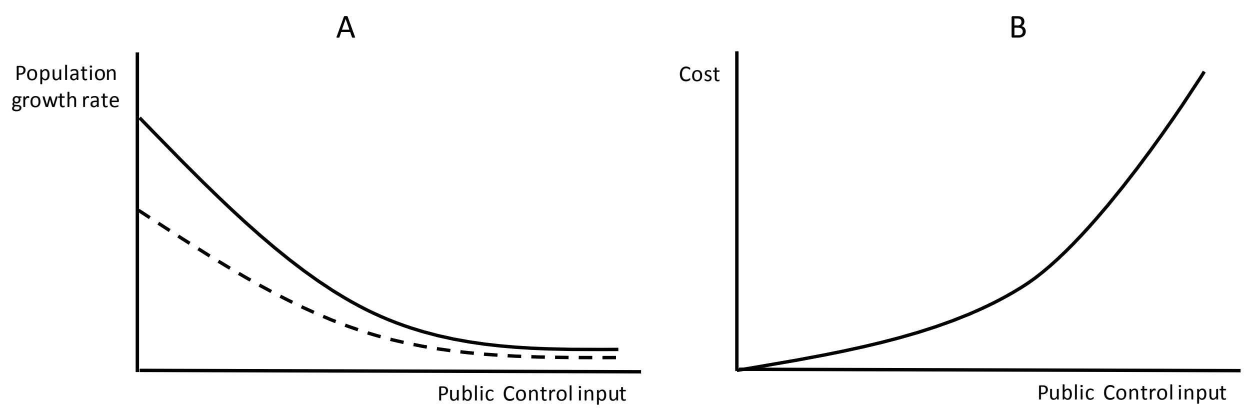

Figure 10. (A) An example of the possible relationship between biological parameters as measured by population growth rate and varying amounts of public input into control; and (B) the likely shape of the relationship between cost and level of public control input.

Understanding the effect of an investment activity in pest control involves recognising its effects on parameters that influence pest population growth (Figure 9)[2]. Each investment strategy is

[2] This is the approach taken in the Program Logic framework and MERI strategies used in Caring for Country applications. The MERI Strategy http://www.nrm.gov.au/funding/previous/meri/meri-strategy.html is part of the Australian Government's strategic approach to measuring achievements of Caring for our Country

likely to affect several parameters at once. The likely primary effects of each of the five investment strategies of interest in this report are given in Table 1. This table was developed based on the discussion of investment strategies in Section 4. The columns of Table 1 can be interpreted as follows:

- National coordination (1) influences activities undertaken by private agents ($\beta_{2,1}$) and, by encouraging concerted actions, it would reduce dispersal (δ).
- R&D (2) may affect all parameters to some extent, depending on the specific activity undertaken. Juvenile survival (γ_J), adult survival (γ_A) and fecundity (γ_F) could be influenced by research that improves control methods and disrupts reproductive success. Detectability (λ) could be influenced by improved traps or better ways of searching. R&D may produce new technologies that increase both private and public control effectiveness (α_1 and α_2).
- Raising awareness of the impact on pests and diseases (3) is likely to influence detectability (λ) and private effectiveness (α_1). It would also improve public effectiveness

Table 1. The potential primary effects of each investment type on parameter values that in turn affect population growth of a pest.

	Investment strategy				
Parameters	National coordination	R&D	Raising awareness	On-ground work	Building Community Capacity
Juvenile survival (γ_J)		✔		✔	
Adult survival (γ_A)		✔		✔	
Fecundity (γ_F)		✔		✔	
Dispersal (δ)	✔				
Detectability (λ)		✔	✔		✔
Private effectiveness (α_1)		✔	✔	✔	✔
Public effectiveness (α_2)		✔	✔	✔	
Public influence ($\beta_{2,1}$)	✔			✔	

investment. It was hoped that the MERI Strategy would facilitate the evaluation of impacts and achievements or investments.

(α_2) when it leads to information on new incursions of pests that in turn leads to better–targeting of government funded control.

- Strategic investment in on-ground work (4) is likely to influence juvenile survival (γ_J), adult survival (γ_A), fecundity (γ_F) and could also change the effectiveness of public and private activities (α_1 and α_2). On-ground works can improve the effectiveness of private actions by promoting the use of better equipment for example. This means that investment in on-ground work might improve public influence ($\beta_{2,1}$) if it increases the willingness of private landholders to undertake pest control.
- Building community capacity to manage pests (5) is likely to influence detectability (λ) and private effectiveness (α_1).

This sort of framework could be used for prospective or retrospective impact evaluation. Software packages such as Stella® (ISEE Systems n.d.) which provides a way to easily visualize and describe complex systems, could be used to obtain parameter values interactively through expert workshops.

Two other issues worth noting are: (1) there is uncertainy in the way particular investments affect parameter values; and (2), there may be interactions between parameter values, for example α_1 may affect γ_J, γ_A, γ_F. These issues would need to be addressed if the basic framework represented in Figure 9 is implemented.

6.2 Mathematical model

Implementing the conceptual model in Figure 9 for decision analysis would require further work outside of the scope of this project. In this section we develop a simplified version of the decision-analysis framework and demonstrate its application to a pest. The point of the framework is to elucidate how a particular investment strategy or set of strategies affects the growth of the pest population overtime, compared to growth that would have taken place without the investment.

The rate at which the population (y_t) of the pest increases at any point in time (t) is represented by the logistic equation:

$$\Delta y_t = \gamma \, y_t \left(1 - \frac{y_t}{\kappa}\right) \tag{7}$$

Where γ is the specific growth rate and κ is the carrying capacity. For a managed infestation, the size of the population in the next time period (y_{t+1}) is given by the size of the population at the start of the current period (y_t) plus the population growth in the current period (equation (1)) minus any decrease in population that results from investment in pest control in the current period:

$$y_{t+1} = y_t + \Delta y_t - y_t P_D(\mathbf{x}_t(\mathbf{z}_t))P_K(\mathbf{x}_t(\mathbf{z}_t)) \quad (8)$$

where P_D represents the probability of detection and P_K is the probability of kill – the probability that a target organism will die each time control is applied. Both probabilities (P_D and P_K) are determined by a set of control variables ($\mathbf{x}_t$) that in turn depend on a set of investment variables ($\mathbf{z}_t$). The control variables include detectability of the pest (λ), the amount of effort spent searching (μ) and the speed of search (s). The variables contained on $\mathbf{z}_t$ are the five investments identified earlier. In essence, **x** and **z** are vectors that contain the decision variables which control the probabilities of detecting and killing an infestation. More formally:

$$\mathbf{x} = [s, \mu, \lambda] \text{ and } \mathbf{z} = [z_1, z_2, ..., z_5]$$

Where z_1 = national coordination, z_2 = R&D, z_3 = raising awareness of the impacts of pests and diseases, z_4 = strategic investment in on-ground work, z_5 = building community capacity to manage pests.

The probability of detection (P_D) shows the expected proportion of the pest population that will be detected as a result of searching (see Cacho et al., 2006, 2007 for more details) and is a function of the level of search coverage (c). With a random search pattern the probability of detection is:

$$P_D = 1 - e^{-c} \quad (9)$$

where c is defined as the ratio of the area actually searched over the total area of the invasion. Expressing coverage on a per-hectare basis:

$$c = \frac{s\,\mu\,\lambda}{10{,}000} \quad (10)$$

where s is the speed of search (m h^{-1}), μ is search effort applied (h ha^{-1}) and λ is the detectability of the pest (m), which is given by a range of factors including the conspicuousness of the pest within the invaded environment, the speed of search and detection capability of the searcher.

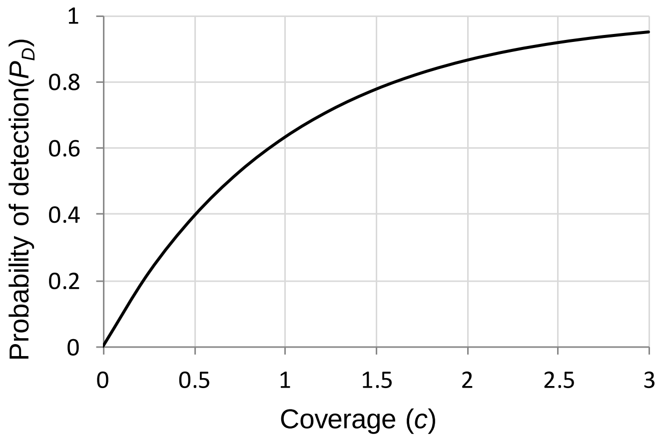

Figure 11. The detection curve obtained with random search (equation (10).

