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Benefit Cost Analysis

Boosting Biosecurity Defences

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1. Executive Summary

- This analysis estimates the likely producer benefits created as a result of the $26.9 million Boosting Biosecurity Defences project. The 11 subprojects involved in the project receive a combined $20 million in funding from the Government of Western Australia's *Seizing the Opportunity* Royalties for Regions initiative.
- A bioeconomic model is used to estimate the likely pest and disease damage avoided through eight of the 11 subproject activities. The avoided damages are compared to costs to provide a benefit cost analysis. Results are summarised in Table 1.
- The highest net benefit is created by subprojects 4, 6 and 7 (*Early detection of emergency animal diseases*, *Build capacity to respond and recover from emergency pest and disease incidents*, and *Awareness and compliance with new biosecurity legislation*, respectively), with a combined net benefit of $106.3 million over 30 years.
- The highest return per dollar invested is created by subproject 3 (*E-Surveillance for pests and diseases of the WA grape industry*). This relatively small subproject is expected to produce $56.40 for every dollar invested in it.
- Combining analyses of the subprojects, an aggregate benefit cost assessment of the Boosting Biosecurity Defences project estimates the project will generate a net benefit in excess of $240 million over the next 30 years.
- Approximately $17.40 of producer benefits are created for ever $1.00 invested in the Boosting Biosecurity Defences project.

Table 1. Boosting Biosecurity Defences return on investment

Subproject	Present value of costs ($ million)	Present value of benefits ($ million)	Net present value ($ million)	Benefit cost ratio
1. State Biosecurity Strategy	na	na	na	na
2. E-Surveillance for pests and diseases in the WA grains industry	1.73	36.50	34.77	22.77
3. E-Surveillance for pests and diseases of the WA grape industry	1.08	61.09	60.01	56.40
4. Early detection of emergency animal diseases 6. Build capacity to respond and recover from emergency pest and disease incidents 7. Awareness and compliance with new biosecurity legislation	7.36	113.63	106.27	15.44
5. Agricultural weed surveillance in the South West to protect industry profitability	0.95	34.11	33.16	38.03
8. Biosecurity research and development fund - *Using innovative technologies to identify and map invasive cacti in the southern Rangelands of WA*	0.15	0.37	0.22	2.44
9. Transforming regional biosecurity response	na	na	na	na
10. Eradication of Medfly in Carnarvon	3.48	10.95	7.47	3.38
11. Wild dog control measures	na	na	na	na
Boosting Biosecurity Defences	**14.76**	**256.64**	**241.89**	**17.39**

2. Introduction

This report estimates the likely return on investment in the Boosting Biosecurity Defences project, henceforth BBD, funded under the Government of Western Australia’s *Seizing the Opportunity* Royalties for Regions (RfR) initiative. This project involves 11 separate activities developed by the Department of Agriculture and Food WA (DAFWA), the WA Biosecurity Council and key industry and community stakeholders.

The total investment received for the BBD project is $26.9 million to be spent between 2013/14 and 2016/17. This includes $6.9 million of cash and in-kind contributions from the Carnarvon Grower Association, Horticulture Innovation Australia Ltd., State Natural Resource Management Office, Council of Grain Grower Organisations and DAFWA. The investment from RfR is $20.0 million.

The economic and social benefits to the State produced by the BBD project will accrue over time from early detection and rapid response to pest and disease incursions. This will avoid producer cost increases and yield reductions over time, reduce the likelihood of losing area-freedom status and reduce the time it takes to regain market access if it is lost.

An economic impact simulation model is used to estimate the likely returns to WA agricultural industries from BBD subprojects achieving their intended outcomes. Results are aggregated to produce a benefit cost analysis for the BBD project as a whole.

Results indicate that a net benefit of $241.9 million will be created by the BBD project over a period of 30 years. The highest net benefit is created by subprojects 4, 6 and 7 (*Early detection of emergency animal diseases*, *Build capacity to respond and recover from emergency pest and disease incidents*, and *Awareness and compliance with new biosecurity legislation*, respectively). However, the highest return per dollar invested is created by subproject 3 (*E-Surveillance for pests and diseases of the WA grape industry*).

The simulation model used to predict the change in invasive species impacts over time attributable to the BBD project is sensitive to changes in several key parameters. These include the probabilities of invasive species entry and establishment, likelihood of detection and several spread parameters. These sensitivities and a lack of certain parameter information mean results are uncertain.

3. Scope

The purpose of this assessment is to estimate the likely agricultural benefits produced by the BBD project over a 30-year period if each subproject attains its intended goals. The technical challenges faced in reaching these goals are not considered as part of the scope for this document; rather what are the likely gains in them doing so.

Subproject goals relate to restricting the abundance, distribution and impact of plant and animal species of biosecurity significance to levels below what they otherwise would have been without the RfR initiative. These include species that have already become established in the State, and those that remain exotic to it.

Numerous terms have been used to describe species of biosecurity importance, including “non-indigenous”, “non-native”, “alien”, “exotic”, “invasive”, “noxious”, “nuisance”, and “weed”. This has caused confusion and misuse of existing terminology, with the term ‘invasive’ being particularly problematic as ecologists use it in reference to species that rapidly spread beyond the location of initial establishment. In contrast, policy and legal documents tend to refer to invasive species as those causing negative effects to human beings, even though invasiveness of a species does not necessarily predict its impact (Ricciardi and Cohen, 2007).

For the purpose of this analysis, an *invasive species* is defined as a species that does not naturally occur in a specific area and whose introduction does or is likely to cause net negative social welfare consequences. Social welfare, itself difficult to define, would ideally encompasses environmental, economic and social impacts (both intended and unintended) of BBD activities. However, due to time constraints, this assessment is limited to agricultural benefits.

4. Methods

4.1. Derivation of benefits

This section contains details of the methodology used to assess the return on investment in the BBD project. In particular, the simulation model used to predict the change in invasive species impacts over time attributable to the project is detailed. It is intended that this will invite critical comment in an appropriate context to refine and potentially build on the assessment.

Readers chiefly concerned with the assessment results may wish to proceed to Section 5 where estimated benefits of specific BBD subprojects are revealed.

Predicting invasive species impacts before they occur involves a great deal of uncertainty. Indeed, even after they occur, when we have actual impact data, we are not necessarily able to make better predictions. A data set only tells us about one possible set of outcomes from a wide range of possibilities. It follows that forecasting likely reductions in invasive species impacts resulting from a broad suite of investments, as with the BBD project, is even more challenging.

Rather than developing a simulation model from scratch to estimate reductions in invasive species impacts over time, an existing model is used that has formed the basis of many peer-reviewed economic assessments (e.g. Cook et al., 2013a, Cook and Fraser, 2014, Cook et al., 2013b, Cook et al., 2011a, Cook, 2008, Cook et al., 2011b). The model has the capability of calculating the economic impacts of a wide variety of pests and diseases over time with and without different prevention and control activities.

Within the model, agricultural areas are denoted i. In the case of exotic species, pest and disease arrival events in these regions are generated using entry and establishment probabilities denoted z^{ent} and z^{est}, respectively. A Markov chain process is used to change z^{ent} and z^{est} over time according to a vector of transitional probabilities that describe the likelihood of moving from one pest state to another. The probabilities z^{ent} and z^{est} are combined to form a probability of arrival for a specific region i, z_i:

$$z_i = z^{ent} \times z^{est} \text{ where } 0 < z_i < 1. \quad (1)$$

A stratified diffusion process combining both short and long distance dispersal is used to predict the area potentially affected by pests and diseases post-establishment in each region i in time period t, A_{it}[1].

This method of calculating the area occupied by an organism over time has been shown to provide a reasonable approximation of spread for a wide range of species (Okubo and Levin, 2002, Dwyer, 1992, Holmes, 1993, McCann et al., 2000, Cook et al., 2011a). It assumes that an invasion diffusing from a point source will eventually reach a constant asymptotic radial spread rate of $2\sqrt{r_i D_{ij}}$ in all directions, where r_i describes a growth factor for an invasive species per year in region i (assumed constant over all affected sites) and D_{ij} is a diffusion coefficient for an affected site j in region i (assumed constant over time) (Lewis, 1997, Shigesada and Kawasaki, 1997, Cook et al., 2011a, Hengeveld, 1989).

Hence, assume that the site of the original outbreak (i.e. the first of a probable series of sites, j) takes place in a homogenous environment in region i and expands by a diffusive process such that area affected at time t, a_{ijt}, can be predicted by:

$$a_{ijt} = z_i\left[\pi\left(2t\sqrt{r_i D_{ij}}\right)^2\right] = z_i\left(4D_{ij}\pi r_i t^2\right). \quad (2)$$

For practical purposes, an estimate of D_{ij} can be derived from the mean dispersal distance ($\bar{\delta}_{ij}$)at an incursion site, where $D_{ij} = \frac{2(\bar{\delta}_{ij})^2}{\pi t}$ (Andow et al., 1990, Cook et al., 2011b, Cook et al., 2010). The variable $\bar{\delta}_{ij}$ is the site-specific average distance (in metres) over which dispersal events occur.

The density of an outbreak within a_{ijt} influences the control measures required to counter its effects, and thus partially determines the value of A_{it}. Assume that in each site j in region i affected, the density, N_{ijt}, grows over time period t following a logistic growth curve until the carrying capacity of the host environment, K_{ij}, is reached:

$$N_{ijt} = \frac{K_{ij}N_{ij}^{min}e^{r_i t}}{K_{ij}+N_{ij}^{min}\left(e^{r_i t}-1\right)}. \quad (3)$$

[1] Parameter estimates for specific species appear in following sections. Due to the uncertainty surrounding some of these parameters, they are specified using a range of distributional forms, rather than simple point estimates. Types of distributions used in this report include: (a) pert – a type of beta distribution specified using minimum, most likely (or skewness) and maximum values; (b) uniform – a rectangular distribution bounded by minimum and maximum values; (c) binomial – returning a zero (failure) or one (success) based on a number of trials and the probability of a success; (d) discrete - a distribution in which several discrete outcomes and their probabilities of occurrence are specified; (e) Poisson - a discrete distribution returning only integer values greater than or equal to zero with a specified mean value.

Here, N_{ij}^{min} is the size of the original outbreak at site j in region i and r_i is the intrinsic rate of density increase in region i (assumed to be the same as the intrinsic rate of area increase) (Cook et al., 2011b).

In addition to a_{ijt} and N_{ijt}, the size of A_{it} depends on the number of nascent foci or *satellite* population sites in year t, s_{it}, which can take on a maximum value of s_i^{max} in any year (Moody and Mack, 1988). These sites result from events external to the initial outbreak itself, such as weather phenomena or human activities, which periodically jump the expanding population beyond the invasion front (Cook et al., 2011b). A logistic equation is used to generate changes in s_{it} as an outbreak continues:

$$s_{it} = \frac{s_i^{max} s_i^{min} e^{\mu_i t}}{s_i^{max} + s_i^{min}(e^{\mu_i t} - 1)} \quad (4)$$

where μ_i is the intrinsic rate of new foci generation in region i (assumed constant over time) and s_i^{min} is the minimum number of satellite sites generated in region i.

Given equations (2)-(4), A_{it} can be expressed as:

$$A_{it} = \sum_{j=1}^{m} \left(a_{ijt} N_{ijt}\right)^{s_{it}} \text{ where } 0 \leq A_{it} \leq A_i^{max}. \quad (5)$$

In terms of preventing pest and disease naturalisation in WA, eradication is the only government incursion response activity simulated in the model. Assume that eradication is immediately commenced once susceptible industries and government have been alerted to the presence of a pest or disease in the State.

The detection that triggers the response is, on average, assumed to occur in 60% of incursion events simulated by the model using a binomial distribution (i.e. binomial(1.0,0.6)). The probability that the eradication attempt will successfully remove an incursion is assumed to decline exponentially at an average rate of $e^{-0.15 A_{it}}$, where A_{it} is the area affected in region i in year t (Cook and Fraser, 2014).

If this does not occur before the invasive has spread to a pre-defined maximum area, A^{erad}, the eradication attempt is aborted[2]. This does not mean that the invasive now spreads unimpeded within the virtual world of the model since it is assumed on-farm management schemes will be put in place and adjusted according to the needs of host industries. However, this will add to growing costs as the frequency of these activities increase and are not guaranteed to be 100% effective.

The spread of pests and diseases is connected dynamically with the costs of eradication and on-farm control by multiplying the area affected by a constant marginal damage cost (or an average damage cost) to reveal the total damage

[2] A range of factors will affect this decision in reality, including the number and location of sites, proximity to alternative hosts, industry size and the number of simultaneous eradication programs for other species.

cost, d. For outbreaks involving less than A^{erad}, area is multiplied by eradication costs, but when the area affected spreads beyond A^{erad} the remaining area is multiplied by an average on-farm management cost.