The probability of detection is associated with a *detection curve*, representing the proportion of pests that are detected, or the probability of detecting a single target, as a function of coverage. The detection curve associated with equation (9) is shown in Figure 11 – as coverage increases the probability of detection also increases, but at a decreasing rate. This reflects diminishing marginal returns to search effort.

The three control variables in **x** can have positive values even in the absence of government investment if the pest imposes costs to individuals. For example, people may control rabbits or weeds on their property, even in the absence of government programs, because these pests damage crops and reduce yields. For pests that cause public damage (i.e. reductions in biodiversity) but no private damage, the value of μ is likely to be zero unless there is some public investment ($z > 0$). This investment may consist of direct action (i.e. increase the value of μ by funding eradication programs) or may stimulate private actions (i.e. provide funding for materials to motivate individuals to donate their labour in controlling infestations).

The functional relationships between investments activities (**z**) and control activities (**x**) are unknown. We would expect the exact shape of those relationships to be dependent on the particular features of the pest, the environment invaded, the human population in the area and the type and size of investment. For example, the probability of kill (P_K) depends on the method and technology used to treat pests. In the case of weeds the value of P_K could differ between spraying herbicide and pulling plants. Investments in R&D can result in better chemicals which increase the P_K value of spraying. In the case of rabbit control, the choice of technology may be between dropping baits from the air and poisoning rabbits in their burrows. The effectiveness and costs of these methods differs and government investment can influence the extent which they are used. Further, national coordination can improve the effectiveness of both methods if the pests are attacked simultaneously over wide areas.

Some pest control activities will result in a shift along the detection curve. For example, if investment strategies lead to an increase in s, μ or λ, then coverage would increase, leading to an increase in the probability of detection, and ultimately, a reduction in population (an increase in the value of the third term in equation (8)). Investing in R&D technologies that allow search speed (s) to increase without affecting detectability (λ) would increase coverage in equation (10) and hence the probability of detection in equation (9). This is equivalent to moving right along the detection curve (Figure 11). This could be the case if investing in unmanned aerial vehicles increases s by more than it reduces λ, or reduces costs so that more effort (μ) can be applied with a given budget. Certain activities undertaken as part of building community capacity (eg. training to identify pests) would also result in increases in s or λ, and hence an increase in the number of pests removed from the population.

Values of other model parameters could also be changed by investing in particular activities. For example, investing in techniques that improve the probability of killing the pest when it is treated would remove a greater number of pests from the population (P_K in equation 8 would increase) for a given level of search effort. Investment in certain types of R&D (e.g. improved sprays, poisons, and application methods), building community capacity activities (adoption of new techniques) and on ground works would conceivably also influence the probability of kill.

The growth parameters in equation (7) could also be affected by some investments. For example biological control would reduce the population growth rate (γ).

Each new pest control activity will cost money to undertake but, because activities lead to a reduction in pest population, they will also result in benefits, measured as avoided damages. To evaluate whether the investment is worth undertaking, all benefits and costs associated with the activities through time need to be identified and quantified in monetary terms. The return on investment can be calculated using either net present value (NPV) or benefit-cost ratio (BCR) measures (see section 3.1):

$$NPV = \sum_{t=1}^{T} \frac{B_t - TC_t}{(1+r)^t} \qquad (11)$$

$$BCR = \frac{\sum_{t=1}^{T} B_t (1+r)^{-t}}{\sum_{t=1}^{T} TC_t (1+r)^{-t}} \quad (12)$$

where B_t and TC_t represent the benefits and costs, respectively, that accrue in year t, r is the discount rate and T is time horizon of the evaluation. Most benefits accrue on a per hectare basis, and so should be calculated as:

$$B_t = \left(y_{t,base} - y_{t,with\ investment} \right) D_t \quad (14)$$

where D_t represents the sum of all damages ($/ha invaded) and the term within the brackets is the reduction in pest population (ha). In reality, calculating the value of damages can be difficult, especially when pests cause damage to the natural environment because the value of this damage is not observable from the marketplace. Estimating the value that society places on biodiversity, for example can be expensive and time-consuming (see Sinden and Thampapillai, 1995; and Sinden et al. 2013 for a discussion).

Annual Costs (*TC*) from the proposed investments will be the sum of all variable (*Cv*) and fixed costs (*CF*), as follows:

$$TC_t = \left(\sum_{j=1}^{n} Cv_{t,j} \right) y_t + \sum_{f=1}^{w} CF_{t,f} \quad (15)$$

Where there are *n* variable costs and *w* fixed costs. In equation (15) variable costs are calculated by assuming costs accrue only to the area currently being managed for the pest. However, for some pests, such as weeds, costs may be applied to the 'total area ever managed' if a seedbank still remains in the years following removal of the above ground population. Where this is the case equation (15) would need to be modified.

6.3 Application

Below we show how a general understanding of these relationships can be gained by applying the mathematical model to a simple example.

In this application a pest has covered 30 ha of the 100ha suitable for invasion. The pest has a very high growth rate, $\gamma = 0.34$, and if left uncontrolled it will spread to 95% of its range (95ha) within 15 years, leading to negative impacts on agricultural land and surrounding natural habitat. Some control work is already underway, but the local pest-management authority believes more

Table 2. The proposed investment strategy, corresponding activity, parameters affected by each activity and the estimated cost of each investment

Investment strategy	Specific activity	Parameters affected	Total Cost
R&D	Biological control	γ	$60,000
Building community capacity	Training workshops on correct application of poison baits	P_K	$15,000
Building community capacity	Information sessions to improve search performance	s, λ	$15,000

could be done and is considering whether to invest in some specific control activities in an attempt to reduce population spread more quickly. It will only invest in the activities if the benefits of doing so (avoided damages to agriculture and the environment) outweigh the costs of the proposed activities.

The investments under consideration fall into the categories of R&D and Building Community Capacity (Table 2). Specifically, the authority is thinking of investing in biological control to slow the growth rate (γ), training workshops to demonstrate the correct application of poison baits and thus improve the effectiveness of control (P_K), and information sessions about the when and how to search more effectively. It is thought that the latter will increase the value of s and λ, and thus coverage. The cost of each activity is shown in Table 2.

After the proposed investments are chosen and their effects on model parameters clarified, the next step is to calculate the population growth with (*with investment*) and without (*base*) the proposed investments. This requires values for parameters in Equations (8) to (11) for the *base* and *with investment* cases. The parameter values for the current application are given in Table 3, with those affected by the proposed investment strategies in bold font.

The model can be implemented in an Excel spreadsheet (see Supplementary Material for example). The size of the pest population over time (equation (8)) should be calculated with the *base* parameter values to obtain the trajectory $y_{t,base}$ (no change from current situation) and again for the *with investment* parameter values to obtain $y_{t,\ with\ investment}$. The model should be run for a number of years appropriate to the investments being undertaken. In the current example the model is run for 25 years.