Algebraically, the total damage cost associated with a specific pest or disease in region i in time t, d_{it}, can be expressed as:

$$d_{it} = \begin{cases} E_{it}A_{it} \text{ if } A_{it} \leq A_{it}^{erad} \\ Y_{it}P_tA_{it} + V_{it}A_{it} \text{ if } A_{it} > A_{it}^{erad} \end{cases}. \quad (6)$$

Here, E_{it} is the present value of eradication cost per hectare in region i in year t; A_{it}, as stated above, is the area affected by an invasive species in region i in year t weighted by the probability of incursion and density of infestation/infection; A_{it}^{erad} is the maximum technically feasible area of eradication in region i in year t; Y_{it} is the mean change in agricultural yield resulting from a pest or disease becoming established across region i in year t; P_t is the prevailing domestic price for an affected commodity in year t - 1; and V_{it} is the increase in variable cost of production per hectare induced by on-farm management methods in region i in year t.

By summing the production losses over each time step, total damage ($\sum_{i=1}^{n} d_{it}$) are estimated over a 30-year period with (d_{it}^{w}) and without the BBD project (d_{it}^{wo}). The difference between these values represents the gross benefits (g) generated for producers as a result of each of the sub-projects.

$$g = \sum_{i=1}^{n} d_{it}^{wo} - \sum_{i=1}^{n} d_{it}^{w}. \quad (7)$$

In sections 5.1 to 5.11, an estimate of g is produced for specific subprojects.

As these values are calculated over 30-year time frames, it is important to note that future benefits and costs are *discounted*. We use a traditional exponential discounting method with a constant discount rate of 5% per annum. This has an erosive effect on benefits and costs that increases with time, and as such future benefits and costs can be seen to fall in *real* terms over successive time periods irrespective of pest or disease prevalence.

The choice of discount rate should therefore consider the extent to which social time preferences are relevant (i.e. dictating a lower discount rate, e.g. 2-3% per annum) or private time preferences (i.e. indicating a higher discount rate, e.g. 5-7% per annum). There is no prescribed discount rate to use in the analysis of biosecurity projects *per se*, but for publicly-funded projects it consists of a margin on top of a private discount rate of around 3% (Commonwealth of Australia, 2006). This margin, which we arbitrarily assume is 2%, reflects the costs incurred by society in the transfer of money from the private sector to the public sector.

4.2 Project costs

The total investment in the BBD project is $26.9 million. This comprises of $20.0 million in RfR funding and $6.9 million of cash and in-kind contributions from the Carnarvon Grower Association, Horticulture Innovation Australia Ltd., State Natural Resource Management Office, Council of Grain Grower Organisations and DAFWA (Cousins, 2015).

All project funds are planned to be dispensed between 2013/14 and 2016/17 in 11 separate subprojects. These are listed along with their total costs in Table 2. Note project management costs ($750,000) are not listed in the table.

Table 2. Boosting Biosecurity Defences subproject costs

Subproject	Cost
1. State Biosecurity Strategy	$315,000
2. E-Surveillance for pests and diseases in the WA grains industry	$2,084,737
3. E-Surveillance for pests and diseases of the WA grape industry	$1,315,000
4. Early detection of emergency animal diseases	$2,100,000
5. Agricultural weed surveillance in the South West to protect industry profitability	$1,159,000
6. Build capacity to respond and recover from emergency pest and disease incidents	$5,650,000
7. Awareness and compliance with new biosecurity legislation	$1,120,000
8. Biosecurity research and development fund	$3,500,000
9. Transforming regional biosecurity response	$4,008,000
10. Eradication of Medfly in Carnarvon	$4,200,000
11. Wild dog control measures	$671,000
Boosting Biosecurity Defences	**$26,122,737**

4.3. Attribution

The attribution rate apportions benefits specifically to the project, and is dependent on the innovations of subprojects being adopted by producers and the broader biosecurity community. This in turn depends on a host of factors, including the availability of information about the innovation, adopter characteristics (e.g. age, income, experience), characteristics of the social system (e.g. management support, social attitudes to new ideas and technology), and the networks through which innovations are communicated (Lyytinen and Damsgaard, 2001).

Given the breadth of subprojects and diversity of activities being undertaken, to truly map the adoption of methods and ideas produced by the BBD project would require a detailed study of stakeholders and governments, their histories and networking using multiple perspectives including political models, institutional models and theories of team behaviour (Lyytinen and Damsgaard, 2001). However, time and information constraints have prevented the derivation and use of specific attribution curves for each subproject.

Rather, the approach taken was to use a generic attribution curve. The Rogers diffusion of innovations curve, shown in cumulative form in Figure 1 (Rogers, 2010), is a standardised adoption curve used to describe the way new ideas, products and production techniques are adopted within communities over time. Diffusion of innovations theory has been used in the areas of public health, communication, marketing, political science, and most other behavioural and social science disciplines (Rogers et al., 2005). We use it here to summarise the adoption of innovations from each of the BBD subprojects.

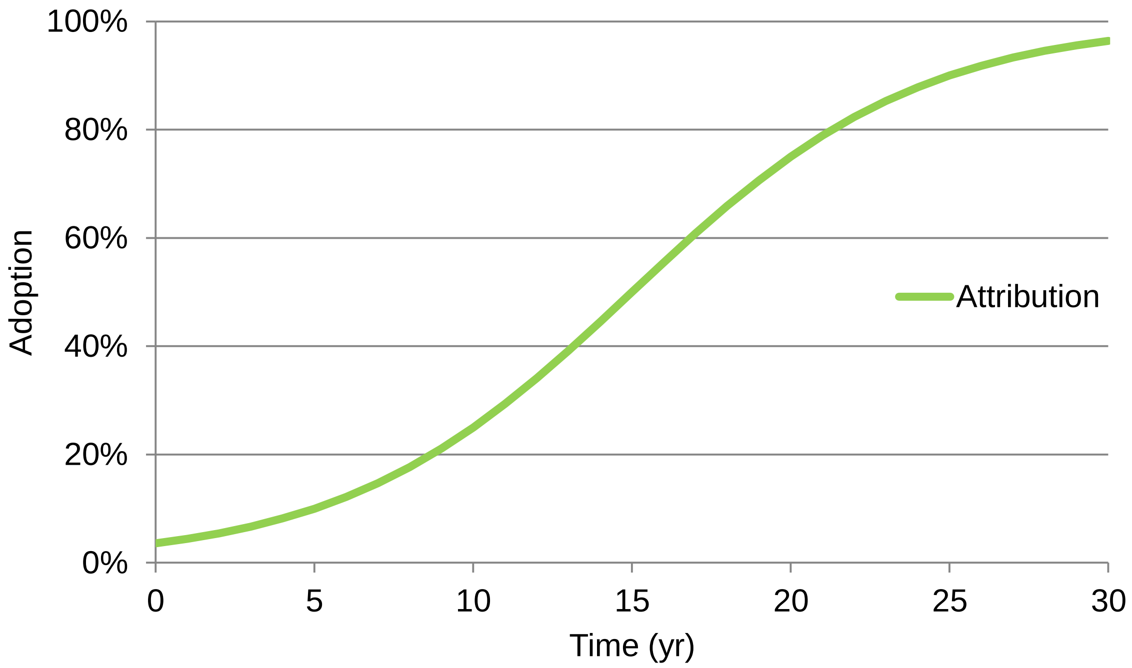

Figure 1. Cumulative diffusion of innovations model (Rogers, 2010)

5. Results

5.1. Subproject 1: State Biosecurity Strategy

5.2.1. Background

This subproject concerns the development of a *WA Biosecurity Strategy* for the period 2015-25. The strategy, released on the 21st November 2016, provides a broad framework to manage emerging and ongoing animal and plant pest and disease risks, including weeds and zoonotic diseases. DAFWA developed the strategy in partnership with the Department of Parks and Wildlife, Department of Fisheries, Forest Products Commission and Department of Premier and Cabinet.

5.2.2. Cost

This subproject involves a total investment of $315 000. This consists of $165 000 of DAFWA in-kind resources and $150 000 RfR funds.

5.2.3. Benefit

Not applicable.

5.2.4. Return on investment

Due to its general, non-specific nature, subproject 1 is not evaluated as part of this assessment.

Note however that from an economics standpoint, the effectiveness of the strategy is compromised by the use of the Invasion Impact Curve (Agriculture Victoria, 2015) to guide investment decisions[3].

[3] The generalised invasion curve is an abstract sigmoid curve implying certainty between the area affected by an invasive species and the time since its arrival in a new region. Unsubstantiated and unexplained benefit cost ratios are put forward in Agriculture Victoria (2015) that suggest returns to investment decline with the area occupied and that an appropriate intervention (particularly by governments) lies in prevention and eradication. This is misleading and has the potential to generate perverse outcomes when used as a policy guide.

5.2. Subproject 2: E-Surveillance for pests and diseases in the WA grains industry

5.2.1. Background

This subproject aims to enhance pest and disease surveillance and diagnostic capacity for the WA grains industry. It will draw from existing databases containing grains surveillance data and build a single database that can be augmented through the use of citizen-science activities.

Specifically, this involves the development of a freely available smartphone App called *MyPest Guide* that provides users with a real-time diagnostic tool. The App encourages community involvement and greatly improves the effectiveness of surveillance information provided by the general public. Using Bayesian statistical methods to calculate the probability of area freedom from exotic pests and diseases, the information gathered can reduce the probability of losing market access.

In addition, subproject 2 aims to improve grains industry capacity to manage exotic pest and disease incursions by identifying key threats and conducting a gap analysis of people, infrastructure and resources, and planning remedial actions.

5.2.2. Cost

This subproject involves a total investment of $2 084 000. This is made up of $1 054 000 from DAFWA, $30 000 from the Council of Grain Grower Organisations Western Australia (COGGO) and $1 000 000 from the RfR initiative.

5.2.3. Benefit

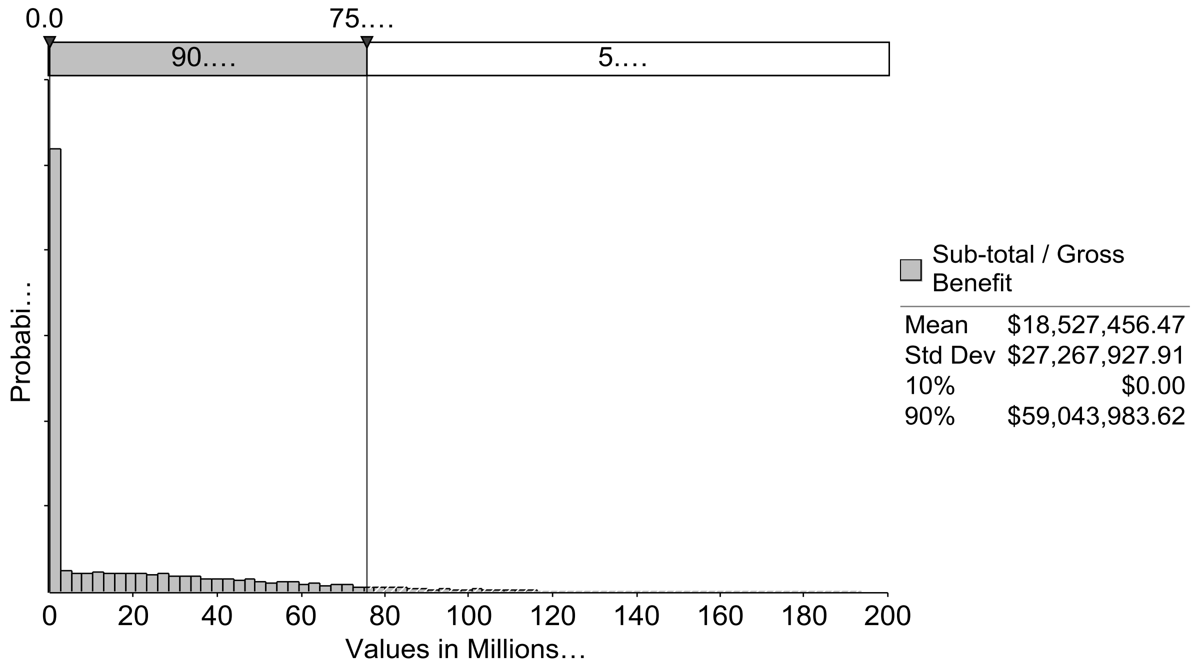

Figure 2. Estimated benefit of subproject 2

5.2.4. Return on investment

Using the mean of the distribution of model outputs shown in Figure 2 as our measure of the gross value returned by the project (or g, from equation (7)), the benefit cost ratio for subproject 2 is estimated to be between 1.2 and 22.8. The assumptions on which this is based are detailed in Appendix 1, Table A1. The distributions of benefit cost ratios produced by the subproject 2 are shown in Figure 3 for 10, 20 and 30-year time frames. This assessment is based on a small sample of the pests and diseases that could potentially be affected by the subproject, but it is clear that the longer the time frame we consider the higher the return on investment.