Table 3. Parameters and their values used in the *base* and *with investment* simulations

Parameter	Description	Value	
		Base	With I
Demographic parameters			
Y_0	Initial area invaded (ha)	30	
γ	growth rate	0.34	**0.25**
K	Carrying capacity (ha)	100	1000
P_K	probability of kill	0.6	**0.8**
s	speed of search (m/h)	300	**350**
λ	Expected sweep width (m)	8	**10**
μ	average search effort (h/ha)	2.5	2.5
Economic parameters			
r	Discount rate (%)	7	7
C_B	Cost of biological control ($/y), y 1-3		**20,000**
C_{Tr}	Cost of training workshops ($/y), y 1 only		**15,000**
C_{In}	Cost of information materials ($/y), y 1 only		**15,000**
D	Damage to agriculture and natural habitat from pest ($/ha)	500	500
Calculated parameters			
c	coverage	0.60	**0.88**
P_D	probability of detection	0.45	**0.58**

Population growth curves are shown in Figure 12 for three cases: uncontrolled growth, the *base* (current) situation, and the situation that is expected to result from the additional investment. In the current situation, the pest population would continue to decline, albeit very slowly (middle line). Modelling shows that the proposed investment activities are likely to result in a much

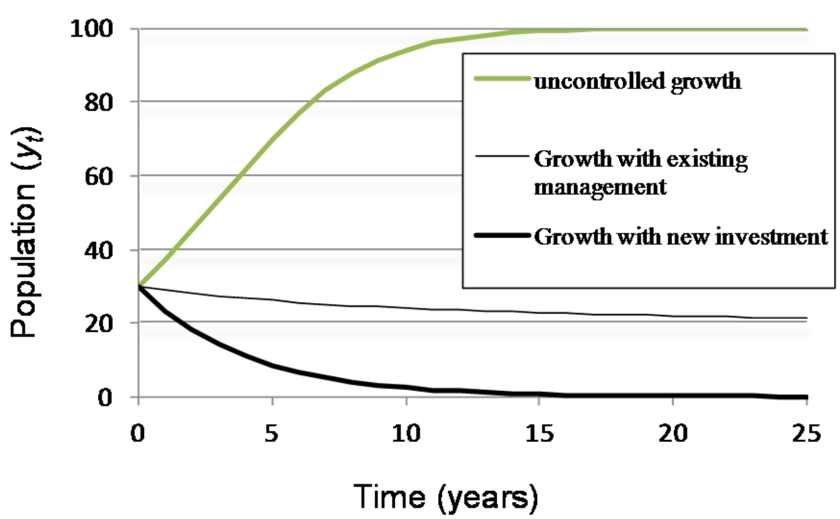

Figure 12. Population growth curves for uncontrolled growth (top line), growth under existing controls (middle line) and growth under the planned investment activities (lower line)

faster decline in the size of the population (lower line) – within 5 years the pest population is a third of its original size and by year 15 it has reached negligible levels.

To understand the impact of these investments a benefit-cost analysis needs to be undertaken. For the current example, the costs incurred as a result of the Building Community Capacity activities accrue only in year 1 while the costs of the R&D are spread over the first three years of the project (Table 3). The benefits are measured as avoided damage (equation 14).

Results of the modelling show an NPV of $18,895 and a BCR of 1.22, indicating that benefits of investing in the three activities outweigh the costs of doing so, and the project would be worth proceeding. There are of course always uncertainties associated with parameter values, and sensitivity analysis should be undertaken.

6.4 Summary

Clearly, the way investment activities are incorporated in the above framework would vary depending on the pest and its location, and on the specific activities undertaken. The framework is reasonably simple but does provide an accessible technique for assessing the impact of investment activities on pest populations.

This framework could be used in several ways:

- as a starting point to determine the mix of activities that would reduce the pest population to a particular level,
- to understand how investment activities can be expected to impact on the pest population over time, and
- to indicate what data would need to be collected for meaningful quantitative analysis of an investment strategy.

7 Case Studies

Case studies will now be used to focus on the benefits and costs of investment in the alternative management strategies discussed in Section 4, and where possible, a benefit-cost ratio (BCR) will be calculated (see Section 3.1). By undertaking this return on investment (ROI) analysis we should be able to identify activities and investment strategies that can maximise the return on public investment. Murdoch et al. (2007) provide a useful example of a ROI analysis in conservation and Boyd et al. (2012) provide a review of ROI and how it has been applied in conservation.

At the start of the project, potential case studies were the WoNS Phase 3 weeds, and species that have recently been the focus of eradication or containment programmes such as RIFA in Queensland and European House Borer in Western Australia. Initial consultation with stakeholders in the Department of Agriculture, Fisheries and Forestry (DAFF) resulted in the European Rabbit (*Oryctolagus cuniculus*) and the water weed salvinia (*Salvinia molesta*) being selected as case studies for further analysis. These two species were chosen because there appeared to be good information on species' extent, spread rate, costs of control, and an understanding of impacts (Table 4). In addition, investments had been made under each of the five investment strategies for managing each pest.

Table 4. Available data for each case study

Description	Rabbits	Salvinia
Demographic		
birth rate/reproduction rate	✓	✓
Fecundity	✓	✓
Years to maturity	✓	n/a
Max longevity of adults	✓	
Survival rate	✓	
Growth rate	✓	✓
Spread rate	✓	✓
Maximum 'carrying capacity'		✓
Effectiveness of biological control	✓	✓
GIS over time		✓
Economic		
Cost of biological control	✓	✓
Cost of manual control	✓	
Cost of chemical control	✓	✓
Cost of mechanical control	✓	
Impact on agricultural production	✓	✓
Impact on biodiversity		
Impact on tourism		✓

Information on investment strategies and key biological data for each pest were collected by ABARES and summarised in Raphael and Walters (2012) and we draw heavily on their report in this Section.

7.1 Case Study 1: European rabbit

The European rabbit, *Oryctolagus cuniculus*, was introduced to mainland Australia in 1859. The rabbit is now estimated to inhabit 70% or 5.33 million square kilometres of Australia (West 2008), making it one of the most widely distributed and abundant mammals in the landscape (Williams et al. 1995). Rabbits are able to adapt to a range of climatic conditions and are highly reproductive. Many effective control techniques are available, from trapping and shooting to warren destruction and biological control.

Rabbits have devastating impacts on agriculture and the environment in Australia. Agricultural impacts include damage to horticultural and grain crops, and competition with livestock for food, leading to reduced carrying capacity and farm output. Estimates of annual losses in agricultural production range from $113 million (McLeod 2004) to $600 million (ACIL 1996). Environmental impacts of rabbits include land degradation through digging and browsing which leads to a loss of vegetation cover; loss in soil fertility and siltation of water supplies; slope instability and soil erosion (DEWHA 2008a). As a result of their continual grazing on native vegetation, regeneration is prevented, and food and shelter for native fauna is reduced. Denuding of the native vegetation exposes native fauna to increased predation by introduced predators. Rabbits also result in negative social impacts when they reduce the amenity value of the landscape.

In response to the impacts of rabbits, successive Australian Governments have invested in a range of rabbit management activities over many decades. These activities can be classed as fitting into one of the five alternative investment categories under discussion, national coordination, R&D, raising awareness of impacts, on-ground control, and building community capacity. Using data from Raphael and Walters (2012) and information received at a workshop of rabbit experts[3], we have identified a set of activities that will be analysed in more detail in an attempt to understand ROI in rabbit management (Table 5).

[3] Workshop held 5-6th February 2013 at the University of New England. Participants were: Tony Pople and Mike Brennan (Biosecurity Qld); Jeanine Baker (DAFF); Andrew Woolnough (Biosecurity Vic); Tarnya Cox (NSW DPI); Bruce Warburton (Landcare Research, NZ), Greg Mutze (PIRSA), Paul Martin (UNE/IACRC), Oscar Cacho (UNE); and Susie Hester (UNE/ACERA).

Table 5. Details of investment in rabbit management, categorised by investment strategy

	Rabbits (*Oryctolagus cuniculus)*		
Investment strategy	**Activity** and Outcome	Description of Benefits and Costs	Data
National coordination	**Threat Abatement Plan (TAP):** a more coordinated response to the impacts of rabbits on biodiversity	**Benefit:** reduced rabbit population **Cost:** costs of revieweing TAP in 2005 and revising in 2008	**Benefits:** n/a **Costs:** $52,750
	Invasive Animals CRC-funded Rabbit Project Management: coordinates stakeholder interests, maintains network, improves knowelege on control	**Benefit:** reduced rabbit population, controls efficacy improves **Costs:** cost of salaries, travel, field days and workshops	**Benefits:** n/a **Costs:** $485,000 plus $142,500 in-kind
Research and Development	**Biocontrol:** Myxomatosis – reduced pest population	**Benefit:** reduction in rabbit population on agricultural land and in natural habitat **Cost**: research programme costs	**Benefits:** **Costs:**
	Biocontrol: Rabbit Haemorrhagic Disease Virus (RHDV) – reduced pest population	**Benefit:** reduction in rabbit population on agricultural land and in natural habitat **Cost**: research programme costs	**Benefits:** $106m annually to agriculture **Costs:** $12m
Raising awareness of impacts	**RabitScan** provides information on pest location and density as supplied by members of the community	**Benefit:** improved knowledge of pest location and density **Cost:** cost of setting up website, IT salaries, web hosting costs	**Benefits:** n/a **Costs:** $115,000
On-ground work	**500+ projects** funded by the Australian Government e.g. **Bulloo Downs project in south-west Qld –** demonstration of correct warren ripping techniques	**Benefit:** reduce rabbit density and spread **Cost:** costs of research, materials, labour	**Benefit:**$5m **(**cattle production) **Cost:** $500,000
Building community capacity	**Publication of *Rabbits: a threat to conservation and natural resource management*** – knowlege and best-practice guidance for land managers	**Benefit:** unclear **Cost:**publication costs	**Benefit:n/a** **Cost:** >$7,000

7.1.1 National Coordination

Two publicly funded activities were identified as investments in national coordination: (i) development and implementation of a Threat Abatement Plan (TAP) in 1999 and subsequent revision in 2008 and (ii), the Invasive Animals CRC's (IACRC) Rabbit Project Management.

The Threat Abatement Plan (TAP) established a national framework to guide and coordinate Australia's response to the impacts of rabbits on biodiversity. The TAP has been reviewed and revised several times. Interestingly, the review undertaken by Hart (2005) found that it was difficult to accurately determine the extent to which the TAP had reduced the impacts of rabbits on biodiversity. DEWHA (2008) commented that is caused by lack of nationally consistent data on the distribution and density of rabbits and their impacts, and the challenges of linking outcomes in rabbit population changes to the outputs of the rabbit TAP. Nevertheless it was found that rabbit-related projects initiated under the TAP had positively contributed to reducing the impacts of rabbits. While costs of developing, reviewing and revising the TAP are available, its impacts have not been valued and so a BCR cannot be calculated.

Under the second national coordination activity, the IACRC rabbit project management coordinator was responsible for coordinating all stakeholder interests in rabbit control and maintaining a network through, among other methods, the Rabbit Management Advisory Group (RMAG). The terms of reference of the RMAG were to maximise the benefits of new R&D in rabbit control for agriculture and the wider community, and to identify future research and education needs. It is thought that the RMAG was successful in re-invigorating collaborative research on rabbits by enabling various research, industry and government organisations to exchange information and common concerns about rabbits. It also allowed RMAG members to better understand rabbit research carried out by the IACRC as well as work being undertaken by other organisations not affiliated with the IACRC.

The Rabbit Project Management project also involved investment in capacity-building through a number of activities: establishing demonstration sites to provide training and advice for rabbit management; developing desktop studies to investigate the future of rabbit control; and developing and delivering extension materials on best practice rabbit management. In addition, collaborative relationships with research teams overseas have been established or maintained and are an important outcome of this project.

Information on the cost of implementing the Rabbit Management Project are available, including estimates of in-kind donations, however outcomes of the project were not valued. Raphael and Walters (2012) argue that evaluation of the role of the National Wild Dog Facilitator project may give an indication of the benefits of a similar position for rabbit management. This facilitator position has proven to be effective in limiting the impact of wild dogs in Australia and the impact evaluation by Chudleigh et al (2011) found that the project had a benefit-cost ratio of 5.1 to 1 (when benefits are calculated over 15 years at a 5% discount rate), or 8.0 to 1 when the benefits are considered over 30 years. Note that this analysis considered only the economic impacts of the facilitator that could be readily measured – it did not measure the environmental or social benefits.

7.1.2 Research and Development

A number of successful rabbit biocontrol agents (agents in their own right, or vectors which can enhance the effectiveness of the biocontrol agent) have been introduced or become established in Australia. These include: myxoma virus in 1950; European rabbit flea, *Spilopsyllus cuniculi*, in 1968; Spanish rabbit flea, *Xenopsylla cunicularis*, in 1993; and rabbit haemorrhagic disease virus (RHDV) in 1995. These agents have been very effective in reducing rabbit numbers following their release (Figure 13). Cooke et al. (2013) estimated that biological control of rabbits in Australia has resulted in a cumulative benefit of up to $96 billion (present value) for the wool, sheep meat and cattle industries over the last 60 years. In calculating this estimate the authors noted that it cannot be assumed that without biological controls, Australia would still have a serious rabbit problem – it is likely that other solutions would have been found. It is also acknowledged that the actions of government agencies, farmers, and other land managers in relation to rabbit control also impacted on rabbit control. To take these other factors into account the authors applied the concept of a loss–expenditure frontier which allows for an economic trade-off between production losses and

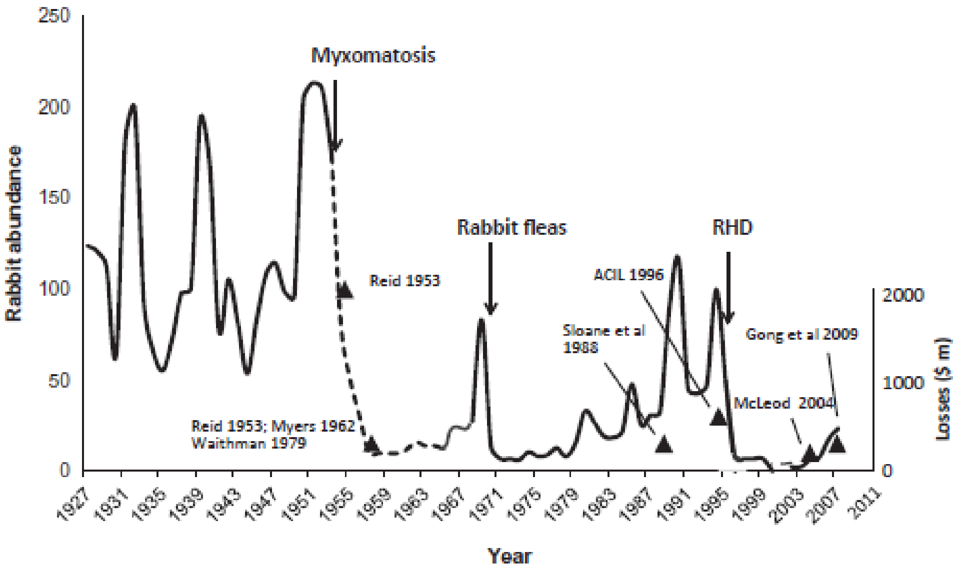

Figure 13. Diagram showing how rabbit abundance in semi-arid South Australia has varied through time in response to the release of biological control agents. Black triangles show when estimates of Australia-wide economic losses to rabbits were undertaken. Source: Cooke et al. (2013).

expenditure on rabbit control. Using published studies on rabbit control, the authors were able to create loss-expenditure frontiers for the 'with' and 'without' biological control scenarios, enabling calculation of the benefits of biocontrol.

Cooke et al. (2013) calculated the introduction of myxomatosis produced a net benefit of about A$54 billion (2011 dollars) in the 45 years following its release, despite its eventual decline in effectiveness. Note that the cost of developing the virus was not located, although the BCR is likely to be large. The development and release of the RHD virus cost approximately A$12 million over 8 years and resulted in an immediate increase in benefits to Australia's livestock industries of around A$350 million annually (Saunders et al. 2010), again a very favourable BCR.

7.1.3 Raising awareness of impacts

RabbitScan is an interactive community website for 'citizen science' that allows users to record sightings of rabbits, locations of damage and control activities. Information is uploaded onto interactive maps, and information may be used by pest-control agencies and the wider community. The cost of developing RabbitScan is difficult to estimate because it is contained within FeralScan along with interactive sites for a range of vertebrate pest species. Use and impact of RabbitScan has not been evaluated.

Awareness of rabbits is also raised through the website feral.org.au. This website was originally developed with funding from the National Feral Animal Control Program (now APARP) of $115,000 (exclusive of GST) over two years (2006-2008), to provide a reliable, comprehensive and freely-available source of information on pest animals and to assist users to make management decisions. Feral.org.au is currently managed and maintained by the Invasive Animals CRC, with one part-time (50%) staff member dedicated to its maintenance.

Although the benefits of such investments are difficult to quantify in terms of improved rabbit management in the field, the IACRC collects information using Google Analytics about the use of the feral.org.au site. For example, for the 6 month period (September 2011 - February 2012), there were 136,438 page-views. The IACRC staff member responsible for managing feral.org.au receives informal positive email feedback about the site, although no formal evaluations have been conducted.