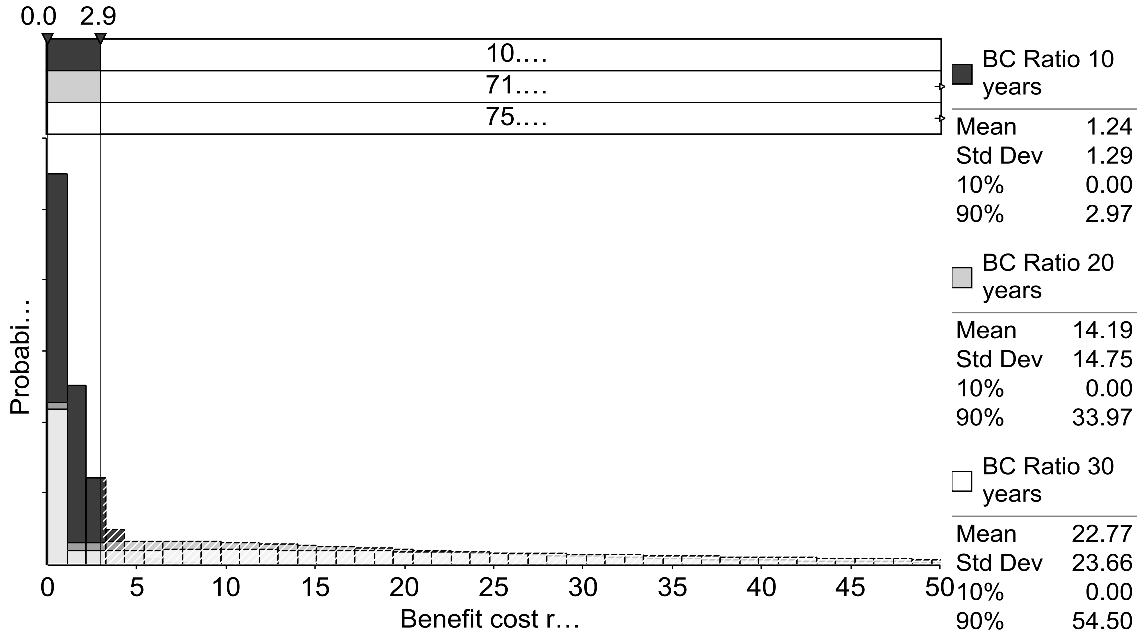

Figure 3. Estimated return per dollar invested in subproject 2

5.3. Subproject 3: E-Surveillance for pests and diseases of the WA grape industry

5.3.1. Background

This subproject aims to influence the behaviour of wine and table grape producers in relation to their understanding and participation in pest and disease surveillance and diagnostic activities. It will promote the early detection of exotic pests and disease incursions via a hybrid system for surveillance and diagnosis activities combining elements of the DAFWA HortGuard™ and South Australian Phylloxera systems.

This will involve the development and application of e-tools linking the *MyPest Guide* smartphone app to viticulture. Over time, this will decrease the amount of time new pest and disease arrivals are present before detection occurs and a response is initiated. The damages prevented accrue over subsequent time periods, and can be evaluated using a set of case study examples of some of the species affected by the subproject.

5.3.2. Cost

This subproject involves a total investment of $1 315 000; comprising of $479 000 from DAFWA and $836 000 from the RfR initiative.

5.3.3. Benefit

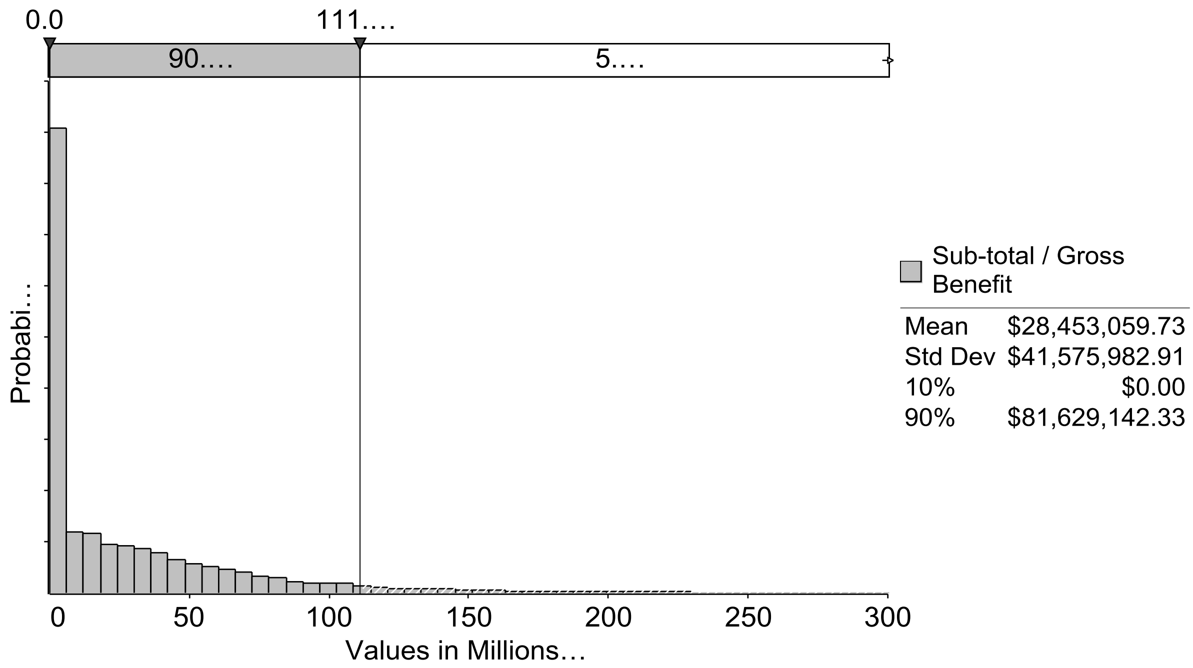

Figure 4. Estimated benefit of subproject 3

5.3.4. Return on investment

If we take the mean of the distribution of model outputs shown in Figure 4 as our estimate of the gross value of the project, the benefit cost ratio for subproject 3 is estimated to be 3.1 over 10 years, and as high as 56.4 over 30 years. The assumptions on which this is based are detailed in Appendix 1, Table A2.

Distributions of benefit cost ratios produced by subproject 3 are shown in Figure 5 for 10, 20 and 30-year time frames.

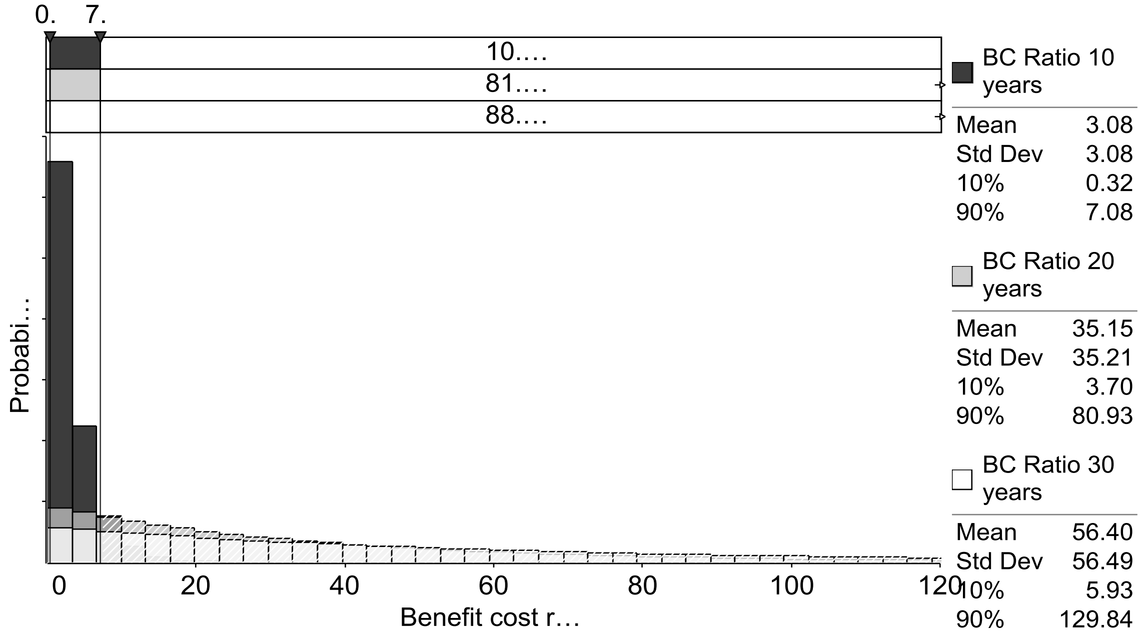

Figure 5. Estimated return per dollar invested in subproject 3

Despite this assessment being based on a small sample of the pests and diseases that could potentially be affected by the subproject, it indicates a high return on investment. Since WA is an importer of grapes a pathway exists through which exotic pests and diseases can enter the State. It follows that the pests and diseases potentially impacted by the subproject have a relatively high probability of entry and establishment.

5.4. Subproject 4: Early detection of emergency animal diseases

5.4.1. Background

Subproject 4 is designed to reduce response time to animal disease incursions, lowering the expected number of properties affected at the time of detection in WA. In this analysis, the value of damage prevented if the project achieves objectives is estimated using foot-and-mouth disease (FMD) as a case study. The subproject's influence on supply chain communication networks is simulated as an increase in the likelihood of FMD detection.

Simulation modelling by Garner and Beckett (2005) found time to detection of FMD in WA is 39 days and that the disease would be established on 36 properties by the time of detection. This finding used a specific set of assumptions about the nature and extent of an incursion, but in reality entry and establishment scenarios are highly uncertain, as is detection probability.

In this analysis, the benefits of subproject 4 are combined with those of subprojects 6 (*Build Capacity to Respond and Recover from emergency pest and disease incidents*) and 7 (*Awareness and compliance with new biosecurity legislation*). See sections 5.6 and 5.7, respectively.

Meat and livestock export market losses will be large following detection, but if eradication is successful these markets will be restored. If unsuccessful export losses will persist, as will susceptible livestock production cost increases due to the need for vaccinations 1-2 times per year. This assumes the correct vaccine for the specific strain of the virus detected will be available.

The likelihood of detection is expected to increase as a result of investment in subproject 4. The cost of eradication is assumed to fall by 5% as a result of subprojects 6 and 7.

Parameters used in the assessment appear in Appendix 1, Table A3.

5.4.2. Cost

Subproject 4 involves a total investment of $2 100 000; comprising of $500 000 from DAFWA consolidated funds and $1 600 000 from the RfR initiative.

Subproject 6 involves a total investment of $5 650 000 (see section 5.6.2).

Subproject 7 involves an investment of $1 120 000 (see section 5.7.2).

Total investment across subprojects 4, 6 and 7 is $8 870 000.

5.4.3. Benefit

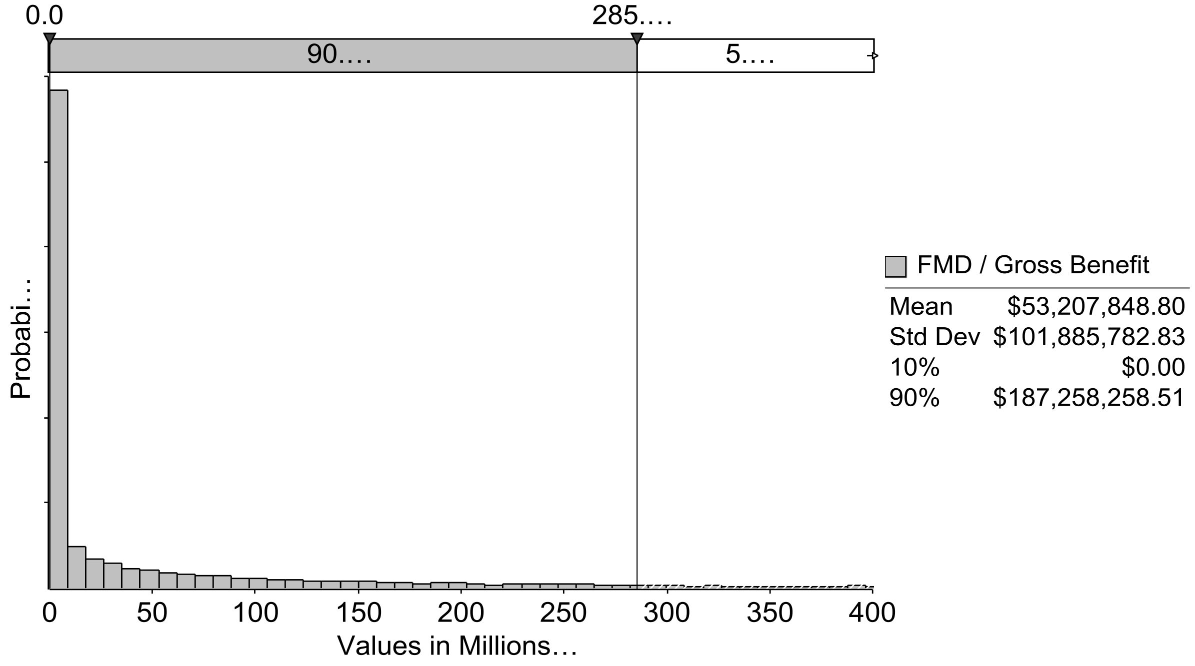

Figure 6. Estimated benefit of subprojects 4, 6 and 7

5.4.4. Return on investment

Taking the mean of the distribution of model outputs shown in Figure 6 as our estimate of the gross value of benefits generated by subprojects 4, 6 and 7, the benefit cost ratio for the combined subprojects is approximately 15.4 over the 30 year period simulated. Distributions of benefit cost ratios produced by the model are shown in Figure 7 for 10, 20 and 30-year time frames.

Note that while the subproject is expected to make a net loss over the first 10 years of the assessment, by the end of the 30-year period the return on investment is likely to large (i.e. $15.44 returned for each $1.00 invested in these subprojects). These returns are calculated on the basis of a single case study, FMD.

The assumptions on the FMD simulation model is based are detailed in Appendix 1, Table A3. By the end of the 30-year estimation period, subprojects 4, 6 and 7 are estimated to have a combined net present value of $106.3 million.

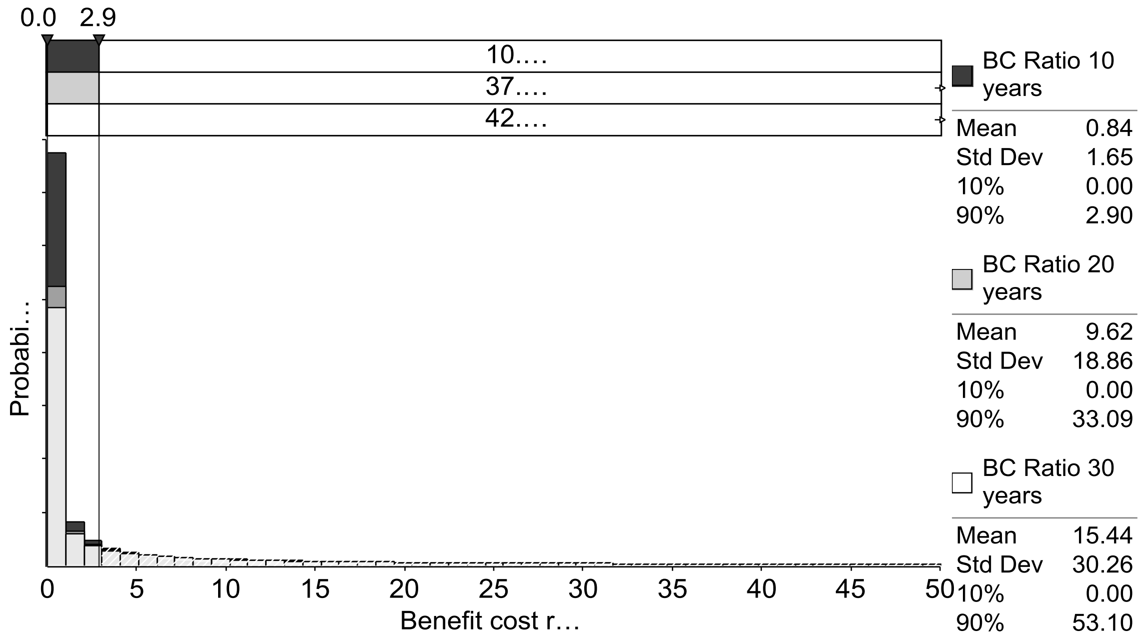

Figure 7. Estimated return per dollar invested in subprojects 4, 6 and 7

Once again, there is a large amount of uncertainty regarding the entry and establishment of emergency animal diseases and their detection. Moreover, this uncertainty is epistemic, and cannot be reduced by experimentation. It follows that the mean gross benefit value calculated here is highly uncertain.

5.5. Subproject 5: Agricultural weed surveillance in the South West to protect industry profitability

5.5.1. Background

Subproject 5 aims to develop enhanced weed surveillance methods for 20 declared weeds affecting intensive horticultural production in the South West region.

Of the species targeted in the project, 15 are to be selected by DAFWA and 5 by community stakeholders. Information concerning their abundance and distribution in the region is to be collected and interpreted using DAFWA staff expertise in cooperation with Recognised Biosecurity Groups.

Reporting methods and procedures for new and established species are to be refined with the view to reducing the time between detection in an area and response.

This is to be achieved primarily via the development of the *MyWeedWatcher* smartphone app but may also involve drone technology. Weed damage prevented will accrue over time and can be evaluated using a set of case study species affected by the subproject.

5.5.2. Cost

This subproject involves a total investment of $1 159 000 and is 100% funded through the RfR initiative.

5.5.3. Benefit

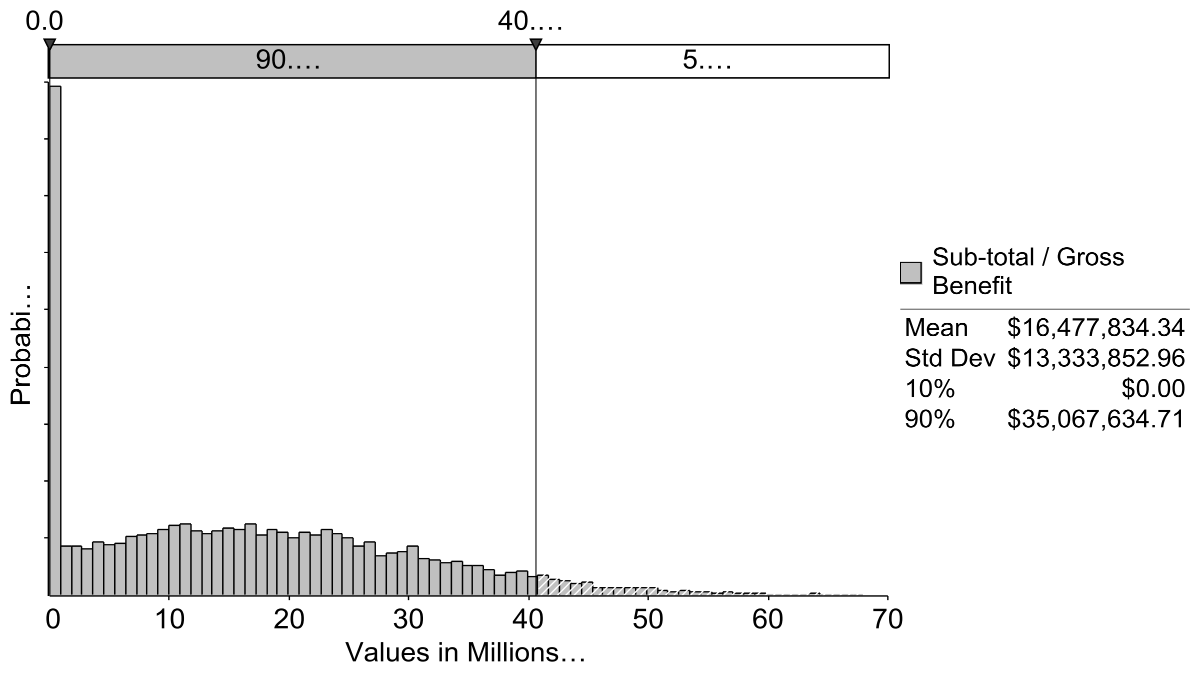

Figure 8. Estimated benefit of subproject 5

5.5.4. Return on investment

Using the mean of the distribution of model outputs shown in Figure 8 as an estimate of the gross value of the project, the benefit cost ratio for subproject 5 is estimated to be 2.1 over the first decade of the subproject, and 38.0 by the end of the third decade. At the end of the 30-year estimation period the subproject is expected to have a net present value of approximately $33.16 million. The assumptions on which this is based are detailed in Appendix 1, Table A4.

Distributions of benefit cost ratios produced by the model are shown in Figure 9 for 10, 20 and 30-year time frames. Note that the benefits include losses prevented in regions outside of the South West in cases where weeds can spread to warmer and drier regions.

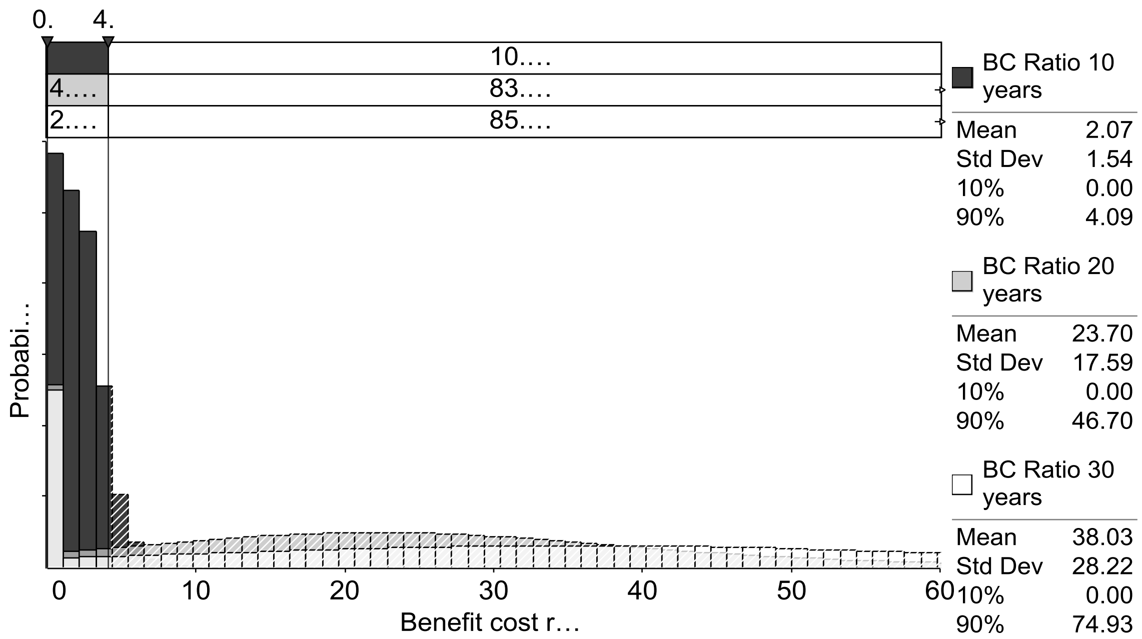

Figure 9. Estimated return per dollar invested in subproject 5

5.6. Subproject 6: Build capacity to respond and recover from emergency pest and disease incidents

5.6.1. Background

This subproject is designed to address crucial factors affecting the ability of the agrifood sector in WA to recover following a biosecurity emergency response. It comprises of eight separate components, which include:

A Training for 275 DAFWA staff emergency response management;

B Recovery component targeting communication with local government and emergency management groups to raise community awareness regarding biosecurity emergencies;

C Purchase and implementation of software programs to enhance (i) interagency support and logistics management (*Web EOC*), and (ii) incursion operations and planning (*MAX*);

D Supports DAFWA staff gaining experience with real incursions occurring within Australia to enhance skills and performance in biosecurity emergency situations;

E Improving laboratory management and cataloguing of field samples collected in biosecurity emergencies;

F Training industry liaison officers to contribute local industry knowledge and industry involvement in emergency responses;

G Planning for large scale destruction of livestock biomass as part of a state or national 'stamp out' response policy;

H Supporting the FMD simulation exercise, *APOLLO* (2016).

5.6.2. Cost

This subproject involves a total investment of $5 650 000. Of this, $5 000 000 is received from RfR funds, while the remainder if from DAFWA consolidated funds.

5.6.3. Benefit

Please see section 5.4.3. Parameters used in the assessment appear in Appendix 1, Table A3.

5.6.4. Return on investment

The return on investment to this subproject is evaluated together with subprojects 4 and 7. Please see section 5.4.4.

5.7. Subproject 7: Awareness and compliance with new biosecurity legislation

5.7.1. Background

This subproject seeks to improve awareness of and compliance with the *Biosecurity and Agricultural Management Act 2007* (Parliament of Western Australia, 2007), or BAM Act. It aims to do so via four activities:

A. Swill Feeding – Develop an education package for high-risk community groups regarding swill feeding risks and risk management;

B. Sheep Traceability – Develop a communication plan to extend knowledge of the National Livestock Identification System (NLIS) requirements to sheep producers via a series of regional workshops and through the creation of a sheep NLIS helpdesk;

C. Regulatory Training – Develop a tailored Certificate III in Government course that includes units of competency focused on statutory compliance for DAFWA officers appointed as inspectors under the BAM Act;

D. Work instructions/Procedural documents – Draft and distribute twenty procedural documents to relevant DAFWA officers.

5.7.2. Cost

This subproject involves a total investment of $1 120 000. Of this, $120 000 represents DAFWA in-kind support, and $1 000 000 is received from the RfR initiative.

5.7.3. Benefit

Please see section 5.4.3. Parameters used in the assessment appear in Appendix 1, Table A3.

5.7.4. Return on investment

The return on investment to this subproject is evaluated together with subprojects 4 and 6. Please see section 5.4.4.

5.8. Subproject 8: Biosecurity research and development fund

5.8.1. Background

Subproject 8 makes $3 200 000 available to fund research projects developing solutions to significant pests and diseases affecting WA. Grants of between $50 000 and $500 000 per year will be offered over a three-year period beginning 2015.