7.1.4 Strategic investment in on-ground work

Over 500 projects involving on-ground work were identified as relating in some way to rabbit management. These had been funded through various Australian Government programmes such as the National Heritage Trust (NHT), National Action Plan for Salinity and Water Quality and most recently through Caring for our Country. We discuss one of these, a three year project at Bulloo Downs Station to determine the cost and effectiveness of rabbit warren ripping (Berman et al. 2011). Bulloo Downs is a 10,000km^2 property in south-west Queensland used for cattle production. Between 2001 and 2004 approximately 55,000 warrens were ripped on the property at a cost of $275,000. The total value of the onground work and additional research was estimated as $475,000. Post-control economic benefit was estimated as $5,000,000. This is calculated from the additional cattle that could be produced on the property and did not include the environmental benefits of the reduction in rabbit population. The resulting BCR is 10.5.

7.1.5 Building community capacity

Two publications on rabbits were identified as activities whose focus was to build community capacity. The first, *Managing vertebrate pests: Rabbits* was published in 1995 by then Bureau of Resource Sciences and CSIRO Division of Wildlife and Ecology. Development and publication costs were unable to be obtained. The book is posted in electronic form on feral.org.au. In the period 1 January 2011 and 1 March 2012, there were 324 page-views for this publication. Due to lack of data it wasn’t possible to obtain a BCR.

The second publicaion, *Rabbits: a threat to conservation and natural resource management* (Cooke n.d.) provides land managers with some guidance on assessing and measuring rabbit impacts on their property and how to take effective action to manage these impacts. The publication was used in pest-management courses at tertiary institutions and was heavily promoted amongst Landcare groups. Estimates on the costs of publication were available but it is difficult to find a metric by which to measure impact of the publication. As a result, no BCR was calculated.

7.2 Case Study 2: Salvinia

Salvinia (*Salvinia molesta)* is an aquatic weed; a free-floating fern with root-like structures that form dense mats in freshwater ecosystems (Figure 14A). In Australia, salvinia was first recorded in Sydney in 1952 (CRC AWM 2003) and is now distributed widely in coastal waterways in eastern Australia, in the top end of the Northern Territory, with some isolated infestations in Western Australia, Victoria and inland Queensland (Figure 14B).

Salvinia can have significant environmental, social and economic impacts. Because it forms a thick sheet up to one metre deep on water bodies, it affects water storage, water quality, flow and levels, impacting on irrigators, recreational users, and wildlife. It also has detrimental impacts on functioning freshwater ecosystems and their biodiversity (Petroeschevsky 2009), can exacerbate the impacts of flooding, degrade the quality of drinking water, impede access of stock to water and harbour disease vectors such as mosquitoes (Page and Lacey 2006).

In response to its impacts, salvinia was listed as a WoNS in 1999 which triggered funding for a range of activities under each of the five investment strategies previously discussed. Raphael and Walters (2012) identified a set of salvinia management activities that will be analysed in an attempt to understand ROI in the management of this pest (Table 6).

A

B

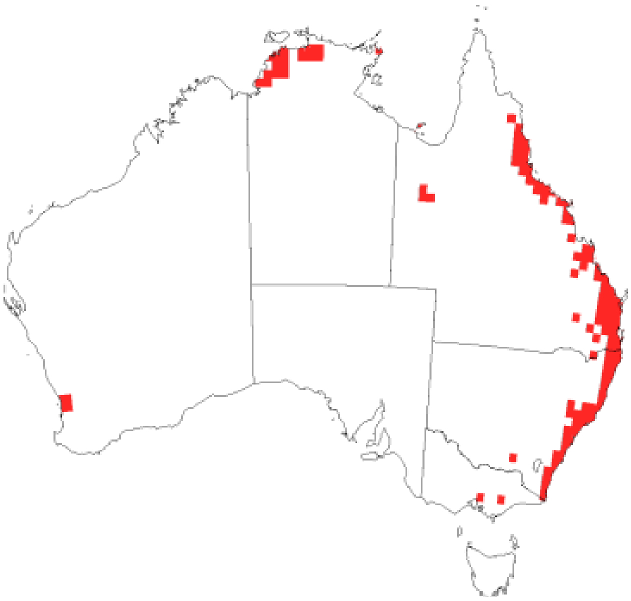

Figure 14. (A) Salvinia; (B) Map showing 2011 distribution of salvinia, red indicates present, white indicates absent, Source Hennecke and Raphael (2012).

Table 6. Details of investment in salvinia management, including cost, categorised by investment strategy. Note that n/a indicates data were not available.

Salvinia (*Salvinia molesta)*			
Investment strategy	**Activity** and Outcome	Description of benefits and costs	Data
National coordination	**National Aquatic Weeds Management Group** (NAWMG) – provides leadership on aquatic weeds, implements *Salvinia Strategic Plan*, reviews Plan's achievements.	**Benefit:** Many achievements – salvinia now a Phase 2 WoNS so national coordination will reduce. **Cost:** costs of travel and time spent in meetings, cost of Plan development	**Benefits:** n/a **Costs:** n/a
	WoNS coordinator – implements actions identified in strategic plan for 3 aquatic weeds, provides support to the NAWMG, coordinates and implements national communication and extension plan to increase community awareness, evaluate and report on activities.	**Benefit:** reduced spread and density of weed; reduced impact on agriculture, the environment and social welfare; cost savings. **Cost:** Salary plus on-costs for WoNS coordinator position available 02/3 − 09/10.	**Benefits:** n/a **Costs:** 2.6m
Research and Development	**Biocontrol**: development stared in 1978. *Cryptobagous salviniae* first released in Austrlia in 1980.	**Benefit:** very significant reductions in impact of weed, in some cases permanent control of salvinia resulted **Cost**: unclear.	**BCR:** 27.5 (for 3 water weeds) **Costs:**4.2m
	Various projects funded under: Weed CRC; National Land and Water Resources Audit; 08/09 National Weeds and Productivity Research Program (NWPRP); and CSIRO.	**Benefit:** difficult to determine salivina-related benefits **Cost**: difficult to determine salivina-related benefits	**Benefits:** n/a **Costs:** n/a
	NWPRP – included research into the impacts and control of aquatic weeds including salvinia	**Benefit:** information on control efficacy, new control method **Cost:** cost of trials	**Benefits:** **Costs:** $26,500
Raising awareness of impacts	**Publication of education materials** for nurseries, public, landholders, water users – reduction in the sale and cultivation of salvinia	**Benefit:** reduction in the spread of the weed and associated benefits for water users, and the environment **Cost:** publication and distribution costs	**Benefits:** n/a **Costs:** n/a
On-ground work	**40 projects** funded since 1995		
	e.g. Salvinia management on Hawkesbury – removal of weed 2004-05	**Benefit:** reduced damages for water users **Cost:** cost of labour and materials to remove weed	**Benefits:** n/a **Costs:** $1.8m
	Lakeland Downs salvinia eradication project - eradication	**Benefits:** reduction in damage caused to biodiversity, and water users. **Cost:** eradication programme	**Benefits:** n/a **Costs:** $107,000 plus volunteer support

Building community capacity	**Salvinia control Manua**l (2006) – information on biology, ecology, history of spread, management	**Cost**: development and publishing costs: **Benefits:** unclear	**Cost:** $79,600 **Benefits:** n/a
	Aquatic weed identification workshops – 2,000 people trained, new detections of weeds	**Cost:** funded by NHT, state, local and industry. **Benefits:** new detections found earlier resulting in lower control costs than otherwise would have been the case.	**Costs:** n/a **Benefits:** n/a
	Salvinia biocontrol workshops – improved adoption of biocontrol agents	**Cost:** Cost of developing and running workshops. **Benefits:** reduced spread resulting in less damage to industries that are water users	**Cost:** $2.2m (includes a number of species) **Benefits:** n/a

7.2.1 National Coordination

Classification as a WoNS resulted in development of a strategic plan for management of salvinia and appointment of a national coordinator whose role was to implement the actions identified in the plan. The national coordinator for salvinia was also responsible for the management of two other aquatic weeds – cabomba and alligator weed. Additional roles of the coordinator were to:

- support the national aquatic weeds management group (NAWMG) who also provide leadership on aquatic weed management;
- coordinate implementation of the national communication and extension plan to increase community and industry knowledge of the impacts of WoNS weeds,
- foster partnerships and networks with stakeholders nationally to support the implementation of the strategic plan (including the nursery and aquarium industries' cooperation and attitudes to managing aquatic weeds),
- monitor, evaluate and report on implementation of the strategic plan,
- provide expert advice and information about invasive plant issues, and
- collaborate with the National Weeds Management Facilitator and participate in WONS coordinators' group activities.