In the first round of funding, $2 500 000 from the Fund was distributed across seven projects that successfully nominated for funds. Of these, the Goldfields Nullarbor Rangelands Biosecurity Association (GNRBA) project entitled *Using innovative technologies to identify and map invasive cacti in the southern Rangelands of WA* is used as a case study.

The GNRBA project involves a $158 500 Fund investment to identify and map invasive cacti in the southern Rangelands of WA. Species targeted include coral cactus (*Cylindropuntia fulgida*), Hudson pear (*C. rosea* and *C. tunicate*) and devil's rope cactus (*C. imbricata*).

Four locations of 80ha were initially selected (Menzies, Mertondale, Coolgardie and Tarmoola Station), but detailed mapping of cacti will now only be carried out for the Coolgardie and Tarmoola Station sites. Large infestations in these areas will be mapped using a near-infrared camera mounted to an unmanned aerial vehicle, while ground-based thermal imaging technology will be used to identify infestations obscured by shrub and woodland canopies.

Information generated by the project concerning the location and density of infestations will lower the costs of control (i.e. via reduced search costs) and more effective targeting of management effort. Benefits are only calculated for the goldfields region despite the capacity for cacti to infest other regions.

5.8.2. Cost

Subproject 8 involves a total investment of $3 500 000 received from the RfR initiative.

The GNRBA grant for the *Using innovative technologies to identify and map invasive cacti in the southern Rangelands of WA* project involves a total investment of $158 000.

5.8.3. Benefit

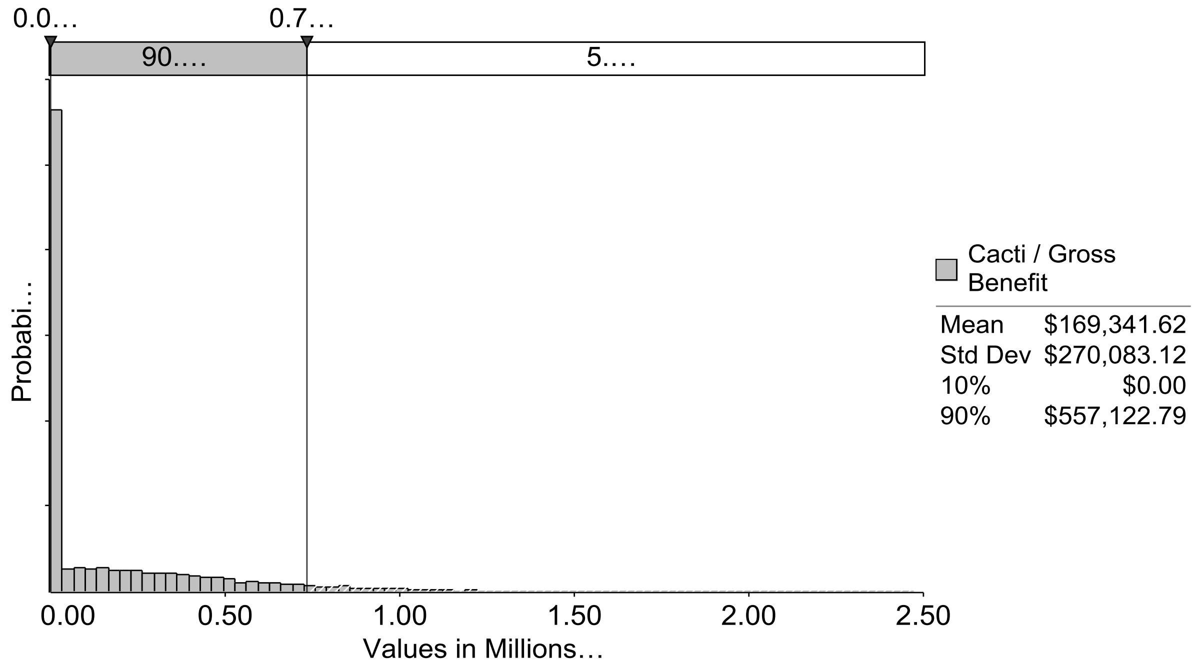

Figure 10. Estimated benefit of *Using innovative technologies to identify and map invasive cacti in the southern Rangelands of WA* project funded under subproject 8

5.8.4. Return on investment

Using the mean of the distribution of model outputs shown in Figure 10 as an estimate of the gross value of benefit generated, the benefit cost ratio for by the *Using innovative technologies to identify and map invasive cacti in the southern Rangelands of WA* project is estimated to be 2.4 by the end of the 30-year estimation period. The net present value for the project is estimated as $0.2 million. The assumptions on which this is based are detailed in Appendix 1, Table A5.

Figure 11 shows the distributions of benefit cost ratios produced by the model for 10, 20 and 30-year estimation periods. The further in time benefits are projected, the higher the returns on investment in the project.

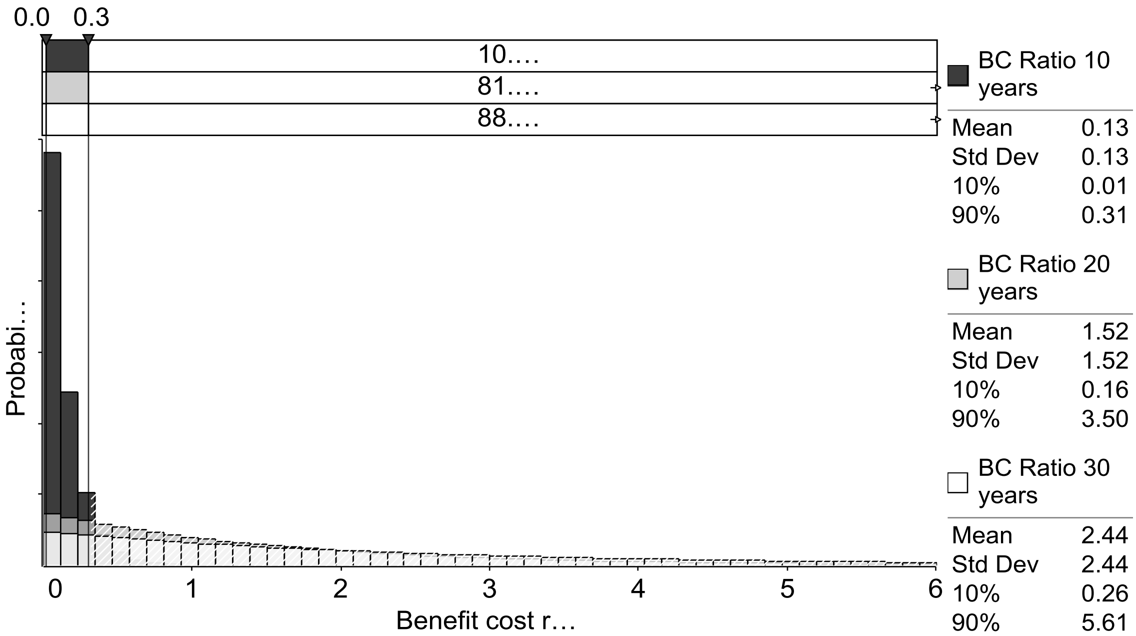

Figure 11. Estimated return per dollar invested in the *Using innovative technologies to identify and map invasive cacti in the southern Rangelands of WA* project funded under subproject 8

5.9. Subproject 9: Transforming regional biosecurity response

5.9.1. Background

The focus of subproject 9 is established pest management and changing the governance structure from a ‘top down’ government led approach to a ‘bottom up’ community coordinated approach. This is in line with DAFWA’s adoption of the National Framework for Management of Established Pests and Diseases of National Significance via a community co-ordinated approach, with Recognised Biosecurity Groups (RBGs) forming the basis of established invasive species management.

5.9.2. Cost

This subproject involves a total investment of $3 308 000 from the RfR initiative and a further $700 000 from the State Natural Resource Management Office.

5.9.3. Benefit

Not applicable.

5.9.4. Return on investment

Subproject 9 is not evaluated as part of this assessment.

However, with regard to the National Framework for Management of Established Pests and Diseases of National Significance using the invasion impact curve (Agriculture Victoria, 2015) as the basis for shifting the control of established species from government to community, please see section 5.2.4.

5.10. Subproject 10: Eradication of Medfly in Carnarvon

5.10.1. Background

Subproject 10 aims to eradicate Mediterranean fruit fly (*Ceratitis capitata*, or Medfly) from the Carnarvon horticulture precinct. This will lower the variable cost of production for fruit and vegetables from the region.

Experience overseas (e.g. USA, Mexico and Chile) has shown that it is possible to achieve Medfly eradication provided reintroduction events can be controlled (Mumford et al., 2001). This subproject relies on the relative isolation of Carnarvon enabling the ongoing exclusion of Medfly once eradication has been achieved.

Restrictions on broad-spectrum organophosphorus insecticide use have increased the significance of Medfly as pest of WA horticulture (APVMA, 2010, Mengersen et al., 2012, Cook and Fraser, 2014). This is particularly true in regional economies highly dependent on susceptible industries, such as Carnarvon in the State's midwest region. Here, agriculture contributes over $100 million to the regional economy (ABS, 2015).

5.10.2. Cost

This subproject involves a total investment of $4 200 000. This comprises of $1 100 000 from the RfR initiative, $1 500 000 DAFWA in-kind funds, $1 000 000 from Horticulture Innovation Australia Ltd. and $600 000 from the Carnarvon Grower Association.

5.10.3. Benefit

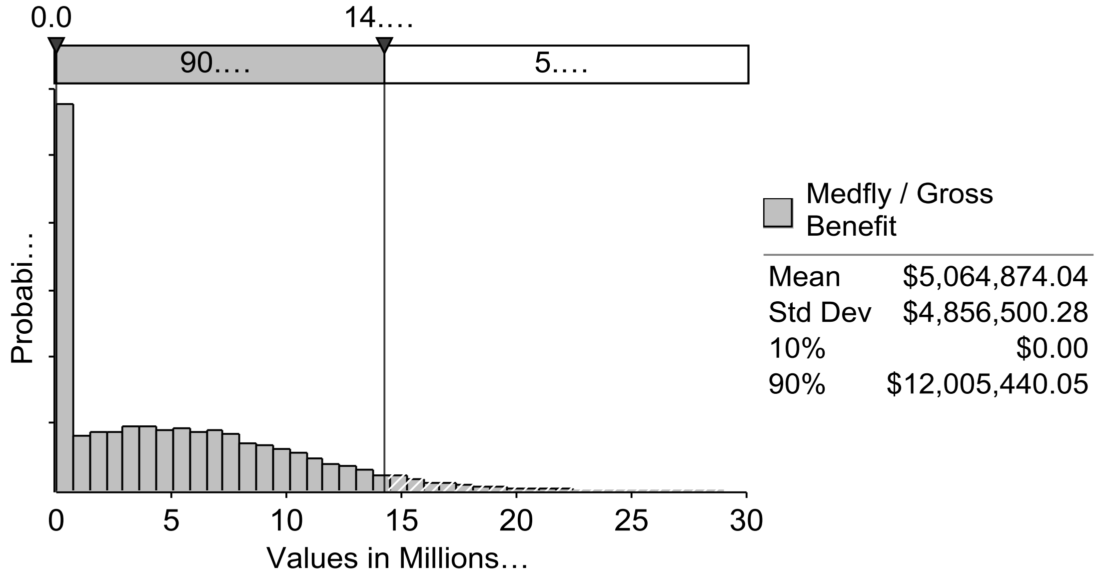

Figure 12. Estimated benefit of subproject 10

5.10.4. Return on investment

Using the mean of the distribution of model outputs shown in Figure 12 as an estimate of the gross value of benefit generated, the benefit cost ratio for the eradication of Medfly from Carnarvon is estimated to be 3.4 by the end of the 30-year estimation period. The net present value for the project is estimated to be $7.47 million. As noted in the assumptions on which this assessment is based (detailed in Appendix 1, Table A6), only a sub-sample of crops potentially affected by the project have been included.

Figure 13 shows the distributions of benefit cost ratios produced by the model for 10, 20 and 30-year estimation periods. This figure shows that while short-term returns to investment in the subproject are negative, they are healthy in the medium to long term as the producer benefits of Medfly eradication accumulate.

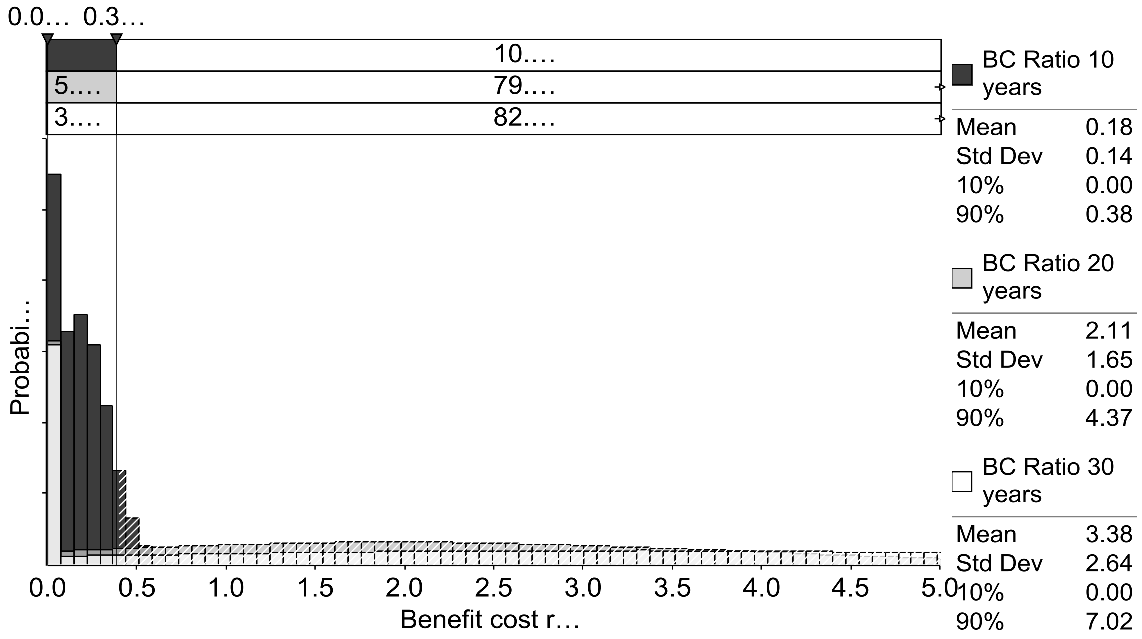

Figure 13. Estimated return per dollar invested in subproject 10

5.11. Subproject 11: Wild dog control measures

5.11.1. Background

Subproject 11 will investigate the likely costs and benefits of different wild dog management strategies, and how these affect WA rangeland livestock production. The subproject will focus on southern rangeland areas in which the Carnarvon, Meekatharra and Goldfields Recognised Biosecurity Groups operate, and make a detailed study of interactions between wild dogs and livestock within specific sites of interest. Control techniques to be explored include trapping, ground and aerial baiting, professional hunters and trappers, bounties and exclusion fencing.

5.11.2. Cost

This subproject involves a total investment of $671 000, comprising of $596 000 from the RfR initiative and $75 000 from DAFWA.

5.11.3. Benefit

Not applicable.

5.11.4. Return on investment

Subproject 11 is not evaluated as part of this assessment.

5.12. Synthesis

Using the individual assessments of sections 5.1 to 5.11 in an aggregated assessment of the BBD project is very difficult. Ideally, we would run all 20 pest and disease simulations simultaneously. However, using such a large ensemble of creates a great deal of model instability. Computationally, when we consider many of the species involved are polyphagous pests and diseases (i.e. spread occurs in a number of different crops for each species), simulating their movement across all crops over a 30-year period is extremely complicated.

To enable the aggregation of subproject results, distributions were fitted to subproject model outputs, and these fitted distributions were then used to represent individual species benefits generated by the project in a separate model.

Unfortunately, this aggregated model is aspatial, which means there is an element of double counting in the calculations. If, for example, multiple pest and disease outbreaks occur in one single year affecting a common crop, our method of aggregating project benefits does not account for overlapping damages.

Keeping in mind this upward bias, the net impact of the project is seen in Figure 14. Here, the distributions of net present value for the BBD project in the aggregated model is shown for 10, 20 and 30-year estimation periods. From an initial net loss of $0.8 million over the first 10 years, the project is expected to post net benefits of approximately $241.9 million by year 30.

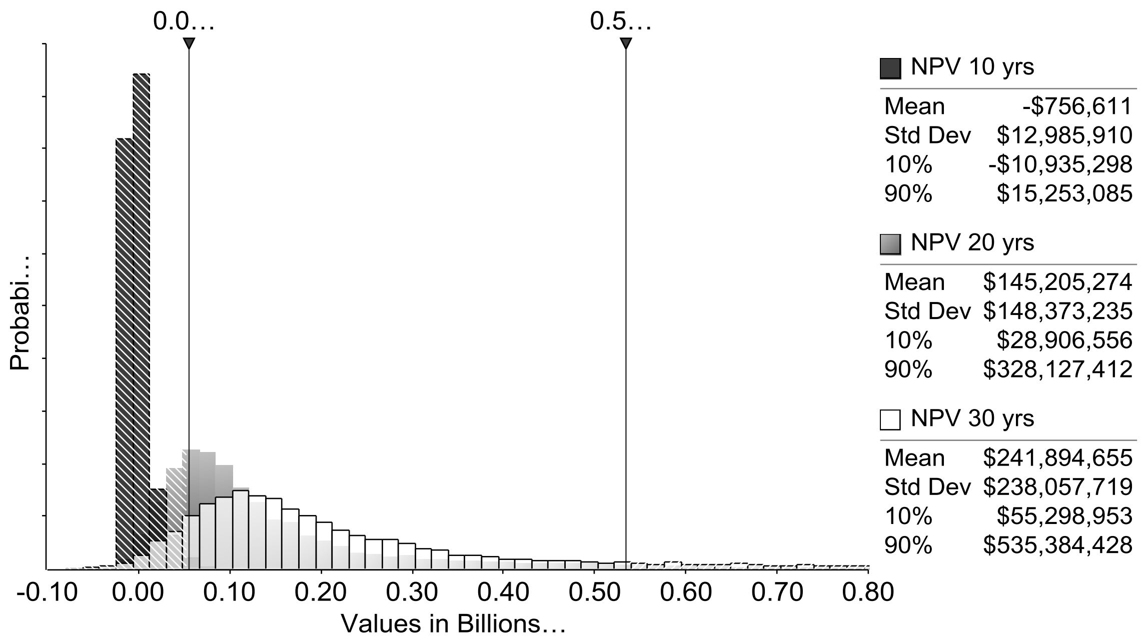

Figure 14. Distribution of simulated pest and disease impacts with and without the BBD project

Distributions of benefit cost ratios expected from the project are shown in Figure 15. As with Figure 14, separate distributions are displayed for 10, 20 and 30-year estimation periods. The influence of time on results can be seen in the description of the three distributions on the right-hand-side of the figure. The mean benefit cost ratio increases from 1.0 to 17.4 as we increase the time period from 10 years to 30 years. This is despite the erosive effects of the discount rate.

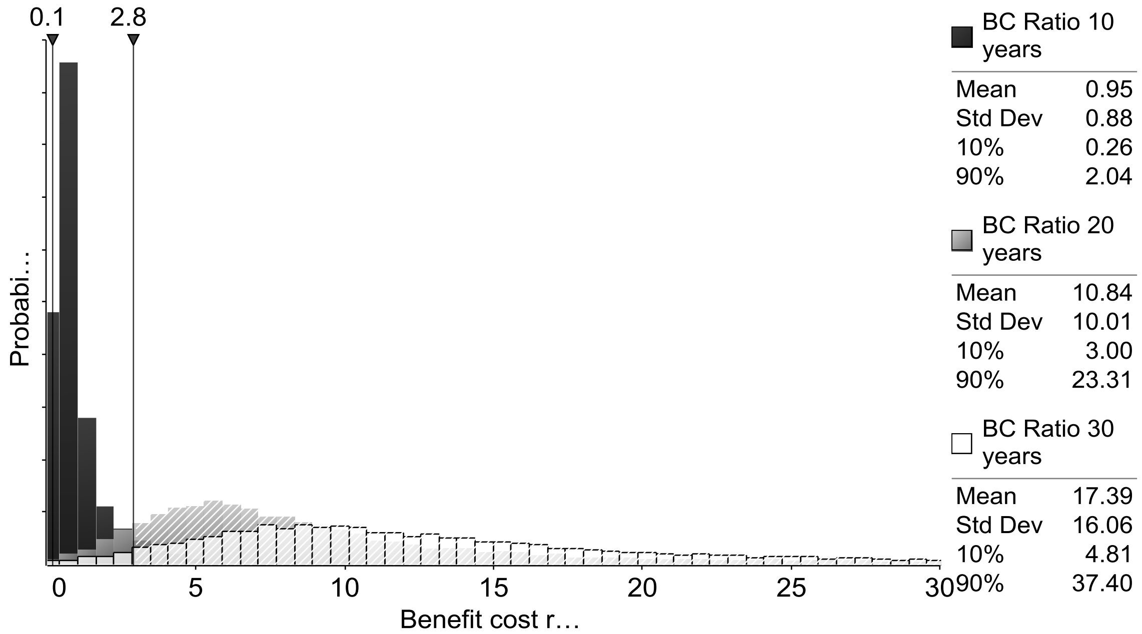

Figure 15. Estimated return on investment from the BBD project

Returns on investment in the project increase with time as the benefits of pest and disease damages prevented accumulate. As the costs of the project cease beyond 2017, the longer the length of time over which we calculate the benefits the larger those benefits are relative to costs.

This is further revealed in Table 3 in which the present (or discounted) value of benefits, present value of costs, net present value and benefit cost ratio are shown for the 10, 20 and 30-year time frames. All costs are incurred within the 10-year time frame, while benefits accrue over the 20 and 30-year periods.

Table 3. Estimated return on investment from the Boosting Biosecurity Defences project over time

	10 years	20 years	30 years
Present value of benefits ($M)	14.00	159.96	256.65
Present value of costs ($M)	14.76	14.76	14.76
Net present value ($M)	-0.76	145.20	241.89
Benefit cost ratio	**0.95**	**10.84**	**17.39**

Figure 8 and Table 3 reveal returns on investment in the project to be large over the medium (≈ 20-year) and long (≈ 30-year) term using the set of case studies outlined in sections 5.1 to 5.11, but are small in the short term (≈ 10 years). Returns grow over time as a result of the initial investment reducing future damage. This makes the choice of time frame critical when assessing the relative success of the project.

In view of the uncertainty surrounding parameters describing invasive species arrival and spread processes in the model, the sensitivity of gross benefit calculations (i.e. g, recalling Eq. 7) to key assumptions must be tested to gauge the robustness of predictions. Parameters were sampled from a uniform distribution with a maximum (minimum) of +50 per cent (-50 per cent) of the original values entered in to the model using Monte Carlo simulation. The Spearman's rank correlation coefficients relating the sampled model parameter values and changes in g were then calculated.

The numerical value of the Spearman's rank correlation coefficient is denoted ρ, where $-1.0 \leq \rho \leq 1.0$. If g has a tendency to increase when a parameter increases ρ is positive, and vice versa. A ρ value of zero indicates that there is no tendency for g to increase or decrease, while a ρ of one indicates that they are perfect monotone functions of each other. Parameters and their ρ values are presented in Figure 16.

The sensitivity tests indicate that g is most responsive in simulations involving exotic invasive species threats. Changes in the probability of entry and establishment produce the largest sensitivity (i.e. ρ value of 0.51). Results are also responsive to the intrinsic rate of affected area growth (0.23), the population diffusion coefficient (0.22), the probability of detection (-0.18) and the increased variable cost of production (0.10).

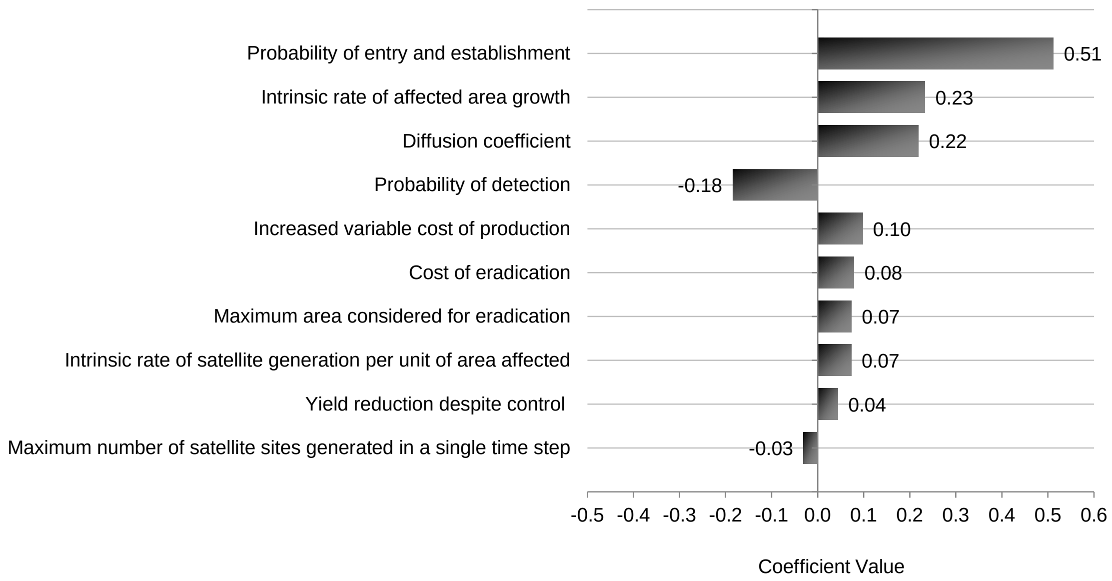

Figure 16. Sensitivity analysis

Note that the Spearman statistics are ordinal, and hence do not explain *direct* sensitivity of parameters to predicted g values. Correlation does not imply causation, and we are unable to definitively state that a change in one input parameter will result in specific change in g based on the Spearman correlation coefficients given in Figure 16.