Key outcomes from implementing the salvinia strategic plan that may be linked to national coordination are:

- Establishment of biological control rearing facilities at key locations throughout the introduced range of salvinia in the Northern Territory, New South Wales and Queensland.
- Establishment of funding arrangements (user pays) for biological control facilities in Brisbane and NSW to ensure facilities operate beyond initial funding periods.
- Eradication of outlier infestations at selected sites on the NSW south coast and in Western Australia.
- Agreement on best-management practices for salvinia which were subsequently documented in the salvinia control manual.
- Support of regional bodies who have incorporated salvinia management into their weed management plans.

While the costs for the postion of national coordinator of aquatic weeds were available for most years since its inception in 2003, the combined achievements of the strategic plan were not valued, thus a BCR for this activity could not be derived. Hennecke and Raphael (2012) evaluated the effectiveness of national coordination for each of the WoNS in terms of whether it resulted in a reduction in weed spread. Results from their spatial analysis of pre- and post-WoNS declaration datasets showed salvinia decreased in distribution, but this decrease in distribution was not valued. The authors also noted other potentially important influences on distribution – habitat/ecological considerations, changed control methods – and the difficulty in isolating the effect of national coordination from these.

7.2.2 Research and Development

Publicly funded R&D into salvinia biocontrol through CSIRO resulted in the release of a weevil, *Cyrtobagous salviniae*, which has proven to be an extrememly effective biocontrol agent for salvinia. Use of this agent has become the primary control technique for salvinia since the early 1980s. The weevil is very effective, especially in tropical and subtropical environments and in most cases, provides permanent control of the weed to a level where further control is unnecessary (Scott and Laut 2009).

A Weeds CRC project examined the return on investment of the Australian weed biocontrol effort (which examined multiple weed biocontrol programs, including salvinia biocontrol) found an overall benefit:cost ratio (BCR) of 23.1, providing a strongly positive return on investment (Page and Lacey 2006). The biocontrol program for the three water weeds salvinia, water hyacinth and water lettuce was found to have a BCR of 27.5 at a discount rate of 8.0% (Page and Lacey 2006).

Following on from the salvinia weevil’s successful implementation in tropical Australia, significant additional research was undertaken in the 2000s to assess and document factors affecting weevil performance in temperate parts of Australia. The major outcome from this research was to demonstrate that the weevil was more effective in temperate climates than previously thought. These results have allowed improved adoption of the weevil as a biological control agent in sub tropical and temperate climates in Australia (Sullivan et al. 2011), but benefits of this biocontrol deployment are not available so BCR could not be calculated.

Raphael and Walters (2012) identified 6 additional publicly funded R&D projects involving some aspect of salvinia management, but lack of data meant BCRs could not be calculated for any of these projects.

7.2.3 Raising awareness of impacts

A number of education materials have been published about salvinia for a wide variety of stakeholder groups: the nursery/garden and aquarium industries; garden and aquarium enthusiasts; the general public and landholders; and recreational water. Education and awareness activities have included the production of brochures, media articles, DVDs, articles in publications of both the pet and nursery trade, posters and displays. Information on the costs and benefits of these public awareness education activities was generally not available.

7.2.4 Strategic investment in on-ground work

Once salvinia becomes established in an area a number of control options are available depending on climate, extent of the infestation, nature and use of the water body. These are mechanical removal or harvesting, manual removal, applicaton of herbicides, use of booms, and biological control.

Since 1995 at least 40 projects that relate in some way to salvinia management have been publicly funded. Typical examples of investment in strategic on-ground work in salvinia control are provided by (i) salvinia management in the Hawkesbury-Nepean river catchment (NSW) and (ii) Lakeland Downs salvinia eradication project (Qld).

Intensive management efforts were applied to salvinia in the Hawkesbury-Nepean catchment during 2004-2005. Control techniques used were broadscale harvesting and subsequent removal of the biomass, use of booms to contain salvinia, follow-up herbicide treatment and release of the salvinia weevil (*Cyrtobagous salviniae*). In total, the on-ground work cost $1.8m and was all publicly funded. As a result of the project the population of salvinia was reduced to manageable levels and no longer interferes with river usage or environmental values, although the value of benefits (avoided losses) from salvinia control was not measured. Because benefits were not measured a BCR was not able to be obtained.

On-ground control in the Lakeland Downs project was part of a project that had various objectives in addition to removal of salvinia from a 240 hectare dam and more than 9km of waterways in Queensland's Cape York Peninsula. Salvinia was successfully removed from the dam and surrounding waterways over a 4-year period, using a combination of herbicide, manual removal and containment booms. The component of this project which addressed salvinia control on Cape York Peninsula was worth $107,000. Significant in-kind support for the project came from various groups – the Laura Indigenous Rangers, Queensland Parks and Wildlife Service, NAWMG, Cook Shire Council, Cape York Weeds and Feral Animals Program, Biosecurity Queensland and local landholders. Again, benefits from salvinia removal were not quantified so a BCR was not obtainable for this investment activity. It is worth noting that this on-ground project also provided useful information about eradication of salvinia on a relatively large scale, and how communities can be successfully involved in weed management.

One recommendation for further work in this area is to undertake a meta-analysis on the 40 projects that relate to salvinia management to understand how control effort, size of infestation and characteristics of the invaded water body affect success of the project.

7.2.5 Building community capacity

Several projects were identified that could be categorised as activities where building community capacity was the focus: (i) Development of a salvinia control manual; (ii) aquatic weed identification workshops and associated training materials; and (iii) salvinia biocontrol workshops.

The salvinia control manual was published in 2006 by the NSW Department of Primary Industries (NSWDPI). It provides a detailed and comprehensive account of the biology, ecology and history of spread of salvinia, available control methods, and guidelines on their optimal use in various locations and conditions. The manual was widely promoted to provide information on best practice to those attempting to carry out management of this aquatic weed. The cost of developing the manual was $79,600, provided to the NSW Department of Primary Industries (NSW DPI) as a grant from the Natural Heritage Trust. Unfortunately no data are available on the benefits of investing in development of the manual.

A National Heritage Trust grant also funded workshops and associated resources aimed at training community groups in aquatic weed identification. Now known as Recognising Water Weeds, the workshops have been well attended with each state holding ongoing workshops with minimal, if any, input from the national WoNS program. Over 2,000 people (weeds officers, community, Waterwatch) have been trained in aquatic weed identification across all states. Importantly these workshops have resulted in detections of new infestations of salvinia. The funds used to train the 2,000 people were obtained from state, industry or local sources, in addition to original NHT funds for resource development. Benefits and costs of this programme were not available.

The third community capacity project involved the funding of a series of salvinia biological control workshops through a Caring for our Country grant. These workshops were part of a four-state multi-jurisdictional project entitled ‘Community implementation of biological control of weeds across south-eastern Australia’ and used a proven community-based model (implemented previously with bridal creeper and Paterson's curse) to implement biocontrol programs. The entire project was valued at $2,176,448 and included a number of other weed species (blackberry, gorse, boneseed, bridal creeper and bitou bush). Again, benefits of the salvinia part of this program were not identified and valued so no estimate of ROI could be calculated.

7.3 Summary

Undertaking a return on investment analysis retrospectively, as previously discussed, is difficult if measures by which to evaluate success are not explicitly stated, key data are missing, and it is difficult to isolate the effects of particular activities on outcomes. BCRs were calculated for R&D for both case studies, and for on-ground work with rabbits. While both were high, it is difficult to draw general conclusions about ROI for the range of investment strategies. Meta-analysis and simulation could be used to determine parameter values to calculate benefits and costs, but this is out of the scope of the project.