6. Conclusion

This report has used a bioeconomic model to estimate the likely returns to investment in BBD subprojects over a 30-year period. The model estimates the reduction in expected pest and disease damage with each subproject compared to without it. This prevented damage constitutes the benefits of the subprojects, which are then compared to the costs of each t provide a benefit cost analysis.

Results for each subproject are as follows. Note that results assume BBD subprojects achieve their intended outcomes:

- Subproject 1: State Biosecurity Strategy is not included in the assessment due to the general, non-specific nature of benefits flowing from the project;
- Subproject 2: E-Surveillance for pests and diseases in the WA grains industry is estimated to produce $22.77 for every $1.00 invested;
- Subproject 3: E-Surveillance for pests and diseases of the WA grape industry is estimated to produce $56.40 for every $1.00 invested;
- Subprojects 4, 6 and 7: Early detection of emergency animal diseases, Capacity to Respond and Recover and Awareness and compliance with new biosecurity legislation, respectively, are estimated to be produce a combined $15.44 for every $1.00 invested. Due to time constraints, this is only evaluated on the basis of a single animal disease case study (foot-and-mouth disease);
- Subproject 5: Agricultural weed surveillance in the South West to protect industry profitability is estimated to produce $38.03 for every $1.00 invested;
- Subproject 8: Biosecurity research and development fund is estimated to produce $2.44 for every $1.00 invested. Due to time constraints, this is only evaluated on the basis of a single case study (*Using innovative technologies to identify and map invasive cacti in the southern Rangelands of WA*);
- Subproject 9: Transforming regional biosecurity response is not included in the assessment;
- Subproject 10: Eradication of Medfly in Carnarvon is estimated to produce $3.38 for every $1.00 invested;
- Subproject 11: Wild dog control measures is not included in the assessment.

Aggregating these subproject assessments, it is estimated that a net benefit of $241.9 million will be created for the WA agricultural sector as a result of the BBD project over a period of 30 years. These results are sensitive to changes in several uncertain model parameters, including the probabilities of exotic species' entry and establishment, the likelihood of detection and various spread parameters.

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8. Appendix

Table A1. Parameter values: Subproject 2 – E-Surveillance for pests and diseases in the WA grains industry

Description	*With* scenario*		*Without* scenario	
Cost of eradication, *E* ($/ha).	Khapra beetle Karnal bunt Cabbage Seedpod Weevil Ug99 Wheat stem sawfly	Uniform(1.0×10^6,1.0×10^7) Uniform(1.0×10^6,1.0×10^7) Uniform(5.0×10^5,1.0×10^6) Uniform(1.0×10^6,1.0×10^7) Uniform(1.0×10^6,1.0×10^7)	Same as *With* scenario (")	
Increased variable cost of production, *V* ($/ha).	Khapra beetle Karnal bunt Cabbage Seedpod Weevil Ug99 Wheat stem sawfly	Uniform(1.50,3.75) 0 0 Discrete[(0.0,13.5,27.0)(0.5,1.0,1.0)] Uniform(3,5)	"	
Intrinsic rate of affected area growth, *r* (wk^{-1}).	Khapra beetle Karnal bunt Cabbage Seedpod Weevil Ug99 Russian wheat aphid	Pert(0.20,0.35,0.50) Pert(1,2,3) Pert(0.20,0.35,0.50) Pert(1.0,1.25,1.5) Pert(0.20,0.35,0.50)	"	
Intrinsic rate of satellite generation per unit of area affected, μ (#/ha).	Khapra beetle Karnal bunt Cabbage Seedpod Weevil Ug99 Wheat stem sawfly	Pert(5.0×10^{-2},7.5×10^{-2},1.0×10^{-1}) Pert(1.0×10^{-2},2.5×10^{-2},5.0×10^{-2}) Pert(1.0×10^{-3},5.5×10^{-3},1.0×10^{-2}) Pert(1.0×10^{-2},2.5×10^{-2},5.0×10^{-2}) Pert(5.0×10^{-2},7.5×10^{-2},1.0×10^{-1})	"	
Maximum area affected, A^{max} (ha).	Khapra beetle Karnal bunt Cabbage Seedpod Weevil Ug99 Wheat stem sawfly	6.0×10^6 4.7×10^6 1.1×10^6 4.7×10^6 3.5×10^6	"	
Maximum area considered for eradication, A^{erad} (ha)	Khapra beetle Karnal bunt Cabbage Seedpod Weevil Ug99 Wheat stem sawfly	Pert(5.0×10^3,7.5×10^3,1.5×10^4) Pert(5.0×10^3,7.5×10^3,1.5×10^4) Pert(5.0×10^3,7.5×10^3,1.5×10^3) Pert(5.0×10^3,7.5×10^3,1.5×10^3) Pert(5.0×10^3,7.5×10^3,1.5×10^3)	"	
Maximum density, *K* (#/ha).	Khapra beetle Karnal bunt Cabbage Seedpod Weevil Ug99 Wheat stem sawfly	Uniform(1.0×10^3,1.0×10^4) Uniform(1.0×10^4,1.0×10^5) Uniform(1.0×10^3,1.0×10^4) Uniform(1.0×10^2,1.0×10^3) Uniform(1.0×10^4,1.0×10^5)	"	
Maximum number of satellite sites generated in a single time step, s^{max} (#).	Khapra beetle Karnal bunt Cabbage Seedpod Weevil Ug99 Wheat stem sawfly	Pert(30,40,50) Pert(10,15,20) Pert(10,15,20) Pert(70,85,100) Pert(30,40,50)	Khapra beetle Karnal bunt Cabbage Seedpod Weevil Ug99 Wheat stem sawfly	Pert(10,15,20) Pert(5.0,7.5,10.0) Pert(5.0,7.5,10.0) Pert(30,40,50) Pert(10,15,20)
Minimum density, N^{min} (#/ha).	Khapra beetle Karnal bunt Cabbage Seedpod Weevil Ug99 Wheat stem sawfly	Pert(0.00,0.025,0.050) Uniform(1.0×10^4,1.0×10^5) Pert(0.00,0.025,0.050) 1.0×10^{-8} Pert(0.00,0.025,0.050)	Same as *With* scenario (")	
Diffusion coefficient, *D* (ha/wk).	Khapra beetle Karnal bunt Cabbage Seedpod Weevil Ug99 Wheat stem sawfly	Pert(1.0,1.5,2.0) Pert(4,6,8) Pert(2,3,4) Pert(4,6,8) Pert(2,3,4)	"	
Prevailing price for affected commodities, *P* ($/T).	Barley Canola Wheat Oats	213 542 280 176	"	
Probability of detection, (%)	Khapra beetle Karnal bunt Cabbage Seedpod Weevil Ug99 Wheat stem sawfly	binomial(1.0,0.4) binomial(1.0,0.4) binomial(1.0,0.4) binomial(1.0,0.4) binomial(1.0,0.4)	Khapra beetle Karnal bunt Cabbage Seedpod Weevil Ug99 Wheat stem sawfly	binomial(1.0,0.8) binomial(1.0,0.8) binomial(1.0,0.8) binomial(1.0,0.8) binomial(1.0,0.8)
Yield reduction despite control, *Y* (%).	Barley Canola Wheat Oats	Uniform(0,20) Uniform(0,20) Uniform(0,20) Uniform(0,20)	Same as *With* scenario	

* Cook (2015) and Cook et al. (2011b).

Table A2. Parameter values: Subproject 3 – E-Surveillance for pests and diseases of the WA grape industry

Description	*With* scenario*		*Without* scenario	
Cost of eradication, *E* ($/ha).	Pierce's disease Grapevine phylloxera Brown marmorated stink bug Grapevine fanleaf virus Grapevine leaf rust	Uniform(1.0×10^6,1.0×10^7) 3.0×10^4 Uniform(5.0×10^5,1.0×10^6) Uniform(1.0×10^6,1.0×10^7) Uniform(1.0×10^6,1.0×10^7)	Same as *With* scenario (")	
Increased variable cost of production, *V* ($/ha).	Pierce's disease Grapevine phylloxera Brown marmorated stink bug Grapevine fanleaf virus Grapevine leaf rust	Discrete[(0,40,80,120)(1,1,1,1)] Pert(2.0×10^4, 3.0×10^4, 4.0×10^4) Discrete[(0,10,20,30)(1,1,1,1)] 725 725	"	
Intrinsic rate of affected area growth, *r* (wk^{-1}).	Pierce's disease Grapevine phylloxera Brown marmorated stink bug Grapevine fanleaf virus Grapevine leaf rust	Pert(0.20,0.35,0.50) Pert(0.10,0.15,0.20) Pert(0.20,0.35,0.50) Pert(1.0,1.25,1.5) Pert(0.20,0.35,0.50)	"	
Intrinsic rate of satellite generation per unit of area affected, μ (#/ha).	Pierce's disease Grapevine phylloxera Brown marmorated stink bug Grapevine fanleaf virus Grapevine leaf rust	Pert(5.0×10^{-2},7.5×10^{-2},1.0×10^{-2}) Uniform(1.0×10^{-3},1.0×10^{-2}) Pert(1.0×10^{-2}, 2.5×10^{-2},5.0×10^{-2}) Pert(1.0×10^{-2},2.5×10^{-2},5.0×10^{-2}) Pert(5.0×10^{-2},7.5×10^{-2},1.0×10^{-1})	"	
Maximum area affected, A^{max} (ha).	Pierce's disease Grapevine phylloxera Brown marmorated stink bug Grapevine fanleaf virus Grapevine leaf rust	1.1×10^4 5.5×10^3 1.1×10^4 1.1×10^4 1.1×10^4	"	
Maximum area considered for eradication, A^{erad} (ha)	Pierce's disease Grapevine phylloxera Brown marmorated stink bug Grapevine fanleaf virus Grapevine leaf rust	Pert(5.0×10^3,7.5×10^3,1.5×10^4) Pert(5.0×10^3,7.5×10^3,1.5×10^4) Pert(5.0×10^3,7.5×10^3,1.5×10^3) Pert(5.0×10^3,7.5×10^3,1.5×10^3) Pert(5.0×10^3,7.5×10^3,1.5×10^3)	"	
Maximum density, *K* (#/ha).	Pierce's disease Grapevine phylloxera Brown marmorated stink bug Grapevine fanleaf virus Grapevine leaf rust	Uniform(1.0×10^4,1.0×10^5) Uniform(1.0×10^3,1.0×10^4) Uniform(1.0×10^3,1.0×10^4) Uniform(1.0×10^2,1.0×10^3) Uniform(1.0×10^4,1.0×10^5)	"	
Maximum number of satellite sites generated in a single time step, s^{max} (#).	Pierce's disease Grapevine phylloxera Brown marmorated stink bug Grapevine fanleaf virus Grapevine leaf rust	Pert(30,40,50) Pert(10,15,20) Pert(50,60,70) Pert(30,40,50) Pert(50,60,70)	Pierce's disease Grapevine phylloxera Brown marmorated stink bug Grapevine fanleaf virus Grapevine leaf rust	Pert(10,15,20) Pert(5.0,7.5,10.0) Pert(30,40,50) Pert(10,15,20) Pert(30,40,50)
Minimum density, N^{min} (#/ha).	Pierce's disease Grapevine phylloxera Brown marmorated stink bug Grapevine fanleaf virus leaf rust	Pert(0.00,0.025,0.050) Pert(0.00,0.025,0.050) Pert(0.00,0.025,0.050) Pert(0.00,0.025,0.050) Grapevine Pert(0.00,0.025,0.050)	Same as *With* scenario (")	
Diffusion coefficient, *D* (ha/wk).	Pierce's disease Grapevine phylloxera Brown marmorated stink bug Grapevine fanleaf virus Grapevine leaf rust	Pert(1.0,1.5,2.0) Pert(0.50,0.75,1.00) Pert(0.20,0.35,0.50) Pert(1.0,1.5,2.0) Pert(1.0,1.5,2.0)	"	
Prevailing price for affected commodities, *P* ($/T).	Grapes	1430	"	
Probability of detection, (%)	Pierce's disease Grapevine phylloxera Brown marmorated stink bug Grapevine fanleaf virus Grapevine leaf rust	binomial(1.0,0.6) binomial(1.0,0.6) binomial(1.0,0.6) binomial(1.0,0.6) binomial(1.0,0.6)	Pierce's disease Grapevine phylloxera Brown marmorated stink bug Grapevine fanleaf virus Grapevine leaf rust	binomial(1.0,0.8) binomial(1.0,0.8) binomial(1.0,0.8) binomial(1.0,0.8) binomial(1.0,0.8)
Yield reduction despite control, *Y* (%).	Grapes	Uniform(0,10)	Same as *With* scenario	

* Cook (2003) and Cook (2011).