1443

8 Recommendations

In this report we give details of different types of publicly funded investments aimed at managing established pests. The aim of this project was to evaluate these different investment strategies using a set of case studies with a view to informing the development of future Australian Government policies for management of established pests and diseases. The case studies were to be used to evaluate retrospectively the costs and benefits of alternative investment strategies.

Lack of data on rabbit and salivinia management hampered efforts to undertake a return on imvestment analysis for each of these established pests, and it appears that data will continue to be an issue in such impact evaluation unless data-collection practices are improved.

Given poor data availablility we describe how evaluation could be undertaken using a decision-analysis framework and demonstrate its application to a typical pest-management scenario. This framework could be used in various ways:

- as a starting point to determine the mix of activities that would reduce the pest population to a particular level,
- to understand how investment activities can be expected to impact on the pest population over time, and
- to indicate what data would need to be collected for meaningful quantitative analysis of an investment strategy.

In order to improve investment evaluation of publicly funded pest-management activities in the future we recommend that:

- data collection for the purposes of quantitative impact evaluation be given a high priority with the costs of collection included in project budgets. The suggested decision-analysis framework in this report could be used to guide data collection.

- impact evaluation be addressed prospectively (before the investment is undertaken) rather than retrospectively (after the programme has finished). Objectives of the different activities and measures by which success could be evaluated should be clearly stated at the outset, and data should be collected on these measures during the project so that meaningful quantitative impact evaluation can be undertaken.

- the trigger for all investment in pest-management activities be determined by the level of public net benefits (public benefits minus public costs), with cost recovery of private benefits undertaken when possible.

- the decision-analysis framework suggested in this report be used to inform both prospective and retrospective evaluation of pest management activities. This framework focuses attention on the key biological parameters.
- where retrospective evaluation is the only option for pest-management evaluation, that a meta-analysis of all available data on selected programmes be undertaken. This would allow exploration of significant relationships between measures of success (e.g population change or population density) and independent variables such as total budget, pest characteristics, types of investment activities etc.

9 References

ACIL (1996) *The economic importance of wild rabbits to the rural production in Australia*. Report to the International Wool Secretariat. ACIL Economic and Policy Pty Ltd., Canberra.

Antony G, Scanlon J, Francis A, Kloessing K and Nguyen Y (2009) Revised benefits and costs of eradicating the red imported fire ant. Queensland Department of Primary Industries and Fisheries, Brisbane.

AWC (Australian Weeds Committee) (2012) *Weeds of National Significance 2012*. Department of Agriculture, Fisheries and Forestry, Canberra, ACT.

Baxter PWJ and Possingham HP (2011) Optimising search strategies for invasive pests: learn before you leap. *Journal of Applied Ecology*, 48, 86–95.

Belton V and Steward T (2002) Multiple Criteria Decision Analysis: an integrated approach, Kluwer Academic Publishers.

Berman D, Brennan M and Elsworth P (2011) How can warren destruction by ripping control European wild rabbits (*Oryctolagus cuniculus)* on large properties in the Australian arid zone? *Wildlife Research*, 38, 77-88.

Bertheau C, Brockerhoff EG, Roux-Morabito G, Lieutier F And Jactel H (2010) Novel insect-tree associations resulting from accidental and intentional biological ‘invasions’: a meta-analysis of effects on insect fitness. *Ecology Letters*, 13, 506-515.

Boyd J, Epanchin-Neill R and Siikamäki J (2012) Conservation return on investment analysis: A review of results, methods, and new directions. Discussion Paper 12-01, Resources for the Future, Washington DC.

Buhle E R, Margolis M and Ruesink JL (2005) Bang for buck: cost-effective control of invasive species with different life histories. *Ecological Economics* 52(3): 355-366.

Cain J (2001) *Planning Improvements in Natural Resources Management*. Centre for Ecology and Hydrology, Wallingford, Oxfordshire, UK.

Cacho OJ, Wise R, Hester S and Sinden J (2008) Bioeconomic modeling for control of weeds in natural environments. *Ecological Economics*, 65, 559−568.

Cacho OJ and Hester SM (2011) Deriving efficient frontiers for effort allocation in the management of invasive species. *Australian Journal of Agricultural and Resource Economics*, 55: 72-89.

Cacho O, Reeve I, Tramell J and Hester S (2012) Post-border surveillance techniques: review, synthesis and deployment - subproject 2d Valuing community engagement in biosecurity surveillance, Final Report ACERA project 1004B2d, Australian Centre of Excellence for Risk Analysis, University of Melbourne.

Chadès I, Martin TG, Nicol S, Burgman MA, Possingham, HP and Buckley YM (2011) General rules for managing and surveying networks of pests, diseases, and endangered species. *Proceedings of the National Academy of Sciences*, 108(20), 8323-8328.

Chaskin RJ, Brown P, Venkatesh S and Vidal A (2001) *Building Community Capacity*, Walter d Gruyter, Inc., New York.

Chudleigh P, Simpson S and Lai J (2011) Economic Analysis of the National Wild Dog Facilitator Project. 2011. Invasive Animals Cooperative Research Centre, Canberra, Australia.

CIE (Centre for International Economics) (2001) Control of Bitou bush: a benefit-cost analysis, chapter 7 in *The CRC for weed management systems: an impact assessment*. Glen Osmond, South Australia, CRC for weed management systems.

Cook D and Proctor W (2007) Assessing the threat of exotic plant pests. *Ecological Economics*. 63, 594-604.

Cooke B, Jones R and Gong W (2010) An economic decision model of wild rabbit *Oryctolagus cuniculus* control to conserve Australian native vegetation. *Wildlife Research*, 37, 558–565.

Cooke B, Chudleigh P, Simpson S and Saunders G (2013) The economic benefits of the biological control of rabbits in Australia, 1950-2011, *Australian Economic History Review*, 53(1), 91-107.

Cooke B (n.d.) Rabbits: a threat to conservation and natural resource management, http://www.rabbitfreeaustralia.org.au/BRS_Rabbit_Booklet_lr.pdf (accessed 1 June 2013).

CSIRO Sustainable Ecosystems (2007) Multi Criteria Analysis Tool (MCAT) User Guide (beta version), St Lucia Qld, Australia, 2007, 29 pages,

Dambacher JM, Shenton W, Hayes KR, Hart BT and Barry S (2007) Qualitative modelling and Bayesian network analysis for risk-based biosecurity decision making in complex systems, Final Report ACERA project 06/01, Australian Centre of Excellence for Risk Analysis, University of Melbourne.

Darin GMS, Schoenig S, Barney JN, Panetta FD and DiTomaso J (2011) WHIPPET: A novel tool for prioritizing invasive plant populations for regional eradication. *Journal of Environmental Management*. 92. 131-139.

Decision Systems Laboratories (n.d.) About GeNIe and SMILE, http://genie.sis.pitt.edu/.

DEWHA (2008) *Threat abatement plan for competition and land degradation by rabbits,* Department of the Environment, Water, Heritage and the Arts, Canberra.

Elton EJ, Gruber MJ, Brown SJ and Goetzmann WN (2003) *Modern Portfolio theory and investment analysis*, 6th ed. John Wiley and sons, Inc., United States of America.

Galligan DT, Ramberg C, Curtis C, Ferguson J, Fetrow J (1991) Application of portfolio theory in decision tree analysis. *Journal of Dairy Science*, 74, 2134-2144.

Galligan DT and Marsh WE (1988) Application of Portfolio Theory for the Optimal Choice of Dairy Veterinary Management Programs. *Preventive Veterinary Medicine*, 5, 251-261

Gertler PJ, Martinez S, Premand P, Rawlings LB and Vermeersch CMJ (2011) *Impact evaluation in practice*, The World Bank, Washington.

Gong W, Sinden J, Braysher M and Randel J (2009) *The economic impacts of vertebrate pests in Australia,* Invasive Animal Cooperative Research Centre, Canberra.

Gujarati D (2004) Basic Econometrics, Fourth edition, McGraw Hill.

Gurevitch J and Hedges L (1999) Statistical issues in ecological meta-analyses. *Ecology*, 80(4), 1142-1149.

Hart (2005) *A review of the Commonwealth Government's threat abatement plans for feral goats, feral rabbits, feral cats and the European red fox*. Bureau of Rural Sciences, Canberra.

Hastings A, Hall RJ and Taylor CM (2006) A simple approach to optimal control of invasive species. *Theoretical Population Biology* **70**, 431–435.

Hennecke B and Raphael B (2012) Effectiveness of national coordination in reducing spread of WoNS, ABARES (Report to client prepared for the Sustainable Resource management Division, DAFF), Canberra, June.

House of Representatives Standing Committee on Agriculture, Fisheries and Forestry (2005) *Taking control: a national approach to pest animals*. House of Representatives, Canberra.

Hurley MV, Lowell KE, Cook DC, Liu S, Siddique A-B and Diggle A (2010) Prioritizing Biosecurity Risks Using a Participatory Decision-Making Tool. *Human and Ecological Risk Assessment*, 16(6), 1379-1394.

IGAB (Intergovernmental agreement on biosecurity) (2012) National Biosecurity Research and development capability audit, IGAB – Research, Development and Extension Working Group, July 2012, Canberra.

ISEE Systems (n.d.) Stella® Systems thinking for education and research, http://www.iseesystems.com/softwares/Education/StellaSoftware.aspx

ISSN (Invasive Species Specialist Group of the IUCN Species Survival Commission), Global Invasive Species Database, http://www.issg.org/database/welcome/

Kean JM, Suckling DM, Tobin PC, Lee DC, Stringer LD, Flores Vargas R, Smith GR, Fletcher J, Macbeth F, McCullough DG, Herms DA, Sullivan NJ, Campbell D et al. (2014) Global eradication and response database. http://b3.net.nz/gerda (accessed 6 January 2014).

Khandker SR, Koolwal GB and Samad HA (2010) Handbook on impact evaluation: Quantitative methods and practices, The International Bank for Reconstruction and Development/The World Bank, Washington.

Kiker GA, Bridges TS, Varhjese A, Seager TP and Linkov I (2005) Application of multicriteria decision analysis in environmental decision making. *Integrated Environmental Assessment and Management* 1(2): 95-108.

Kompas, T and Che, N (2001) An Economic Assessment of the Potential Costs of Red Imported Fire Ants in Australia. Consultancy report. ABARE, Canberra.

Leung B, Finnoff D, Shogren J and Lodge D (2005) Managing invasive species: Rules of thumb for rapid assessment. *Ecological Economics* **55,** 24–36.

Liu S, Proctor W and Cook D (2010) Using an integrated fuzzy set and deliberative multi-criteria evaluation approach to facilitate decision-making in invasive species management. *Ecological Economics*. 69, 2374-2382.

Loyd KT and DeVore JL (2010) An evaluation of feral cat management options using a decision analysis network. *Ecology and Society* 15(4): 10. [online] URL: http://www.ecologyandsociety.org/vol15/iss4/art10/

Maguire LA (2004) What Can Decision Analysis Do for Invasive Species Management? *Risk Analysis*, 24(4), 859-868.

Margoluis R, Stem C, Salafsky N and Brown M (2009) Using conceptual models as a planning and evaluation tool in conservation. *Evaluation and Program Planning*, 32, 138-147

Markowitz HM (1952) Portfolio selection. *Journal of Finance*, 7 (1), 77–91.

McGinty S (2003) The literature and theories behind community capacity building. In: *Sharing Success: an Indigenous perspective*. Common Ground Publishing, Altona, VIC, Australia, pp. 65-93.

McLeod R (2004) *Counting the cost: impact of invasive animals in Australia.* Pest Animals Control Cooperative Research Centre, Canberra.

Mendoza GA and Martins H (2006) Multi-criteria decision analysis in natural resource management: A critical review of methods and new modelling paradigms. *Forest Ecology and Management*. 230, 1-22.

Murdoch W, Polasky S, Wilson KA, Possingham HP, Kareiva P and Shaw R (2007) Maximizing return on investment in conservation. *Biological Conservation*, 139: 375-388.

Norsys Software Corporation (n.d.) Netica™ Application, http://www.norsys.com/netica.html.

Page AR and Lacey KL (2006) *Economic impact assessment of Australian weed biological control, CRC for Australian Weed Management Technical Series #10*. CRC for Australian Weed Management, Adelaide.

Pannell DJ (2008) Public: private benefits framework version 3, INFFER Working Paper 0805, University of Western Australia. http://dpannell.fnas.uwa.edu.au/dp0902.htm

Petroeschevsky A (2009) *Review of progress towards the Salvinia strategic plan 2008-2009*. NSW Department of Industry and Investment, Grafton Primary Industries Institute, Grafton, NSW.

Prattley DJ, Morris RS, Stevenson MAR and Thornton R (2007) Application of portfolio theory to risk-based allocation of surveillance resources in animal populations. *Preventive Veterinary Medicine* **81**, 56–69.

Pyŝek, P. and D. M. Richardson (2010) Invasive species, environmental change and management, and health. *Annual Reviews of Environment and Resources,* 35, 25-55.

Raitzer J (2003) Benefit-Cost Meta-Analysis of Investment in the International Agricultural Research Centres of the CGIAR, Prepared on Behalf of the CGIAR Standing Panel on Impact Assessment, Food and Agriculture Organization of The United Nations.

Raphael B and Walters S (2012) *Post-border investment return*, internal draft for ACERA 1104D,

Ravallion M (2001) The mystery of the vanishing benefits: an introduction to impact evaluation. *The World Bank Economic Review*, 15: 115-140.

Regan TJ, McCarthy MA, Baxter PWJ, Panetta FD and Possingham HP (2006) Optimal eradication: when to stop looking for an invasive plant. *Ecology Letters*, 9, 759–766.

Rolfe J and Bennett J (2006) Choice modelling and the transfer of environmental values, chapter 1 in Rolfe and Bennett (eds) *Choice modelling and the transfer of environmental values. Edward Elgar Publishing Ltd,* Cheltenham, UK.

Roy AD (1952) Safety first and the holding of assets. *Econometrica* 20 (3), 431–449.

Saunders G, Cooke B, McColl S and Peacock T (2010) Modern approaches for the biological control of vertebrate pests: an Australian perspective. *Biological Control*, 52, 288–95.

Saaty TL (1980) The analytic hierarchy process. Planning, setting priorities, resource allocation. McGraw Hill, New York.

Scott JK and Laut P (2009) AWC's Review of the implementation of the *Salvinia molesta* (Salvinia) Strategic Plan. Australian Weeds Committee, Canberra.

Sinden JA and Thampapillai DJ (1995) *Introduction to benefit-cost analysis*. Longman, Melbourne.

Sinden JA, Downey P, Cacho O and Hester S (2013) Economic efficiency, site selection, and funding policies to protect native plant communities from the weed, bitou bush, in Australia, *Journal of Environmental Management*, 128, 1071-1080

Sullivan PR, Postle LA and Julien M (2011) Biological control of *Salvinia molesta* by *Cyrtobagous salviniae* in temperate Australia, *Biological Control*, 57: 222–228.

Van Klinken RD, Seabrook L, Smith C, Ryan J and McAlpine C (2008) Using spatial models and a Bayesian belief network to predict risk of parkinsonia invasion at a landscape scale in northern Australia, Paper presented at the 16th Annual Australian Weeds Conference, p194.

Varis O (2006) "Belief networks for modelling and assessment of environmental change." *Environmetrics* 6(5): 439-444.

VICDPI (n.d.) Biosecurity Strategy for Victoria, Department of Primary Industries and the Environment, Victoria, http://www.dpi.vic.gov.au/agriculture/about-agriculture/biosecurity/strategy/full-document, accessed March 2013.

Walshe T and Burgman M (2010) A framework for assessing and managing risks posed by emerging diseases. *Risk Analysis*. 30(2), 236-249.

West P (2008) *Assessing invasive animals in Australia 2008.* National Land and Water Resources Audit and Invasive Animals CRC, Canberra.

Williams CK, Parer I, Coman BJ, Burley J and Braysher ML (1995) *Managing vertebrate pests: rabbits*. Bureau or Resource Sciences/CSIRO Division of Wildlife and Ecology, Australian Government Publishing Services, Canberra.

Yokomizo H, Possingham HP, Thomas MB and Buckley YM (2009) Managing the impact of invasive species: the value of knowing the density-impact curve. *Ecological Applications* **19**(2), 376–386.