Table A3. Parameter values: Subproject 4 – Early detection of emergency animal diseases; Subproject 6 – Build capacity to respond and recover from emergency pest and disease incidents; and Subproject 7 – Awareness and compliance with new biosecurity legislation

Description	*With* scenario*		*Without* scenario	
Cost of eradication, *E* ($/ha).	FMD	Uniform(20,000,000.0$\times 10^{7}$,4.0$\times 10^{7}$)	Uniform(1.8$\times 10^{7}$,3.6$\times 10^{7}$)	
Increased variable cost of production, *V* ($/hd).	FMD	15	Same as With scenario (")	
Intrinsic rate of affected area growth, *r* (wk^{-1}).	FMD	Pert(1.50,1.75,2.00)	"	
Intrinsic rate of satellite generation per unit of area affected, μ (#/hd).	FMD	Pert(0.10,0.15,0.20)	"	
Maximum population affected, A^{max} (hd).	FMD	5.4$\times 10^{7}$	"	
Maximum population considered for eradication, A^{erad} (hd).	FMD	Pert(5.0$\times 10^{3}$,7.5$\times 10^{3}$,1.5$\times 10^{3}$)	"	
Maximum density, *K* (#/hd).	FMD	Uniform(1.0$\times 10^{6}$,1.0$\times 10^{7}$)	"	
Maximum number of satellite sites generated in a single time step, s^{max} (#).	FMD	Pert(50,60,70)	"	
Minimum density, N^{min} (#/hd).	FMD	Pert(0.00,0.025,0.050)	"	
Diffusion coefficient, *D* (hd/wk).	FMD	Pert(14,18,22)	"	
Prevailing price for affected commodities, *P* (c/kg).	Cattle and calves Milk Pigs and pig meat Sheep and lamb	550 250 400 550	"	
Probability of (re-)entry and establishment (%).	FMD	Uniform(3.0$\times 10^{-5}$,7.0$\times 10^{-2}$	"	
Probability of detection, (%).	FMD	binomial(1.0,0.7)	FMD	binomial(1.0,0.6)
Reduction in export earnings attributable to a loss of pest/disease area freedom (%)	FMD	Pert(70,85,100)	Same as *With* scenario (")	
Yield reduction despite control, *Y* (%).	FMD	Uniform(0,30)	"	

* Waage et al. (2005). Note that the probability of FMD's entry and establishment in WA is considered relatively low. This has the effect of lowering the 'expected' gross benefits of subprojects 4,6 and 7.

Table A4. Parameter values: Subproject 5 – Agricultural weed surveillance in the South West to protect industry profitability

Description	*With* scenario*		*Without* scenario	
Cost of eradication, *E* ($/ha).	Jointed goatgrass	Uniform(1.0×10^3,1.5×10^3)	Same as *With* scenario (")	
	Branched broomrape	Uniform(1.0×10^3,1.5×10^3)		
	Hoary cress	Uniform(1.0×10^3,1.5×10^3)		
	Creeping knapweed	Uniform(1.0×10^3,1.5×10^3)		
	Golden dodder	Uniform(1.0×10^3,1.5×10^3)		
Increased variable cost of production, *V* ($/ha).	Jointed goatgrass	Uniform(1.50,3.75)	"	
	Branched broomrape	Uniform(50,150)		
	Hoary cress	Uniform(15,30)		
	Creeping knapweed	Uniform(15,30)		
	Golden dodder	Uniform(50,150)		
Intrinsic rate of affected area growth, *r* (wk^{-1}).	Jointed goatgrass	Uniform(1.0,1.5)	"	
	Branched broomrape	Pert(1,2,3)		
	Hoary cress	Pert(0.50,0.75,1.00)		
	Creeping knapweed	Pert(1.0,1.25,1.5)		
	Golden dodder	Pert(0.20,0.35,0.50)		
Intrinsic rate of satellite generation per unit of area affected, μ (#/ha).	Jointed goatgrass	Pert(5.0×10^{-2},7.5×10^{-2},1.0×10^{-1})	"	
	Branched broomrape	Pert(5.0×10^{-2},7.5×10^{-2},1.0×10^{-1})		
	Hoary cress	Pert(1.0×10^{-3},5.5×10^{-3},1.0×10^{-2})		
	Creeping knapweed	Pert(1.0×10^{-2},2.5×10^{-2},5.0×10^{-2})		
	Golden dodder	Pert(5.0×10^{-2},7.5×10^{-2},1.0×10^{-1})		
Maximum area affected, A^{max} (ha).	Jointed goatgrass	4.6×10^6	"	
	Branched broomrape	1.1×10^6		
	Hoary cress	1.0×10^6		
	Creeping knapweed	4.7×10^6		
	Golden dodder	2.0×10^3		
Maximum area considered for eradication, A^{erad} (ha)	Jointed goatgrass	Uniform(500,1000)	"	
	Branched broomrape	Uniform(500,1000)		
	Hoary cress	Uniform(500,1000)		
	Creeping knapweed	Uniform(500,1000)		
	Golden dodder	Uniform(500,1000)		
Maximum density, *K* (#/ha).	Jointed goatgrass	Uniform(1.0×10^4,1.0×10^5)	"	
	Branched broomrape	Uniform(1.0×10^4,1.0×10^5)		
	Hoary cress	Uniform(1.0×10^3,1.0×10^4)		
	Creeping knapweed	Uniform(1.0×10^3,1.0×10^4)		
	Golden dodder	Uniform(1.0×10^4,1.0×10^5)		
Maximum number of satellite sites generated in a single time step, s^{max} (#).	Jointed goatgrass	Pert(30,40,50)	"	
	Branched broomrape	Pert(10,15,20)		
	Hoary cress	Pert(10,15,20)		
	Creeping knapweed	Pert(70,85,100)		
	Golden dodder	Pert(30,40,50)		
Minimum density, N^{min} (#/ha).	Jointed goatgrass	Pert(1,2,3)	"	
	Branched broomrape	Pert(1,2,3)		
	Hoary cress	Pert(1,2,3)		
	Creeping knapweed	Pert(1,2,3)		
	Golden dodder	Pert(1,2,3)		
Diffusion coefficient, *D* (ha/wk).	Jointed goatgrass	Pert(1.0,1.5,2.0)	"	
	Branched broomrape	Pert(4,6,8)		
	Hoary cress	Pert(2,3,4)		
	Creeping knapweed	Pert(4,6,8)		
	Golden dodder	Pert(2,3,4)		
Prevailing price for affected commodities, *P* ($/T).	Barley	213	"	
	Canola	542		
	Carrot	750		
	Oats	176		
	Onion	900		
	Potato	750		
	Tomato	1800		
	Wheat	280		
Probability of detection, (%)	Jointed goatgrass	binomial(1.0,0.4)	Jointed goatgrass	binomial(1.0,0.6)
	Branched broomrape	binomial(1.0,0.4)	Branched broomrape	binomial(1.0,0.6)
	Hoary cress	binomial(1.0,0.4)	Hoary cress	binomial(1.0,0.6)
	Creeping knapweed	binomial(1.0,0.4)	Creeping knapweed	binomial(1.0,0.6)
	Golden dodder	binomial(1.0,0.4)	Golden dodder	binomial(1.0,0.6)
Yield reduction despite control, *Y* (%).	Barley	Uniform(0.0,0.1)	Same as *With* scenario	
	Canola	Uniform(0.0,0.1)		
	Carrot	Uniform(0.0,1.0)		
	Lupins	Uniform(0.0,0.1)		
	Oats	Uniform(0.0,0.1)		
	Onion	Uniform(0.0,1.0)		
	Potato	Uniform(0.0,1.0)		
	Tomato	Uniform(0.0,1.0)		
	Wheat	Uniform(0.0,0.1)		

* Cook (2015) and Cook et al. (2011b).

Table A5. Parameter values: *Using innovative technologies to identify and map invasive cacti in the southern Rangelands of WA* project funded under subproject 8

Description	*With* scenario*		*Without* scenario	
Cost of eradication, *E* ($/ha).	Coral cactus Hudson pear Devil's rope cactus	Uniform(300,500) Uniform(300,500) Uniform(300,500)	Coral cactus Hudson pear Devil's rope cactus	Uniform(100,200) Uniform(100,200) Uniform(100,200)
Increased variable cost of production, *V* ($/ha).	Coral cactus Hudson pear Devil's rope cactus	Discrete({100,200,300}{1,1,0.5}) Discrete({100,200,300}{1,1,0.5}) Discrete({100,200,300}{1,1,0.5})	Same as *With* scenario (")	
Intrinsic rate of affected area growth, *r* (wk^{-1}).	Coral cactus Hudson pear Devil's rope cactus	Pert(0.20,0.35,0.50) Pert(0.20,0.35,0.50) Pert(0.20,0.35,0.50)	"	
Intrinsic rate of satellite generation per unit of area affected, μ (#/ha).	Coral cactus Hudson pear Devil's rope cactus	Pert(1.0×10^{-5},6.0×10^{-4},1.0×10^{-3}) Pert(1.0×10^{-5},6.0×10^{-4},1.0×10^{-3}) Pert(1.0×10^{-5},6.0×10^{-4},1.0×10^{-3})	"	
Maximum area affected, A^{max} (ha).	Coral cactus Hudson pear Devil's rope cactus	7.7×10^{11} 7.7×10^{11} 7.7×10^{11}	"	
Maximum area considered for eradication, A^{erad} (ha)	Coral cactus Hudson pear Devil's rope cactus	Pert(5.0×10^{6}, 7.5×10^{6},1.0×10^{7}) Pert(5.0×10^{6}, 7.5×10^{6},1.0×10^{7}) Pert(5.0×10^{6}, 7.5×10^{6},1.0×10^{7})	"	
Maximum density, *K* (#/ha).	Coral cactus Hudson pear Devil's rope cactus	Pert(1.0×10^{4},5.5×10^{4},1.0×10^{5}) Pert(1.0×10^{4},5.5×10^{4},1.0×10^{5}) Pert(1.0×10^{4},5.5×10^{4},1.0×10^{5})	"	
Maximum number of satellite sites generated in a single time step, s^{max} (#).	Coral cactus Hudson pear Devil's rope cactus	Uniform(5,10) Uniform(5,10) Uniform(5,10)	"	
Minimum density, N^{min} (#/ha).	Coral cactus Hudson pear Devil's rope cactus	1.0×10^{-4} 1.0×10^{-4} 1.0×10^{-4}	"	
Diffusion coefficient, *D* (ha/wk).	Coral cactus Hudson pear Devil's rope cactus	Pert(5.0×10^{3},6.25×10^{3},7.5×10^{3}) Pert(5.0×10^{3},6.25×10^{3},7.5×10^{3}) Pert(5.0×10^{3},6.25×10^{3},7.5×10^{3})	"	
Prevailing price for affected commodities, *P* ($/kg).	Beef Wool	1.75 7.09	"	
Probability of detection, (%)	Coral cactus Hudson pear Devil's rope cactus	Binomial(100,0.8) Binomial(100,0.8) Binomial(100,0.8)	Coral cactus Hudson pear Devil's rope cactus	Binomial(100,0.4) Binomial(100,0.4) Binomial(100,0.4)
Yield reduction despite control, *Y* (%).	Beef Wool	Uniform(0.0,2.0) Uniform(0.0,2.0)	Same as *With* scenario	

* Cook (2015) and Cook et al. (2011b).

Table A6. Parameter values: Subproject 10 – Eradication of Medfly from Carnarvon

Description	*With* scenario*	*Without* scenario
Cost of eradication, E ($/ha).	Pert(2.0×10^4,3.0×10^4,4.0×10^4)	0
Increased variable cost of production, V ($/ha).	Pert(50,100,150)	Same as *With* scenario (")
Intrinsic rate of affected area growth, r (wk^{-1}).	Pert(0.20,0.35,0.50)	"
Intrinsic rate of satellite generation per unit of area affected, μ (#/ha).	Pert(1.0×10^{-2},3.0×10^{-2},5.0×10^{-2})	"
Maximum area affected, A^{max} (ha).	Citrus 1440 Mango 840 Stone 600 Table grapes 240 Tomato 390	"
Maximum area considered for eradication, A^{erad} (ha)	3,500	0
Maximum density, K (#/ha).	Pert(100,550,1000)	Same as *With* scenario (")
Maximum number of satellite sites generated in a single time step, s^{max} (#).	Pert(50,60,70)	"
Minimum density, N^{min} (#/ha).	Pert(1,2,3)	"
Diffusion coefficient, D (ha/wk).	Pert(5.0×10^5,6.0×10^5,7.0×10^5)	"
Prevailing price for affected commodities, P ($/T).	Citrus 2000 Mango 5000 Stone 1500 Table grapes 2500 Tomato 1800	"
Probability of detection, (%)	na	Binomial(1.0,0.6)
Yield reduction despite control, Y (%).	Pert(2.0,3.5,5.0)	Same as *With* scenario

* Cook and Fraser (2014). Note that only a small sub-sample of crops influenced by the project are included in the assessment. Medfly is known to affect most commercial fruit crops and over 60 native fruit species (Hooper and Drew, 1989), but given restrictions in the stochastic model used in this assessment it is not possible to include all potentially-affected crops.